EUMETSAT

Altimeter Wave and Wind data for Mariners and Scientific Community

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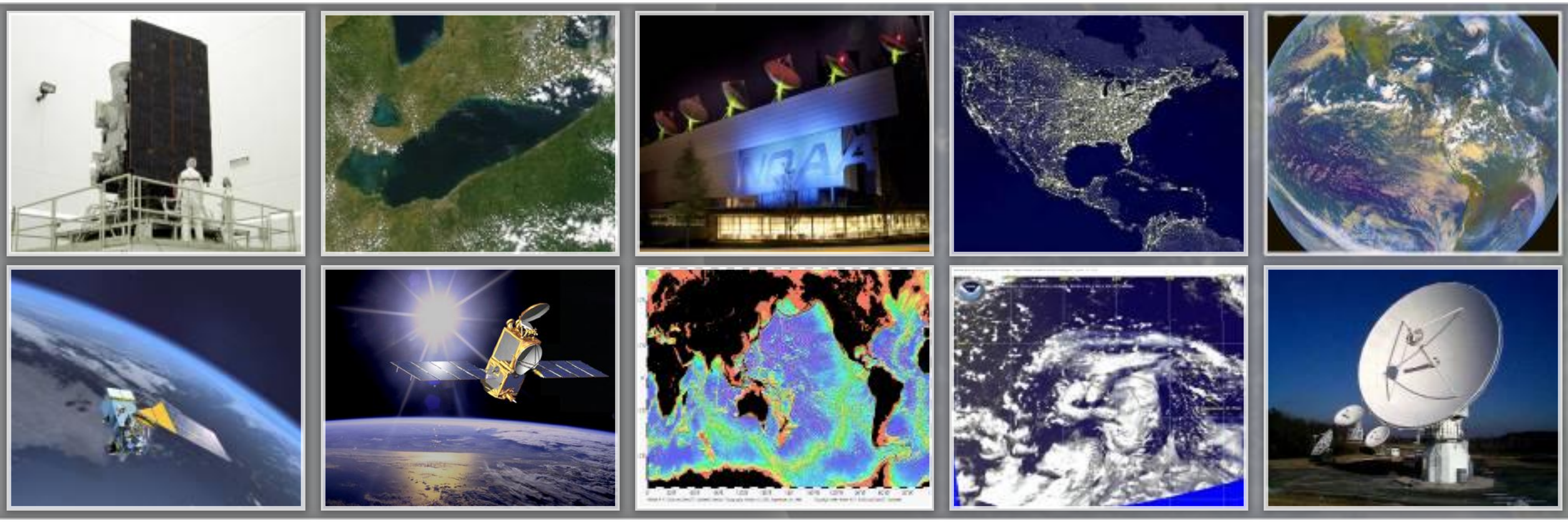
National Oceanic and Atmospheric Administration



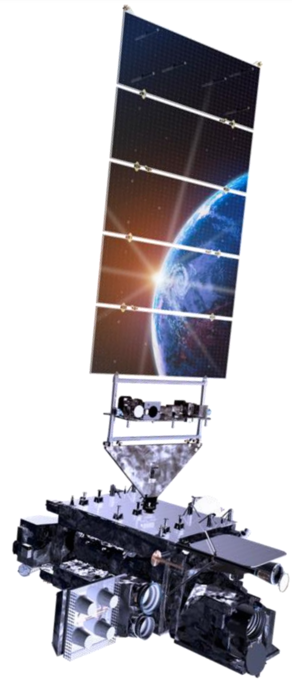
http://www.noaa.gov

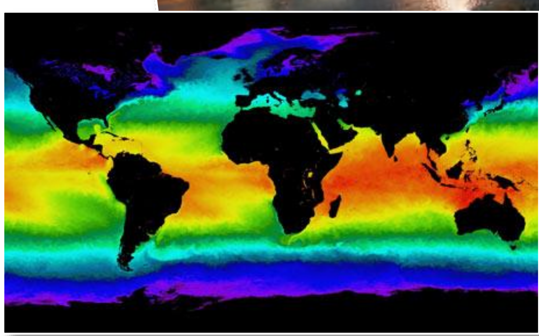
NOAA Satellite and Information Service

NOAA Organization

- National Ocean Service
- National Environmental Satellite, Data, & Information Service
- Oceanic & Atmospheric Research
- National Marine Fisheries Service
- National Weather Service
- Office of Marine and Aviation Operations

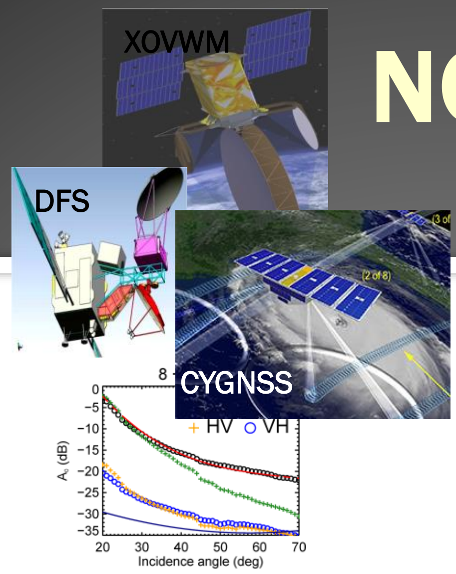
NOAA Satellite and Information Service (NESDIS)

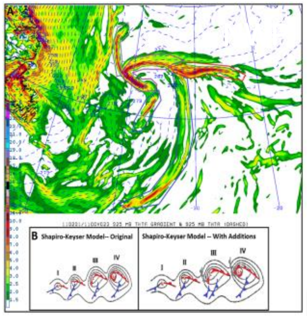


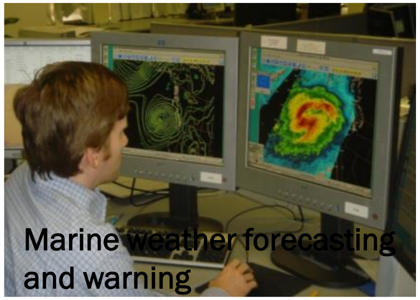


Our mission is to deliver accurate, timely, and reliable satellite observations and integrated products and to provide long-term stewardship for global environmental data in support of the NOAA mission.

NOAA Ocean Winds Team





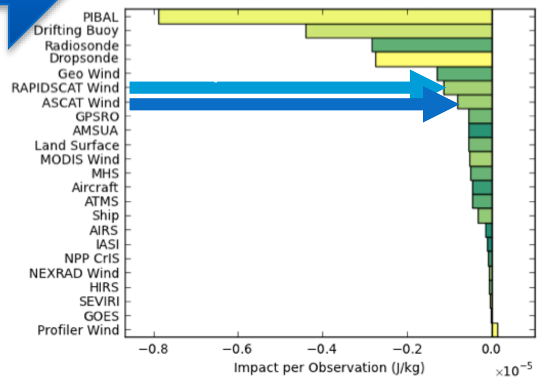


Development,calibration, validation and product improvements of current scatterometer and radiometer satellite measurements

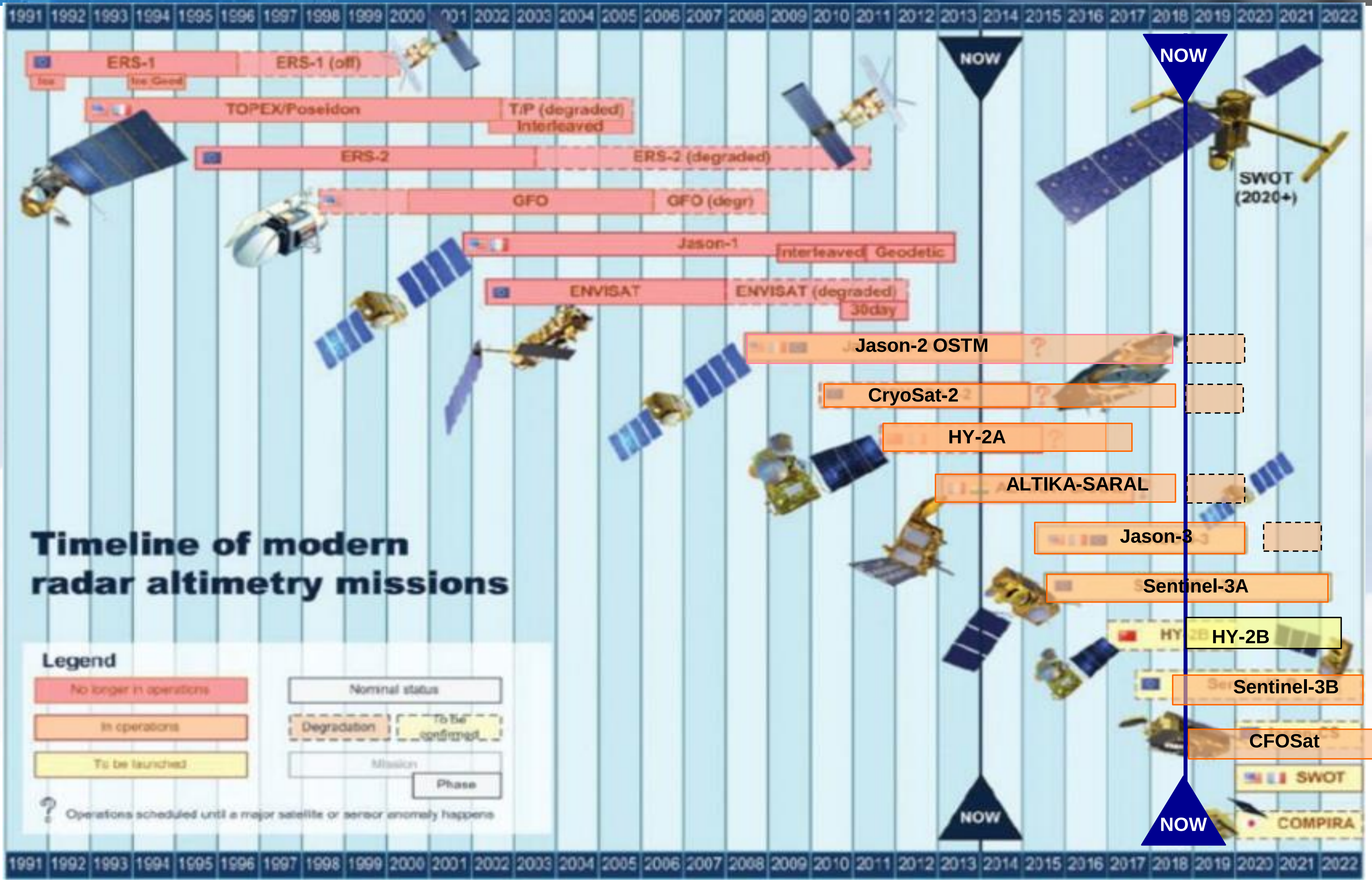
New instrument design and risk reduction for future satellite instruments

New insights into physics of hurricane force winds within extratropical storms

R20



History of Modern Altimetry Missions



Frequencies of Current Sensors

	Agency	Launch	Altitude	Name	Frequency	Repeat Cycle	Inclination
Jason-2/3 	CNES / NASA / Eumetsat / NOAA	2008 /2016	1336 km	Poseidon-3	Ku and C-band	10 days	66°
Cryosat 	ESA	2009	720 km	SIRAL	Ku-band	369 days	92°
Saral	ISRO / CNES	2009	800 km	AltiKa	Ka-band	35 days	92°
No NRT Data Access							
Sentinel 3	ESA	2012	814 km	SRAL	Ku and C-band	27 days	98.5°
CFOSAT	CNES	2018	520km	SWIM	Ku-band	13 days	98^0

- **Sea Surface Height**
- **Significant Wave Height**
- **Sea Surface Wind**
- **Sea Ice**

Frequencies Used and Their Impact

- **Ku band (13.6 GHz):**

  Best compromise between the capabilities of the technology (relating to power emitted), sensitivity to atmospheric perturbations, and ionospheric electrons.

- **C band (5.3 GHz):**

  More sensitive to ionospheric perturbation than Ku, and less sensitive to the effects of atmospheric liquid water. Its main function is to enable correction of the ionospheric delay.

- **S band (3.2 GHz)**

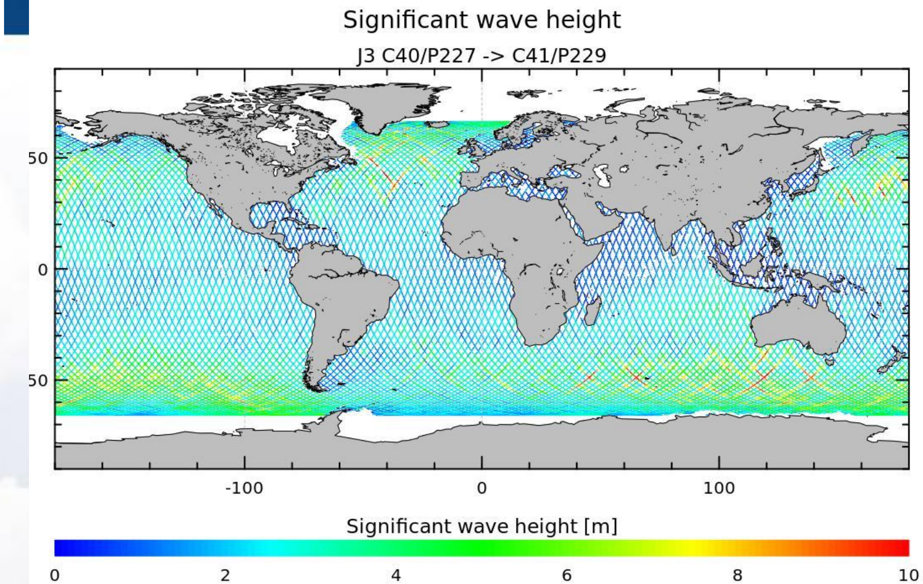
  S band is also used in combination with the Ku-band measurements, for the same reasons as the C band.

- **Ka band (35 GHz):**

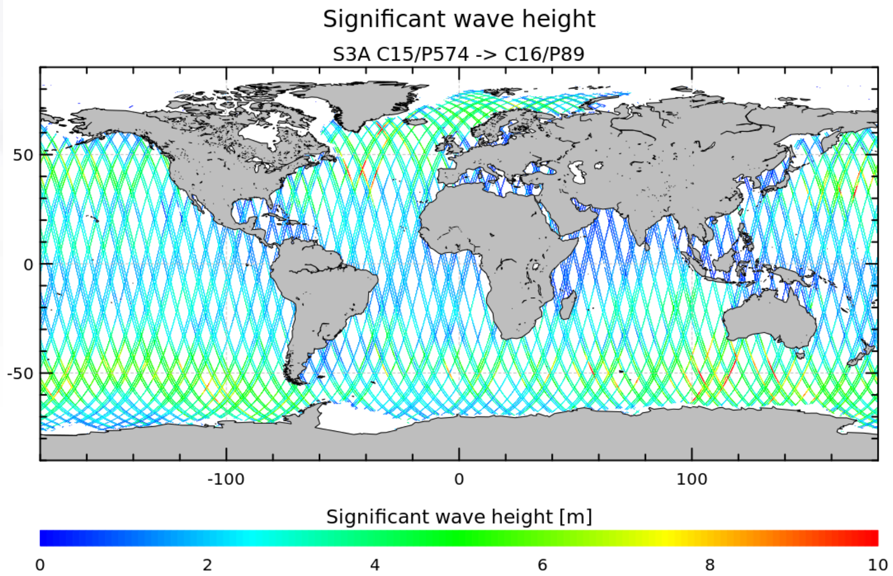
  Due to international regulations governing the use of electromagnetic wave bandwidth, a larger bandwidth is available than for other frequencies, thus enabling higher resolution, especially near the coast. It is also better reflected on ice. However, attenuation due to water or water vapour in the troposphere is high, meaning that no measurements are produced when the rain rate is higher than 1.5 mm/h.

