INTERNATIONAL THWAITES GLACIER COLLABORATION

Initial Environmental Evaluation

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Science Foundation

Submitted to the Polar Regions Department, Foreign and Commonwealth Office, as part of an application for a permit / approval under the UK Antarctic Act 1994.

Submitted by:
British Antarctic Survey

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IEE Prepared by:
Constantia Consulting Ltd.
Christchurch
New Zealand

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List of Acronyms and Abbreviations

ATCM	Antarctic Treaty Consultative Meeting
ATCPs	Antarctic Treaty Consultative Parties
AMIGOS	Automated Meteorology Ice Geophysics and Ocean Sesnors
ApRES	Automated Phase-sensitive Radion Echo Sounding
ASL	Amundsen Sea Low
ASMA	Antarctic Specially Managed Area
ASPA	Antarctic Specially Protected Area
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
BAS	British Antarctic Survey
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CCAS	Convention for the Conservation of Antarctic Seals
CDW	Circumpolar Deep Water
CEP	Committee for Environmental Protection
COMNAP	Council of Managers of National Antarctic Programs
CTD	Conductivity, temperature and depth
DNV	Det Norske Veritas (vessel classification society)
DOMINOS	Disintegration of Marine Ice-Sheets using Novel Optimised Solutions
EIA	Environmental Impact Assessment
ESM	Eastern Shear Margin
FCO	Foreign and Commonwealth Office
GHC	Geological History Constraints
GHOST	Geophysical Habitat of Subglacial Thwaites
GPS	Geographical Positioning System
HSM	Historic Site or Monument
HWD	Hot Water Drill
IBA	Important Bird Area
IDDO	International Drilling Design and Operations
IEE	Initial Environmental Evaluation
ITGC	International Thwaites Glacier Collaboration
IUCN	International Union for the Conservation of Nature
LTG	Lower Thwaites Glacier
MELT	*None*
MT	Magnetotelluric
NERC	Natural Environment Research Council
NSF	National Science Foundation
PROPHET	Process, Divers, Prediction: Modelling the History and Evolution of Thwaites
RAF	Royal Airforce
RAM Drill	Rapid Air Movement Drill
ROV	Remotely Operated Vehicle
RPA	Remotely Piloted Aircraft
SB9	*None*

SCAR	Scientific Committee on Antarctic Research
TAGS	Thwaites Aero-Geophysical Survey
TARSAN	Thwaites Amundsen Regional Survey and Network
THOR	Thwaites Offshore Research
TIME	Thwaites Interdisciplinary Margin Evolution
USAP	United States Antarctic Program
VME	Vulnerable Marine Ecosystems
WAIS	West Antarctic Ice Sheet

Non-Technical Summary

Introduction

Since the 1990s, satellites have shown accelerating ice loss driven by ocean change in five neighbouring glacier catchments in west Antarctica, including the Thwaites Glacier. The rate of ice loss in this region has doubled in six years and now accounts for about 10 percent of global sea-level rise.

The U.S. National Science Foundation (NSF) and the UK's Natural Environment Research Council (NERC) have developed a joint programme of research with the objective to substantially improve both decadal and longer-term (century-to-multi-century) projections of ice loss and sea-level rise originating from the Thwaites Glacier.

The International Thwaites Glacier Collaboration (ITGC) will have a direct and significant impact on understanding the stability of marine ice sheets and the West Antarctic Ice Sheet (WAIS) and will contribute to the ice-sheet modelling community's capability to simulate ice sheets and to reduce the uncertainties in sea-level projections.

The NERC and NSF partnership will facilitate eight research projects across the Thwaites Glacier region. Logistical support will be jointly provided by the United States' Antarctic Program (USAP) and the British Antarctic Survey (BAS). It is the largest joint UK-U.S. project undertaken on the southern continent in 70 years.

The field programme will span five seasons from 2018/19 to 2022/23.

This document assesses the environmental consequences that could or will arise from the ITGC. It has been prepared in accordance with the Initial Environmental Evaluation provisions of Annex I to the Protocol on Environmental Protection to the Antarctic Treaty.

Statutory Requirements for the EIA

All activities in Antarctica are subject to the provisions of a series of international agreements that constitute the Antarctic Treaty System.

The Protocol on Environmental Protection to the Antarctic Treaty (the Protocol) was adopted by the Antarctic Treaty Consultative Parties (ATCPs) in 1991. It entered into force in January 1998.

Article 8 of the Protocol requires an environmental impact assessment to be prepared in advance of any activity taking place in the Antarctic Treaty Area. The level of the environmental impact assessment is determined by whether the activity in question is identified as having 'less than', 'no more than', or 'more than' a minor or transitory impact on the environment.

The detailed procedures for preparing and processing environmental impact assessments are set out in Annex I to the Protocol. If a proposed activity is determined, by means of a preliminary assessment, to have less than a minor or transitory impact, then it may proceed. If an activity is determined as being likely to have no more than a minor or transitory impact, then an Initial Environmental Evaluation (IEE) must be prepared. This environmental impact assessment has been prepared at the level of an IEE.

The EIA provisions of the Protocol are enacted in UK law through the Antarctic Act 1994 and Antarctic Act 2013 and Antarctic Regulations 1995/490 (as amended).

In the U.S., the EIA provisions of the Protocol are implemented through regulations at 45C.F.R. Part 641 – Environmental Assessment Procedures for Proposed national Science Foundation Actions in Antarctica. The U.S. Antarctic Conservation Act (ACA), as amended, 16 U.S.C. § 2401, et seq., protects Antarctic native mammals, birds, plants, and their ecosystems.

This environmental impact assessment will be submitted to the U.K. Foreign and Commonwealth Office under relevant UK legislation.

The Convention for the Conservation of Antarctic Seals (CCAS, 1972), aims to protect Antarctic seals from commercial exploitation. It entered into force in 1978. The UK and the U.S. are signatories to the Convention.

Article 5 of the Convention and paragraph 6(a) of the Annex to the Convention set out exchange of information obligations on all Parties. These provisions require Contracting Parties to provide an annual summary of information on all seals killed or captured by their nationals.

Seals research will be undertaken as part of the ITGC and information that meets the exchange of information requirements of the Convention will need to be provided to the Depository Government (the UK) on an annual basis throughout the campaign.

Scope of the EIA

The geographical scope of the EIA includes:

- the Thwaites Glacier and Thwaites ice-shelf;
- the glacial areas / shear margins immediately adjacent to the Thwaites Glacier including parts of Pine Island Glacier;
- parts of the Dotson Glacier and ice-shelf
- ice-free, in-land locations including the Hudson Mountains and Mt Murphy;
- several islands and islets in Pine Island Bay;
- Areas of the Amundsen Sea and Pine Island Bay for marine research including in front of the Thwaites, Crosson and Dotson ice shelves;
- the area of the Ronne Entrance on the south western side of the Antarctic Peninsula and associated ice shelves which will be used to offload vehicles and fuel for the BAS traverses;
- the traverse route between the vessel offload in Ronne Entrance and the depot site of SB9 and the traverse route between SB9 and the Thwaites Glacier research area.

The EIA will seek to assess the actual or potential environmental consequences arising from:

- the logistical support activities that will be provided to the ITGC including:
    - U.S. and UK over-ice traverses including those that will be undertaken to provide fuel and those that will be undertaken to support research (such as the seismic traverses);
    - Other over-ice vehicles such as skidoos that will be used to access research sites from several of the camp locations;

    - Aircraft activities undertaken in direct support of the ITGC including BAS Twin Otters used for aero-geophysical surveys and helicopters used to deploy equipment and personnel;
    - Vessel operations when providing support to the ITGC in the Pine Island Bay / Amundsen Sea area;
    - The establishment of fuel caches at selected locations;
    - The establishment of field camps and several locations;
    - Emissions arising from the burning of fossil fuels by vehicles and field camps;

and

- the programme of research to be undertaken including:
    - The deployment, operation and partial recovery of static monitoring equipment both on, within and under the Thwaites Glacier and at various marine locations in Pine Island Bay;
    - The deployment of expendable (unrecoverable) research equipment;
    - The deployment, operation and recovery of tethered and autonomous underwater survey vehicles both in Pine Island Bay and beneath the Thwaites Glacier;
    - The recovery of glacial and geological cores and the use of glaciological and geological coring equipment;
    - The recovery of surface geological samples;
    - The recovery of marine sediment cores and the use of sediment coring devices in both open-water (from vessels) and under-ice scenarios (through hot-water drilled holes);
    - The use of drilling equipment to drill holes into and through the Thwaites Glacier;
    - The conduct of active and passive seismic measurements across the Thwaites Glacier;
    - The use of penetrative radars from aircraft and on snow for investigation of the glacier and ice shelf;
    - The instrumentation of two seal species.

The following activities are excluded from the scope of this EIA:

- The general operation of the various research vessels in Antarctic waters beyond their immediate support to the ITGC campaign;
- The general operation of U.S. and UK aircraft beyond their immediate support to the ITGC campaign;
- The operation of the U.S. WAIS divide camp, which has been operational for several seasons and continues to support a number of research projects in addition to the ITGC programme;
- The research cruise to be undertaken by the Nathaniel B Palmer during the 2019/20 season and all associated marine research activities to be conducted from the vessel, which will involve a programme of marine seismic surveying. These marine research activities are considered to some extent in this IEE, but will be assessed in more detail by means of a separate EIA that will be prepared by NSF and additionally assessed through the review process required by the U.S. Marine Mammal Protection Act;
- The operation of the Korean Polar research and resupply vessel *Araon*, even when operating in support of the ITGC within the Amundsen Sea area. The activities to be conducted from the Araon e.g. the deployment of the AUV, is considered in this IEE, but the operation of the *Araon* itself, whilst mentioned in this EIA, will be assessed and authorised by the relevant South Korean competent authority;

- The U.S. aircraft rotations between McMurdo Station and the WAIS Divide camp, which will be undertaken in support of a range of U.S. research programmes of which one will be the Thwaites Glacier campaign.

Description of planned activities

The entire Thwaites programme research initiative comprises eight interconnected and inter-dependent research projects. Six of these research projects will involve on-ice research activities. The project will involve more than 60 scientists and students and will span five seasons of field research from 2018/19 to 2022/23.

Research projects

The eight ITGC research projects are:

1. Geological History Constraints (GHC) which aims to obtain geological evidence from the Thwaites and Pine Island glacier system (the 'Thwaites system') that will show whether and when glaciers were less extensive than they are at present;
2. Geophysical Habitat of Subglacial Thwaites (GHOST) which aims to assesses the basal conditions which could allow for the rapid retreat of the Thwaites Glacier grounding line;
3. The MELT project which will observe, quantify and model the Thwaites ice-ocean system in the grounding zone, to firmly establish the physics linking ocean forcing and ice-sheet response;
4. Thwaites-Amundsen Regional Survey and Network (TARSAN) which aims to better constrain the dominant processes at and near the Thwaites Glacier grounding zone, especially their spatial and temporal variability, as well as atmospheric and oceanic drivers of these processes;
5. Thwaites Offshore Research, (THOR) which will conduct integrated marine geological and geophysical investigations seaward of the Thwaites Glacier grounding line to deliver detailed records of change and boundary conditions that will improve projections of the glacier's contribution to sea-level rise;
6. Thwaites Interdisciplinary Margin Evolution (TIME), which will examine the role of shear margin dynamics in the future evolution of the Thwaites drainage basin;
7. Disintegration of Marine Ice-Sheets Using Novel Optimised Solutions, (DOMINOS), which aims to address uncertainties in the processes that control ice sheet dynamics using a novel ice-dynamics model suite (this project requires no field support), and
8. Processes, drivers, prediction: modelling the History and Evolution of Thwaites (PROPHET; also requiring no field support), which will rely on three independent numerical models of ice flow, coupled to an ocean circulation model so as to:
   a. improve understanding of the interactions between the ice and the bedrock;
   b. analyze how sensitive the Thwaites Glacier is to external changes, such as changes in ocean-induced melt under its floating extension or calving front position;
   c. assess the processes that may lead to a collapse of Thwaites, and
   d. forecast future ice loss of Thwaites.

Research activities

A range of glaciological, geological and marine measurements will be undertaken throughout the ITGC field campaign, using a variety of instruments and equipment. This will include:

1. Glaciological measurements including:
    a. Active seismic reflection surveys using explosive sources (both on the surface and at depth within the ice) as well as vibration sources (vibroseis) from a powered vehicle;
    b. Passive seismic measurements that utilise micro-earthquakes to assess sub-surface geology;
    c. Magnetotelluric measurments that use electrical current flows in ice sheets and the underlying crust;
    d. Radar surveys to measure bed topography using static equipment and equipment towed behind a skidoo;
    e. Multi-sensor arrays that record a range of data from above, within and beneath the ice (in the sub-shelf ocean cavity);
    f. Gravity measurements using portable gravimeters;
    g. Tiltmeters to measure small changes in glacier level;
    h. Global positioning system (GPS) stations to measure glacial and ice-shelf movement;
    i. Airborne geophysical measurements from a Twin Otter aircraft including radar, lidar, gravity and magnetic measurements.
2. Oceanographic measurements including:
    a. The fitting of instruments to elephant and Weddell seals to record temperature and salinity profiles as the seals move through the water column;
    b. The deployment of autonomous underwater vehicles (AUVs) including beneath ice shelves to record a range of oceanographic information as well as seabed and sub-surface ice-shelf topography;
    c. Autonomous ocean gliders to record a range of oceanographic information in front of ice-shelves;
    d. Autonomous surface vehicles to measure ocean surface information;
    e. A remotely piloted (tethered) vehicle that will be deployed through hot-water drilled holes in the ice shelf to make measurements in the sub-shelf cavity;
    f. Helicopter launched oceanographic profilers to make measurements within small patches of open water that occur seasonally in disrupted ice between the eastern and western ice shelves;
    g. Tethered microstructure profilers that will be deployed from research vessels;
    h. Bathymetric and sub-bottom profiles using vessel-mounted sonar systems;
    i. Recovery and redeployment of ocean moorings that collect a range of data at deep ocean locations.
3. Geological sampling involving:
    a. Taking geological cores at depth beneath the ice, and

   b. Surface geological sampling on nunataks and islands in Pine Island Bay.;

4. Marine sediment coring involving:
   a. Using a range of coring devices to take sediment cores in Pine Island Bay and in front of ice-shelves;
   b. Using hot-water drilled holes in the ice-shelf to take sub-shelf sediment cores.
5. Ocean water sampling.
6. Ice coring.

Logistical activities

Field activities will be undertaken between late November and late January each season. Logistics support and personnel will be mobilised each season via aircraft through the U.S. McMurdo Station and the U.S. WAIS Divide camp. Twin Otter aircraft will deploy personnel to target research locations from the WAIS Divide camp.

Ship supported research will be undertaken between late January and March in the 2018/19, 2019/20 and 2020/21 seasons and will be supported by U.S., UK and South Korean polar research vessels.

Over snow tractor traverses will be used to deliver fuel, camping and scientific equipment into the field campaign area in the 2018/19 and 2019/20 seasons. Over snow tractor traverses will also support research activities in the 2020/21 and 2021/22 seasons.

Hot water and mechanical drill systems will be used to drill into and through the glacier and ice sheets for the purposes of deploying seismic charges and instrumentation.

A number of tented field camps will be established during the campaign at location on the Thwaites and Dotson glaciers.

The ITGC campaign will be a 'fuel hungry' research programme and approximately 500,000litres of fuel is anticipated to be required. Significant quantities of fuel will be required for operating over-snow vehicles and aircraft, running generators to power research equipment (*e.g.* hot-water and geological drills), as well as for cooking and heating in field camps over four seasons of activity.

Fuel will be delivered to Antarctica by ship or air-dropped from LC130 Hercules aircraft. Fuel will be transported into the ITGC campaign area in fuel bladders and fuel drums.

Alternatives

Several alternatives have been considered in the planning phase of the ITGC campaign with a view to reducing the environmental impacts of the activities.

Do not proceed

Not undertaking the ITGC campaign was rejected because of the global relevance of the research that needs to be undertaken in this sector of Antarctica.

Alternative locations

Moving some or all of the planned research and logistics to alternative sites in Antarctica was rejected on the basis that alternative locations would not provide information of the same significance for future sea level rise and would be sub-optimal for collecting the data required to achieve the research objectives. In addition, whilst the location is remote and has seen relatively little human activity, the ITGC programme will be able to utilise existing U.S. and UK logistics hubs without having to establish new ones.

Independent projects

The six field projects could be run individually and at a smaller scale. However, this option was rejected because of the potential for duplication of logistics effort over a longer period of time and the loss of coordination and synergy across the various projects.

Alternative timing

Reducing the period of operation within and across seasons would have potential for reducing the intensity and duration of some of the identified impacts.

However, it is considered that attempting to do so would significantly compromise the potential for achieving the research objectives, with very little incremental gain in reducing environmental impacts.

Some changes have been made to the scheduling of two of the projects so as to smooth the on-ice logistical support more evenly across the field seasons.

No particular seasonal sensitivities have been identified in this assessment, given that for the most part activities will be being undertaken towards the end of the annual breeding period and in most cases well away from known concentrations of wildlife.

Consequently, no further changes to the timing and duration of the field activities were considered necessary.

Reduced scale of the research

Reducing the number of sites, people and transport movements would lessen the known impacts and the likelihood of possible impacts. However, logistical support is already being planned carefully so as to maximise efficiency and reduce identified impacts. While further marginal reductions in impacts could be achieved through a reduced programme, this would have a corresponding reduction in science outcomes. This has not been chosen due to the significance of the research being conducted.

Alternative technology and methods

The projects are in several cases already utilising state-of-the-art technology and methods to gather the required data. Only two of the projects will be using invasive sampling (instrumentation of seals and collection of geological material). These are a comparatively small component of the research programme and complement the non-sample-based data collection.

The selected technologies are therefore the considered the most efficient options to achieve the scientific objectives.

Alternative logistical support

The proposed logistics involve a mixture of ship, air and surface transport.

Overall, the planning process has attempted to find the most efficient and cost effective means of meeting all research objectives whilst minimising environmental impacts. The current plan as set out in this IEE is considered the most optimal, although further opportunities for improvement will be reviewed on an annual basis as the field work progresses.

Existing environmental state

The area of West Antarctica that will be the focus of this research programme is one of the least visited parts of Antarctica.

The Thwaites Glacier is roughly the size of Britain and up to 3km thick at its maximum. It is approximately 480km long, and over 650km across at its widest point. Thwaites and neighbouring Pine Island Glacier are among the largest but also the fastest melting glaciers in Antarctica. Thwaites and Pine Island Glaciers are already major contributors to sea level rise and will have a key influence on future sea levels.

Glaciology

The vast majority of West Antarctic is ice covered. Of the Amundsen Sea's numerous glaciers, ice shelves and ice tongues, the Pine Island Glacier and Thwaites Glacier systems are particularly important because of their size and rate of change. Pine Island Glacier is currently Antarctica's fastest melting glacier, retreating at 4km a year with annual discharge of over 130 gigatonnes. Thwaites too is rapidly changing – throughout the 1990s the flow at its centre remained fairly constant, but it widened along the sides, and increased its 30 ± 15% mass deficit by a further 4% in just 4 years.

Geology and geomorphology

Marie Byrd Land is composed of igneous and metamorphic rock formed during the separation of New Zealand from Antarctica during the breakup of Gondwana, underlain by very old Precambrian basement or sedimentary sequences. The majority of the land is ice covered and below sea level. Ice free outcrops are small but numerous, including islands and nunataks. The most extensive areas of ice free land are found inland in the Ellsworth Mountains. The soils are shallow frost sorted till with permafrost below, very low in nutrients and biomass.

A series of extensional volcanic features extends from Pine Island to the Ross Sea, in the West Antarctic Rift System (WARS).

Oceanography

The continental shelf of the Amundsen Sea extends around 400km offshore from the southernmost point of Pine Island Bay, narrowing to 100km wide west of Siple Island. Warm Circumpolar Deep Water has been shown to flood the Amundsen Sea continental shelf. Glacially formed troughs in the shelf play a key role in the ingress of this warm water, which reaches under the floating glacier tongues and ice shelves. Models show a correlation between the amount of CDW ingress and the thinning and acceleration of Amundsen Sea glaciers.

Sea ice

Sea ice extent in the Bellingshausen and Amundsen Seas ranges from approximately 0.5 to 2.5 million km^2 each year. The Amundsen Sea Low (ASL) has deepened in recent decades which has driven southerly winds resulting in decreased sea ice extent in the Bellingshausen Sea. Sea ice extent in the Bellingshausen Sea is influenced by the Southern Annular Mode (SAM; positive SAM correlates with decreased sea ice extent), and by ocean changes although these are not well understood.

Significant polynyas (areas of open water within the sea ice) regularly form to either side of the Thwaites Glacier tongue: the Amundsen Sea Polynya in front of the Dotson Ice Shelf, an area of open water up to 80,000 km^2 and the Pine Island Polynya in front of the Pine Island Ice Shelf.

Marine ecosystem

The combination of upwelling of Circumpolar Deep Water and release of sediments from glacial melt provides nutrients, particularly iron, so that the polynyas of the Amundsen Sea have the highest concentrations of phytoplankton anywhere in Antarctica. This biomass gives rise to increased krill and upper-trophic level predators, such as seabirds, particularly at the shelf break.

A variety of fish species have been identified in the Bellingshausen and Amundsen Seas. *Dissostichus mawsoni* (Antarctic toothfish) is harvested in the region under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR).

Several Adélie and Emperor penguin colonies (identified by BirdLife International as Important Bird and Biodiversity Areas) breed in the intended operational area, including six Emperor colonies each comprising more than 1% of the global population.

Blue petrels, Antarctic petrels, Antarctic prion, snow petrels, southern giant petrels, Wilsons storm petrel, Arctic tern and skuas also occur in the area.

Minke whales forage in the Amundsen and Bellingshausen Seas although no population estimates are available. Humpback whales have been satellite tracked travelling from the Kermadec Islands to the Bellingshausen Sea. Sperm whales, killer whales and beaked whales (species unknown) have also been observed.

Southern elephant seals, leopard seals, Weddell seals and crabeater seals are all found in the area.

Terrestrial environment

Ellsworth Land is has a mean altitude of 1,801.5m and a mean annual temperature of -24.9^{o}C, while Marie Byrd Land averages 1,054.8m altitude and -17.4^{o}C.

Thwaites Glacier had a mean accumulation of 0.457 ± 0.066 mwe yr^{-1} (metres of water equivalent) between 1980 and 2009. While Thwaites showed no trend in either measured or modelled accumulation, nearby systems have been experiencing increased snowfall.

Marie Byrd Land and Ellsworth Land are each distinct biogeographic regions and prolonged isolation of the ice free areas within them has given rise to biota with little similarity with other regions and high degrees of endemism. Relatively little investigation of the terrestrial biota in the Marie Byrd and Ellsworth areas has been undertaken and few sparse observations and collections of lichen and moss species exist. Few invertebrate observations and collections have been made from the area.

Human activity

A number of facilities have been established in West Antarctica over the past 60 years. Byrd Station (80°00′53″S 119°33′56″W) was operated by the United States from 1956 to 1972. The original base (which lasted just four years) and the replacement station are both buried under at least 30 metres of snow. Since this time a summer-only 'surface camp' maintaining a ski-way has been used periodically to support field logistics. Camps and aircraft refuelling facilities have also operated at Pine Island Glacier, WAIS Divide and Siple Dome over the last decade.

The nearest currently operational UK and US year-round bases are Rothera Station (UK), South Pole Station (US) and McMurdo Station (US).

Protected and managed areas

There are no Antarctic Specially Protected or Antarctic Specially Managed Areas designated within the area of operation. No Historic Sites and Monuments (HSM) are designated in the operational area.

None of the spatial management tools used by CCAMLR - Marine Protected Areas, CCAMLR Ecological Monitoring Programme sites or registered Vulnerable Marine Ecosystems (VME) - are in place in the Bellingshausen and Amundsen Seas CCAMLR sectors (88.2 and 88.3).

Assessment of environmental impacts

The actual or potential environmental impacts of the activity are assessed by means of a four-step analysis involving:

i. identifying the **outputs** *i.e.* the physical change imposed on or an input released to the environment;
ii. identifying the **exposure** *i.e.* the interaction between an identified potential output and the environment;
iii. identifying the **impacts** *i.e.* the change in environmental values or resources attributable to the activity;
iv. assessing the **significance** of the identified impacts by considering the spatial extent, duration, intensity and likelihood of occurrence of the potential impacts to each environmental element.

For the purposes of this environmental impact assessment the ITGC has been divided into the following aspects:

1. Research activities, which have been further divided into:
    - The deployment of data collection instruments and equipment (including on, within and under the glacier and ice-shelves as well as open ocean deployed instruments), and
    - Direct sampling (*i.e.* geological cores, ice cores and sediment cores and samples).
2. Logistical and support activities, which have been further divided into:
    - Ice drilling, *i.e.* hot water and RAM drilling
    - Vehicle, vessel and aircraft operations;
    - Establishment and operation of field camps, and
    - Fuel management.

Even with no treatment measures in place the majority of activities are assessed as being likely to pose either low or medium risk to the environment. The fact that most research activities are non-invasive and will occur either in remote glaciological or marine settings reduces the potential environmental impact.

Nevertheless, treatment measures or controls have been identified as being practicable in moderating anticipated impacts in almost all cases. The application of these treatments will ensure greater confidence that the impacts will either be eliminated or minimised.

The raw risk score of a number of outputs are assessed as posing either a high or very high risk to the environment. These are:

- The potential disturbance to one or more seals during the seal tagging work as well as the consequential impacts on the behaviour and capabilities of instrumented seals;
- The risk of introducing non-native species into ice-free terrestrial environments or into the marine environment from a range of activities and equipment deployment;
- The introduction of artificial marine noise from multiple sources during most seasons of the ITGC campaign with potential impacts on the health and behaviour of native marine mammals in the vicinity;
- The potential for a large scale pollution event from the release of large volumes of fuel either into the marine environment *e.g.* from a vessel, or in to the glaciological environment *e.g.* from the rupture of a fuel bladder.

In each of these cases the treatment measures that will be put in place are considered likely to be effective in reducing the environmental risk to medium or low *i.e.* either no more than, or less than a minor or transitory environmental impact.

Cumulative environmental impacts

The assessment also noted a number of outputs that have the potential for a cumulative environmental impact either in conjunction with other ITGC activities, or in conjunction with past, planned or reasonably foreseeable activities in the region. These were the cumulative environment impacts:

- of atmospheric emissions from multiple sources across the four seasons of the research campaign;
- on native marine mammals from multiple anthropogenic noise sources within and across three of the four seasons of the campaign and in conjunction with planned IODP drilling activities in the region during the 2018/19 season;
- of items of equipment being left in or lost to the environment across four seasons of the research campaign, which will add to previously lost items in the region and across Antarctica;
- of the introduction of non-native species into ice-free terrestrial or marine environments;
- of relocating native terrestrial species between ice-free locations.

With no treatment in place each of these risks were scored as either 'high' or 'very high'. However, in each case the planned treatment measures are considered likely to reduce the risk score to medium in each case *i.e.* no more than minor or transitory.

Overall, with the identified treatment options rigorously applied, the outputs from all activities have been assessed as being likely to have no more than a minor or transitory impact on the environment.

Record keeping

This assessment has not identified the need for dedicated monitoring to be undertaken during the ITGC campaign.

Most of the research will involve non-invasive data gathering. Where invasive sampling is undertaken, *i.e.* geological samples and marine sediment cores, the actual or potential impacts of those activities are identified in this assessment as likely to be no more than minor or transitory.

Nonetheless, records will be maintained in many cases both for scientific research purposes as well as for post-season / post-campaign reporting. These records will include:

- The quantities of explosives used;
- The location, type and volume of any fuel or other hazardous substances spills;
- The type and location (as accurately as may be possible) of any equipment inadvertently lost to the environment;
- The type and location of any equipment that is unrecoverable;
- All benthic / sediment and water column sampling locations and the volumes of sediment recovered;
- All geological sampling and coring locations and the quantities of material recovered;
- Any significant observed wildlife disturbance events, including any wildlife fatalities - which will be immediately reported to BAS and/or NSF;
- Any observed non-native species incursions or any items of equipment contaminated with biological material or soil;
- The types and volumes of fuel that are used throughout the course of the campaign, which will be used to calculate the greenhouse gas emissions for inclusion in annual carbon reporting obligations.

Gaps in knowledge and uncertainties

There remain a number of unknowns that have been identified in this course of this environmental imp[act assessment.

The **weather** in Antarctica can be highly variable both between and within summer seasons. This variability and unpredictability may require a number of adjustment to plans, both within and between seasons.

Sea ice is extremely persistent in the Amundsen Sea meaning that precise locations of ship-based activities including equipment deployment and sediment sampling cannot be predicted.

Some **non-recovery of equipment** is anticipated including cabling and instruments that will become locked into the ice. This IEE has not attempted to quantify the materials that will remain in the ice after the ITGC. Provide records are maintained throughout the ITGC campaign it should be possible to estimate total quantities of unrecoverable equipment on conclusion of the research programme.

Not all **fuel** figures are currently known. Actual fuel burnt during the ITGC campaign will likely vary depending on a range of factors, including, vehicle efficiency, changes to operational planning or weather conditions. Therefore the figures used in this EIA and the calculations of predicted emissions are indicative only.

The details of some **equipment to be used is not fully known** at the time of preparation of this IEE and some equipment is still under development. However it is not expected that the final options will alter the current assessment of effects.

The EIA has not evaluated the full acoustic profile of the various sources of marine noise that will occur during the ITGC campaign. No modelling has been undertaken. This makes the assessment of **cumulative effects of marine noise** challenging and remains a gap in this assessment.

The general locations for terrestrial surface geological sampling have been rarely visited previously, if at all, and there are a few biological records. Overall, **information on terrestrial biota is very sparse** and flora and fauna at the specific sites to be visited may well be different from those sampled previously.

Summary and conclusions

This environmental impact assessment has been undertaken on a worst-case scenario evaluation. Consequently, with no treatments in place, a number of activities were assessed as posing a ‘high’ or ‘very high’ risk to the environment with impacts potentially being more than a minor or transitory.

However, in almost all cases practicable treatment options have been identified. The ITGC research programme aims to prevent or reduce potential environmental impacts through careful planning, training, execution and the availability of highly experienced operators and technicians. The two national Antarctic programmes that will be undertaking or supporting the majority of the activities have many decades of experience of operating in the region. Provided the identified mitigation measures are adhered to, the environmental impacts of the Expedition are considered to be largely avoidable or can be minimised to an acceptable level.

Overall, this IEE considers that the potential environmental impacts arising from the ITGC campaign will have **no more than a minor or transitory impact** on the environment.

It is concluded that this level of predicted impact is acceptable given the significant scientific knowledge that will be gained as a result of undertaking the Expedition.

1. Introduction

"There's one issue that will define the contours of this century more dramatically than any other, and that is the urgent and growing threat of a changing climate."

President Barak Obama, UN Climate Change Summit, September 2014

A collapse of the West Antarctic Ice Sheet (WAIS) could raise the global sea level by about 5 meters. Since the 1990s, satellites have shown accelerating ice loss driven by ocean change in five neighbouring glacier catchments in the region, including Thwaites Glacier, that drain more than one third of the WAIS. The rate of ice loss there has doubled in six years and now accounts for about 10 percent of global sea-level rise.

The importance of reducing uncertainty around future predictions in the behaviour of the WAIS has been underscored by the Scientific Committee on Antarctic Research in its "Horizon Scan 2020" (Kennicutt, 2014). Further, the U.S. National Academy of Sciences, Engineering, and Medicine report (A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research, 2015) places prediction of ice mass loss from the West Antarctic Ice Sheet (WAIS) as the top priority for Antarctic research and singles out Thwaites Glacier as a "region of particular concern" (Figure 1).

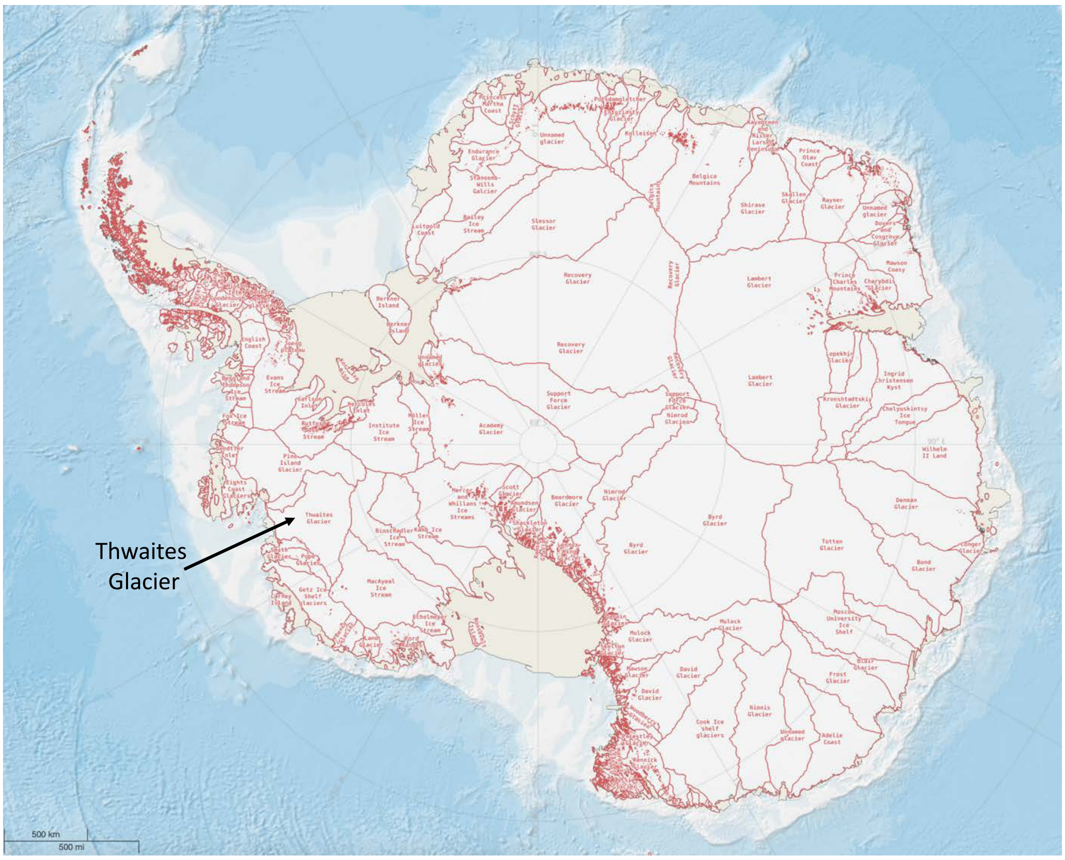

Figure 1. Thwaites Glacier location in Antarctica. Base map: www.add.scar.org

To address this imperative the U.S. National Science Foundation (NSF) and the UK's Natural Environment Research Council (NERC) have developed a joint programme of research with the objective to substantially improve both decadal and longer-term (century-to-multi-century) projections of ice loss and sea-level rise originating from Thwaites Glacier.

The International Thwaites Glacier Collaboration (ITGC) will have a direct and significant impact on understanding the stability of marine ice sheets and specifically the West Antarctic Ice Sheet in the vicinity of Thwaites Glacier, and will contribute to the ice-sheet modelling community's capability to simulate ice sheets and to reduce the uncertainties in sea-level projections. In addition, the programme will contribute to improving risk assessments that coastal communities need for decisions about adaptation and long-term planning.

The NERC and NSF partnership will facilitate eight research projects across the Thwaites Glacier region. Logistical support will be jointly provided by the United States' Antarctic Program (USAP) and the British Antarctic Survey (BAS). It is the largest joint UK-U.S. project undertaken on the southern continent in 70 years.

The ITGC programme of glaciological, geological and marine research focussed on the Thwaites Glacier and Pine Island Bay area of Antarctica will take place over five seasons from 2018/19 through to 2022/23.

This document assesses the environmental consequences that could or will arise from the ITGC. It has been prepared in accordance with the Initial Environmental Evaluation provisions of Annex I to the Protocol on Environmental Protection to the Antarctic Treaty. This level of assessment follows a Preliminary Environmental Evaluation, which found that the Expedition's planned activities are likely to have **no more than a minor or transitory effect** on the Antarctic environment, provided proposed mitigation measures are implemented.

2. Statutory Requirements and Guidance Material

All activities in Antarctica are subject to the provisions of a series of international agreements that constitute the Antarctic Treaty System. These international agreements are enforced through domestic legislation enacted by those countries with active Antarctic involvement, achieved through, for example, the mounting of regular research expeditions and/or establishing a presence in Antarctica through the operation of Antarctic stations or bases.

This Chapter of the EIA:

- describes the relevant international agreements and domestic legislation that will apply to the International Thwaites Glacier Collaboration (ITGC), and
- summarises relevant measures agreed under the auspices of the Antarctic Treaty System.

Given the collaborative nature of the ITGC between the United Kingdom and United States, the applicable domestic legislation for both countries is referenced in this Chapter for completeness (respectively in Sections 2.2.1 and 2.2.2). However, it is intended that this EIA, which covers most of the planned ITGC joint logistics and research activities, will be submitted to the UK's competent authority (the Foreign and Commonwealth Office) for approval. Further details on the scope of this EIA are set out in Chapter 3.

2.1 International Requirements

2.1.1 The Protocol on Environmental Protection to the Antarctic Treaty

The Protocol on Environmental Protection to the Antarctic Treaty (the Protocol) was adopted by the Antarctic Treaty Consultative Parties (ATCPs) in 1991. It entered into force in January 1998.

Article 3 of the Protocol sets out environmental principles for the conduct of activities in Antarctica. Article 3 provides that the protection of the Antarctic environment and the intrinsic value of Antarctica, including its wilderness and aesthetic values and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.

Article 3 also requires that activities in the Antarctic Treaty area are planned and conducted so as to limit adverse impacts on the Antarctic environment and that those activities must be planned and conducted on the basis of information sufficient to allow prior assessments of, and informed judgments about, their possible impacts on the Antarctic environment. Such judgements must take account of:

i. the scope of the activity, including its area, duration and intensity;
ii. the cumulative impacts of the activity, both by itself and in combination with other activities in the Antarctic Treaty area;
iii. whether the activity will detrimentally affect any other activity in the Antarctic Treaty area;
iv. whether technology and procedures are available to provide for environmentally safe operations;
v. whether there exists the capacity to monitor key environmental parameters and ecosystem components so as to identify and provide early warning of any adverse effects of the activity and to

provide for such modification of operating procedures as may be necessary in the light of the results of monitoring or increased knowledge of the Antarctic environment and dependent and associated ecosystems; and

vi. whether there exists the capacity to respond promptly and effectively to accidents, particularly those with potential environmental effects.

Article 8 of the Protocol formalises these requirements by requiring an environmental impact assessment to be prepared in advance of any activity taking place in the Antarctic Treaty Area. The level of the environmental impact assessment is determined by whether the activity in question is identified as having less than a minor or transitory impact; a minor or transitory impact; or more than a minor or transitory impact on the environment.

The detailed procedures for preparing and processing environmental impact assessments are set out in Annex I to the Protocol. If a proposed activity is determined, by means of a preliminary assessment, to have less than a minor or transitory impact, then it may proceed. If an activity is determined as being likely to have no more than a minor or transitory impact, then an Initial Environmental Evaluation (IEE) must be prepared. If an IEE indicates the potential for the activity to have more than a minor or transitory impact, or if such an impact is otherwise determined to be likely, then a Comprehensive Environmental Evaluation (CEE) must be prepared.

Preliminary assessments and IEEs are processed within the domestic legal and administrative systems of each Antarctic Treaty Party. Draft CEEs are however, required to be made publicly available, and to be made available for consideration by the Antarctic Treaty System's Committee for Environmental Protection (CEP). The CEP's advice on the quality of a draft CEE is provided to the Antarctic Treaty Consultative Meeting (ATCM). Comments and advice provided by other Antarctic Treaty Parties and the ATCM must be addressed in a final CEE, which is used as the basis for making a decision about whether and how the activity in question will be conducted.

The Committee for Environmental Protection (CEP) has prepared guidance material to assist those preparing EIAs. The most recent version of these guidelines was adopted by the 28th ATCM (Resolution 1 (2016) refers). These guidelines have been consulted in the preparation of this EIA.

The EIA method used to meet these obligations is outlined in Chapter 7.

2.1.2 The Convention for the Conservation of Antarctic Seals

The Convention for the Conservation of Antarctic Seals (CCAS), which is aimed at protecting the stocks of Antarctic seals from commercial exploitation, was signed on 1 June 1972. It entered into force in 1978. The UK and the U.S. are signatories to the Convention.

The objective of the Convention is to protect and enable scientific research on Antarctic seals and to maintain a satisfactory balance in the Antarctic ecosystem.

Article 5 of the Convention and paragraph 6(a) of the Annex to the Convention set out exchange of information obligations on all Parties to the Convention. These provisions require Contracting Parties to the Convention to provide before 30 June each year a summary of statistical information on all seals killed or captured by their nationals and vessels under their respective flags in the Convention area, in respect of the preceding period 1 March to the last day in February.

Seals research will be undertaken as part of the ITGC (see Section 4.3.1.2) and information that meets the exchange of information requirements of the Convention will need to be provided to the Depository Government (the UK) on an annual basis throughout the campaign.

2.1.3 The Convention on the Conservation of Antarctic Marine Living Resources

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was negotiated by the Antarctic Treaty Consultative Parties and adopted at the Conference on the Conservation of Antarctic Marine Living Resources which met in Canberra, Australia in May 1980.

The Convention applies to all Antarctic populations of finfish, molluscs, crustacea and sea birds found south of the Antarctic Convergence. The objective of the Convention is the conservation of Antarctic marine living resources, where the term 'conservation' includes rational use.

There are no activities being undertaken by the ITGC that require regulation under CCAMLR. A check has also been undertaken to assess the potential for any conflicts that might arise with marine areas of particular interest to CCAMLR. This is addressed in Chapter 6.

2.2 National Requirements

2.2.1 United Kingdom

The EIA provisions of the Protocol are enacted in UK law through the Antarctic Act 1994 and Antarctic Act 2013 and Antarctic Regulations 1995/490 (as amended). The provisions of the legislation apply to any person who is on a British expedition to Antarctica, where a British expedition is defined as an expedition "that is organised in the United Kingdom, or the place of final departure for Antarctica of the persons on the expedition was in the United Kingdom". The Act applies to both governmental and non-governmental activities in Antarctica.

The Act is administered by the Foreign and Commonwealth Office (FCO) and the Secretary of State makes the final determination on whether an activity may proceed taking into account the FCO's recommendations. It is an offence under the Act to enter Antarctica without a permit issued by the Secretary of State.

The Act also prohibits the following activities unless a permit is obtained:

- undertaking mineral resource activities
- intentionally, killing, injuring, capturing, handling or molesting any native mammal or native bird
- intentionally disturbing native mammals or native birds
- removing or damaging any native plant so as to significantly affect its local distribution or abundance, or significantly damaging a concentration of native plants
- causing significant damage to the habitat of any native mammal, bird, plant or invertebrate
- introducing any species of non-native animal or plant
- entering an Antarctic Specially Protected Area (ASPA), or an area designated as protected by CCAMLR
- damaging, destroying or removing a designated historic site or monument

Those activities relevant to the ITGC programme that include mineral resource activities for scientific research and interference with native mammals will need to be covered by a specialist activities permit. The relevant permit application for these activities will be submitted to the UK Foreign and Commonwealth Office (FCO) before end of December 2018.

Other logistical activities associated with the ITGC project will be covered by the BAS Operating Permit, which is organised directly between BAS and the FCO.

The Secretary of State has discretion under the Act to set conditions regarding the proposed activity. Such conditions may relate to, for example, managing compliance, undertaking environmental monitoring and post-activity reporting. Under the provisions of the Act, non-compliance is an offence carrying a penalty of up to two years imprisonment or a fine or both.

2.2.2 United States of America

In the U.S., the EIA provisions of the Protocol are implemented through regulations at 45C.F.R. Part 641 – Environmental Assessment Procedures for Proposed national Science Foundation Actions in Antarctica.

The Antarctic Conservation Act (ACA), as amended, 16 U.S.C. § 2401, et seq., protects Antarctic native mammals, birds, plants, and their ecosystems. The law applies to all U.S. citizens going to Antarctica, whether or not they go to Antarctica with the USAP, and all Antarctic expeditions that originate from the United States and applies to both governmental and non-governmental activities in Antarctica.

Without a permit it is illegal to:

- take native mammals or birds
- engage in harmful interference
- enter Antarctic Specially Protected Areas (ASPAs)
- introduce species to Antarctica
- introduce substances designated as waste
- discharge designated waste
- import certain Antarctic items into the USA or export them to another country

Penalties for any person found to be in breach of the ACA include a fine of up to approximately US$28,000, one-year imprisonment per violation, removal from Antarctica, cancellation of a grant, and/or sanctions by their employer.

The U.S. National Science Foundation manages the ACA permit application process for all applicants.

2.3 Applicable ATCM Measures and Resolutions

In addition to the general provisions of the Protocol outlined above, the ATCM has, over time adopted a suite of additional agreements (in the form of Recommendations, Resolutions or Measures) several of which are pertinent to the ITGC in that they relate specifically to the issue of Antarctic scientific research, logistical and operational activities, or environmental management.

Relevant Recommendations, Resolutions and Measures are highlighted here for completeness and will be taken into account in this environmental impact assessment and in the conduct of the ITGC.

2.3.1 Scientific research in Antarctica

Measures related to scientific research in Antarctic and relevant to the ITGC include:

- Recommendation I-II (1961) – Exchange of Scientific Personnel
- Recommendation I-III (1961) – Availability of Scientific Data
- Recommendation I-V (1961) – Scientific and Technical Cooperation with International Organisations (WMO)
- Recommendation XIV-3 (1987) – Regulations for Scientific Drilling
- Recommendation XV-14 (1989) – Promotion of International Scientific Cooperation
- Recommendation XVI-12 (1991) – Seismic Data Library System
- Resolution 4 (1998) – National Antarctic Data Centres
- Recommendation VIII-10 (1975) – Protection and study of Antarctic marine living resources
- Resolution 2 (2014) – Cooperation, Facilitation and Exchange of Meteorological and Related Oceanographic and Cryospheric Environmental Information
- Resolution 5 (2014) – Strengthening Cooperation in Hydrographic Surveying and Charting of Antarctic Waters
- Resolution 6 (2015) – The Role of Antarctica in Global Climate Processes
- Resolution 5 (2018) – SCAR's Environmental Code of Conduct for Terrestrial Scientific Field Research in Antarctica

2.3.2 Logistical and operational activities in Antarctica

Measures related to logistical and operational activities in Antarctic and relevant to the ITGC include:

- Recommendation VII-8 (1972) – Common Transport Facilities
- Resolution 2 (2004) – Guidelines for the Aircraft Near Concentrations of Birds
- Resolution 6 (2008) – Maritime Rescue Coordination Centres and Search and Rescue in the Antarctic Treaty Area
- Resolution 6 (2010) – Improving the Co-ordination of Maritime Search and Rescue in the Antarctic Treaty Area
- Resolution 3 (2012) – Improving Co-operation in Antarctica
- Resolution 8 (2012) – Improved Co-ordination of Maritime, Aeronautical and Land-based Search and Rescue
- Resolution 1 (2013) – Air Safety in Antarctica
- Resolution 4 (2013) – Improved Collaboration on Search and Rescue in Antarctica
- Resolution 1 (2014) – Fuel Storage and Handling
- Resolution 5 (2014) – Strengthening Co-operation in Hydrographic Surveying and Charting of Antarctic Waters

2.3.3 Environmental Management in Antarctica

Measures related to environmental management in Antarctica and relevant to the ITGC include:

- Resolution 2 (2005) – Guidelines for Environmental Monitoring
- Resolution 3 (2006) – Ballast Water Exchange
- Resolution 3 (2007) – Long-term Monitoring
- Resolution 2 (2013) – Antarctic Clean-Up Manual
- Resolution 5 (2015) – Important Bird Areas in Antarctica
- Resolution 1 (2016) – Revised Guidelines for Environmental Impact Assessment in Antarctica
- Resolution 4 (2016) – Non-native Species manual
- Resolution 2 (2017) – SCAR's Code of Conduct for the Exploration and Research of Subglacial Aquatic Environments

2.4 COMNAP guidance material

The Council of Managers of National Antarctic Programs (COMNAP) provides a forum for cooperation among National Antarctic Programs that have responsibility for delivering and supporting scientific research in the Antarctic Treaty Area on behalf of their respective governments.

COMNAP has developed guidance material that is also relevant to the ITGC, including:

- A Checklist for Supply Chain Managers for the Reduction of Risks of Introduction of Non-native Species
- COMNAP Guide to Emergency Response and Contingency Planning
- The Antarctic Flight Information Manual
- COMNAP Fuel Manual

All of the above obligations and guidance material have been taken into account in the preparation of this EIA and, where relevant, in the various control measures identified to minimise the impacts of activities undertaken by the ITGC in Antarctica.

Consideration of the additional provisions of the Protocol as they relate to waste management, prevention of marine pollution and area protection and management are considered in later chapters of this EIA.

3. Scope of the Initial Environmental Evaluation

This environmental impact assessment evaluates the environmental consequences that will or could arise from the International Thwaites Glacier Collaboration (ITGC) - a five-season programme of glaciological, geological and marine research focussed on the Thwaites Glacier and Pine Island Bay area of Antarctica (Figure 1).

The ITGC, which is described in detail in Chapter 4, will be undertaken during austral summer seasons 2018/19 through to and including 2022/23.

The ITGC is a significant programme of collaborative research jointly funded by the United States' National Science Foundation (NSF) and the United Kingdom's Natural Environment Research Council (NERC). Logistical support to the ITGC will jointly be provided by the United States' Antarctic Program (USAP) and the British Antarctic Survey (BAS).

Researchers from a number of U.S. and UK research institutes will participate in the ITGC and will utilise and deploy a range of research techniques and equipment in Antarctica.

Additional collaboration will involve the Korean Polar Research Institute (KOPRI) which will make its Polar research and resupply vessel, *Araon*, available during the 2019/20 season.

This Chapter describes the scope of the EIA and provides the rationale for what is and what is not included within the scope.

3.1 Area and Activities that are included in the EIA scope

The geographical scope of the EIA (Figure 3) is the area of west Antarctica that includes:

- the Thwaites Glacier and Thwaites ice-shelf;
- the glacial areas / shear margins immediately adjacent to the Thwaites Glacier including parts of the Pine Island Glacier;
- parts of the Dotson Glacier and ice-shelf
- ice-free, in-land locations including the Hudson Mountains and Mt Murphy;
- several islands and islets in Pine Island Bay;
- Areas of the Amundsen Sea and Pine Island Bay for marine research including in front of the Thwaites, Crosson and Dotson ice shelves;
- the area of the Ronne Entrance on the south western side of the Antarctic Peninsula and associated ice shelves which will be used to offload vehicles and fuel for the BAS traverses;
- the traverse route between the vessel offload in Ronne Entrance and the depot site of SB9 and the traverse route between SB9 and the Thwaites Glacier research area.

The EIA will seek to assess the actual or potential environmental consequences arising from:

- the logistical support activities that will be provided to the ITGC including:
    - U.S. and UK over-ice traverses including those that will be undertaken to provide fuel and those that will be undertaken to support research (such as the seismic traverses);
    - Other over-ice vehicles such as skidoos that will be used to access research sites from several of the camp locations;
    - Aircraft activities undertaken in direct support of the ITGC including BAS Twin Otters used for aero-geophysical surveys and helicopters used to deploy equipment and personnel;
    - Vessel operations when providing support to the ITGC in the Pine Island Bay / Amundsen Sea area;
    - The establishment of fuel caches at selected locations;
    - The establishment of field camps and several locations;
    - Emissions arising from the burning of fossil fuels by vehicles and field camps;

and

- the programme of research to be undertaken including:
    - The deployment, operation and partial recovery of static monitoring equipment both on, within and under the Thwaites Glacier and at various marine locations in Pine Island Bay;
    - The deployment of expendable (unrecoverable) research equipment;
    - The deployment, operation and recovery of tethered and autonomous underwater survey vehicles both in Pine Island Bay and beneath the Thwaites Glacier;
    - The recovery of glacial and geological cores and the use of glaciological and geological coring equipment;
    - The recovery of surface geological samples;
    - The recovery of marine sediment cores and the use of sediment coring devices in both open-water (from vessels) and under-ice scenarios (through hot-water drilled holes);
    - The use of drilling equipment to drill holes into and through the Thwaites Glacier;
    - The conduct of active and passive seismic measurements across the Thwaites Glacier;
    - The use of penetrative radars from aircraft and on snow for investigation of the glacier and ice shelf;
    - The instrumentation of two seal species.

3.2 Activities that are excluded from the EIA scope

The ITGC will be undertaken within the framework of ongoing logistical and research activities being undertaken by the UK and U.S. Antarctic programs. Accordingly, the following activities are excluded from the scope of this EIA:

- The general operation of the various research vessels in Antarctic waters beyond their immediate support to the ITGC campaign;
- The general operation of U.S. and UK aircraft beyond their immediate support to the ITGC campaign;

- The operation of the U.S. WAIS divide camp, which has been operational for several seasons and continues to support a number of research projects in addition to the ITGC programme;
- The research cruise to be undertaken by the Nathaniel B Palmer during the 2019/20 season and all associated marine research activities to be conducted from the vessel, which will involve a programme of marine seismic surveying. These marine research activities are considered to some extent in this IEE, but will be assessed in more detail by means of a separate EIA that will be prepared by NSF;
- The operation of the Korean Polar research and resupply vessel *Araon*, even when operating in support of the ITGC within the Amundsen Sea area. The activities to be conducted from the Araon e.g. the deployment of the AUV, is considered in this IEE, but the operation of the *Araon* itself, whilst mentioned in this EIA, will be assessed and authorised by the relevant South Korean competent authority;
- The U.S. aircraft rotations between McMurdo Station and the WAIS Divide camp, which will be undertaken in support of a range of U.S. research programmes of which one will be the Thwaites Glacier campaign.

4. Description of the Planned Activities

4.1 Research projects

It is known that the amount of ice flowing out of the Thwaites Glacier region has nearly doubled over the last 30 years. Warm ocean water from the Amundsen Sea circulates under the ice, causing it to melt. Melting loosens the ice from the bedrock below, causing it to flow faster and eventually to retreat into the deeper and thicker ice areas where it is likely to speed up even more.

The ITGC programme will explore the ocean and marine sediments, measure currents flowing toward the deep ice, and examine the stretching, bending, and grinding of the glacier over the bedrock below. The project will involve more than 60 scientists and students.

The entire Thwaites programme research initiative comprises eight interconnected and inter-dependent research projects. Six of these research projects will involve on-ice research activities. Two do not require time in Antarctica and will utilise data obtained from the other projects. The projects are schematically represented in figure 2 and described in the sub-sections below.

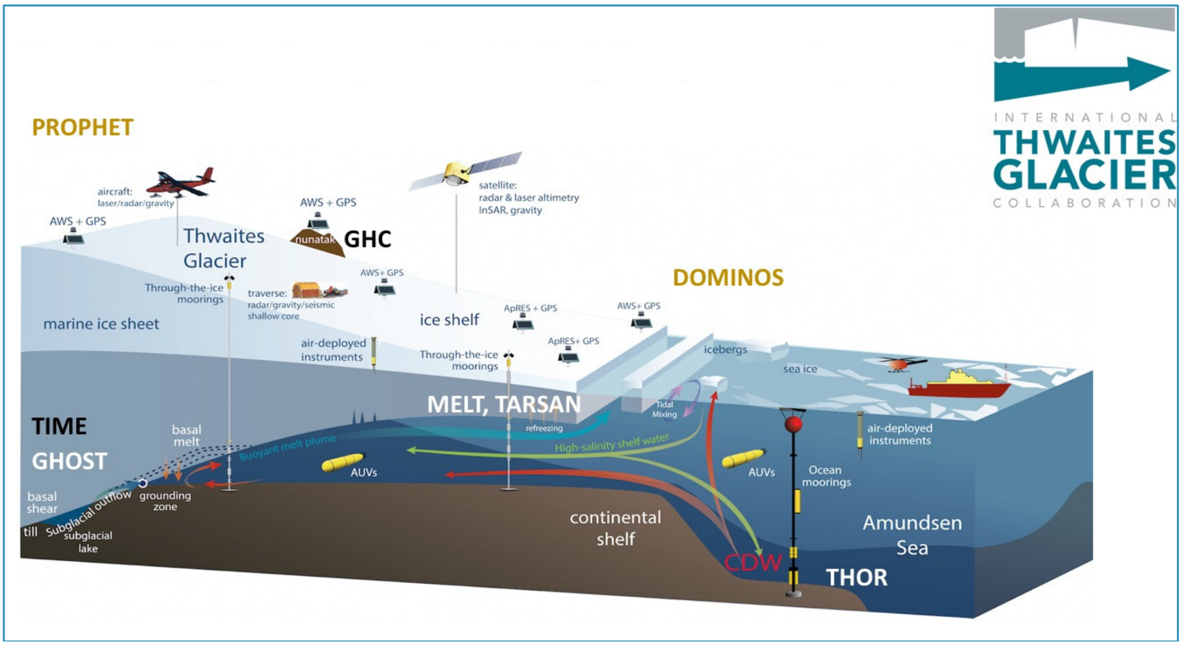

Figure 2. Schematic providing an overview of the eight research projects. Source: Scambos et al., 2017.

4.1.1 GHC

The GHC project will examine the Geological History Constraints on the magnitude of the grounding-Line retreat in the Thwaites Glacier System.

Determining the conditions under which the Thwaites and Pine Island Glacier grounding lines have retreated and re-advanced in the past is critically relevant to determining whether or not present-day grounding-line retreat is irreversible.

GHC researchers propose to obtain geological evidence from the Thwaites and Pine Island glacier system (the 'Thwaites system') that will show whether and when glaciers were less extensive than they are at present. This is important due to concern that currently observed grounding line retreat in the Thwaites system may be irreversible and lead to globally significant sea-level impacts.

GHC goals are to:

1. determine whether previous grounding-line retreat-advance cycles, as suggested by existing geological evidence, occurred in the late Holocene;
2. establish under what climate and sea-level boundary conditions they took place.

4.1.2 GHOST

The project entitled Geophysical Habitat of Subglacial Thwaites (GHOST) aims to address the overarching question: will basal conditions allow for the rapid retreat of the Thwaites Glacier grounding line?

Projecting the retreat rate of the Thwaites Glacier, and whether it can stabilize without completely deglaciating the marine basins of West Antarctica, are of critical importance in a warming world. The GHOST project aims to learn whether basal conditions allow for rapid retreat of the Thwaites Glacier grounding line or whether retreat may slow or stop on the transverse ridge about 70 km inland, and to learn whether englacial and subglacial conditions allow for the Thwaites Glacier to rapidly expand its boundaries and deglaciate adjacent marine basins.

GHOST researchers intend to conduct a coordinated geophysical program, with interactive modeling, to characterize the bed of the glacier at key locations using active-source seismic surveys, natural-source seismic monitoring, profiling and phase-sensitive radar, and electrical and gravity methods.

GHOST researchers propose to learn where the glacier bed is hard and basal motion follows a viscous law, or soft with a more plastic behavior, to identify the radar signatures of these different beds so they can be mapped into more crevassed regions, and ultimately to inform models to assist in understanding whether stabilisation during retreat is likely or not.

The project aims to:

1. Conduct geophysical surveys over the subglacial ridge that models suggest would be the location of the next relatively stable grounding line, after the Thwaites Glacier retreats from its current grounding line;
2. Extend these surveys along a transect that follows a flowline of the Thwaites Glacier near its centerline, to comprehensively characterize the bed of the glacier for properties that are essential constraints to numerical ice-sheet models, including the distribution of sediments and water, high-resolution 3D bed topography, and a quantitative estimate of important bed properties such as sediment porosity and roughness, and deeper properties including geothermal flux and flexural thickness affecting isostatic response that may help stabilize against retreat;
3. Conduct similar geophysical surveys along a transverse line that crosses the eastern shear margin of the Thwaites Glacier in order to assess both variability across flow as well as the likelihood of margin migration;
4. Leverage new geophysical constraints to improve understanding of the stability of the Thwaites Glacier using ice-sheet models and satellite remote sensing.

4.1.3 MELT

This project will observe, quantify and model the Thwaites ice-ocean system in the grounding zone, to firmly establish the physics linking ocean forcing and ice-sheet response. The time-dependent cavity will be thoroughly surveyed and instrumented with ocean monitoring devices. Melting will be observed by a network of autonomous sensors as well as from space over an extended period. The response of the glacier will also be observed.

The primary objective of the project is to quantify how the contribution of the Thwaites Glacier to sea-level rise depends on the oceanographic conditions near the glacier.

To meet this objective, MELT researchers will aim to improve representation of two crucial processes in model simulations: the melt rate at the base of the ice shelf in an ocean model, especially in the grounding zone, and an ice sheet model's treatment of the grounding line. To achieve this, MELT proposes three interrelated modeling studies, with the key processes carefully validated using the results of targeted field experiments. MELT will aim to deliver:

1. A physics-based scheme describing ocean melting in the grounding zone of the Thwaites Glacier, suitable for inclusion in numerical ocean models of sub-ice shelf cavities;
2. Verification of the treatment of grounding-line dynamics in the commonly-used class of ice-sheet models used for projections of the Thwaites Glacier;
3. An optimized and validated parameterization of heat and salt transport across the ice-ocean boundary layer beneath the entire Thwaites Ice Shelf, to enable numerical models to predict basal melt rate reliably;

MELT will also produce two ancillary science deliverables:

- A dramatically-improved cavity geometry for the Thwaites Glacier for use in ocean models;
- A probability distribution of the 21st century sea-level contribution from the Thwaites Glacier, given a range of ocean forcing guided by present-day observed variations in the Amundsen Sea.

4.1.4 TARSAN

Ice-sheet models suggest that the mass loss from glaciers in the Amundsen Sea Embayment (ASE) will accelerate in the near future, initiating an eventual collapse of the West Antarctic Ice Sheet (WAIS) and raising the global sea level by up to 2.5 meters in as short as 500 years. Such model predictions, however, still lack understanding of the dominant processes at and near grounding zones, especially their spatial and temporal variability, as well as atmospheric and oceanic drivers of these processes. The Thwaites-Amundsen Regional Survey and Network (TARSAN) project aims to constrain these processes for the Thwaites and the Dotson Ice Shelves.

The TARSAN project aims to:

1. install a number of atmosphere-ice-ocean multi-sensor stations on the ice shelves for two years to provide sub-daily continuous observations of concurrent oceanic, glaciologic, and atmospheric conditions;
2. measure ocean properties on the continental shelf adjacent to ice-shelf fronts (using a range of methods including seal tagging, glider-based and ship-based surveys and existing moored and CTD-cast data) and into sub-ice-shelf cavities (using Autonomous Underwater Vehicles (AUVs)) to detail ocean transports and heat fluxes; and

3. constrain current ice-shelf and sub-ice-shelf cavity geometry, ice flow, and firn properties for the ice-shelves (using radar, active-source seismic and gravimetric methods) to better understand the impact of ocean and atmosphere on the ice-sheet change.

4.1.5 THOR

The THOR project (Thwaites Offshore Research) will examine the records of external drivers and resulting behaviour of the Thwaites Glacier.

The THOR project's primary objective is to conduct integrated marine geological and geophysical investigations seaward of the contemporary Thwaites Glacier grounding line to deliver detailed records of change and boundary conditions that, when incorporated into numerical models, will improve projections of the glacier's contribution to sea-level rise.

THOR researchers will aim to improve knowledge of processes that influence glacial dynamics, and which may contribute to collapse of marine ice sheets, especially those which, because they occur over decadal to millennial time scales, are poorly understood and not reliably simulated in models.

Specific project objectives are to:

1. Characterize seabed boundary conditions, *i.e.*, bathymetry and substrate characteristics, in the sub-ice-shelf cavity and on the inner shelf, so as to establish:
    a. the pathways along which warm water is steered to the grounding line;
    b. the bed topography that the grounding line has retreated from in the recent past; and
    c. the locations, dimensions, and substrate character of former ice shelf pinning points.
2. Obtain sediment proxy records of water mass distribution and temperatures, the main external drivers of change, focusing particularly on recent centuries and aiming for decadal resolution. Records will be obtained from proxies measured on sediment cores collected from beneath and in front of the ice shelf, better informing the incursion of circumpolar deep water into the sub-ice shelf cavity and to the grounding line.
3. Improve knowledge of processes leading to the potential collapse / retreat of the Thwaites Glacier, including mechanisms of recent ice unpinning from the seabed and the influence of subglacial meltwater delivery to the grounding line.
4. Determine the history of past change in positions of the grounding line, calving zone, and ice shelf pinning points, and in delivery of sediment and meltwater to the grounding line, spanning the Holocene with a particular focus on changes that have occurred over the past few centuries

4.1.6 TIME

The research project 'Thwaites Interdisciplinary Margin Evolution' (TIME), will examine the role of shear margin dynamics in the future evolution of the Thwaites drainage basin.

Understanding the controls on the Eastern Shear Margin of the Thwaites Glacier is fundamental to predicting future contribution of this region to sea level rise.

TIME researchers propose to use a combination of geophysical field observations, process-based models of shear margin dynamics, and regional ice flow models to investigate the potential impact of shear margin dynamics on near-future contribution of the Thwaites Glacier drainage basin to eustatic sea-level changes.

TIME hypotheses are:

1. **The eastern shear margin of Thwaites is not fixed by subglacial geology or topography**. This hypothesis focuses on subglacial controls on margin migration. Lateral migration of glacier shear margins can have a powerful impact on mass balance of fast flow glaciers unless changes in shear margin location are hindered by fixed factors such as bed topography, bed roughness, and subglacial geology. In the absence of such strong controls, shear margin locations are determined more dynamically by glaciological processes.

   The TIME project will use seismic and radar techniques to test if the Eastern Shear Margin is of the 'fixed' or 'dynamic' type. TIME will also record changes in internal layering (strain), attenuation (temperature) and basal reflectivity (melting) across the shear margin using autonomous (phased array) radar systems;

2. **The eastern shear margin can migrate laterally at high rates**. If a shear margin is not fixed by subglacial factors its location can change in response to external forcings (*e.g.* ice acceleration and thinning) or internal dynamics (*e.g.* subglacial hydrological fluctuations). Its potential (in)stability is controlled to a significant extent by the degree to which ice within a shear margin is weaker than ice on both sides of the margin. Mechanisms of shear margin softening include: (i) development of preferred ice crystal fabric, (ii) crevassing, and (iii) warming of ice due to high shear heating.

   The TIME project will use seismic and radar methods to evaluate the strength of preferred fabric orientation at selected field sites. TIME will also use GPS surveys to accurately determine surface ice flow velocities across the Eastern Shear Margin. GPS measurements of surface velocities, strains and strain rates over two years will allow researchers to check if the Eastern Shear Margin may be already undergoing lateral migration.

3. **Rapid lateral shear margin migration in the Thwaites drainage basin may significantly accelerate mass loss**. Future rapid outward migration of the Eastern Sheer Margin can play a particularly pivotal role in accelerating regional contribution to eustatic sea level rise because it can lead to gradual merging of fast flowing areas in the Thwaites Glacier and Pine Island Glacier basins. Geophysical field observations collected as part of the proposed project will be used to inform a new generation of process-based numerical models of shear margin dynamics to evaluate potential rates of shear margin migration within the Thwaites Drainage Basin in the coming decades to centuries. These results, in turn, will be used to constrain a larger scale ice sheet model capable of quantifying the impact of margin migration on ice flow in the wider region and thereby offering realistic predictions for interactions between two key ice drainage basins, West Antarctic Ice Sheet stability and sea level rise.

4. **New shear margins may form within the Thwaites drainage basin under the conditions of significant future thinning**. This new scientific idea may have significant consequences for projecting the future sea level contributions from the Thwaites Glacier drainage basin and the West Antarctic Ice Sheet overall. To address this hypothesis TIME will develop a process-based model and undertake field observations to characterise the eastern shear margin, which will be used in the higher-order Community Ice Sheet Model to be developed by the Thwaites Programme.

4.1.7 DOMINOS AND PROPHET

The final two ITGC projects do not require on-ice support and are thus not addressed further in this EIA. The projects will develop a series of models that will be constrained by the data collected during the six on-ice research projects described above.

The modelling projects are:

1. The DOMINOS project (Disintegration of Marine Ice-Sheets Using Novel Optimised Solutions), which aims to address uncertainties in the processes that control ice sheet dynamics using a novel ice-dynamics model suite.
2. The PROPHET project (Processes, drivers, prediction: modelling the History and Evolution of Thwaites) which will rely on three independent numerical models of ice flow, coupled to an ocean circulation model so as to:
    a. improve understanding of the interactions between the ice and the bedrock;
    b. analyze how sensitive the Thwaites Glacier is to external changes, such as changes in ocean-induced melt under its floating extension or calving front position;
    c. assess the processes that may lead to a collapse of Thwaites, and
    d. forecast future ice loss of Thwaites.

The ITGC research programme is overseen by a joint U.S. / UK Science Coordination Office.

4.2 Season by season overview

The ITGC research campaign will operate over a period of five seasons: 2018/19 to 2022/23, with peak research and logistical support activity occurring over the 2019/20, 2020/21 and 2021/22 seasons.

The areas of activity throughout the duration of the research programme, and the primary camp locations are shown in Figure 3. Research activities will be focussed on the Thwaites Glacier but will involve camps and other logistical infrastructure at several locations within Ellsworth Land and Marie Byrd Land, as well as marine-based activities in the Amundsen Sea and Pine Island Bay.

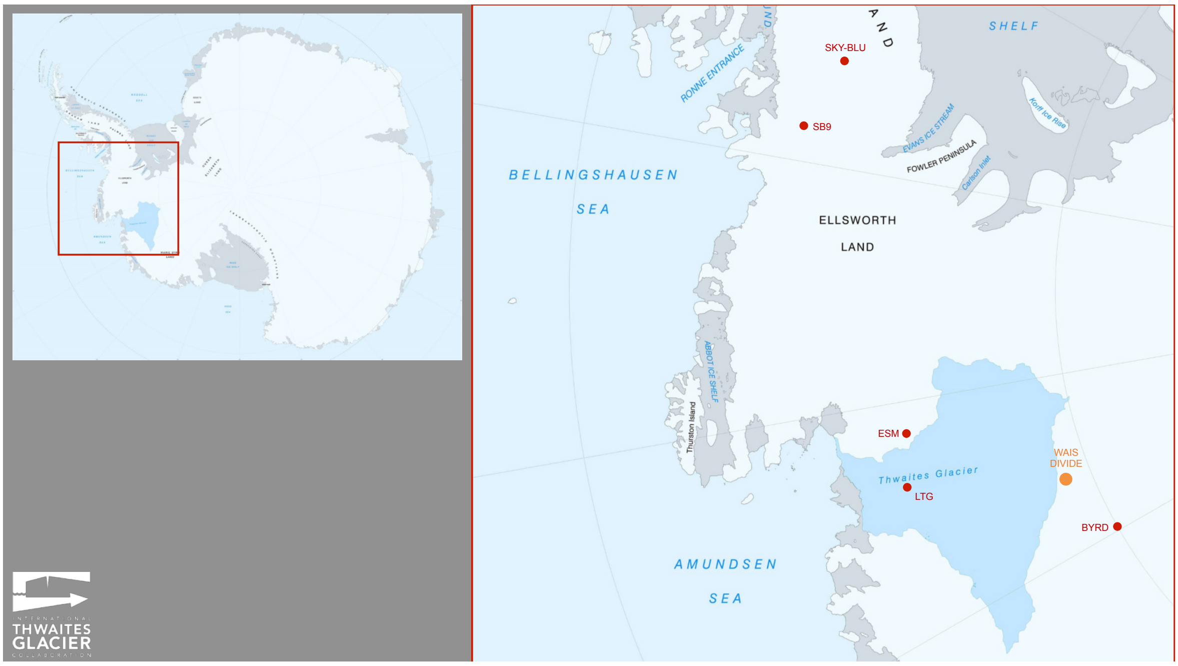

Figure 3. Area of activity for the four-season research campaign showing the primary logistical support hubs. SkyBlu = UK-maintained blue-ice runway; SB9 = UK forward logistics hub; ESM = Eastern Sheer Margin camp; LTG = Lower Thwaites Glacier camp; WAIS Divide

In broad terms, activities will commence in late November each season with the mobilisation of logistics support and personnel via aircraft through the U.S. McMurdo Station and through the (already established) U.S. WAIS Divide camp (Figure 3).

The U.S. Byrd Surface camp has been reopened for the ITGC campaign and will act as a supplies alternate to WAIS Divide camp. Supplies will be traversed between Byrd and WAIS Divide camp by tractor traverse, or from Byrd to other field hubs by air or tractor traverse.

As the primary field gateway, WAIS Divide camp will be the main hub for science personnel and science equipment transfers from McMurdo Station and thus links to the continent from Christchurch, New Zealand. During the primary science seasons most personnel and science equipment moves will route through Christchurch, McMurdo and WAIS Divide camp.

The Lower Thwaites Glacier (LTG) site is a previously operated U.S. field location and will act as the hub camp for projects operating on the lower part of the Thwaites Glacier, as well as for the aero-geophysics flights during the 2018/19 season.

The camp site at the Eastern Shear Margin (ESM) will be selected early in the 2018/19 season during the BAS-operated operational traverse (see below) and will be one of the primary camps to support the TIME project. Both LTG and ESM camps will act as primary locations for fuel caches.

On-ice research activity will be undertaken between late November and late January each season (Figure 4), with the exception of additional helicopter supported research during the 2019/20 season which will run into February.

Ship supported research in the 2018/19, 2019/20 and 2020/21 seasons will be undertaken between late January and March (Figure 4).

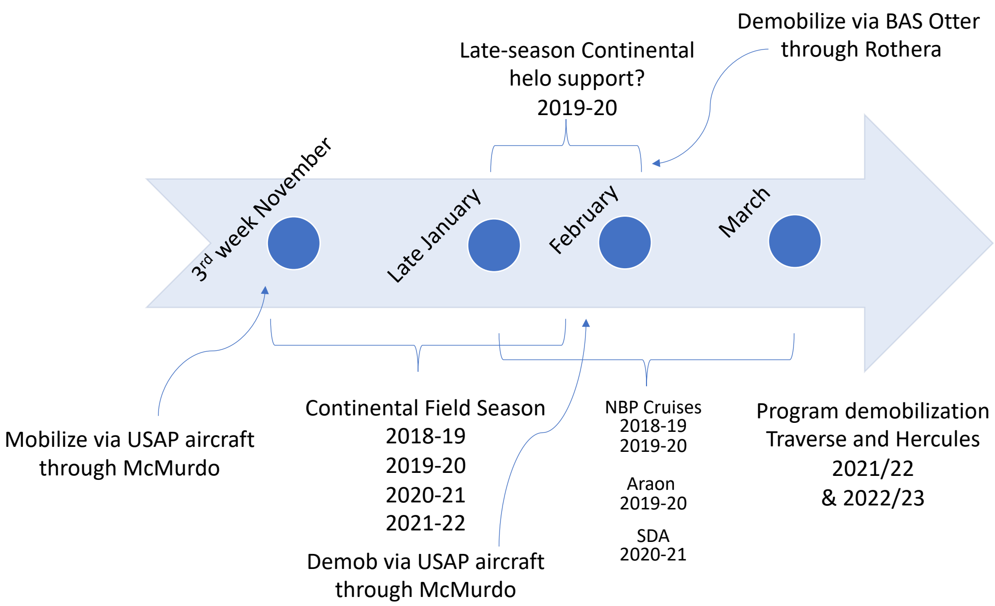

Figure 4. Summary overview of the timing of activities in each of the ITGC field seasons.

The main areas of activity for each of the six research programmes are summarised in Figure 5. The following sections provide more detail on the planned activity for each season.

Figure 5. Overview of the primary areas of research activity for each of the research programmes.

4.2.1 2018 – 2019 Season

The 2018/19 season will be a heavy logistics season with most research undertaken from the Nathaniel B Palmer in Pine Island Bay.

In early January 2019 the UK vessels RRS Ernest Shackleton and HMS Protector will arrive at the Ronne Inlet and will offload traverse vehicles (four Pisten Bullys, 14 skidoos), sledges including a living caboose for the traverse, field equipment (including ice drills), the Alfred Wegener Institute Vibroseis truck and associated geophone streamer (which will be used by the GHOST project during the 2020/21 and 2021/22 season), field food, explosives (1.6 tonnes) and detonators (which will be used by the GHOST and MELT projects in later seasons) and fuel (408,000 litres of AVTUR which will be moved in fuel bladders, plus 80 x 205 litre drums of MOGAS and 2 x 205 litre drums of kerosene).

When combined with equipment already at the offload site this will generate a four-vehicle traverse fleet with two associated living cabooses.

The offloading point and traverse route between the coast in Ronne Inlet and SB9 was surveyed by BAS field staff during November and December 2017. Ideally, the vessels will position themselves alongside the Stange Ice Shelf and offload all items directly on to the ice shelf. Sea ice conditions may prevent this, in which case offload may need to take place on to the sea ice (near to Smyley Island) and items ferried on to the ice shelf (and onward to SB9) via tractor train.

This offload process is expected to take up to one month with all items ultimately being moved to SB9 (Figure 6a).

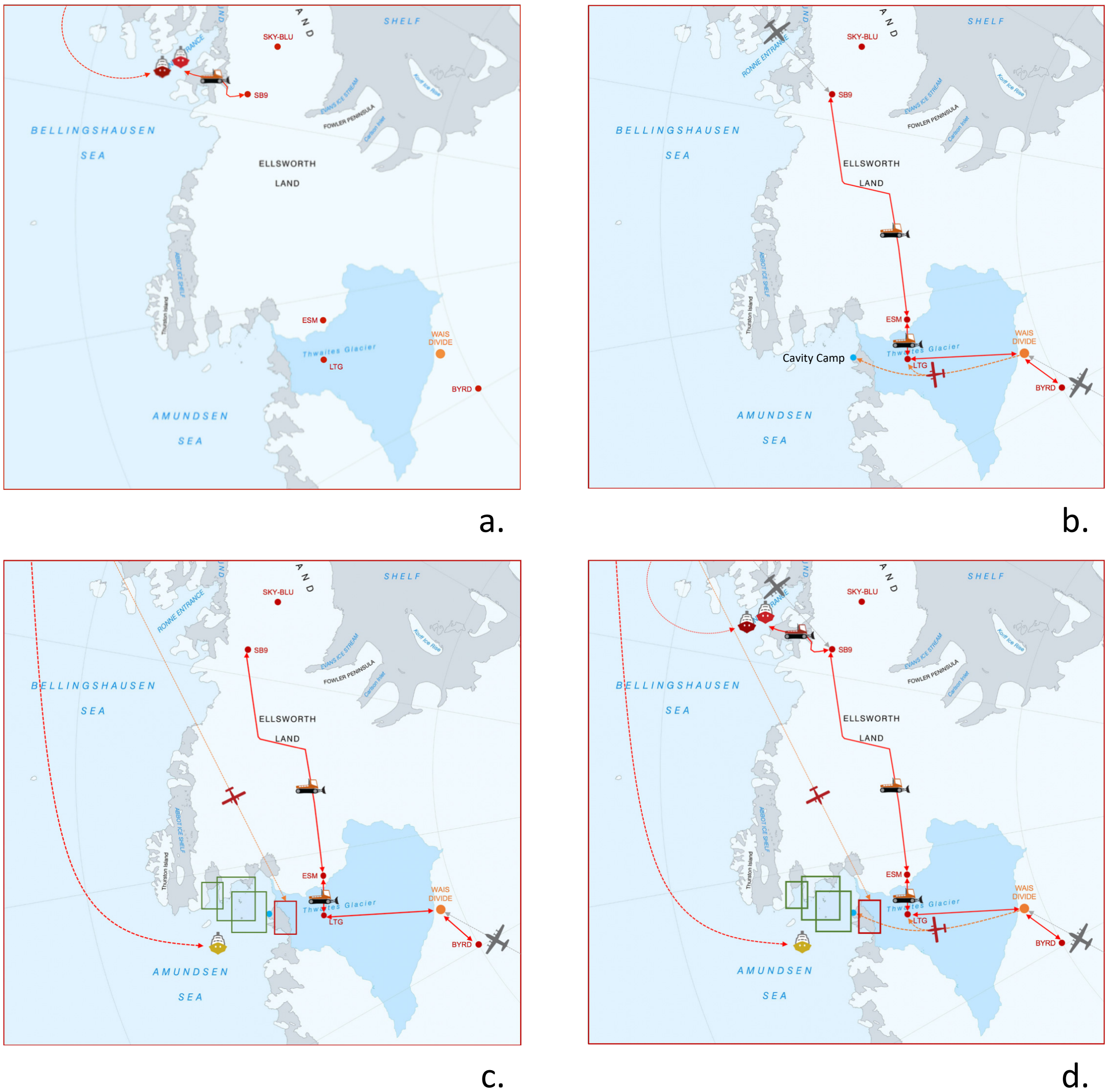

Figure 6. Schematic overview of the primary activities to be undertaken during the 2018-2019 season. See text for descriptions.

In early January 2019, an RAF LC-130 Hercules aircraft operating from Punta Arenas in southern Chile, will deliver an additional 45,000 litres of drummed fuel (approximately 250 x 180 litre drums) to SB9 (or Sky Blu as a back-up depending upon weather conditions) via air drop (Figure 6b). Eight to 10 aircraft rotations from Punta Arenas will be required for this fuel delivery.

A further 45,000 litres of drummed fuel (250 x 180 litre drums) will be moved from Sky Blu down to SB9 during the 2018/19 summer.

In total 498,000 litres of fuel (AVTUR) plus 80 x 205 litre drums of MOGAS and 2 x 205 litre drums of kerosene, will input to the ITGC campaign via SB9.

On completion of the ship offload, the four tractor trains will be assembled and undertake an over-snow traverse into the ITGC campaign area to deliver fuel and equipment and establish the ESM field camp (Figure 6b).

All four tractor trains will continue on from ESM and undertake a traverse onto the Thwaites Glacier to the site designated for the LTG camp where further fuel and supplies will be cached.

Two tractor trains will also continue on from LTG to WAIS Divide camp (where the Vibroseis truck and geophone streamer will be overwintered) and on to Byrd Station where they will collect further fuel and move it back to WAIS Divide camp.

On completion of the delivery of equipment and fuel, the four BAS tractor trains will be moved back to SB9 and Sky Blu where they will over winter.

Fuel will be cached at LTG camp by U.S. traverse in December 2018 to support the BAS aero-geophysics campaign to be undertaken later in the 2018/19 season.

In late December 2018 / early January 2019, US LC-130 Hercules aircraft will deliver supplies and research personnel from the TIME and MELT projects to the West Antarctic Ice Sheet (WAIS) camp from McMurdo Station (Figure 6b). Up to 38 rotations between McMurdo and WAIS Divide camp are anticipated.

Some testing of seismic devices will be undertaken near the WAIS Divide camp by TIME researchers.

U.S. Twin Otter aircraft will move MELT project researchers to undertake camp site assessments in the coastal margin / grounding zone area of the Thwaites Ice-shelf (Cavity Camp) as well as at LTG camp (Figure 6b).

Some seismic work will be undertaken in the vicinity of the Cavity camp and in the downstream portion of the eastern ice tongue by a GHOST team on behalf of MELT.

In mid- to late January 2019 a UK (BAS) Twin Otter will deploy from Rothera to undertake an aero-geophysical survey of the Thwaites Glacier grounding line (Figure 6c). The aircraft will operate from and refuel at the LTG camp utilising fuel and camp equipment pre-positioned by the U.S. The survey is expected to comprise five personnel and 40 hours of flying over a period of approximately two weeks. A few additional flying hours will be devoted to surveying across the grounding line for the MELT project (which will be repeated in the 2019/20 season).

Between late January and early March 2019, the US *Nathaniel B Palmer* will support a range of research activities in the Amundsen Sea Embayment / Pine Island bay area (Figure 6c – green boxes) in support of the THOR, GHC and TARSAN projects. This will include putting personnel ashore on the Edwards Island (and potentially on to sea ice) to undertake tagging of seals (TARSAN) and collecting of surface rocks, penguin bones and guano (GHC). Marine research from the Nathaniel B Palmer in support of the TARSAN and THOR projects will involve: multibeam bathymetric surveys; sub-bottom profiling; sediment coring; AUV deployment (together with cNODE transponders); glider deployment and CTD profiling.

The AUV deployment in this season will be mostly in open water for equipment testing purposes. It is possible that a short deployment of the AUV beneath the Cosgrove ice shelf may be undertaken – again for equipment testing purposes.

Figure 6d provides an overview of all planned activities during the 2018-2019 season.

4.2.2 2019 – 2020 Season

The 2019/20 season will be a busy season with all but one of the research projects commencing activities in the field.

In October 2019 the BAS operational traverse (four Piston Bullys) will begin a traverse from SB9 to the WAIS divide camp to move the remaining fuel and food (Figure 7a).

Commencing towards the end of November 2019, US LC-130 Hercules aircraft will be used to deliver equipment, supplies, fuel and personnel to WAIS divide camp. Up to 37 rotations between McMurdo Station and the WAIS divide camp are anticipated (Figure 7a and 7b).

Research personnel will be moved into the field by U.S. Twin Otter or Basler aircraft from the WAIS divide camp during November 2019 (Figure 7b). These deployments will include:

- a TIME project team of up 4 personnel to ESM camp for a period of up to 60 days. This group will undertake a series of geophysical measurements using GPS, radar and seismometers. The TIME project team will also establish a secondary camp in the vicinity of ESM to undertake measurements using the same instruments;
- GHC project teams will be deployed to Mt. Murphy (6 personnel) and to the Hudson Mountains (4 personnel) for a period of 42 days. At Mt. Murphy the team will undertake surface rock sampling, radar surveying as well as sub-ice rock coring using the Winkie drill. In the Hudson Mountains the team will operate between two camps (moved either by snowmobile or Twin Otter) to undertake surface rock sampling and radar surveying;
- a number of MELT project teams will deploy to the Thwaites Ice shelf (via Cavity Camp) for a period of 60 days to undertake a series of measurements and to deploy instruments. This will include:
    - a team of three personnel undertaking active seismic measurements on the eastern Thwaites Ice Shelf;
    - a team of three personnel (from the nine drilling personnel noted below) deploying tiltmeters and ApRES radar instruments along a line that crosses the Thwaites Glacier grounding zone;
    - a team of up to nine personnel that will operate from Cavity Camp and drill three holes through the ice shelf into the ocean cavity using a hot water drill. Sediment cores will be recovered from the sea floor through these holes (for the THOR project), oceanographic measurements will be made and a number of (long-term / permanent) sub-ice shelf moorings will be deployed through the holes. A hot water drilled hole will also be established above the grounding zone. Here also a sediment core will be recovered, and in-ice instruments will be deployed;

- a TARSAN project team of 12 personnel deployed to the Dotson Ice Shelf for a period of 42 days. The team will use a hot water drill to drill into the ocean cavity and deploy AMIGOS III instrument arrays within and beneath the ice shelf. The team will also travel across the ice shelf on skidoos and undertake a series of active seismic measurements as well as gravimetric measurements and radar surveys;

- a second TARSAN project team of six personnel will deploy to the Thwaites Ice Shelf via Cavity Camp. This team will share a hole drilled by the MELT team and equipment that is drilled into the cavity and will deploy a series of (permanent) instruments. Surface instruments will also be deployed, and radar surveys undertaken.

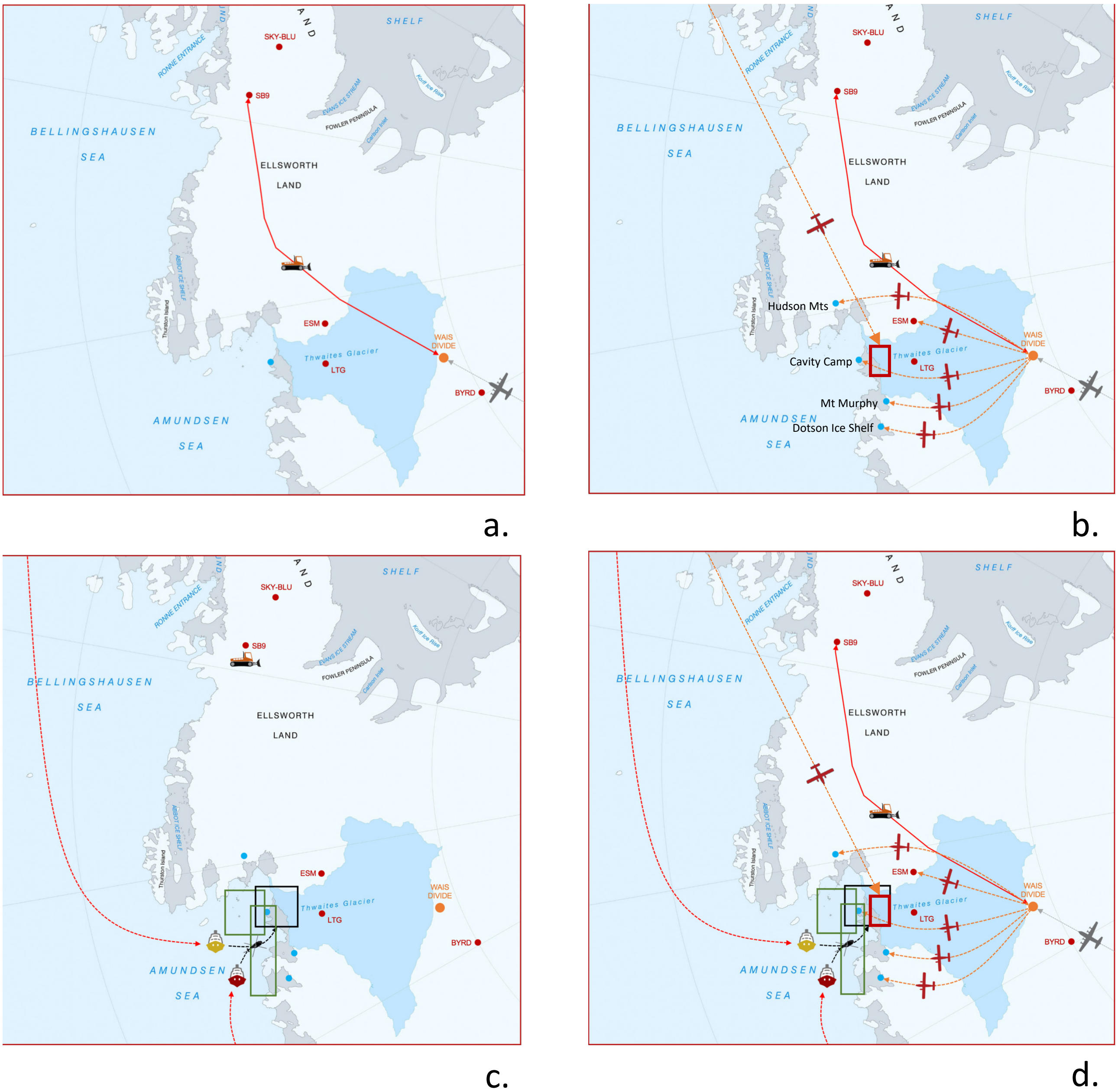

Figure 7. Schematic overview of the primary activities to be undertaken during the 2019-2020 season. See text for descriptions.

A BAS Twin Otter will undertake a few hours of aero-geophysical survey across the Thwaites Glacier grounding line for the MELT project to measure inter-seasonal change and therefore obtain vertical strain rates in the ice (Figure 7b).

The marine component of the 2019/20 season will commence in February 2020 and will be supported by the U.S.' *Nathaniel B Palmer* and South Korea's *Araon* (Figure 7c). The *Nathaniel B Palmer* will provide helicopter support to deploy ice coring and sediment coring drill teams from the MELT and THOR projects to the Thwaites Glacier grounding zone area.

The *Nathaniel B Palmer* will also support the THOR project by undertaking a seismic reflection survey in front of the Thwaites Ice Shelf / Pine Island Bay area as well as conducting a multibeam bathymetric survey and sub-bottom profiles. THOR researchers will also take a series of sediment cores from the vessel at multiple locations in Pine Island Bay[1].

The *Araon* will deploy the Hugin AUV for the TARSAN project to undertake survey work beneath the Dotson and Thwaites Ice Shelves. CTD profiling will also be undertaken from the *Araon*. Potentially the *Araon* will also provide helicopter support for a two-person TARSAN project team who will be instrumenting Elephant and Weddell seals.

Helicopter support may also be provided to the MELT project to deploy the expendable profilers at key locations within and in front of the Thwaites Ice Shelf.

Figure 7d provides an overview of planned activities during the 2019-2020 season.

4.2.3 2020 – 2021 Season

The start of the 2020/21 season mirrors that of the previous two seasons. In late October 2020 a tractor train of two Piston Bullys will undertake an operational traverse from SB9 to the WAIS divide camp to supplement food and fuel supplies (Figure 8a).

Towards the end of November 2020 U.S. LC-130 Hercules aircraft will rotate between McMurdo Station and the WAIS divide camp transporting equipment, supplies, fuel and personnel to WAIS divide camp. Up to 35 rotations are anticipated (Figure 8a).

From late November 2020, 18 to 20 researchers, plus support staff from the GHOST project will begin a two-season over-ice traverse from the WAIS divide camp travelling along the length of the Thwaites Glacier to the grounding zone area. The traverse is expected to operate for 60 days (Figure 8a). The scientific traverse will utilise a combination of U.S. Caterpillar tractors and sledges, fuel bladders and camping equipment. Several skidoos will also form part of the traverse for local travel and research activity out from the main traverse route.

Along the length of the GHOST scientific traverse researchers will undertake active seismic measurements (using explosives and vibroseis sources), passive seismic measurements, radar surveys, gravimetric measurements and magnetotelluric measurements.

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[1] As recorded elsewhere in this EIA, a separate environmental impact assessment will be undertaken for all activities to be supported by this research cruise.

On completion of the traverse during the 2020/21 season the traverse vehicles and equipment will be depoted at WAIS Divide camp from where the research will be redeployed the following season.

During November 2020 U.S. Twin Otter aircraft will be used to deploy researchers to key locations in the field from the WAIS Divide camp.

Ten TIME project researchers will be deployed to the second ESM camp (Figure 8b) to undertake a series of active (explosive) seismic surveys in the eastern shear margin area.

A team of six GHC project researchers will be deployed to the Hudson Mountains (Figure 8b) to undertake surface rock sampling and deploy the Winkie drill system to take sub-ice geological cores at a number of locations. The teams will used skidoos to travel between sampling sites.

BAS Twin Otters will also deploy two researchers from the MELT project to the Cavity Camp area for data and instrument recovery (Figure 8b).

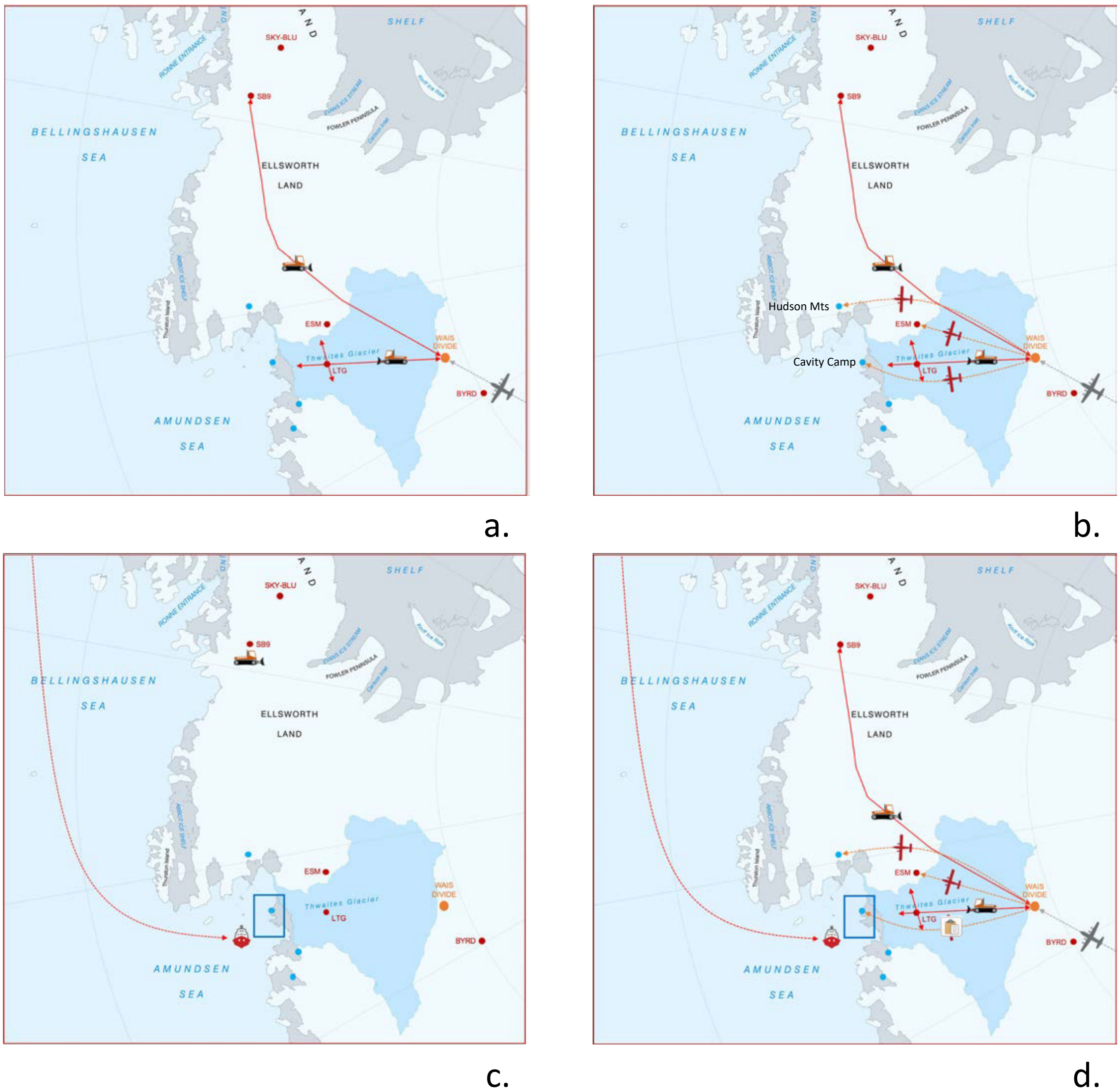


Figure 8. Schematic overview of the activities to be undertaken during the 2020-2021 season. See text for descriptions.

In February 2021 the *RRS Sir David Attenborough* will begin a 48 to 50 day research cruise in support of the TARSAN project in the Pine Island Bay area (Figure 8c). 30 TARSAN researchers and ships technicians will be aboard. The research cruise will deploy AUVs beneath the Thwaites and/or Dotson ice shelves and deploy cNODE transponders on the sea floor in front of the ice shelves to support data transmission by and navigation of the AUVs. The TARSAN researchers will also deploy ocean gliders in front of the ice shelves, undertake microstructure profiling at key marine locations and deploy autonomous surface vehicles.

Figure 8d provides an overview of planned activities during the 2020-2021 season.

4.2.4 2021 – 2022 Season

The 2021/22 season will involve completion of the field components of the GHOST and TIME research projects and recovery of remaining instruments and equipment (Figure 9a).

Research personnel will again be moved into the ITGC campaign area via U.S. LC-130 Hercules operating between McMurdo Station and WAIS Divide camp. The project will be supported by 30 C130 rotations from McMurdo in this season.

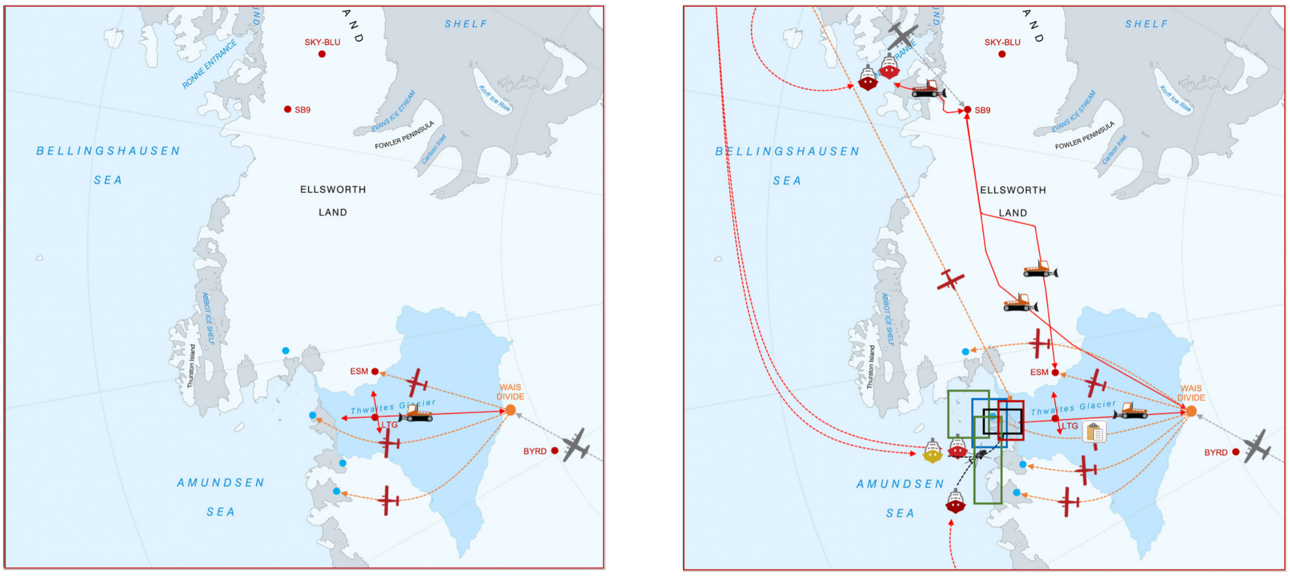
During November up to 20 researchers from the GHOST project will be transported through WAIS Divide camp and out to the site at which the traverse concluded in the previous season. The GHOST scientific traverse will then continue for a further 60 days conducting active seismic measurements (using explosives and vibroseis sources), passive seismic measurements, radar surveys, gravimetric measurements and magnetotelluric measurements.

At the end of the scientific traverse, the tractor train will return to WAIS Divide camp.

During November 2021, ten TIME project researchers will be deployed to the ESM camp (Figure 9b) to undertake a series of active (explosive) seismic surveys in the eastern shear margin area. They will also recover any deployed equipment and camp equipment at the end of the field work.

Three researchers from the TARSAN project will be deployed in late 2021 for day trips to the Dotson and Thwaites Ice Shelves to recover deployed equipment.

Figure 9b provides a schematic overview of activities to be undertaken over all four seasons.



a. b.

Figure 9. Schematic overview of the activities to be undertaken during the 2021-2022 season (a) and a schematic overview of activities for all four seasons of the programme (b).

4.2.4 2022 – 2023 Season

During the 2022/23 season recovery of final field infrastructure will be consolidated at WAIS Divide for return to McMurdo station and the BAS traverse will be remobilised to its next tasking and point of recovery as appropriate. This effectively marks the end of operational support to the ITGC campaign.

4.3 Research Activities

A wide range of research equipment will be utilised by each of the on-ice research projects. The equipment to be used is described in this section of the IEE. The outputs from the use of the equipment in Antarctica that will or may interact with the environment are highlighted here. The actual or potential impacts are considered in more detail in Section 7 below.

4.3.1 Deployment of Data Collection Instruments and Equipment

4.3.1.1 Glaciological survey

A number of instruments and research methods will be used to gather data on a range of parameters on, within and beneath the Thwaites Glacier.

Active seismic surveys

Numerous studies have demonstrated the value of high-resolution seismic reflection data in characterizing basal glacial environments (e.g. Anandakrishnan et al., 1998; King et al., 2007; Peters et al., 2007). Seismic data can image the ice and subglacial lithology at scales ranging from meters to kilometres, allowing separation of regions with water-saturated tills or with bedrock (*e.g.* Blankenship et al., 1987; Peters et al., 2007; 2008). Analyses of the travel time, amplitude and phase of basal reflections and their variation with angle provide unique information about the physical properties of the material directly below the ice-bed interface, as well as characteristics of the ice above and of materials well below the bed.

The GHOST, MELT, TARSAN and TIME projects intend to utilise active seismic methods in order to collect such data in key areas of the Thwaites Glacier basin. Large volumes of explosives (potentially up to 13,000kg) will be moved in to the ITGC area of operation to support what will be a significant component of the research effort across most seasons of the ITGC programme.

Traditional over-snow seismic reflection profiling involves the placement and detonation of explosive charges, both on the snow/ice surface as well as at selected depths in the ice, whilst manually moving a string of cabled geophones which receive the reflected sound waves (Figure 10).

GHOST will undertake active seismic measurements along the centre of the Thwaites Glacier and will aim to cover a distance of about 300km over two field seasons. A second target area for the GHOST project is the Thwaites Glacier eastern shear margin. The GHOST project will drill shot holes using either a hot-water drill or the Ice Drilling Design and Operations (IDDO) RAM drill (see below) to depths of 20m and 60m. Explosive charges of 300 to 450g will be placed in the holes which will be backfilled with ice and snow prior to detonation. The geophone spread will be 2km long, with geophones spaced every 10m.

The TARSAN project will undertake active seismic measurements along the eastern Thwaites ice shelf and the central Dotson ice shelf grounding line (because much of the Thwaites ice shelf is unsafe for ground-based surveys). For high resolution profiling the TARSAN project will use an array of 48 40Hz single-channel geophones spaced at 20m with 0.5Kg explosive shots spaced at 240m and 10m deep in the ice. For point source soundings the TARSAN project will use a short spread of 12 geophones spaced 1m apart to record the reflection from a single 0.5Kg shot detonated at 5m. All shot holes will be drilled with a portable steam drill (see below).

The MELT project will undertake active seismic surveys in the vicinity of the grounding zone and the ice shelf cavity more broadly during the 2018/19 and 2019/20 seasons. A hot water drill will be used to create the shot holes for the seismic data acquisition similar to the process used by the TARSAN project above.

The TIME project will utilise the Poulter technique of above-ground explosive shooting to make their seismic reflection project feasible. The research will be undertaken in the Eastern Shear Margin (ESM) zone of the Thwaites Glacier to test if the ESM is of the 'fixed' or 'dynamic' type.

Figure 10. Active seismic measurements being carried out on the Pine Island Glacier, Antarctica. Source: Polargeo, Public Domain

Outputs

The outputs from active seismic measurements that will or may interact with the environment are:

- Residues at the point of detonation of explosives at various depths within the ice;
- Surface debris (soot and plastic casings) from above-ground shootings;
- Energy release in the form of audible noise – if detonation occurs near to or at the ice surface;
- Energy release in the form of heat from the explosion;
- Explosives packaging, which cannot be returned to the UK must be destroyed in Antarctica;
- The potential release of battery acid from the detection equipment.

Vibroseis measurements

The GHOST project will utilise the over-snow vibroseis-source acquisition technique to extend both the spatial coverage and the depth penetration of the seismic data. The vibroseis source is a truck (Figure 11a) equipped with a vibrator pad positioned at the centre of balance of the truck. The pad is lowered to the surface of the glacier and the truck is lifted hydraulically so that its full weight is resting on the pad. A typical exploration signal at the vibrator pad consists of a sinusoidal ground displacement that sweeps from a low frequency to a high frequency during an interval of 10 to 20 seconds.

The Vibroseis acquisition system gives high-quality subglacial structure and stratigraphy data, as well as bed reflectivity, at much faster production rates than with explosives-based methods (Eisen et al., 2015, Kristoffersen et al., 2014). Seismic vibrators are often the preferred sources for vertical seismic profile (VSP) surveys as they are repeatable, controllable, have high energy, have a low environmental impact, and are cost-effective (Dean et al., 2013).

GHOST will use the EnviroVibe, an 8.5T, hydrodynamic vibrator system vehicle (Industrial Vehicles Inc., USA; Figure 11a) that can nominally excite vertical pressure-wave sweeps in the range of 10 to 300Hz. For lower-altitude sites with a thinner firn column and more-consolidated surface (as expected on Thwaites Glacier) a sweep of 10-250Hz at 80% peak force will be used. The Vibroseis data are collected by a 1.5km-long snow streamer with 60 channels spaced at 25m (Eiken et al., 1989). Each channel consists of a group of eight 14Hz geophones mounted in a gimballed configuration and spaced at 3.125m. The streamer is towed over the snow surface behind the Vibroseis truck (Figure 11b).

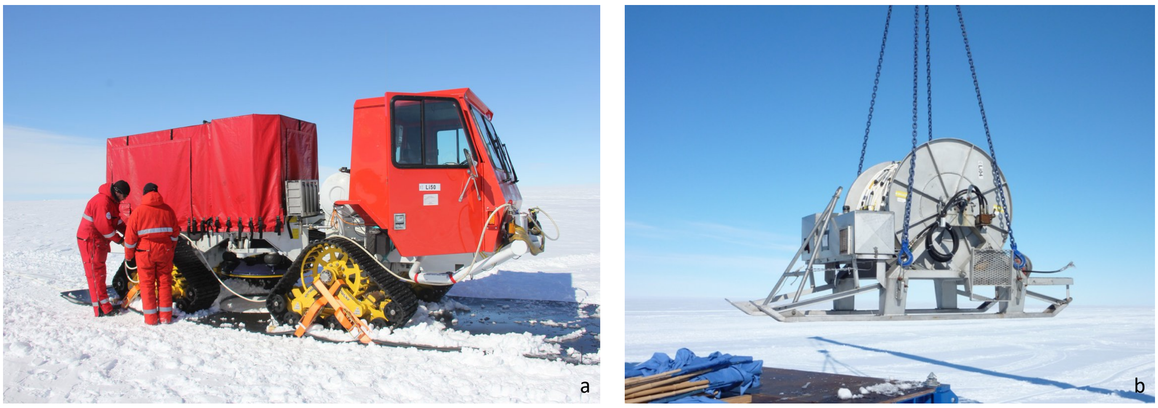


Figure 11. Vibroseis truck (a) and coiled streamer array (b) to be used by the GHOST project. Source: Alfred Wegener Institute

Outputs

The outputs from the use of the vibroseis truck that will or may interact with the Antarctic environment are:

- Noise emissions from the running of the equipment including engine noise and the generation of seismic vibrations;
- Emissions to air as a result of burning fossil fuels to power the equipment;
- Accidental spills of fuel during refuelling operations.

Passive seismic measurements

Basal microearthquakes can be useful in helping to identify locations and strengths of ice-geology 'sticky spots' (Winberry et al., 2011; 2013), and can reveal information on the basal flow of the glacier (Zoet et al., 2013a, b). An existing array of seismographs (established through the 'Polenet' programme) is established to record basal events beneath the Thwaites Glacier. However, the large distance between stations (130 km) and the small size of basal events has made it difficult to estimate accurate locations or magnitudes of seismic events.

The GHOST project will install a dense network of passive seismic stations along the central part of the lower Thwaites Glacier (approximately 50Km from the eastern shear margin) in order to detect and map locations, times and magnitudes of basal seismicity.

The seismometer instrumentation consists of a broad-band sensor, a data logger, a solid-state storage device, a GPS antenna to provide timing and location, and power supplied by a combination of non-rechargeable lithium batteries, lead-acid rechargeable batteries, and solar panels.

There are three field components for each station: a large insulated box with external connectors houses the data logger, batteries, and a heating pad; the sensor which is isolated with a fiberglass insulating covering beneath a hard plastic dome; and the solar panels, with GPS and iridium antennae attached. In most installations the equipment box is buried just deep enough to be snow covered with the sensor similarly buried several meters distant (Figure 12).

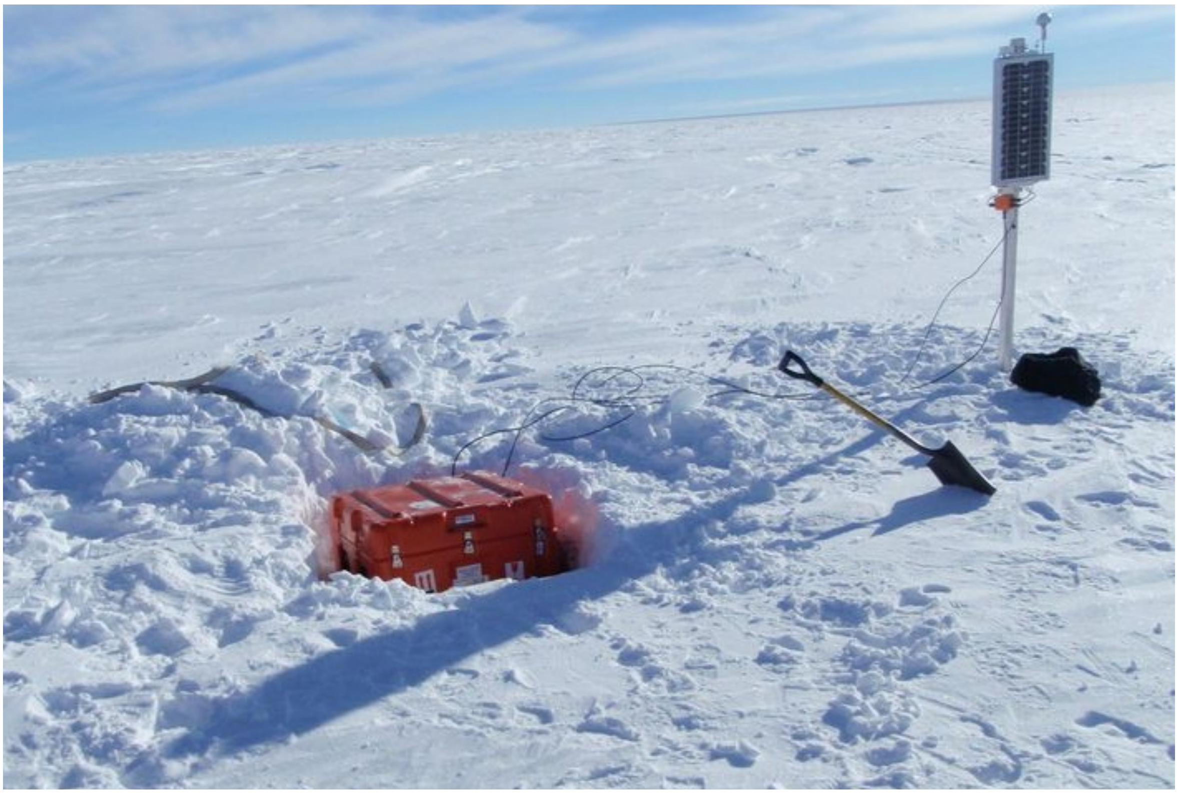


Figure 12. Passive seismic station established in Antarctica. Source: Smithsonian.com. Image: Amanda Lough

In the first year, the seismometer array will be focused especially on the lower Thwaites Glacier centre line, to monitor basal seismic events from this key stabilizing feature (Smith, 2006), and to assess seismic events originating from the floating portion. The first-season data will guide deployment of a focused array in the second season (either continuing at Ridge A or moved to the Shear Margin).

Outputs

The outputs from the deployment of the passive seismic instrumentation that will or may interact with the environment are very few, but include:

- The potential release of battery acid from the detection equipment;
- The potential loss of the equipment if it cannot be re-located at the end of the season.

Magnetotelluric measurements

The GHOST project will collect magnetotelluric (MT) measurements to constrain the geothermal heat flux and elastic thickness of the crust beneath the Thwaites Glacier.

Geomagnetic field fluctuations induce electrical current flows in ice sheets and the underlying crust, and the MT technique can measure the accompanying electrical and magnetic fields at the surface. These MT data are then used to produce images of bulk electrical resistivity within the ice and the underlying crust (Wannamaker et al., 2004).

The GHOST project will acquire MT data along the seismic traverses and expects to record between one and two MT stations per day (Figure 13), for approximately 10 km spacing along the approximately 400 km of traverse lines in the two field seasons. For this the researchers will use two modern digital MT receiver systems from the NERC's Geophysical Equipment Facility. These systems will consist of Zonge Zen receivers with 32-bit ultra-wideband data loggers and high-frequency induction coil magnetometers.

Outputs

The outputs from the deployment of the magnetotelluric instrument that will or may interact with the environment are very few, but include:

- The potential release of battery acid from the detection equipment.

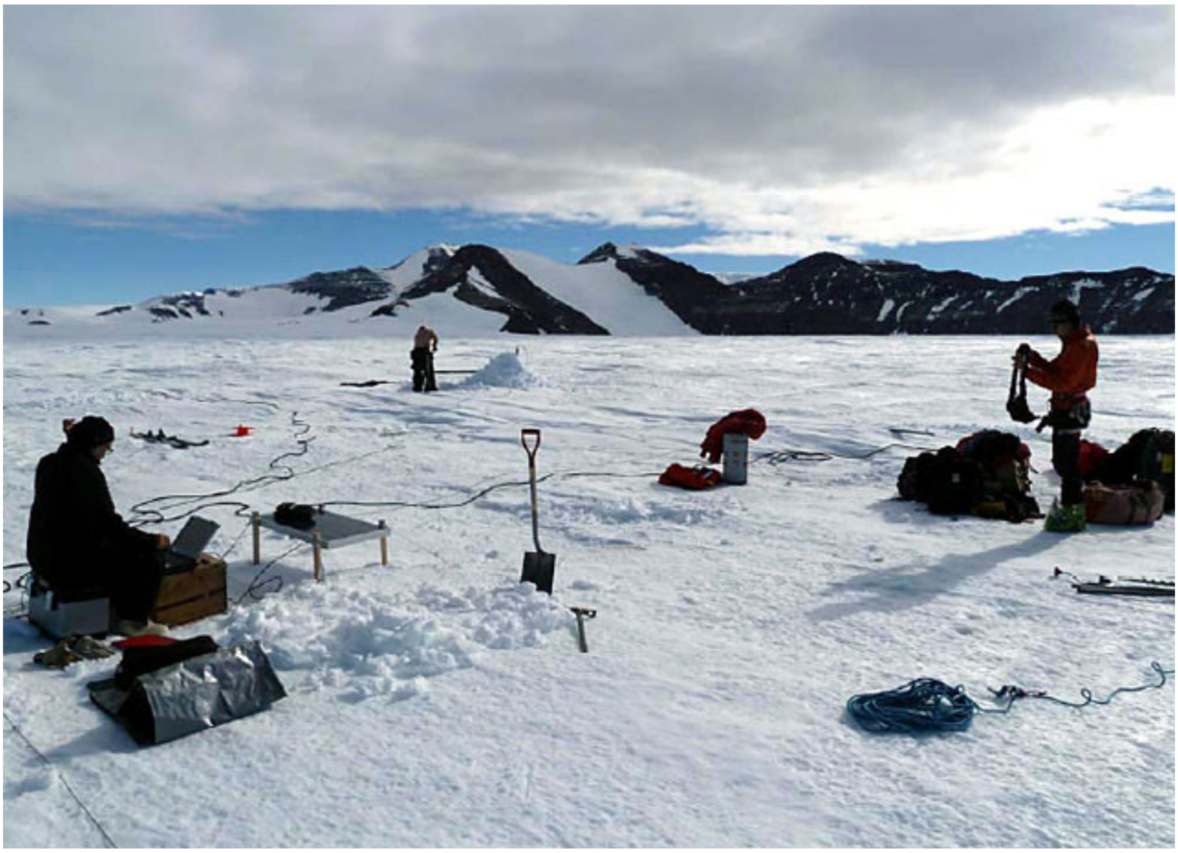


Figure 13. A U.S. field team sets up a magnetotelluric station near the Trans-Antarctic Mountains during the 2010/11 season. Image: Phillip Wannamaker. Source: https://antarcticsun.usap.gov

Radar surveys

The GHOST and GHC projects will undertake radar surveys at several locations to map aspects of the bed topography as well as to constrain englacial deformation so as to test the predictions of ice-flow models.