Inclination Angle and Coverage

Jason - 2/3
66^0 inclination



Envisat/Saral(Altika)/Sentinel 3a/CFOSAT
88-98^0 inclination

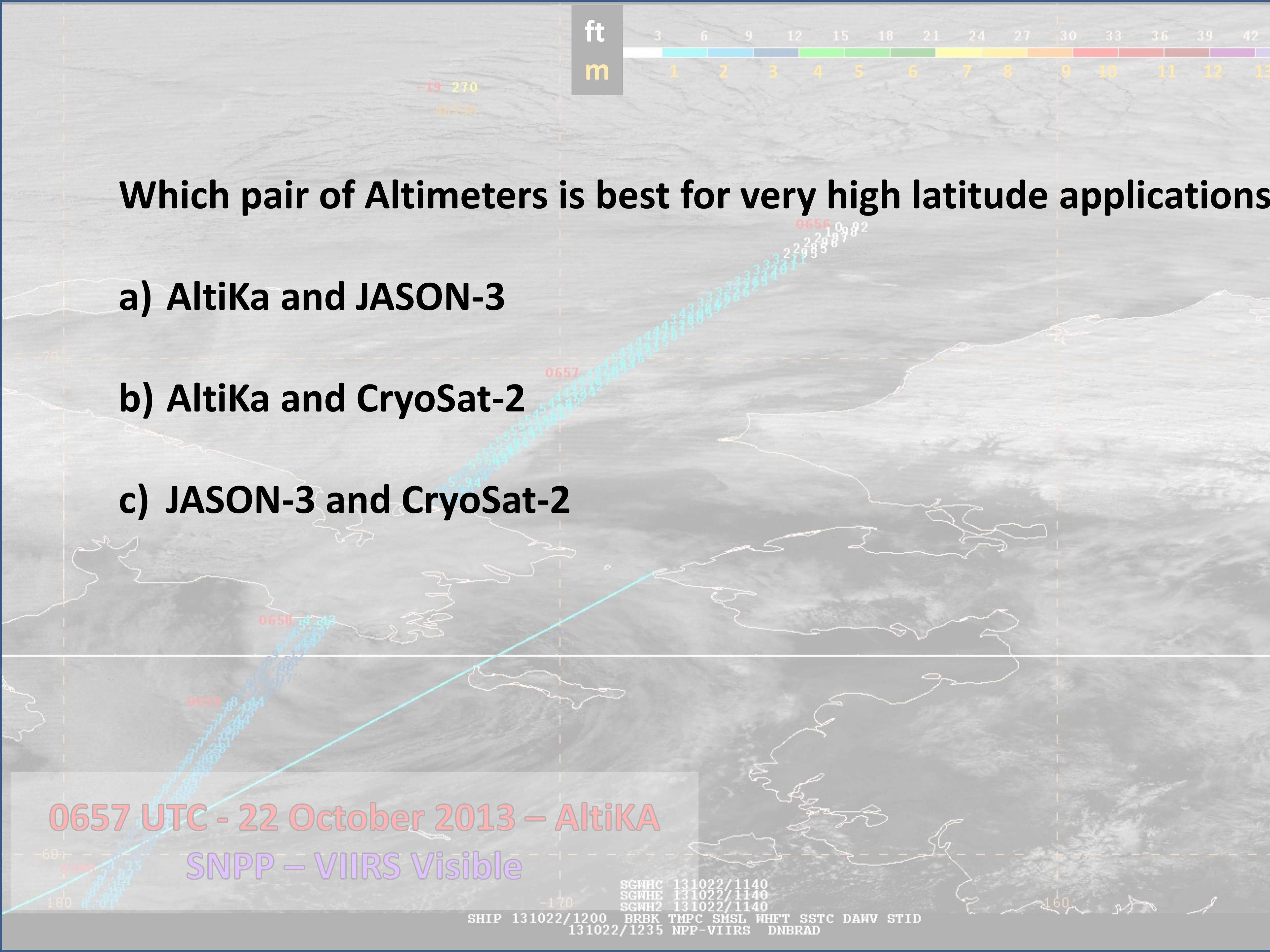


Which pair of Altimeters is best for very high latitude applications

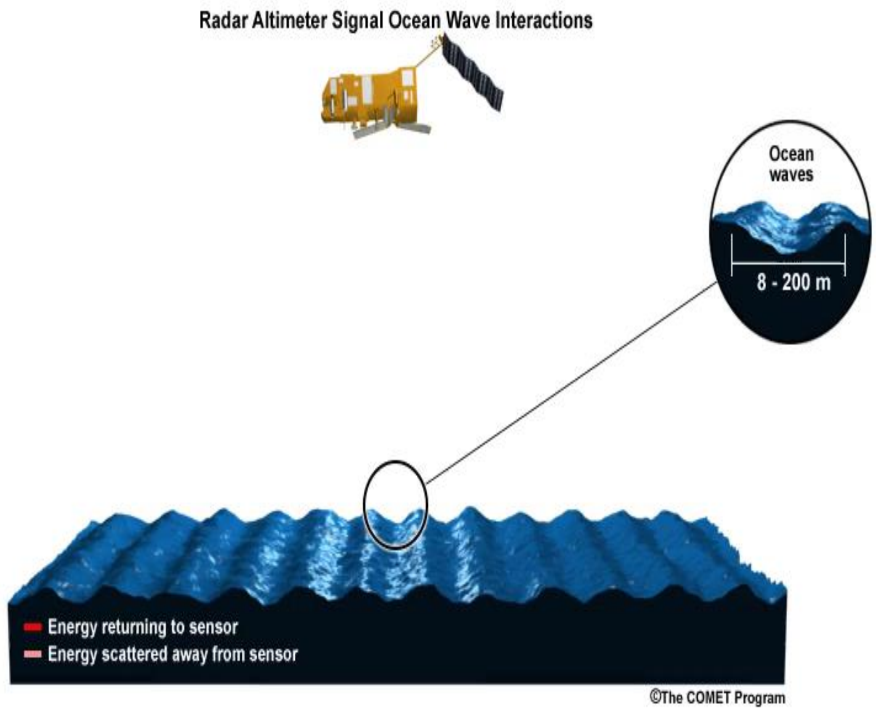
a) AltiKa and JASON-3

b) AltiKa and CryoSat-2

c) JASON-3 and CryoSat-2



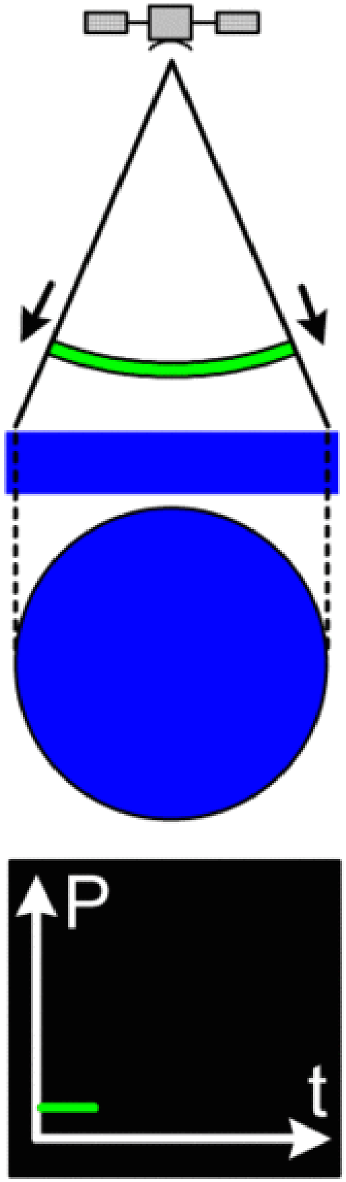
Altimetry Basics



- The altimeter transmits a short pulse of microwave radiation with known power toward the surface.
- The pulse interacts with the rough surface and part of the incident radiation reflects back to the altimeter.
- The power in the returned signal is detected by a number of gates (bins) each at a slightly different time

- Sea Surface Height
- Significant Wave Height
- Sea Surface Wind
- Sea Ice

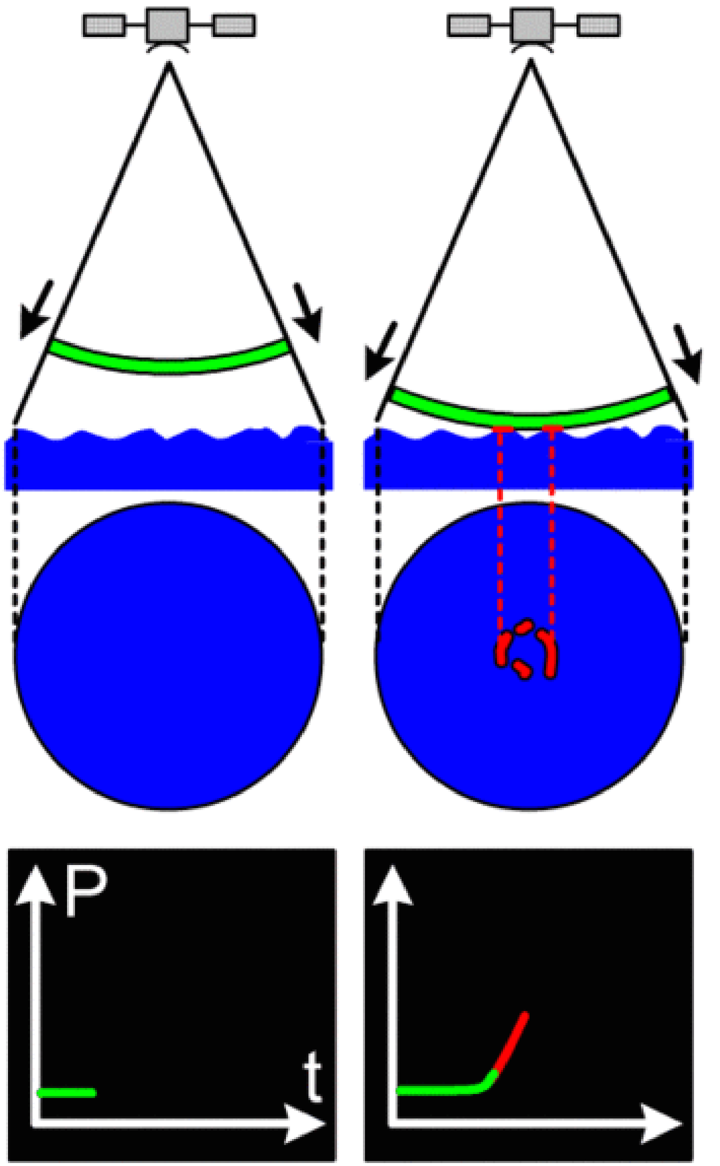
Ideally Calm Surface



Before radiation hits ocean surface we measure:

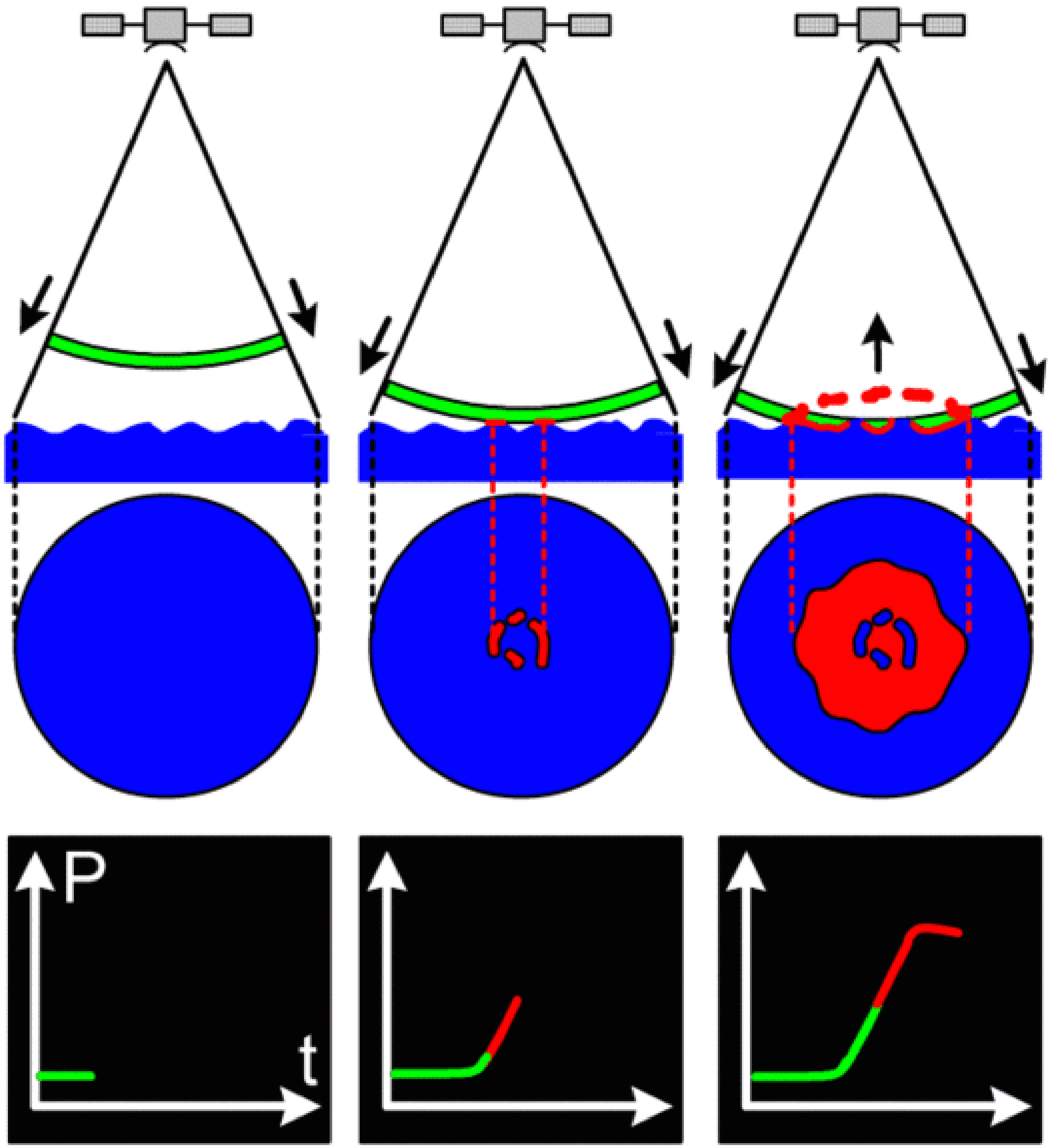
Noise Power: parasite reflection of the pulse in the ionosphere and atmosphere, in addition to the instrument electronic noise.

rough sea



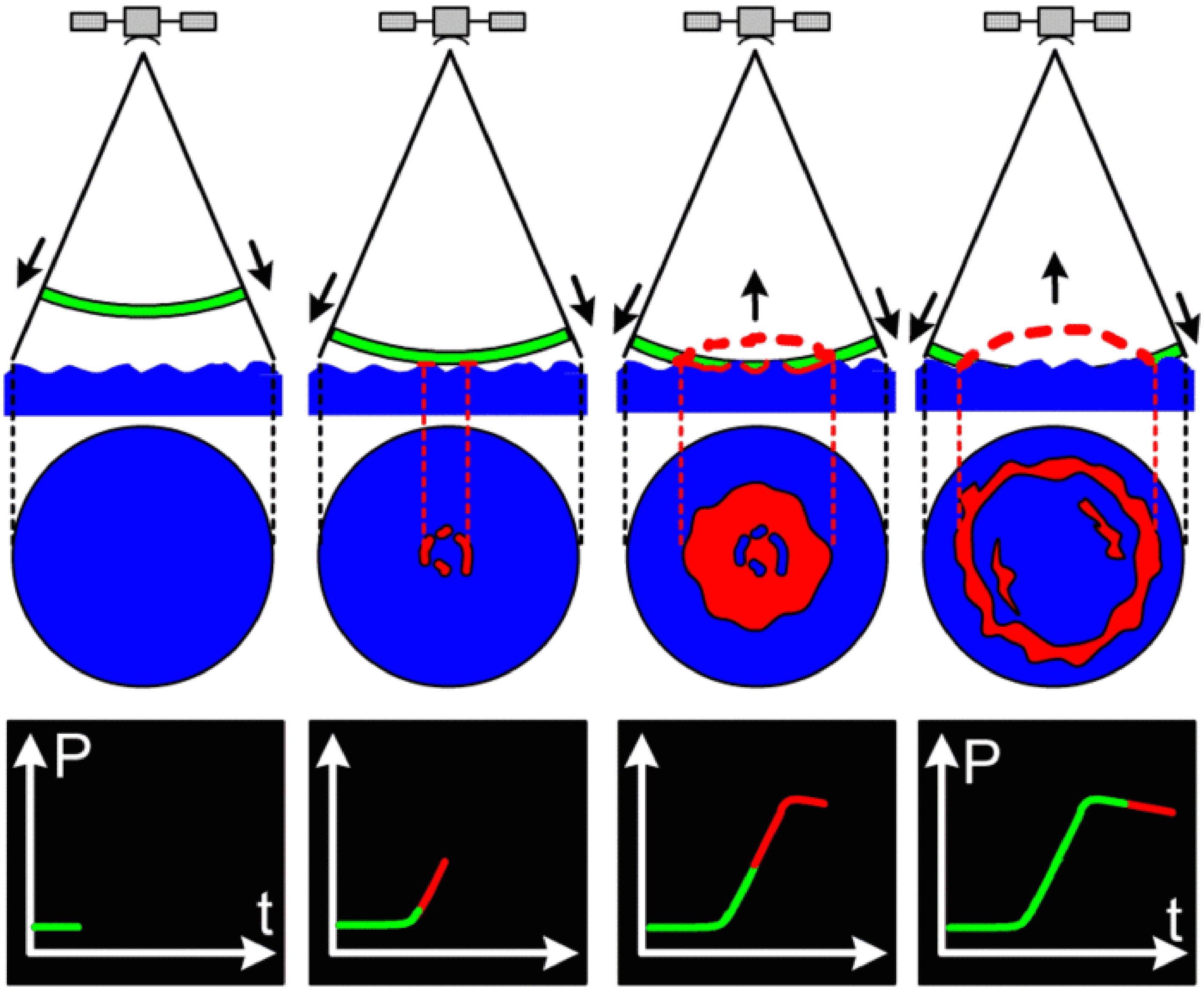
In sea swell or rough seas, the wave strikes the crest of one wave and then a series of other crests which cause the reflected wave's amplitude to increase more gradually.

rough sea



The returning echoes are a blend of thousands of little echoes from within the footprint, some coming from the troughs of waves, some coming up from wave peaks. With waves up to many metres in height, this creates a mish-mash of echoes from varying heights.

rough sea



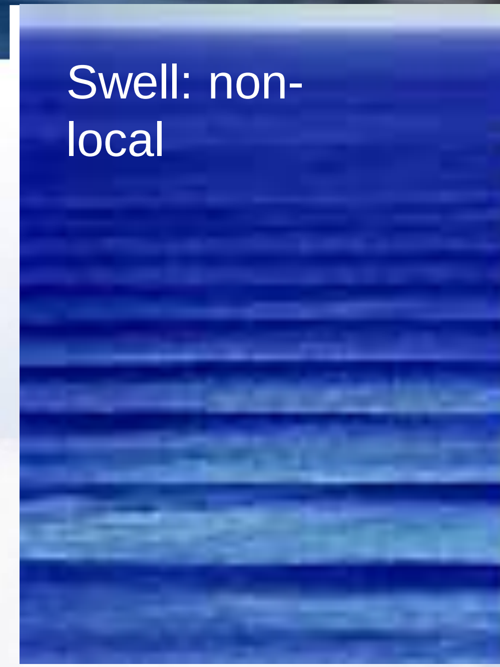
As a result of random distribution of the ocean wave facets at any instant, each individual return signal is very noisy, but averaging of up to 1000 successive echo pulses can reduce this.