Bed topography will be mapped by GHOST by undertaking a 10Km wide swath radar survey along the transect that will follow the centre line of the Thwaites Glacier. The data will be gathered using a towed 3MHz mono-pulse radar system that will be run across the flow line of the glacier at 500m line spacing (Figure 14). A similar towed radar technique will be utilised by GHC researchers in both Hudson Mountains and at Mt. Murphy.

Figure 14. An example of a BAS-operated swath radar system being used on the Brunt Ice Shelf. Source: British Antarctic Survey

Englacial structure and deformation in the Thwaites Glacier will be measured using an array of Automated Phase-sensitive Radio Echo Sounding (ApRES) systems. ApRES instruments yield time series of ice shelf thickness change at precisions of ~1 mm. ApRES is a low-power, 200-400 MHz, light-weight instrument with a 1-second chirp, run by a controller. The instrumentation and data logger are housed within a plastic box, which along with a 100 AH battery are buried in a shallow hole. The transmit and receive aerials are spaced a few metres each side of the box and are also buried (Figure 15). Each system will record for a nominal 12 months and has the ability to process and send data via satellite link.

Figure 15. Photograph of an ApRES system deployed on the Ronne Ice Shelf, Antarctica. The ApRES is the yellow case positioned between the two antennas. Source: Nicholls et al., 2015.

ApRES devices will be deployed in the grounding zone area in the 2018/19 and 2019/20 seasons; season, along a 40Km section of the Thwaites Glacier 'centre line' traverse during seasons 2020/21 and 2021/22 as well as along a 20Km transect crossing the eastern shear margin in the 2020/21 season (Figure 8a).

Two ApRES devices will also be deployed by the TARSAN project adjacent to the AMIGOS III instrument arrays (which are described below).

Outputs

The outputs from these radar surveys that will or may interact with the environment include:

- The potential release of battery acid from the detection equipment in both the towed and ApRES equipment;
- The potential loss of the ApRES equipment if it cannot be located or recovered. It is noted that surface instruments such as the ApRES equipment may become inaccessible either by Twin Otter or helicopter due to glacial movement or crevassing. Irrecoverable equipment will be lost into the ice and ultimately to the marine environment.

Multi-sensor installations

The TARSAN project will deploy a number of multi-sensor installations at selected locations on the Thwaites ice shelf. The 3rd generation Automated Meteorology Ice Geophysics and Ocean Sensors (AMIGOS III) are similar to automated weather stations, but with a larger array of sensors (Figures 16 and 17).

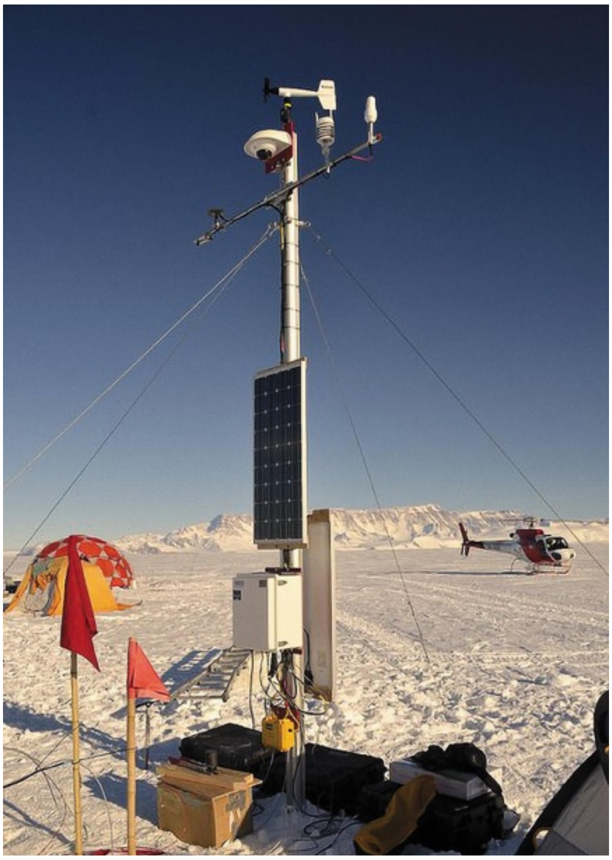


Figure 16. An AMIGOS II instrument array installed on the Nansen Ice Shelf Antarctica. Source: Smithsonian Air & Space Magazine. Image: Ronald Russ.

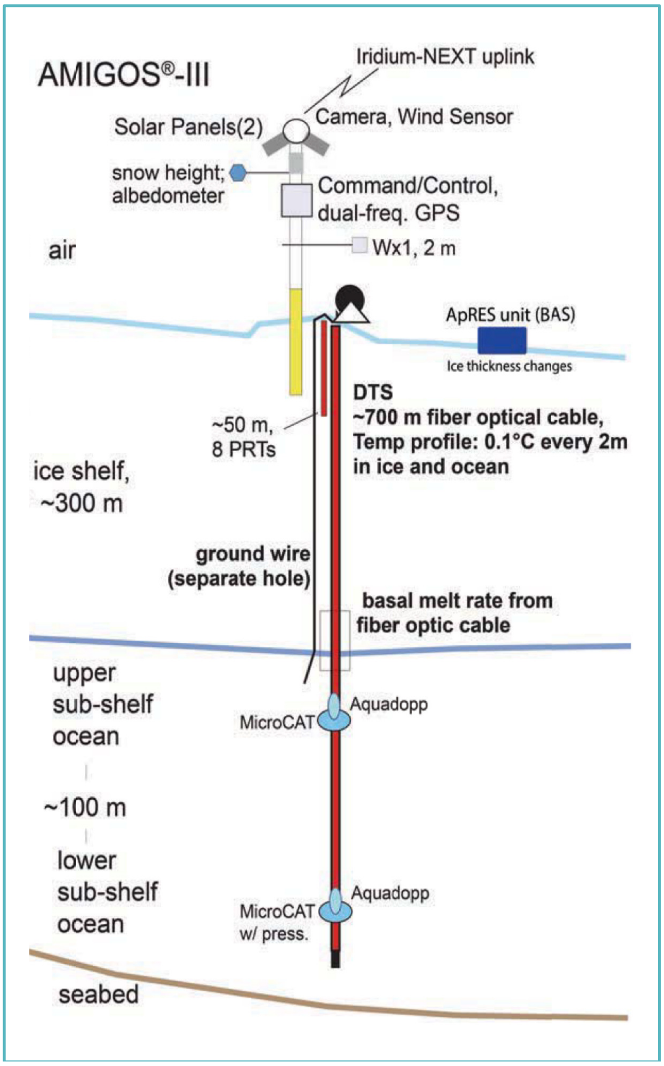


Figure 17. Schematic showing the array of instruments that will be installed on the AMIGOS III system. Source: Pettit et al., 2017, NSF project proposal 1738992

Three AMIGOS III stations will be deployed for a continuous period of two years throughout the Thwaites Glacier research campaign. They will be installed in the 2019/20 season and recovered in the 2021/22 season. One AMIGOS III instrument array will be installed close to the grounding line on the Thwaites Glacier and potentially two arrays will be installed on the Dotson Glacier.

A UAF hot water drill (see above) will be used at each location to drill two holes. A small diameter hole (13-15 cm) will be used to install a grounding wire for the inductive modem that will be used to relay oceanographic data to the surface installation of the AMIGOS III. A larger diameter hole (20 cm) will be used to install the oceanographic instruments and an integrated fibre-optic temperature profiler for the ice / ocean layers (Figure 17).

Figure 17 summarises the instrumentation to be included on the AMIGOS array which includes:

- Surface data logger and power unit;
- Iridium-NEXT modem and antenna for telemeting data;
- Power sources: a combination of 2 x 80W solar panels for summer and lithium and 4 x 100amp-hr lead-acid batteries for winter;
- Camera system;
- Meteorological sensors including an albedometer and snow height sensor;
- Ice motion and strain sensors deployed into the ice shelf;
- two micro conductivity and temperature sensors located 30m above the seabed and 30m below the sub-surface of the ice, and
- two current meters installed at the same locations to record under-ice current strength and direction.

Additional intra- and sub-ice shelf instrument arrays will be installed by the MELT project above and below the grounding zone and into the ice-shelf cavity (Figure 18).

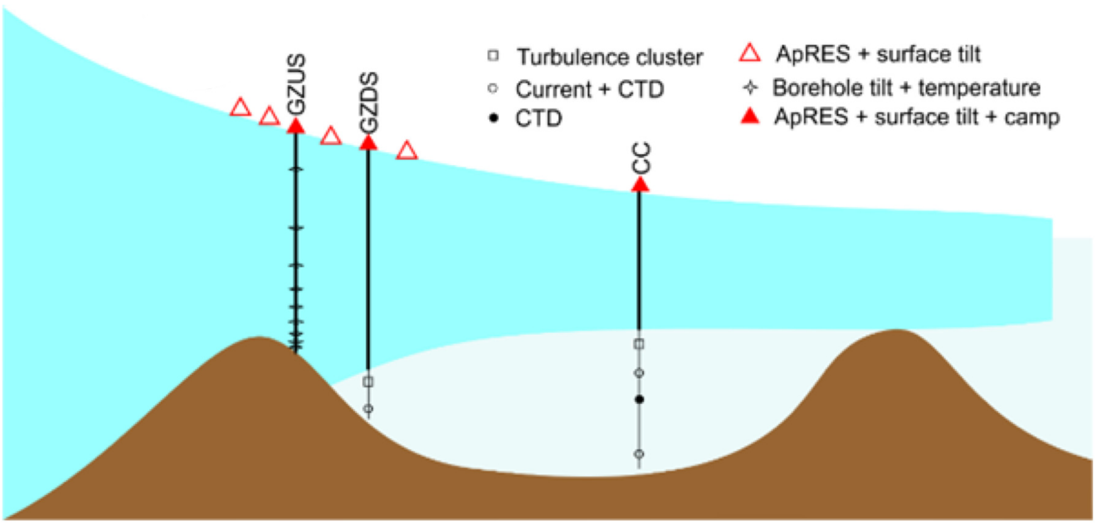


Figure 18. Schematic showing the deployment of intra- and sub-ice shelf instruments. CC – Cavity Camp; GZUS – Grounding Zone Upstream; GZDS – Grounding Zone Downstream; CTD – Conductivity, Temperature and Depth sensor.

Outputs

The outputs from the deployment of these AMIGOS III and ice-shelf arrays that will or may interact with the environment include:

- The potential release of battery acid from the detection equipment;
- The irrecoverability of sensors and cables that are deployed within and beneath the glacier or ice-shelf. Irrecoverable equipment will be lost into the ice and ultimately to the marine environment.

Gravimeters

Gravity measurements will be made by both the GHOST and TARSAN projects using simple portable recording instruments such as the Scintrex CG-5 Autograv gravimeter (Figure 19).

Figure 19. An example of the CG-5 Autograv gravimeter that will be used by the GHOST and TARSAN projects.

Outputs

The outputs from deployment of tiltmeters that will or may interact with the environment are:

- The potential release of battery acid from the detection equipment.

Tiltmeters

Tiltmeters are sensitive inclinometers capable of measuring very small changes in the vertical level (Figure 20). The MELT project will undertake a series of tiltmeter measurements during the summer season. Tiltmeters will not be deployed over winter.

Figure 20. A deployed tiltmeter on the Darwin Glacier, Antarctica in 2016. Image: Dana Floricioiu. Source: https://www.dlr.de

Outputs

The outputs from deployment of tiltmeters that will or may interact with the environment are:

- The potential release of battery acid from the detection equipment.

GPS Instruments

A series of global positioning system (GPS) stations will be deployed by the TIME project during the 2019/20 season in the region of the eastern shear margin so as to record ice motion on daily, seasonal and annual time-scales. They will be recovered in the 2012/22 season.

GPS stations (Figure 21) consist of a receiver and antenna, a 2m mounting pole and cables. Power is provided by means of sealed gel lead-acid batteries. Solar panels and/or a wind turbine may also be deployed as additional power sources.

Figure 21. A BAS researcher at a GPS station. Source: https://www.bas.ac.uk

Outputs

The outputs from deployment of GPS equipment that will or may interact with the environment are:

- the potential release of battery acid from the detection equipment;
- the potential loss of the equipment to the environment if it fails and cannot be relocated.

Airborne Geophysical Survey

The Thwaites Aero-Geophysical Survey (TAGS) will be undertaken in parallel to the ITGC during the 2018/19 summer season. TAGS aims to provide detailed aero-geophysical data coverage of the entire Thwaites Glacier system including the offshore cavity beneath the floating ice shelf, the grounding line region, lakes in the centre of the catchment, and a profile to the ice divide. Data collected will include PASIN airborne radar (ice sheet thickness and bed conditions), a snow radar (shallow ice sheet layers), a lidar (ice sheet surface elevation), gravity sensors (sub-ice shelf bathymetry and geology), and magnetic sensors (sub surface geology).

The main activity will be 40 hours of airborne survey during late January and early February 2019, flown from the LTG camp using a BAS Twin Otter aircraft (Figure 22).

Figure 22. A BAS Twin Otter aircraft equipped with aero-geophysical survey equipment. Image: Sam Witt / British Antarctic Survey. Source: https://www.euronews.com

To support the TAGS work, GPS and magnetic base stations will be deployed at the LTG field camp. These will be removed on completion of the aerial survey work.

Outputs

The outputs from the TAGS that will or may interact with the environment are:

- Emissions from the burning of fossil fuels during aircraft operations;
- Accidental spills of fuel during aircraft refuelling operations;
- Noise from the operation of the aircraft.

4.3.1.2 Instrumentation of seals

Sensors will be glued to the heads of a number of Weddell and elephant seals each summer (Figure 23). 12-15 tags to be fitted in each of the 2018/19, 2019/20 and 2020/21 field seasons by researchers from the TARSAN project.

The sensors transmit temperature and salinity profiles several times each day providing data on depth profiles throughout the winter each year (Boehme et al., 2009). Elephant seals haul out on the Edwards Islands in Pine Island bay and this species will be targeted in the first instance. Weddell seals are found on sea ice floes in Pine Island Bay area and throughout the Amundsen Sea embayment. These two species are chosen because they make deep dives, usually to the sea bed, and remain in the region over winter.

The spatial and temporal resolution of the dataset that will be generated from the deployment of these devices will enable researchers to investigate the different roles of surface atmospheric and ocean advective fluxes in modifying the waters on the continental shelf before they enter the ice-shelf cavities.

Figure 23. An elephant seal from the Kerguelen islands with a logger device attached. Image: C. Guinet (CEBC/Chize, France). Source: https://www.smithsonianmag.com

The seal instrumentation work will be undertaken by highly experienced researchers. The procedure for attaching the instruments is well established and documented (McConnell et al., 2010; Fedak et al., 2002; Russell et al., 2016; Sharples et al. (2012)).

Individual seals are selected on the basis of their appearance (*i.e.* health) and their location from the water (breathing hole, beach). Seal health is assessed using a number of visual clues including general appearance, body condition (lean vs fat), condition of fur and flippers, and the face including eyes. Detailed assessments are also made when an animal is under control, with no further action taken to deploy an instrument if there are any underlying health concerns.

Once a seal is selected, one person will carefully approach the seal to a distance of 1-2m. A pressurized dart delivered via a blowpipe (regulated in UK), will inject the anaesthetic drug Zoletil (a mixture of tiletamine and zolazepam from Virbac) at a dose of 0.8 - 1.0mg per 100kg. After delivery the person retreats to an unobtrusive distance while the Zoletil takes effect. Usually this takes 10 to 15 minutes. The level of sedation is checked after 8-10 minutes. If the level of sedation seems acceptable the deployment procedure is initiated by placing a towel over the seals eyes (regulated in the UK) while working to reduce stimulation. This enables work under relatively light anaesthesia. Normally no restraint is necessary.

A CTD-Satellite Relayed Data Logger is then glued to the fur on the head or upper neck region using two-component industrial epoxy glue (regulated in the UK). Potentially a whisker sample, a skin sample and a blubber biopsy will be collected (both regulated in UK) while the glue for the tag is setting. Both whisker and blubber samples provide means to assess diet through isotopes and fatty acid analysis allowing the seal's diet to be elucidated. The skin sample will also enable researchers to track and identify the seal through DNA analysis without any non-permanent or permanent ID tags (*e.g.* flipper tags).

Prior to moving away from the instrumented seals, a 20ml dose of a broad-spectrum antibiotic (Terramycin) is administered intramuscularly to prevent bacterial infections (regulated in the UK).

The whole procedure takes between 20 and 60 minutes in total. The attached instruments are lost during the seal's next moult.

Outputs

The outputs from the activities involved in instrumenting the seals that will or may impact the environment and wildlife include:

- Disturbance to some or all individuals of a seal colony *e.g.* by the landing of helicopters or small boats to deploy researchers, or the movement of researchers within the colony;
- Distress to the individual seals that are selected for anaesthetising and instrumentation;
- A change in the behaviour or capability of the instrumented seals such as a reduction in their foraging ability whilst the instrument is attached;
- Introduction of non-native species to ice-free locations in Antarctica;
- Artificial relocation of native flora and micro-fauna species between ice-free locations as researchers move between seal colonies;
- Release to the environment of the data logger instruments when the seals moult.

4.3.1.3 Autonomous and Tethered Marine Instruments and Equipment

Several types of autonomous and tethered marine vehicles will be used to collect a range of data both in open water and sub-ice shelf locations.

Autonomous Underwater Vehicle

Autonomous Underwater Vehicles (AUVs) are programmable, robotic vehicles that, depending on their design, can drift, drive, or glide through the ocean without real-time control by human operators. Some AUVs communicate with operators periodically or continuously through satellite signals or underwater acoustic beacons to permit some level of control.

AUVs allow scientists to conduct other experiments from a surface ship while the vehicle is off collecting data elsewhere on the surface or in the deep ocean. Some AUVs can also make decisions on their own, changing their mission profile based on environmental data they receive through sensors while under way.

Two AUVs will be used during the ITGC.

The Hugin 3000 AUV is a state-of-the-art AUV that is able to navigate beneath sea ice and ice shelves (Figure 24). It is fitted with an array of sensors including upward and downward looking sonars, a side-scan sonar and a sub-bottom profiler. It can record temperature, salinity, current velocity, turbulence, dissolved oxygen and a range of other variables (Dutrieux et al., 2014).

The Hugin 3000 AUV is rated to 3000 metres depth, with a range (away from the mother ship) of up to 300 km.

Figure 24. Kongsberg Hugin 3000 AUV. Source: https://www.km.kongsberg.com/

The TARSAN project will make use of a HUGIN 3000 AUV provided by the University of Gothenburg. The AUV will make surveys, each of several days' duration, at fixed depths and at fixed distances from the ice shelf above it or from the sea bed below it, at speeds of approximately 1 m/s.

In addition, the TARSAN project will utilise NERC's Autosub Long range (Figure 25).

The Autosub Long Range AUV is a new type of AUV with a range of 6000km, an endurance of six months and a depth rating of 6000m. This AUV will collect similar data to the Hugin 3000.

Figure 25. NERC Autosub Long Range. Source: https://www.noc.ac.uk/

The information collected by the AUVs will bridge the data gap between the ice-front gliders (see below) and the through-ice AMIGOS measurements (see below), surveying long sections into the cavity (Figure 29; Kimura et al., 2016). The resulting data will be used to evaluate water mass pathways, quantify turbulent mixing, identify forcing mechanisms and their variability.

To support the navigation of and data transmission from the AUVs, several cNODE transponders (Figure 26) will be deployed on the sea floor in front of the ice shelf (Wolbrecht et al, 2015).

Figure 26. The family of Kongsberg cNODE transponders. From left the cNODE Maxi, Midi, Mini and MiniS. Source: https://www.km.kongsberg.com/

The transponders will be recovered at the end of each AUV deployment by triggering an auto release system. The weights that will be used to secure the transponders to the seafloor will not be recoverable.

A remotely piloted aircraft (RPA) will also be used during AUV deployment and recovery. Two rotary wing Dji Phantom Pro 4 RPA will be taken on the cruise (Figure 27).

Figure 27. Dji Phanton Pro 4 remotely piloted aircraft. Source: https://www.dji.com/phantom-4-pro

During AUV operations one of the RPA units will be flown to assist with the safe deployment and recovery of the AUV. Knowledge of sea ice cover gained from the RPA will assist with planning of safe missions and recoveries. Knowing whether the AUV is at the surface will provide safe recovery in the event of a problem with AUV communication.

In addition, the RPA will assist with ground-truthing measurements for the AUV by providing aerial photographs of the sea ice that the Hugin AUV is measuring from below. This is needed in order to document what kind of sea ice the AUV is measuring.

RPA will only fly over the water and sea ice around the ship during AUV during deployment and will remain in line-of-sight of the operator (Erin Petit pers. comm.).

Outputs

The outputs from these AUV surveys that will or may interact with the environment include:

- Water turbulence and disturbance through the functioning of the on-board propeller and the movement of the AUV through the water;
- Heat and light emissions from the operation of the power system and on-board equipment;

- Noise emissions from the operation of the power system and on-board sonar and sub-bottom profiler equipment;
- The potential introduction of non-native marine species if the AUV has picked up biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of the AUV to the marine environment if the AUV suffers power or equipment failure and us unable to return to the supporting vessel;
- The potential release to the marine environment of ‘drop weights’ carried by the AUV in case it needs to surface in an emergency;
- Noise emissions from the placement of the transponder units on the seafloor;
- The potential loss to the marine environment if the transponder units cannot be recovered and the certain loss to the environment of the transponder anchor units which cannot be recovered;
- Noise emissions from the operation of the RPA unit in proximity to the supporting vessel;
- The potential loss to the marine environment if the RPA unit fails whilst operating away from the support vessel.

Ocean Gliders

Ocean gliders (Figure 28) are buoyancy driven mobile sensor platforms with interchangeable and customizable science bays (Webb et al., 2001; Davis et al., 2003; Schofield et al., 2007). These 1.5m ‘bullet-shaped’ autonomous underwater vehicles profile the water column in a saw-tooth pattern by shifting small amounts of ballast to dive and climb at ~15–20cm/s. Wings and vehicle shape result in horizontal speeds of ~20–30cm/s, or ~20km per day depending on ambient current conditions. Vehicle navigation is done using ‘dead-reckoning’ to a set waypoint. When the glider surfaces its iridium satellite phone antenna transmits data to shore and receives new mission characteristics depending on the sampling strategies designed by the operator. Oceanographic data is collected at five-second intervals resulting in high vertical resolutions. Gliders have been used in numerous difficult to sample environments including in the Western Antarctic (Kahl et al., 2010; Schofield et al., 2013) and in the Pine Island Bay region in 2014.

Gliders can collect a range of data including temperature, salinity, dive-average current velocity, chlorophyll concentration and dissolved oxygen.

Gilders are ideally suited for repeated surveys along the ice shelf front (Miles et al., 2016), closer to the ice shelf than it would be safe to go with a ship, complementing simultaneous under-ice surveys with the AUVs (Figure 29).

Two gliders will be deployed by TARSAN project researchers in front of each of the Thwaites and Dotson ice shelves for observational periods of days to weeks (Eriksen et al., 2001) during the 2020/21 season. The gliders will collect data along the shelf fronts which, combined with the under-ice AUV data, will build up a 3-D, time-evolving picture of shelf-cavity exchanges.

Figure 28. Images of ocean gliders in use in Antarctica waters. Images: a) Andrew Thompson, CalTech, b) Damien Guihen, British Antarctic Survey

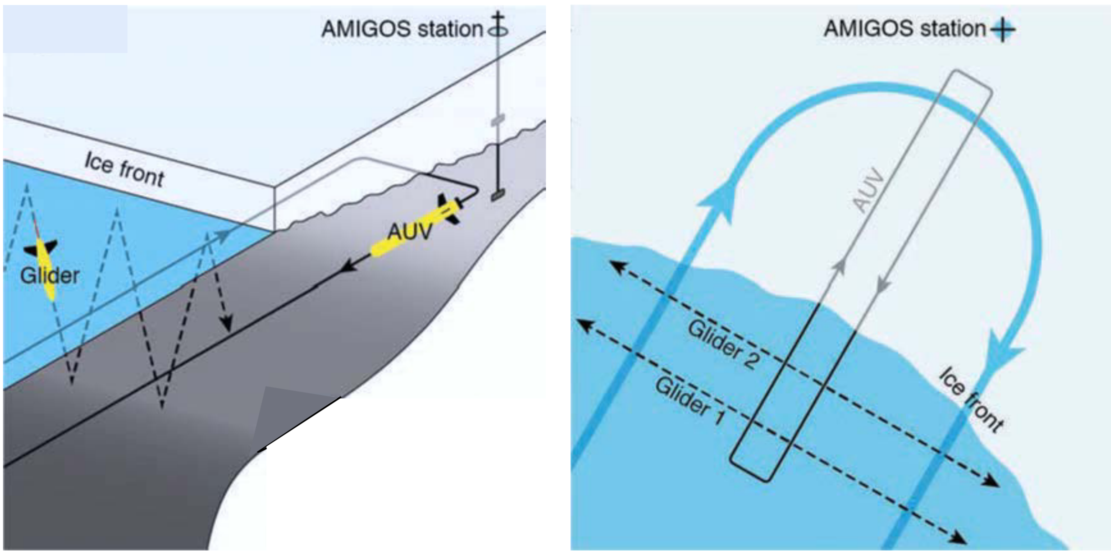


Figure 29. Schematic showing the AUV and Glider paths in proximity to the AMIGOS installation. Source: TARSAN project proposal.

Outputs

The outputs from the operation of the marine gliders that will or may interact with the environment include:

- The potential introduction of non-native marine species if the gliders have picked up biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of the gliders to the marine environment if they suffer power or equipment failure and are unable to be relocated and recovered.

Autonomous Surface Vessels

Autonomous Surface Vehicles (ASVs) are powered by renewable (wave and solar) energy and are capable of long-duration at-sea missions (Figure 30). Satellite links enable the telemetering of a range of data depending upon the sensors that are fitted. Through all wave directions the vessels are propelled forward by four keel-mounted foils positioned fore and aft. They are highly capable even in stormy seas and in flat calm, the system can be assisted by an auxiliary propeller.

The TARSAN project will deploy one or potentially two autonomous surface vehicles (ASV) during the 2020/21 season in the Amundsen Sea / Pine Island Bay area. One of the ASVs will be an AutoNaut device (Figure 30).

Outputs

The outputs from the operation of the ASVs that will or may interact with the environment include:

- The potential introduction of non-native marine species if the ASVs have picked up biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of the ASVs to the marine environment if they suffer power or equipment failure and are unable to be relocated and recovered.

Figure 30. Autonav ASV. Source: http://autonautusv.com

Icefin Remotely Operated Vehicle

Icefin is a remotely-operated (tethered) vehicle (ROV) developed by NASA and the Georgia Institute of Technology (US) (Figure 31). It is a state-of-the-art platform that it is ideally suited to undertake detailed exploration of under-ice locations. Icefin's instrumentation will include standard conductivity-temperature-depth (CTD), dissolved oxygen (DO) sensor, camera, acoustic Doppler current profiler, and a multi-beam echo-sounder.

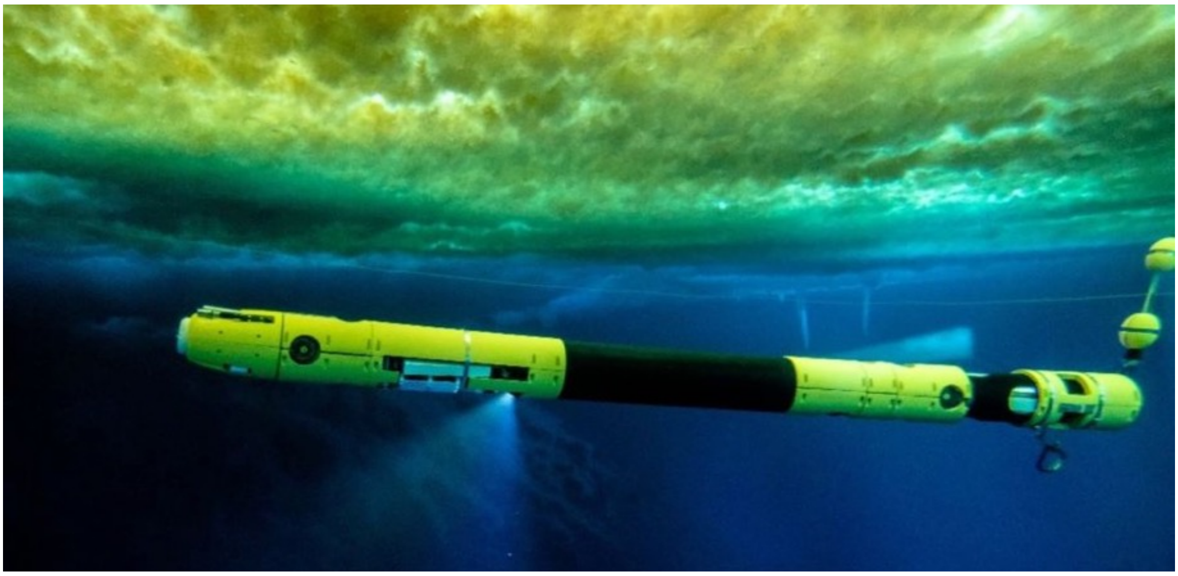


Figure 31. The Icefin ROV being tested beneath the sea-ice in McMurdo Sound. Image: Georgia Tech.

The MELT project will undertake a survey of the sub-ice-shelf cavity near to the sub-ice shelf grounding zone by using 'icefin'. It will be deployed via a hot-water drilled borehole (Spears et al., 2016).

Outputs

The outputs from the operation of 'icefin' that will or may interact with the environment include:

- Water turbulence from the operation of the small propeller and the movement of the instrument through the water;
- Noise, heat and light emissions from the operation of the power system and on-board equipment and sensors;
- The potential introduction of non-native marine species if the equipment has picked up biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of 'icefin' to the marine environment if it cannot be recovered through the ice hole *e.g.* due to entanglement of the umbilical cable.

Air-launched expendable profilers

The MELT project will undertake additional observations beneath / within the ice shelf utilising helicopter-launched expendable oceanographic profilers (AXCTD and AXCP – current, temperature and depth (CTD) profilers; Figure 32) into small patches of open water (Gladish et al., 2015) that occur seasonally in the disrupted ice between the eastern and western ice shelves. The probes will be deployed during the 2019/20 and 2020/21 seasons will yield two dozen CTD profiles and one dozen velocity profiles per field season from otherwise inaccessible parts of the glacial / marine system.

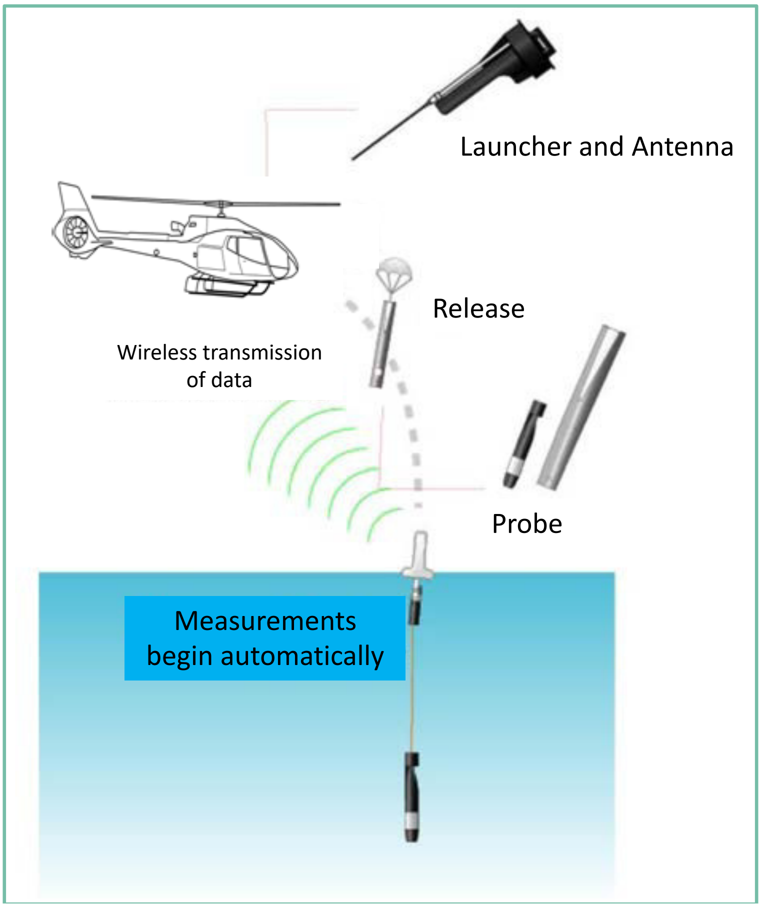


Figure 32. Schematic showing the deployment of expendable CTD profilers. Image adapted from http://www.tsk-jp.com

Outputs

The outputs from the operation of the expendable profilers that will or may interact with the environment include:

- The loss of the profilers to, and long-term persistence and decay of the profilers in the environment following data collection.

VMP-2000 tethered microstructure profiler

The TARSAN project will use a (UK supplied) vertical microstructure profilers (VMP) for making small-scale measurements in the water column. VMPs are long, slender devices with the instruments contained at the nose of the profiler. These profilers contain shear probes, which are very fragile airfoil section strain instruments that are highly sensitive (Figure 33).

Figure 33. A vertical microstructure profiler being deployed from the RRS James Clark Ross. Image: Povl Abrahamsen, British Antarctic Survey

Deployed from a stationary vessel, the turbulence profiler falls under its own weight at constant speed. Small shear currents that the profile descends through cause a deflation of the shear sensors. The shear measurement and internal accelerometers can provide information about small scale mixing processes in the water column.

When the maximum depth is reached the profiler is recovered either with a winch on a slack line or by dropping ballast weights for an untethered profiler. Tethered profilers can be deployed to around 200–2000m, but untethered instruments can go to 6000m.

Untethered profilers use a combination of recovery aids including acoustic navigation and pressure telemetry while submerged, and radio direction finding, satellite beacons, lights and flags to allow the support vessel to locate them on the surface.

Parameters measured by the instrumentation include:

- Conductivity (used for calculating salinity)
- Temperature
- Pressure (to infer depth)
- Current
- Turbulence/shear
- Fluorescence

Outputs

The outputs from the operation of the microstructure profiler that will or may interact with the environment include:

- Water turbulence from the descent and recovery of the profiler as it move vertically through the water column;
- The potential introduction of non-native marine species if the equipment has picked up biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of the equipment to the marine environment if it cannot be recovered *e.g.* due to entanglement of the umbilical cable.

Bathymetric surveying and sub-bottom profiling

The research vessel Nathaniel B Palmer (US) will undertake surface and sub-surface bathymetric surveys for the THOR project in front of the Thwaites ice shelf using multi-beam echo-sounding, sub-bottom profiling, and marine seismic surveys[2].

The multi-beam echo sounding system built into the vessel consists of Kongsberg Maritime (KM) EM120 transmit and receive arrays, both installed in 2002, and an EM122 transceiver unit installed in June 2014. The multibeam system sends out an array of sound pulses in a fan shape and returns depths from underneath the ship and from either side as well. By way of example, the multibeam system on the UK's

[2] As noted in the EIA scope (Chapter X), the environmental implications of the marine seismic survey from the Nathaniel B Palmer cruise scheduled for the 2019/20 season will be assessed in a separate environmental impact assessment (EIA) to be prepared by the US National Science Foundation (NSF). The NSF EIA will cover all activities to be undertaken from the Nathaniel B Palmer during that season.

RRS James Clark Ross has 288 beams and can map a swath width of about 4 times the water depth (Figure 34).

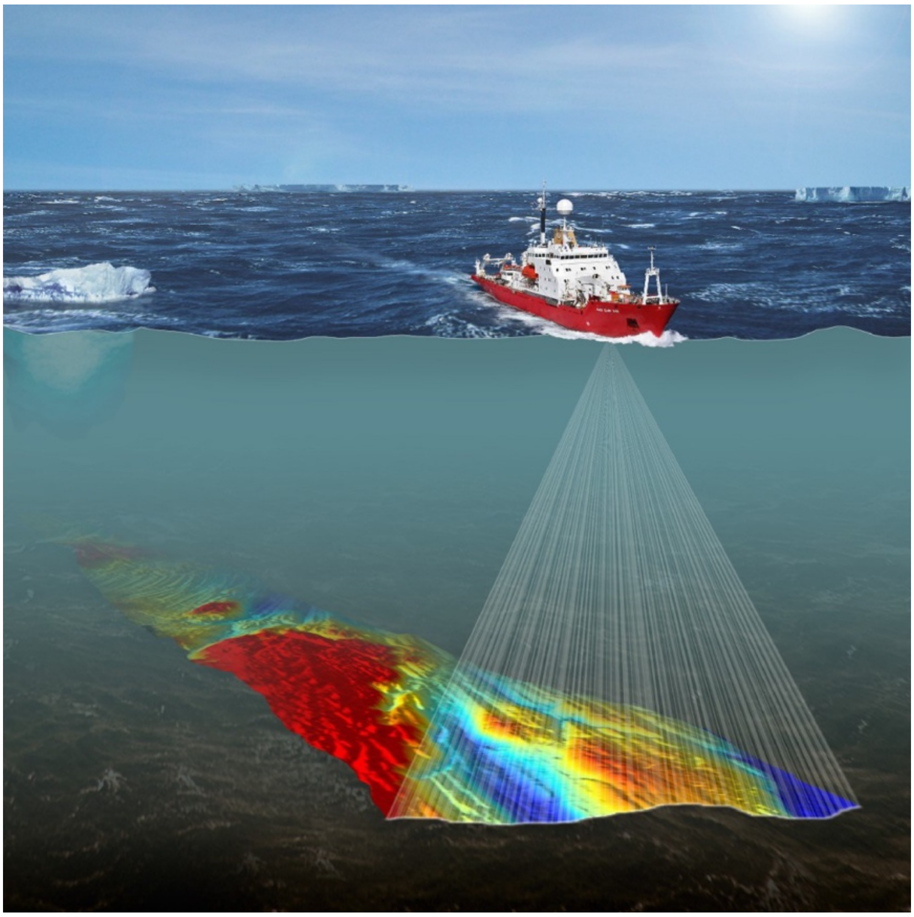


Figure 34. Schematic depicting the multi-beam echo sounding system used by the RRS James Clark Ross. Source: British Antarctic Survey.

The multibeam bathymetric surveys will be conducted from the Nathaniel B Palmer during the 2018/19 and 2019/20 field seasons for the THOR project.

Sub-bottom profiling systems are low frequency acoustic systems employed to identify and characterize layers of sediment or rock under the seafloor. The portions of the sound pulse that penetrate the seafloor are both reflected and refracted as they pass into different layers of sediment. The sub-bottom profiler installed on the Nathaniel B Palmer is a Knudsen 3.5kHz unit (3260 Chirp, 10kW) which utilises a 'chirp' system. Instead of emitting sound at a fixed frequency (the rate at which a full sound wave is transmitted), a chirp system sweeps through a wide-frequency band (three to four kilohertz wide) that allows the outgoing signal to be more powerful and able to resolve geologic layering or features at a higher resolution.

Outputs

The outputs from the operation of multi-beam and sub-bottom profiling acoustic survey that will or may interact with the environment include:

- Noise emissions from the operation of the multibeam and sub-bottom profiling equipment that will add to the noise emissions from the operation of the vessel and noise emitted from other marine-deployed equipment during the same seasons.

Ocean moorings

In 2012 nine ocean moorings were deployed in the Amundsen Sea as part of the NERC iSTAR (ice sheet stability) programme. Seven of these moorings were recovered in 2014 by the *RRS James Clark Ross*; one could not be located, and one was in its expected position, but did not rise when released.

Five of the moorings were redeployed in 2014 (in a slightly different configuration) at depths greater than 600m, and were intended to be recovered in 2017/18, though this did not happen.

The moorings now form part of the Ocean Forcing of Ice-sheet Change (OFIC) project funded through the NERC National Capability Centre funding stream. The servicing and re-deployment of the moorings will be undertaken from the *Nathaniel B Palmer* cruise in the 2018/19 season and will be one of the contributions that BAS will make to the ITGC programme. The data collected will be particularly relevant to the MELT and TARSAN projects.

Instruments attached to the moorings include current meters, temperature, conductivity, and pressure loggers, all of which use lithium metal batteries.

Outputs

The outputs from the recovery and redeployment of the moorings that will or may interact with the environment include:

- The potential non-recovery of the moorings if they fail to release from their anchors;
- The non-recovery of the mooring anchors which will remain in place on the se-bed.

4.3.2 Sampling

4.3.2.1 Geological sampling

'Winkie' geological drill / corer

The Winkie drill system (Figure 35) is a light-weight and highly portable drilling system that can be deployed by helicopter or Twin Otter aircraft. The drill system is capable of ice augering and ice coring as well as drilling geological cores both at the surface and beneath ice. The drill system is capable of obtaining short, 33mm diameter geological cores up to a maximum depth of 120m below the surface. The Winkie drill is powered by a 5Kw petrol-driven generator.

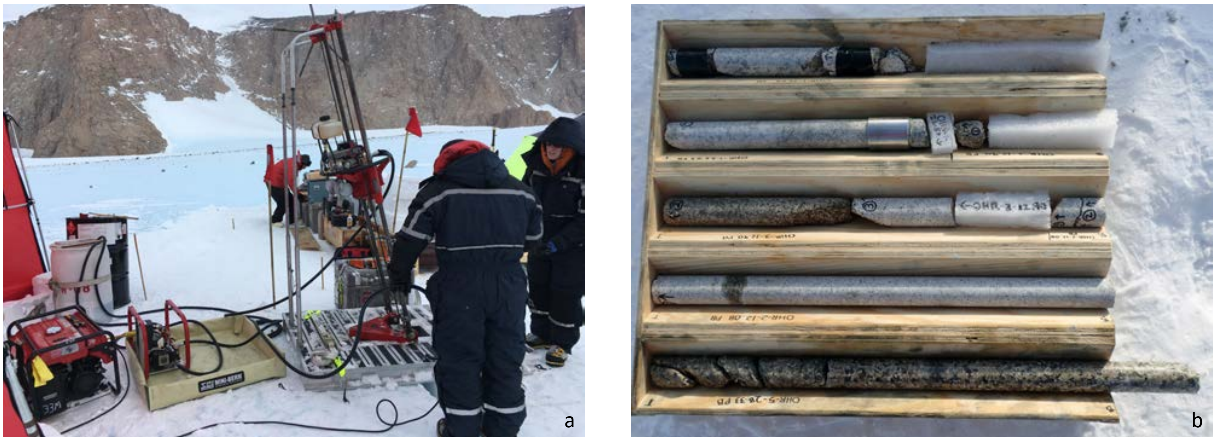


Figure 35. The Winkie drill in operation in the Ohio mountain range in Antarctica during the 2016/17 field season (a) and cores obtained during the same drilling activity (b). Images: (a) Grant Boeckmann, (b) Sujoy Mukhopadhyay. Source: https://icedrill.org/equipment/winkie-drill.shtml

The drill system requires the use of a drilling fluid, for which 'Isopar K' will be used. Isopar K fluid is a volatile isoparaffinic hydrocarbon liquid. Approximately 800 litres of Isopar K will be transported to the field site in each drilling season. During drilling, fluid circulation takes place in a closed system. Depending on the depth of the borehole, approximately 160-240 litres of fluid is present in the circulation system at any one time.

Approximately 12 litres of ethanol will also be available at each drilling site as a contingency. Ethanol may be used within the closed system to help release a stuck drill bit.

The Winkie drill system will be used by the GHC project for obtaining geological cores in the vicinity of Kay Peak (Mt Murphy) and at selected sites adjacent to the Hudson Mountains. The Winkie drill will be used to drill at least 1.5m of bedrock core from each of the access holes.

A second drill system – the Stampfli drill (Figure 36), will be used to drill through the firn covering the target geology. The Stampfli drill is an electromechanical drill that takes a 57 mm diameter ice core. It is a very lightweight, PI-operable system capable of collecting core down to 100-meters depth. The drill is configured with a winch and cable for 100m depth and is powered by batteries, which can be charged by either a small generator or a set of solar panels. The drill is very field portable. The drill system fits inside one helicopter or twin otter and is packed in pieces that can be lifted by one person and transported by a human on foot or skis.

All geological coring using the drill systems described above will be undertaken on snow/ice surfaces. None will be undertaken on ice-free ground.

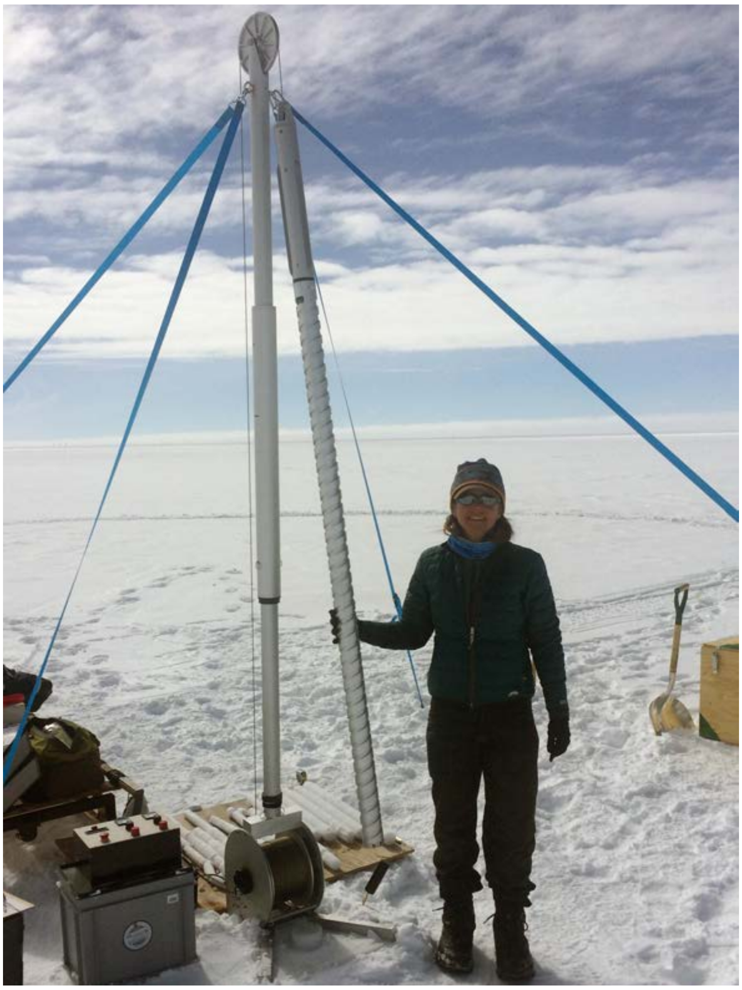


Figure 36. The Stampfli ice drill being tested in the field in Greenland. Image: Michael Jayred. Source: https://icedrill.org/icebits/topic.shtml?ID=181

Outputs

The outputs from the operation of the Winkie drill / coring system that will or may interact with the environment include:

- The potential loss of drilling fluid into the substrata *e.g.* through equipment failure;
- The potential loss of ethanol into the substrata if ethanol is used to release a 'stuck' drill;
- The physical removal of geological material from the environment through the drilling and coring activity;
- Noise emissions from the operation of the drill system;
- Atmospheric emissions from the burning of fossil fuels to power the drilling equipment;
- The potential release of fossil fuels into the environment if fuel is spilt *e.g.* during refuelling of the generator that is used to power the drill system.

Surface geological sampling

Surface geological sampling will be undertaken at several target for the purpose of cosmogenic-nuclide exposure dating. This will involve the use of hammer and chisel, as well as a powered rock saw and drill.

Cosmogenic-nuclide exposure-dating relies on the measurement of trace nuclides (*e.g.* 3 He, 10 Be, 14 C, 21 Ne, 26 Al, and 36 Cl), that are produced by cosmic-ray bombardment within rocks and minerals exposed at the Earth's surface. This method is commonly used to date glacial deposits exposed above the present Antarctic ice sheet, because significant production of these nuclides only occurs within a few meters of the Earth's surface, whereas glacially transported clasts are typically quarried at the glacier bed where they have not been exposed to the cosmic-ray flux. As such, cosmogenic-nuclide concentrations in glacial deposits are proportional to the age of the deposit (Dunai, 2010; Balco, 2011).

Surface geological samples will be collected by GHC project researchers from islands in Pine Island Bay, Mt Murphy and the Hudson Mountains during the 2018/19, 2019/20 and 2020/21 seasons.

Outputs

The outputs from the collections of surface geological samples that will or may interact with the environment include:

- The removal of rocks and geological material from the environment;
- Noise from the operation of the rock saw and drill;
- The potential release of fossil fuel into the environment if fuel is spilt *e.g.* during refuelling of the drill and saw;
- The introduction of non-native terrestrial species on to ice-free areas through biologically contaminated clothing or equipment;
- The potential artificial relocation of native terrestrial biota if people (and their clothing, boots and equipment) pick up biological material from one ice-free location and are then moved to another ice-free location.

4.3.2.2 Marine sediment coring and water sampling

Kasten corer

The Kasten corer is a gravity coring device used for sediment coring. It is square-sided with a 150mm square core, often available in 2, 3 or 4m lengths. The Kasten core uses a track and tilt system for deployment / retrieval and is suitable for full-ocean depth coring. An advantage of the Kasten corer is that cores can be opened immediately after retrieval as one side of the core barrel can be removed giving access to the entire length of the core (Figures 37a and 37b).

Kasten cores will be obtained at multiple target locations by THOR project researchers operating from US and/or UK research vessels over the 2018/19 and 2019/20 seasons.

Gravity corer

Longer, single-barrel sediment cores will be collected through the use of a gravity coring system (Figure 37c).

Such coring systems can be assembled with different length cores from 3m to a maximum of 24m. The coring unit is deployed from the vessel using a dedicated coring deployment system comprising a winch, overhead coring boom and core handling system.

The coring unit consists of the head weight, coring tube, removable inner core liner and core catcher. The trigger core reaches the bottom first and triggers the release of the main core which free-falls to the bottom and penetrates the silt. The tube is drawn back out of the silt with core catchers preventing the silt from coming out of the coring tube.

Gravity cores will be obtained at multiple locations from research vessels operating in front of the Thwaites Glacier by the THOR project over the 2018/19 and 2019/20 seasons.

Percussion gravity-corer

Lightweight 'percussion' corers have been developed for collecting sediment cores from sub-ice shelf settings. These use a common deployment system and tether with other field instruments and are compact enough to be transported by a Twin Otter aircraft.

The corer for sub-ice shelf coring developed by BAS in collaboration with Austrian engineering company UWITEC consists of a core cutter, core catcher and lined 3m long steel barrel (Figure 37d). Percussion is driven via a manually operated hammer mounted on a hammer rod with a striking plate. In deeper subglacial locations (more than 1km of tether), the corer has been modified so that the weights are hoisted, then released automatically by a triggered release mechanism, resulting in more efficient percussion.

In the field, the corer has been deployed via a davit winch or by tethering the corer to a skidoo via an 'A' frame sheave. Up to five 11 kg hammer weights can be added to the corer which has proved effective at recovering sediments, even in relatively hard semi-consolidated glacial material (Hodgson et al., 2016).

The BAS percussion corer will be used by THOR project researchers in the 2019/20 season to acquire sub-ice shelf sediment cores at four sites selected in tandem with oceanographers proposing to drill through the ice shelf as part of the MELT project. Sub-shelf sediment corers are also likely to be taken by the THOR team member or another at the TARSAN sites on the Dotson ice shelf.

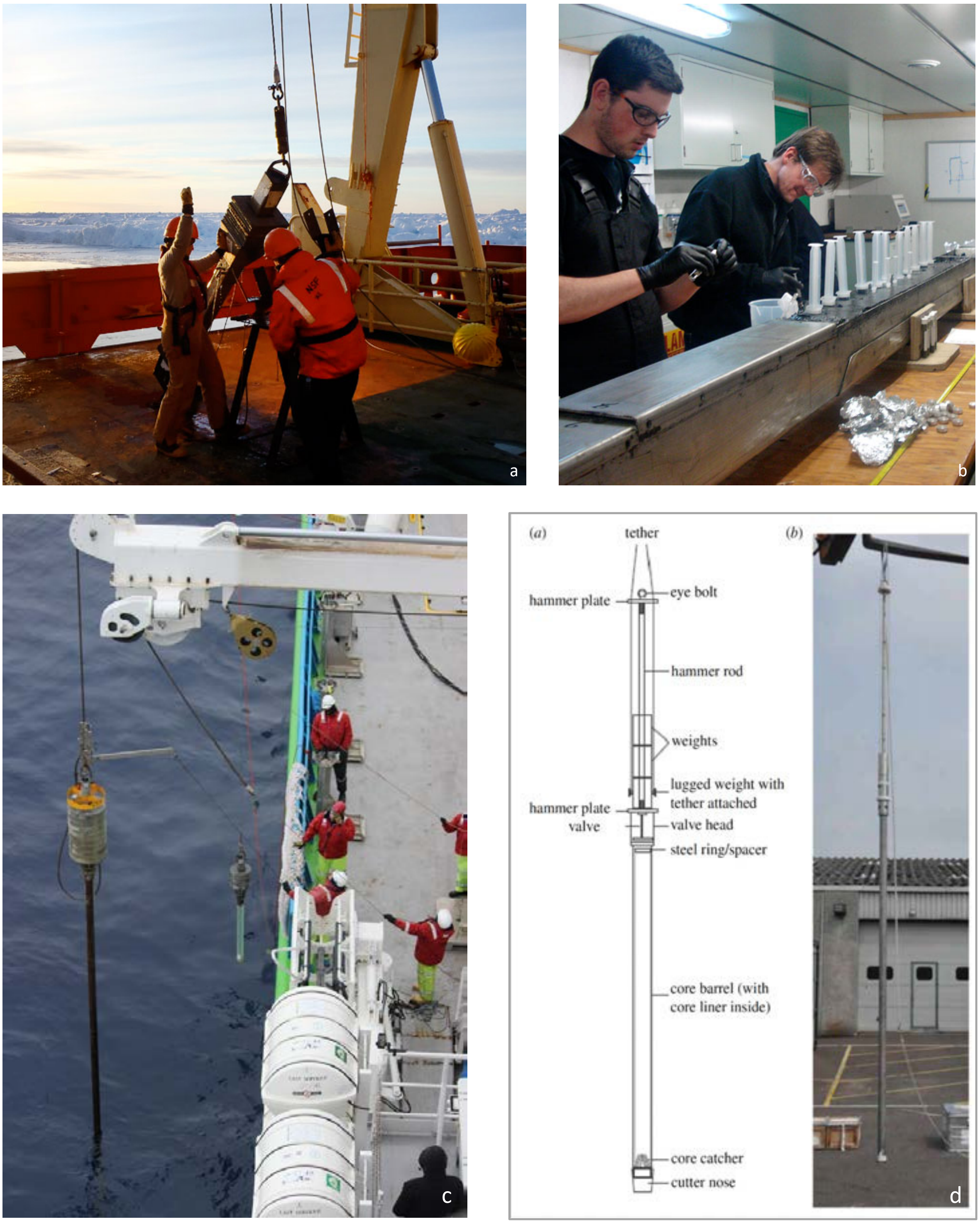


Figure 37. Coring devices that will be used during the ITGC campaign include the Kasten corer (a and b), a gravity corer (c) and the BAS/UWITEC percussion corer designed for use in sub-ice shelf settings (d). Image sources: a and b: USAP Antarctic Sun, https://antarcticsun.usap.gov/science/contentHandler.cfm?id=2675; c: http://mnf.csiro.au/Vessel/Investigator-2014/Equipment/Sediment-coring.aspx; d: reproduced from Hodgson et al., 2016.

Multi-corer

A multi-corer is a gravity coring instrument that allows for multiple short cores to be taken in close proximity at the same time (Figure 38) and provides a series of undisturbed samples of the seafloor. This device can be used to study local fauna variations. Samples of the sediment / water interface can also be taken by this device.

The multi-corer is lowered from a research vessel to the seafloor by a cable. A weight is attached on the top of the construction. When the multi-corer touches the seafloor, this weight pushes the assembled cores into the seafloor.

Figure 38. Example of a multi-corer being deployed from RV Meteor around South Georgia in 2017. Photo Oliver Hogg, British Antarctic Survey. Source: http://www.gov.gs/march-17-newsletter/

A multi-corer will be used to collect samples at multiple locations from research vessels operating in front of the Thwaites Glacier by the THOR project over the 2018/19 and 2019/20 seasons.

Box corers

A box corer is used at target locations to take samples of the surface of the sea floor. The box corer allows for a relatively intact sample to be taken of the upper part of the sea floor supporting investigations of the benthic micro- to macro-fauna, geochemical processes and sedimentology (Figure 39).

Box coring devices will be used to collect samples at multiple locations from research vessels operating in front of the Thwaites Glacier by the THOR project over the 2018/19 and 2019/20 seasons.

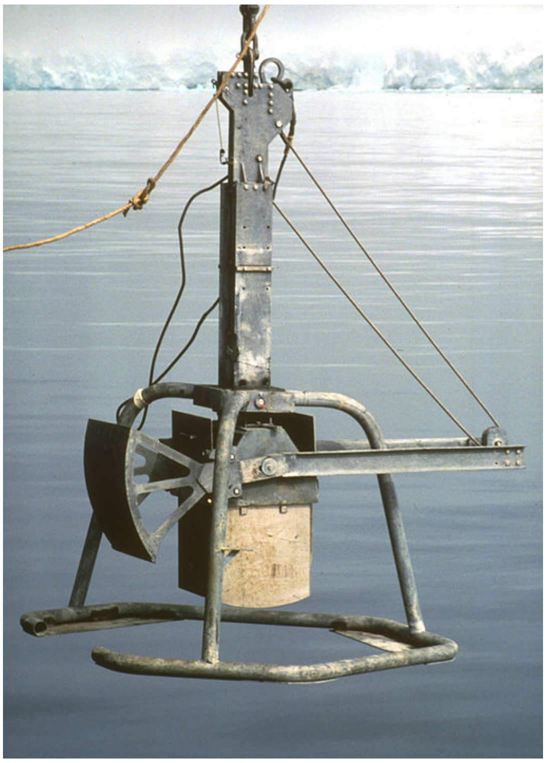


Figure 39. An example of a box corer being deployed from the German Polar research vessel Polarstern in the Southern Ocean. Source: H. Grobe, 2006. Alfred Wegener Institute for Polar and Marine Research. From Wikimedia Commons.