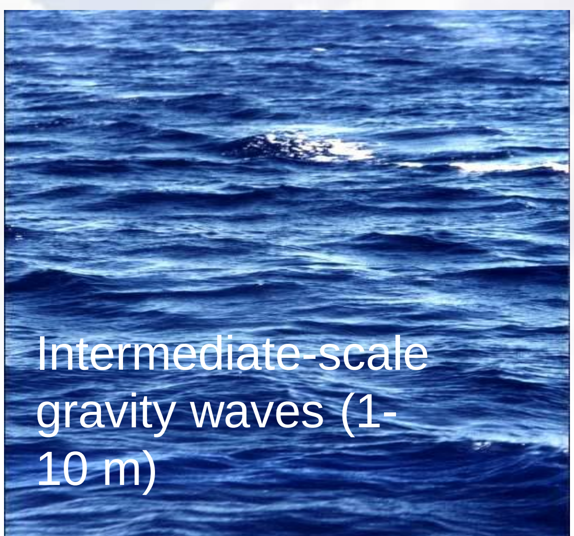
The pulse repetition frequency is thousands per second

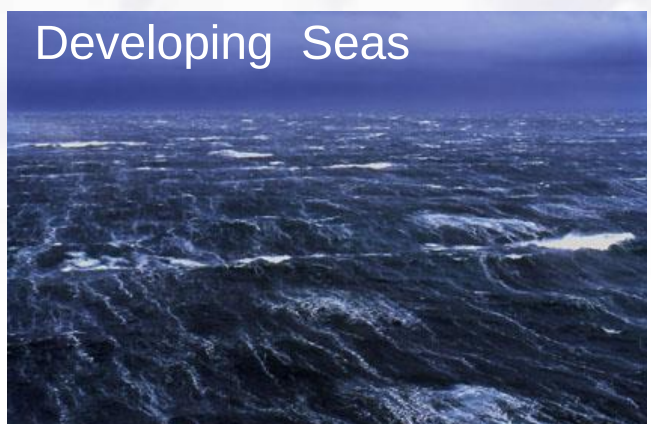
- 1800 for Jason 2/3
- Usually data are transmitted to the ground at ~20Hz and then averaged to ~1 Hz

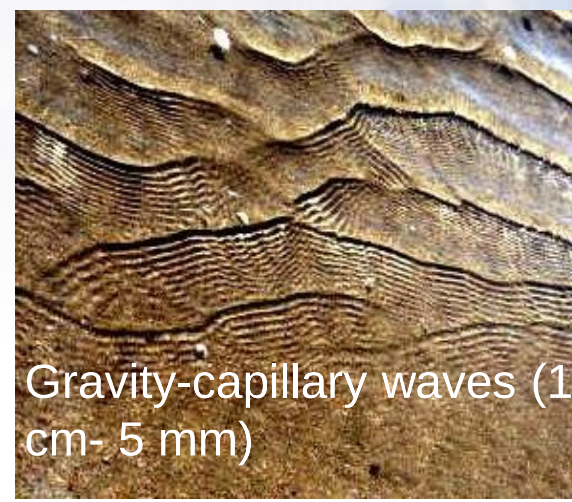
A Rough Ocean Surface and Altimetry

- The full spectrum enfolds quasi-linear ocean gravity waves, breaking waves, nonlinear wave-wave interactions and small-scale wave dynamics.
- Altimetry can get at both the short ripples (wind speed) and the elevation variance (SWH)

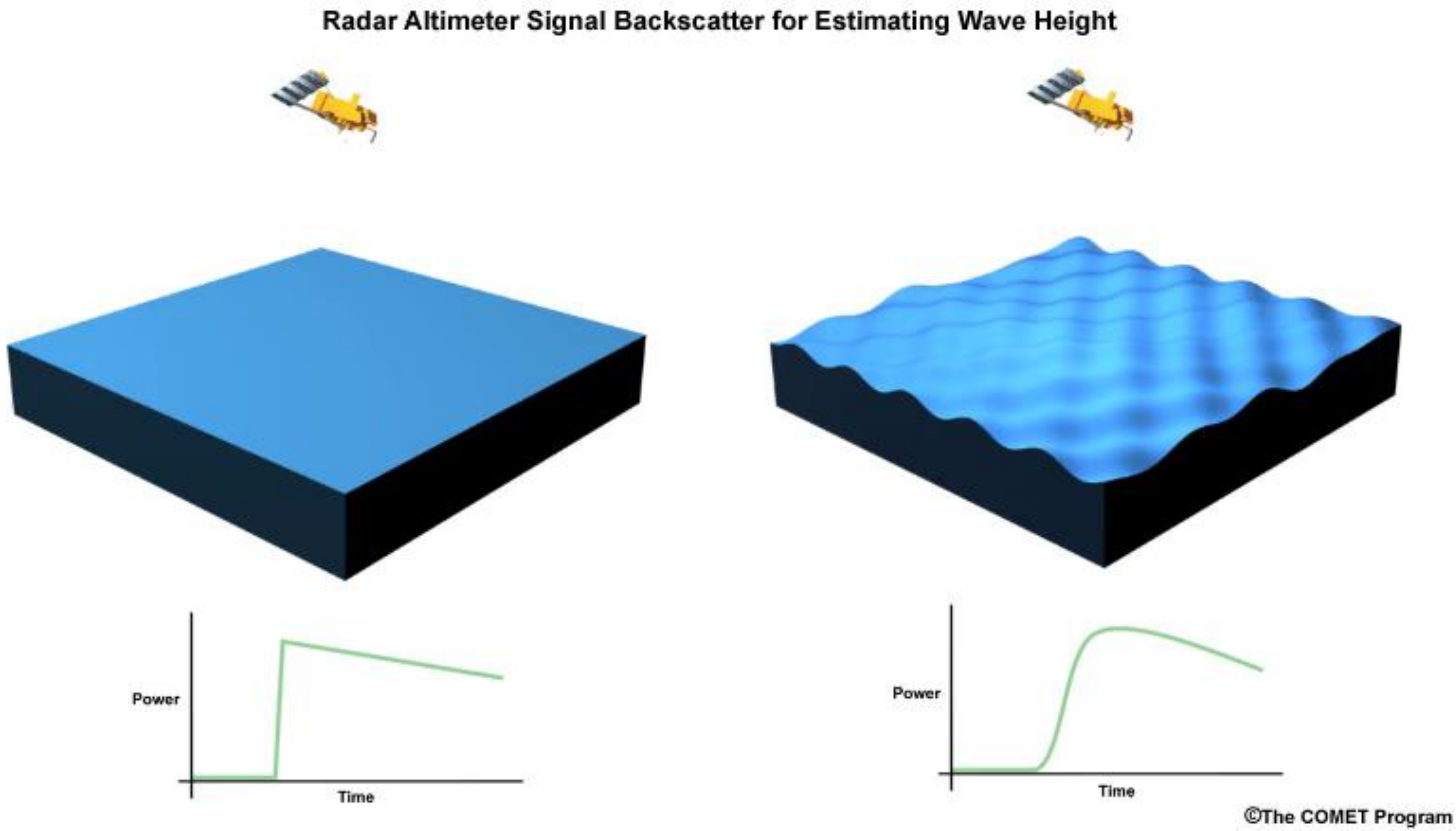




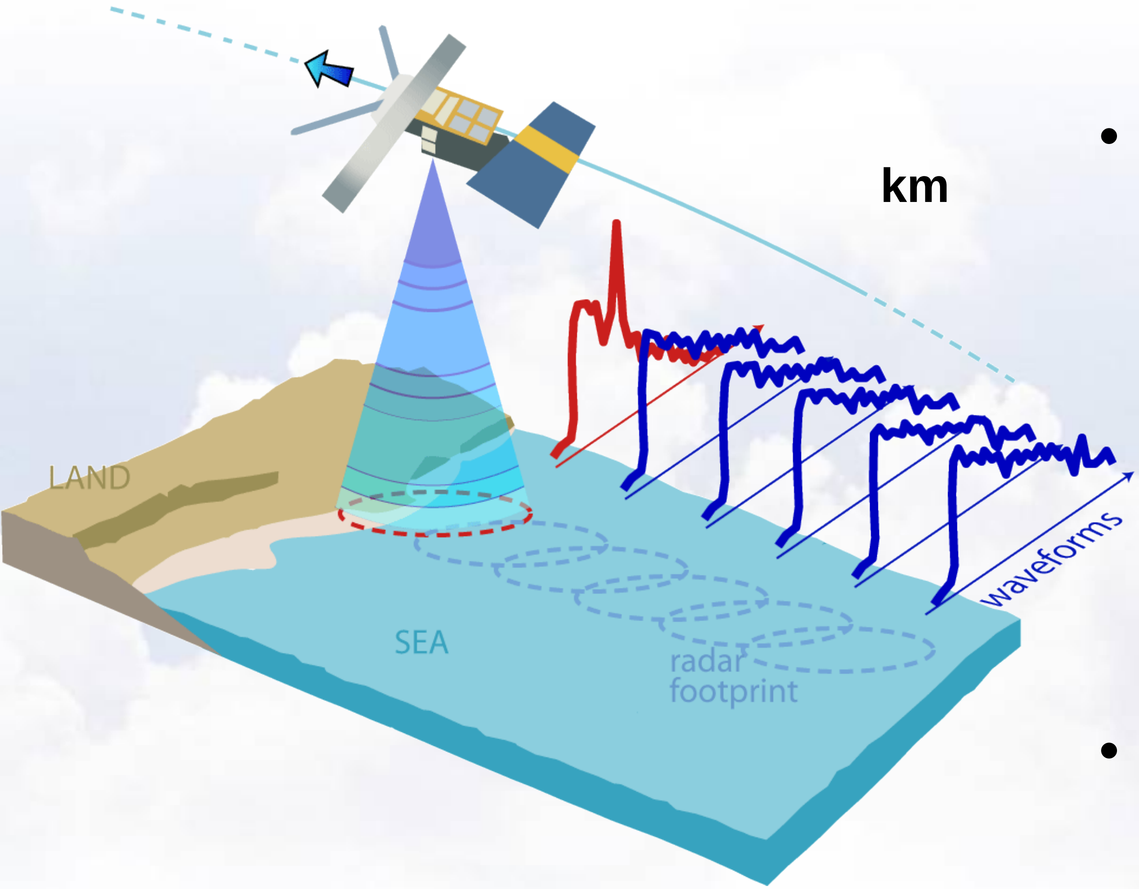




Flat vs Rough Surface Responses



Altimeter Swath

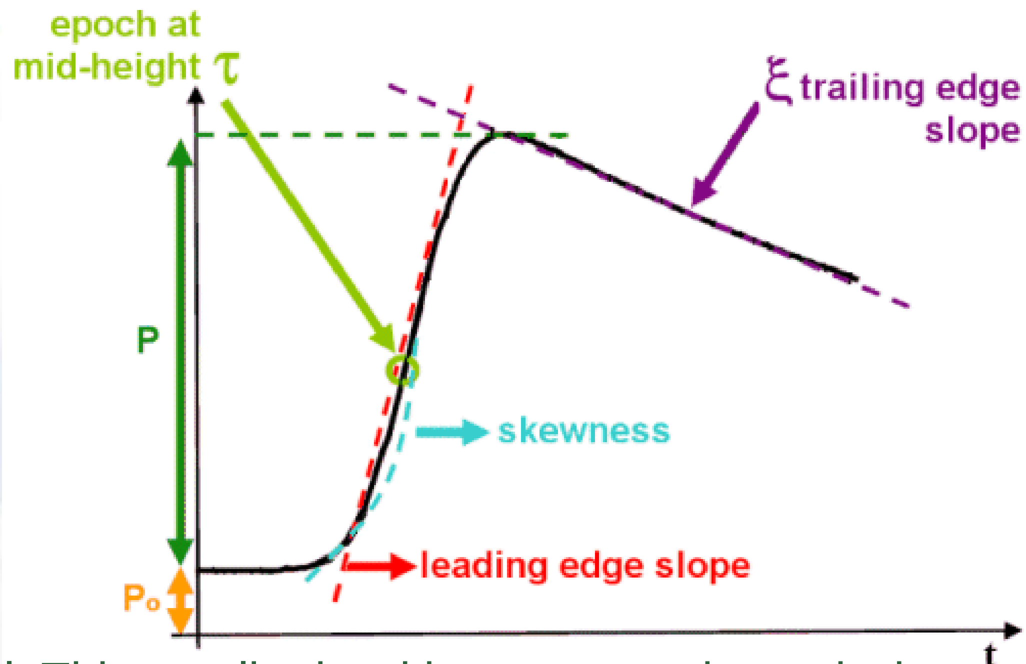


- The beam illuminates a circle of ocean surfaces 2 to 10 km wide
  - A calm sea narrower footprint ~ typically 2 km
  - A rough sea wider footprint ~10 km.
- Sampling 1 hz ~ 6-7km

Altimetric Measurements Over the Ocean

Over an ocean surface, the echo waveform has a characteristic shape. From this shape, six parameters can be deduced, by comparing the real (averaged) waveform with the theoretical curve:

- **Epoch at mid-height**: The time the radar pulse took to travel the satellite-surface distance (or 'range') and back again.



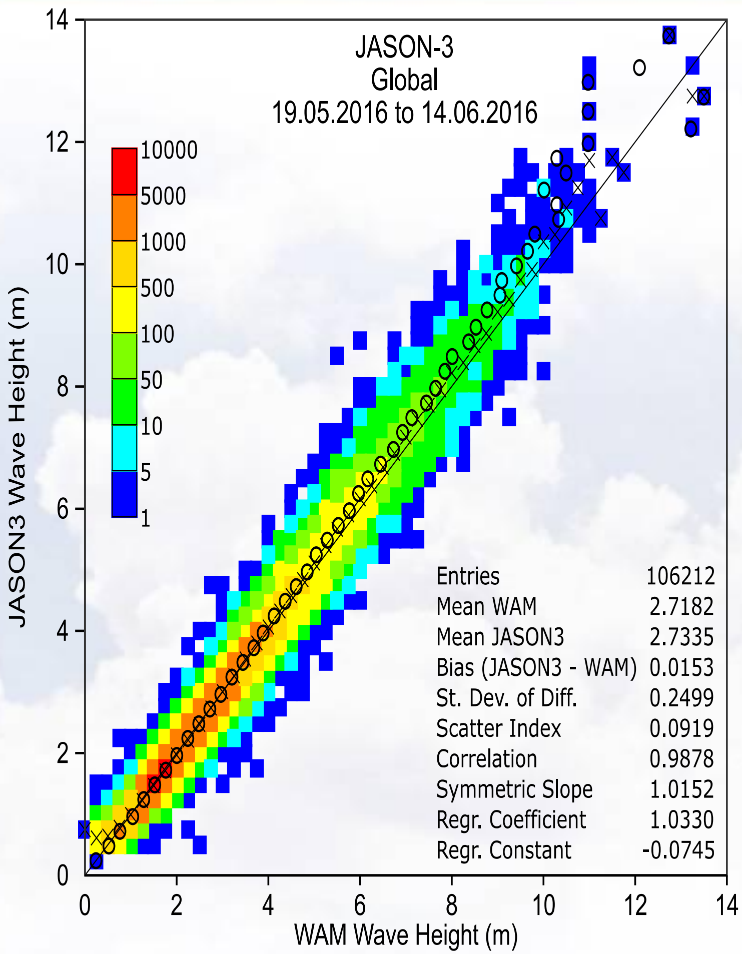
- **P:** the amplitude of the useful signal. This amplitude with respect to the emission amplitude gives the backscatter coefficient, sigma0.
- **Po:** thermal noise
- **Leading edge slope**: this can be related to the significant wave height (SWH)
  - SWH is defined as the highest 1/3 of the surface ocean waves\
  - Higher SWH ➔smaller leading edge slope
- Skewness: the leading edge curvature
- **Trailing edge slope:** mispointing of the radar antenna (i.e. any deviation from nadir of the radar pointing).