Outputs (all marine coring devices)

The outputs from the sampling of marine sediments using the various coring devices that will or may interact with the environment include:

- The potential introduction of non-native marine species if the coring devices have picked up or are contaminated with biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of coring devices to the marine environment *e.g.* if the cable tethers break or become entangled and are required to be cut, or if the corer cannot be recovered from the sea floor;
- The physical removal of sediment material from the sea floor.

CTD and water samplers

The TARSAN project will utilise a Conductivity-Temperature-Depth (CTD) and water sampling device. These are standard measuring and sampling devices used in oceanographic research (Figure 40).

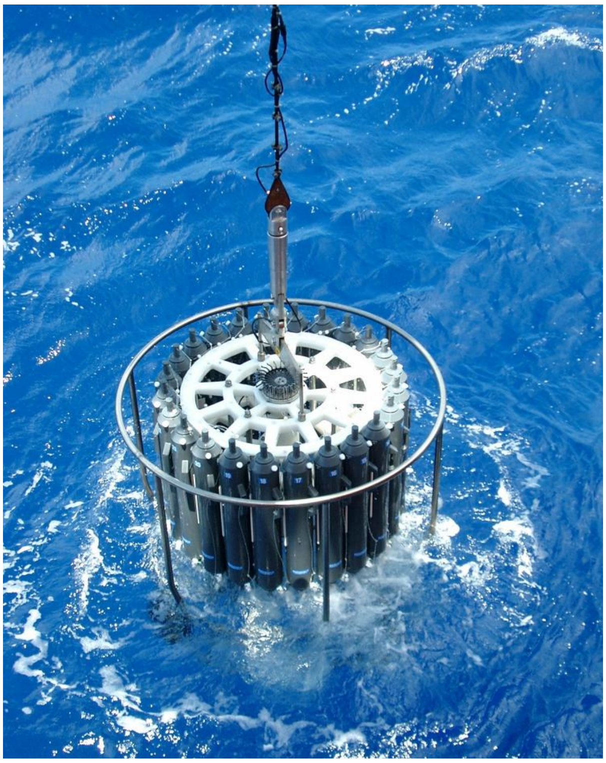


Figure 40. The NERC CTD and water sampling device. Source: http://noc.ac.uk/facilities.

As well as conductivity, temperature and depth measurements the sensors are able to collect dissolved oxygen and chlorophyll measurements. Sensors are attached to a 'rosette', which includes 24 x 10-litre bottles that can be shut at any specified depth to collect water samples. These water samples are then measured for salinity, dissolved oxygen and other concentrations, and are used to verify the readings that the sensors provide.

Outputs

The outputs from the operation of the CTD equipment that will or may interact with the environment include:

- The potential introduction of non-native marine species if the CTD equipment has picked up or is contaminated with biological material from previous operations (particularly operations in other cold-water environments);
- The potential loss of the CTD equipment to the marine environment *e.g.* if the cable tether breaks or becomes entangled and is required to be cut.

4.3.2.3 Ice sampling

Kovacs ice corer

Kovacs ice corers provide a straightforward means of obtaining ice cores (Figure 41) The core barrel is a light weight filament wound composite tube about 1.15 m long with plastic flighting. The cutting shoe is aluminium, and the cutting teeth are heat-treated steel. The drive head is stainless steel and aluminium and can be coupled and uncoupled from the core barrel. Kovacs ice corers include extension rods to allow for cores of varying depths to be obtained.

The drill can be used manually or with a power attachment (Figure 41 inset).

Figure 41. Kovacs ice corer being used in Antarctica. Image shows hand-held and (inset) powered versions. Image: https://kovacsicedrillingequipment.com/photo-gallery/

The TARSAN project will drill several firn cores of between 15 and 20m depth using a Kovacs ice corer. These will be photographed and measured in the field for density and melt layer thickness and frequency.

Outputs

The outputs from the operation of the kovacs drill that will or may interact with the environment include:

- The physical removal of snow and ice samples;
- Atmospheric emissions from the burning of fossil fuels (if the powered version of the drill is used);
- The potential release of fossil fuels into the environment if fuel is spilt *e.g.* during refuelling of the power unit for the drill.

4.4 Logistical Support Activities

Ice drilling equipment will be used to prepare access holes in glaciers and ice shelves to support the deployment of drilling equipment; to deploy data collection instruments within and beneath the glacier, or to deploy explosives for active seismic measurements. The various types of drilling equipment are described below.

4.4.1 Ice Drilling

4.4.1.1 Hot water drills

A number of hot water drilling systems will be utilised by most of the research projects and across most seasons of the campaign. Hot water drills will be sourced from several providers including: BAS (Figure 42), Pennsylvania State University, Victoria University Wellington, University of Alaska Fairbanks and the Ice Drilling Design and Operations (IDDO) group at the University of Wisconsin.

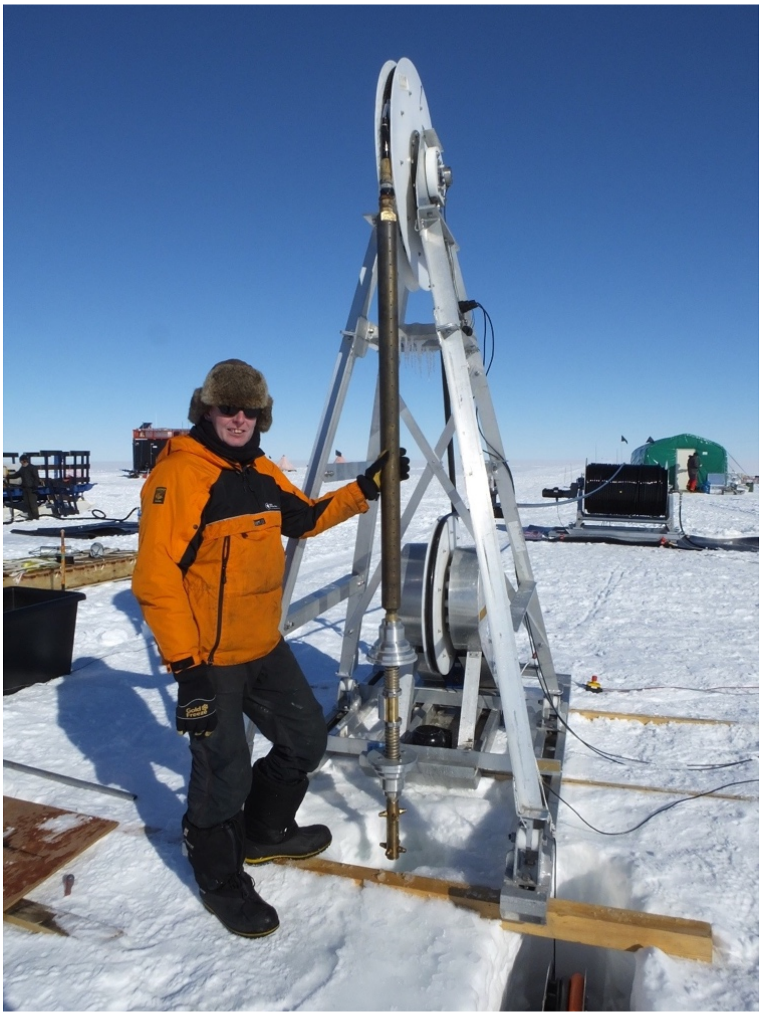


Figure 42. BAS hot-water drilling system. Source: https://www.bas.ac.uk

Hot-water drilled holes will be established to enable direct observations and sampling of the ocean cavity and seabed beneath floating ice shelves and sediments beneath grounded ice. A variety of instruments will be lowered down prepared subglacial access holes to capture a range of data. The various instruments that will be used in this way are discussed above.

Hot water drills will also be used during the ITGC programme to drill 'shot holes' at selected locations on the Thwaites Glacier to emplace explosives in support of the active seismic field activities.

The drilling systems all use petrol-fuelled generators, and water-heaters powered by aviation fuel to heat the drill water to around 90°C. By way of example, the BAS 1,000m system uses high pressure pumps to deliver 120 litres of water per minute down the drill hose. The resultant 0.75MW of heating power can melt a 30cm diameter hole at up to 1.7 metres per minute (Makinson and Anker, 2014).

Hot water drills will be used to support the MELT, GHOST, TARSAN, THOR and TIME research projects during the first three seasons of the ITGC programme. Hot water drilling systems will be transported to research sites in several ways including by over-ice traverses and aircraft.

4.4.1.2 Rapid Air Movement (RAM) drill

The Rapid Air Movement (RAM) Drill (Figure 43) has been by Ice Drilling Design and Operations (IDDO) of the Ice Drilling Program Office (IDPO). The RAM drill is used to create small-diameter shot holes in snow and ice for seismic geophysical exploration. It is a system in which high-velocity air drives rotating cutters and blows the ice chips from the hole. The cutting drill motor hangs on a hose that carries the air from the surface and is reeled out as the hole deepens. It has been used three times in West Antarctica, where it routinely achieved depths of 90 meters.

IDDO is currently redeveloping the drill system to reduce overall weight, whilst maintaining current drilling capacity and including scalable components for either shallow (approximately 40m depth) deployments or for full 100m depth deployments.

The RAM drill will be used to support the TIME and GHOST research projects during the 2019/20, 2020/21 and 2021/22 seasons.

Outputs

The outputs from the operation of the drilling systems that will or may interact with the environment include:

- The physical disturbance of the snow / ice environment through the drilling of the holes;
- Atmospheric emissions from the burning of fossil fuels to power the drills;
- The potential release of fossil fuels into the environment if fuel is spilt *e.g.* during refuelling of the drill units;
- Noise from the operation of the power units for the drill systems.

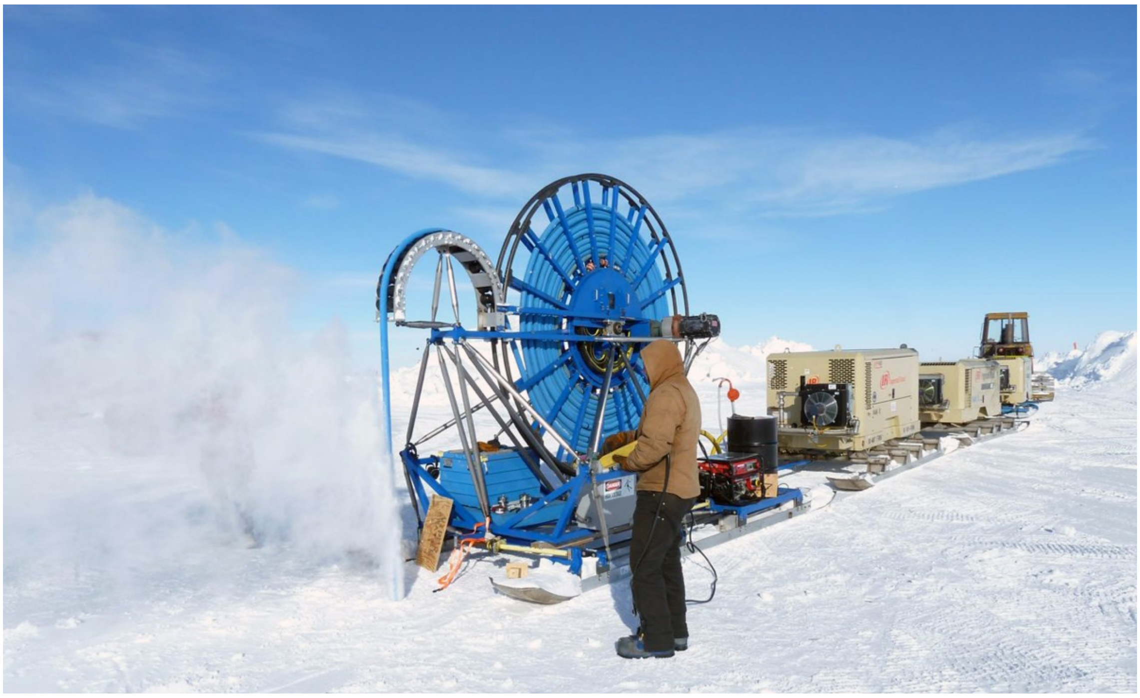


Figure 43. RAM drill being tested in Antarctica during the 2010-2011 Antarctic season. Note: some modifications to the system may have been made since the image was taken. Image: M. DuVernois. Source: https://icedrill.org/equipment/ram.shtml

4.4.2 Vehicles, Vessels and Aircraft

4.4.2.1 Traverse / Over-snow transport systems

Over-snow traverses will be used each season of the ITGC campaign either to deploy equipment and fuel, establish field camps or to support research activity (*e.g.* seismic data collection).

Traverses will vary in their configuration depending upon the intended purpose *i.e.* supporting logistics (such as fuel deployment) or supporting research (such as seismic profiling).

The first operational traverse will be undertaken in the 2018-2019 season and will move equipment and fuel from SB9 to the ESM camp. It will consist of four Kassbohrer Pisten Bully 300 (PB 300) tractors towing a mix of poly sleds, Lehmann Sledges and a caboose living module (see example of a BAS tractor traverse in figures 44 and 45).

The Pisten Bully PB300 Polar version is widely used in Antarctic operations and particularly for ‘tractor train’ traverses. It is a tracked vehicle which can pull 40 to 60 tonnes. With steel tracks fitted it weighs 8.4 tonnes. Configurations can include snow blades and living ‘caboose’.

Figure 44. An example of an over-ice traverse arrangement. Source: British Antarctic Survey.

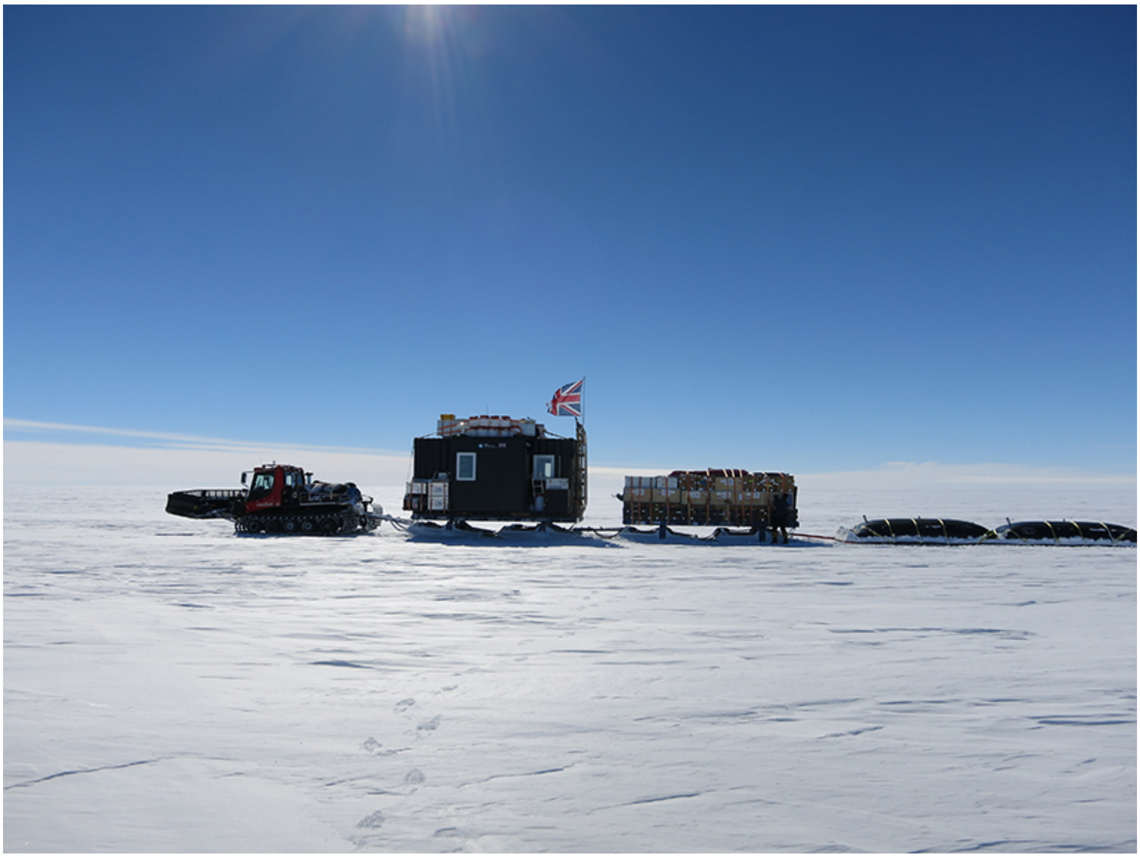


Figure 45. An over-ice traverse arrangement including a PB 300 tractor, two Lehmann sledges and a 'poly' sled fitted with two fuel bladders. Source: British Antarctic Survey.

A BAS operated traverse comprising four PB 300 vehicles and sledges will operate between SB9 and the Thwaites Glacier operational area (including the LTG camp and WAIS divide) during the 2018/19 and 2019/20 seasons delivering fuel, scientific equipment and other supplies. The operational traverse will also be used to establish field fuel caches *e.g.* those required in the region of the ESM (for the TIME project) and will provide flexibility for field flying by providing a mobile fuel cache. The operational traverse will also help with managing food and fuel distribution and any late cargo moves.

It is anticipated that the operational traverse support system will contribute up to 42 Hercules flights of effort throughout the duration of the research programme. Additionally it will save considerable feeder aircraft hours and the associated fuel burn from the WAIS Divide camp, by pre-deploying science equipment, fuel and camp supplies to the point of use or nearest depot site to the requisite work sites.

An additional PB 100 vehicle (U.S. provided) will support the two 60-day scientific traverses in the 2020/21 and 2021/22 seasons in support of the GHOST project.

During the winter traverse equipment will be positioned on a snow berm to raise it above the snow surface and minimise winter burial (Figure 46).

Figure 46. Traverse equipment prepared for overwintering. Source: British Antarctic Survey.

Skidoos

Snowmobiles (or skidoos) will be provided by both the UK and U.S. These vehicles will be used by smaller field parties and will be deployed either by aircraft or from the larger scientific traverses (Figure 47).

Skidoos are simple to ride with just a thumb throttle and a brake. They have a fully automatic transmission and a track underneath with skis at the front to steer. These smaller vehicles are used for personal transport and for towing Nansen sledges.

Figure 47. Skidoo in operation in Antarctica. Source: British Antarctic Survey

Outputs (all over-ice vehicles)

The outputs from the operation of the over-ice vehicles that will or may interact with the environment include:

- Atmospheric emissions from the burning of fossil fuels to power the vehicles;
- The potential release of fossil fuels into the environment if fuel is spilt *e.g.* during refuelling of the vehicles;
- Noise from the operation of the vehicles.

4.4.2.2 Air transport

A number of fixed-wing and rotary-wing aircraft will be used to support the ITGC through each of the operational seasons (Figure 48).

Figure 48. Aircraft that will be used during the ITGC campaign. (a) US Air Force ski-equipped LC-130 (Image: Capt. David S. Price. Source: www.army.mil), (b) British Antarctic Survey Twin Otter (Source: www.bas.ac.uk), (c) Ken Borek DC-3 Basler (Image: Roland Warner. Source: www.antarctica.gov.au), and (d) helicopter operating from the Nathaniel B Palmer during the 2009/10 season. (Image: Adam Jenkins, NSF. Source: www.USAP.gov).

LC-130 Hercules

The Lockheed LC-130 Hercules is an American four-engine turboprop military transport aircraft (Figure 48a). It is ski-equipped and able to use both snow/ice and hard runway surfaces. It is particularly useful for bulky and heavy equipment, with a rear cargo ramp and a payload of up to 45 tonnes. This aircraft will be used during the ITGC to transport people, fuel and equipment from McMurdo Station to the WAIS Divide field camp. The aircraft will have a nominal transfer payload of 8,000kg (circa 18,000 lbs) to WIAS Divide.

Twin otter

The Canadian built de Havilland DHC-6 Twin Otter is a 19-passenger short take-off and landing utility aircraft that is widely used in Polar environments (Figure 48b). It can be configured for fewer passengers and more cargo and can be fitted with ski or wheeled landing gear. The payload is 5.5 tonnes. Several Twin Otter aircraft supplied by the U.S. contractor (Kenn Borek Air) and UK (British Antarctic Survey) will be used during the ITGC to deploy and support field camps as well as to undertake aero-geophysical surveys.

Basler

The Basler is a modified DC-3 aircraft (Figure 48c). The Basler aircraft provided by the U.S. contractor (Kenn Borek Air) can accommodate up to 18 passengers in addition to the two pilots, and has a maximum payload of 3.8 tonnes. The Basler will be based at the WAIS Divide camp and will be used for deploying field camps and heavier field equipment within the Thwaites Glacier area of research activity.

Helicopters

It is expected that Nathanial B Palmer will carry two helicopters (type and make unknown at time of writing) (Figure 48d). The helicopters will be used to deploy small field teams for short periods ashore from the vessel (*e.g.* those undertaking seal tagging or geological sampling) as well as for deploying the expendable ocean profilers (Figure 32).

The Korean research vessel *RV Aaron* is expected to carry one or two AS350 helicopters (known as a squirrel or A-Star helicopters). These can carry 5 passengers and around one tonne of equipment. These helicopters will potentially be used in a similar manner to the helicopters from the Nathaniel B Palmer and deploy small field teams for short periods ashore.

Outputs (all aircraft)

The outputs from the operation of the over-ice vehicles that will or may interact with the environment include:

- Atmospheric emissions from the burning of fossil fuels to power the aircraft;
- The potential release of fossil fuels into the environment if fuel is spilt *e.g.* during refuelling of the aircraft;
- Noise from the operation of the aircraft and in particular from the use of helicopters in the Pine Island Bay, and other coastal locations.

4.4.2.3 Marine transport

Polar Research and Resupply Vessels

Five Polar research and resupply vessels will support the ITGC campaign during the four seasons of operation (Figure 49).

The *Nathaniel B Palmer* (Figure 49a) is the NSF's Antarctic research icebreaker. It can accommodate up to 39 scientists with a crew of 22. It is 6,174 tonne, 94m long with 18m beam and 6.8m draught and ice-classed A2, capable of breaking three feet of level ice at three knots.

The *RRS Ernest Shackleton* (Figure 49b) is a 5,455 tonne ice class DNV ICE-O5 research vessel. The vessel is 80m long with 17m beam and 6.15m draft. The *RRS Ernest Shackleton* carries 22 crew and up to 50 expedition personnel.

HMS Protector (Figure 49c) is a 5,000 tonne, DNV ICE-O5, DP2 class icebreaker which carries up to 100 people. She is 89m long with an 18m beam and 8.35m draught.

The 15,000 tonne *RSS Sir David Attenborough* (Figure 49d) is currently under construction. Once completed the vessel will be 128m long with a beam of 24m and a draught of 7m. The *Sir David Attenborough* will carry 30 staff and up to 60 expedition personnel. The vessel will be rated Polar Class PC4 and will be capable of breaking ice up to 1m thick at 3 knots.

The RV *Aaron* (Figure 49e) is the research vessel of the Korean Polar Research Institute (KOPRI). The vessel is 6,950 tonne and classed as DNV Polar-10 icebreaker. The vessel is 109.5m long with a 19m beam and a 9.9m draft. The *RV Araon* carries 25 crew and up to 60 science personnel.

Figure 49. Research and resupply vessels that will be used during the ITGC. (a) Nathaniel B. Palmer (U.S.). Source: www.nsf.gov. (b) RRS Ernest Shackleton (UK). Source: www.bas.ac.uk. (c) HMS Protector (UK). Source: www.royalnavy.mod.uk. (d) RRS Sir David Attenborough (UK). Source: www.bas.ac.uk. (e) Araon (Korea). Source: www.polarforskningsportalen.se.

Small boats and launches

Smaller inflatable boats, rigid-inflatable boats and launches may be used in the Pine Island Bay / Amundsen Sea area for the purposes of assisting with the launching and recovery of research equipment (for example the AUVs; Figure 50) or for landing researchers ashore.

Outputs (all vessels)

The outputs from the operation of polar vessels and small launches that will or may interact with the environment include:

- Atmospheric emissions from the burning of fossil fuels to power the vessels;
- Noise emissions to air and the marine environment from the operation of the vessel's engines and on-board machinery;
- Waste generated on-board including grey-water and sewage which will be discharged to the marine environment;
- Water turbulence as a consequence of propeller wash and the use of thrusters;
- The potential introduction of non-native species through hull fouling or ballast water exchanges;
- The potential accidental release of fossil fuels into the environment if fuel is spilt *e.g.* as a result of hull damage of equipment failure.

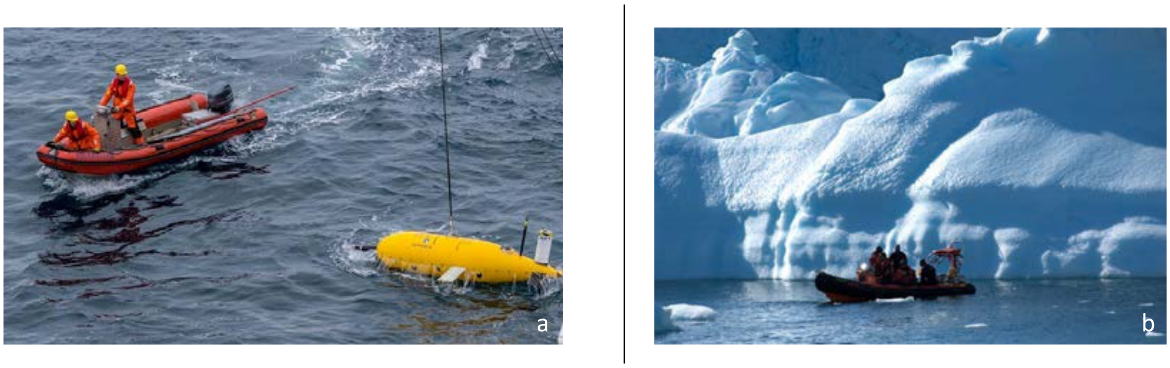


Figure 50. Small rigid-hulled inflatable boats being used to support the recovery of an AUV (a) and to deploy researchers (b). Sources: www.nerc.ac.uk and www.bas.ac.uk.

4.4.3 Establishment and Operation of Field Camps

A number of field camps will be established throughout the first four seasons of the ITGC. Some of these will be relatively large, for example the Lower Thwaites Glacier camp, which will serve as a hub in support of several of the projects, and others will be smaller, for example the temporary camps that will be established by field teams in or near the Hudson Mountains.

In all cases camp sites will be established on snow or ice.

The larger camps may include Weatherhaven, Polarhaven or 'Rac' tents which will provide mess and science support purposes (Figure 51) as well as Scott (pyramid) tents and / or geodesic tents for accommodation (Figure 52).

The scientific traverse that will be undertaken by the GHOST project will also establish a series of short-term camps along the traverse route (Figure 53).


Figure 51. A Weatherhaven tent being used as a mess tent at WAIS Divide camp.


Figure 52. Small Antarctic field camp utilising Scott or Pyramid tents for accommodation. Source: www.bas.ac.uk.


Figure 53. A typical traverse camp which utilise a towed caboose, which acts as a mess, a larger 'Polar Haven' or 'Rac' tents for science support purposes and geodesic (mountain) tents for sleeping. Source: www.bas.ac.uk.

Outputs (all camps)

The outputs from the establishment and operation of field camps that will or may interact with the environment include:

- The production and potential release to the environment of waste including general waste (paper, plastic and cardboard) and food waste;
- The potential loss to the environment of camping equipment a materials *e.g.* items blowing away in high winds or storms;
- The intentional release to the environment of human waste (for some camp sites only);
- Emissions to air from the burning of fossil fuels for heating and cooking.

4.4.4 Fuel Management

The ITGC will be a 'fuel hungry' research programme. Significant quantities of fuel will be required for operating over-snow vehicles and aircraft (Figure 54), running generators to power research equipment (*e.g.* hot-water and geological drills), as well as for cooking and heating in field camps over four seasons of activity. Several fuel types will be used throughout the ITGC including JET-A1, AVTUR, AVCAT and MOGAS.

Figure 54. U.S. Twin Otter aircraft being refuelled in the field during the 2012/13 field season. Image: Geoff Sims. Source: http://newt.phys.unsw.edu.au/~z3318051/spd/spd-all.php

Fuel transport via over-snow traverse

The vast majority of fuel will be transported in 1,500 gallon fuel bladders (Figure 55) or in 205 litre fuel drums (Figure 56) and will be stored at its destination in a mix of 1,500 and 10,000 gallon bladders.

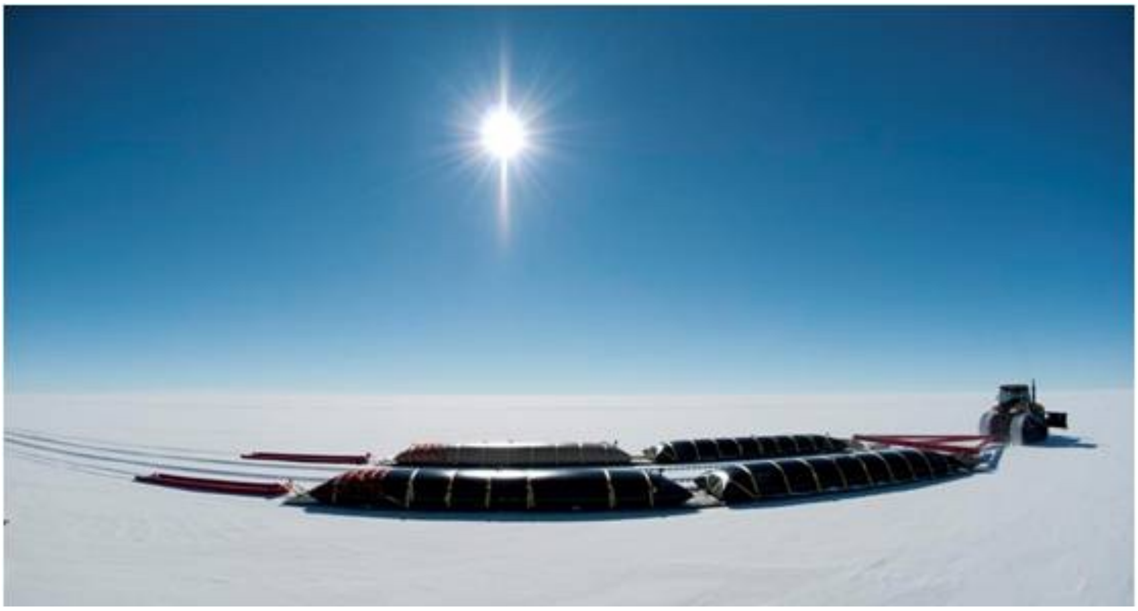


Figure 55. Fuel bladders being towed during the UK iStar research programme. Image: Simon Garrod. Source: www.istar.ac.uk.

Figure 56. BAS Twin Otter aircraft being loaded with 205 litre fuel drums in the field in Antarctica. Source: www.antarctica.gov.au.

Fuel will largely be delivered to the ITGC operational area from the east via Sky Blu and SB9 (Figure 6) though additional fuel will be delivered by C130 Hercules from McMurdo Station via the U.S. WAIS Divide camp (Figure 6).

In January 2019 season the *RRS Ernest Shackleton* and *HMS Protector* will offload and fill fuel bladders in the vicinity of the Stange Ice Shelf (Figure 57). Empty fuel bladders will be off-loaded on to the ice shelf and filled via flexible hosing connected to the bladders. If the vessels can get alongside and offload directly on to the ice-shelf at a location known as Case Corner, then fuel will be transferred directly into 38,000 litre (10,000 U.S. gallon) holding bladders (Figure 57). If the vessels are unable to get alongside the ice-shelf, due to sea ice conditions, then a sea-ice offload will be required. In this scenario, fuel will be transferred to smaller 5,800 litre (1,500 U.S. gallon) bladders to move the fuel onto the ice-shelf where a second transfer will be made into the larger 38,000 litre (10,000 US gallon) bladders. This double handling of the fuel is the least preferred option as it is a slower process and increases the risk of a spill occurring.

Once filled the bladders (and other offloaded equipment and supplied) will be moved inland to the staging area of SB9 (Figure 6). The transfer process to move fuel and other supplies from the ships to SB9 is anticipated to take one month and will in itself burn around 27,000 litres of fuel.

The vessels will also deliver 80 x 205 litre drums of petrol/mogas and 2 x 205 litre drums of kerosene, all of which will be delivered to the ITGC project for skidoos and generators.

Figure 57. ATL Cargo-Flex™ fuel bladders being filled from the RRS Ernest Shackleton. Source: Wikimedia Commons

The fuel bladders are all ATL Petro-Flex or Cargo-Flex bladders that have been used in Antarctica in traverse situations on many occasions with no failure.

All hose connections are self-sealing Avery Hardoll (Intrico Products) couplings which prevents fuel from being spilled as hoses are coupled and un-coupled.

A total of 408,000 litres of fuel is planned to be delivered from the vessels by means of the process described above. An additional 45,000 litres (250 drums) of fuel will be transferred in stages from the BAS Sky-Blu blue ice runway to SB9. A further 45,000 litres (250 drums) will be delivered to SB 9 in early January by RAF air drop (see below). These 500 drums of fuel will likely be left at SB9 during the 2019 winter and will be moved south to the Thwaites Glacier area during the 2019/20 operational traverses.

In total, 498,000 litres of fuel will be delivered into the system via SB9 and the BAS operational traverse.

Approximately 93,000 litres (along with other supplies and equipment including field camp infrastructure and skidoos) will be driven down to the Thwaites Glacier area during the 2018/19 season by means of the BAS operational traverse. It is estimated that approximately 36,000 litres of fuel will be burnt to deliver around 57,000 litres via this method *i.e.* approximately 1 litre of fuel is burnt for every 1.5 to 1.6 litres that is delivered.

Remaining fuel and equipment will be delivered via the same operational traverse during the 2019/20 season and distributed as required among the various projects and camps.

The U.S. will also deliver fuel into the ITGC operational area via its WAIS Divide camp (Figure 6). Fuel will be delivered from McMurdo Station to WAIS Divide via LC-130 aircraft. The U.S. will undertake a tractor traverse in the 2018/19 season using Caterpillar 55 tractors from WAIS Divide into the Thwaites catchment, to deliver fuel and other supplies to the ESM and LTG camp locations (Figure 6).

Precise volumes to be delivered via this route are unknown, but will include 100 x 205 litre drums of aviation fuel to support the BAS aero-geophysics programme (see Pg 57, Section 4.3.1.1)[3].

Air-dropped fuel

As noted above, the RAF will deliver 240 x 205 litre drums of AVTUR via air drop in January 2019 (see example image in Figure 58). It is anticipated that 8 to 10 rotations of the aircraft will be undertaken (likely between 1 and 10 January) to deliver up to 32 drums of fuel packed into separate pallets on each rotation.

An RAF Hercules aircraft will be used for the air drop and will operate from Punta Arenas in southern Chile.

The exact location of the air drop in Antarctica will depend upon weather conditions at the time and will either be at the BAS Sky Blu airfield or at the SB9 staging location (Figure 5). If the drums are dropped at Sky Blu then staff already based at Sky Blu (from the Rothera support team and with supervision from staff with airdrop training) will be responsible for retrieving the dropped drums. If the drums are dropped at SB9 then either Sky Blu staff or staff from the tractor traverse team will be responsible for retrieving them.

[3] The U.S. traverse via WAIS Divide will also deliver explosives, fuels and scientific equipment that might contain hazards *e.g.* batteries.

The air drop will generate pallet waste, which comprises cardboard compression tubes, plywood boards in 4' square sections, as well as parachutes, webbing and nets. The nets and parachutes will be recovered for reuse. If SB9 is the site for the air drop these will be taken directly to *HMS Protector* by tractor traverse. If Sky Blu is used for the air drop these items will be removed to Rothera by DASH 7 aircraft and returned to the UK.

The ply boarding will be used for field project requirements and the cardboard tubes will need to be disposed of via the Rothera waste system.

Figure 58. Fuel drums being air-dropped in Antarctica from an Australian C-17 aircraft. Source: www.antarctica.gov.au.

Outputs (all fuel handling activities)

The handling of fuel in the field carries the risk of an accidental release of fuel into the environment. For the ITGC programme this may occur as a result of:

- One or more fuel drums rupturing on impact during the air drop;
- Leaking fuel drums;
- Leaking or burst fuel bladders;
- Leaking fuel hose during fuel delivery from the vessels.

Additional outputs that will or may interact with the environment include:

- The production of waste items (wood and cardboard) from the airdrop which may be lost to the environment.

5. Alternatives

The EIA process needs to consider options and alternatives that have the potential to eliminate or reduce the potential impacts on the Antarctic environment.

Examples of alternatives include: use of different locations or sites for the activity; opportunities for international cooperation; use of different technologies in order to reduce the outputs (or the intensity of the outputs) of the activity, and different timing for the activity.

The alternative of not proceeding with the proposed activity should always be included in any analysis of environmental impacts of the proposed activity (CEP EIA Guidelines, 2016).

This Chapter describes the alternatives that have been considered as part of the planning for the ITGC.

5.1 Do not proceed

Collectively, Antarctic ice sheets hold enough water to raise global sea level by 58m (Fretwell et al., 2013). Their melting is therefore of critical importance. The West Antarctic Ice Sheet (WAIS) is marine based (below sea level) and inherently more unstable than the East Antarctic Ice Sheet. Between 1992 and 2017, ocean-driven melting caused rates of ice loss from West Antarctica to increase from 53 ± 29 billion to 159 ± 26 billion tonnes per year (Fretwell et al., 2013).

Understanding past and present changes to the WAIS and predicting future changes and their impact is essential to climate change modelling and to the information needs of coastal communities globally.

The significance of undertaking this work has been reinforced by the Antarctic research community (Kennicutt et al., 2014) and by the U.S. and UK research funding agencies that issued the request for proposals for this work.

Consequently the ‘do not proceed’ option was rejected.

5.2 Alternative locations

The Amundsen Sea outlet glaciers are key to the thinning of the WAIS (Joughin and Alley, 2011). Melting of the Thwaites Glacier is already responsible for around 4% of current global sea level rise (ITGC, 2018), and observations show unequivocally that the Thwaites Glacier ice-ocean system is undergoing the largest changes of any ice-ocean system in Antarctica (Scambos et al., 2017). The Thwaites Glacier system is therefore the preferred location for understanding and modelling climate change impacts related to melting of the WAIS.

In the 80 research questions identified by SCAR’s “Horizon Scan 2020”, a key recurring theme is the need to understand how, where and why ice sheets lose mass (Kennicutt et al., 2014). The U.S. National Academy of Sciences, Engineering, and Medicine report (*A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research*, 2015) places prediction of ice mass loss from the West Antarctic Ice Sheet (WAIS) as the top priority for Antarctic research, and singles out Thwaites Glacier as a “region of particular concern”.

While around 10% of Antarctic glaciers are retreating more than 25m a year, the Pine Island and Thwaites Glaciers are unique in their rate of change and scale.

Accordingly, alternative locations would not provide information of such significance for future sea level rise and were considered sub-optimal for collecting the data required to achieve the research objectives. In addition, whilst the location is remote and has seen relatively little human activity, the logistics will utilise existing U.S. and UK sites such as Sky-Blu, WAIS Divide and Byrd.

5.3 Independent projects

This major programme incorporates eight separate projects. One alternative is for these projects to operate individually at a smaller scale. Running the projects individually may have some reduction of impacts due to the smaller numbers of people and amounts of cargo to be moved in any one season, but each would still require significant ship or air support. This would mean duplication of logistics and therefore a similar or greater cumulative impact over potentially a much longer time span for the project.

Operating the projects together will maximise the scientific outcomes possible, and the timeliness of results. The programme's dedicated Science Coordination Office will increase efficiency and effectiveness of the research.

Running independent projects was therefore rejected in favour of looking for logistical and research synergies across all six field projects.

5.4 Alternative timing / reduced period of operation

Reducing the period of operation within and across seasons would have potential for reducing the intensity and duration of some of the identified impacts.

However, it is considered that attempting to do so would significantly compromise the potential for achieving the research objectives, with very little incremental gain in reducing environmental impacts.

Attempting to reduce the period of activities within each season would inevitably lead to the need to add additional seasons of activity if the same research objectives are to be achieved. This option may have potential to increase the overall impacts with more logistical effort required to support the research over a greater number of seasons (particularly when taking account of annual mobilization and demobilization requirements).

Adjusting the currently planned field programme so that it operates over a different set of four seasons, is unlikely to have any environmental benefit.

Some adjustments have been made during the planning period to the timing and overlap of the individual research projects during each field season. For example, the GHOST and TIME projects have each been delayed by a season. This has had the benefit of 'smoothing' the on-ice logistical requirements (including the amount of cargo and people being moved in and out of the field) more evenly over the science-support seasons of operation, potentially with some (albeit small) environmental benefits (Figure 59).

The timing of activities being undertaken within any one season is dependent upon best available weather and sea ice conditions and the availability and accessibility of logistical assets to support the field work. The timing of the marine cruises is determined primarily by the period during which ship access is possible to Pine Island Bay for example. No particular seasonal sensitivities have been identified in this assessment, given that for the most part activities will be being undertaken towards the end of the annual breeding period and in most cases well away from known concentrations of wildlife.

Consequently, no further changes to the timing and duration of the field activities were considered necessary.

Figure 59. Graphs showing the effects of smoothing the various projects over each of the four field seasons on the amount of people and cargo being moved in and out of the field.

5.5 Reduced scale of the research programme

Reducing the scale of activity could reduce environmental impacts by reducing the overall environmental exposure to the outputs from the activity. Cumulative impacts include emissions to air, noise, equipment lost to or left in the environment, and potential introduction or relocation of species.

Reducing the number of sites, people and transport movements would lessen the known impacts and the likelihood of possible impacts. Therefore, the scientific work being carried out has been carefully prioritized to ensure that unnecessary activities or movements. Emissions are being minimised as much as possible through efficiency of logistics, and potential impacts will be minimised or avoided through mitigation controls. While further marginal reduction in impacts could be achieved through a reduced programme, this would have a corresponding reduction in science outcomes. This has not been chosen due to the significance of the research being conducted.

Minimising the spatial extent of a proposed activity may assist in mitigating impacts, for example by avoiding sensitive areas or constraining an activity to an already impacted site. Maximum use will be made of already impacted sites, but the science objectives cannot be met without working in a wider range of sites, given the complexity of the Thwaites Glacier system. There are no Antarctic Specially Protected or Managed Areas in the operational area, nor Historic Sites and Monuments or areas designated under CCAMLR. Operations will largely avoid known breeding sites, and ice-free areas will be visited only when necessary for geological sampling and seal tagging, in which circumstances appropriate controls will be in place.

Accordingly, it is concluded that there is no measurable environmental benefit to be gained from attempting to reduce the spatial scale of the Expedition.

5.6 Alternative Technology and Methods

The GHOST and TIME projects will use state-of-the-art radar techniques to understand sub-surface glacial structure, which is non-invasive. To be robust, however, some seismic data will need to be captured to verify and complement the radar data.

The seismic survey will be conducted using a vibroseis truck (seismic source) with snow streamers (receivers). This technology has only been applied to ice environments since 2010 (Eisen et al, 2015). The alternative seismic source is to use only the traditional explosives. Explosives are much lighter to transport, but the process is more effort intensive, requiring drilling of holes, placement, charging and detonation of explosive shots. Relying on explosive seismic surveying would therefore require a longer time to complete and therefore need more fuel and supplies. In addition, some debris from explosives is usually unrecoverable from the ice.

TARSAN will collect oceanographic data using recorders attached to seals. While this will cause brief disturbance to the seals during attachment, together with submarine glider-based surveys it will allow data collection from a wide geographic area. These approaches have been trialed and proven in the region. More conventional methods would not be able to access areas beneath the ice and would create greater impact (*e.g.* fuel use, emissions).

For some research there is no practicable alternative technique to physical sampling, *e.g.* to analyse sediment, rock, and seawater. These are a comparatively small component of the research programme and complement the non-sample-based data collection.

The selected technologies are therefore the considered the most efficient options to achieve the scientific objectives.

5.7 Alternative Logistical Support

The proposed logistics involve a mixture of ship, air and surface transport.

One alternative would be to not use over-snow surface transport and instead rely on air support for the various field camps. Although this would lessen direct interaction with the snow/ice environment, it would mean a significant increase in fuel use and emissions. Comparisons for the South Pole Overland Traverse found that delivery of fuel using modern low resistance sleds used 60% less fuel than flying fuel by ski equipped Hercules (LC130), with 42% less carbon emissions (Lever and Thur, 2014). The tractor train for this Expedition may save as many as 42 Hercules flights; although it is noted that additional fuel burn by the two ships is required to deliver the fuel and equipment from Rothera to the Stange ice shelf area.

Surface transport as the sole mode is not possible - air and/or ship transport is required to get materials to Antarctica, and it would not be practicable to use surface transport all the way from, for instance, major existing research stations, because of the time and hazards involved.

Shipping is the most energy efficient of the three transport methods but is obviously limited to accessible waters. Using ship operations only would not allow all research goals to be met.

The West Antarctic Ice Sheet (WAIS) Divide camp will be the main logistical hub for LC-130 Hercules aircraft supply flights and Twin Otter aircraft personnel movements. This will reduce the need for fuel supplies at the subsidiary camps.

Using all three transport platforms is therefore the preferred option.

Overall, the planning process has attempted to find the most efficient and cost effective means of meeting all research objectives whilst minimising environmental impacts. The current plan as set out in this IEE is considered the most optimal, although further opportunities for improvement will be reviewed on an annual basis as the field work progresses.

6. Description of the Existing Environmental State

6.1 Introduction

The Thwaites Glacier is roughly the size of Britain and up to 3km thick. It is approximately 480km long, and over 650km across at its widest point. Thwaites and neighbouring Pine Island Glacier are among the largest but also the fastest melting glaciers in Antarctica. This project will traverse over 1,000km to cross them both. Thwaites and Pine Island Glaciers are already major contributors to sea level rise and will have a key influence on future sea levels, both in terms of the grounded ice they hold, as well as their effect on the stability of the wider West Antarctic Ice Sheet.

These vast features are located in the Amundsen Sea Embayment, one of the least visited coastal areas of Antarctica. Almost always covered with sea ice, the Amundsen Sea was relatively unexplored until the late 1980s, when research cruises began to gather information about the area (Nitsche et al., 2017), which included discovery of polynyas, and a highly productive ice edge, with increased phytoplankton, krill and upper-trophic level predators, particularly at the continental shelf break.

While terrestrial ice and snow-free areas are sparse, they are biologically significant, providing breeding sites for birds and habitat for terrestrial fauna including unique species assemblages. There are no year-round facilities in the immediate vicinity, but camps have been established on Pine Island Glacier and the West Antarctic Ice Shelf Divide in recent years. Runway facilities operate during summer at Sky-Blu and Union Glacier to the East and former stations Byrd and Russkaya lie to the west of the operational area.

6.2 Glaciology

The West Antarctic Ice Sheet, which covers the part of Antarctica west of the Trans Antarctic Mountains, has outlets in the Ross Sea, Amundsen Sea and Weddell Sea. Of the Amundsen Sea's numerous glaciers, ice shelves and ice tongues, the Pine Island Glacier and Thwaites Glacier systems (Figure 60) are particularly important because of their size and rate of change.

Thwaites Glacier was first mapped by the United States Geological Survey (USGS) from surveys and aerial photography in 1959-66 as a floating glacier tongue over 60km long with a grounded iceberg tongue 110km long. The Crossen Ice Shelf, Dotson Ice Shelf and Getz Ice Shelf are to the west. Pine Island, Cosgrove and Abbott Ice Shelves are to the east of Thwaites, with the the Abbott Ice Shelf extending further to the east into Ellsworth Land, bordered by the Bellingshausen Sea.

Interest in the region increased with the discovery in 1994 that the ice shelf at the terminus of the Pine Island Glacier was melting orders of magnitude faster than the Ross and Filchner-Ronne Ice Shelves, and subsequently that other Amundsen Sea ice shelves have high melt rates and increased velocity of tributary glaciers (Figure 61; Nitsche et al., 2017). Pine Island Glacier is currently Antarctica's fastest melting glacier, retreating at 4km a year with annual discharge of over 130 gigatonnes (Shean et al., 2017). Thwaites too is rapidly changing – throughout the 1990s the flow at its centre remained fairly constant, but it widened along the sides, and increased its 30 ± 15% mass deficit by a further 4% in just 4 years (Rignot et al., 2002). Observations show unequivocally that the Thwaites Glacier ice-ocean system is undergoing the largest changes of any ice-ocean system in Antarctica (Scambos et al., 2017). As major outlets of the WAIS, Pine

Island and Thwaites Glaciers both play a key role in stability of the sheet and have been described as "*a plug holding back enough ice to pour 11 feet (3.4m) of sea-level rise into the world's oceans*" (Holthaus, 2017).

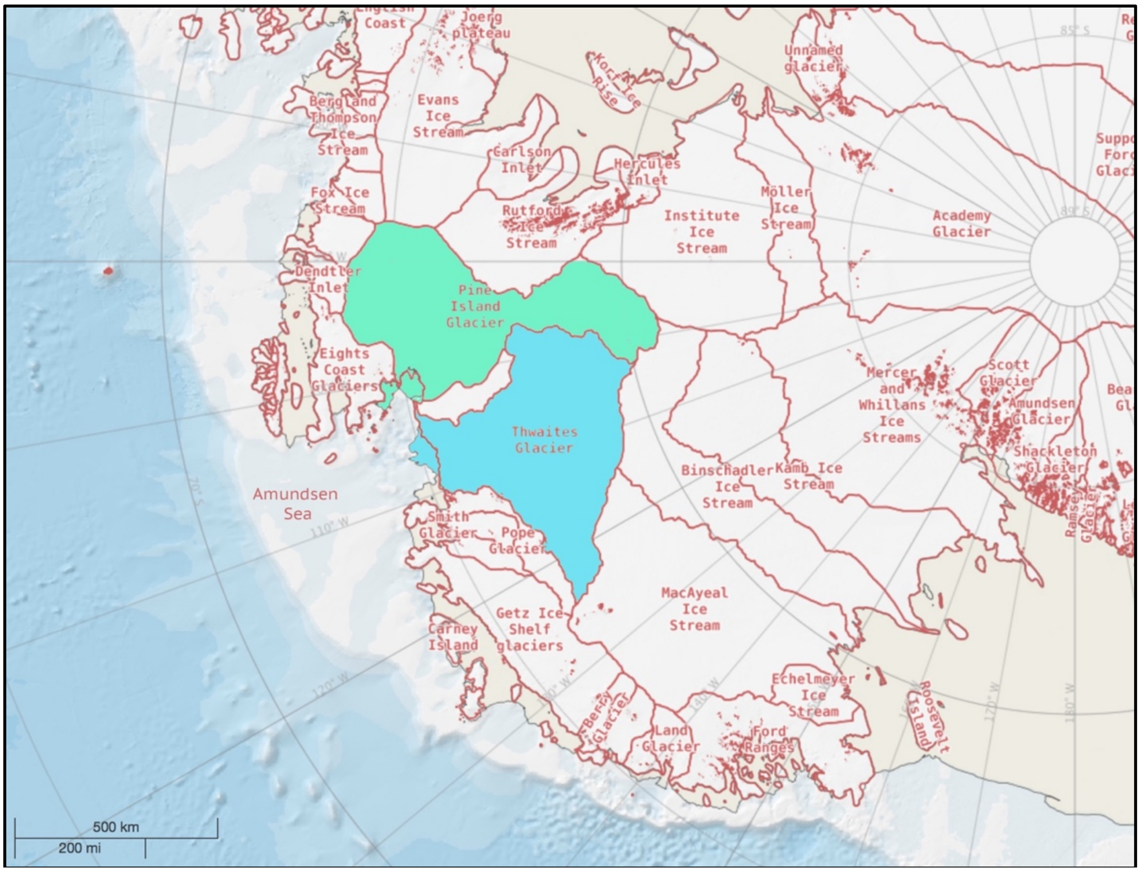


Figure 60. Pine Island and Thwaites Glaciers. Catchment areas and associated ice shelves are shaded. Source: www.add.scar.org

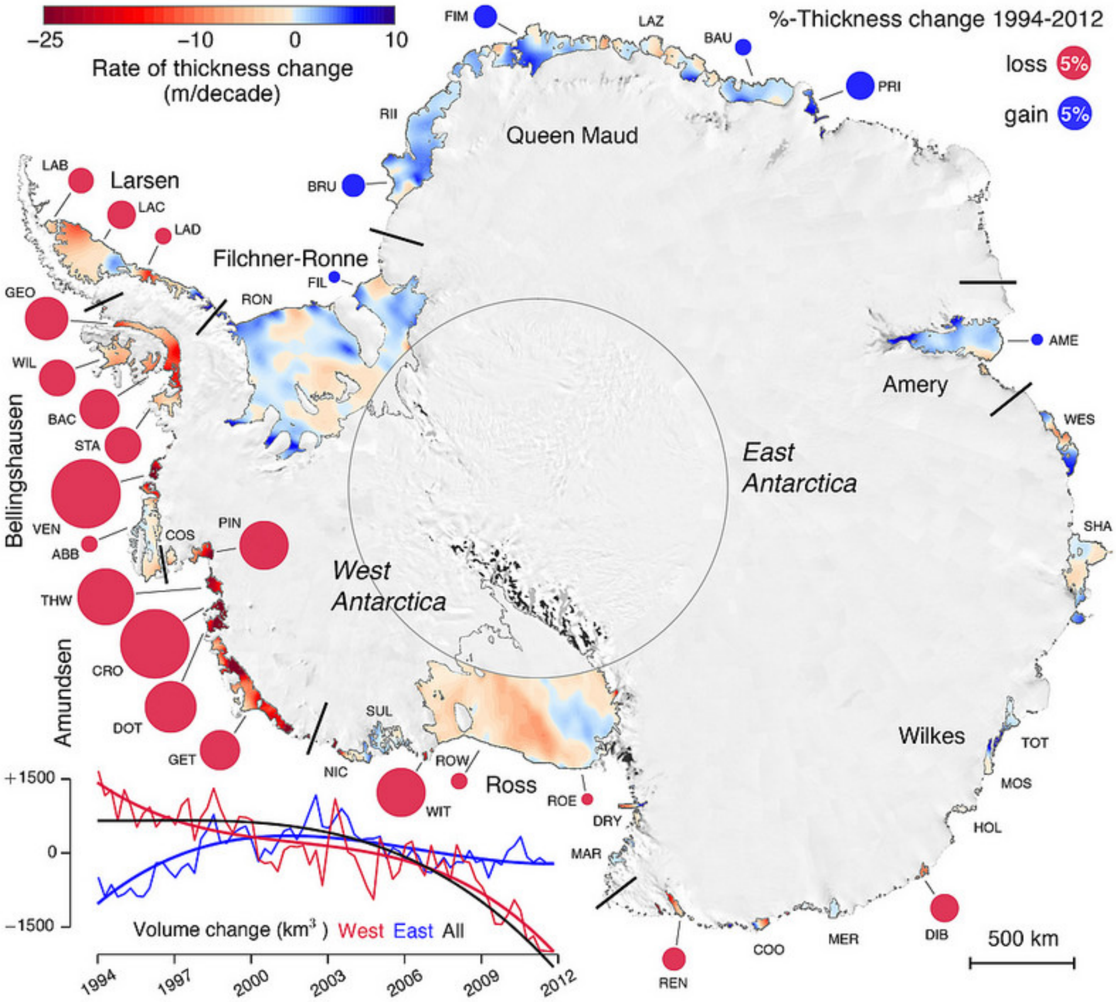


Figure 61. Eighteen years of change in thickness and volume of Antarctic ice shelves. Circles represent percentage of thickness lost (red) or gained (blue) in 18 years. Background is the Landsat Image Mosaic of Antarctica (LIMA). Source: Paolo et al., 2015.

6.3 Geology and geomorphology

Marie Byrd Land is composed of igneous and metamorphic rock formed during the separation of New Zealand from Antarctica during the breakup of Gondwana, underlain by very old Precambrian basement or sedimentary sequences (Mukasa and Dalziel, 2000). The majority of the land is ice covered and below sea level (Spiegel et al., 2015). Ice free outcrops are small but numerous, including islands and nunataks. The most extensive areas of ice free land are found inland in the Ellsworth Mountains. The soils are shallow frost sorted till with permafrost below, very low in nutrients and biomass (Bockheim et al., 2015; Tin et al, 2013).

A series of extensional volcanic features extends from Pine Island to the Ross Sea, in the West Antarctic Rift System (WARS). There may be as many as 138 volcanoes throughout West Antarctica (Figure 62), including the presently active Mt. Erebus, recently active Mt. Siple and Mt. Waesche, and there are indications of a volcanic heat source in the Hudson mountains, upstream of the Pine Island Ice Shelf (Loose, 2018). The Hudson Mountains Subglacial Volcano is thought to have erupted last in 325BC (Corr and Vaughan, 2008).

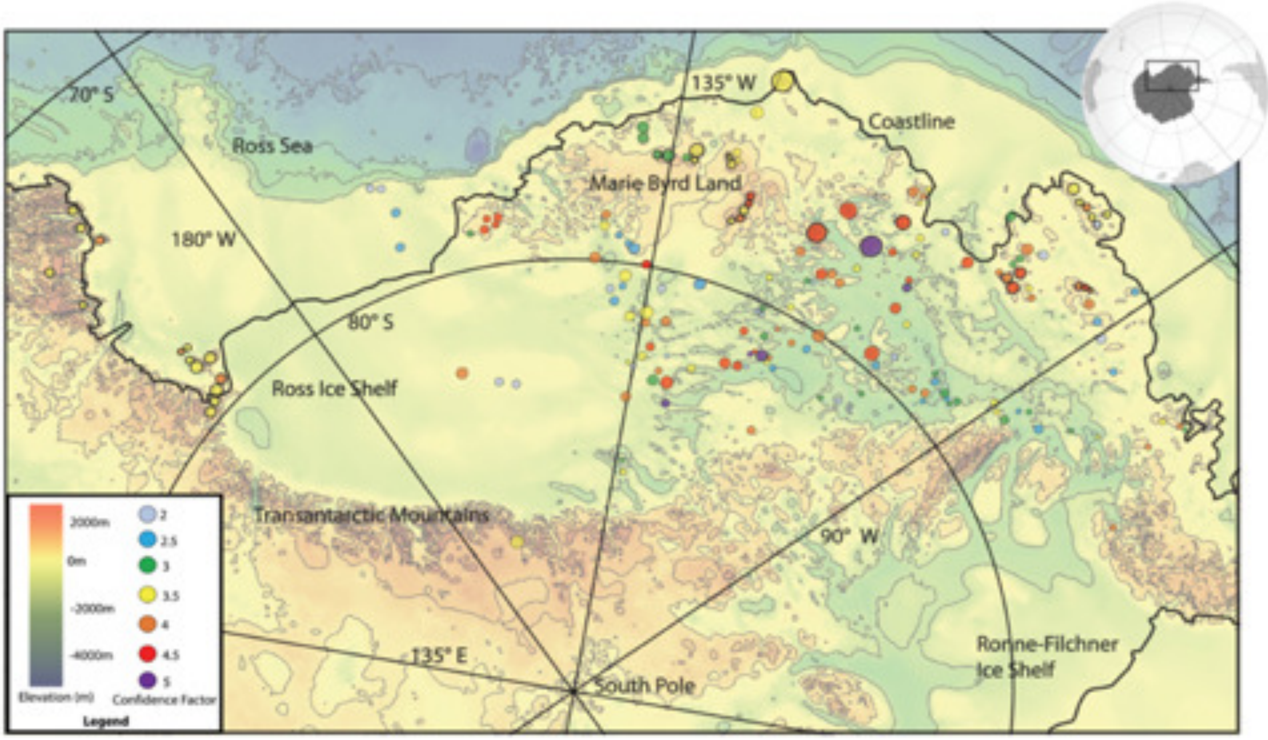


Figure 62. Possible volcanoes across the West Antarctic Rift System. Circle colour represents the confidence factor used to assess the likelihood of cones being subglacial volcanoes, circle size is proportional to the cone's basal diameter, and circles with black rims represent volcanoes that have been confirmed in other studies. Source: van Wyk de Vries, 2017.