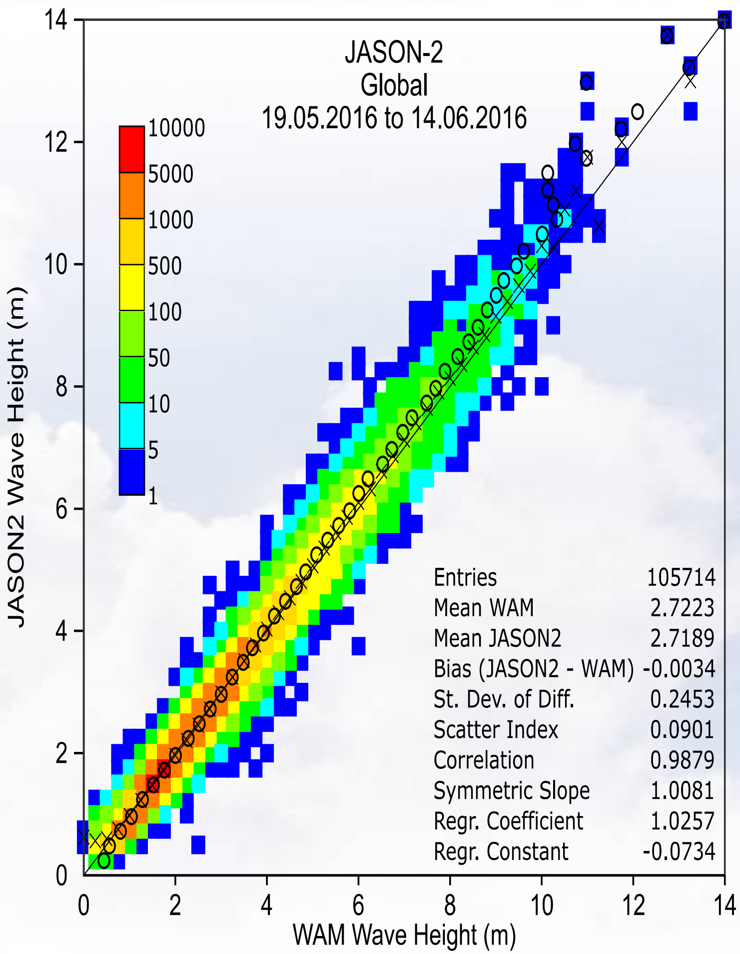
Diameters of Effective Footprint

H_s (m)	Cryosat, Saral, Sentinel Effective footprint (km) (800 km altitude)	Jason 2/3 Effective footprint (km) (1335 km altitude)
0	1.6	2.0
1	2.9	3.6
3	4.4	5.5
5	5.6	6.9
10	7.7	9.6
15	9.4	11.7
20	10.8	13.4

From Chelton et al 1989

Jason-3/2 SWH comparison against ECMWF model

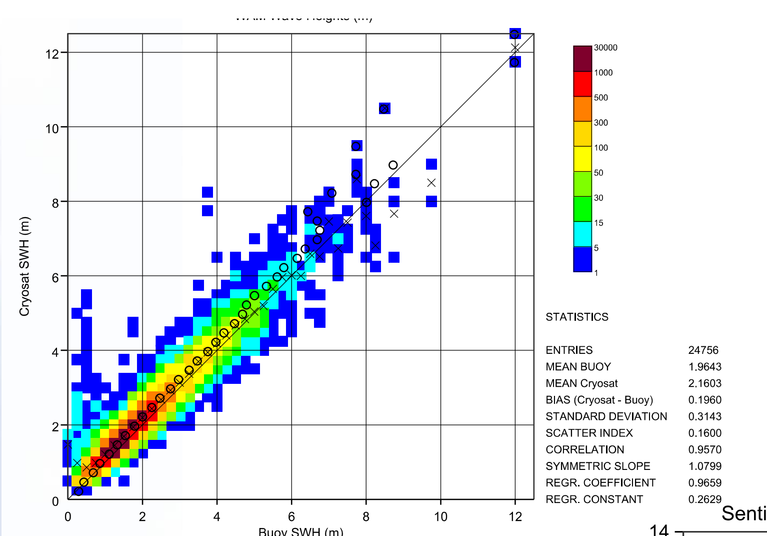




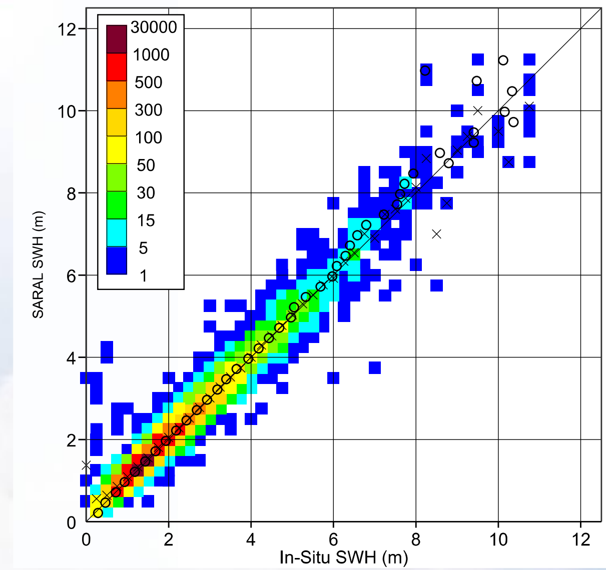
Mean bias ~0.015m
STD ~0.25m

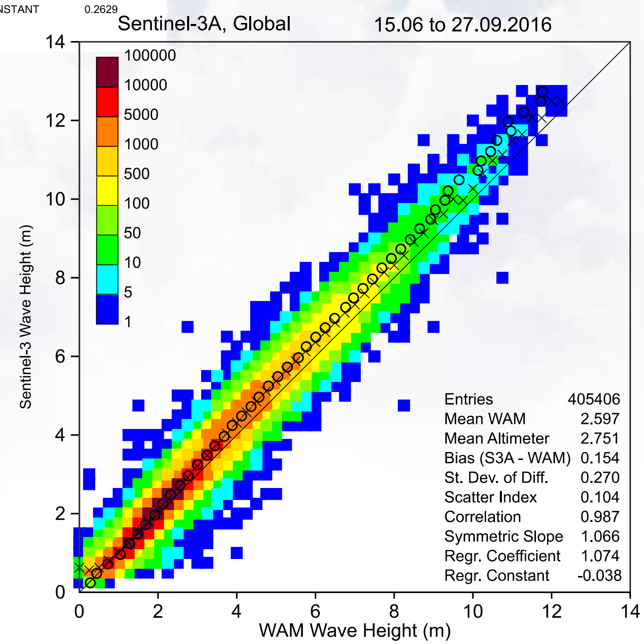
Comparison with Buoys
ECMWF Study

CryoSat



Saral/Altica

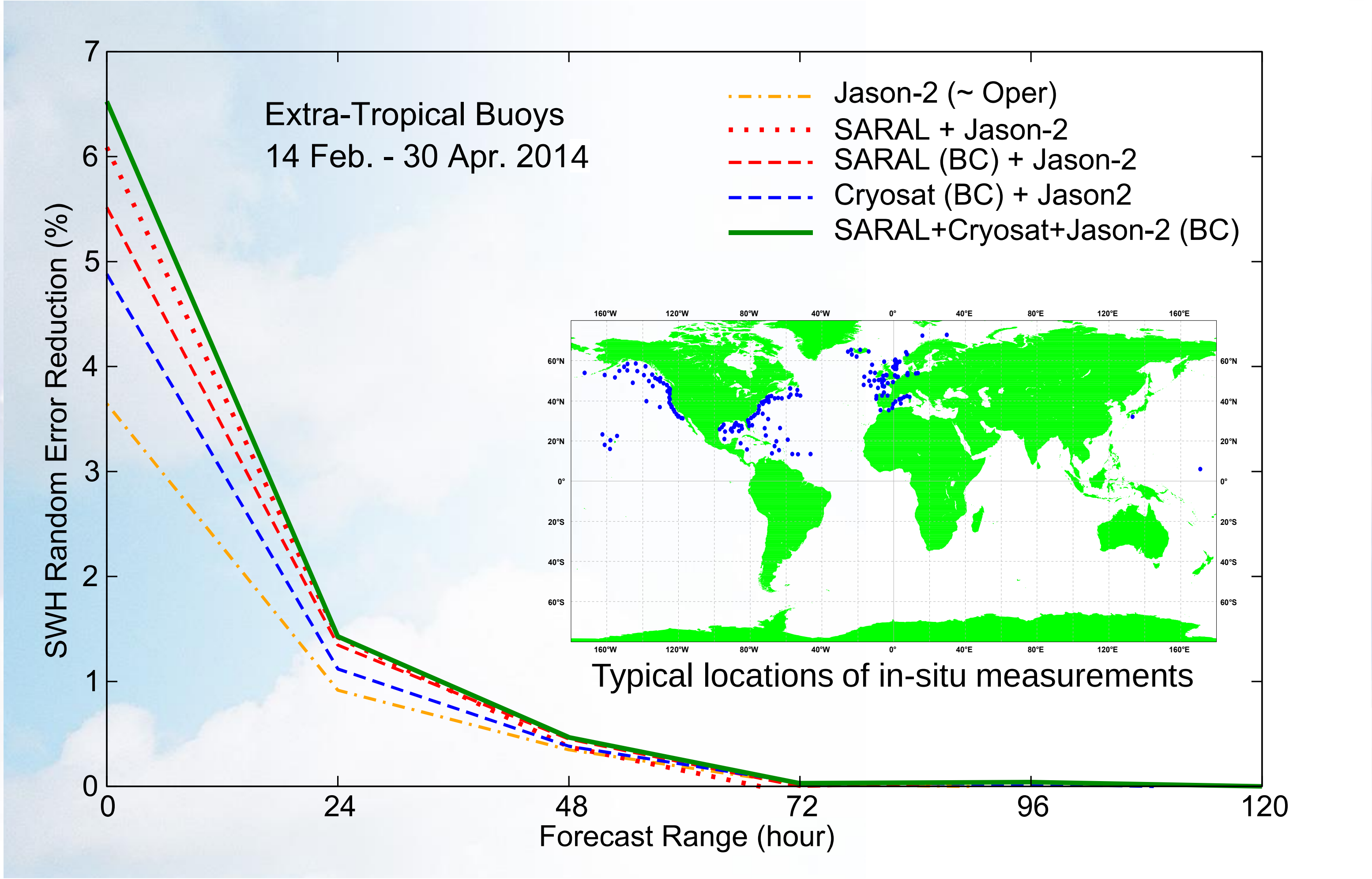




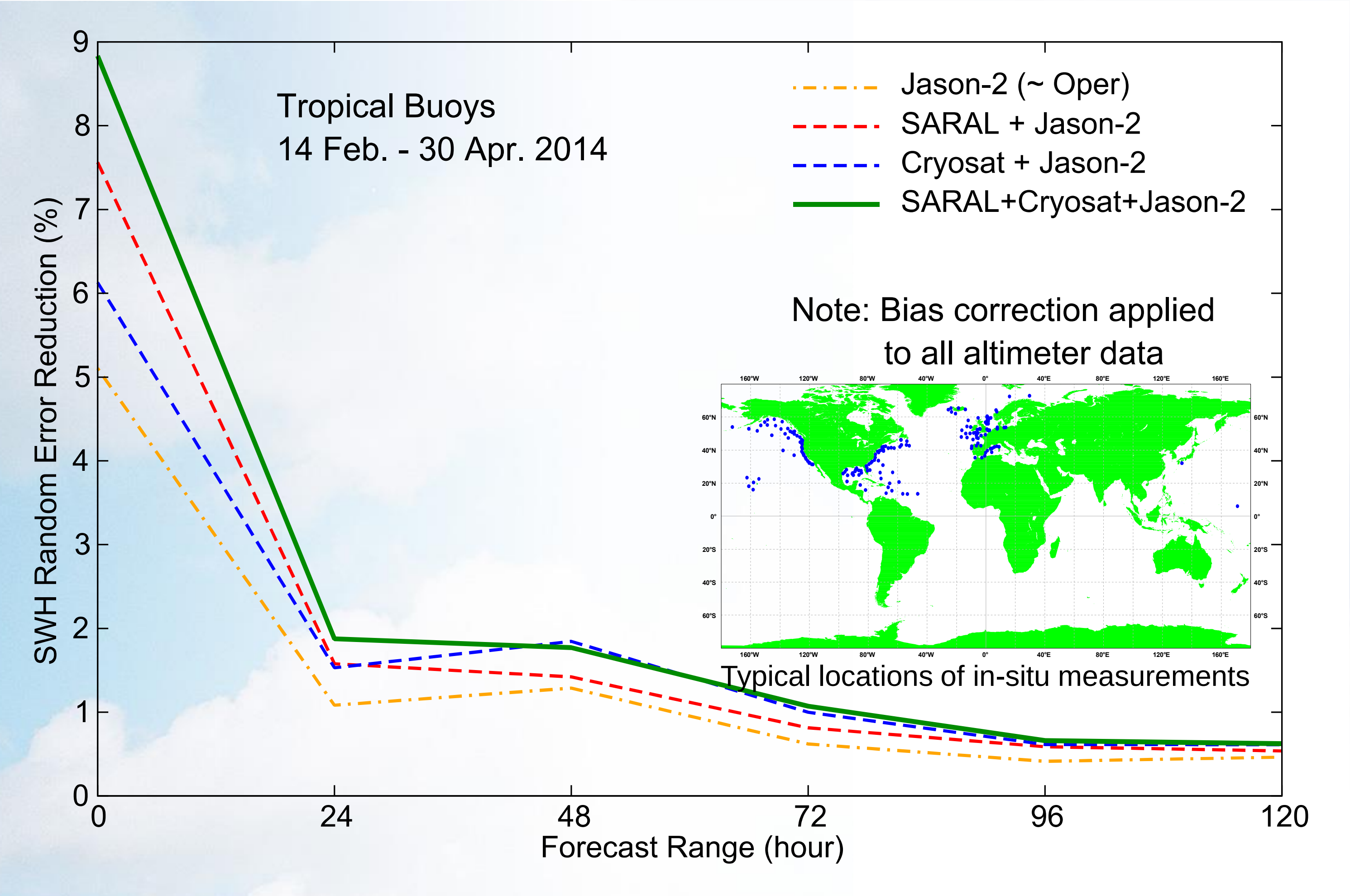
Mean bias ~0.15-0.2m
STD ~0.25-0.3m

Sentinel 3A
15 Jun – 9 Sep 2016

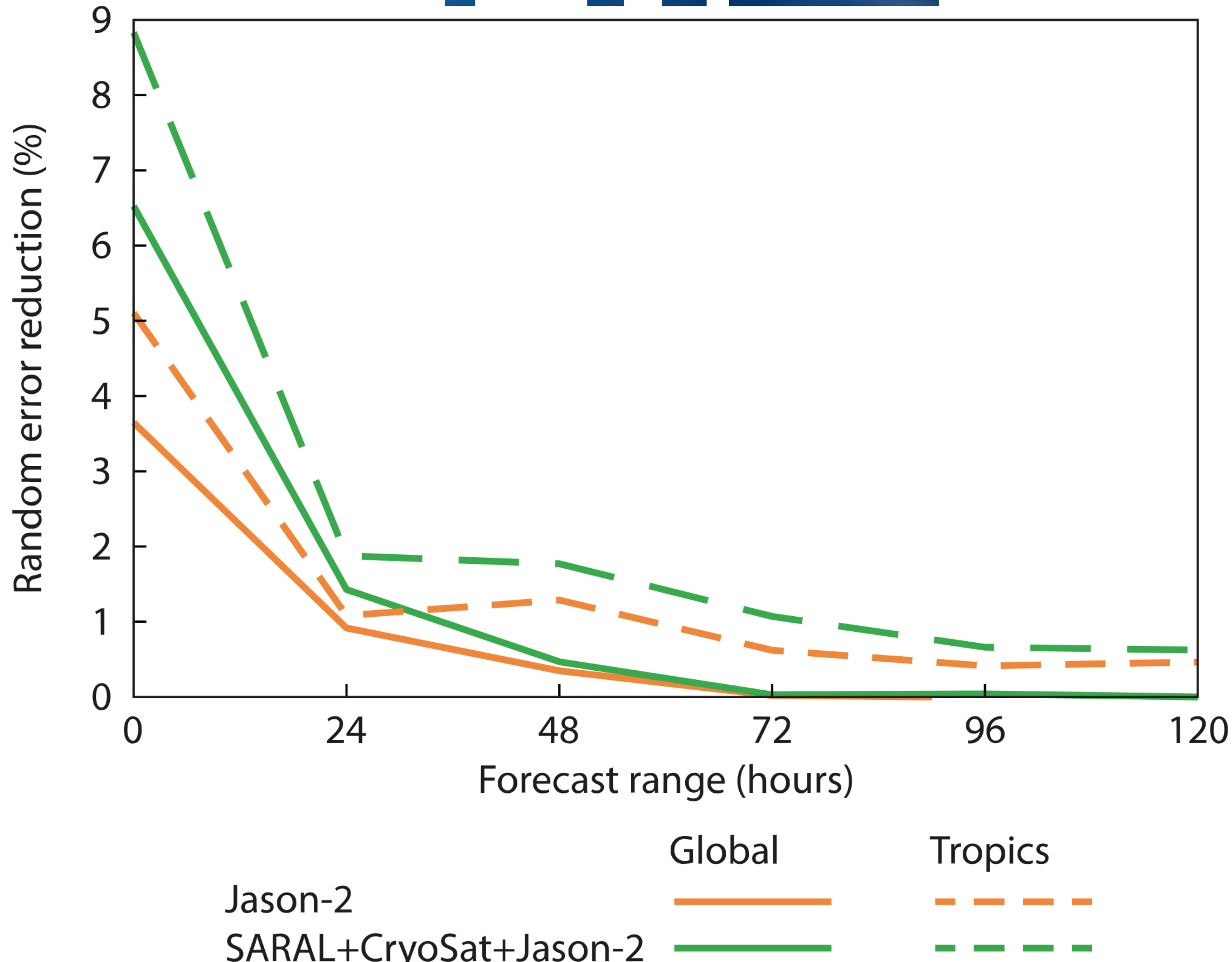
Impact of assimilating altimeter data on SWH error as verified against ExtraTropical in situ data
Feb – Apr 2014