6.4 Oceanography

The continental shelf of the Amundsen Sea extends around 400km offshore from the southernmost point of Pine Island Bay, narrowing to 100km wide west of Siple Island (Figure 63). The shelf has deep, rugged troughs created by past glacial activity. These form two trough systems, one in Pine Island Bay and the other off the Dotson and eastern Getz Ice Shelves, with a maximum depth of 1600m. In general, the shelf slope is 2o - 5o and the average depth at the shelf breaks 500m (Nitsche et al., 2007).

Warm Circumpolar Deep Water has been shown to flood the Amundsen Sea continental shelf (Jacobs, 2006 cited in Thoma et al., 2008). The glacially formed troughs in the shelf play a key role in the ingress of this warm water (Walker et al., 2007), which reaches under the floating glacier tongues and ice shelves. Models show a correlation between the amount of CDW ingress and the thinning and acceleration of Amundsen Sea glaciers. Similar processes are occurring in the Bellingshausen Sea (Graham et al., 2010). Recent research using recorders attached to elephant and Weddell seals to collect year round data has sown that the CDW actually increases in winter (Mallett et al., 2018)

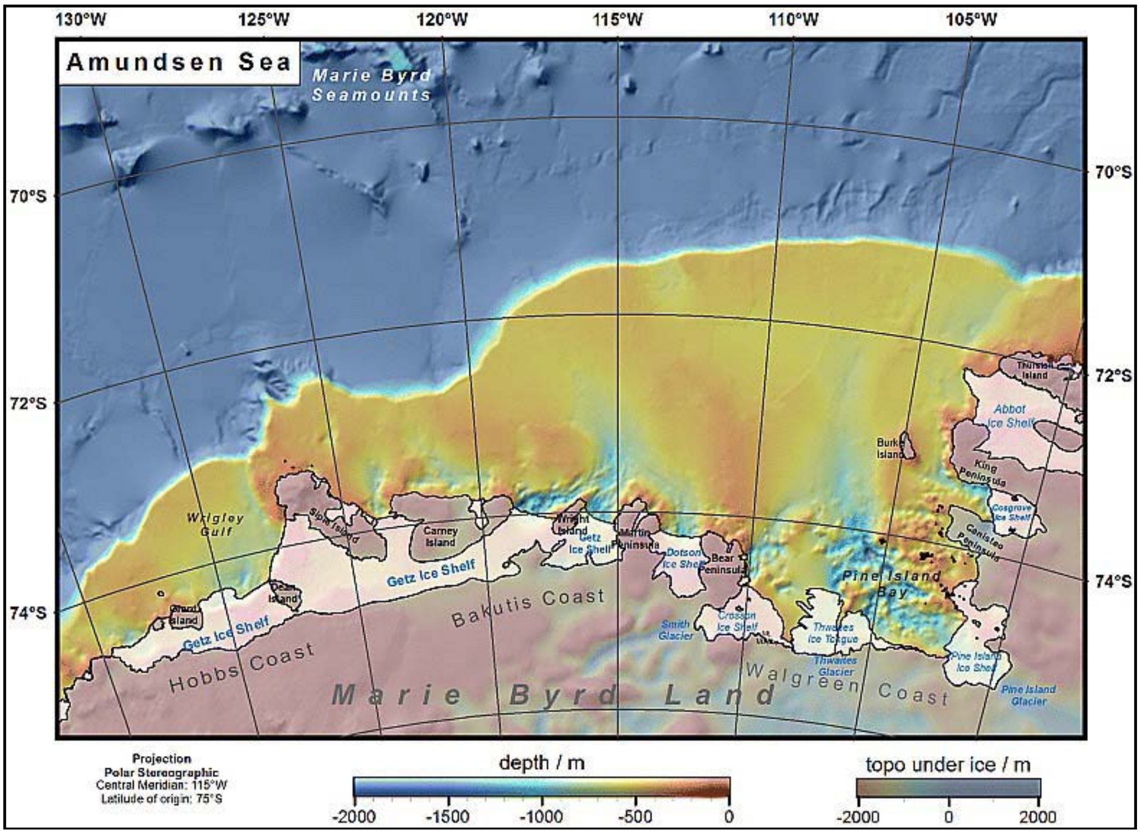


Figure 63. Amundsen Sea Continental Shelf. Source: Ntsche et al., 2007.

6.4.1 Sea ice

Sea ice extent in the Bellingshausen and Amundsen Seas ranges from approximately 0.5 to 2.5 million km^2 each year (Figure 64). The Amundsen Sea Low (ASL) has deepened in recent decades (Turner et al., 2009 cited in Turner et al., 2016). This has driven southerly winds resulting in increased sea ice extent in the Ross Sea, but decreased sea ice extent in the Bellingshausen Sea. Sea ice extent in the Bellingshausen Sea is influenced by the Southern Annular Mode (SAM; positive SAM correlates with decreased sea ice extent), and by ocean changes although these are not well understood (Turner et al., 2016).

Significant polynyas (areas of open water within the sea ice) regularly form to either side of the Thwaites Glacier tongue, the Amundsen Sea Polynya in front of the Dotson Ice Shelf, an area of open water up to 80,000 km^2 (Yager et al., 2016) and the Pine Island Polynya in front of the Pine Island Ice Shelf.

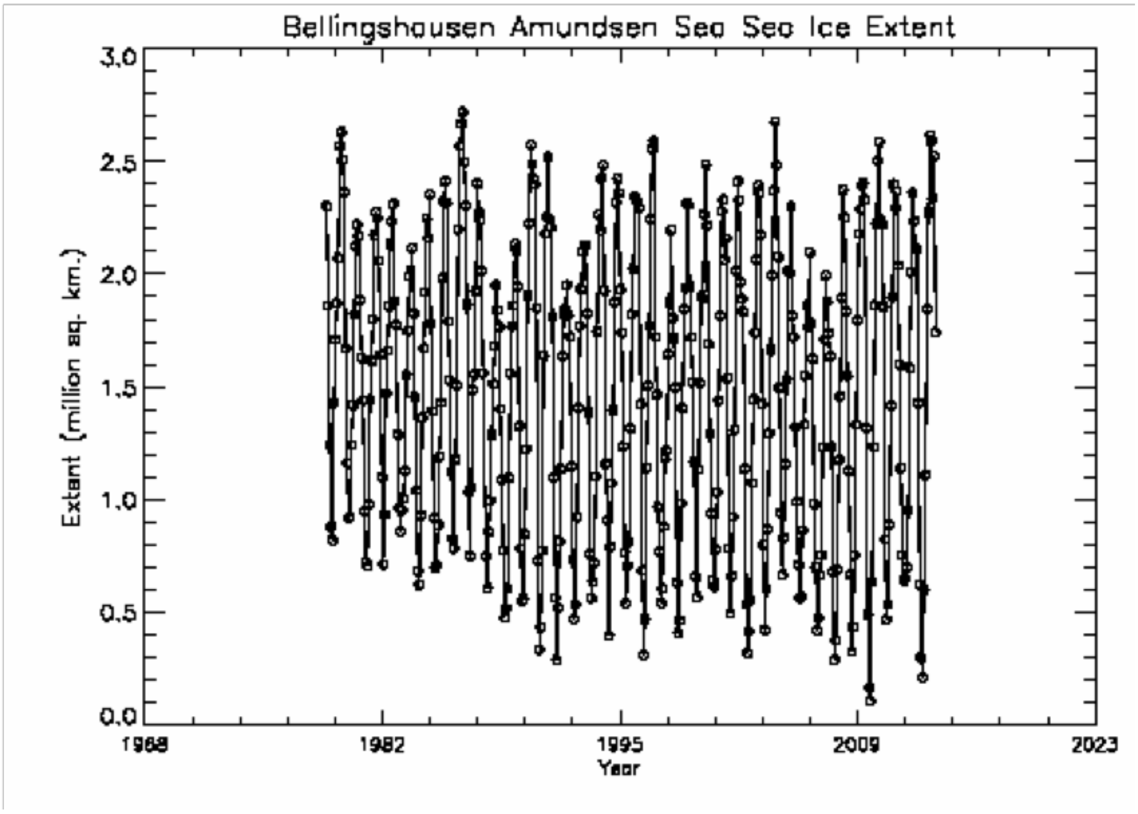


Figure 64. Sea ice extent in the Bellingshausen and Amundsen Seas. Source: National Snow and Ice Data Centre (https://nsidc.org/data/pm/bellingshausen)

6.5 Marine ecosystem

The Amundsen Sea Polynya is the fourth largest in Antarctica and the most productive, with summertime chlorophyll a concentrations exceeding 20 µg L^{-1} (Yager et al., 2016). The combination of upwelling of Circumpolar Deep Water and release of sediments from glacial melt provides nutrients, particularly iron, so that the polynyas of the Amundsen Sea have the highest concentrations of phytoplankton anywhere in Antarctica (Gerringa, 2012). This biomass gives rise to increased krill and upper-trophic level predators, such as seabirds, particularly at the shelf break (Ainley et al., 1998).

Only a handful of research voyages have been conducted in the Amundsen Sea, but the research which has been undertaken shows distinctive biological communities at various levels. The bacterial communities that accompanied the *Phaeocystis* phytoplankton bloom in the Amundsen Sea polynya during the austral summers of 2007–2008 and 2010–2011 were distinct from those of the Antarctic Circumpolar Current and off the Palmer Peninsula (Delmont, 2014). Amundsen Sea shelf benthic communities are dominated mobile echinoderms (starfish, urchins, brittlestars and sea cucumbers) rather than large sedentary sponges as found in other Antarctic seas (Linse, 2013). The isopod fauna appears to be rich, with many new species and different composition from other Antarctic seas studied (Kaiser et al., 2009).

6.5.1 FISH

A variety of fish species have been identified in the Bellingshausen and Amundsen Seas (Table 1) *Dissostichus mawsoni*, Antarctic toothfish, is harvested in the region under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR).

Scientific name	Common name
Dissostichus mawsoni	Antarctic tooth fish
Chionobathyscus dewitti	Crocodile icefish
Amblyraja georgiana	Antarctic starry skate
Bathyraja eatonii	Eaton's skate
Macrourus whitsoni	Whitson's grenadier
Muraenolepis orangiensis	Patagonian moray cod
Muraenolepis microps	Smalleye moray cod
Antimora rostrata	Blue antimora
Aethotaxis mitopteryx	Longfin icedevil
Cynomacrurus piriei	Dogtooth grenadier
Cyclothone microdon	Veiled anglemouth
Stomias gracilis	Barbeled dragonfish

Table 1. Fish species observed in the Amundsen and Bellingshausen Seas. Source: Duhamel et al, 2014

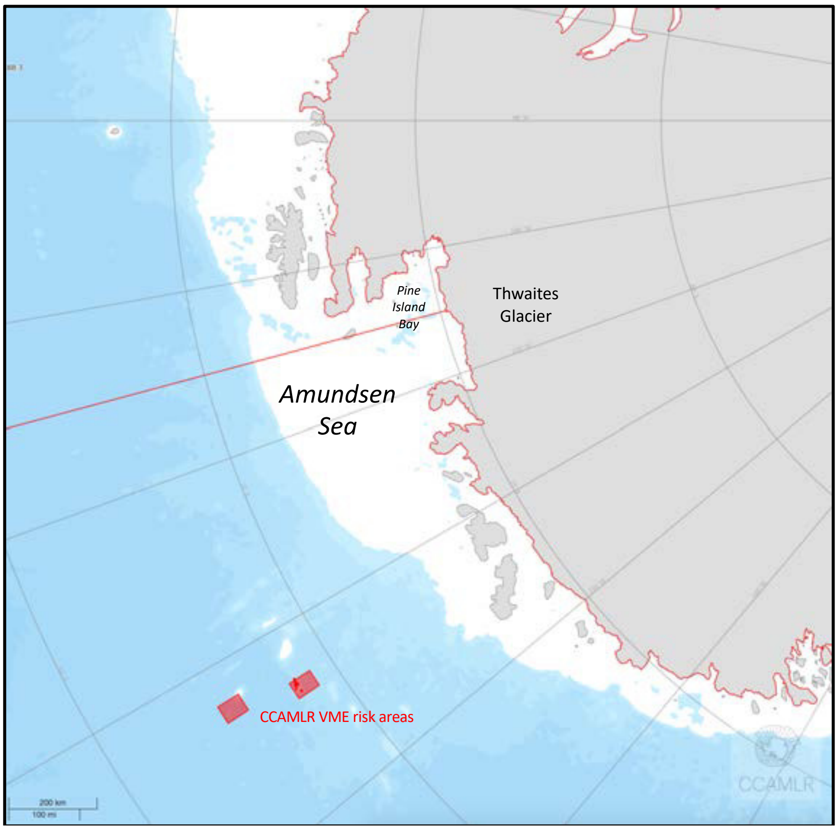


Figure 65. Vulnerable marine ecosystems (VMEs) risk areas identified by CCAMLR within the vicinity of the Amundsen Sea. Source: http://gis.ccamlr.org

None of the spatial management tools used by CCAMLR - Marine Protected Areas, CCAMLR Ecological Monitoring Programme sites or registered Vulnerable Marine Ecosystems (VME) - are in place in the Bellingshausen and Amundsen Seas CCAMLR sectors (88.2 and 88.3). Two fine-scale VME risk areas have been defined, however (Figure 65). This means that VME indicator taxa (such as sponges and corals) have been frequently identified during bottom fishing.

6.5.2 Birds and mammals

Several Adélie and Emperor penguin colonies (identified by BirdLife International as Important Bird and Biodiversity Areas) breed in the intended operational area (Figure 66), including six Emperor colonies each comprising more than 1% of the global population (Table 2). Total Adélie penguin numbers are increasing, and the species is listed by IUCN as 'least concern'. However some regional populations are decreasing. Although Amundsen Sea Adélie colonies are not systematically monitored, climate modelling and what population data is available suggest that they are experiencing favourable conditions like the growing Ross Sea colonies (Cimino, 2016). The Amundsen Sea colonies are projected to have less than 5 years "novel climate" to 2099 (Cimino, 2016).

Emperor penguins are listed by the IUCN as 'near threatened'. Between 1978 and 2010 the Bellingshausen and Amundsen Seas experienced significant decreases in sea ice, and a small emperor penguin colony located in Dion Islands, off the Antarctic Peninsula, disappeared. Projections suggest that by 2100 the total Emperor penguin population decline will be 78% over three generations, however the Amundsen Sea colonies will be among the slower to decline (Jenouvrier, 2014).

Blue petrels, Antarctic petrels, Antarctic prion, snow petrels, southern giant petrels, Wilsons storm petrel, Arctic tern and skuas also occur in the area (Ainley, 1998, Ropert-Coudert et al., 2014). All of these are listed as 'least concern' by IUCN.

Croxall et al. (1995) report several confirmed snow petrel breeding sites in the Amundsen Sea and Bellingshausen Sea areas, the largest being over 1000 pairs at Notebook Cliffs, Mt Murphy. Five further, smaller colonies are also found around Mt Murphy (Greenfield and Smellie, 1992). Three breeding colonies were identified in the Fosdick Mountains, two in the Perry and nearby Demas Ranges, and one in the Snow Nunataks. Three further possible breeding sites around the Snow Nunataks are reported, as well as at Mt Nickens, Mt Moses and Martin Peninsula (Figure 67).

Minke whales forage in the Amundsen and Bellingshausen Seas (Lee et al., 2017). Although no population estimates are available, Ainley describes minke whales as "abundant in the deep pack ice of the Amundsen and southern Bellingshausen seas". Humpback whales have been satellite tracked travelling from the Kermadec Islands to the Bellingshausen Sea (Tremlett, 2016). Sperm whales, killer whales and beaked whales (species unknown) have also been observed (Ainley, 2007, Ropert-Coudert et al., 2014).

Southern elephant seals, leopard seals, Weddell seals and crabeater seals are all found in the area (Birdlife International, 2018; Mallett et al., 2018; Gelatt and Siniff, 1999).

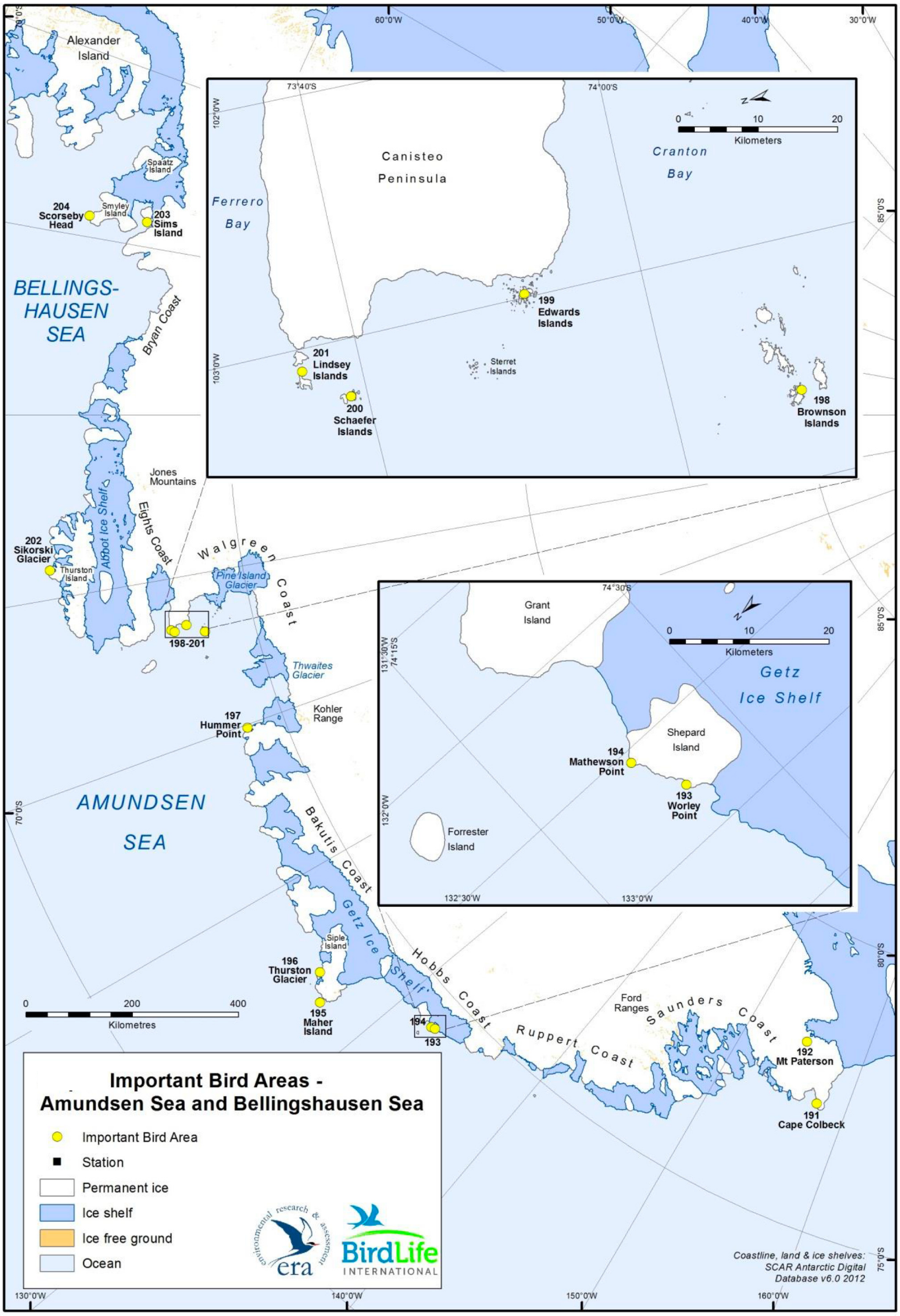


Figure 66. Location of Important Bird Areas in the Bellingshausen and Amundsen Sea areas. Source: Harris et al., 2015.

Site	Main breeding species	Other breeding species	Other species present
Schaefer Islands	28 033 breeding pairs Adelie penguin		
Brownson Islands	5732 Emperor Penguins*	15 962 breeding pairs Adélie Penguin	
Edwards Islands	58 058 breeding pairs of Adélie Penguin*		Southern Elephant Seals
Hummer Point, Bear Peninsula	9457 Emperor Penguins*		
Lindsey Islands	52 670 breeding pairs Adélie Penguin*	South Polar Skuas	Southern Elephant Seals Leopard Seals
Schaefer Islands	28 033 breeding pairs Adelie penguin		
Scoresby Head, Smylie Island	6061 Emperor Penguins*		Southern Elephant Seals
Sikoski Glacier, Noville Peninsula	3568 Emperor Penguins*		
Sims Island	14 784 breeding pairs of Adélie Penguin	South Polar Skuas	

Table 2. Important Bird and Biodiversity Areas in the Amundsen and Bellingshausen Sea region. Source: BirdLife International (2018) Important Bird Areas factsheets, http://www.birdlife.org on 12/09/2018. *1% or more of global population

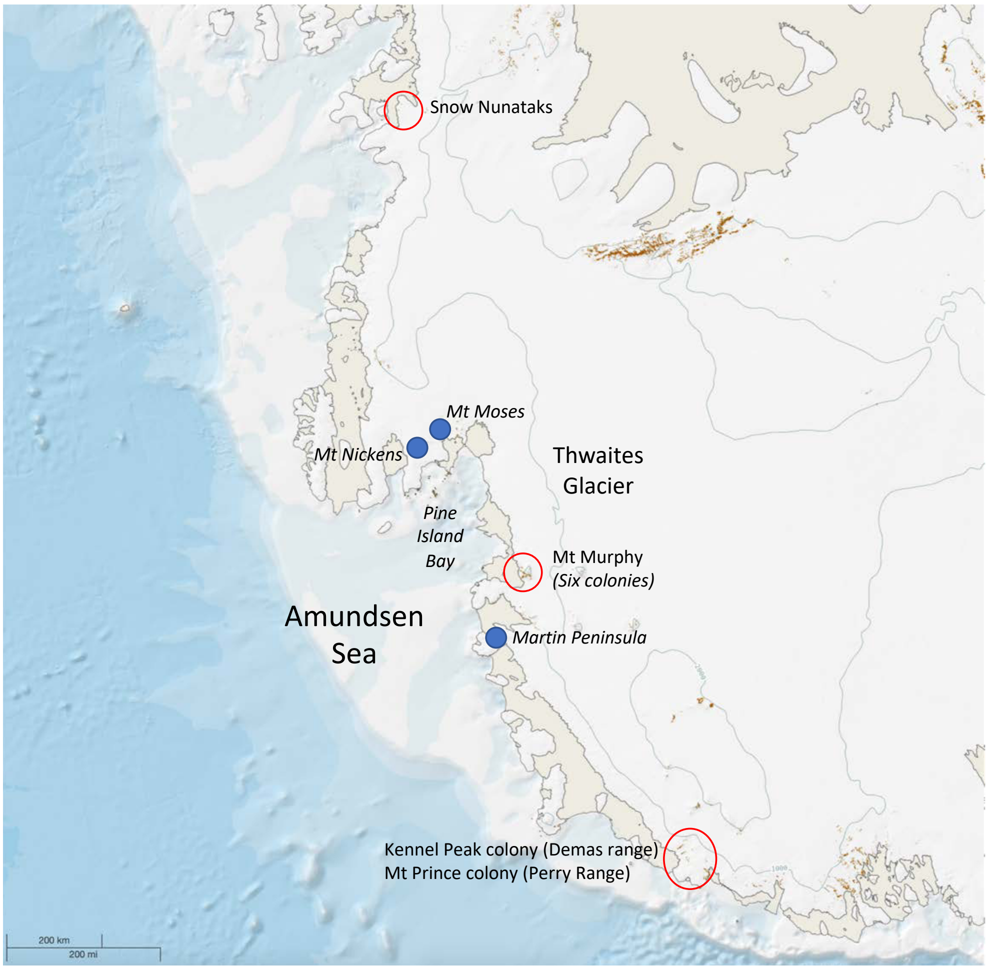


Figure 67. Known (red circles) and possible (blue dots) snow petrel breeding sites in Marie Byrd Land / southern Antarctic Peninsula. Source: Greenfield and Smellie, 1992, and Croxall et al., 1995.

6.6 Terrestrial environment

6.6.1 Climate

Ellsworth Land is has a mean altitude of 1,801.5m and a mean annual temperature of -24.9°C, while Marie Byrd Land averages 1,054.8m altitude and -17.4°C (Terrauds and Lee, 2016). The surface temperature at Byrd Station has risen by 0.22°C per decade between 1958 and 2012 (Nicholas and Bromwich, 2014).

Thwaites Glacier had a mean accumulation of 0.457 ± 0.066 mwe yr^{-1} (metres of water equivalent) between 1980 and 2009 (Medley et al., 2013). While Thwaites showed no trend in either measured or modelled accumulation, nearby systems have been experiencing increased snowfall. At Ferrigno and Bryan Coast (east of Thwaites), snow accumulation between 2000 and 2009 was 27% higher and 31% higher respectively than from 1712 to 1899 (Thomas, 2015).

6.6.2 Terrestrial biota

Marie Byrd Land and Ellsworth Land are each distinct biogeographic regions (see Figure 68, Terauds and Lee, 2016), and prolonged isolation of the ice free areas within them has given rise to biota with little similarity with other regions and high degrees of endemism (McGaughran et al., 2011).

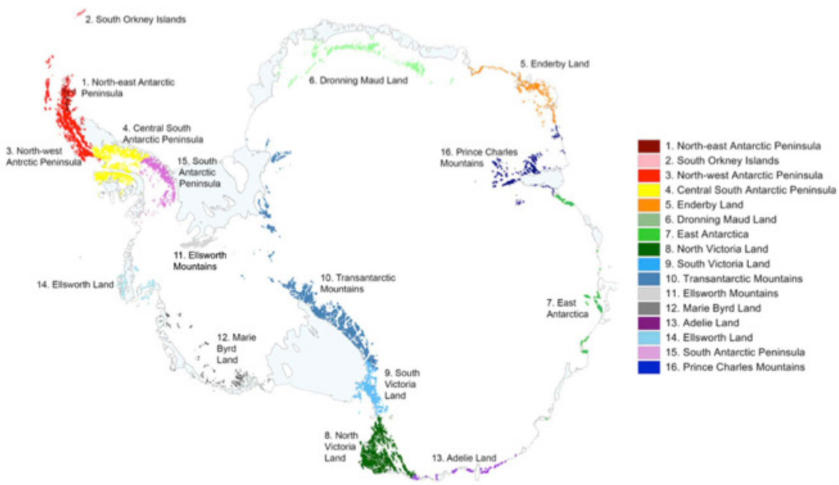


Figure 68. Antarctic Conservation Biogeographic Regions (version 2). Source: Terauds and Lees, 2016

Relatively little investigation of the terrestrial biota in the Marie Byrd and Ellsworth areas has been undertaken. Paul Siple, biologist of the Second Byrd Expedition (1933-1935), collected extensively from the Ford Ranges area in western Marie Byrd Land. Analysing these samples and some from the Sentinel Range in the Ellsworth Mountains, Dodge (1966) described the lichen flora of Marie Byrd Land and Ellsworth Land as “an ancient flora surviving on nunataks during the last ice age and spreading northward with the return of milder climate”. Likewise, the mosses collected by the expedition were described as “representative of a few extremely hardy, vigorous remnants of a former climax vegetation that have managed to maintain a hold on life in the face of increasingly rigorous conditions of almost unbelievable severity" (Bartram, 1938).

Samples have since been taken in the Hudson Mountains (sampling by Laudon in 1961), Turtle Peak in the Mt. Murphy Range (sampling by Smellie in 1990), and Mt. Woollard (sampling by Smith in 1984), which are still housed in collections at Harvard and the British Antarctic Survey (H. Peat, personal communication, August 2018). Lichens have also been collected from an oasis at Russkaya station, Lindsey Island near the Canisteo Peninsula; and Maish Nunatak and Mt. Moses in Hudson Mountains (Andreev et al., 2008). The brief report available notes: "In the basalt environment of the Hudson Mountains, *Usnea antarctica* was mostly found". The lichen *Lecania brialmontii* and algae *Prasiola crispa* dominated in the penguin rookeries on Lindsey Island".

Invertebrates are also present at ice-free areas. The records closest to the operational area are from nunataks north east of the Ellsworth Mountains. Unusual fauna communities have been found on the here, including five tardigrade species and at least two rotifer species. The tardigrade *Echiniscus corrugicaudatus* is a new species (McInnes, 2009), as appears to be another from the genus *Ramazzottius*. The tardigrades comprise two consumer trophic levels, with *Milnesium cfr tardigradum* being a predator. Notably, nematode worms are absent, which is exceptional not only in an Antarctic context but also for soils worldwide (Maslen and Convey, 2006; Convey and McInnes, 2005).

Table 3 summarises known terrestrial biota.

Location	Lichens	Mosses	Invertebrates
Ellsworth nunataks: Sky-Hi Nunataks Mt Mende Merrick Mountains Behrendt Mountains Quilty Nunataks Hauberg Mountains Haag Nunataks (Convey and McInnes, 2005)	Crustose lichens: *Acarospora gwynnii* *Buellia frigida* *B. grisea* *B. pallida* *Caloplaca citrina* *Candelariella flava* *Carbonea vorticosa* *Lecanora flotowiana* *L. physciella* *L. polytropa* *L. sverdrupiana* *Lecidea cancriformis* *Pleopsidium chlorophanum* *Rhizoplaca melanophthalma* Foliose lichens: *Pseudephebe minuscula* *Usnea sphacelata*	*Ceratodon purpureus* *Coscinodon lawianus*	Tardigrades: *Echiniscus sp.* *Diphascon sanae* *Hebesuncus ryani* *Ramazzottius sp.* *Milnesium cfr tardigradum* Rotifers: *Bdelloidea*
Hudson Mountains (H. Peat, pers comm, 2018)	*Usnea sphacelata*		
Mt Woollard (H. Peat, pers comm, 2018)	*Rhizoplaca melanophthalma*		
Lindsey Islands (Andreev et al, 2008)	*Lecania brialmontii*		
Turtle Peak (H. Peat, pers comm, 2018)	*Caloplaca lewis-smithii* *Caloplaca saxicola* *Lecanora expectans* *Physcia caesia* *Xanthoria elegans*	*Grimmia sp.*	

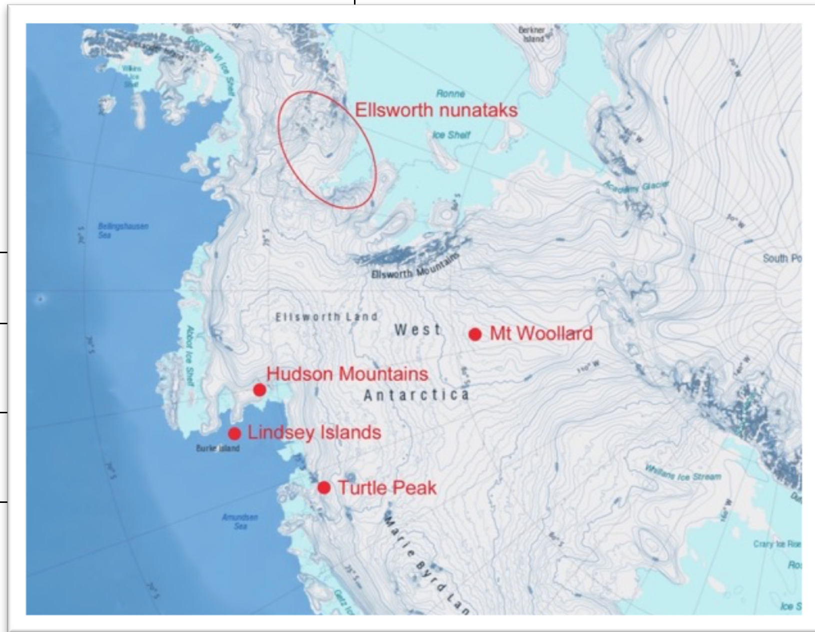


Table 3. Terrestrial species identified in the Amundsen Sea region of Ellsworth Land and Marie Byrd Land

6.7 Human activity

A number of facilities have been established in West Antarctica over the past 60 years (Figure 69). Byrd Station (80°00′53″S 119°33′56″W) was operated by the United States from 1956 to 1972. The original base (which lasted just four years) and the replacement station are both buried under at least 30 metres of snow. Since this time a summer-only 'surface camp' maintaining a ski-way has been used periodically to support field logistics. Camps and aircraft refuelling facilities have also operated at Pine Island Glacier, WAIS Divide and Siple Dome over the last decade.

Figure 69. Sites of human presence in West Antarctica. Base map from www.add.scar.org

The former Soviet Russkaya Station (74°46′00″S 136°48′10″W) was opened in 1980 and closed in 1990. It remains 'mothballed'.

From 1987 to 2010 Adventure Network International (now Antarctic Logistics & Expeditions, ALE) operated a camp and runway at Patriot Hills in the Ellsworth Mountains, and since then it has been a backup runway while the main operations are now at Union Glacier. The camp provides a base for local sightseeing in surface vehicles, flights to the South Pole and access to Vinson Massif, the highest mountain in Antarctica.

The runway operates from November to January. IAATO data shows 371 tourists landed at Union Glacier in the 2017/18 summer (https://iaato.org/tourism-statistics).

The British Antarctic Survey established Sky-Blu as a logistical depot in 1993 and it has become an increasingly important staging post over the years, with a groomed blue ice runway now supported by a camp year-round to enable Dash-7 flights.

The Chilean base Teniente Arturo Parodi Alister and a blue ice runway were located 1km from the Patriot Hills ALE camp from 1999 to 2013, when they were relocated to Union Glacier and reopened as Estación Polar Científica Conjunta Glaciar Unión. It operates from November to January each year.

The nearest currently operational UK and US year-round bases are Rothera Station (UK), South Pole Station (US) and McMurdo Station (US).

6.8 Protected and managed areas

As illustrated in Figure 70, Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs) are conspicuously absent from West Antarctica. The nearest ASPAs are: 170 Marion Nunataks, Charcot Island; 119 Davis Valley and Forlidas Pond, Dufek Massif; and several ASPAs on and around Ross Island. The nearest ASMAs are located on the Antarctic Peninsula, at the South Pole, and in the McMurdo Dry Valleys in Victoria Land.

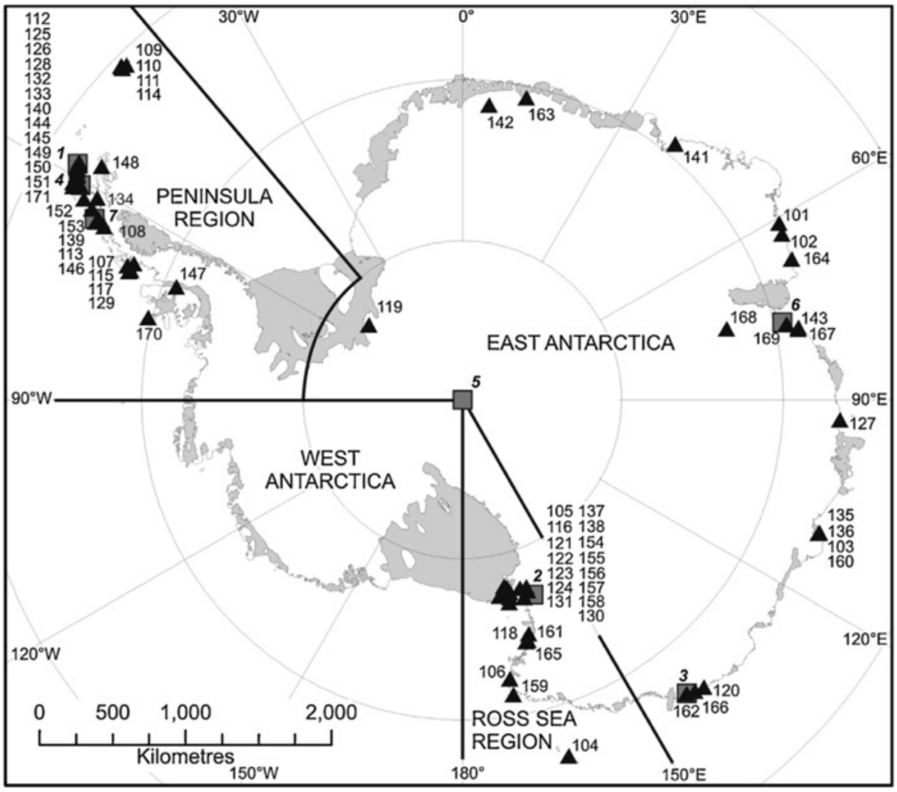


Figure 70. Map of Antarctic Specially Protected Areas (triangles) and Antarctic Specially Managed Areas (squares) showing absence of Areas in West Antarctica. Source: Hughes et al 2013.

No Historic Sites and Monuments (HSM) are designated in the operational area (Figure 71). The nearest HSM is 66 Prestrud's Cairn on Edward VII Peninsula.

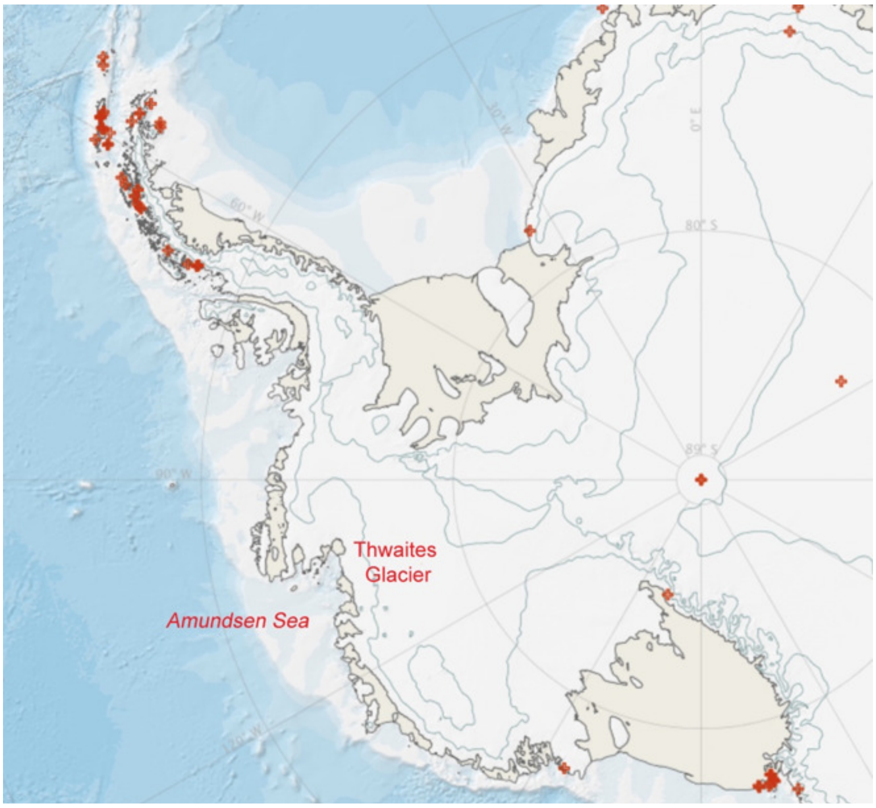


Figure 71. Map of Historic Sites and Monuments. Red crosses show listed HSMs. Source: www.add.scar.org

7. Assessment of the Environmental Impacts

Having described the nature and scale of the proposed activity and reviewed the current environmental state, this chapter of the IEE assesses the actual or potential impacts that will or could occur as a result of the planned activities.

7.1 Methods and Data

The actual or potential environmental impacts of the activity are assessed by means of a four-step analysis involving:

i. identifying the **outputs** *i.e.* the physical change imposed on or an input released to the environment as the result of an action or activity such as emissions, dust, mechanical action on the substrate, fuel spills, noise, light, wastes, heat, introduced species, etc., arising from the proposed activities described in Section 4;

ii. identifying the **exposure** *i.e.* the interaction between an identified potential output and the environment including flora and fauna, freshwater, marine, terrestrial and atmospheric environments;

iii. identifying the **impacts** *i.e.* the change in environmental values or resources attributable to the activity;

iv. assessing the **significance** of the identified impacts by considering the spatial extent, duration, intensity and likelihood of occurrence of the potential impacts to each environmental element – with reference to the three levels of significance identified by Article 8(1) of the Protocol (*i.e.* less than, no more than, or more than a minor or transitory impact).

7.2 Outputs

An output is a physical change (*e.g.* movement of sediments by vehicle passage or noise) or an entity (*e.g.* emissions, an introduced species) imposed on or released to the environment as the result of an action or an activity (EIA Guidelines, 2016).

For the purposes of this environmental impact assessment the ITGC has been divided into the following aspects:

1. Research activities, which have been further divided into:
   - The deployment of data collection instruments and equipment (including on, within and under the glacier and ice-shelves as well as open ocean deployed instruments), and
   - Direct sampling (*i.e.* geological cores, ice cores and sediment cores and samples).
2. Logistical and support activities, which have been further divided into:
   - Ice drilling, *i.e.* hot water and RAM drilling
   - Vehicle, vessel and aircraft operations;
   - Establishment and operation of field camps, and
   - Fuel management.

Consideration is also given to assessing the impacts of the ITGC as a whole campaign across all four seasons on the wilderness values of this area of West Antarctica.

The outputs of the various activities that were highlighted in Section 4 are summarised in Table 4 below.

ACTIVITY	OUTPUTS										
	Atmospheric emissions (burning fossil fuels)	Noise emissions	Light emissions	Heat emissions	Air turbulence	Mechanical action (physical disturbance to substrate)	Fuel or hazardous substances spills	Wastes (Including unrecoverable equipment)	Water turbulence	Introduced species or relocation of native species	Disturbance or removal of native fauna and/or flora
Research Activities											
Deployment of data collection instruments on, within and under glaciers and ice-shelves											
Active seismic research		✓		✓		✓	✓	✓			
Passive seismic research							✓	✓[1]			
Passive measurements ***e.g.*** **radar surveys, gravimetric measurements, tiltmeters etc**							✓	✓[1]			
Multi-sensor instruments ***e.g.*** **AMIGOS III**							✓	✓[2]			
Aero-geophysical survey	✓	✓					✓				
Instrumentation of seals								✓[2]		✓	✓
Autonomous vehicles ***e.g.*** **AUVS, ASVs, ROV, gliders and expendable profilers**		✓	✓	✓				✓[1,2]	✓	✓	✓
Marine tethered microstructure profiler								✓[1]	✓	✓	
Bathymetric surveying		✓									✓
Direct sampling											
Geological drilling / coring	✓	✓				✓	✓				✓
Geological sampling		✓				✓	✓			✓	✓
Marine sediment coring						✓		✓[1]		✓	

ACTIVITY	OUTPUTS										
	Atmospheric emissions (burning fossil fuels)	**Noise emissions**	**Light emissions**	**Heat emissions**	**Air turbulence**	**Mechanical action** (physical disturbance to substrate)	**Fuel or hazardous substances spills**	**Wastes** (Including unrecoverable equipment)	**Water turbulence**	**Introduced species or relocation of native species**	**Disturbance or removal of native fauna and/or flora**
CTD and water sampling								✓[1]		✓	
Ice coring	✓					✓	✓				
Logistical support activities											
Ice drilling *e.g.* hot water drills or RAM drill	✓	✓				✓	✓				
Over-snow traverses	✓	✓					✓				✓
Air transport	✓	✓					✓				
Marine transport Vessels and boat activities	✓	✓					✓	✓	✓	✓	✓
Field camps	✓						✓	✓			
Fuel handling and storage							✓	✓			

Table 4 (This page and previous page). Outputs from the activities to be undertaken during the ITGC campaign that have potential to impact the Antarctic environment. [1]Only if equipment is accidentally lost. [2]Items of equipment likely to be or will be unrecoverable.

The overview of outputs provided in table 4 suggests atmospheric emissions (from the burning of fossil fuels) and noise will occur as a result of several research and logistical support activities. The heavy reliance on fuel presents the risk of fuel spills for most activities. And most activities either will or may result in the production of 'waste' in various forms including items that will not be recoverable on conclusion of the research programme. The potential to introduce non-native species or relocate native species beyond their natural range is also a potential output for a number of research and logistical activities. Disturbance of native wildlife may also occur only in relation to a number of activities that will be undertaken during the ITGC campaign.

7.3 Exposures

Exposure is the process of interaction between an identified potential output (Section 7.2) and an environmental element or value (EIA Guidelines, 2016).

The environmental elements that are potentially exposed to the activities being undertaken by the Expedition and their outputs (identified in Table 4) are summarised in Table 5.

Note: The exposure of an activity's output may vary in significance in differing environments and is not accounted for in this table. The significance of the actual or potential impacts is assessed in Section 7.5 below.

OUTPUT OF ACTIVITIES	ENVIRONMENTAL ELEMENTS THAT WILL / MAY BE IMPACTED						
	FLORA AND FAUNA	FRESHWATER *(ponds, streams, rivers, lakes)*	MARINE *(including sea ice)*	GLACIOLOGICAL *(glaciers, ice sheet and ice shelves)*	TERRESTRIAL *(ice-free ground, soil and rocks)*	ATMOSPHERE	WILDERNESS VALUES
Atmospheric emissions				✓		✓	
Noise emissions	✓		✓				
Light emissions	✓		✓				
Heat emissions			✓	✓			
Air turbulence							
Mechanical action				✓	✓		✓
Fuel spills	✓		✓	✓			✓
Wastes (Including unrecoverable equipment			✓	✓			✓
Water turbulence			✓				
Introduced species / relocated native species	✓		✓				✓
Removal of native fauna &/or flora							
Presence / Visual disturbance					✓		✓

Table 5. Overview of those environmental elements that have been identified as potentially being susceptible to the outputs of the activities being undertaken by the TGC campaign.

The target locations for the research programme means, not surprisingly, that most outputs have potential to impact either marine or glaciological environments. A number of outputs have potential to impact native fauna and flora and in a number of cases wilderness values could be affected by the anticipated outputs of the ITGC programme.

7.4 Impacts and Mitigation Measures

This section considers the potential environmental impacts that will or may occur as a consequence of the identified outputs from the various activities identified in Section 7.3 above.

This impact assessment considers the worst-case impacts of outputs that have been identified. The actual or potential impacts are summarised in Table 8. Table 8 also assesses the level of risk associated with the actual or potential impacts according to the spatial extent, duration, severity and likelihood of the impact occurring.

The following definitions are used to describe the different types of impact:

A **direct impact** is a change in environmental values or resources that results from direct cause-effect consequences of interaction between the exposed environment and an activity or action (*e.g.* decrease of a limpet population due to an oil spill, or a decrease of a freshwater invertebrate population due to lake water removal) (EIA Guidelines, 2016).

An **indirect impact** is a change in environmental values or resources that results from interactions between the environment and other impacts - direct or indirect (*e.g.* alteration in seagull population due to a decrease in limpet population which, in turn, was caused by an oil spill) (EIA Guidelines, 2016). Indirect impacts may not be known until a direct impact occurs.

A **cumulative impact** is the combined impact of past, present and reasonably foreseeable activities. Cumulative impacts may occur over time and should be assessed by looking at other human activities occurring in the proposed locations. As with indirect impacts, cumulative impacts may not be identified until a direct impact has occurred (EIA Guidelines, 2016).

Cumulative impacts are considered in Section 7.6 below.

7.4.1 Deployment of Data Collection Instruments and Equipment

7.4.1.1 Glaciological survey

As recorded in Section 4 above a range of survey equipment will be used and/or deployed onto the Thwaites Glacier and ice-shelf with a range of actual or potential impacts on the environment.

Active seismic surveys – explosive source

Active seismic surveys using explosive sources will or may result in the following impacts:

a. Residues at the point of detonation of explosives at various depths within the ice;
b. Energy release in the form of noise, particularly if detonation occurs near to, or at the ice surface;
c. Energy release in the form of heat;
d. *In situ* disposal of excess explosives and explosives packaging, which cannot be recovered from the field;
e. The potential release of battery acid from the detection equipment.

a. Explosive residues

Impact type: direct and cumulative

The explosive action will leave traces of contaminants in the ice at the point of detonation. This will add to the small amounts of contaminants from previous and future seismic surveys in West Antarctica.

Treatment and Mitigation:

- There are no treatments for this impact. Residues will be left behind as a result of explosives use, but only in small (trace) amounts.
- The total amount of explosives to be used by the ITGC to achieve the stated research objectives will be reduced as a consequence of using the vibroseis equipment as an alternative source for active seismic measurements (see below).

Record keeping:

Records will be maintained of the amounts of explosives used throughout the ITGC campaign.

b. Noise

Impact type: direct

The detonation of explosives close to or at the surface of the ice will release some energy in the form of noise which has the potential to disturb any nearby wildlife.

Treatment and Mitigation:

- The ITGC seismic work will be undertaken at remote locations on glaciers and ice-shelves and at considerable distances from any known concentrations of wildlife. As such disturbance is assessed as being highly unlikely and no further treatment is considered to be necessary.

Record keeping:

In the very unlikely event that the active seismic survey work causes disturbance to wildlife, records will be taken, and it will be reported.

c. Heat

Impact type: direct

The detonation of explosives will release some energy in the form of heat.

Treatment and Mitigation:

- Any heat that is generated will dissipate rapidly into the ice or cold Antarctic air with negligible consequences. Accordingly, no additional treatment is considered to be necessary.

d. Explosives disposal and burning of explosives packaging

Impact type: direct and cumulative

Under international transport regulations explosives packaging and un-used explosives are still classed as hazardous goods and would require dedicated (non-passenger) flights just to remove them. Consequently, it is more economical and environmentally appropriate to destroy excess explosives and explosives packaging *in situ*. Excess explosives (should any remain at the end of the season) will be destroyed by controlled detonation. Explosives packaging will be destroyed by supervised open burning, which will lead to pollution of local snow / ice environment and will make a cumulative contribution to regional and global atmospheric pollution.

Treatment and Mitigation:

- The management of explosives and disposal of excess materials will be undertaken in accordance with the BAS and USAP Explosive's Code of Conduct and by trained and competent explosives experts;
- Researchers will be diligent in their calculations of the amounts of explosives required so as to minimise the amounts required to be disposed of at the end of the season;
- If there are any excess explosives, they will be destroyed in a controlled manner well away from any wildlife;
- Burning of explosives packaging will be minimised by using small pits dug into the snow;
- Only small quantities of packaging are burned at a time and only in light or no wind conditions;
- Once completed, burn pits will be re-covered with fresh snow to avoid ash spreading far.

Record keeping:

Records will be maintained of the quantities and locations where excess materials were detonated / burnt.

e. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use.
- All batteries are sealed lead-acid Absorbent Glass Mat (AGM) batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in an aluminium case or similar, such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

Active seismic surveys – vibroseis source

Seismic surveys using vibration as a source will or may result in the following impacts:

a. Low frequency vibrations and noise disturbance to nearby wildlife;
b. Emissions to air from the burning of fossil fuel to power the equipment;
c. Pollution of snow / ice environments as a result of an accidental spill event *e.g.* during refuelling of the equipment.

a. Low frequency vibrations and noise

Impact type: direct

Noise will be generated from the running of the vibroseis truck engine and from the generation of seismic waves.

Treatment and Mitigation:

- The vibroseis measurements will be undertaken at remote locations on glaciers and ice-shelves and at considerable distances from any known concentrations of wildlife. Accordingly, the risk of disturbance to wildlife is assessed as being highly unlikely and no further treatment is considered to be necessary.

Record keeping:

In the very unlikely event that the active seismic survey work causes disturbance to wildlife, records will be taken, and it will be reported.

b. Emissions from burning fossil fuel

Impact type: direct and cumulative

The burning of fossil fuels to power the vibroseis equipment will result in the emission of gases and that will pass into the atmosphere and add to regional and global atmospheric pollution, and particulates that will settle out on the glacier surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- The equipment will be serviced prior to departure for Antarctica to ensure it runs and operates as efficiently as possible.
- Emissions will be minimised by running the equipment only when required.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

Passive seismic surveys

Passive seismic surveys will be undertaken through the deployment of seismometer instruments at several locations on the glacier and ice shelf.

Under normal operations the seismometers have no impact on the environment in which they are deployed. Potential environmental impacts may occur if the:

a. batteries used to power the equipment are damaged and leak battery acid, or
b. equipment cannot be recovered (if for example its location is lost).

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in an aluminium case or similar, such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

b. Irrecoverable equipment

Impact type: direct and cumulative

If the equipment cannot be recovered it will remain in the environment for many decades. It will be carried along with the ice and ultimately will be deposited in the marine environment at an unpredictable location, where it will decay causing a small amount of local pollution.

Treatment and Mitigation:

- All equipment will be GPS locatable and will be marked with flags well above the level of anticipated annual snow cover.

Record keeping:

Any lost or irrecoverable equipment will be recorded and reported.

Magnetotelluric measurements

Magnetotelluric (MT) measurements do not require long-term deployment of equipment. The ITGC researchers will undertake MT measurements on a regular basis by deploying the necessary equipment, taking the measurements and immediately recovering the equipment. Actual or potential environmental impacts may occur:

a. if the batteries used to power the equipment are damaged and leak battery acid.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in an aluminium case or similar, such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

Ice penetrating radar survey

The towed, 3MHz mono-pulse, surface radar survey does not require the deployment of any equipment and produces few outputs that could impact the environment. Actual or potential environmental impacts may occur:

a. if the batteries used to power the receiver equipment are damaged and leak battery acid.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.

- The receiver equipment and batteries are contained in an aluminium case or similar, such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:
Any spill events will be recorded and reported.

Automated Phase-sensitive Radio Echo Sounding (ApRES) measurements

ApRES measurements require the deployment of equipment on the glacier / snow surface for around 12 months. Actual or potential environmental impacts may occur if the:

a. batteries used to power the equipment are damaged and leak battery acid;

b. deployed instruments cannot be recovered the following season.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in a case such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:
Any spill events will be recorded and reported.

b. Irrecoverable equipment

Impact type: direct and cumulative

If the equipment cannot be located the following season, *e.g.* due to power failure, and significant snow build-up, then it will remain trapped in the ice for many years and decades and will be transported through the ice and will ultimately be released into the marine environment at an unpredictable location.

Treatment and Mitigation:

- All deployed equipment will be recovered to the fullest extent practicable;
- All deployed ApRES equipment will be GPS locatable and will be physically marked with flags to assist in finding the equipment the following season;
- Construction materials have been selected for low toxicity and degradability.

Record keeping:

Any unrecoverable equipment will be recorded and reported.

Multi-sensor AMIGOS III instruments

AMIGOS III instruments will be deployed on the Thwaites and Dotson glaciers. Actual or potential environmental impacts may occur:

a. if the batteries used to power the equipment are damaged and leak battery acid;
b. as a result of not being able to recover all of the 'in-ice' and 'below-ice' sensors and cables on completion of the measurements.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in a case such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

b. Irrecoverable sensors and cables

Impact type: direct and cumulative

The sensors and cables that will be deployed within and through the hot-water drilled holes will become frozen into the glacier within a very short period of time. It will be impracticable to recover these sensors and cables and would require significant resources and time to attempt to do so, with limited likelihood of success. Items that cannot be recovered will remain trapped in the ice for many years and decades and will add to other unrecovered equipment in Antarctica. Ultimately the items will be transported through the ice and will be released into the marine environment at an unpredictable location.

Treatment and Mitigation:

- All deployed AMIGOS III equipment will be GPS locatable and will be physically marked with flags to assist in finding the equipment the following season;
- All surface equipment and cables from the AMIGOS III instruments will be recovered on conclusion of the measurements;

- Construction materials have been selected for low toxicity and degradability.

Record keeping:
All unrecoverable items will be recorded and reported.

Gravimetric measurements

Gravimetric measurements do not require long-term deployment of equipment. The ITGC researchers will use a gravimeter to undertake regular measurements and immediately recover and re-stow the equipment. Actual or potential environmental impacts may occur:

a. if the batteries used to power the equipment are damaged and leak battery acid.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are enclosed such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

Tiltmeter measurements

Tiltmeter measurements do not require long-term deployment of equipment. The ITGC researchers will use tiltmeters to undertake measurements at selected locations for short periods during the austral summer only. Actual or potential environmental impacts may occur:

a. if the batteries used to power the equipment are damaged and leak battery acid.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are enclosed such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

GPS measurements

GPS instruments will be deployed in the area of the eastern Shear Margin for approximately two years. Actual or potential environmental impacts may occur:

a. if the batteries used to power the equipment are damaged and leak battery acid;
b. as a result of not being able to recover the instruments on completion of the measurements.

a. Potential release of battery acid

Impact type: direct and cumulative

If any batteries were to leak, then hazardous substances (*e.g.* sulphuric acid) would be lost to the environment (albeit on to snow and ice in this case and not on to ice-free ground) and would add to additional pollution events that have occurred in Antarctica in the past.

Treatment and Mitigation:

- All equipment is designed for low-temperature field use and will be checked for intactness and functionality prior to deployment.
- All batteries are sealed lead-acid AGM batteries which significantly reduces the risk of any release of hazardous substances.
- The receiver equipment and batteries are contained in a case such that in the unlikely event that a battery was damaged, any hazardous substances would be contained.

Record keeping:

Any spill events will be recorded and reported.

b. Irrecoverable sensors and cables

Impact type: direct and cumulative

The antenna, receiver unit, cables and batteries that will be deployed could be unrecoverable if the units fail and cannot be relocated at the end of the measurement period. Items that cannot be recovered will remain trapped in the ice for many years and decades and will add to other unrecovered equipment in

Antarctica. Ultimately the items will be transported through the ice and will be released into the marine environment at an unpredictable location.

Treatment and Mitigation:

- The units will be GPS marked, and will be physically marked with flags to assist in finding the equipment in subsequent seasons;
- Construction materials have been selected for low toxicity and degradability.

Record keeping:

All unrecoverable items will be recorded and reported.

Aero-geophysical surveys

Aero-geophysical survey flights will be undertaken over a period of a few weeks during the 2018/19 season with the aircraft operating from the LTG camp. Actual or potential environmental impacts may occur:

a. from the burning of fossil fuels during aircraft operations;

b. as a result of accidental spills of fuel during aircraft refuelling operations;

c. from the noise generated from the operation of the aircraft.

a. Burning of fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels during aircraft operations will occur. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and particulates that will settle out on the glacier surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- Aircraft will be serviced prior to departure for Antarctica to ensure they run and operate as efficiently as possible;
- Emissions will be minimised by flying aircraft only as required to meet scientific objectives.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

b. Accidental fuel spill

Impact type: direct and cumulative

Any accidental spill event that occurs during, for example, the refuelling of the aircraft will result in fuel being lost into the local snow / ice environment. Any fuel spilt on snow and ice is challenging to recover. Fuel can penetrate quickly into the firn layer and its distribution within the snow and ice will depend upon the conditions at the time. During warmer temperatures the ice is more porous, and fuel will flow quickly through and into the ice. Under colder conditions the ice is less porous and spilt fuel will migrate less (Raymond et al., 2017). If a spill event were to occur, any unrecoverable fuel will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- All refuelling operations will be undertaken by a minimum of two people;
- Refuelling operations will be undertaken using spill mats, absorbent wipes etc. in accordance with standard field practices;
- Spill kits will be available at locations were fuel is stored and transferred;
- Fuel spill response training will be provided to those undertaking fuel handling in the field.