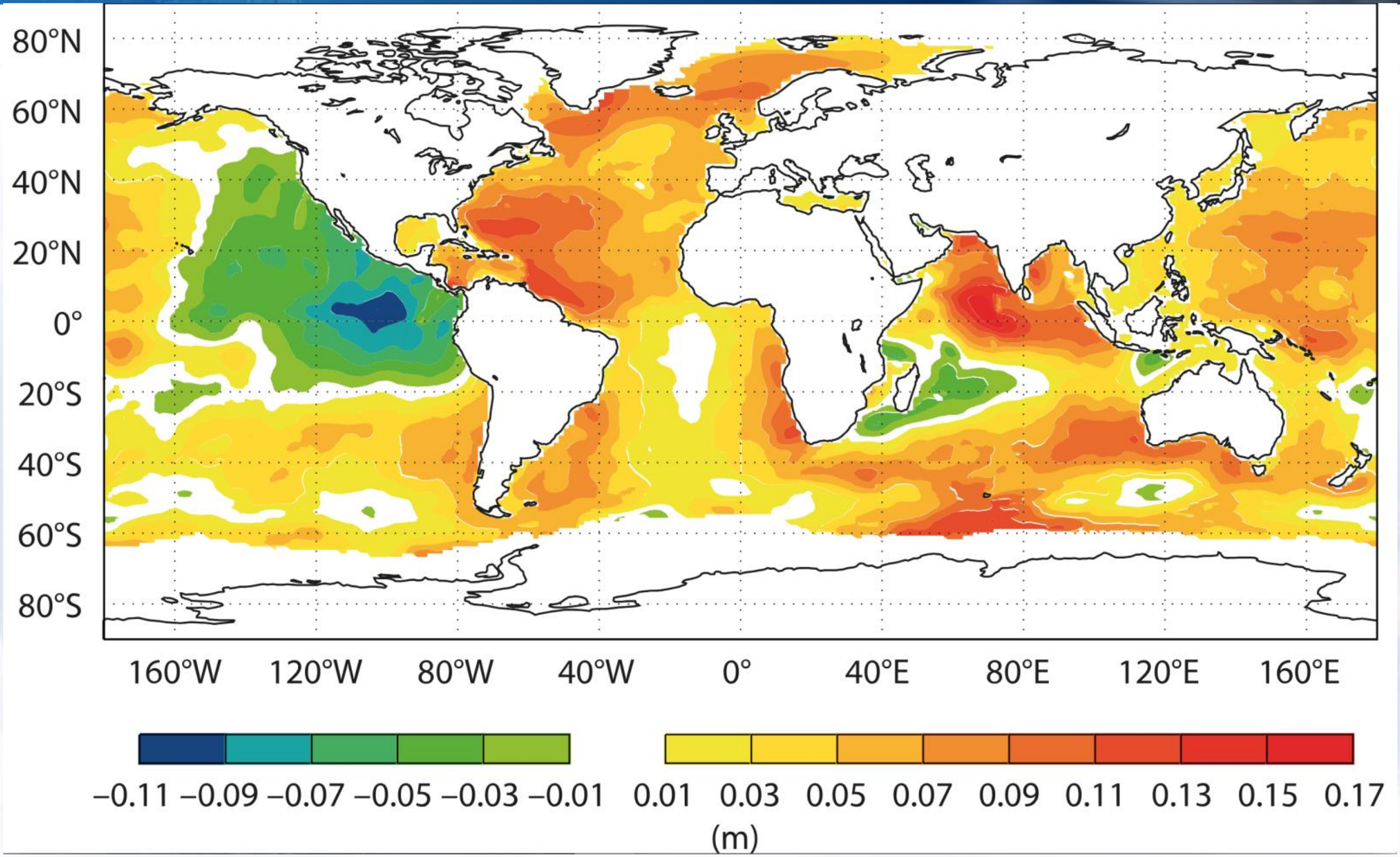


Impact of assimilating altimeter data on SWH error as verified against Tropical in situ data Feb – Apr 2014



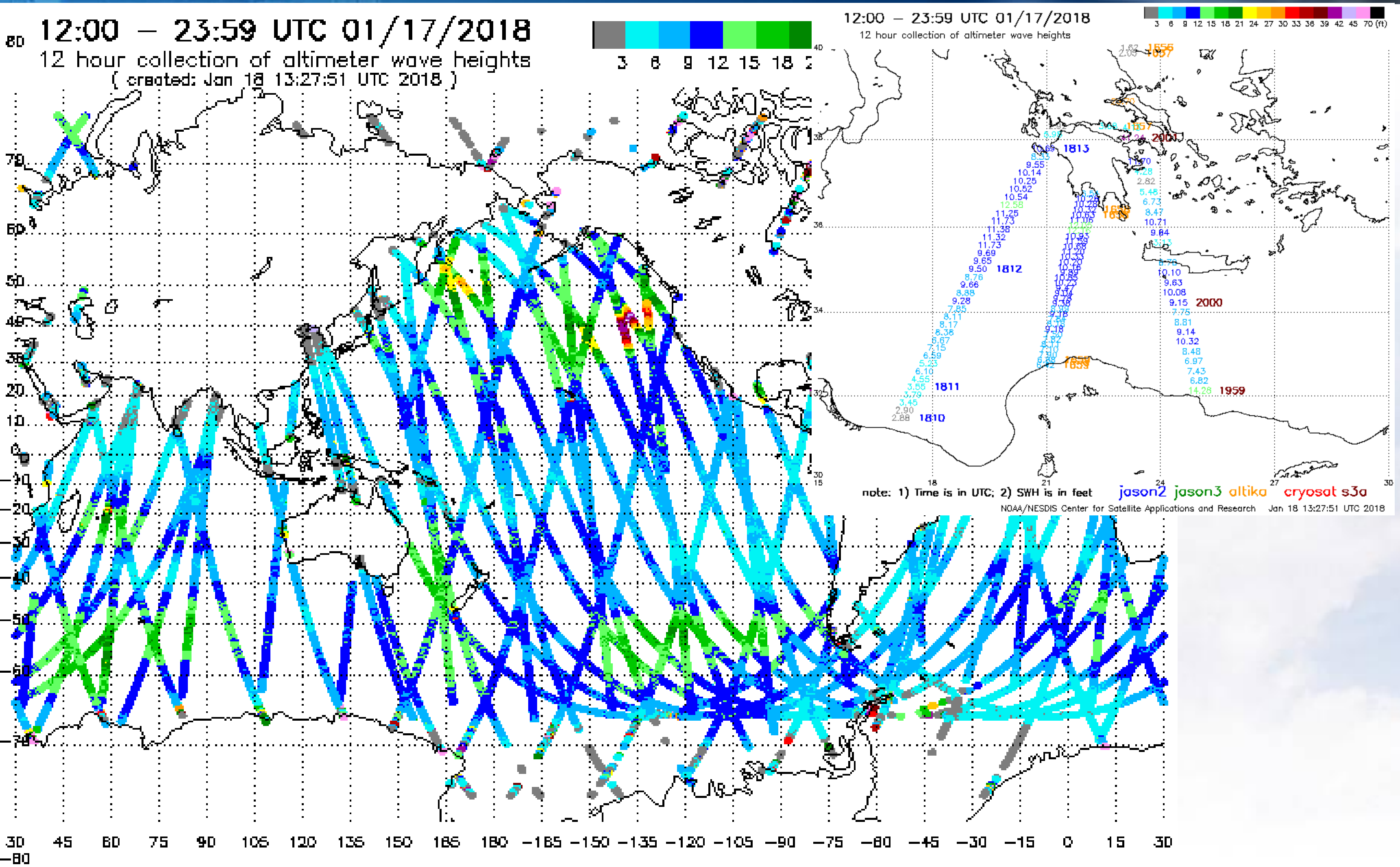
Impact of assimilating altimeter data on reducing the SWH random error in an ECWAM stand-alone model run at a resolution of 0.25° as verified against in-situ buoy data, averaged over the period 14 February to 30 April 2013





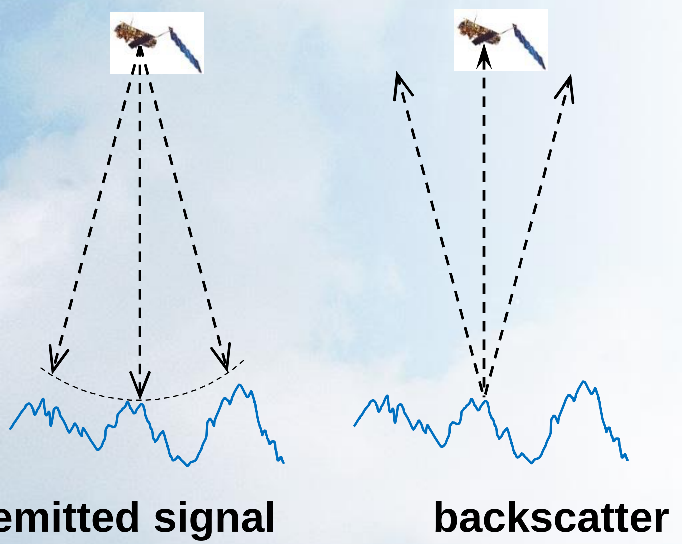
Mean impact, in June and July 2016, of assimilating Jason-3, CryoSat-2 and SARAL SWH data on the SWH analysis, expressed as the difference in SWH between an ECWAM standalone model run at a resolution of 0.25° (IFS Cycle 42r1) assimilating data from the three satellites and another model run without any data assimilation

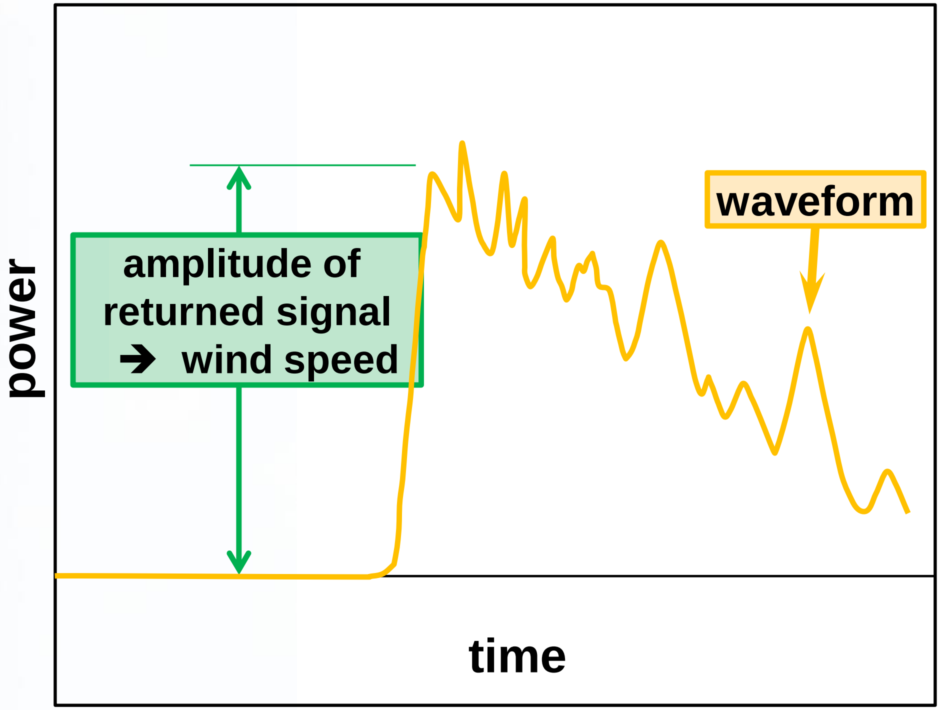
NRT Altimeter SWH on NOAA Web Site



http://manati.star.nesdis.noaa.gov/datasets/SGWH.php/

Altimeter Wind Speeds

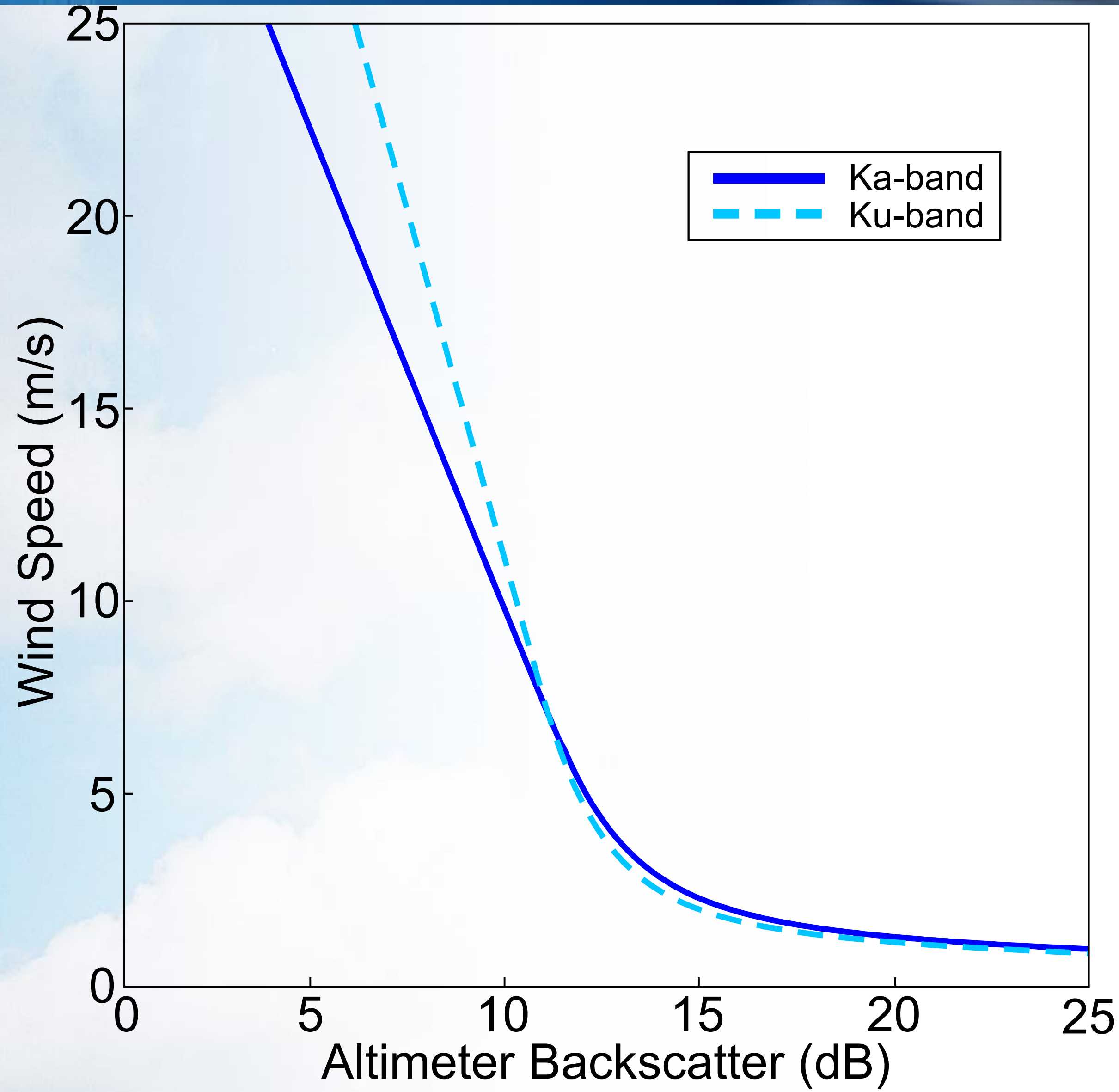




- **backscatter** is related to water surface **mean square slope (mss).**
- **mss** can be related to **wind speed.**
- Stronger wind ➔ higher mss ➔ smaller backscatter.

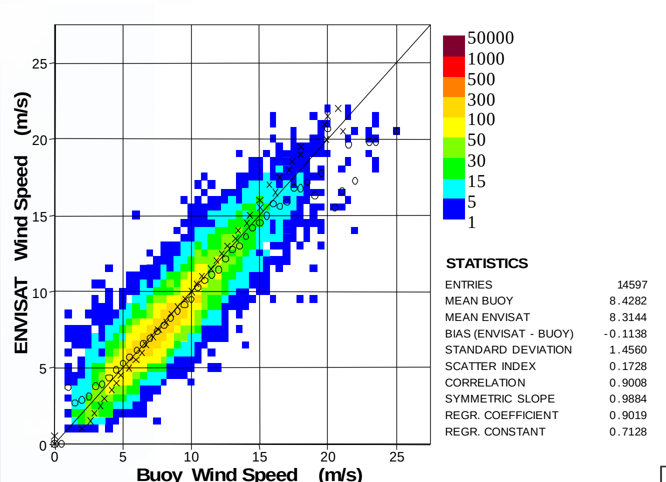
- **Errors** are mainly due to algorithm assumptions, waveform retracking (algorithm), unaccounted-for attenuation & backscatter.

Relationship Between Altimeter Backscatter and Ocean Wind Speed

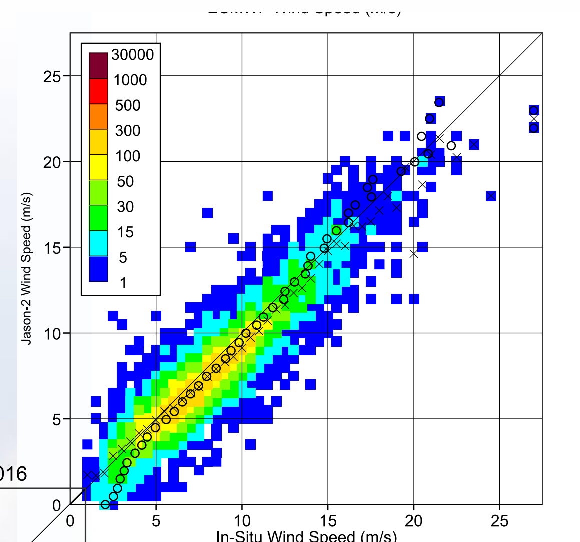


Wind Speed Comparison with Buoys ECMWF Study

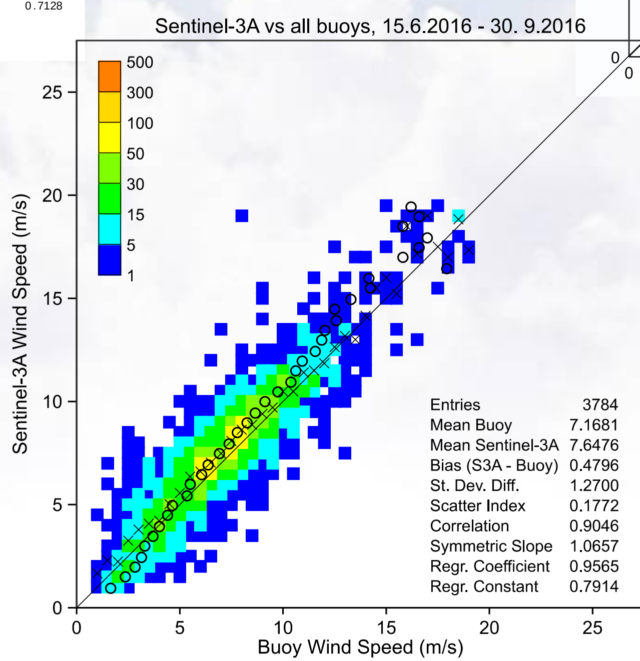
Envisat
1 Jan 2011- 31 Dec 2011



Jason-2
1 May 2013 - 14 Apr 2014



Mean Bias ~0.5m/s
STD ~1.3m/s



Sentinel 3A
15 Jun – 9 Sep 2016

Rain Effects

The radar signal is attenuated by the rain as it travels to and from the Earth's surface

The radar signal is scattered by the raindrops. Some of this scattered energy returns to the instrument

The roughness of the sea surface is increased because of the splashing due to raindrops

SWH Data Quality Dropouts/Outliers

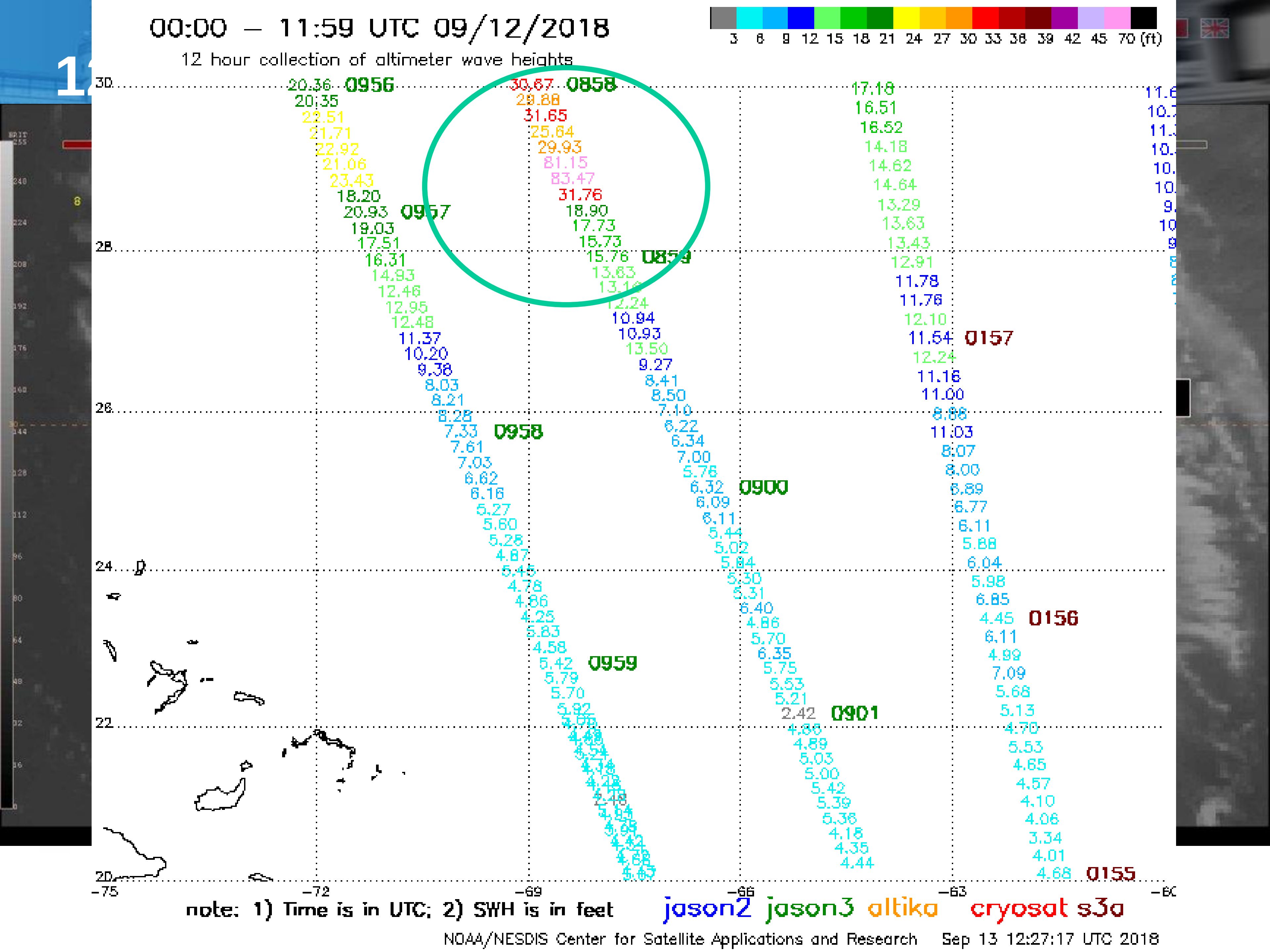
Key factor explaining drop outs is non-oceanlike waveform

Reasons for waveforms that are not typical rough ocean returns

- Slick or very smooth water patches
- Transitions from land to sea
- Sea ice
- Very heavy rain

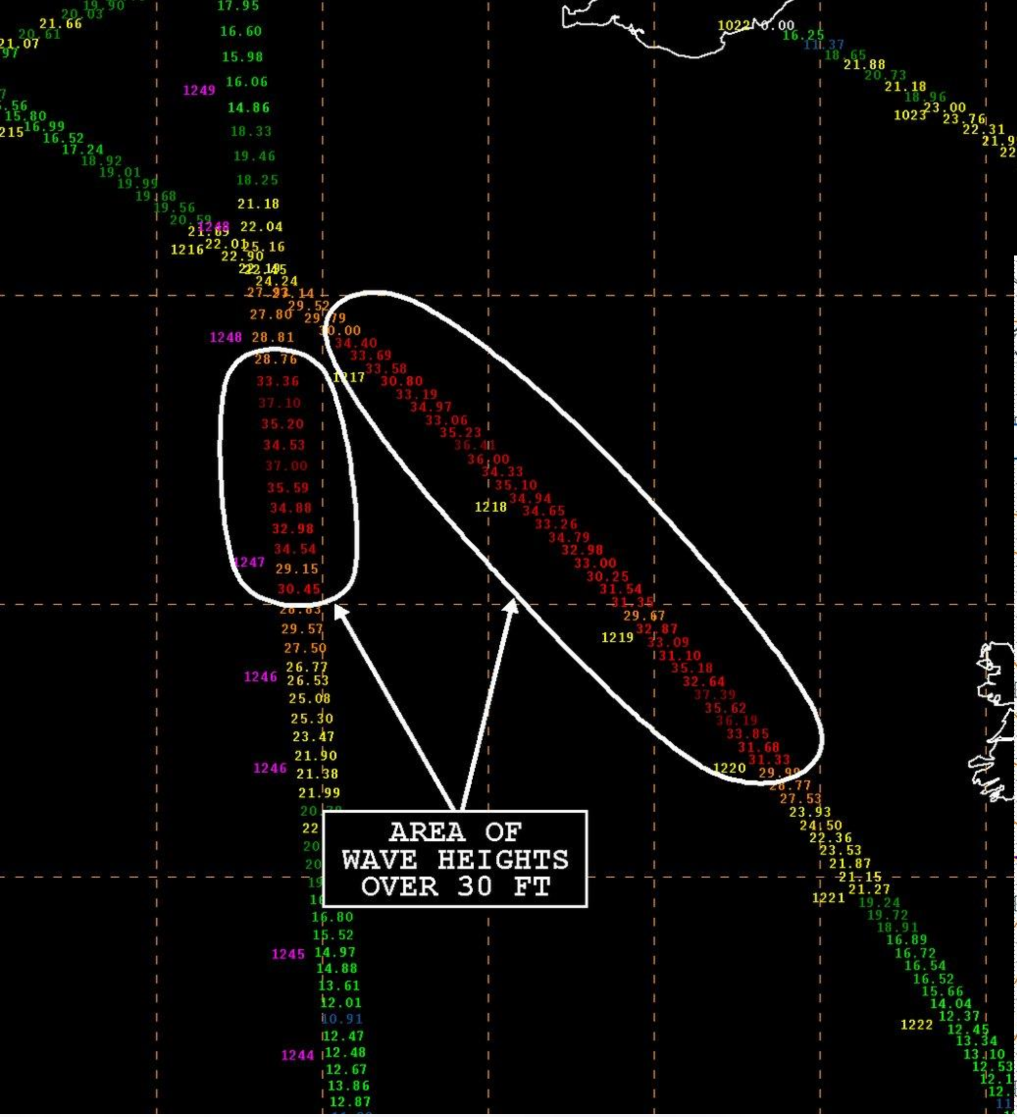
Data drop out determination

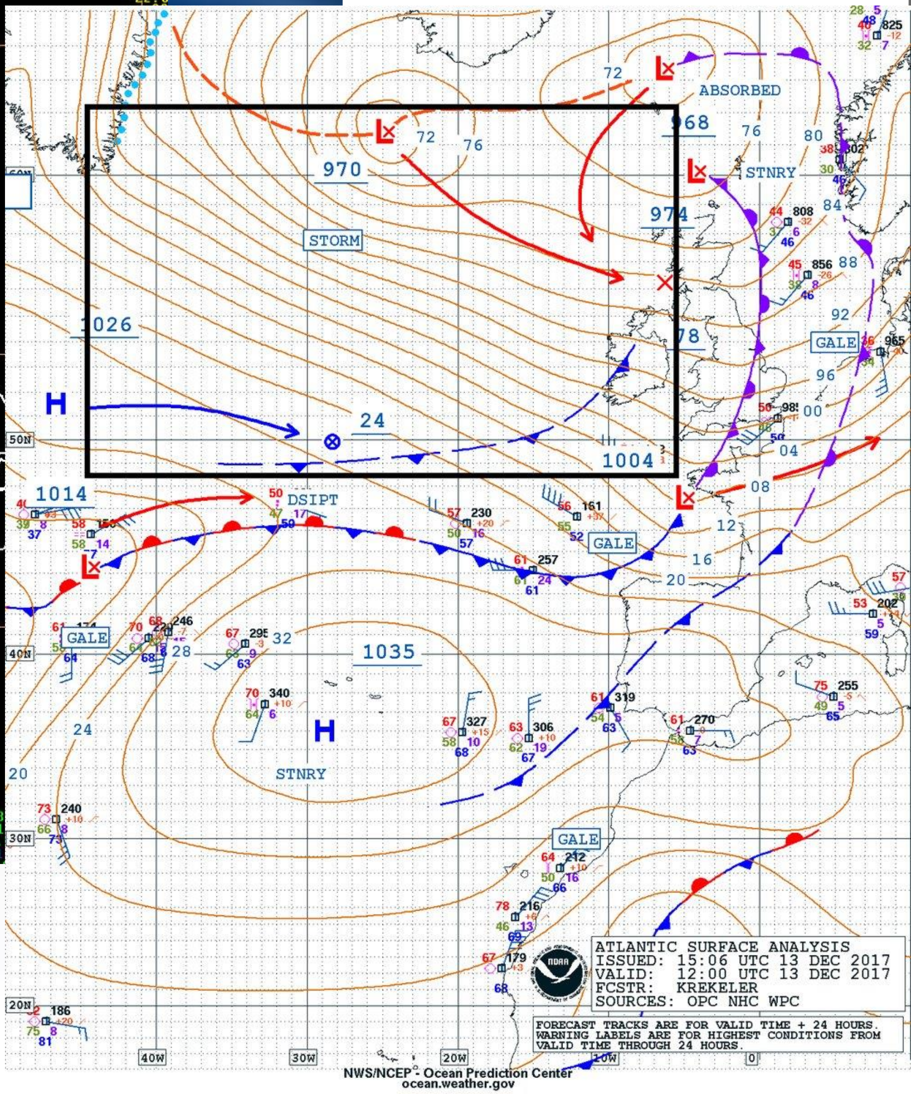
- Look for SWH data quality flag and/or wind speed data quality
- Look at altimeter wind speed and at RMS of SWH and wind speed averaging
- Each altimeter can differ in amount of NRT SWH dropouts
- Typically a very small percentage of the data


00:00 – 11:59 UTC 09/12/2018
12 hour collection of altimeter wave heights
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 70 (ft)
0956
0957
0958
0959
0858
0859
0900
0901
0157
0156
0155
note: 1) Time is in UTC; 2) SWH is in feet
jason2 jason3 altika cryosat s3a
NOAA/NESDIS Center for Satellite Applications and Research Sep 13 12:27:17 UTC 2018