Record keeping:

Any fuel spill events will be recorded and reported.

c. Noise from aircraft operations

Impact type: direct

Aircraft operations have the potential to cause disturbance leading to changes in the behaviour, physiology and the breeding success of wildlife. The level of impact will vary according to the intensity, duration and frequency of disturbance, the species involved and the phase in their breeding season. Most Antarctic species are particularly sensitive to disturbance between late September and early May - the period when Antarctic helicopter and fixed wing operations usually occur (Aircraft Guidelines, 2015).

Article 3 of Annex II to the Protocol prohibits the flying or landing of helicopters and or other aircraft in a manner that disturbs concentrations of birds and seals.

In general, disturbance effects on Antarctic wildlife appear to have been underestimated suggesting a more precautionary approach to activities in the vicinity of wildlife is required (Coetzee and Chown, 2016).

Treatment and Mitigation:

- Most aircraft operations will be undertaken over glaciers and ice-shelves and some distance from known locations of bird, penguin and seal colonies significantly reducing the likelihood of disturbance;
- Locations of wildlife colonies in the Thwaites Glacier area will be made known to pilots;
- The Guidelines for the Operation of Aircraft Near Concentrations of Birds will be made available to and followed by pilots.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

7.4.1.2 Instrumentation of seals

Section 4.3.1.2 describes the scientific rationale and procedure for attaching instruments to Elephant and Weddell seals and the outputs that may occur. The process of attaching these instruments will or may result in the following impacts:

a. Disturbance of bird and seal colonies through vehicle operations near to the colonies (*e.g.* helicopters or small boats used to land researchers) as well as researchers moving among the colonies;
b. Distress to seals selected for instrumentation during the tagging procedure;
c. A change in a seal's behaviour and/or capability as a result of the fitted instrument *e.g.* a reduction in diving or foraging ability;

Additional environmental impacts that may result from this aspect of the research project are:

d. The potential to introduce non-native species to ice-free locations in Pine Island Bay through the landing of people and equipment;
e. The potential to relocate native species between ice-free locations as researchers and their equipment are moved between sites.

a. Disturbance of colonies

Impact type: direct

Aircraft, small boat operations and people on foot all have the potential to cause disturbance among seals which may lead to changes in their behaviour, physiology and potentially breeding success. The level of impact will vary according to the intensity, duration and frequency of disturbance, the species involved and the phase (timing) in their breeding season.

Most species are particularly sensitive to disturbance between late September and early May - the period when Antarctic field operations usually occur (Aircraft Guidelines, 2015).

Article 3 of Annex II to the Protocol prohibits the flying or landing of helicopters and the use of small boats in a manner that disturbs concentrations of birds and seals. The same article also prohibits wilful disturbance of concentrations of birds and seals by persons on foot.

In general, disturbance effects on Antarctic wildlife appear to have been underestimated suggesting a more precautionary approach to activities in the vicinity of wildlife is required (Coetzee and Chown, 2016).

Treatment and Mitigation:

- Helicopter pilots will be briefed on the risks of disturbance and on the known location of bird and seal colonies in the Pine Island Bay area and instructed to avoid such colonies;
- Helicopter pilots will be provided with a copy of and will be briefed on the Guidelines for the Operation of Aircraft Near Concentrations of Birds noting the proximity of penguin and flying bird colonies in the area;
- Landing sites for helicopters and small boats will be carefully selected to minimise disturbance (without compromising the safety of researchers);
- The researchers undertaking this work are highly trained and experienced at working with and among Antarctic seals and will oversee all field operations so as to minimise disturbance risks;

- Initial selection of seals to be instrumented is undertaken at distance from the colony so as to minimise disturbance.

Record keeping:

Any significant disturbance events, over and above expected disturbance levels for this type of work, will be recorded and reported.

b. Distress to individual seals during tagging procedure

Impact type: direct

The sedation and handling of individual seals carries the risk of both acute and chronic stress effects. In the past, human impact studies have focused on observable (largely acute) impacts such as changes to a species' immediate behaviour (van Polanen Petel et al., 2007). More recently attention has been given to physiological changes (*e.g.* heart rate, stress hormone release etc.) that occur in species which are subject to human disturbances (Hogg and Rogers, 2009), and which may result in less obvious, chronic effects.

There are very few studies on human disturbance impacts of Antarctic seals with most studies concentrating on the impacts on Antarctic birds and penguins (Tin et al., 2009). In a sub-Antarctic setting, Engelhard et al. (2002) found no significant differences in any behavioural variables examined between disturbed and undisturbed Elephant seals on Macquarie Island suggesting that human disturbance did not appear to have significantly contributed to the population decline observed there (Engelhard et al., 2002).

However, as noted above, disturbance effects on Antarctic wildlife appear to have been underestimated suggesting a more precautionary approach to activities in the vicinity of wildlife is required (Coetzee and Chown, 2016).

Treatment and Mitigation:

- The seal capture, handling and tagging will be carried out by trained and experienced personnel from the UK's Sea Mammal Research Unit (SMRU);
- All researchers hold personal licences to conduct the work under the UK Animal (Scientific Procedures) Act 1986 (issued by the Home Office) and work in Antarctica will follow the same rules and procedures;
- The capture and tagging protocols have been refined over many years of tagging seals globally, but have recently been reviewed and approved by the University of St Andrews' Teaching and Research Ethics Committee (UTREC) and the Animal Welfare and Ethics Committee (AWEC);
- For each tagging effort a health and safety risk assessment will be carried out and reviewed by the safety officer of the Sea Mammal Research Unit;
- SCAR's Code of Conduct for the use of animals for scientific purposes will be adhered to.

Record keeping:

Any significant disturbance events, over and above expected disturbance levels for this type of work, will be recorded and reported. In the very unlikely event that a fatality occurs it will be reported **immediately** to BAS and NSF environmental offices.

c. Change in seal behaviour or capability due to fitted instrument

Impact type: direct

The use of fitted telemetry devices for monitoring seal behaviour has increased as technology advances have made such instruments smaller, more reliable and cheaper. The data acquisition potential from seal tags, particularly in remote locations is significant (Boehme et al., 2010; Heywood et al., 2016).

However, external devices have the potential to influence an animal's hydrodynamics, behaviour and energy expenditure and, therefore, can impede the individual animal. Simulations using computational fluid dynamics calculations have demonstrated that externally fitted devices can alter the hydrodynamics of a seal, which is expected to alter its physiology and behaviour and thus its use of the ecosystem (Hazekamp et al., 2010).

However, several studies of tagged seals in the wild have suggested that there are no long-term effects that can be attributed to the fitting of the external devices (Walker et al., 2012; Field et al., 2011; Mazzaro and Dunn, 2009; McMahon et al., 2008).

Treatment and Mitigation:

- Highly trained and experienced researchers from the UK's Sea Mammal Research Unit will fit the devices;
- Only healthy individuals are selected for tagging. Health assessments are made using visual clues including general appearance, body condition (lean vs fat), condition of fur and flippers, and the face including eyes;
- Research suggests no long-term effects on seal behaviour;
- The instruments will fall off naturally as the seal moults, usually within less than 12 months of the device being fitted.

d. Potential introduction of non-native species to ice-free locations in Pine Island Bay

Impact type: indirect and cumulative

Whilst not specifically linked to the seal tagging work, it is now well documented and understood that the deployment of researchers and their accompanying bags and equipment carries the potential to introduce non-native species to ice-free locations in Antarctica (Chown et al., 2012; Hughes and Convey, 2010; Hughes et al., 2010; Ricciardi, 2008).

Elephant seals tend to haul out on ice-free areas and congregate on beaches and shores for resting and breeding. Heywood et al., 2016 confirm the presence of Elephant seals on the Edwards Island in Pine Island Bay, which will be the target location for the seal tagging work during the ITGC.

The targeting of Weddell seals for tagging is most likely to occur on sea ice and large ice floes as this is their preferred haul-out habitat. Consequently, the tagging of Weddell Seals will not carry the same risks of introducing non-native species.

Treatment and Mitigation:

- Relevant controls and guidance will be made available to and followed by the researchers. This will include:
    - the CEP's non-native species manual;

  - BAS and USAP non-native species manuals and protocols, and
  - SCAR's code of conduct for terrestrial scientific research in Antarctica.
- Equipment, clothing and boots will be checked prior to deployment to Antarctica and prior to deployment to each ice-free location in Pine Island Bay;

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

e. Potential relocation of native Antarctic species between ice-free locations in Pine Island Bay

Impact type: direct and cumulative

Other than its general provisions regarding avoidance of detrimental changes in the distribution, abundance or productivity of Antarctic fauna and flora, the Protocol on Environmental Protection to the Antarctic Treaty includes no specific controls regarding human-mediated transfer of native Antarctic species between locations (Hughes and Convey, 2010).

Nonetheless, there is increasing awareness of regional variations in species abundance and distribution (Terauds and Lee, 2016) and that some ice free locations in Antarctica have distinct flora and fauna (Fraser et al., 2012; Convey et al., 2008; Pugh and Convey, 2008). As noted in Section 6 above, the Thwaites Glacier / Pine Island Bay area is one of the least sampled areas of Antarctic and knowledge of the terrestrial biodiversity of ice-free locations in this part of the Antarctic is poor (Peat et al, 2007; Helen Peat pers com; Peter Convey pers com).

The implications of human transfer of taxa between locations can range from the modification of the genetic structure of populations to changes in local biodiversity and subsequent effects on community dynamics. Given the differences between regions, intra- regional transfer of indigenous species also needs to be minimised. Such accidental movement of indigenous biota could compromise scientific studies of molecular adaptation, regional evolution and biogeography and reduce the inherent value that Antarctica offers as a system with very limited anthropogenic influence (SCAR, 2018).

Treatment and Mitigation:

- Researchers will be alerted to the risks of relocating biota between ice-free locations and the controls needed to reduce the risk;
- Boots, gaiters, clothing, equipment and bags will be inspected and cleaned (*e.g.* brushed) prior to departure from a site – particularly if relocating directly;
- In situations where researchers return to the support vessel between visits ashore, the opportunity will be taken to re-check and clean clothing and equipment;
- SCAR's code of conduct for terrestrial scientific research in Antarctic will be followed;
- Given the limited knowledge of the biology of some of these ice-free locations, researchers will be provided with some simple guidance material and asked (to the extent practicable) to undertake a basic biological assessment of the sites visited (Appendix A).

7.4.1.3 Autonomous and tethered marine instruments and equipment

Section 4 describes the range of instruments and equipment that will be deployed in the marine environment in the Pine Island Bay area and under ice shelves. The actual or potential environmental impacts of the equipment are considered below.

Deployment of autonomous underwater vehicles (AUVs)

The deployment of AUVs in ice covered waters of the Amundsen Sea, Pine Island Bay area and under ice shelves carries a number of environmental risks:

a. Physical disturbance of sessile and mobile marine organisms as a result of (minor) water turbulence in the immediate area of operation of the AUVs;
b. The AUVs will produce minor heat and light emissions throughout their deployment;
c. Auditory disturbance or physical harm to marine animals through the introduction of noise from the general operation of the AUVs as well as the sonar equipment on-board;
d. The introduction of non-native species if the AUVs are contaminated with biological material from outside of Antarctica;
e. Pollution of the marine environment if the AUVs fail to return to the support vessel *e.g.* through equipment failure. This includes the potential loss to the environment of 'drop weights' from the AUVs if a 'return-to-surface' trigger is activated.

a. Physical disturbance of marine biota through water turbulence

Impact type: direct

The operation of the AUVs will produce a small degree of water turbulence in the immediate area of operation of the vehicle. Only the water in the immediate vicinity of operation of the vehicle will be affected. This will be negligible and dissipate rapidly.

No reported disturbance events associated with the operation of AUVs could be found in a literature search.

Treatment and Mitigation:

- None required.

b. Heat and light emissions from the AUVs

Impact type: direct

The deployment of the AUVs in the marine environment and beneath the ice-shelves will introduce some artificial heat and light though this will be negligible. Any light impacts will be transitory as the AUV passes by. Any heat produced by the AUVs will rapidly dissipate in the cold Antarctic waters.

Treatment and Mitigation:

- None required.

c. Auditory impacts on marine animals

Impact type: direct / indirect / cumulative

The AUV units themselves are relatively quiet, however the operation of the sonar equipment on-board the AUVs will introduce some noise into the marine environment with potential to impact marine animals.

Anthropogenic underwater noise is recognised as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa (Williams et al., 2015). The impact of marine noise varies greatly depending upon the source, frequency, duration, marine conditions, location and in terms of its impact on different taxa.

Underwater noise from shipping is increasingly recognised as a significant and pervasive pollutant with the potential to impact marine ecosystems on a global scale (Clark et al., 2009; Merchant et al., 2015; Williams et al., 2014).

The understanding of the possible impacts of anthropogenic noise on the marine environment and on the auditory mechanism of marine mammals in particular has been improved by experimental work on captive animals. A focus has been on the sound levels needed to produce Temporary Threshold Shift (TTS) in marine mammal hearing. TTS is the condition of reduced sensitivity of hearing produced by loud noise. It is reversible but if it is repeated persistently, the cumulative effect can lead to Permanent Threshold Shift (PTS) or, in the extreme, deafness. Knowing the levels at which TTS starts allows an understanding of what sound pressure levels represent the start of potential hearing damage and allows a precautionary limit to be defined for sound exposure. The scarcity of such knowledge has been a major problem for assessing the impacts of anthropogenic noise (Richardson et al., 1995).

There is very little in the academic literature that specifically addresses the impacts of marine noise from the operation of AUVs, though this is likely due to the very low risk that such devices pose.

In May 2004 a SCAR Action Group undertook an assessment of the risks to the Antarctic marine environment posed by acoustic instruments that are or could be used in the Southern Ocean, including acoustic releases, echo sounders, multibeam echo sounders, sub-bottom profilers and small and large seismic (airgun) systems (Boebel et al., 2005).

The Action Group's assessment of the effects of echo-sounders (albeit vessel based and not AUV based) suggested that a temporary threshold shift effect in marine animals was unlikely, though some minor displacement of animals in the immediate vicinity of the ship (*i.e.* within a few metres) was possible (Boebel et al., 2005).

The Action Group's assessment of the effects of a 3.5kHz sub-bottom profiler (again ship-mounted and not AUV mounted) was that they were likely to be similar to other single beam systems, though risks for individuals [in the immediate vicinity of survey] were considered to be slightly higher because of the wider beam width and lower frequency content (Boebel et al., 2005).

The Action Group's assessment of the effects of multibeam echo sounders on a ship suggested that temporary threshold shift effect in marine animals was again unlikely. However, the Action Group agreed that some displacement from the survey area might occur for a period of days during the systematic mapping of an area. Potential injuries might conceivably occur to individuals in narrow sea ways where animals could be driven onto islands or held near the surface as has been suggested for beaked whale stranding events albeit associated with military systems (Jepson et al., 2003). The SCAR Action Group could not see how adverse effects at the population level could occur through the use of multibeam echo sounders (Boebel et al., 2005).

Sonar systems on the AUVs are less powerful than ship-mounted systems and are designed to return signals from targets that are relatively close (within a few hundred metres).

The likelihood of encounters between marine animals and the AUVs that will be operated during the ITGC is assessed as being low. Whilst there are no population estimates for key marine species (cetaceans and pinnipeds) in the Pine Island Bay area, the density of such species is unlikely to be high compared to other areas of Antarctica. When the AUVs are operating under ice shelves, encounters with cetaceans and pinnipeds is assessed as being extremely unlikely.

Treatment and Mitigation:

- Prior to the deployment of the AUVs a watch will be undertaken to ensure that no marine animals are obviously close to the ship. If individuals or groups of cetaceans or pinnipeds are observed, the AUV deployment will be delayed;
- AUV deployments will be relatively short (periods of days) and will be undertaken towards the end of the breeding season (late January at the earliest).

Record keeping:

In the very unlikely event that a significant disturbance event is observed, the nature of the disturbance and the species involved will be recorded and reported.

Note: There will be multiple anthropogenic sources of marine noise during the ITGC, including from the operation of vessels and small boats, echo sound and multibeam surveys, sub-bottom profiling, a seismic reflection survey, as well as operation of the AUVs and cNODE transponders. All of which will be undertaken during the 2019/20 season cruise of the Nathaniel B Palmer, and some of which will be undertaken during other seasons of the ITGC campaign.

The cumulative impacts of these multiple marine noise sources is briefly considered in section 7.6 below. However, as noted elsewhere, a separate environmental impact assessment for the 2019/20 Nathaniel B Palmer cruise is being prepared in the U.S. for assessment by NSF.

d. Introduction of non-native marine species

Impact type: indirect and cumulative

The introduction of non-native species represents one of the most significant threats to biodiversity globally (IUCN, 2018).

Although invasions to southern hemisphere, high-latitude terrestrial ecosystems are now well described (Frenot et al., 2005; Hughes et al., 2015), the same is not true for marine systems. Recent studies have suggested some potential mechanisms for marine introductions to Antarctic coastlines including with rafts of marine debris (Barnes and Fraser, 2003) and on vessel hulls (Lewis et al., 2003, 2004; Hughes and Ashton, 2016). Together, these reports indicate that, despite the apparent isolation of the Southern Ocean, marine introductions can occur, though to date only a single non-native species establishment has been recorded from within the Antarctic marine environment (Clayton et al., 1997). Surveillance and monitoring of the Antarctic marine environment and marine vectors remains extremely limited however (Hughes and Ashton, 2016).

Antarctica's marine ecosystems have been isolated for millennia and demonstrate high levels of endemism, increasing the susceptibility of these ecosystems to the impacts of invasive species (Hughes and Ashton, 2016). Any introductions would have an indirect impact on the marine environment through the potential introduced competition for habitat, as well as a reduction in the research value at locations 'contaminated' with non-native marine species that have been artificially introduced to the region.

Scientists and scientific research equipment have been identified as presenting a particularly high risk of introducing non-native species to Antarctica (Chown et al., 2012).

Any fouling of the AUVs with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments. The Hugin 3000 AUV is owned by the University of Gothenburg and potentially has been used in Arctic waters.

The establishment of a non-native marine species in the marine environment of the Amundsen Sea is likely to be low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the AUV operators (CEP, 2016).
- The AUVs will be inspected and cleaned prior to deployment to Antarctica.
- The AUVs will be inspected and if necessary cleaned prior to each deployment in Antarctica.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

e. Pollution of the marine environment through loss of the AUVs and/or their drop weights

Impact type: direct and cumulative

The deployment of autonomous and remotely operated vehicles under ice-shelves and beneath sea ice increases the risk of equipment loss compared to open water environments.

Any AUV operation beneath ice shelves, where little or no data exist on cavity morphology, is high-risk but high-reward science. So, too, is AUV deployment beneath a drifting canopy of sea ice, even though only a few metres thick, given that open water can come and go on the timescale of hours and even minutes. In the unlikely event that an AUV failed to return to the surface / support ship, it would be unrecoverable and would need to be abandoned.

A UK AUV was lost beneath the Fimbul Ice Shelf in 2005 and the UK's Natural Environment Research Council (NERC) acknowledged at the time that the risks of AUV loss were high prior to sanctioning that science programme. Whilst the risks of loss of an AUV remain, they are assessed as being significantly less than 13 years ago. Technology has improved and modern AUV technology includes sophisticated collision avoidance systems (Pebody, 2008). The AUVs to be used on this Expedition are among the most advanced available. There is also considerably more expertise and experience available in the operation of and planning for AUV deployments.

The Expedition will take a cautious approach to all under-shelf operations. AUV missions will gradually build up in duration and distance travelled as knowledge and experience is gained. Missions will begin with flights along the front of the ice shelf to collect sea bed bathymetric data beneath the shelf using the side scan sonar. This will then be followed by a short duration mission under the ice shelf at about 100m above the sea floor to collect further bathymetric data and map the terrain. The bathymetric data will be used to develop a digital terrain model, which will be used to help plan a safe escape route for the AUV back to the ship. Only when a safe operating route has been determined will the AUV be used to survey beneath the ice shelf.

The operation of the AUVs also carries the risk of the loss of drop-weights. Hugin AUVs are neutrally buoyant vehicles during mission operations. Upon complete loss of battery power, or in the event of other critical error states, the AUV control system will either default to or initiate an emergency ascent.

Potential causes are critical height errors, propulsion failures, or terrain avoidance requirements outside of the operating envelope of the vehicle. When power is lost to the AUV, the attached weights will drop by default as they are held in by power. These systems are in place to ensure a safe recovery of the AUV, although such scenarios are less effective if the AUV is operating under ice.

Commercial operators of Hugin AUVs (Ocean Infinity per comm.) have placed the risk of an emergency event involving the release of the AUV drop-weights as 0.7% per hour of operation.

With the drop-weights released (two per AUV: one aft and one at the front) the AUV becomes positively buoyant and will float to the surface. The drop-weights are approximately 17kg each and are constructed of steel.

If the drop-weights are released they will fall quickly to the sea-floor where they will remain and likely become colonised over time.

In the unlikely event that AUV equipment is lost, it would decay over many decades resulting in a small amount of local pollution and impact.

Treatment and Mitigation:

- The AUVs incorporate sophisticated collision avoidance and navigation systems;
- The use of the cNODE transponders (see below) will improve communication with and navigation by the AUVs;
- The AUVs will be operated by highly experienced specialist technicians and operators;
- The Expedition will adopt a 'build-up' approach to AUV missions *i.e.* short duration, near-vessel deployments increasing to longer and more distant missions. AUV testing will be undertaken in the 2018/19 season prior to under-ice deployment in 2019/20;
- The risk of an emergency event involving the release of the drop-weights is low, and has been calculated as 0.7% per hour of operation (0.7 per 100 hours of operation);
- It is noted that the Expedition has the benefit of learning from past under-ice surveys by AUVs and will draw on this previous experience where possible (Nichols et al., 2006; Graham et al., 2013; Dowdeswell et al., 2008);

- A pre-deployment risk assessment will be undertaken

Record keeping:

In the unlikely event that an AUV is lost, the location will be recorded and reported.

Deployment of cNODE transponders

The deployment of cNODE transponders will or may result in the following environmental risks:

a. Auditory disturbance or physical harm to marine animals through the introduction of anthropogenic noise;
b. Pollution of the marine environment if the transponder units cannot be recovered and through the irrecoverability of the transponder anchor units.

a. Auditory disturbance or physical harm to marine animals through the introduction of noise

Impact type: direct / indirect / cumulative

The cNODE transponders (the exact number to be used is not known at the time of writing) will be deployed on the seafloor in front of the Thwaites and Dotson ice shelves in each of three seasons in order to support the accuracy of navigation of and data transmission from the AUVs. One transponder will be deployed through the ice into the ocean cavity beneath the Thwaites Glacier.

The transponders operate between 21 and 31kHz, though the specific details of the configuration and intended operating parameters of the devices are not known at time of writing.

As recorded above, anthropogenic underwater noise is recognised as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa (Williams et al, 2015).

The SCAR Action Group that convened in 2004 to assess the risks to the Antarctic marine environment posed by acoustic instruments did not consider the impacts of transponders specifically (Boebel et al.,, 2005). The literature includes some assessments of the effects of underwater data transmission devices. Kastelein et al., (2005, 2006) determined that underwater communication signals can induce avoidance behaviour at levels between 97dB and 113dB in harbour porpoises and above 107dB for harbour seals.

Overlap of the noise signal from the transponders with marine mammal and cetacean activity in Pine Island Bay area is possible. Whilst there are no population estimates for key marine species (cetaceans and pinnipeds) in the Pine Island Bay area, the density of such species is unlikely to be high compared to other areas of Antarctica. Noise effects from the transponders, if any, are most likely to involve avoidance by and / or temporary displacement of marine mammals.

Treatment and Mitigation:

- Deployment of the transponders will be for relatively short periods of time (days) compared to the breeding season;
- Deployments will occur towards the end of the breeding season;
- Pinger devices to release and recover the transponders at the end of the survey work will be single pulses only.

Record keeping:

In the unlikely event that disturbance events are observed, the location and species involved will be recorded and reported.

b. Pollution of marine environment

Impact type: direct / cumulative

The cNODE transponders will be recovered at the end of the survey work each season. This is achieved by sending an acoustic signal to a release device allowing the transponders to return to the surface where they are picked up.

If the release device fails the transponders will be irrecoverable by other means and will remain on the sea floor where they potentially will be colonised by sessile organisms and slowly decay over many years and decades.

The anchor devices to keep the transponders on the sea floor will not be recovered. They will be of inert material and will remain on the sea floor where they potentially will be colonised by sessile organisms. Any material left on the sea floor will add, cumulatively to other lost or deployed marine equipment from past and planned future research activity.

Treatment and Mitigation:

- The release mechanisms are tried and tested technology with a low failure rate.

Record keeping:

Any unrecovered equipment will be recorded, including its location, and reported.

Deployment of Remotely Piloted Aircraft (RPA) units during deployment / recovery of AUVs

The use of rotary wing RPA units in and around the support vessel to support the deployment / recovery of the AUVs, will or may result in the following environmental risks:

a. Disturbance of wildlife through noise emissions and visual impacts;
b. Pollution of the marine environment in the event the equipment is lost *e.g.* through equipment malfunction or collision.

a. Noise / visual disturbance of wildlife

Impact type: direct

The deployment of RPA units will create some noise, which in combination with the visual presence of the RPA has the potential to disturb wildlife. The use of RPA units in Antarctica has increased significantly in recent years for research purposes. This new technology potentially could have undesirable and unforeseen impacts on wildlife, the risks of which are currently little understood (Hodgson and Koh, 2016). Different wildlife populations can respond idiosyncratically to an RPA units in proximity depending on a variety of factors, including the species, environmental and historical context, as well as the type of machine and its method of operation (Hodgson and Koh, 2016; Rummler et al., 2016). In general, disturbance effects on Antarctic wildlife appear to have been underestimated suggesting a more precautionary approach to activities in the vicinity of wildlife is required (Coetzee and Chown, 2016).

The operation of the RPA units during the ITGC will be confined to the immediate vicinity around the support vessel and will assist with deployment and recovery of the AUVs. As such no encounters with colonies of birds, penguins or seals ashore is likely to occur.

Encounters with individuals or small groups of birds (*e.g.* birds or penguins foraging at seas) or seals (*e.g.* hauled out on ice floes) cannot be ruled out.

The issue of safe environmentally sound operation of RPA in Antarctica has been the subject of considerable discussion within the Antarctic Treaty Consultative Meeting (ATCM) and in particular its advisory Committee for Environmental Protection. At its 41st meeting in 2018, the ATCM adopted new *Environmental guidelines for the operation of Remotely Piloted Aircraft Systems (RPAS) in Antarctica* (ATCM Resolution, 2018a).

In parallel the Council of Managers of National Antarctic Programs (COMNAP) has also developed the *Antarctic RPAS Operator's Handbook* (COMNAP, 2017).

Treatment and Mitigation:

- The RPA will be operated by a highly trained and experienced pilot[4] at all times and only in the immediate vicinity of the support vessel;
- The RPA will be operated in full conformance with the available guidance material notably the COMNAP *Antarctic RPAS Operator's Handbook* (COMNAP, 2017) and the ATCM's *Environmental guidelines for the operation of Remotely Piloted Aircraft Systems (RPAS) in Antarctica* (ATCM, 2018a);
- RPA will not be launched in the vicinity of large congregations of wildlife;
- wildlife observations in the vicinity of the launch site will be undertaken prior to deployment of the RPA;
- Relevant U.S. Antarctic programme flying protocols will be followed at all times.

Record keeping:

In the unlikely event that a disturbance incident occurs, records of the timing, location and nature of the disturbance event and the species involved will be made and reported.

b. Pollution of the marine environment

Impact type: direct / cumulative

If lost to the marine environment, an RPA unit will eventually find its way to the sea floor where it will decay over a long period of time. This will result in direct, pollution impacts at the immediate site where the unit settles, and add to the range of other (un-quantified) equipment lost to the environment in Antarctica over several decades of marine research.

[4] The pilots will be: Johan Rolandsson – trained and certified by SweDron, and Aleksandra Mazur – trained by Airborn and SweDron, certified by Polish Civil Aviation Authority.

Treatment and Mitigation:

- The RPA units will be fully serviced and tested prior to deployment in Antarctica;
- The RPA units will be operated by fully trained and competent pilots;
- The RPA units will only be flown in favourable weather conditions and not in windy or low visibility conditions;
- The guidance provided by the COMNAP RPAS Handbook will be followed at all times;
- Relevant U.S. and UK national Antarctic programme flying protocols will be followed at all times.

Record keeping:

Any lost equipment will be recorded, including its location, and reported.

Deployment of marine gliders

The deployment of a number of marine gliders in front of the Thwaites and Dotson ice shelves will or may result in the following environmental risks:

a. The introduction of non-native species if the gliders are contaminated with biological material from outside of Antarctica;
b. Pollution of the marine environment in the event that the equipment is lost *e.g.* through equipment malfunction or collision with ice.

a. Introduction of non-native species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the glider units with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species in the marine environment of the Amundsen Sea as a result of deployment of the gliders is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the ‘guiding principles’ of the Manual, will be made available to researchers (CEP, 2016).
- The gliders will be inspected and cleaned prior to deployment in Antarctica.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

b. Pollution of marine environment through loss of equipment

Impact type: direct / cumulative

Any autonomous vehicle deployments carry the risk of loss of equipment through, for example, equipment failure, collision or extreme weather events (Harris et al., 2016). Glider deployments in ice covered waters carry additional risks compared to deployments in open water settings.

Gliders will be deployed in front of the Thwaites and Dotson ice shelves during the ITGC in the 2018/19 and 20/21 seasons.

If the gliders cannot be recovered they will likely remain afloat or if damaged sink to the sea floor. The equipment will decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean over many decades.

Treatment and Mitigation:

- The gliders will be serviced and checked for functionality prior to deployment in Antarctica;
- Risk assessments will be completed prior to deployment

Record keeping:

Any lost equipment will be recorded, including its last known location, and reported.

Deployment of Autonomous Surface Vehicles (ASVs)

The deployment of a number of ASVs will or may result in the following environmental risks:

a. The introduction of non-native species if the ASVs are contaminated with biological material from outside of Antarctica;
b. Pollution of the marine environment in the event that the equipment is lost *e.g.* through equipment malfunction or collision with ice;

a. Introduction of non-native species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the ASVs with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species in the marine environment of the Amundsen Sea as a result of deployment of the ASVs is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the ASV operators (CEP, 2016).
- The ASVs will be inspected and cleaned prior to deployment in Antarctica;
- A pre-deployment risk assessment will be undertaken.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

b. Pollution of marine environment through loss of equipment

Impact type: direct / cumulative

Any autonomous vehicle deployments carry the risk of loss of equipment through, for example, equipment failure, collision or extreme weather events (Harris et al., 2016). ASV deployments in ice covered waters carry additional risks compared to deployments in open water settings.

Two ASVs will be deployed in the Amundsen Sea area during the ITGC in the 2020/21 season.

If the ASVs cannot be recovered they will likely remain afloat or if damaged sink to the sea floor. The equipment will decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean over many decades.

Treatment and Mitigation:

- The ASVs will be serviced and checked for functionality prior to deployment in Antarctica;
- A pre-deployment risk assessment will be undertaken.

Record keeping:

Any lost equipment will be recorded, including its last known location, and reported.

Deployment of 'icefin' remotely operated vehicle (ROV)

The deployment of 'icefin' into the ocean cavity beneath the Thwaites Glacier will or may result in the following environmental impacts:

a. Physical disturbance of marine organisms as a result of (minor) water turbulence in the immediate area of operation of the ROV;
b. The minor introduction of artificial noise, heat and light throughout ROV operations;

c. The introduction of non-native species if the ROV is contaminated with biological material from outside of Antarctica;
d. Pollution of the sub-ice shelf marine environment if the ROV cannot be recovered through the ice hole *e.g.* as a result of entanglement of the cable.

a. Physical disturbance of marine biota through water turbulence

Impact type: direct

The operation of the ROV will produce a small degree of water turbulence in the immediate area of operation of the vehicle. Only the water in the immediate vicinity of operation of the vehicle will be affected. This will be negligible and dissipate rapidly.

Treatment and Mitigation:

- None required.

b. Noise, heat and light emissions from the ROV

Impact type: direct

The deployment of the ROV in the sub-ice shelf marine environment will introduce some artificial noise, heat and light though in each case this will be negligible. The ROV is 'low noise' and will not encounter any mobile marine organisms in its planned area of operation. Any light impacts will be transitory as the ROV passes by. Any heat produced by the ROV will rapidly dissipate in the cold sub-shelf waters.

Treatment and Mitigation:

- None required.

c. Introduction of non-native species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the ROV with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species in the sub-ice shelf environment is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the ASV operators (CEP, 2016).
- The ROV will be inspected and cleaned prior to deployment in Antarctica.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

d. Pollution of marine environment through loss of equipment

Impact type: direct / cumulative

Deploying the ROV through 10s of metres of ice shelf carries some risk that it may not be recoverable, *e.g.* as a result of entanglement of the communications cable.

If the ROV cannot be recovered through the ice hole it will likely sink to the sea floor beneath the ice shelf and will decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean over many decades.

Treatment and Mitigation:

- The ROV has been tested in other under-ice situations with no problems encountered;
- The ROV will be serviced and checked for functionality prior to deployment in Antarctica;
- The ROV will be operated by experienced researchers and technicians;
- The ROV will be deployed for relatively short-term missions (hours) to avoid risk of closure or malformation of the hot water drilled ice hole.

Record keeping:

Any lost equipment will be recorded, including its last known location, and reported.

Deployment of expendable oceanographic profilers

The deployment of expendable oceanographic profilers will result in the following environmental impacts:

a. Pollution of the sub-ice shelf / marine environment as a consequence of irrecoverability of the profilers.

a. Pollution of ice-shelf and marine environment

Impact type: direct / cumulative

The oceanographic profilers are designed to be expendable and will not be recovered once the survey work has been completed.

The equipment will remain in the marine environment and decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean over many decades.

Treatment and Mitigation:

- The materials used to construct the profilers have been selected for low toxicity.

Record keeping:

The number and approximate location of the profilers deployed will be recorded and reported.

Deployment of tethered micro-structure profilers

The deployment of the tethered oceanographic micro-structure profilers will or may result in the following environmental impacts:

a. The introduction of non-native species if the profiler is contaminated with biological material from outside of Antarctica;
b. Pollution of the marine environment if the profiler cannot be recovered *e.g.* as a result of entanglement of the cable;
c. Physical disturbance of pelagic marine organisms as a result of (minor) water turbulence during deployment and recovery of the profiler.

a. Introduction of non-native species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the profiler with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the ASV operators (CEP, 2016).
- The profiler will be inspected and cleaned prior to deployment in Antarctica.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

b. Pollution of marine environment through loss of equipment

Impact type: direct / cumulative

The deployment and recovery of deep-sea benthic sampling equipment carries a degree of risk of loss, through cable breaks, cable snagging (*e.g.* on the winch, resulting in a failure to recover the equipment and the need to cut the cable) or the equipment becoming caught on the seafloor. Successful sampling in the deep sea using equipment at the end of hundreds of metres of cable is time-consuming and requires special skill (Gage and Bett, 2008). An additional factor in Polar waters relates to the degree of pack ice cover and the potential for pack ice to move into the sampling area during equipment deployment and hampering recovery.

A search of the literature suggests that loss of such equipment is rare, with risks reduced through the use of standardised safe operating procedures and techniques (Mudroch and Azcue, 1995).

In the unlikely event that the profiler cannot be recovered it will sink to the sea floor and will decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean over many decades.

Treatment and Mitigation:

- The profiler will be deployed and recovered by trained and experienced technicians and researchers;
- The profiler and winch system will be checked and serviced prior to deployment to Antarctica;
- Risk assessments will be undertaken prior to the deployment of all equipment from vessels.

Record keeping:

Any lost equipment will be recorded, including its last known location, and reported.

c. Physical disturbance to pelagic marine animals during deployment and recovery.

Impact type: direct

The profiler will create minor water turbulence during deployment and recovery with the potential for minor and temporary disturbance of pelagic biota.

Treatment and Mitigation:

- Marine wildlife checks will be undertaken prior to the deployment of the equipment, and deployment delayed if necessary.

Record keeping:

Any disturbance or interference events will be recorded and reported.

Multibeam bathymetric and sub-bottom profiling surveys[5]

The multibeam bathymetric and sub-bottom profiling surveys will or may have the following environmental impacts:

[5] As recorded elsewhere in this EIA, a separate EIA will be undertaken for the entire 2019/20 cruise of the Nathaniel B Palmer, including the multibeam and sub-bottom profiling that will be undertaken as part of that cruise. However, multibeam sub-bottom profile surveys will also be undertaken during the 2018/19 cruise, which is why they have been considered here.

a. Auditory disturbance or physical harm to marine animals through the introduction of anthropogenic noise from the acoustic equipment.

a. Auditory impact on marine animals

Impact type: direct / indirect / cumulative

As noted above, anthropogenic underwater noise is recognised as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa (Williams et al, 2015).

There is no literature specifically addressing the impacts of multibeam bathymetric survey and sub-bottom profiling equipment, though these are not understood to have any known impacts on marine mammals.

As recorded above, the 2004 SCAR Action Group's assessment of the effects of multibeam echo-sounders suggested that a temporary threshold shift effect in marine animals was unlikely, though some minor displacement of animals in the immediate vicinity of the ship (*i.e.* within a few metres) was possible (Boebel et al., 2005).

The Action Group's assessment of the effects of a 3.5kHz sub-bottom profiler was that they were likely to be similar to other single beam systems *i.e.* low risk to individuals and populations. Risks to individuals [in the immediate vicinity of survey] were considered to be slightly higher because of the wider beam width and lower frequency content (Boebel et al., 2005).

The likelihood of encounters between vessels operating in Pine Island Bay during the ITGC and marine wildlife is difficult to assess. Whilst there are no population estimates for key marine species (cetaceans and pinnipeds) in the Pine Island Bay area, the density of such species is likely to be lower than other areas of Antarctica.

Treatment and Mitigation:

- Acoustic surveys will be undertaken in strict conformity with NSF operating protocols;
- Prior to the initiation of the surveys, a watch will be undertaken to ensure that no marine animals are obviously close to the ship. If individuals or groups of cetaceans or pinnipeds are observed, the survey will be delayed.

Record keeping:

In the unlikely event that a significant disturbance event is observed, the nature of the disturbance and the species involved will be recorded and reported.

Permanently deployed intra- and sub-ice shelf instruments

The installation of strings of sensors and instruments within and below the ice shelf will have the following environmental impacts:

a. Pollution of the sub-ice shelf / marine environment as a consequence of the irrecoverability of the cables and sensors.

a. Pollution of ice-shelf and marine environment

Impact type: direct / cumulative

The cables and sensors deployed into and beneath the Thwaites Glacier and ice-shelf will not be recoverable. The hot water drilled hole is expected to seal within a matter of weeks following deployment of the instruments. Attempting to recover the cables and sensors would require a significant amount of resource (time, fuel for drilling, camping and logistical support) with very little likelihood of success.

The equipment will remain in the ice until it breaks away from the glacier as an iceberg. When the ice melts the cables and instruments will ultimately end up in the sea at an unpredictable location where they will decay over many years or decades and cumulatively add to the lost or unrecovered equipment that has accumulated in the Southern Ocean.

Treatment and Mitigation:

- The materials used to construct the sensors have been selected for low toxicity.

Record keeping:

The approximate quantities of unrecoverable materials will be recorded and reported.

7.4.2 Direct Sampling

As recorded above, the majority of the data collected through the ITGC will be from non-invasive means. Some direct sampling will take place through the GHC and THOR projects. Samples to be collected include geological samples (surface samples and rock cores); marine sediment cores and ice cores.

7.4.2.1 Geological sampling

Geological drilling / coring – Winkie Drill

The use of the Winkie drill system to collect sub-surface geological samples will or may result in the following environmental impacts:

a. Potential release of hazardous substances to the environment (*i.e.* drilling fluid Isopar K and/or ethanol);
b. Removal of geological material;
c. Disturbance of wildlife (bird colonies) through the noise generated by the drilling system;
d. Emissions to air through burning fossil fuel to run the drilling system;
e. Pollution of the local snow / ice environment if an accidental spill of fuel or drilling fluid occurs *e.g.* whilst refuelling the generators to power the drill system, or when handling the drilling fluid drums.

a. Potential release of hazardous substances

Impact type: direct

Isopar K will be used as a drilling fluid for the Winkie drill. The drill system is effectively a closed system, though some loss of fluid (normally less than 10%) may occur. Losses may occur due to evaporation from the filtration system and containment berm, leakage and transfer losses, and incomplete bailing. Under normal conditions, less than 1 to 2 litres of fluid are expected to remain in the hole after drilling is complete.

In some circumstances it is possible that drilling fluid is lost into unsealed fractures in the rock; although under expected conditions at the identified drilling sites it is likely that fractures will be ice-filled and therefore sealed. If fractures are present it is possible that this could result in loss of up to 50% of the fluid in the system at the time. Such loss would be into the subsurface geology. Releases at the surface are unlikely (with the exception of small evaporative losses), as the fluid handling system will be in a secondary containment berm.

The material safety data sheet for Isopar K records that it biodegrades at a moderate rate and does not persist in the environment. It is rapidly degraded in air. Because of its low solubility in water and volatility, acute or chronic toxicity to aquatic organisms is not expected.

Small quantities of ethanol will be taken to the drilling site, but will only be used to release a stuck drill. This is not normally required. Under normal operating conditions, any ethanol introduced into the drill will also remain within the closed loop system, though potentially small volumes may be lost to the environment into any unsealed fractures in the rock.

Treatment and mitigation:

- Trained and experienced drillers and researchers will operate the equipment;
- Any fluids lost into the environment are likely to be very small volumes and will dissipate into rock fractures below the surface;
- The drilling fluid to be used biodegrades at a moderate rate and does not persist in the environment;
- Spill kits will be available on site if a surface spill does occur.

Record keeping:

Any spills that occur and any significant releases of drilling fluid will be recorded and reported.

b. Physical removal of geological material (cores)

Impact type: direct

The geological sampling will intentionally result in the removal of a number of geological cores from bedrock situated beneath the current snow/ice surface.

The implications of this activity for the environment are minimal and there are few treatment options available.

Treatment and Mitigation:

- Drilling locations will be carefully selected so as to maximise research benefit from the core samples that will be taken.

Record keeping:

All core locations will be recorded for research purposes and will be reported.

c. Noise disturbance to wildlife

Impact type: direct

Human disturbance to wildlife is summarized in the Antarctic Environments Portal by Coetzee and Chown (2014), (www.environments.aq). They note that sustained disturbance can vary significantly, depending upon the species, the location, the time and the nature of the disturbance. Human disturbance to Antarctic wildlife can cause declines in breeding success (Tin et al., 2009; Ellenberg et al., 2007; McClung et al., 2004), and induce physiological stress (McClung et al., 2004; Regel and Putz, 1997) which can cause behavioural changes (Weimerskirch et al., 2002; Engelhard et al., 2002), and could be the cause of direct mortality (Cooper et al., 1994). In some cases, wildlife can become accustomed to human activity and be relatively unaffected by it. Some well-studied populations show no major observable changes following disturbance (Burger and Gochfel., 2007). In other cases, human activities have been shown to cause significant disturbance to wildlife (Cooper et al., 1994; Saraux et al., 2011; Rounsevell and Binns 1991).

Coetzee and Chown (2014) report that an individual animal's response to stress can vary widely as a function of extrinsic factors such as the type of disturbance, its form and its magnitude. Disturbance also varies with intrinsic factors such as the species, colony size and breeding stage, and different individual responses. Few studies have considered all of these factors, making it difficult to draw conclusions or conduct a meta-analysis of the results across the diverse range of studies (de Villiers 2008).

Research to date likely underestimates the potential impacts of human disturbance to wildlife as behavioural responses may obscure more subtle and potentially severe physiological responses (Fowler 1999; Coetzee and Chown, 2016).

It is likely that most drilling activity will take place well away from any known wildlife concentrations. It is possible (though unlikely) that drilling in or near to Mt. Murphy during the 2019/20 season by GHC researchers may be in proximity to snow petrel colonies. Six snow petrel colonies are reported in the Mt. Murphy region (see Section 6.5.2), but the precise locations have not been able to be identified.

Treatment and Mitigation:

- A pre-drilling, visual survey of the area will be undertaken to identify and record any nearby bird colonies;
- A 'ramp up' approach will be adopted if drilling activities are undertaken in proximity to identified bird colonies in which 'new noise' is slowly introduced to allow some time for birds to become accustomed.

Record keeping:

Any observed disturbance events will be recorded and reported.

d. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the drill generators will occur. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates will settle out on the ice/snow surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- All generators will be serviced prior to departure for Antarctica to ensure they run and operate as efficiently as possible;
- Emissions will be minimised by only using the generators when required for drilling purposes.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

e. Accidental spill of hazardous substances including fuel and drilling fluid

Impact type: direct and cumulative

Any accidental spill event that occurs during, for example, the refuelling of a generator could result in fuel being lost into the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- Field fuel volumes will be minimised to the extent practicable;
- All fuel and other hazardous substances will be stored in bunds to the extent practicable and regular checks on the integrity of the drums will be undertaken;
- Spill kits will be available at locations were fuel is stored and transferred;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard field practices.

Record keeping:

Any fuel or other hazardous substances spill event will be recorded and reported.

Geological sampling – surface rock samples

The collection of surface geological samples will or may result in the following environmental impacts:

a. Removal of geological material;
b. Disturbance of wildlife as a result of vehicle activity and the movement of people near concentrations of wildlife;
c. The potential introduction of non-native species to ice-free locations through the landing of people and equipment;
d. The potential relocation of native species between ice-free locations as researchers and their equipment are moved between sites.

a. Removal of geological material

Impact type: direct

The geological sampling will intentionally result in the removal of a number of geological samples from surface locations on island in Pine Island Bay and in-land nunataks.

No existing samples from this part of Antarctica exist that would be available to support the objectives of the GHC research project.

The implications of the geological removal for the environment are minimal and there are few treatment options available.

Treatment and Mitigation:

- Sampling locations will be carefully selected so as to maximise research benefit from the samples that will be taken;
- SCAR's code of conduct for terrestrial scientific field research in Antarctica will be followed.

Record keeping:

All sample locations will be recorded for research purposes and will be reported.

b. Disturbance of wildlife

Impact type: direct

Some geological sampling is planned for small islands in Pine Island Bay, including the Edwards Islands.

As recorded above, aircraft, small boat operations and people on foot all have the potential to cause disturbance among seals leading to changes in their behaviour, physiology and potentially breeding success. The level of impact will vary according to the intensity, duration and frequency of disturbance, the species involved and the phase in their breeding season.

Most species are particularly sensitive to disturbance between late September and early May - the period when Antarctic field operations usually occur (Aircraft Guidelines, 2015).

In general, disturbance effects on Antarctic wildlife appear to have been underestimated suggesting a more precautionary approach to activities in the vicinity of wildlife is required (Coetzee and Chown, 2016).

Treatment and Mitigation:

- Helicopter pilots will be briefed on the risks of disturbance and on the known location of bird and seal colonies in the Pine Island Bay area and instructed to avoid such colonies;
- Helicopter pilots will be provided with a copy of and will be briefed on the Guidelines for the Operation of Aircraft Near Concentrations of Birds noting the proximity of penguin and flying bird colonies in the area;
- Landing sites for helicopters and small boats will be carefully selected to minimise disturbance (without compromising the safety of researchers);
- Small boat landings will be preferred over helicopters if practicable and does not compromise personnel safety;
- The researchers will carefully select routes to geological sampling locations so as to eliminate or minimise any disturbance.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

c. Introduction of non-native species to ice-free locations

Impact type: indirect / cumulative

As recorded above the introduction of non-native species represents one of the most significant threats to biodiversity globally (IUCN, 2018).

There are several reported examples of non-native species introductions and establishments into terrestrial Antarctic environments almost all of which are attributed to human activity (Hughes et al., 2015; Houghton et al., 2016).

Most known Antarctic non-native species have been found within the Antarctic Peninsula region, but some have been reported from other areas of Antarctica (Frenot et al., 2005; Hughes et al., 2015). Changing climate conditions (particularly in West Antarctica) and growing human activity in Antarctica increase the risk of further introductions and expansion of the range of already established non-native species (Chown et al., 2012; Duffy et al., 2017).

Scientists and scientific research equipment have been identified as presenting a particularly high risk of introducing non-native species to Antarctica (Chown et al., 2012).

Treatment and Mitigation:

- All clothing and equipment will be cleaned and inspected prior to deployment in Antarctica;
- Relevant guidance in the CEP's non-native species manual will be followed;
- SCAR's code of conduct for terrestrial scientific research in Antarctica will be followed.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

d. Artificial relocation of native species

Impact type: direct / cumulative

As noted above, there is increasing awareness of regional variations in species abundance and distribution (Terauds and Lee, 2016) and that some ice free locations in Antarctica have distinct flora and fauna (Fraser et al., 2012; Convey et al., 2008; Pugh and Convey, 2008). As noted in Section X above, the Thwaites Glacier / Pine Island Bay area is one of the least sampled areas of Antarctic and knowledge of the terrestrial biodiversity of ice-free locations in this part of the Antarctic is poor (Peat et al, 2007; Helen Peat pers com; Peter Convey pers com).

There is an increasing awareness that Human activities may potentially transfer native Antarctic species to areas within Antarctica where they are not found naturally, which could disrupt established ecosystems and lead to homogenization of the biota (Hughes and Convey, 2010).

Treatment and Mitigation:

- Researchers will be alerted to the risks of relocating biota between ice-free locations and the controls needed to reduce the risk;
- Boots, gaiters, clothing, equipment and bags will be inspected and cleaned (*e.g.* brushed) prior to departure from a site – particularly if relocating directly;
- In situations where researchers return to a camp or ships, the opportunity will be taken to re-check and clean clothing and equipment prior to the next visit to ice-free ground;
- SCAR's code of conduct for terrestrial scientific research in Antarctic will be followed;
- Given the limited knowledge of the biology of some of these ice-free locations, researchers will be provided with some simple guidance material and asked (to the extent practicable) to undertake a basic biological assessment of the sites visited (Appendix A).

7.4.2.2 Marine Sediment Coring and Water Sampling

Marine sediment coring

The collection of marine sediment cores in open water and under ice locations will or may result in the following environmental impacts:

a. The potential introduction of non-native marine species as a result of contaminated coring devices;
b. Pollution of the marine environment through the loss of sampling equipment;
c. Physical disturbance to benthic marine locations.

a. Introduction of non-native marine species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the coring equipment with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the ASV operators (CEP, 2016).
- All sampling equipment will be inspected and cleaned prior to deployment to Antarctica and between deployments if necessary.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

b. Pollution through loss of sampling equipment

Impact type: direct and cumulative

The deployment and recovery of deep-sea benthic sampling equipment carries a degree of risk of loss, through cable breaks, cable snagging (*e.g.* on the winch, resulting in a failure to recover the coring device and the need to cut the cable) or the equipment becoming caught on the seafloor. Successful sampling in the deep sea using equipment at the end of hundreds to thousands of metres of cable is time-consuming and requires special skill (Gage and Bett, 2008). An additional factor in Polar waters relates to the degree of pack ice cover and the potential for pack ice to move into the sampling area during equipment deployment and hampering recovery.

A search of the academic literature suggests that loss of such equipment is rare, with risks reduced through the use of standardised safe operating procedures and techniques (Mudroch and Azcue, 1995).

The accidental loss of benthic sampling equipment would result in direct, though minor impact to the seafloor where the equipment settled and, if unrecoverable, an addition to the range of other (un-quantified) equipment lost to the environment in Antarctic over several decades of marine research.

Treatment and Mitigation:

- Sampling will be undertaken by experienced coring technicians;
- All benthic coring equipment will be carefully deployed according to weather and ice conditions and forecasts;
- Sampling locations will be carefully selected to maximise research benefits;

Record keeping:

Any lost equipment will be recorded and reported.

c. Physical disturbance of the benthic environment

Impact type: direct and cumulative

The deployment of all benthic sampling equipment for the purposes of collecting sediment cores will result in physical disturbance to small areas of the benthos.

Physical disturbance is likely to be highly localised, though multiple benthic locations adjacent to and beneath the ice-shelf are intended to be sampled.

The coring work will result in an immediate and direct disruption to the benthic environment within the (small) footprint of the coring device.

The coring work to be carried out during the ITGC will add to the sampling and coring work undertaken by previous and future research programmes.

Any samples taken at depths up to approximately 500m will be within the zone for iceberg scour (Dowdeswell and Bamber, 2007). Within the ice-berg scour zone it is assumed that the Antarctic benthos never reaches peak maturity and that iceberg scouring is among the five most significant disturbances that any large ecosystem on earth experiences (Gutt and Starmans, 2002). Accordingly, the disruption caused by the coring activity of the ITGC within this zone is likely to be negligible compared to the ongoing 'natural' sediment perturbation that occurs.

Treatment and Mitigation:

- Benthic disturbance from sampling undertaken at depths beyond the keel of icebergs will be unavoidable, though highly localised.
- Sites will be carefully selected to ensure maximum research benefit.

Record keeping:

Records will be maintained of the sites of all coring activity.

Oceanographic profiling and water sampling

The deployment of the CTD / water sampler may result in the following impacts on the Antarctic marine environment:

a. The potential introduction of non-native marine species as a result of biologically contaminated equipment;

b. The potential pollution of the marine environment if the equipment is lost and cannot be recovered.

a. Introduction of non-native marine species

Impact type: indirect / cumulative

As noted above, in a global context the introduction of non-native species is one of the biggest threats to biodiversity.

Any fouling of the CTD / water sampling equipment with marine species from outside of Antarctica presents a risk of transfer of non-native species into the region, particularly if the equipment has been used in other cold water environments.

The likelihood of establishment of a non-native marine species is low; though irreversible if it were to occur. Cumulatively, such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

Treatment and Mitigation:

- Relevant guidance information available through the Non-Native Species Manual developed by the Committee for Environmental Protection, and in particular the 'guiding principles' of the Manual, will be made available to and adopted by the ASV operators (CEP, 2016).
- All sampling equipment will be inspected and cleaned prior to deployment to Antarctica and between deployments if necessary.

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

b. Pollution through loss of sampling equipment

Impact type: direct and cumulative

The deployment and recovery of deep-sea benthic sampling equipment carries a degree of risk of loss, through cable breaks, cable snagging (*e.g.* on the winch, resulting in a failure to recover the coring device and the need to cut the cable) or the equipment becoming caught on the seafloor. Successful sampling in the deep sea using equipment at the end of hundreds to thousands of metres of cable is time-consuming and requires special skill (Gage and Bett, 2008). An additional factor in Polar waters relates to the degree of pack ice cover and the potential for pack ice to move into the sampling area during equipment deployment and hampering recovery.

A search of the academic literature suggests that loss of such equipment is rare, with risks reduced through the use of standardised safe operating procedures and techniques (Mudroch and Azcue, 1995).

The accidental loss of the CTD / water sampling equipment would result in direct, though minor impact to the seafloor where the equipment settled and, if unrecoverable, an addition to the range of other (un-quantified) equipment lost to the environment in Antarctic over several decades of marine research.

Treatment and Mitigation:

- Sampling will be undertaken by experienced technicians;
- The CTD / water sampling equipment will be carefully deployed according to weather and ice conditions and forecasts.

Record keeping:

Any lost equipment will be recorded and reported.

7.4.2.3 Ice Coring

Ice coring

The short, surface ice cores may result in the following impacts on the Antarctic marine environment:

a. Physical disturbance to the local snow / ice environment;
b. Emissions to air through burning fossil fuel to run the powered version of the Kovacs ice corer;
c. Pollution of the local snow / ice environment if an accidental spill of fuel occurs *e.g.* whilst refuelling the drill motor.

a. Physical disturbance of the snow / ice environment

Impact type: direct

The removal of ice cores in the surface layers of the glacier and / or ice-shelf, will result in physical disturbance at the site of coring.

The ice environment is highly dynamic, and it is likely that the holes created will naturally be removed in a period of days to weeks.

Treatment and Mitigation:

- None required.

b. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the kovacs drill will occur. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates will settle out on the ice/snow surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- The motor for the kovacs drill will be serviced prior to departure for Antarctica to ensure it runs as efficiently as possible;
- Emissions will be minimised by only using the drill when required for research purposes.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

c. Accidental spill of fuel

Impact type: direct and cumulative

Any accidental spill event that occurs during, for example, the refuelling of a generator could result in fuel being lost into the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- Field fuel volumes will be minimised to the extent practicable;
- All fuel will be stored in bunds to the extent practicable and regular checks on the integrity of the containers will be undertaken;
- Spill kits will be available at locations were fuel is stored and transferred;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard field practices.

Record keeping:

Any fuel spill event will be recorded and reported.

7.4.3 Logistical Support Activities

7.4.3.1 Hot water and RAM drilling

As discussed above, a range of instruments and sensors will be deployed into or beneath the glacier and / or ice-shelf. To achieve these deployments holes will be drilled in the ice using either a hot water drill system or a RAM drill.

Hot water and RAM drilling

These ice drilling systems will or may result in the following impacts:

a. Physical disturbance to the ice / snow environment;
b. Emissions to air through burning fossil fuel to run the powered version of the Kovacs ice corer;
c. Pollution of the local snow / ice environment if an accidental spill of fuel occurs *e.g.* whilst refuelling the drill motor.
d. Disturbance of wildlife if operating near concentrations of wildlife.

a. Physical disturbance to the ice / snow environment

Impact type: direct

The drilling of holes in and through the ice will result in physical disturbance at the site of drilling.

The ice environment is highly dynamic, and it is likely that the holes created will naturally be removed in a period of days to weeks.

Treatment and Mitigation:

- None required.

b. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the drill systems will occur. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates will settle out on the ice/snow surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- The generators that are used to power the drill systems will be serviced prior to departure for Antarctica to ensure they run as efficiently as possible;
- Emissions will be minimised by only using the drill systems when required for research purposes.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

c. Accidental spill of fuel

Impact type: direct and cumulative

Any accidental spill event that occurs during, for example, the refuelling of a generator could result in fuel being lost into the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- Field fuel volumes will be minimised to the extent practicable;
- All fuel will be stored in bunds to the extent practicable and regular checks on the integrity of the containers will be undertaken;
- Spill kits will be available at locations were fuel is stored and transferred;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard field practices.

Record keeping:

Any fuel spill event will be recorded and reported.

d. Disturbance of wildlife

Impact type: direct

It is highly unlikely that the hot water drill or the RAM drill will be used in proximity to wildlife. Drilling locations will be on the Thwaites Glacier or ice-shelf some considerable distance from known locations of wildlife.

Treatment and Mitigation:

- In the very unlikely event that the drilling equipment is used near to wildlife, 'new noise' will be slowly introduced (ramping up) to allow the wildlife to become accustomed.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

7.4.3.2 Vehicle, vessel and aircraft operations

Section 4.4.2 describes the range of vehicles, vessels and aircraft that will be used to support the research throughout the ITGC campaign.