Altimetry in Operations

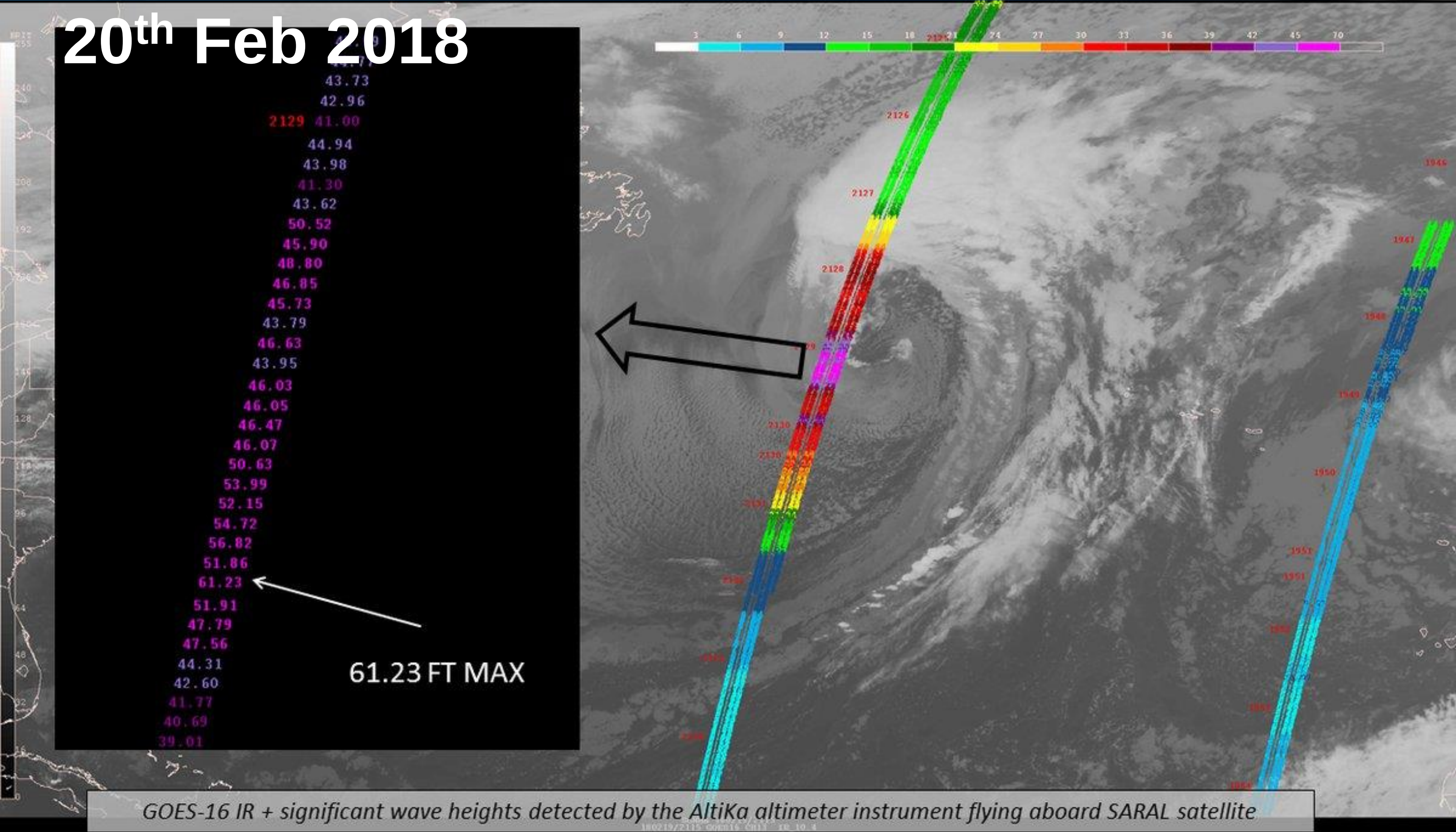
13th Dec 2017





A large fetch of gale to storm force winds, associated with low pressure SW of Iceland, is resulting in sea heights over 30 feet as seen in a wave altimeter pass.

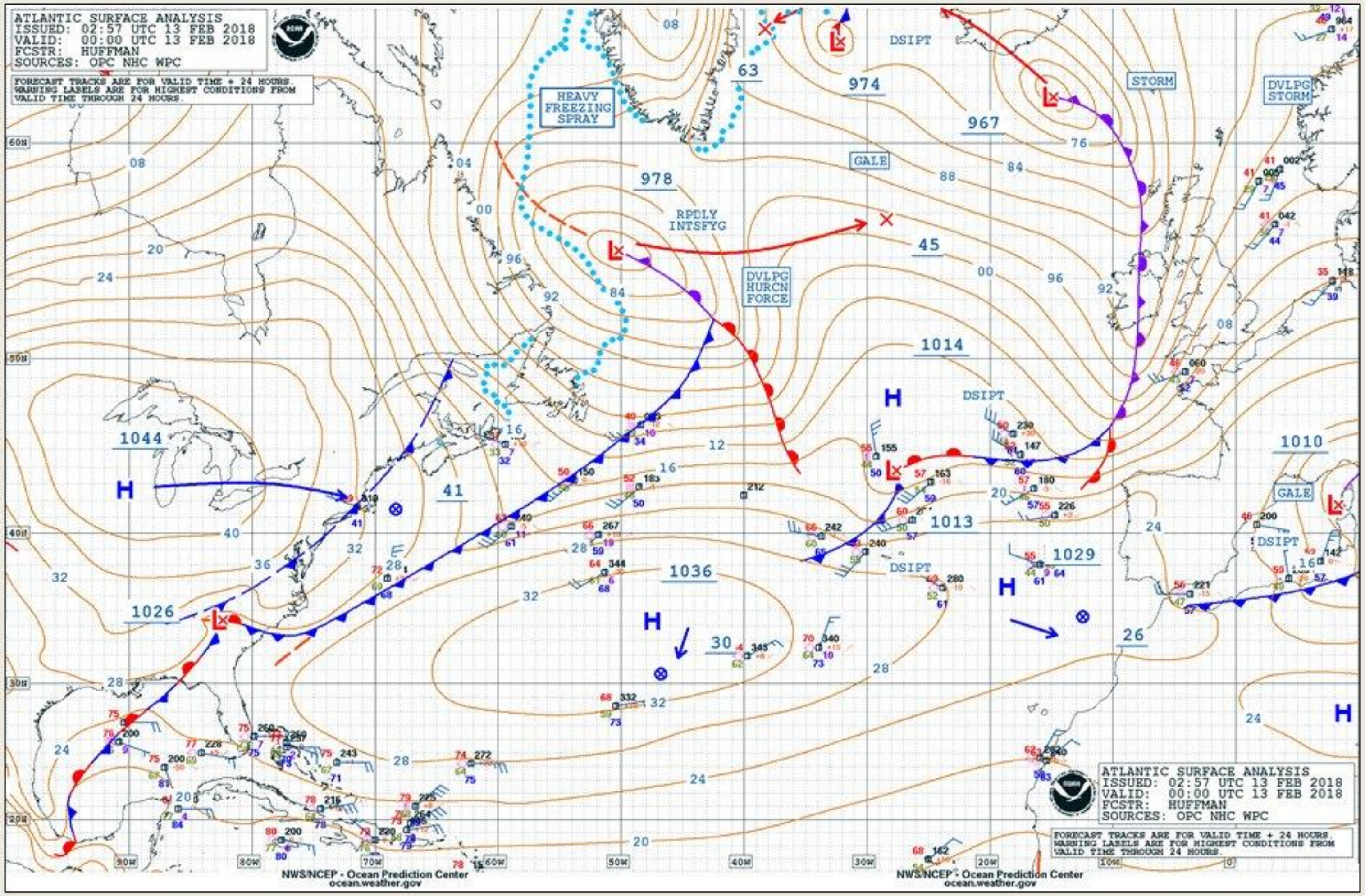
20th Feb 2018



GOES-16 IR + significant wave heights detected by the AltiKa altimeter instrument flying aboard SARAL satellite

Hurricane force low over the Central Atlantic -- earlier swath of data from the altimeter instrument (AltiKa) flying aboard SARAL satellite returned significant wave heights to 61 feet / 18.6 meters in the SW quadrant of low

Hurricane force wind warning continues across the Central Atlantic associated with rapidly intensifying low pressure. Seas are expected to build quickly, well in excess of 40 feet / 12 meters.



ATLANTIC SURFACE ANALYSIS AT 00 UTC, FEB 13

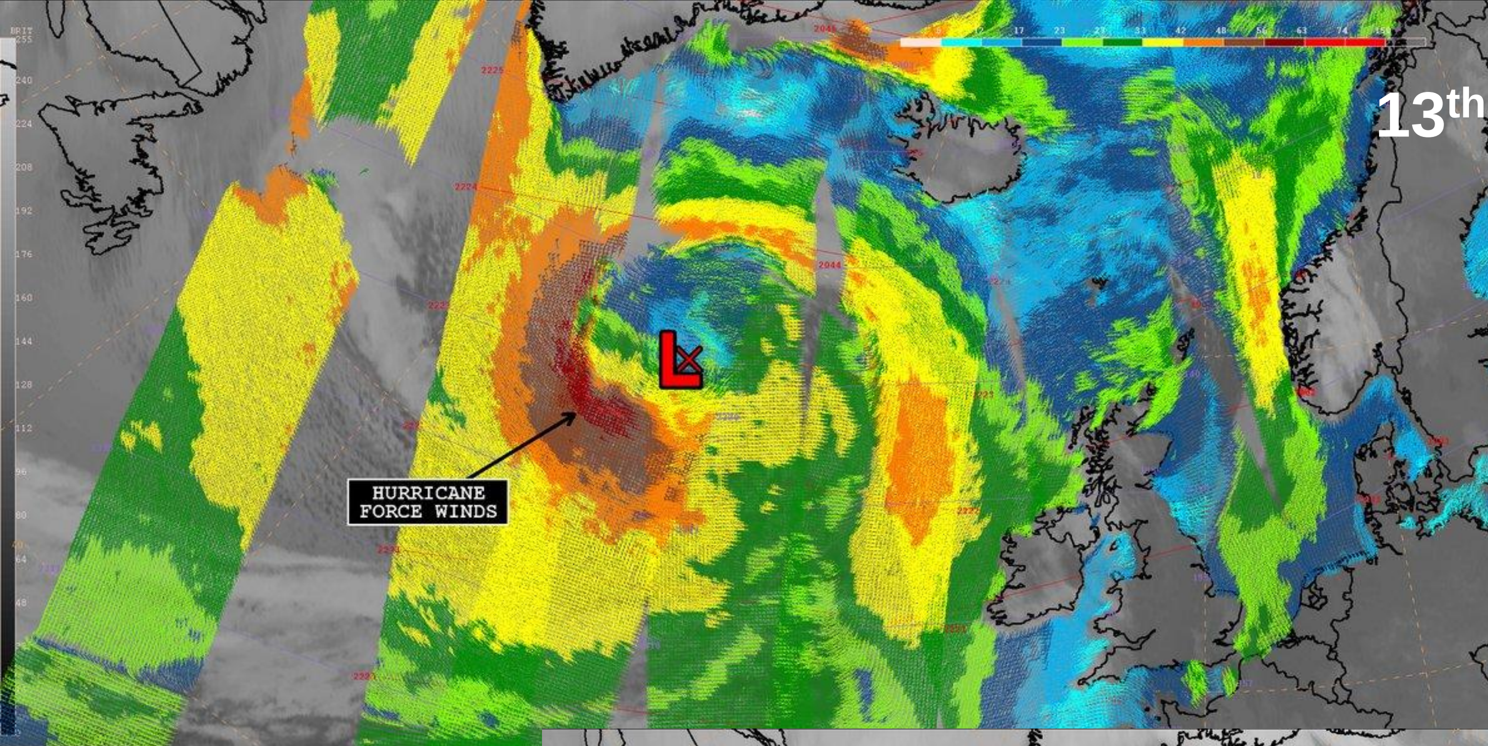
Hurricane force wind warning continues across the Central Atlantic as low pressure rapidly intensifies to 945 hPa during the next 24 hours. Significant wave heights are expected to quickly build well in excess of 12 meters / 40 feet.