Over-snow vehicles and traverses

The use of a range of over-snow vehicles (Pisten Bullys, skidoos, caterpillars etc), will or may result in the following impacts:

a. Emissions to air through burning fossil fuel to run the vehicles;
b. Pollution of the local snow / ice environment if an accidental spill of fuel occurs *e.g.* whilst refuelling the vehicles.
c. Disturbance of wildlife if operating near concentrations of wildlife.

a. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the vehicles will occur each season throughout the ITGC campaign. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates will settle out on the ice/snow surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- The vehicles engines will all be serviced prior to departure for Antarctica to ensure that they run as efficiently as possible;
- Emissions will be minimised to the extent practicable without compromising the safety of personnel.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

b. Accidental spill of fuel

Impact type: direct and cumulative

Any accidental spill event that occurs during, for example, the refuelling of a vehicle could result in fuel being lost into the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- Field fuel volumes will be minimised to the extent practicable;
- All fuel will be stored in bunds to the extent practicable and regular checks on the integrity of fuel containers will be undertaken;
- Spill kits will be available at locations were fuel is stored and transferred including on traverses;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard field practices.

Record keeping:

Any fuel spill event will be recorded and reported.

c. Disturbance of wildlife

Impact type: direct

It is highly unlikely that over-snow vehicles will be used in proximity to wildlife. All vehicle activity will be on routes or at locations that are some considerable distance from known locations of wildlife.

Potentially skidoos might be used in and around Mt. Murphy where colonies of snow petrels are known to occur, but the risk of disturbance is considered to be low.

Treatment and Mitigation:

- In the very unlikely event that vehicles are used near to wildlife, care will be taken to minimise disturbance by careful route planning and avoidance of engine revving etc..

Record keeping:

Any disturbance events that do occur will be recorded and reported.

Aircraft activity

The use of fixed and rotary wing aircraft to support the planned research programme, may result in the following impacts on the environment:

a. Emissions to air through burning fossil fuel to run the vehicles;
b. Pollution of the local snow / ice environment if an accidental spill of fuel occurs *e.g.* whilst refuelling the vehicles.
c. Disturbance of wildlife if operating near concentrations of wildlife.

a. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the aircraft will occur each season throughout the ITGC campaign. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates will settle out on the ice/snow surface.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- The aircraft engines will all be serviced prior to departure for Antarctica to ensure that they run as efficiently as possible;
- Emissions will be minimised to the extent practicable without compromising the safety of personnel.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

b. Accidental spill of fuel

Impact type: direct and cumulative

Helicopters are unlikely to be refuelled ashore as they will operate from ships. Twin Otters will be refuelled in the field.

Any accidental spill event that occurs during the refuelling of aircraft could result in fuel being lost into the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- Field fuel volumes will be minimised to the extent practicable;
- All fuel will be stored in bunds to the extent practicable and regular checks on the integrity of fuel containers will be undertaken;
- Spill kits will be available at locations were fuel is stored and transferred including on traverses;
- Fuel spill response training will be provided to those undertaking fuel handling in the field;
- Refuelling operations will be undertaken by a minimum of two people using spill mats, absorbent wipes etc. in accordance with standard field practices.

Record keeping:

Any fuel spill event will be recorded and reported.

c. Disturbance of wildlife

Impact type: direct

Rotary wing aircraft may be used in Pine Island Bay to deploy researchers and equipment (*e.g.* expendable micro-profilers). This could result in aircraft operating in proximity to wildlife. The risk assessment and treatment options for such activity has been considered in the relevant sub-sections above.

Twin Otter aircraft are unlikely to operate near concentrations of wildlife. The exception may be during the aero-geophysical survey which may bring the aircraft within the vicinity of Mt. Murphy where snow petrels colonies are known.

Treatment and Mitigation:

- Pilots will be instructed to avoid colonies of wildlife in the area;
- Guidelines for the Operation of Aircraft Near Concentrations of Birds will be followed where relevant.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

Vessel activity

Several vessels will be used to support the planned research programme throughout each season of the ITGC campaign, which may result in the following impacts on the environment:

a. Emissions to air through burning fossil fuel to run the vessels;
b. Disturbance of wildlife including marine wildlife;
c. Pollution of the marine environment through the production of general waste, food waste, grey water and sewage;
d. Water turbulence potentially causing sediment disturbance or coastal erosion;
e. The potential introduction of non-native marine species through hull fouling or ballast water exchanges;
f. Pollution of the marine environment if an accidental spill of fuel occurs *e.g.* through equipment failure or if fuel tanks are compromised.

a. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the vessels will occur each season throughout the ITGC campaign. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates may settle out on nearby ice/snow surfaces.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

Few treatment options are available if vessels are to be used to support the research programme.

- All vessels will operate using marine gas oils and none use heavy fuel oils;
- Fuel use will be minimised to the extent possible by maximising operations in open water and minimising the extent to which the vessel is required to 'work ice', which inevitably requires more power and burns more fuel.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

b. Disturbance of wildlife

Impact type: direct / cumulative

Anthropogenic underwater noise is now recognised as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of taxa (Williams et al, 2015). Underwater noise from shipping is increasingly recognised as a significant and pervasive pollutant with the potential to impact marine ecosystems on a global scale (Clark et al., 2009; Merchant et al., 2015; Williams et al., 2014).

The impact of marine noise varies greatly depending upon the source, frequency, duration, marine conditions, location and in terms of its impact on different taxa.

The operation of the vessels in support of the ITGC campaign will introduce noise as a result of the vessel's engines, which will dissipate through air and water.

The operation of the vessels may result in encounters with and disturbance (both audible and visual) to individuals or groups of marine mammals, cetaceans or foraging penguins and sea birds. This may include for example, disturbance of seals resting on ice floes. It is likely that the species concerned will adopt an avoidance approach and move away from the vessel.

Such disturbance events may also be cumulative in combination with other disturbance events that may occur (either to the same individuals or the same species) during the 2018/19 season and in past and future seasons.

The noise from the vessels will add to additional anthropogenic noise sources during the ITGC campaign across several seasons. The cumulative impacts of marine noise from these multiple sources are considered in Section 7.6 below.

Treatment and Mitigation:

- In most situations the vessels will operate some distance from shore and disturbance of any wildlife on land is very unlikely to occur;
- If large groups of marine mammals are encountered when the vessel is underway, the vessel will proceed cautiously including seeking to slow down and avoid such groups so as to minimise interference if safe and practicable to do so.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

c. Pollution of the marine environment from waste generation and vessel discharges

Impact type: direct and cumulative

Several waste types will be produced on-board the various vessels including human waste; food waste; general waste and chemical waste. The volumes of each have not been estimated as no wastes (other than human waste) will be released in the Antarctic.

Only human waste / grey water will be discharged through each of the vessel's sewage management systems.

The release of treated waste water from the vessels will have a direct, though negligible effect on the immediate marine environment. The quality of the discharged water is high, and dispersion and dilution is likely to be rapid.

The release of treated waste water will add to the past and on-going, though likely less than minor and transitory release of waste water from ships in the Southern Ocean.

Mitigation:

- No wastes will be disposed of in the Antarctic Treaty area. All wastes (other than human waste / grey water and explosives packaging) will be retained on-board and disposed of when the vessels return to ports outside of Antarctica in accordance with BAS and USAP waste management procedures.
- The vessel's sewage treatment systems are all compliant with MARPOL, the requirements of IMO Resolution MEPC.159(55) 2006 on the implementation of effluent standards and performance tests for sewage treatment plants, and the requirements of Annex IV to the Protocol.

d. Water turbulence

Impact type: direct

The movement of ships through water may have an impact on the marine environment including through the generation of waves, propeller-induced turbidity and aeration in the water column, ship's wash contributing to coastal erosion, and the re-suspension of sediments (Ellis et al., 2005).

Vessels operating in support of the ITGC campaign will do so exclusively in deep water such that resuspension of sediments will not occur. Even near-coastal operations will be adjacent to the edge of ice-shelves in water many tens to hundreds of metres deep. Consequently, water turbulence, wash and waves from the ships will have limited impact, other than on the already highly mobile sea / pack ice.

Treatment and Mitigation:

- The vessels will operate at some distance from shore and in deep water. Turbulence will occur through normal operations of the vessels, but this will have negligible consequences for the ocean / ice environment of the Amundsen Sea.

e. Potential introduction of non-native marine species

Impact type: indirect and cumulative

Shipping is recognised as a major vector for the global transfer of non-native marine species. Marine species are routinely transferred through ballast water, hull fouling, in sea chests and on ancillary equipment such as launches, rescue boats, anchors, ropes etc. (Coutts and Dodgshun, 2007; Hewitt et al., 2009).

Although invasions to high-latitude terrestrial ecosystems are now well described (Frenot et al., 2005; Hughes et al., 2015), the same is not true for marine systems. Recent studies have suggested some potential mechanisms for marine introductions to Antarctic coastlines including with rafts of marine debris (Barnes and Fraser, 2003) and on vessel hulls (Lewis et al., 2003, 2004; Hughes and Ashton, 2016). Together, these reports indicate that, despite the apparent isolation of the Southern Ocean, marine introductions can occur, though to date only a single non-native species establishment has been recorded from within the Antarctic marine environment (Clayton et al., 1997) though surveillance and monitoring of the Antarctic marine environment and marine vectors remains extremely limited (Hughes and Ashton, 2016).

Increasing marine traffic, including private yachts and military, national operator, fishing and tourist vessels, in the waters around Antarctica may increase the risk of non-native species introductions (Hughes and Ashton, 2016)).

If marine species were introduced the indirect impacts would include potential competition with native species as well as a reduction in the research value at locations 'contaminated' with marine species that have been artificially introduced to the region.

Cumulatively such an occurrence would be further evidence of human induced pressures on the Antarctic environment and Southern Ocean.

The risk of introducing non-native marine species to the Amundsen Sea area is considered to be low. All vessels will be operating in deep water which reduces the likelihood of introduced species (which are more likely to be shallow water algal and invertebrate species) establishing. Further, the abrasive action of any already-encountered ice is likely to have acted so as to strip away most of any fouling (Lewis et al., 2004).

It is noted that the International Maritime Organisation has adopted 'Guidelines for the control and management of ships' biofouling to minimise the transfer of invasive aquatic species' through its Marine Environment Protection Committee in July 2011 (Resolution MEPC.207(62)). However, these guidelines contain no specific measures regarding fouling management in polar locations.

The IMO has also adopted ballast water management guidelines for use within Antarctic waters (Resolution MEPC.163(56); July 2007). The ATCM has also adopted 'Practical guidelines for ballast water exchange in the Antarctic Treaty Area' (Resolution 3 (2006)).

Mitigation:

- All vessels will carry a Ship Sanitation Certificate
- On-board controls will be undertaken in accordance with each national programme's standard protocols and procedures *e.g.* BAS Biosecurity Regulations
- Any ballast water exchanges that occur will be in accordance with the Ballast Water Convention and the ATCM's Ballast Water Guidelines (Resolution 3 (2006)).

Record keeping:

Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported.

f. Pollution of the marine environment through an accidental release of fuel

Impact type: direct, indirect and cumulative

In the extremely unlikely event of significant fuel-related equipment failure or a vessel incident that results in a breach of a vessel's fuel storage tanks, marine gas oil could be released to the marine environment. This may result in some contamination to any wildlife in the immediate vicinity of the incident as well as oil contaminated water and ice.

A release of fuel would have direct consequences for the immediate marine environment any wildlife individuals that could be contaminated or ingest fuel-contaminated water or food *e.g.* krill. Indirect impacts may occur on the young of any individuals contaminated *e.g.* through feeding of fuel-contaminated krill. Cumulative impacts would occur in the sense that any pollution would add to past and potentially future pollution events arising from human activities in Antarctica.

Mitigation:

- All vessels operating in support of the ITGC are modern, highly capable Polar class vessel that meet current design and operational standards for operating in Antarctic ice-covered waters. All vessels carry an International Oil Pollution Prevention Certificate in accordance with MARPOL Annex 1 - Regulations for the Prevention of Pollution by Oil - Regulation 6.
- In the extremely unlikely event that a fuel spill does occur, each vessel has an approved ship oil pollution emergency plan (SOPEP) in accordance with Annex I of MARPOL 73/78. This includes fuel spill response equipment that can be deployed on the vessel to minimise loss of fuel to the environment in accordance with SOPEP rules.
- The vessels will all be captained by a highly experienced officers with several seasons of Antarctic vessel operations.
- All vessels have access to near-real time medium- and high-resolution satellite imagery for weather and ice charts.

Record keeping:

Records will be maintained of any pollution incidents in the very unlikely event of a spill occurring. This will include recording the location of any spill as well as the volume and type of fuel lost to the environment.

Small boat operations

The use of small boats in the Pine Island Bay area for a range of activities including moving researchers ashore, will or may have the following impacts on the environment:

a. Emissions to air through burning fossil fuel to run the outboard motors;
b. Disturbance of wildlife including seals and penguins ashore and wildlife in the sea.

a. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels to power the boats will occur as the boats are used. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates may settle out on nearby ice/snow surfaces.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- All outboard motors are regularly serviced to ensure they run as efficiently as possible;

- Emissions will be minimised to the extent practicable by only using the boats as and when required to support the research.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

b. Disturbance of wildlife

Impact type: direct / cumulative

The operation of small boats close to the shore may result in encounters with and disturbance (both audible and visual) to individuals or groups of marine mammals, cetaceans or foraging penguins and sea birds. This may include for example, disturbance of seals resting on ice floes. It is likely that the species concerned will adopt an avoidance approach and move away from the vessel.

Such disturbance events may also be cumulative in combination with other disturbance events that may occur (either to the same individuals or the same species) during the 2018/19 season and in past and future seasons.

Treatment and Mitigation:

- Small boats will be operated responsibly at all times by trained and experienced crew;
- Slow approaches will be made to land to minimise disturbance of any wildlife on or near the shore;
- Landing sites will be carefully selected to maximise the safety of researchers being put ashore and minimising any disturbance to wildlife;
- If large groups of marine mammals are encountered when the boat is underway, it will proceed cautiously including seeking to slow down and avoid such groups so as to minimise interference if safe and practicable to do so.

Record keeping:

Any disturbance events that do occur will be recorded and reported.

7.4.3.3 Establishment and operation of field camps

Section 4.4.3 describes the field camps that will be established to support the research throughout the ITGC campaign.

Field camps

The establishment of field camps at multiple locations throughout the ITGC campaign, will or may result in the following impacts:

a. Pollution of the Antarctic environment through the production and release of waste including general and food waste;
b. Pollution of the local snow / ice environment through the disposal of human waste;

c. Emissions to air from the burning of fossil fuels for cooking and heating.

a. Waste production

Impact type: direct and cumulative

All field camps will generate waste including general and food waste.

Annex III to the Protocol requires wastes generated at field camps to be removed to supporting stations or ships to the maximum extent practicable.

Both BAS and USAP have well developed field operating procedures to ensure all general and food wastes are removed from field camps, and that field camps are operated to high environmental and safety standards.

Treatment and Mitigation:

- All field camps (and traverses) will be supplied with a copy of the relevant BAS or USAP field manuals and / or waste management handbooks;
- All general and food waste will be packed in appropriate containers and returned to ships or supporting stations on completion of the field season or during aircraft reliefs;
- Good camp management practices will be employed to minimise the risk of any items being blown away during windy / stormy weather
- All ITGC camps will be on snow / ice and not on ice free ground which will minimise overall impacts.

b. Pollution of snow / ice environment from the disposal of human waste.

Impact type: direct and cumulative

All field camps will generate human waste, and where practicable this will be collected in UN approved containers and removed to a supporting station for disposal.

However, this will not be practicable from all field camps and some disposal of human waste to snow and ice will take place. In such cases human waste will be disposed into ice pits and covered with snow. Waste disposed to ice will be entrapped until it is released into the marine environment over a period of years to decades.

Estimates of volumes of human waste likely to be disposed to ice have not been calculated as the numbers of camps (and the numbers of people at those camps) are not known at the time of preparation of this EIA.

Treatment and Mitigation:

- Human waste will be removed from field camps for disposal at supporting stations and ships to the fullest extent practicable.

c. Emissions to air from burning fossil fuels

Impact type: direct and cumulative

Emissions from the burning of fossil fuels for cooking at heating at field camps will occur. The emission of gases will pass into the atmosphere and add to regional and global atmospheric pollution, and any particulates may settle out on nearby ice/snow surfaces.

An emissions assessment for the ITGC as a whole is included in Section 7.6 below.

Treatment and Mitigation:

- All cooking and heating equipment will be cleaned and serviced to ensure it runs as efficiently as possible;
- Emissions will be minimised to the extent practicable by only using cooking and heating equipment as and when required.

Record keeping:

Records will be maintained of the volumes and types of fuel burnt and carbon emissions will be included in national programme emission inventories.

7.4.3.4 Fuel management

Section 4.4.4 describes the methods for transporting and storing fuel in the field throughout the ITGC campaign. As noted above, the ITGC will be a 'fuel hungry' programme and the movement, storage and transfer of large volumes of fuel carries the risk of spills.

Air drop of fuel at Sky Blu or SB9

The airdrop of fuel drums at either Sky Blu or SB9 by an RAF C-130, will or may result in the following impacts:

a. Pollution of the Antarctic environment through the rupture of one or more drums on impact;
b. Pollution of the local snow / ice environment with materials and items used to package the fuel for the air-drop, including wood and carboard, strops, netting and parachutes.

a. Pollution due to a fuel spill

Impact type: direct and cumulative

Any airdrop of fuel carries some risk of spillage due to one or more ruptured or damaged fuel drums.

If any drums are damaged fuel will be lost onto the local snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- The airdrop will be overseen by highly trained and experienced RAF personnel;

- All fuel drums are packed in collapsible carboard and wooden pallets to cushion the impacts;
- The airdrop will take place onto relatively soft snow, which will minimise the likelihood of drums being damaged;
- Ground staff trained in fuel spill response will monitor the airdrop and will be able to respond quickly if a fuel drum is seen to be leaking;
- A spill response kit will be stationed with the ground staff.

Record keeping:

In the unlikely event that a fuel spill occurs, the amount and type of fuel spilt will be recorded and reported.

b. Pollution of the local environment with waste materials from the airdrop

Impact type: direct and cumulative

To ensure all fuel drums are delivered intact they are packed onto pallets and protected with wood and carboard to cushion the impact, and held together with netting and strops.

The descent rate of the packed drums is controlled by a parachute. All of this additional material will need to be managed at the site of the airdrop to avoid it being lost to the Antarctic environment.

Treatment and Mitigation:

- All materials used to pack the fuel drums will be collected by ground staff at the site of the airdrop. Packing materials will be either reused or returned to Rothera for waste disposal. Netting, strops and parachutes will be collected, packed and returned to the RAF.

Record keeping:

In the unlikely event that items are lost to the environment they will be recorded and reported.

Storage of fuel at various locations in the field

Several fuel caches will be established in the field to support the ITGC, which will or may result in the following impacts:

a. Pollution of the Antarctic environment through the rupture of or leakage from one or more fuel containers.

a. Pollution due to a fuel spill

Impact type: direct and cumulative

Fuel will be stored and handled in the field in a variety of containers including small and large fuel bladders, 205 litre drums and smaller hand carried cannisters. All fuel will be stored on snow or ice and not on ice-free ground.

Once a depot is left unattended for the winter, any subsequent fuel leak could potentially result in near-complete emptying of a bladder and the loss of more than 5,000 litres of fuel into the adjacent snowpack.

Failure to secure bladder vents correctly would result in fuel loss during the winter driven by the weight of snow accumulation. Careless digging to remove snow around the bladders could also cause a tear.

If spills were to occur fuel would leak into the snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Treatment and Mitigation:

- All fuel management in the field will be undertaken to well developed and documented field fuel management procedures by BAS and USAP;
- Dedicated fuel handlers ('fuelies') will be stationed at large volume fuel depots;
- Whilst people are on site, the fuel caches will be regularly checked for leaks;
- Field fuel will be bunded to the extent possible. Large fuel storage bladders will be bunded including for overwinter storage;
- Fuel spill kits will be available at every fuel cache. These will include a range of repair materials to deal with partial tears or weeps including 'clam shells' (which can seal a small tear in a bladder), sealing patches and glues;
- Spare bladders will be held at all fuel depots where fuel is stored in bladders. Overpack drums will be held at all sites where large fuel drums are being stored;
- Digging in and around fuel bladders will only be undertaken using plastic-bladed shovels;
- Documented 'close down' procedures will be followed prior to overwintering the fuel. Dry-break couplings on fuel bladders will be backed up by gate valves on all fittings;
- Fuel spill response training will be provided top key personnel prior to departure to Antarctica.

Record keeping:

In the unlikely event that a fuel spill occurs, the amount and type of fuel spilt will be recorded and reported.

Ship to shore transfer of fuel and movement of fuel in bladders

The transfer of fuel from ship to shore and the transport of fuel by traverse in bladders will or may result in the following impacts on the environment:

a. Pollution of the Antarctic environment through the rupture of or leakage from one or more fuel containers or fuel hoses.

a. Pollution due to a fuel spill

Impact type: direct and cumulative

Fuel bladders will be filled directly from the RRS Ernest Shackleton and HMS Protector at the start of the ITGC campaign in January 2019. The transfer of fuel from a vessel to the shore carries the risk of a spill, through for example a split hose or poor coupling.

The transport of fuel in bladders on the traverse carries the risk of a spill from a split or weeping bladder.

If spills were to occur fuel would leak into the snow / ice environment. As recorded above, any fuel or liquid spilt on snow and ice is challenging to recover and can penetrate quickly into the firn layer.

If a spill event were to occur, any unrecoverable liquid will add to previous fuel spill events that have occurred in Antarctica.

Pollution of the Antarctic environment through the rupture of or leakage from one or more fuel containers.

Treatment and Mitigation:

- Ship to shore fuel transfer (filling of bladders) will be carefully managed and supervised with observers deployed to monitor for leaks and spills;
- All joint connections are self-sealing Avery Hardoll couplings to reduce the risk of spills;
- Delivery vessel scuppers are open during refuelling and any leak ship-side will result in fuel retention on-board;
- All fuel management in the field will be undertaken to well developed and documented field fuel management procedures by BAS and USAP;
- BAS and USAP have many seasons of experience in transporting fuel using fuel bladders;
- BAS and USAP traverse manuals / handbooks include guidance on the management and towing of bladders and will be followed at all times;
- BAS and USAP have established oil spill contingency plans for traverse operations;
- The fuel bladders have been tried and tested in Antarctica with no failures to date;
- Fuel bladders are carefully managed and their age, use and condition is routinely monitored and recorded;
- Bladders will be inspected regularly for any sign of leaks;
- A fuel spill kit will travel with the bladders. These include a range of repair materials to deal with partial tears or weeps including ‘clam shells’ (which can seal a small tear in a bladder), sealing patches and glues;
- A spare bladder will travel on all traverses and can be used for fuel transfer in case of a leak.

Record keeping:

In the unlikely event that a fuel spill occurs, the amount and type of fuel spilt will be recorded and reported.

7.5 Summary and evaluation of impacts

Section 7.4 identifies the potential (direct, indirect and cumulative) impacts of the ITGC campaign and the various activities to be undertaken. This section evaluates the identified potential impacts by taking into account the three levels of significance identified in Article 8(1) of the Protocol.

In order to evaluate the significance of a given potential impact, the spatial extent, duration, severity (which also includes a level of reversibility) and likelihood of the identified potential impacts are considered so as to evaluate the overall significance of the potential impact of each activity.

Table 6 outlines the assessment criteria and definitions that have been used when evaluating the spatial extent, duration, intensity and likelihood of the identified potential impacts for the environmental elements (table and methodology modified from Oerter, 2000).

In each case the spatial extent, duration, severity and likelihood are scored 1 to 4 depending on whether each is considered to be 'low', 'medium', 'high' or 'very high'. An overall risk score (before and after treatment) is then calculated as follows:

Risk score = severity score x duration score x severity score x likelihood score

The risk score determines whether the overall risk level is 'low', 'medium', 'high' or 'very high' as set out in table 6.

<table>
<tr><th>Risk score</th><th>Risk level</th><th>Description</th><th>Ref Article 8(1) of the Protocol</th></tr>
<tr><td>1 to 15</td><td>Low</td><td>Acceptable under most circumstances. Impact likely to be managed through normal operating procedures.</td><td>Less than minor or transitory</td></tr>
<tr><td>16 to 35</td><td>Medium</td><td>May be acceptable under certain circumstances. Impact requires ongoing monitoring and possible further treatment.</td><td>No more than minor or transitory</td></tr>
<tr><td>36 to 143</td><td>High</td><td>Unacceptable in most circumstances. Senior Management to be notified. Further treatment options must be explored.</td><td rowspan="2">More than minor or transitory</td></tr>
<tr><td>144 to 256</td><td>Very High</td><td>Unacceptable. Senior management to be alerted. Significant further treatment must be explored. Only senior management can approve proceeding if risk cannot be further treated to reduce risk level.</td></tr>
</table>

Table 6. Risk assessment criteria.

		Criteria for assessment			
Impact	***Environment Element***	***Low (1)***	***Medium (2)***	***High (3)***	***Very High (4)***
SPATIAL EXTENT OF IMPACT Area or volume where changes are likely to occur	***Freshwater Marine Terrestrial Atmosphere***	*Local extent* — *Confined to the site of the activity.*	*Partial extent* — *Some parts of an area are partially affected.*	*Major extent* — *A major sized area is affected.*	*Entire extent* — *Large-scale impact; causing further impact.*
	Flora and Fauna	*Confined disturbance of fauna and flora within site of activity, e.g. individuals affected.*	*Some parts of the community are disturbed.*	*Major disturbance in community, e.g. breeding success is reduced.*	*Impairment at population level.*
DURATION OF IMPACT Period of time during which changes in the environment are likely to occur	***Freshwater Marine Terrestrial Atmosphere***	*Short term* — *Several weeks to one season; short compared to natural processes.*	*Medium term* — *Several seasons to several years; impacts are reversible.*	*Long term* — *Decades; impacts are reversible.*	*Permanent* — *Environment will suffer permanent impact.*
	Flora and Fauna	*Short compared to growth period/ breeding season.*	*Medium compared to growth/ breeding season.*	*Long compared to growth/ breeding season.*	*Permanent*
SEVERITY OF IMPACT A measure of the amount of change imposed on the environment due to the activity	***Freshwater Marine Terrestrial Atmosphere***	*Minimal Affect* — *Natural functions and processes of the environment are minimally affected. Reversible.*	*Affected* — *Natural functions or processes of the environment are affected but are not subject to long-lasting changes. Reversible.*	*High* — *Natural functions or processes of the environment are affected or changed over the long term. Reversibility uncertain.*	*Irreversible* — *Natural functions or processes of the environment are permanently disrupted. Irreversible or chronic changes.*
	Flora and Fauna	*Minor disturbance. Recovery definite.*	*Medium disturbance. Recovery likely.*	*High levels of disturbance. Recovery slow and uncertain.*	*Very high levels of disturbance. Recovery unlikely.*
LIKELIHOOD *Chance of the occurrence of the impact*	***All elements***	*Should not occur under normal operation and conditions.*	*Possible but unlikely.*	*Likely to occur during span of project. Probable.*	*Certain to occur / unavoidable.*

Table 7. Assessment criteria for evaluating the spatial extent, duration, intensity and probability of the potential environmental impacts (modified from Oerter, 2000).

Table 1.Evaluation of the potential environmental impacts of the Expedition activities on the Antarctic environment.

						Pre-treatment risk assessment						Post-treatment risk assessment					
Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
	Research Activities																
	Deployment of Data Collection Instruments and Equipment																
	Glaciological Survey																
1	Active seismic measurements - explosives	**GHOST, MELT, TARSAN, TIME**	Detonation of explosives at depth within the ice and on the ice/snow surface	Contamination / residue at site of detonation	Direct	1	2	1	4	8 Low	• Some reduction in the total amount of explosives to be used will be achieved by using a vibroseis source for some of the survey work • Some larger items of debris may be recoverable if observed	1	2	1	4	8 Low	Less than minor or transitory
			Spill / release of battery acid from recording equipment on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Equipment will only be operator controlled and will not be left unattended • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	1	1	1	1 Low	Less than minor or transitory
			Explosives packaging (mostly cardboard) cannot be removed from site due to constraints on aircraft transportation	Open burning of packaging leading to pollution of local snow / ice environment and cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	2	3	6 Low	• This is the only practicable option for dealing with waste explosives packaging • Impact of burning the packaging minimised by using small pit dug in the snow • Only small quantities are burned at a time • Fire is continuously monitored • Once completed, the pit is re-covered with fresh snow • Management and use of explosives to be undertaken in accordance with the BAS and US Explosive's Code of Conduct - *NB: the UK and U.S. guidance material is being rationalised to ensure common standards are employed during the ITGC* The volumes of excess explosives will be minimised by thorough calculations of the amounts required.	1	1	2	3	6 Low	Less than minor or transitory
			Energy release in the form of noise (particularly if the explosion occurs close to the ice surface)	Disturbance of nearby wildlife	Direct	2	1	2	3	12 Low	• Detonations at depth within the ice will not produce noise that will cause any disturbance • Active seismic work, including surface detonations, will be undertaken at considerable distances from known colonies of wildlife	1	1	2	1	2 Low	Less than minor or transitory
			Energy release in the form of heat	Melting of ice and snow	Direct	2	1	1	3	6 Low	• Heat impacts will be highly constrained to the immediate area of detonation.	1	1	1	2	2 Low	Less than minor or transitory
2	Active seismic measurements - Vibroseis	**GHOST**	Noise emissions from the running of the vibroseis equipment	Disturbance of nearby wildlife	Direct	2	1	2	3	12 Low	• Vibroseis measurements will be undertaken at remote locations on the Thwaites Glacier and at considerable distance from any known wildlife colonies	1	1	2	1	2 Low	Less than minor or transitory
			Fuel use for powering equipment resulting in emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	2	4	8 Low	• Emissions will be minimised by restricting running time as far as is practicable • All equipment will be serviced prior to deployment in Antarctica to ensure it operates efficiently	1	1	2	4	8 Low	Less than minor or transitory
			Accidental spills of fuel *e.g.* during re-fuelling operations	Pollution of local snow / ice environment	Direct / Cumulative	1	2	1	3	6 Low	• Field fuel management will be undertaken in accordance with BAS / USAP field operations manuals • Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored fuel to check for leaks / spills • Fuel spill response training for at least one member of the team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	2	4 Low	Less than minor or transitory

						Pre-treatment risk assessment						Post-treatment risk assessment					
Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
3	Passive seismic measurements	**GHOST, TIME**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
			Irrecoverability of equipment *e.g.* due to power failure and build-up of snow cover over the instruments	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	3	24 Medium	• All deployed instruments will be GPS marked and flagged • Equipment and instrumentation will be recovered to the fullest extent practicable Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	2	16 Medium	No more than minor or transitory
4	Magnetotelluric measurements	**GHOST**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	1	1	2	2 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Equipment will only be left unattended for a few days, but will be well-marked to assist recovery • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	1	1	1	1 Low	Less than minor or transitory
5	Ice-penetrating radar survey	**GHC, GHOST, TARSAN**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Equipment will only be operator controlled and will not be left unattended • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
6	Installation of year-round glaciological monitoring equipment - ApRES instruments	**MELT**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
			Irrecoverability of equipment *e.g.* due to the inability to locate the deployed equipment the following season	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	3	24 Medium	• All deployed instruments will be GPS marked and flagged • Equipment and instrumentation will be recovered to the fullest extent practicable Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	3	12 Low	Less than minor or transitory

						Pre-treatment risk assessment						Post-treatment risk assessment					
Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
7	Installation of year-round glaciological and oceanographic monitoring equipment including AMIGOS III instruments	**MELT, TARSAN**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
			Irrecoverability of in- and beneath-ice instruments / sensors / cables due to them being 'frozen in'	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	4	32 Medium	• All deployed instruments will be GPS marked and flagged • Equipment and instrumentation will be recovered to the fullest extent practicable • Construction materials have been selected for low toxicity and degradability • Impact of attempting to recover items frozen into the ice shelf is likely to exceed impact of leaving it in place Records will be maintained of approximate quantities and types of unrecoverable equipment and reported through standard BAS / USAP reporting procedures.	1	4	1	4	16 Medium	No more than minor or transitory
8	Gravimetric measurements	**TARSAN**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	1	1	2	2 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Equipment will only be operator controlled and will not be left unattended • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	1	1	1	1 Low	Less than minor or transitory
9	Installation of tiltmeters	**MELT**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Equipment will only be deployed for short-term (within season) and will not be left to over winter • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
10	Installation of GPS equipment	**TIME**	Spill / release of battery acid on to local snow / ice environment	Pollution of local snow / ice environment	Direct	1	2	1	2	4 Low	• All equipment is designed for low temperature field use and will be checked prior to deployment to Antarctica • Only sealed lead-acid AGM batteries will be used • Recording equipment is normally contained *e.g.* within an aluminium box Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	1	2 Low	Less than minor or transitory
			Equipment may not be recoverable if it fails and cannot be relocated	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	4	32 Medium	• All deployed instruments will be GPS marked and flagged • Construction materials have been selected for low toxicity and degradability Records will be maintained of approximate quantities and types of unrecoverable equipment and reported through standard BAS / USAP reporting procedures.	1	4	1	4	16 Medium	No more than minor or transitory

						Pre-treatment risk assessment						Post-treatment risk assessment					
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11	Aero-geophysical survey	**BAS Thwaites Aerogeophysical Survey (TAGS)**	Fuel use for aircraft flights - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	2	1	2	4	16 Medium	• Aircraft will be fully serviced prior to use during the ITGC • Emissions will be minimised by restricting aircraft survey work as far as is practicable	2	1	1	4	8 Low	Less than minor or transitory
			Accidental spills of fuel during aircraft re-fuelling operations	Pollution of local snow / ice environment	Direct / Cumulative	1	2	2	3	12 Low	• Refuelling operations will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being transferred / used • Fuel spill response training will be provided to members of the air operations team Any spill events will be recorded & reported through standard BAS / USAP procedures.	1	2	2	2	8 Low	Less than minor or transitory
			Noise of aircraft operations	Disturbance to some or all individuals in a colony of wildlife	Direct	2	2	2	2	16 Medium	• Most surveys will be undertaken over the glacier and ice-shelf and well away from known concentrations of wildlife • Pilots will be instructed to avoid colonies of wildlife • The Guidelines for the Operation of Aircraft will be followed Any observed, significant disturbance events will be recorded and reported immediately to BAS and NSF.	1	1	2	1	2 Low	Less than minor or transitory
	Instrumentation of Seals																
12	Instrumentation of Elephant and Weddell seals	**TARSAN**	Human activity including vehicle activity (helicopters or small boats) in the vicinity of seal (and potentially other wildlife) colonies	Disturbance to some or all individuals in nearby bird and seal colonies	Direct	2	2	2	3	24 Medium	• Pilots will be instructed to avoid colonies of wildlife • The Guidelines for the Operation of Aircraft Near Concentrations of Birds will be followed • Landing sites for aircraft and small boats will be carefully selected to avoid disturbance • Trained, competent and experienced researchers will undertake the seal tagging work under licence from the UK Home Office • Initial selection of seals is undertaken at distance to avoid wider disturbance Any significant disturbance events will be recorded and reported immediately to BAS & NSF.	2	2	2	2	16 Medium	No more than minor or transitory
			Isolation and anaesthetising of individual seals for tagging	Distress to instrumented individuals during tagging process	Direct	3	2	3	3	54 High	• The seal capture, handling and tagging will be carried out by trained, competent and experienced personnel from the UK's Sea Mammal Research Unit (SMRU); • All researchers hold personal licences to conduct the work under the UK Animal (Scientific Procedures) Act 1986 (issued by the Home Office); • The capture and tagging protocols have been refined over many years of tagging seals globally, but have recently been reviewed and approved by the University of St Andrews' Teaching and Research Ethics Committee (UTREC) and the Animal Welfare and Ethics Committee (AWEC); • For each tagging effort a health and safety risk assessment will be carried out and reviewed by the safety officer of the Sea Mammal Research Unit; • SCAR's Code of Conduct for the use of animals for scientific purposes will be followed. Any significant disturbance event that clearly results in distress to an individual or a fatality event will be recorded and reported immediately to BAS and NSF.	2	2	3	2	24 Medium	No more than minor or transitory
			Instruments attached to seals for several months	Change in seal behaviour and/or capability due to fitted instrument *e.g.* reduction in foraging ability	Direct	2	3	3	3	54 High	• Trained, competent and experienced researchers will fit the devices • Healthy individuals only will be selected for tagging • Experience and research suggests negligible effects on seal behaviour or capability • Device is lost during the seal's next moult (likely less than a 12 month period)	2	2	2	2	16 Medium	No more than minor or transitory
			Introduction of non-native terrestrial species to islets and islands in Pine Island Bay as a result of biologically contaminated boots and clothing	Non-native species are introduced and potentially establish in the local terrestrial environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • SCARs code of conduct for terrestrial scientific research in Antarctica will be made available to and followed by the researchers • U.S. and BAS protocols to minimise the risk of introducing non-native species will be followed at all times *e.g. BAS Biosecurity Handbook* Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Relocation of personnel between ice-free locations in Pine Island Bay	Artificial relocation of native Antarctic species beyond their current range	Direct / Cumulative	3	4	4	3	144 Very High	• Information will be provided to researchers to raise awareness of the risks • Clothing, bags and rucksacks will be checked and cleaned prior to moving between locations • Boots and gaiters will be checked and cleaned prior to moving between locations • SCARs code of conduct for terrestrial scientific research in Antarctica will be made available to the researchers and followed • A quick guide will be developed to ask researchers to assess and record native biota at each of the sites to be visited	2	2	4	2	32 Medium	No more than minor or transitory

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	Autonomous and Tethered Marine Instruments and Equipment																
13	Deployment of Hugin AUVs beneath ice shelves	**TARSAN**	Water turbulence from operation of AUV propellers	Potential disturbance to sessile and mobile marine biota	Direct	1	1	1	2	2 Low	No treatment is possible. Turbulence will occur though the effects will be negligible.	1	1	1	2	2 Low	Less than minor or transitory
			Heat and light emissions from operation of AUV equipment and power sources	Heat loss to local marine environment and introduction of artificial light	Direct	1	1	1	2	2 Low	No treatment is possible. Some heat and light emissions will occur though the effects will be negligible.	1	1	1	2	2 Low	Less than minor or transitory
			Introduction of artificial marine noise from the operation of the AUV and the sonar and sub-bottom profiler systems on the AUV	Auditory disturbance and / or physical harm to marine animals	Direct / Indirect / Cumulative	2	2	2	3	24 Medium	• Prior to the deployment of the AUVs a watch will be undertaken to ensure that no marine mammals are obviously close to the ship - in which case activities will be delayed • Deployments will be relatively short (periods of days) • Deployments will be undertaken towards the end of the breeding season *Encounters with marine mammals and cetaceans in the intended area of operation of the AUVs are considered to be low in open water situations to extremely unlikely when operating under ice shelves*	2	2	2	2	16 Medium	No more than minor or transitory
			Introduction of non-native marine species as a result of biologically contaminated AUVs	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • AUVs will be inspected and cleaned prior to sending to Antarctica • AUVs will be inspected and if necessary cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of equipment through failure to return	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	2	4	1	3	24 Medium	• AUVs have been tried and tested in under-ice operations • Sophisticated technology is included on modern AUVs including collision avoidance technology • Transponder use will assist AUV communications and accuracy of navigation • Experienced technicians will oversee AUV operations • A 'build-up' approach will be adopted. Short 'test' missions followed by longer surveys • A growing body of experience of operating AUVs under ice shelves will be drawn on where possible • Operations will be risk assessed Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	2	4	1	2	16 Medium	No more than minor or transitory
			Potential release of AUV drop-weights in the event of 'return-to-surface trigger'	Drop weights will sink to sea floor and persist in marine environment for many decades	Direct / Cumulative	1	4	1	2	8 Low	• The automatic 'triggers' for releasing drop-weights will be adjusted for under-ice operations	1	4	1	2	8 Low	Less than minor or transitory
14	Deployment of cnode transponder units (to assist with AUV navigation and data transfer)	**TARSAN**	Introduction of artificial marine noise from the transponder units and 'pinger' release devices	Auditory disturbance and / or physical harm to marine animals	Direct / Indirect / Cumulative	2	2	2	3	24 Medium	• Deployments will be relatively short (periods of days) • Deployments will be undertaken towards the end of the breeding season • Pinger devices to recover the transponders at the end of the survey period will be single pulses only *Overlap of the noise signal from the transponders with marine mammal and cetacean activity is possible, but unlikely to be constraining on the animals with avoidance the most likely scenario.*	2	2	2	2	16 Medium	No more than minor or transitory
			Potential irrecoverability of device(s) *e.g.* if auto-release fails or transponder unit fails	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	1	2	8 Low	• Tried and tested technology with very low failure rate Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	1	4 Low	Less than minor or transitory
			Transponder anchor devices will not be recovered	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	1	4	16 Low	No treatment options available, but impacts will be negligible. The location of the unrecoverable anchor devices will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	4	16 Low	Less than minor or transitory

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15	Deployment of rotary wing RPA (to assist with safe deployment / recovery of AUVs)	**TARSAN**	Noise emissions from the operation of the RPA units	Potential disturbance to nearby wildlife	Direct	2	1	2	2	8 Low	• RPA will only be used for short duration / near-vessel activities • RPA will be operated by trained and competent pilots • COMNAP RPAS Handbook guidance will be made available to the pilots and followed at all times • ATCM Environmental guidance for RPAS operations will be made available to the pilots and followed • RPAS will not be operated in the vicinity of wildlife concentrations • Bird observations will be undertaken prior to planned launch Any disturbance events will be recorded and reported immediately to BAS and NSF.	2	1	1	1	2 Low	Less than minor or transitory
			Potential loss of RPA units into the sea through equipment malfunction or collision (*e.g.* with the vessel)	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	1	2	8 Low	• RPA units will be serviced and tested prior to deployment in Antarctica • Experienced, trained and competent pilots will operate the RPA units • Careful deployment of RPA according to weather conditions • COMNAP RPAS Handbook guidance will be made available to the pilots and followed at all times • Relevant national Antarctic programme protocols will be followed at all times Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	1	4 Low	Less than minor or transitory
16	Deployment of marine gliders in front of ice shelves	**TARSAN**	Introduction of non-native marine species as a result of biologically contaminated gliders	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • Gliders will be inspected and cleaned prior to sending to Antarctica • Gliders will be inspected and if necessary cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of gliders *e.g.* through equipment failure or collision with ice	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	2	4	1	2	16 Medium	• Gliders are a proven technology - though operations in ice-covered waters do present additional challenges Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	2	4	1	2	16 Medium	No more than minor or transitory
17	Deployment of autonomous surface vehicles *e.g.* 'autonaut ASV'	**TARSAN**	Introduction of non-native marine species as a result of biologically contaminated ASVs	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • ASVs will be inspected and cleaned prior to sending to Antarctica • ASVs will be inspected and if necessary cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of vehicle due to equipment failure or becoming trapped in pack ice	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	1	2	8 Low	• ASVs will be checked and serviced prior to deployment Last known location of any unrecovered USVs will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	2	8 Low	Less than minor or transitory

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18	Deployment of 'icefin' ROV beneath glacier (through hot water drilled hole)	**MELT**	Water turbulence from operation of ROV propeller	Potential disturbance to sessile marine biota	Direct	1	1	1	2	2 Low	No treatment is possible. Turbulence will occur though the effects will be negligible.	1	1	1	2	2 Low	Less than minor or transitory
			Noise emissions	Potential disturbance to marine wildlife	Direct	1	1	1	1	1 Low	No treatment is possible. Icefin is 'low noise'. Encounters with wildlife beneath the ice shelf are extremely unlikely to occur.	1	1	1	1	1 Low	Less than minor or transitory
			Light emissions	Potential disturbance to marine wildlife	Direct	1	1	1	1	1 Low	No treatment is possible. Light emissions are minor and any exposure to sessile organisms will be transient and of negligible consequence.	1	1	1	1	1 Low	Less than minor or transitory
			Heat emissions	Heat loss to local marine environment	Direct	1	1	1	2	2 Low	No treatment is possible. Some heat emission will occur though the effects will be negligible.	1	1	1	2	2 Low	Less than minor or transitory
			Introduction of non-native marine species as a result of biologically contaminated gliders	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • Icefin will be inspected and cleaned prior to sending to Antarctica • Icefin will be inspected and if necessary cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of equipment through entanglement or inability to retrieve through ice hole	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	2	4	1	3	24 Medium	• Experienced operators will oversee deployment of icefin • Technology has been tested in other under-ice situations • Short-term deployments will minimise risks of closure of ice hole Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	2	4	1	2	16 Medium	No more than minor or transitory
19	Deployment of expendable oceanographic profilers into glacial fissures	**MELT**	Equipment is designed to be expendable and will not be recovered	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	4	32 Medium	• Construction materials have been selected for low toxicity and degradability Records will be maintained of all permanently deployed equipment and reported through standard BAS / USAP reporting procedures.	1	4	1	4	16 Medium	No more than minor or transitory
20	Deployment of tethered microstructure marine profiler (VMP-2000)	**TARSAN**	Introduction of non-native marine species as a result of biologically contaminated profiler	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • Profiler will be inspected and cleaned prior to sending to Antarctica • Profiler will be inspected and if necessary cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of equipment *e.g.* due to cable breaking, malfunctioning or becoming tangled	Equipment will persist in the environment for years to decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	2	16 Medium	• Trained and experienced operators will deploy equipment • All equipment will be serviced and checked prior to use in Antarctica • Risk assessments will be completed for all equipment to be deployed from vessels Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	2	1	8 Low	Less than minor or transitory
			Water turbulence during descent and recovery	Potential disturbance to marine wildlife	Direct	1	1	2	2	4 Low	• Marine wildlife observations will be undertaken prior to deployment of any equipment from ships and deployment delayed if disturbance is possible	1	1	2	1	2 Low	Less than minor or transitory
21	Marine multi-beam bathymetric and acoustic sub-bottom profiling survey	**THOR**	Introduction of artificial noise into the marine environment	Auditory disturbance and / or physical harm to marine mammals	Direct / Indirect / Cumulative	2	3	2	3	36 High	• The acoustic survey equipment will be operated to standard NSF protocols, which include prior observation for marine wildlife • A separate EIA will be undertaken for the Nathaniel B Palmer 2019/20 cruise which will also involve marine seismic surveying • *Any BAS supported surveys will be undertaken in accordance with the NERC Marine Environmental research Policy*	2	2	2	2	16 Medium	No more than minor or transitory
22	Recovery and re-deployment of ocean moorings	**BAS**	Non-recovery of equipment including mooring anchors	Equipment will persist in the environment for decades and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	4	2	2	16 Medium	• Equipment has been designed, tested and used in the Southern Ocean for many years Mooring anchors cannot be recovered, but approximate locations will be recorded and reported. Locations of mooring re-deployments will be recorded.	1	4	2	1	8 Low	Less than minor or transitory

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	Direct Sampling																
	Geological sampling																
23	Geological drilling activity - Winkie drill system	**GHC**	Potential loss of drilling fluids - ISOPAR-K	Release of 'hazardous' chemicals to the environment	Direct	2	2	2	4	32 Medium	• Under normal operating conditions, drilling fluid is contained within a closed system - less than 10% of the fluid in the system is usually lost *e.g.* through evaporation • Drilling fluid is normally recovered on completion of drilling and re-drummed for future use • Experienced and trained drillers will operate the equipment • Any fluid lost will be into rock fissures below the surface • Drilling fluid biodegrades at a moderate rate and does not persist in the environment • Spill kits will be on site for any accidentally spilt fluid on the surface Any lost or spilt drilling fluid will be recorded and reported through standard BAS / USAP reporting procedures.	2	2	1	2	8 Low	Less than minor or transitory
			Possible use of ethanol to release 'stuck' drills - with subsequent loss to the environment	Release of 'hazardous' chemicals to the environment	Direct	2	2	2	3	24 Medium	• Only small quantities of ethanol are needed in cases of a 'stuck' drill • Ordinarily ethanol remains within the closed system of the drill • Any ethanol lost will be into rock fissures below the surface • Spill kits will be on site for any accidentally spilt ethanol on the surface Any lost or spilt ethanol will be recorded and reported through standard BAS / USAP reporting procedures	2	2	1	1	4 Low	Less than minor or transitory
			Recovery of geological core material	Physical disturbance through removal of geological material	Direct	1	4	2	3	24 Medium	• Drilling / coring locations will be carefully selected to maximise research benefit Sampling locations will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	2	3	24 Medium	No more than minor or transitory
			Noise emissions from powering the drill	Potential disturbance of nearby wildlife at some drilling sites	Direct	2	1	2	3	12 Low	• A pre-drilling survey of the area will be undertaken to identify and record any nearby bird colonies • Slow introduction of 'new noise' (ramping up) if operating in the vicinity of any identified colonies Any obvious significant disturbance events will be recorded and reported immediately to BAS / NSF.	2	1	2	2	8 Low	Less than minor or transitory
			Fuel use for powering equipment - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	2	4	8 Low	• Generators will be serviced prior to deployment to Antarctica to ensure efficient running • Emissions will be minimised by restricting running time as far as is practicable	1	1	2	4	8 Low	Less than minor or transitory
			Accidental spills of hazardous substances *e.g.* during re-fuelling operations	Pollution of local snow / ice environment	Direct / Cumulative	1	2	1	3	6 Low	• Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored fuel to check for leaks / spills • Fuel spill response training for at least one member of the drilling team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported to BAS / USAP through standard reporting procedures.	1	2	1	2	4 Low	Less than minor or transitory

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24	Geological sampling (no drilling) at several ice-free locations	**GHC**	Sampling / removal of geological material	Removal of geological material	Direct	1	4	1	3	24 Medium	• Sampling locations will be carefully selected to maximise research benefit • SCARs code of conduct for terrestrial scientific research in Antarctica will be made available to and followed by the researchers Sampling locations will be recorded and reported through standard BAS / USAP reporting procedures.	1	4	1	3	24 Medium	No more than minor or transitory
			Human activity including vehicle activity (helicopters or small boats) in the vicinity of wildlife colonies	Disturbance to some or all individuals in nearby bird and seal colonies	Direct	2	2	2	3	24 Medium	• Pilots will be instructed to avoid colonies of wildlife in the area • The (CEP) Guidelines for the Operation of Aircraft Near Concentrations of Birds will be followed • Landing sites for aircraft and small boats will be carefully selected to avoid disturbance • Careful route planning will be undertaken to ensure movement of people across ice-free areas minimises the risk of disturbance to any local wildlife Any significant disturbance events will be recorded and reported immediately to BAS / NSF.	2	2	2	2	16 Medium	No more than minor or transitory
			Introduction of non-native terrestrial species to ice-free locations as a result of biologically contaminated boots and clothing	Non-native species are introduced and potentially establish in the local terrestrial environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance and guiding principles in the CEP's non-native species manual will be followed • Standard US and BAS protocols / manuals to minimise the risk of introducing non-native species will be followed at all times • SCARs code of conduct for terrestrial scientific research in Antarctica will be made available to and followed by the researchers Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Movement of people and their equipment between multiple ice-free locations	Artificial relocation of native Antarctic species beyond their current range	Direct / Cumulative	3	4	4	3	144 Very High	• Information will be provided to the researchers to raise awareness of the risks • Clothing, bags and rucksacks will be checked and cleaned prior to moving between locations • Boots and gaiters will be checked and cleaned prior to moving between locations • SCARs code of conduct for terrestrial scientific research in Antarctica will be made available to and followed by the researchers • A quick guide will be developed to ask researchers to assess and record native biota at each of the sites to be visited	2	2	4	2	32 Medium	No more than minor or transitory
	Marine Sediment Coring and Water Sampling																
25	Marine sediment coring using a range of coring devices (Kasten corer; gravity corer; percussion corer; multi-corer; box corer)	**THOR**	Introduction of non-native marine species as a result of biologically contaminated coring devices	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance in CEP's non-native species manual will be followed • All sampling equipment will be cleaned and inspected prior to expedition deployment • All sampling equipment will be inspected and cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of equipment *e.g.* due to cable breaking, malfunctioning or becoming tangled	Equipment will persist in the environment for many years and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	3	3	2	18 Medium	• Experienced coring technicians will oversee coring activities • Careful deployment of coring devices according to weather and ice conditions • Careful selection of sampling locations Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures.	1	3	3	1	9 Low	Less than minor or transitory
			Recovery of sediment samples from the sea floor	Physical disturbance of benthic environment	Direct	1	2	1	4	8 Low	• Sampling sites will be carefully selected to maximise research benefit Sampling locations will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	4	8 Low	Less than minor or transitory
26	Oceanographic profiling and water sampling with CTD	**TARSAN**	Introduction of non-native marine species as a result of biologically contaminated sampling equipment	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• Relevant guidance in CEP's non-native species manual will be followed • All sampling equipment will be cleaned and inspected prior to expedition deployment • All sampling equipment will be inspected and cleaned prior to each deployment Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	4	4	1	32 Medium	No more than minor or transitory
			Potential loss of equipment *e.g.* due to cable breaking, malfunctioning or becoming tangled	Equipment will persist in the environment for many years and slowly decay causing a small amount of local pollution	Direct / Cumulative	1	3	3	2	18 Medium	• Experienced technicians will oversee sampling activities • Careful deployment of coring devices according to weather and ice conditions Any lost equipment will be recorded and reported through standard BAS / USAP reporting procedures	1	3	3	1	9 Low	Less than minor or transitory

Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Pre-treatment risk assessment: Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Post-treatment risk assessment: Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
	Ice Coring																
27	Ice coring - kovacs ice corer	**TARSAN**	Recovery of snow / ice samples as a result of coring activity	Physical disturbance to local snow / ice environment	Direct	1	1	1	3	3 Low	No treatment options available. Impacts will be negligible.	1	1	1	3	3 Low	Less than minor or transitory
			Fuel use for powering equipment - emissions to air (if powered drill is used)	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	2	4	8 Low	• Emissions will be minimised by restricting running time as far as is practicable	1	1	2	4	8 Low	Less than minor or transitory
			Accidental spills of fuel *e.g.* during re-fuelling operations (if powered drill is used)	Pollution of local snow / ice environment	Direct / Cumulative	1	2	1	3	6 Low	• Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored fuel to check for leaks / spills • Fuel spill response training for at least one member of the team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	2	4 Low	Less than minor or transitory
	Logistical Support Activities																
	Ice Drilling																
28	Hot water & RAM drilling at multiple locations across the Thwaites and Dotson Glaciers	**GHOST, MELT, THOR, TIME**	Drilling action to create the holes	Physical disturbance to the snow / ice environment	Direct	1	1	1	3	3 Low	No treatment options available. Impacts will be negligible.	1	1	1	3	3 Low	Less than minor or transitory
			Fuel use to power the drills and heat water - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	2	4	8 Low	• The generators that power the drill systems will be serviced prior to deployment to Antarctica • Emissions will be minimised by restricting running time as far as is practicable	1	1	2	4	8 Low	Less than minor or transitory
			Accidental spills of fuel *e.g.* during re-fuelling operations	Pollution of local snow / ice environment	Direct / Cumulative	1	2	1	3	6 Low	• Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored fuel to check for leaks / spills • Fuel spill response training for at least one member of the drilling team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	1	2	1	2	4 Low	Less than minor or transitory
			Noise from the power generators	Potential disturbance to nearby wildlife	Direct	1	1	2	2	4 Low	*It is highly unlikely that the hot water or RAM drills will be used in the vicinity of any wildlife. Such drilling will be undertaken on the ice-shelf or glacier, and well away from any known colonies.* • In the very unlikely event that the drilling equipment is used near to wildlife, 'new noise' will be slowly introduced (ramping up) to allow the wildlife to become accustomed	1	1	2	1	2 Low	Less than minor or transitory

						Pre-treatment risk assessment						Post-treatment risk assessment					
Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
	Vehicle , Vessel and Aircraft Operations																
29	Over-ice vehicles and traverses	**All projects, BAS, USAP**	Fuel use for powering vehicles - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	2	2	2	4	32 Medium	• Vehicles will be fully serviced prior to use during the ITGC • Emissions will be minimised by restricting vehicle running times as far as is practicable and without compromising the safety of personnel	2	2	2	4	32 Medium	No more than minor or transitory
			Accidental spills of fuel *e.g.* during re-fuelling operations	Pollution of local snow / ice environment	Direct / Cumulative	2	2	2	3	24 Medium	• Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored / carried fuel to check for leaks / spills • Fuel spill response training for at least one member of the team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.		2	1	2	8 Low	Less than minor or transitory
			Noise emissions	Potential disturbance to nearby wildlife	Direct	2	2	2	2	16 Medium	*It is unlikely that over-ice vehicles will be operated in the vicinity of any known wildlife. In most cases over-ice vehicles will be used on glaciers and the ice sheet well away from any wildlife colonies.* • In the very unlikely event that vehicles are used near to wildlife, care will be taken to minimise disturbance by careful route planning and avoidance of excessive noise such as engine revving. Any observed significant disturbance events will be recorded and reported immediately to BAS and NSF.	1	1	1	2	2 Low	Less than minor or transitory
30	Aircraft activity (fixed and rotary wing)	**BAS, USAP**	Fuel use for powering several aircraft - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	2	2	2	4	32 Medium	• Aircraft will be fully serviced prior to use during the ITGC • Emissions will be minimised by restricting aircraft operations to the extent practicable	2	2	2	4	32 Medium	No more than minor or transitory
			Accidental spills of fuel *e.g.* during re-fuelling operations of Twin Otters at Thwaites Glacier camps	Pollution of local snow / ice environment	Direct / Cumulative	2	2	2	3	24 Medium	• Fuel volumes will be minimised to the extent possible • Fuel containers will be bunded • Spill kits (including pig putty; spill mats and pads and PPE) will be available at all sites where fuel is being used / stored • Regular (at least daily) inspections of stored / carried fuel to check for leaks / spills • Fuel spill response training for at least one member of the team • Fuel transfers (*e.g.* refuelling) will be undertaken by a minimum of two people with spill mats, absorbent wipes used at all times Any spill events will be recorded and reported through standard BAS / USAP reporting procedures.	2	2	1	2	8 Low	Less than minor or transitory
			Noise emissions	Potential disturbance to nearby wildlife *e.g.* helicopter landings on or overflights of islands and coastal areas in Pine Island Bay	Direct	2	2	2	2	16 Medium	• Pilots will be instructed to avoid colonies of wildlife • The (CEP) Guidelines for the Operation of Aircraft Near Concentrations of Birds will be followed • Small boat landings will be preferred for deploying geological and seal tagging parties Any observed significant disturbance events will be recorded and reported immediately to BAS and NSF.	1	1	2	2	4 Low	Less than minor or transitory

						Pre-treatment risk assessment						Post-treatment risk assessment					
Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
31	Vessel activity in Pine Island Bay	**BAS, NSF**	Fuel use for powering multiple vessels - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	2	2	2	4	32 Medium	• All vessels operate on MGO and do not use HFO • Vessels will avoid heavy ice conditions to the extent practicable	2	2	2	4	32 Medium	No more than minor or transitory
			Noise emissions through operation of vessel engines and machinery	Potential disturbance to nearby wildlife	Direct / Cumulative	1	2	2	3	12 Low	• Vessels will operate some distance from shore and any encounters are likely to be 'at sea' • Vessel will proceed cautiously when pods of cetaceans / seals are observed, including slowing down and avoidance if practicable and safe to do so Any observed significant disturbance events will be recorded and reported immediately to BAS or NSF.	1	2	2	2	8 Low	Less than minor or transitory
			Production of waste and release of human waste and grey water	Pollution of the marine environment	Direct	2	2	1	4	16 Medium	• All food and general wastes will be stored on board and disposed of outside the Antarctic Treaty area • Sewage / grey water disposal will be undertaken in compliance with Annex IV to the Protocol, MARPOL and IMO Resolution MEPC.159(55) 2006	2	1	1	3	6 Low	Less than minor or transitory
			Operation of the vessels	Increased water turbulence through propeller wash and thruster use - potentially causing water turbulence, sediment disturbance or coastal erosion	Direct	2	2	2	2	16 Medium	• Vessels will operate some distance from shore and in deep water Turbulence will occur through normal operations but impacts will be negligible.	2	2	1	2	8 Low	Less than minor or transitory
			Introduction of non-native species *e.g.* as a result of hull fouling and/or ballast water exchanges or on-board rodents	Non-native species are introduced and potentially establish in the local marine environment	Indirect / Cumulative	2	4	4	2	64 High	• All vessels will hold a Ship Sanitation Certificate • On-board controls will be undertaken in accordance with each national programme's standard protocols and procedures *e.g. BAS Biosecurity Handbook* • Any ballast water exchanges that occur will be in accordance with the Ballast Water Convention and the ATCM's Ballast Water Guidelines (Resolution 3 (2006))	2	3	3	1	18 Medium	No more than minor or transitory
			Pollution event *e.g.* accidental spill of fuel as a result of hull damage or equipment failure on-board	Pollution of local marine environment and potential contamination of local wildlife	Direct / Cumulative	3	2	3	2	36 High	• All vessels to be used are national Antarctic program vessels that are highly suited to operating in Antarctic waters • Emergency response provisions are covered by each vessels SOPEP, which includes the carriage of spill response equipment onboard • Vessel Masters are highly experienced in operating in Polar ice-covered waters	2	2	2	1	8 Low	Less than minor or transitory
32	Small boat activity in Pine Island Bay area	**BAS, NSF**	Fuel use for powering boats - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	1	1	1	4	4 Low	• Small boats will be fully serviced prior to use during the ITGC • Emissions will be minimised by using boats for essential purposes only	1	1	1	4	4 Low	Less than minor or transitory
			Noise emissions through operation of small boats	Potential disturbance to nearby wildlife	Direct	2	1	2	3	12 Low	• Small boats will be operated by experienced drivers • Slow approaches to shore will be made • Landing sites will be carefully selected to maximise safety and minimise disturbance • Boats will slow down and seek to avoid mammals and cetaceans (or other wildlife) in the water Any observed significant disturbance events will be recorded and immediately reported to BAS or NSF.	2	1	2	2	8 Low	Less than minor or transitory

Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Pre-treatment risk assessment: Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Post-treatment risk assessment: Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
	Establishment and Operation of Field Camps																
33	Establishment and operation of field camps and traverse camps	**All projects, BAS, USAP**	Establishment of camp infrastructure and production of general waste including food, paper, carboard, plastic	Potential pollution of the local ice / snow environment	Direct / Cumulative	2	2	2	3	24 Medium	• All field camps will be operated in accordance with BAS and USAP field manuals and protocols • All waste produced at camps will be separated and returned either to vessels or bases for removal from Antarctica in accordance with US and UK waste management policies / handbooks • Good camp management practices will be employed to minimise the risk of items being blown away or buried • All ITGC camps will be established on snow / ice and not on ice-free ground Any items lost to the environment will be recorded and reported through standard BAS / USAP reporting procedures.	1	1	1	2	2 Low	Less than minor or transitory
			Production of human waste	Potential / actual pollution of the local ice / snow environment	Direct / Cumulative	2	2	1	4	16 Medium	• Where practicable human waste will be collected and removed from field camps for disposal / treatment at bases or vessels • Where it is not practicable to remove human waste from the field, it will be disposed to ice pits. Waste disposed to ice will be entrapped until release into the marine environment over a period of years to centuries.	1	2	1	4	8 Low	Less than minor or transitory
			Fuel use for cooking, heating and powering equipment - emissions to air	Cumulative contribution to regional and global atmospheric pollution	Direct / Cumulative	2	2	2	4	32 Medium	• All cooking / heating equipment will be serviced / cleaned to ensure it burns as efficiently as possible • All equipment will be used on an 'as required' basis to avoid excessive fuel use	1	2	1	4	8 Low	Less than minor or transitory

Sr. No.	Activity	ITGC Project	Environmental Aspect (Outputs)	Potential Impact(s)	Type of Impact (Direct, Indirect, Cumulative)	Pre-treatment risk assessment: Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment (Preventative or Mitigating Measures)	Post-treatment risk assessment: Extent	Duration	Severity	Likelihood	Residual Risk Level	Ref Article 8 of the Protocol
	Fuel management																
34	Air drop of fuel via C-130 at SB9	**BAS**	Rupture of one or more drums of fuel on impact	Potential pollution of snow / ice environment	Direct / Cumulative	3	2	2	3	36 High	• Air drop will be undertaken by highly experienced military personnel • Fuel is packed in collapsible cardboard casing to cushion impact • Airdrop will take place on to snow well away from any wildlife and ice-free ground • A fuel spill response kit will be available at the location of the airdrop in the unlikely event of a spill • Staff trained in fuel spill response will be on the ground during the airdrop Any spilt fuel will be recovered to the extent possible & will be recorded & reported to BAS.	2	2	2	2	16 Medium	No more than minor or transitory
			Waste materials (cardboard & wood) from the packing of drums in pallets prior to air drop	Waste materials released to the environment	Direct / Cumulative	1	2	1	4	8 Low	• All materials used to pack the fuel drums will be collected and either re-used or returned to Rothera for disposal via the normal waste streams or returned to the RAF (*i.e.* netting, strops and parachutes)	1	2	1	2	4 Low	Less than minor or transitory
35	Fuel caches and depots established at multiple locations	**BAS, USAP**	Accidental fuel spill though leakage of drums etc	Potential pollution of snow / ice environment	Direct	2	3	2	3	36 High	• All fuel management in the field will be undertaken to well developed and documented field fuel management procedures by BAS and USAP • Dedicated fuel handlers ('fuelies') will be stationed at large volume fuel depots • Whilst people are on site, the fuel caches will be regularly checked for leaks • Field fuel will be bunded to the extent possible. Large fuel storage bladders will be bunded including for overwinter storage • Fuel spill kits will be available at every fuel cache. These will include a range of repair materials to deal with partial tears or weeps including 'clam shells' (which can seal a small tear in a bladder), sealing patches and glues • Spare bladders will be held at all fuel depots where fuel is stored in bladders Overpack drums will be held at all sites where large fuel drums are being stored • Digging in and around fuel bladders will only be undertaken using plastic-bladed shovels • Documented 'close down' procedures will be followed prior to overwintering the fuel. Dry-break couplings on fuel bladders will be backed up by gate valves on all fittings • Fuel spill response training will be provided to key personnel Any spill event will be recorded and reported through standard BAS / USAP procedures.	2	2	2	2	16 Medium	No more than minor or transitory
36	Use of large volume fuel bladders (filling and towing)	**BAS**	Accidental fuel spill during ship - shore filling of bladders *e.g.* bladder bursts or connecting hose comes loose	Potential pollution of snow / ice environment	Direct	2	2	3	3	36 High	• Bladder type / make has been tried and tested in Antarctica with no failures to date • Bladders are carefully managed and their age, use and condition is recorded • Ship to shore fuel transfer (filling of bladders) will be carefully managed and supervised with observers deployed to monitor for leaks and spills • All joint connections are self-sealing Avery Hardoll couplings to reduce risk of spills • Delivery vessel scuppers are open during refuelling and any leak ship-side will result in fuel retention on-board Any spill event will be recorded and reported through standard BAS reporting procedures or immediately in the event of a large spill.	2	2	2	2	16 Medium	No more than minor or transitory
		BAS, USAP	Accidental spill from a ruptured bladder during towing or delivery of fuel	Potential pollution of snow / ice environment	Direct	2	2	3	3	36 High	• Bladder type / make has been tried and tested in Antarctica with no failures to date • BAS and USAP have many seasons of experience in transporting fuel in this way • Bladders are carefully managed and their age, use and condition is recorded • Bladders will be inspected daily for any sign of leaks • BAS and USAP traverse manuals include guidance on management and towing of bladders and will be followed at all times • BAS and USAP oil spill contingency plans are in place for traverse operations • A fuel spill kit will travel with the bladders and includes equipment and materials to seal any tears • A spare bladder will travel on all traverses and can be used for fuel transfer in case of a leak Any spill event will be recorded and reported through standard BAS reporting procedures or immediately in the event of a large spill.	1	2	2	2	8 Low	Less than minor or transitory

7.6 Cumulative Impacts

As recorded above, **cumulative impacts** occur as a result of the combined impacts of past, present and reasonably foreseeable activities. Cumulative impacts may occur over time and should be assessed by looking at other human activities occurring in the proposed locations. As with indirect impacts, cumulative impacts may not be identified until a direct impact has occurred (EIA Guidelines, 2016).

Cumulative impacts will or may occur during the ITGC campaign, as well as in combination with past and reasonably foreseeable activities in this region of Antarctica. - either during the ITGC campaign *i.e.* the combination of impacts from multiple ITGC activities during the four years of the ITGC, and/or in combination with past and potential future research activities in the region.

7.6.1 Cumulative Impacts during the ITGC campaign

The multi-season, multi-project, multi-operator approach to the ITGC campaign merits particular attention being paid to the issue of cumulative impacts. The assessment above suggests that there are a number of aspects that will or may result in cumulative environmental impacts during the ITGC campaign (Table 8). Those identified aspects are:

a. Fuel use and emissions to air from the burning of fossil fuels
b. Underwater / marine Noise
c. Equipment and other losses to the environment
d. The potential introduction of non-native marine species
e. The potential artificial relocation of native species beyond their current natural range

7.6.1.1 Fuel use and emissions to air

As recorded above, the ITGC campaign will be a fuel-hungry programme of research. Fossil fuels will be used by a range of equipment including: traverse tractors (*e.g.* the PistenBullys and Caterpillars); skidoos; research equipment (*e.g.* hot water and geological drills; the vibroseis equipment); aircraft (LC-130s, Twin Otters, Basler and helicopters), field camps (for cooking and heating), and ships (for marine research cruises, logistical support, and by small boats operated from the ships).

Fuel will be required for such equipment throughout each of the four seasons of the campaign, though it will be used in varying volumes between seasons.

The vast majority of fuel input to the Thwaites Glacier area of operation will come from the BAS supported operational traverse. A total of 498,000 litres of AVTUR will be delivered via SB9, as well 16,400 litres of MOGAS and 410 litres of kerosene.

An additional 20,500 litres of aviation fuel for the aero-geophysics survey will be delivered via WAIS divide, making a total of 518,500 litres of aviation fuel.

The vessels that will be used to support the marine research aspects of the ITGC campaign will also burn fossil fuels and contribute to the emissions. Anticipating the volumes of fuel that are likely to be used by the ships is difficult given that the daily fuel burn will depend upon a range of factors including the amount of time 'on station' deploying over-the-side equipment, the amount of time spent 'working ice' (which inevitably burns more fuel) and the amount of time in open water conditions. Accordingly, the following assessment of fuel to be used by the ships is little more than a very rough estimate.

During the 2018/19 season the *Nathaniel B Palmer* will support a 49 research cruise. Using an estimated average daily fuel use of 20,000 litres / day, the vessel could burn a total of 980,000 litres of fuel for the cruise. This figure is for the period of the cruise only and does not account for the fuel that will be used to sail to and from the Amundsen Sea area.

Also during the 2018/19 season the *RRS Ernest Shackleton* and the *HMS Protector* will be used to deliver fuel to the Stange Ice Shelf region. Each ship will take about 7 days to travel to the region from South America or the Falkland Islands using approximately 10,000 litres / day (140,000 litres in total). Potentially each vessel may spend up to one day per vessel working through sea ice, with a potential fuel use of 20,000 litres / day (40,000 litres in total). Both ships are anticipated to spend approximately 18 days alongside with a combined fuel usage of 7,000 litres / day (126,000 litres in total). In total, the two ships will burn approximately 306,000 litres.

In the 2019/20 season the *Nathaniel B Palmer* will support a second research cruise. The duration of this research cruise is yet to be finalised, but for the purposes of calculating fuel use it is assumed to be a 45 day research cruise. Using the same figures for the *Nathaniel B Palmer* as above, the total fuel usage for this cruise is anticipated to be approximately 900,000 litres.

In the 2020/21 season the *Sir David Attenborough* will support further marine research in the area. Fuel use figures for the *Sir David Attenborough* are not available as the vessel has yet to be finished being built. Assuming fuel use figures similar to the *Nathaniel B Palmer* and a research cruise period of 30 days, the fuel burn for this vessel for this season could be approximately 600,000 litres.

In total, across the four seasons of the ITGC campaign the various vessels could use approximately 2,786,000 litres. The fuel used by all of the vessels is marine gas oil (MGO).

All emissions will include the standard products of combustion of these fuels, including carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates.

Assuming all of the listed above fuel is burnt, table 9 provides an approximation of the amounts of key greenhouse gases that could be generated. This suggests that the ITGC campaign could be expected to generate approximately 9,000 tonnes of carbon dioxide equivalents, including 3 tonnes of methane and 113 tonnes of nitrous oxide.

Fuel type	Volume (litres)	kg CO_2e	kg CH_4	kg N_2O
Aviation fuel (AVTUR / AVCAT)	518,500	1,316,383.36	699.98	12,329.93
MOGAS	16,400	37,807.08	113.16	110.54
Kerosene	410	1,039.87	2.55	2.58
Marine Gas Oil (vessels)	2,786,000	7,730,564.94	1,950.20	101,048.22
Totals		**9,085,795.25**	**2,765.89**	**113,491.27**

Table 9. Amounts of greenhouse gases that may be produced by the burning of fuel across the four seasons of the ITGC campaign. Conversion factors have been taken from the UK Government's 2018 Green House Gas Conversions for Company Reporting. Source: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting.

These emission levels are negligible compared to global volumes, though potentially significant in an Antarctic context. By way of comparison Bharti et al. (2016) calculated CO_2 emissions from the operation of India's Maitri station during a summer period (the precise duration of the assessment is unspecified in the paper) as 265 tonnes, which included emissions from the operation of the base and vehicles. In 2016/17 Antarctica New Zealand reported total annual emissions from the operation of New Zealand's Scott Base and all associated activities including its Christchurch headquarters as 4,773 tonnes of carbon dioxide equivalents (Antarctica New Zealand, 2017).

Using the risk matrix table (7) it is assessed that the raw risk of the cumulative environmental impact of the emissions that will result from this fuel use is 'high' (with a score of 81). Treatment options are not extensive and if research objectives are to be achieved then fuel will inevitably need to be used. However, fuel use can be carefully managed and minimised by ensuring that all equipment and vehicles are well maintained, used optimally and only when required. Both national programmes involved in the field research are highly experienced in careful fuel management which has significant financial as well as environmental benefits. It is also noted that the various field activities associated with the ITGC campaign will occur for a short duration in each summer of the programme. No winter activities are planned, when fuel use would increase significantly. Accordingly, the residual risk score is calculated as 'medium' – no more than minor or transitory (with a score of 24; Table 10).

Activity	Environmental Aspect *(Outputs)*	Potential Impact(s)	Type of Impact *(Direct, Indirect, Cumulative)*	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment *(Preventative or Mitigating Measures)*	Extent	Duration	Severity	Likelihood	Residual Risk Level
Operation of vehicles & equipment	Fuel use & associated emissions to air across all vehicles & equipment throughout four seasons of the ITGC campaign & over a wide geographical area	Pollution of the atmosphere through the release of greenhouse gases	Direct / Cumulative	3	3	3	3	81 High	• All vehicles & equipment are expected to be serviced and maintained to ensure optimal performance and efficiency • All vehicles & equipment will be used only on an 'as required' basis to avoid excessive or un-necessary fuel use and will be run optimally • The operational traverse to deliver fuel into the ITGC area of operation will offer considerable fuel savings over the use of aircraft • The two national programmes involved in the ITGC campaign are highly experienced in careful management (and minimisation) of fuel use in Antarctica • The ITGC campaign will be of fixed duration (maximum of four seasons) & will only operate during the summer period. No fuel will be burnt during the winter period. All fuel use will be recorded and used to calculate an accurate emissions inventory for the ITGC campaign	2	2	2	3	24 Medium

Table 10. Environmental risk assessment of the cumulative impacts of the emissions that will result from the volumes of fuel burnt throughout the entire ITGC campaign.

Fuel use and emissions from the Korean research and resupply vessel, *Araon*, have not been included in the above calculations, but will add to the overall emissions in the area during the ITGC campaign.

7.6.1.2 Underwater marine noise

Artificial marine noise will be introduced to the Amundsen Sea / Pine Island Bay area during three of the four seasons of the campaign as a result of marine research cruises conducted by the *Nathaniel B Palmer* and the *Sir David Attenborough*. Anthropogenic background noise in this area of the Southern Ocean is normally zero. Marine noise will be generated from a number of sources during the ITGC campaign including from the engines and machinery of the research vessels; multibeam bathymetric survey equipment; sub-bottom profilers; sonar equipment on the AUVs; cNODE transponders, and the planned marine seismic survey for the 2019/20 season.

Additional marine noise will be introduced to the area during the 2018/19 season as a consequence of planned research through the International Ocean Discovery Program (IODP), which is an international research program that explores the history and structure of the earth as recorded in seafloor sediments and rocks. Field measurements and geological samples are taken using the drilling vessel *JOIDES Resolution*. The IODP's 379th expedition proposes to core, log, and drill at up to 26 sites (5 primary and 21 alternate) in the Amundsen Sea area of the Southern Ocean (Figure 72) from 18 January – 20 March 2019; coincident with the cruise of the *Nathaniel B Palmer*. The IODP cruise will undertake both drilling activity and marine seismic borehole measurements.

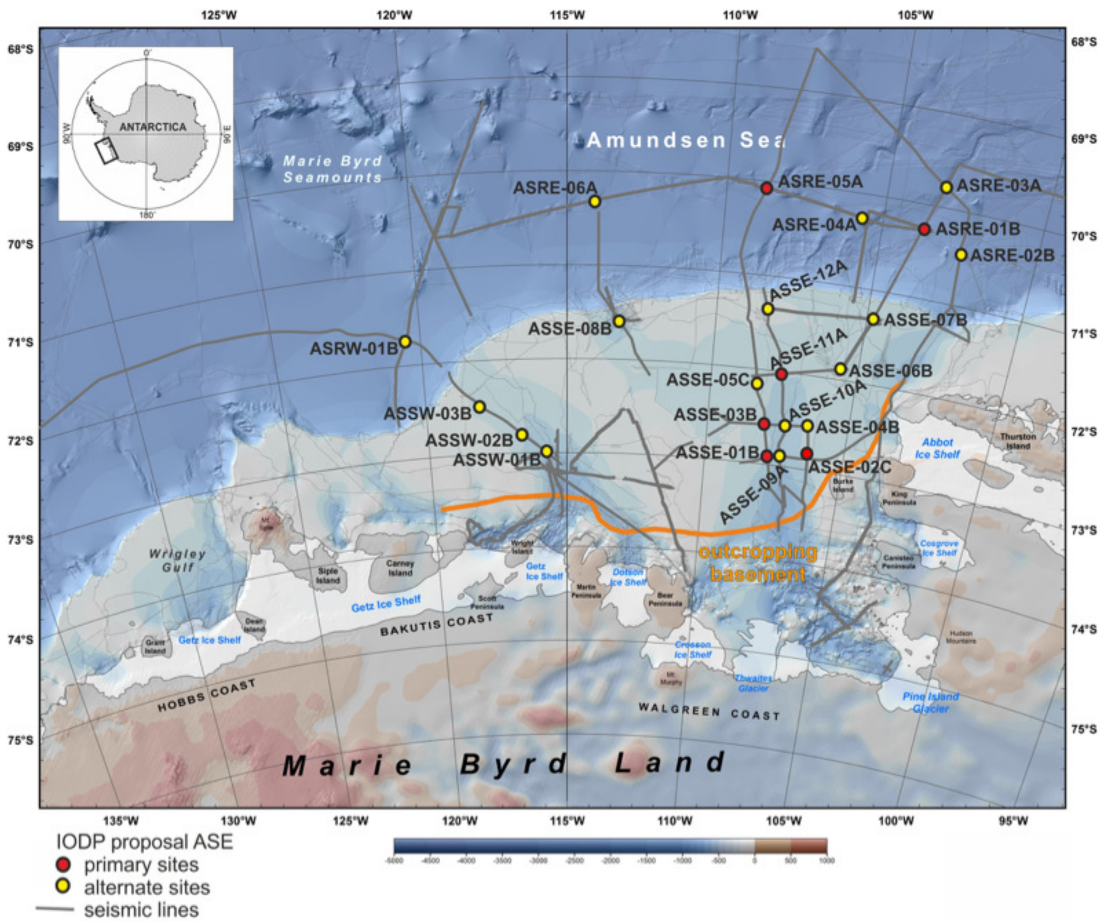

Figure 72. Target locations for the 379th IODP expedition. Red dots show primary target locations and yellow dots alternate locations. Source: IODP Proposal 839, publicly available from http://iodp.tamu.edu/scienceops/expeditions/amundsen_sea_ice_sheet_history.html It is understood that the six primary target locations (red dots in the above) have been refined to five as recorded in the text.

This Initial Environmental Evaluation has not evaluated detailed acoustic profiles for various sources of marine noise that will occur during the ITGC programme of research. Accordingly a thorough and qualitative assessment of the cumulative impacts is not possible.

Using the risk matrix (Table 7) it is assessed that the raw risk of the cumulative environmental impact of anthropogenic noise is 'high' (with a score of 81). As recorded in Sections 7.4 and 7.5 above, the impact of each of the acoustic sources is thought to be low when assessed individually, with marine mammals largely expected to take avoidance action. The geographical area in which the marine research will be undertaken is large and the population density of marine mammals and foraging penguins is anticipated to be low compared to other areas of the Southern Ocean. Introduced underwater noise will mostly be of short duration (with the possible exception of bathymetric surveys and sub-bottom profiling work). Protected Species Observers (PSO) will be on the 2018/19 IODP cruise as well as the 2019/20 cruise of the Nathaniel B Palmer. Some noise sources will be operating under the ice shelf where encounters with marine mammals and penguins are highly unlikely. In most cases marine research will be undertaken towards the end of the breeding season with reduced risk of impacting breeding success. In all cases research measurements and equipment deployment will be overseen by highly experienced researchers and technicians.

As noted elsewhere in this IEE, the 2019/20 cruise of the Nathaniel B Palmer, during which marine seismic surveys will be undertaken, will be the subject of a separate environmental impact assessment, through which additional treatment options may be identified.

With these treatments in place, the residual risk score is calculated as 'medium' – no more than minor or transitory (with a score of 24; Table 11).

Activity	Environmental Aspect *(Outputs)*	Potential Impact(s)	Type of Impact *(Direct, Indirect, Cumulative)*	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment *(Preventative or Mitigating Measures)*	Extent	Duration	Severity	Likelihood	Residual Risk Level
Marine research	Introduction of anthropogenic underwater noise through the deployment and operation of multiple types of marine research equipment and vessels	Auditory disturbance and / or physical harm to marine mammals	Direct / Cumulative	3	3	3	3	81 High	• Not all equipment will be operating all the time in every season • Some equipment will be deployed or operating for short periods of time only • The Amundsen Sea / Pine Island Bay area is a large sea area and avoidance of noise sources is anticipated in most cases • Trained marine mammal observers will be deployed during the two marine seismic cruises to be undertaken • During non-seismic cruises careful marine mammal / wildlife observations by researchers during deployment & operation of equipment with acoustic sources are strongly encouraged so that activities can be moderated so as to mitigate impacts to the extent possible • Most research activity will be undertaken towards the end of the breeding season and impacts on breeding success are considered to be unlikely • All equipment will be operated and overseen by highly experienced researchers and technicians • The 2019/20 cruise will be subject to a separate EIA. Any observed disturbance events will be recorded and reported immediately to BAS and NSF	2	2	2	3	24 Medium

Table 11. Environment risk assessment of the cumulative impacts of marine noise during the ITGC campaign.

7.6.1.3 Equipment loss to the environment

The ITGC campaign will result in a number of items being left in or lost to the environment. This includes, small amounts of debris from the above ground and buried seismic surveys; instruments and cabling that will not be able to be retrieved, *e.g.* those contained within or beneath the ice from the AMIGOS III arrays ;

the expendable oceanographic profilers; the anchors that will be used for the cNODE transponders, and the instruments fitted to the seals when they are lost to the environment when the seals next moult.

Additional items may be left in the environment at the end of the campaign if they cannot be relocated or if equipment failure means that they cannot be recovered.

The items that are left in the glacier / ice-shelf environment will be crushed in the ice and / or carried out to sea as icebergs calve and ultimately small amounts of debris will be deposited in the marine environment at unpredictable locations as they are released from the ice.

It is challenging to quantify the overall amounts and types of material that will be left in the environment after the ITGC programme is complete; though the cumulative quantity is unlikely to be more than a few hundred kilograms.

Most materials that have been used to construct the equipment is not toxic, and dispersal will likely mean that no significant concentrations of material will occur in any one location.

Using the risk matrix (Table 7) it is assessed that if no equipment removal took place then the impacts on the environment would be 'very high' (with a risk score of 108). However, removal of equipment will take place both during and at the end of the four year programme of field research to the fullest extent practicable, and overall quantities that will remain in the environment are not assessed as being substantial, nor likely to have significant negative environmental consequences. Accordingly, the residual risk score is assessed as being 'medium' – no more than minor or transitory (with a score of 18) (Table 12).

Activity	Environmental Aspect *(Outputs)*	Potential Impact(s)	Type of Impact *(Direct, Indirect, Cumulative)*	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment *(Preventative or Mitigating Measures)*	Extent	Duration	Severity	Likelihood	Residual Risk Level
Deployment of research equipment in the field	Several items will not or cannot be recovered on conclusion of the ITGC campaign and will remain in the ice or marine environment	Pollution of the Antarctic glacial and marine environments	Direct / Cumulative	3	3	3	4	108 Very High	• As much equipment and materials will be recovered as possible on conclusion of the ITGC campaign • Items that cannot be recovered are made of low or non-toxic materials • Cumulative quantities of materials to remain in the environment have not been calculated but are not expected to be high • Most items will remain trapped in the ice for many years and will ultimately calve off with ice bergs and be dispersed to the marine environment over a very wide area avoiding high concentrations All unrecoverable items will be recorded and reported at the end of each season to ensure that a full inventory is maintained.	2	3	1	3	18 Medium

Table 12. Cumulative environmental impact risk assessment in relation to materials that will remain in the environment on conclusion of the ITGC campaign.

7.6.1.4 Non-native species introductions

The importation to the Thwaites Glacier region of large quantities of logistics and research equipment over a period of four seasons presents multiple opportunities for introducing non-native species.

Many of the field research and logistical activities will take place on ice and snow with negligible risk of any introduced species establishing in that environment. Of primary concern are those activities that will take place on ice-free locations (*i.e.* geological sampling and instrumentation of seals), and in the marine environment (*i.e.* the deployment of research and sampling equipment).

With no controls in place the cumulative risk of introducing non-native species at some point during the campaign is assessed as being 'high' (with a risk score of 72). However, this is a risk of which the main national Antarctic programmes are acutely aware and for which control measures are routinely applied through for example the BAS Biosecurity Handbook and the USAP 'Don't Pack a Pest' awareness campaign.

It will be important to ensure that researchers and field support staff are aware of the risks and follow all necessary controls. All equipment, including personal items and clothing, will need to be checked and cleaned prior to departure to Antarctica and prior to deployment in the field to the extent practicable; particularly marine research equipment that may recently have been used in other cold water environments.

Provided regular checks and cleaning protocols, as well as vigilance are maintained throughout each season of the ITGC programme, the residual risk is assessed as being 'medium' – no more than minor or transitory (with a risk score of 16) (Table 13).

Activity	Environmental Aspect *(Outputs)*	Potential Impact(s)	Type of Impact *(Direct, Indirect, Cumulative)*	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment *(Preventative or Mitigating Measures)*	Extent	Duration	Severity	Likelihood	Residual Risk Level
Deployment of research equipment in the field	Contaminated equipment introduces non-native species to the Antarctic environment	Non-native species establish in the Antarctic environment with potential impacts on native fauna and flora and the subsequent loss of research value	Indirect / Cumulative	2	3	4	3	72 High	• The majority of equipment and instrumentation will operate or be deployed on snow and ice reducing the risk of non-native species introductions • National Antarctic programmes are alert to the risks and have developed protocols and guidance material that will be followed in accordance with the CEP's non-native species manual and (where relevant) SCAR's code of conduct for terrestrial scientific research in Antarctica • All equipment, including personal clothing / boots etc, to be used in or deployed in ice-free settings or in the marine environment will be inspected and cleaned prior to deployment to Antarctica and re-checked and if necessary cleaned prior to deployment in Antarctica • It will be important for awareness of this risk to be maintained throughout each season of the campaign particularly as familiarity with the locations and the field activities increases Any observations of biologically contaminated equipment or any observations of non-native species will be recorded and reported to BAS and NSF.	2	2	2	2	16 Medium

Table 13. Cumulative environmental impact risk assessment in relation to the introduction of non-native species through the ITGC campaign.

7.6.1.5 Artificial relocation of native species

The movement of personnel between ice-free locations in three of the four seasons of the ITGC programme presents the risk of moving biological material between these locations and establishing native species in locations beyond their current natural range.

The current lack of knowledge on the biology of the ice-free locations that are to be visited makes it challenging to undertake an informed assessment of the risk, which will increase with increasing heterogeneity across the various locations.

With no controls in place the cumulative risk is assessed as being 'very high' (with a risk score of 144); not least due to the fact that any relocation of biological material is likely to be irreversible. It will be important for a precautionary approach to be taken and for appropriate controls to be implemented with vigilance throughout the ITGC campaign in line with the best available advice *e.g.* SCAR's code of conduct for terrestrial scientific research in Antarctica. Regular checks and if necessary cleaning of boots, clothing and equipment when moving between locations will be essential.

It is helpful that only a few researchers from just two of the six field projects will be visiting ice-free locations – GHC and TARSAN. This will not only reduce the risk level, but will also assist in ensuring that these few individuals are fully briefed to the risks and the controls measures that are expected.

It is also suggested that an early (basic) assessment or survey of the biological characteristics at each site should be undertaken on first visit, including collecting photographic information. Collected information will assist in assessing the heterogeneity of the sites being visited and help to review the need for any additional controls that may need to be implemented during the ITGC campaign.

With these controls in place the residual risk of the cumulative impact is assessed as being 'medium' – no more than minor or transitory (with a risk score of 32) (Table 14).

Activity	Environmental Aspect *(Outputs)*	Potential Impact(s)	Type of Impact *(Direct, Indirect, Cumulative)*	Extent	Duration	Severity	Likelihood	Raw Risk Level	Treatment *(Preventative or Mitigating Measures)*	Extent	Duration	Severity	Likelihood	Residual Risk Level
Deployment of researchers across multiple ice-free locations	Artificial relocation of native species beyond their current natural range	Homogenisation of native biology and the subsequent loss of natural environmental and research values	Indirect / Cumulative	3	4	4	3	144 Very High	• The majority of equipment and instrumentation will operate or be deployed on snow and ice reducing the risk of relocating native species – only two projects (GHC and TARSAN) will be visiting ice-free locations and the number of individuals will be small • National Antarctic programmes are alert to the risks and have developed protocols and guidance material that will be followed including reference to SCAR's code of conduct for terrestrial scientific research in Antarctica • A precautionary approach should be adopted with regular checks and cleaning of clothing and equipment when moving between locations, with particular attention paid to boots • It will be important for awareness of this risk to be maintained throughout each season of the campaign particularly as familiarity with the locations and the field activities increases • An assessment of the biological characteristics of the sites being visited will be undertaken by the researchers on first visiting a site. This will inform an assessment of the need for any additional controls to be implemented in future seasons of the ITGC campaign Any obvious relocations (e.g. of soil, algal material or vegetation) will be recorded and reported to BAS and NSF.	2	2	4	2	32 Medium

Table 14. Cumulative environmental impact risk assessment of the potential relocation of native species beyond their current natural range.

7.6.2 Cumulative impacts beyond the ITGC campaign

Human activity in Antarctica, in all its forms, continues to expand across the continent and Southern Ocean. The ITGC research campaign will leave its mark as a result of emissions and equipment that will be left in the environment, as well as any pollution incidents that may occur. Albeit modest in the context of the four years of this particular research campaign, the impacts of the ITGC programme will add to the impacts that have occurred during past activities in Antarctica as well as the impacts that will inevitably arise from future activities in the region.

Any attempt to quantify the contribution that the ITGC campaign will make to such cumulative impacts is currently beyond the capability of this EIA given that the international community has placed limited emphasis on monitoring and assessing these incremental, but nonetheless cumulative impacts across broader spatial and temporal scales (Tin et al., 2009).

7.6.2.1 Climate change

The cumulative impacts arising from human activities in Antarctica, also have potential to add to pressures on the environment and on native Antarctic wildlife that are occurring as a result of changing climate conditions in the region – which this research programme is intended to better understand and quantify.

As recorded in Section 6, the Thwaites Glacier region is changing significantly and the present high rate of thinning and acceleration of the glacier are a concern. Glaciers in this configuration are thought to be vulnerable to runaway retreat.

The large scale climate induced changes that are occurring in the region are potentially attributable to the impacts of human activity well beyond Antarctica. The local-scale impacts that will occur as a result of the ITGC research campaign will be negligible in the context of the effects of these much large pressures and are unlikely to make any measurable contribution. The research knowledge that will be gained as a result of this research programme will far outweigh the anticipated environmental impacts.

7.6.3 Impacts on Wilderness Values

While the Antarctic Treaty Parties have not agreed a definition for the term 'wilderness', it is generally understood to represent a measure of the relative absence of evidence of, or impacts from, human activity (EIA Guidelines, 2016).

The ITGC programme represents a significant body of activity over a sustained four season period in what has been one of the least visited parts of Antarctica. Human presence in the region through the establishment of equipment and field camps and the operation of vessels and vehicles all have potential to detract from the wilderness values of the region.

Although very little will be visible even within a few weeks of the conclusion of the research programme, the knowledge and records of any pollution events that occur and the equipment that will be unrecoverable at the end of the ITGC programme, have potential to detract from the sense of wilderness in this part of Antarctica.

As noted above, the international community has made little progress in defining 'wilderness' in an Antarctic context and any attempt to assess the extent to which the ITGC campaign will detract from the current wilderness values associated with the Thwaites Glacier region is only likely to be speculative. Inevitably however, there will be some incremental loss in such values as a consequence of the cumulative impacts of past, present and future activities in the region.

7.7 Summary of impact assessment

Even with no treatment measures in place the majority of activities have been assessed as being likely to pose either low or medium risk to the environment. The fact that most research activities are non-invasive and will occur either in remote glaciological or marine settings reduces the potential environmental impact.

Nevertheless, treatment measures or controls have been identified as being practicable in moderating anticipated impacts in almost all cases. The application of these treatments will ensure greater confidence that the impacts will either be eliminated or minimised.

The raw risk score of a number of outputs were assessed as posing either a high or very high risk to the environment. These were:

- The potential disturbance to one or more seals during the seal tagging work as well as the consequential impacts on the behaviour and capabilities of instrumented seals;
- The risk of introducing non-native species into ice-free terrestrial environments or into the marine environment from a range of activities and equipment deployment;
- The introduction of artificial marine noise from multiple sources during most seasons of the ITGC campaign with potential impacts on the health and behaviour of native marine mammals in the vicinity;
- The potential for a large scale pollution event from the release of large volumes of fuel either into the marine environment *e.g.* from a vessel, or in to the glaciological environment *e.g.* from the rupture of a fuel bladder.

In each of these cases the treatment measures that will be put in place are considered likely to be effective in reducing the environmental risk to medium or low *i.e.* either no more than, or less than a minor or transitory environmental impact.

The assessment also noted a number of outputs that have the potential for a cumulative environmental impact either in conjunction with other ITGC activities, or in conjunction with past, planned or reasonably foreseeable activities in the region. These were the cumulative environment impacts:

- of atmospheric emissions from multiple sources across the four seasons of the research campaign;
- on native marine mammals from multiple anthropogenic noise sources within and across three of the four seasons of the campaign and in conjunction with planned IODP drilling activities in the region during the 2018/19 season;
- of items of equipment being left in or lost to the environment across four seasons of the research campaign, which will add to previously lost items in the region and across Antarctica;
- of the introduction of non-native species into ice-free terrestrial or marine environments;
- of relocating native terrestrial species between ice-free locations.

With no treatment in place each of these risks were scored as either 'high' or 'very high'. However, in each case the planned treatment measures are considered likely to reduce the risk score to medium in each case *i.e.* no more than minor or transitory.

Overall, with the identified treatment options rigorously applied, the outputs from all activities have been assessed as being likely to have no more than a minor or transitory impact on the environment.

8. Record Keeping / Monitoring

This assessment has not identified the need for dedicated monitoring to be undertaken during the ITGC campaign.

Most of the research will involve non-invasive data gathering. Where invasive sampling is undertaken, *i.e.* geological samples and marine sediment cores, the actual or potential impacts of those activities are identified in this assessment as likely to be no more than minor or transitory.

Nonetheless, records will be maintained in many cases both for scientific research purposes as well as for post-season / post-campaign reporting. These records will include:

- The quantities of explosives used;
- The location, type and volume of any fuel or other hazardous substances spills;
- The type and location (as accurately as may be possible) of any equipment inadvertently lost to the environment;
- The type and location of any equipment that is unrecoverable;
- All benthic / sediment and water column sampling locations and the volumes of sediment recovered;
- All geological sampling and coring locations and the quantities of material recovered;
- Any significant observed wildlife disturbance events, including any wildlife fatalities - which will be immediately reported to BAS and/or NSF;
- Any observed non-native species incursions or any items of equipment contaminated with biological material or soil;
- The types and volumes of fuel that are used throughout the course of the campaign, which will be used to calculate the greenhouse gas emissions for inclusion in annual carbon reporting obligations.

The above information will be recorded in an annual and post-Expedition report and provided to the FCO and NSF.

9. Gaps in knowledge and Uncertainties

No expedition to Antarctica can be planned with absolute certainty, due to the extreme, changeable and unpredictable environmental conditions.

Although the research objectives are clearly described and the research methods and equipment to be used have been identified, there remain a number of unknowns that will require flexibility during the expedition. These are set out below.

9.1 Weather conditions

The weather in Antarctica can be highly variable both between and within summer seasons. Conditions can also change dramatically in short periods of time. This variability and unpredictability may require a number of adjustment to plans, both within and between seasons.

Weather conditions have the potential to impact on the schedule of the ITGC. Inter- and intra-continental flights may be delayed due to poor weather conditions at points of departure or destination, and weather conditions during the operational and scientific traverses will further determine the extent to which research objectives within any one season can be met.

It is possible therefore that activities get 'pushed' from the planned season to subsequent summers.

9.2 Sea ice conditions

Sea ice is extremely persistent in the Amundsen Sea, contributing to its limited previous exploration. In terms of time the vessels are available, ship schedules are planned well in advance and fairly inflexible, so whilst in the region ships must be utilised wherever access can be achieved. Therefore exact locations of ship based activities cannot be predicted. An example is offload of traverse equipment in early 2019, with the Stange Ice Shelf as the preferred location and sea ice near Smyley Island as back-up. A revised location may cause some delays and increased fuel use from longer surface routes.

9.3 Extent of sediment sampling

As noted, marine operations will by necessity be shaped by sea ice and weather conditions. Not all sampling attempts may be successful, and the sampling programme will need to be responsive to preliminary results. The precise number and location of sediment samples to be taken therefore cannot be defined in advance.

9.4 Equipment loss

Some non-recovery of equipment is anticipated, *e.g.* weights released from transponders, the expendable oceanographic profilers and instruments that are frozen into or beneath the ice. It is also possible that weights from an AUV could be dropped in an emergency, or that an AUV itself or other autonomous equipment (*e.g.* glider, RPA, icefin) could fail and be lost to the environment. Moorings, drill equipment, corers etc. are also at some risk of loss.

This IEE has not attempted to quantify the materials that will remain in the ice after the ITGC. Provide records are maintained throughout the ITGC campaign it should be possible to estimate total quantities of unrecoverable equipment on conclusion of the research programme.

9.5 Fuel use

Not all fuel figures are currently known. Actual fuel burnt during the ITGC campaign will likely vary depending on a range of factors, including for example, vehicle efficiency, changes to operational planning or weather conditions. Weather and sea ice conditions will affect schedules and routing, which may result in changes to fuel use. Therefore the figures used in this EIA and the calculations of predicted emissions are indicative only.

Here also, provided records are maintained (annually) of the amounts of fuel burnt each season, more accurate emissions data can be generated after the end of each season.

9.6 Equipment still to be confirmed or under development

The details of some equipment to be used is not fully known at the time of preparation of this IEE, for example the types of helicopters to be carried on the ships. Other equipment is still under development, such as the RAM drill. However it is not expected that the final options will alter the current assessment of effects.

9.7 Marine acoustic assessment

The EIA has not evaluated the full acoustic profile of the various sources of marine noise that will occur during the ITGC campaign. No modelling has been undertaken. The IODP cruise and the 2019/20 research cruise to be supported by the Nathaniel B Palmer will each be assessed through separate EIAs. This makes the assessment of cumulative effects of marine noise challenging and remains a gap in this assessment.

9.8 Unknown terrestrial environments

The general locations for terrestrial surface geological sampling (Pine Island Bay, Mt Murphy and the Hudson Mountains) have been rarely visited previously if at all, and there are a few biological records (see 6.4.2). Only sporadic observations and samples appear to have been undertaken at these locations. Overall, information on terrestrial biota is very sparse and flora and fauna at the specific sites to be visited may well be different from those sampled previously. We know that prolonged isolation of the ice-free areas in this region has given rise to unusual biological communities and high degrees of endemism. It is therefore difficult to predict or indeed verify any impacts on the biota from geological sampling, but in accordance with the SCAR Code of Conduct for Terrestrial Scientific Field Research, clothing and equipment will be thoroughly cleaned before visits and between sites to avoid introduction or transfer of species occurs and precautions to avoid damage to identifiable vegetation will be taken.

Researchers visiting these ice-free locations will be encouraged to undertake a quick biological survey of the sites to the extent practicable (Appendix A).

10. Summary and Conclusion

This IEE has described the proposed activities to be conducted by the ITGC research campaign (Section 4); considered a number of alternatives to various aspects of the Expedition (Section 5); described what is known about the current environmental state (Section 6); assessed the potential environmental impacts that are likely to, or could arise (Section 7); outlined the mitigation measures to prevent or minimise any potential environmental impacts that may occur (Section 7), and described the records that will be maintained of any environmental impacts that do occur (Section 8).

This assessment was undertaken on a worst-case scenario evaluation. Consequently, with no treatments in place, a number of activities were assessed as posing a ‘high’ or ‘very high’ risk to the environment with impacts potentially being more than a minor or transitory.

However, in almost all cases practicable treatment options have been identified. The ITGC research programme aims to prevent or reduce potential environmental impacts through careful planning, training, execution and the availability of highly experienced operators and technicians. The two national Antarctic programmes that will be undertaking or supporting the majority of the activities have many decades of experience of operating in the region. Provided the mitigation measures described in Section 7 (summarised in Table 8) are adhered to, the environmental impacts of the Expedition are considered to be largely avoidable or can be minimised to an acceptable level.

Overall, this IEE considers that the potential environmental impacts arising from the ITGC campaign will have **no more than a minor or transitory impact** on the environment.

It is concluded that this level of predicted impact is acceptable given the significant scientific knowledge that will be gained as a result of undertaking the Expedition.

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Appendix A

Ad hoc Biological Observations Guide / Record Sheet

Context:

Several of the ice-free locations that will be visited during the ITGC Campaign have rarely, and potentially never, been visited before. This makes it challenging to fully assess the actual or potential impacts of the planned activities – particularly with regard to local native biota.

To assist this concern, it is proposed that researchers visiting ice-free locations take some time to observe and record native biota. This will assist in improving the records and information from this rarely visited sector of Antarctica and provides the opportunity to revisit any additional treatments or controls that may be required during the ITGC campaign with regard to these ice-free sites.

Purpose of this document:

To provide a guide to and record sheet for recording biological observations when visiting ice-free locations during the ITGC campaign.

Introduction:

Biota anticipated to be present in the Thwaites area is likely to be quite cryptic (which means physically small, and not the sort of thing you will notice unless initially pointed out to you). Potential habitats include:

- rock and boulder faces (Figure 1);
- along ridge lines and the tops of major boulders;
- crevices between rocks and boulders where any sediment and water can concentrate (these can be very small – the lichens that grow in them may be only a few mm across – Figures 2, 3 and 4);
- flatter areas of 'soil' (e.g. in valleys) and biological soil crusts. These are a major microbial habitat, though very hard for non-experts to identify. The main giveaway is that the surface of the soil sticks together, so when touched or stepped on it does not simply break into dust, but into small plates or fragments (Figure 5);
- freshwater bodies e.g. streams, ponds, moist ground (Figure 6);
- seal wallows if near the coast;
- bird nesting areas inland on rock.

Anticipated biota may include:

- a range of lichens (Figure 1, 2 and 3),
- possibly some mosses,
- freshwater bodies will likely have filamentous algae or mats on their bottoms. If water bodies are under ice, trapped air bubble tracks in the ice are an indicator of cyanobacterial activity (Figure 6). Freshwater bodies may even have tiny crustaceans, though these are likely to be hard to spot;
- seal wallows and nests may also have algal growth in and around them;
- mites and springtails (possibly highly endemic), as well as micro-invertebrates (tardigrades, rotifers, nematodes, again likely to be regionally endemic) - we have no previous survey information on these, but they are in all other places examined. However, at mm to sub-mm size most people are unlikely to spot these, but they will very likely be contained in any vegetation or microbial mats/crusts found.

Observations:

As time allows, it is suggested that researchers use the following checklist to guide and record a biological assessment of the local area in which they are working.

It is suggested that observations start at the broader 'landscape' level and then focus in on more specific habitats e.g. flat coastal areas; any areas of soil; any freshwater locations (ponds, moist ground, streams); any wallow or nesting areas (though be very aware of approach limitations); ridge lines; rocky outcrops and crevices between rocks; slopes and cliffs; moraines; areas of bedrock etc.

Observations within your area of work is all that is expected e.g. if geologists are walking a track to find suitable sampling sites then records along that track will be helpful. Seal taggers are likely to be confined to coastal locations and observations within this area of operation will suffice.

Simple observations and photographic records are all that is expected, which the following checklist is intended to assist.

It will be particularly interesting to use the information to ascertain habitat and/or biological differences between locations e.g. between islands in Pine Island Bay or between nunataks.

Please return completed form(s) to the Environmental Office, British Antarctic Survey c/o Rachel Clarke - racl@bas.ac.uk

Thank you.

Checklist:

Site / Location name.

Observers names.

Time and date of observations.

GPS coordinates.
Either point locations at key habitat / observation sites or boundaries of area surveyed, if possible.

Altitude (if possible).

General description of the site.

e.g. gently sloping rock shore, or undulating rocky / boulder headland etc. Rock type if geological knowledge available. Please note presence and coverage of snow or ice patches. Photographs of the general area would be helpful.

Any key feature(s) of the site.

e.g. large number of ponds, extensive flat ground, geothermal area, streams, seal wallows, penguin / bird colonies, high cliffs etc. Photographs of such features would be helpful.

Approximate area surveyed in detail (m^2).

Observations of biota.

Habitat – *e.g. soils, rock face, rocky crevice, moist ground, pond etc. If ponds, please note if frozen, partial ice coverage or ice free. Please photograph.*

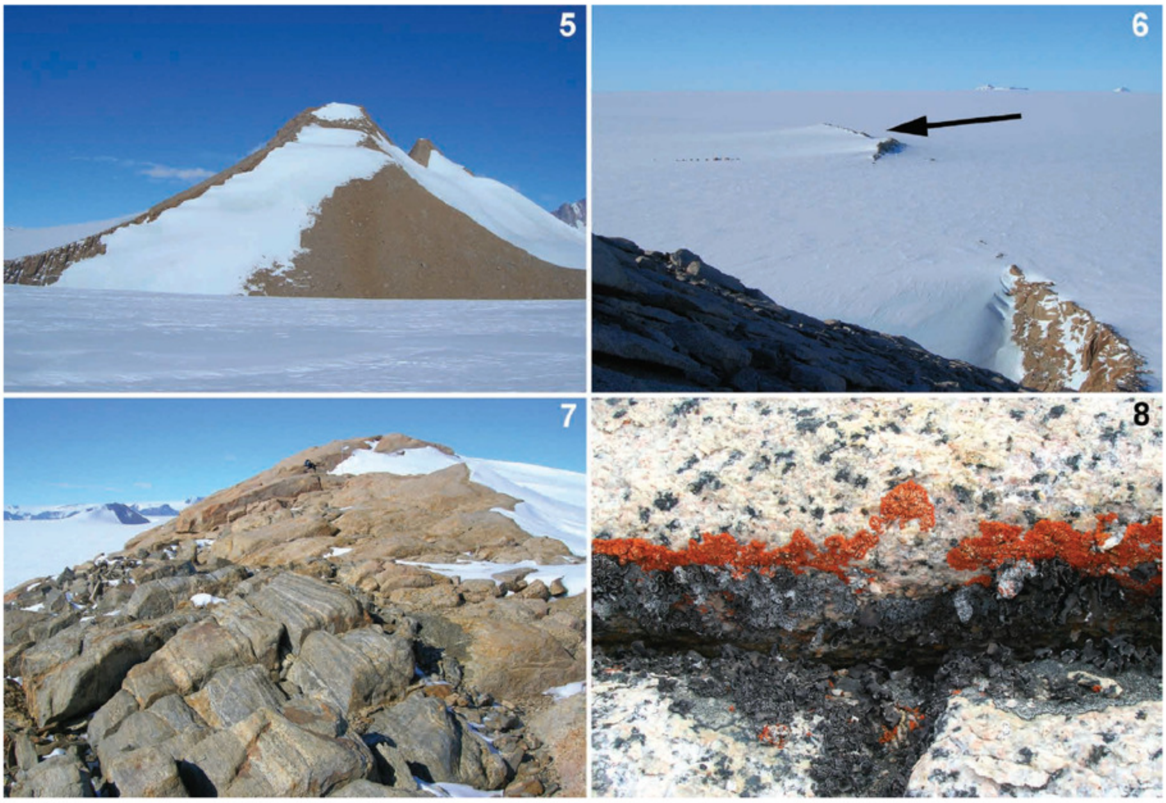
Biota observed – *e.g. alga, lichen, moss etc. Please photograph.*

Extent – *single observation, a few individuals, numerous individuals, extensive coverage etc. Please photograph.*

Other observations.

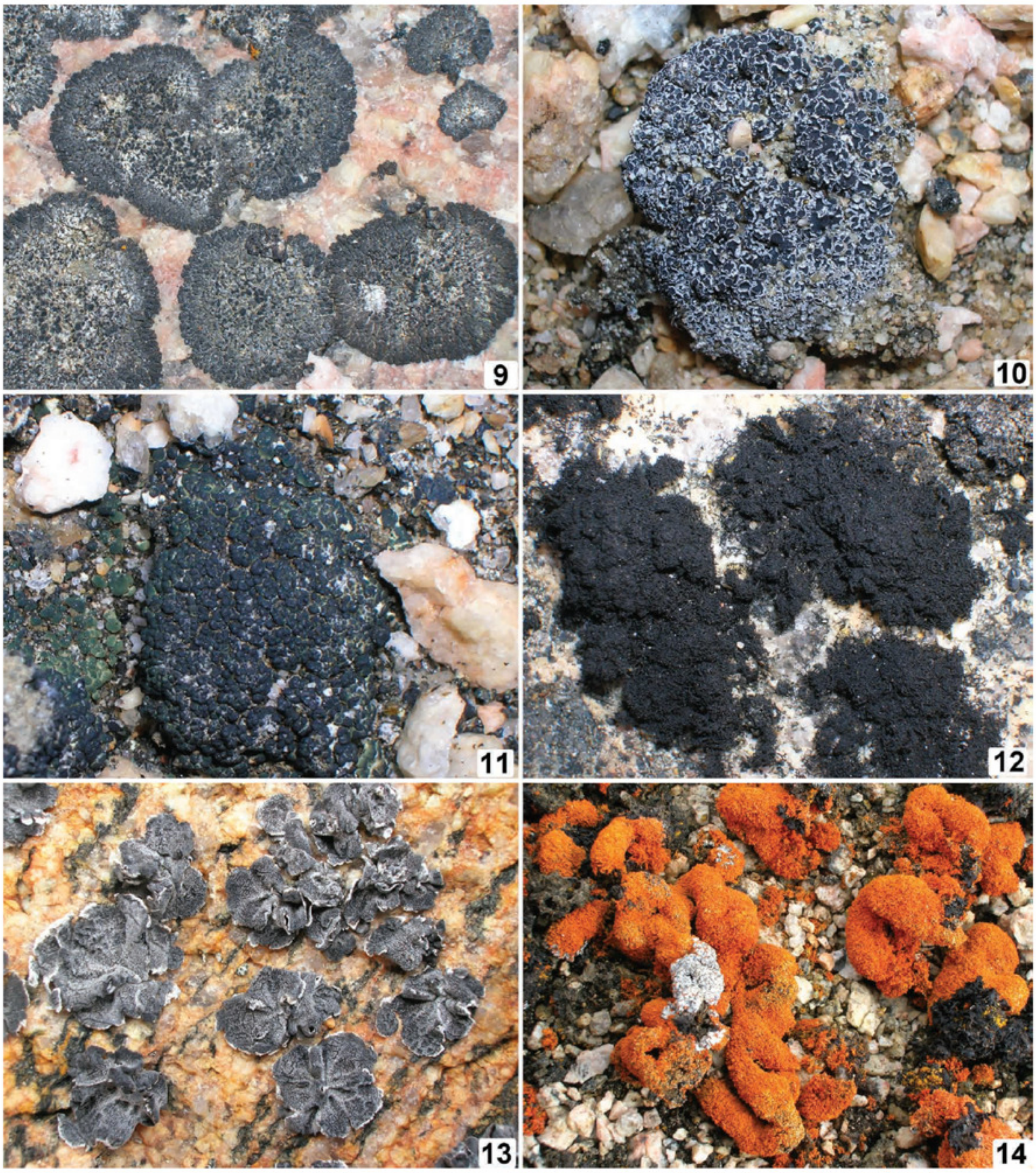
Reference images:

Figure 1. Usnea Antarctica. Image: Milos Bartak, Masaryk University, Czech Republic



FIGURES 5–8. Studied sites in 2007, before the construction of the Belgian Antarctic research station. Fig. 5. Utsteinen Nunatak viewed from the Utsteinen Ridge; Fig. 6. Utsteinen Ridge (arrow) viewed from the eastern side of the Utsteinen Nunatak, with the camp (tents) on the left; Fig. 7. plot 20 of the Utsteinen Ridge; Fig. 8. Granite rock with a crack bordered by a lichen vegetation including *Buellia frigida*, *Physcia caesia*, *Umbilicaria aprina* and *Xanthoria elegans*.

Figure 2. Examples of a nunatak with lichen growing in rock crevices. Figure taken from Ertz, D., Aptroot, A., Van de Vijer, B., Sliwa, L., Moermans, C and Ovstedal, D. 2014. Lichens from the Utsteinen Nunatak (Sor Ronde Mountains, Antarctica), with the description of one new species and the establishment of permanent plaots. Phytotaxia, 191(1): 99-114.



FIGURES 9–14. Diversity of lichens on the Utsteinen Nunatak. Fig. 9. *Buellia frigida*; Fig. 10. *Lecanora expectans*; Fig. 11. *Lecanora fuscobrunnea*; Fig. 12. *Pseudephebe minuscula*; Fig. 13. *Umbilicaria decussata*; Fig. 14. *Xanthomendoza borealis*.

Figure 3. Examples of Antarctic lichen. Figure taken from Ertz, D., Aptroot, A., Van de Vijer, B., Sliwa, L., Moermans, C and Ovstedal, D. 2014. Lichens from the Utsteinen Nunatak (Sor Ronde Mountains, Antarctica), with the description of one new species and the establishment of permanent plaots. Phytotaxia, 191(1): 99-114.

Figure 4. Granite Harbour, Ross Sea Region. Rocky coast with arrows identifying locations of biological material on rock surfaces and in rock crevices. Image: Yvonne Martin, Antarctica New Zealand Pictorial Collection.

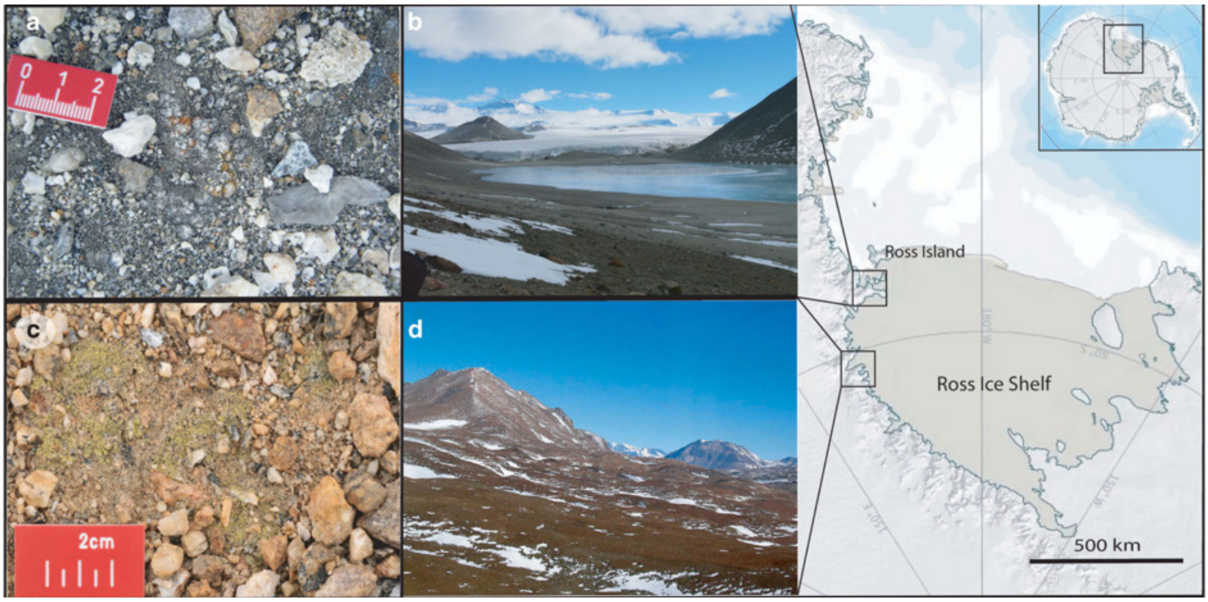


Figure 5. An example of a lichen dominated biological soil crust (figure a and b) from the Garwood Valley in the McMurdo Dry Valleys and a lichen dominated biological soil crust (different species) from Diamond Hill, Darwin Mountains (figures c and d). Figure from: Colesie, C., Green, T.G.A., Haferkamp, I. and Budel, B. 2014. Habitat stress initiates changes in composition, CO2 gas exchange and C-allocation as life traits in biological soil crusts. The ISME Journal 8, 2104-2115.

Figure 6. Air bubbles and cyanobacterial mats (brown patches) caught in lake ice. Lake Bonney, McMurdo Dry Valleys, Antarctica. Image: Andy Thompson, Colorado State University.