@NWSOPC

facebook.com/NWSOPC

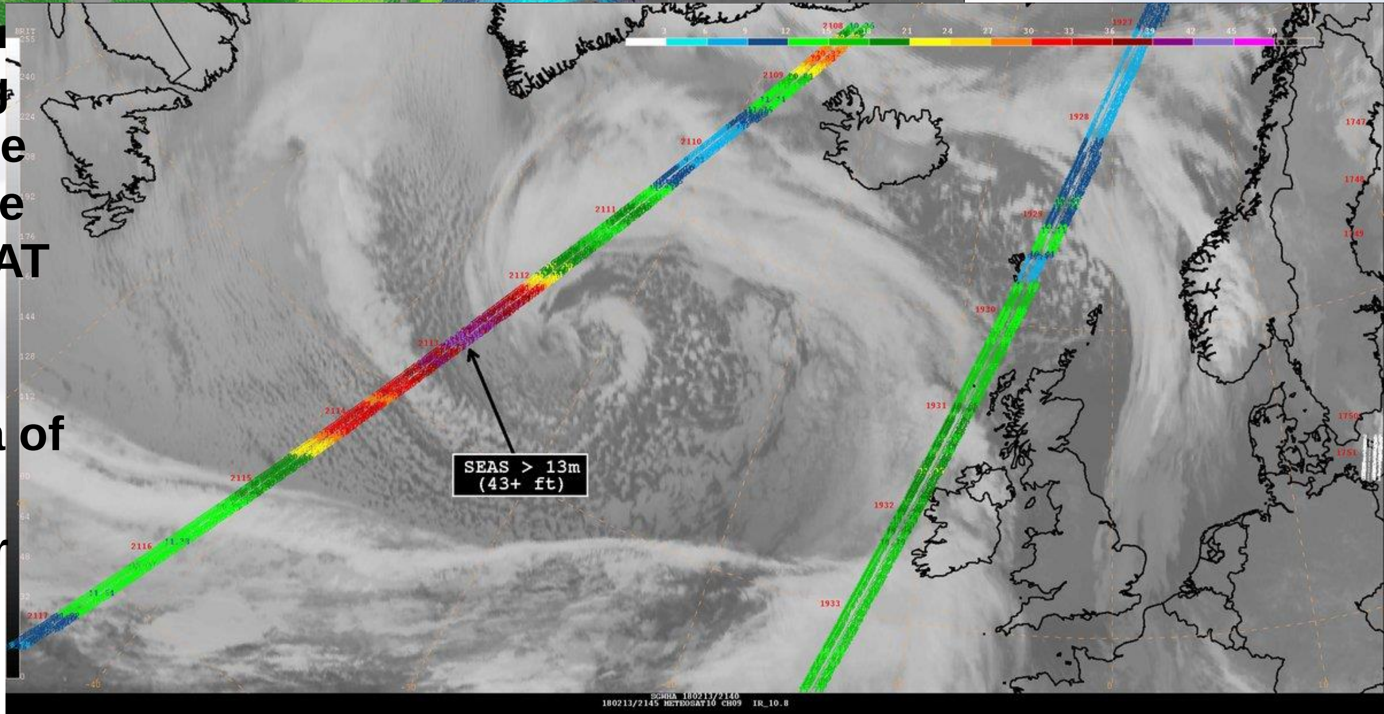
ocean.weather.gov

OCEAN PREDICTION CENTER



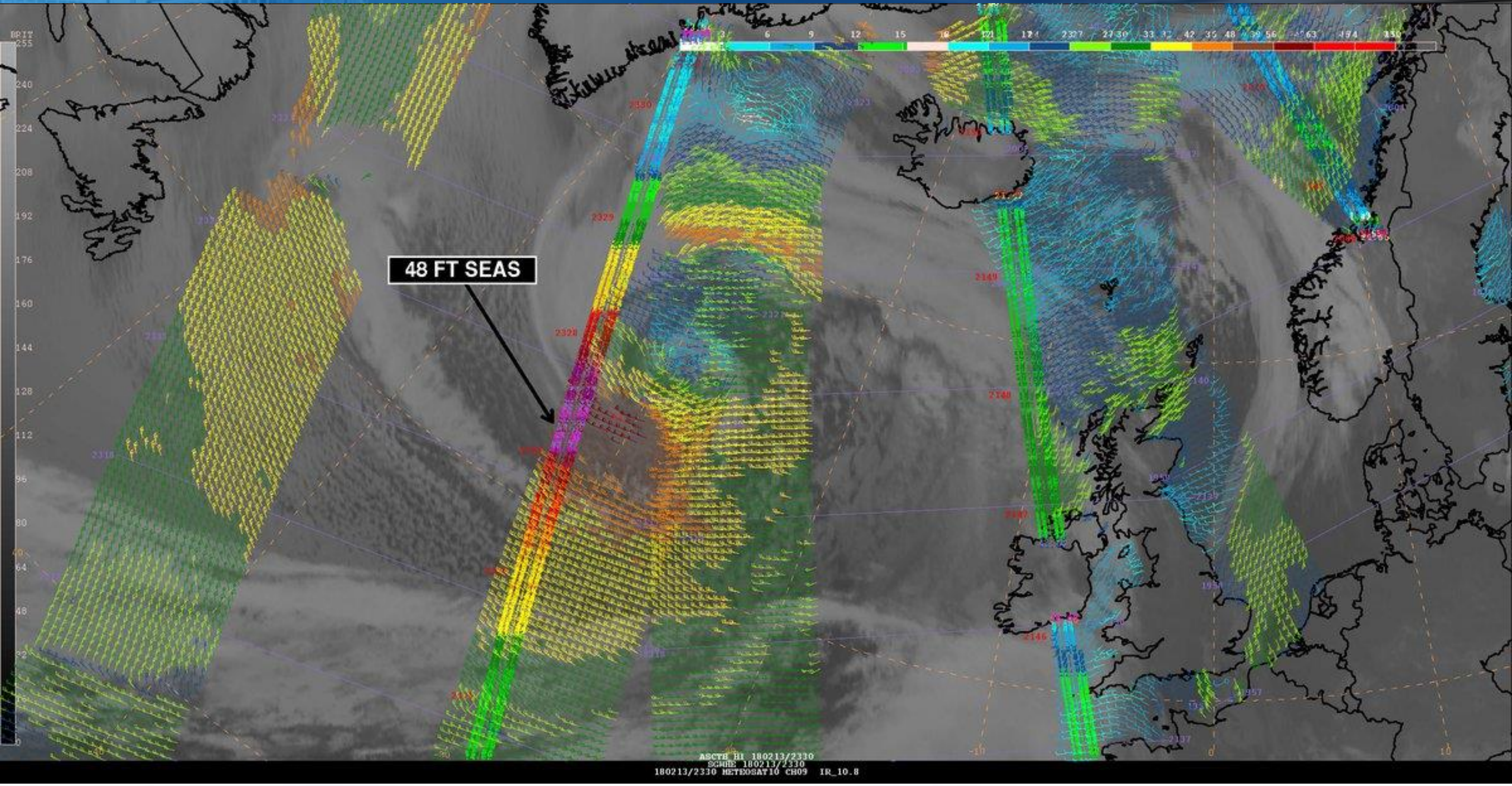
13th Feb 2018

ASCAT 22:23Z



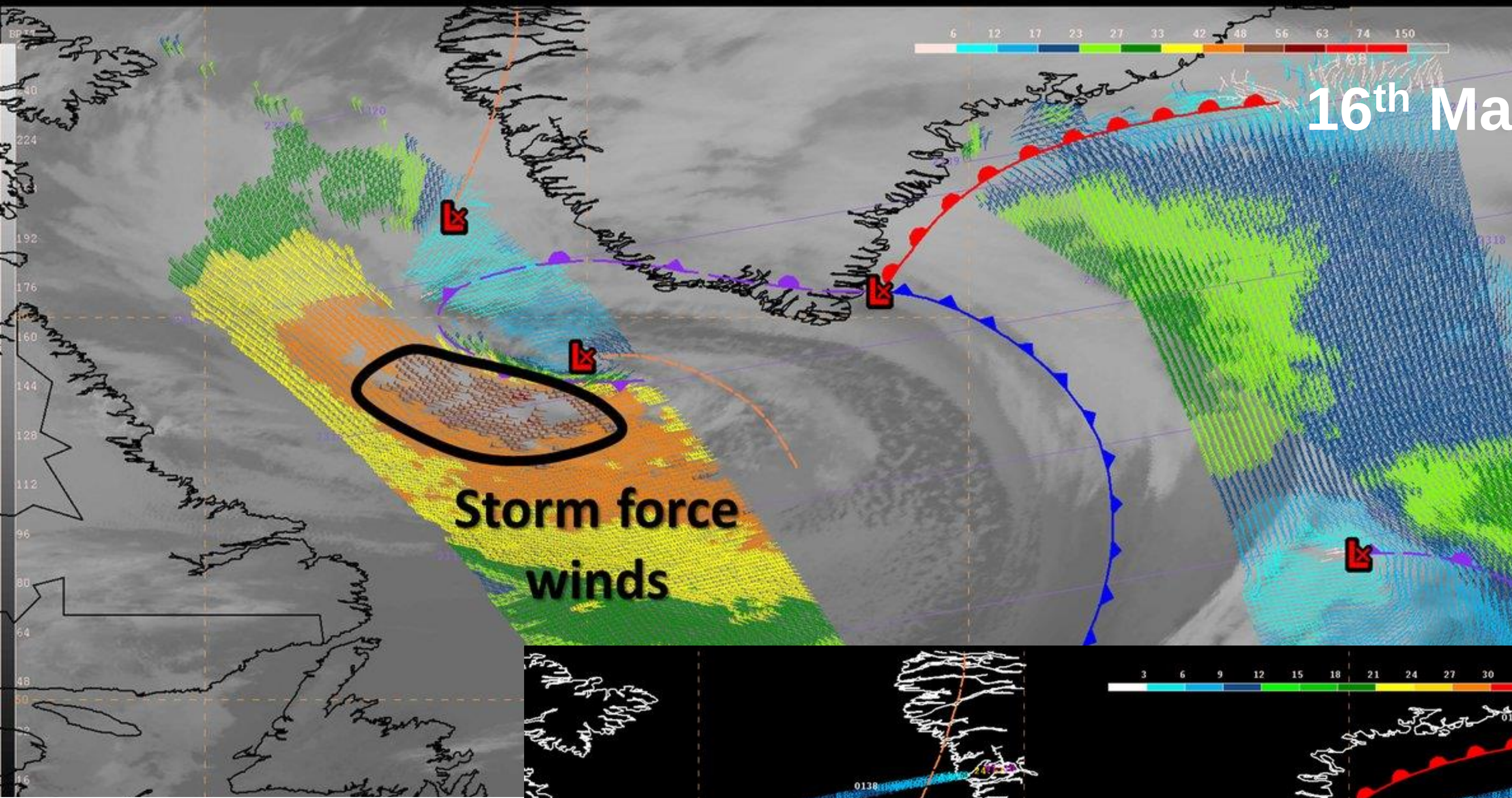
Satellites are providing incredible data from the north Atlantic hurricane force low. Recent ASCAT retrievals confirm hurricane force winds with an expansive area of gales over 1000 nm across! Altika altimeter sampled seas to 13m (43+ft) just after 21Z

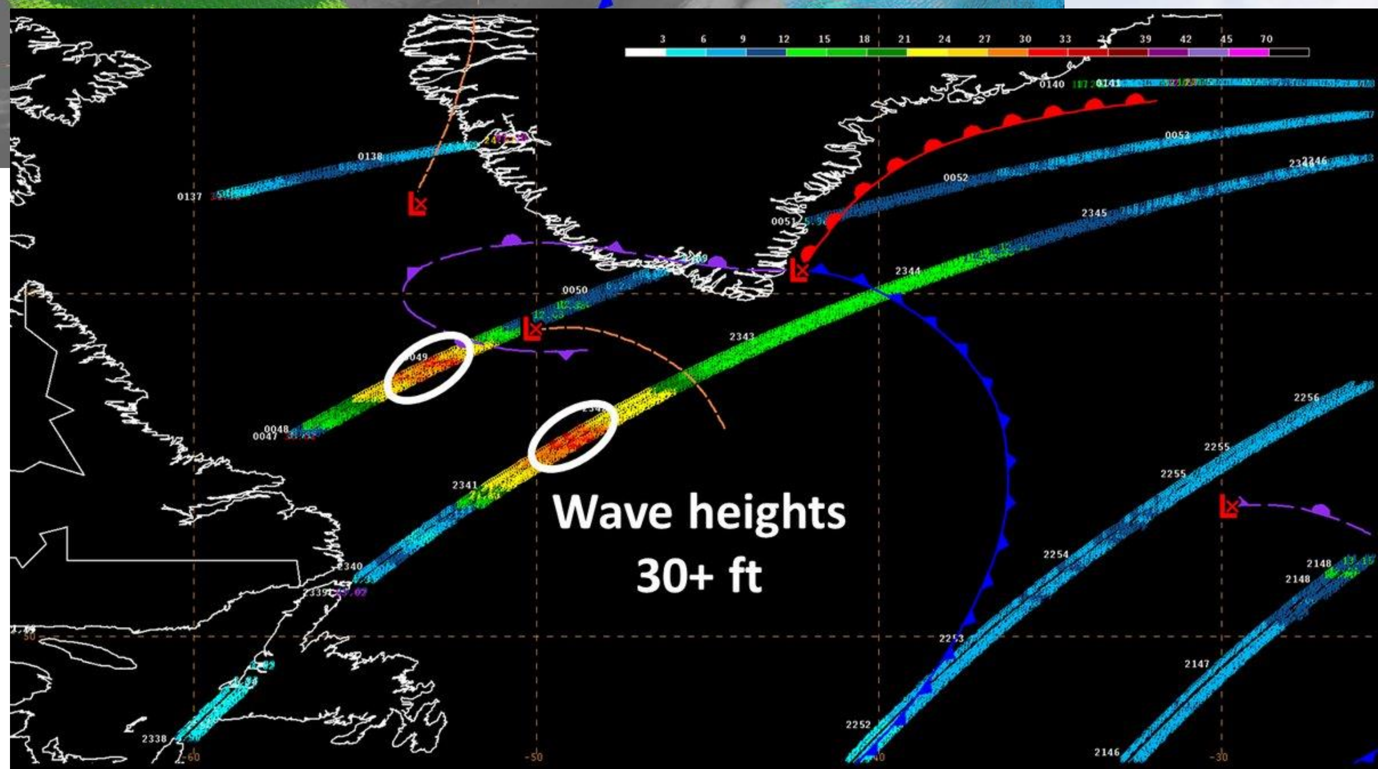
13th Feb 2018



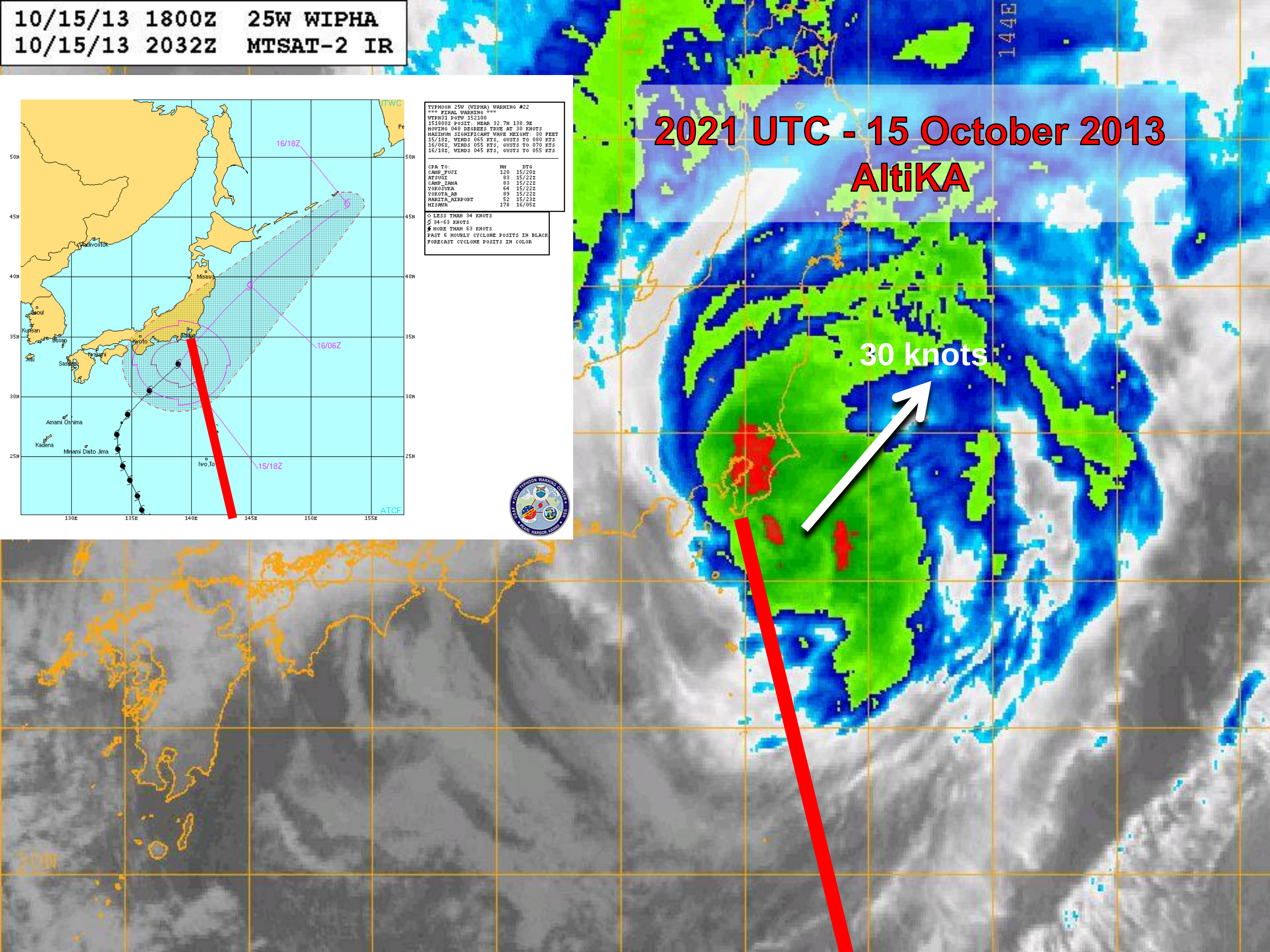
UPDATE: Sentinel-3 altimeter pass from around 2330 UTC today captured seas to 48 ft with the Atlantic hurricane force low

16th May 2018

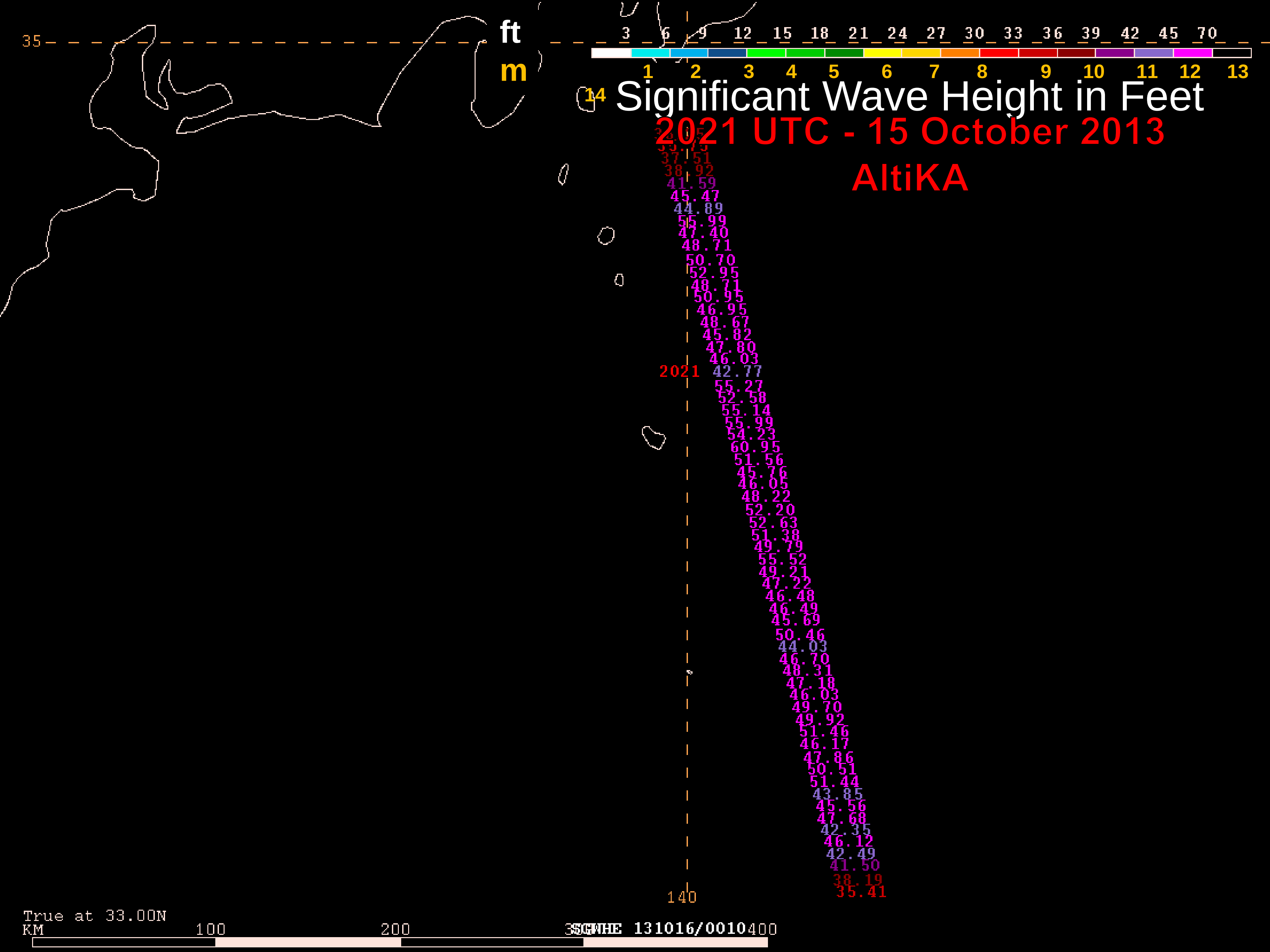


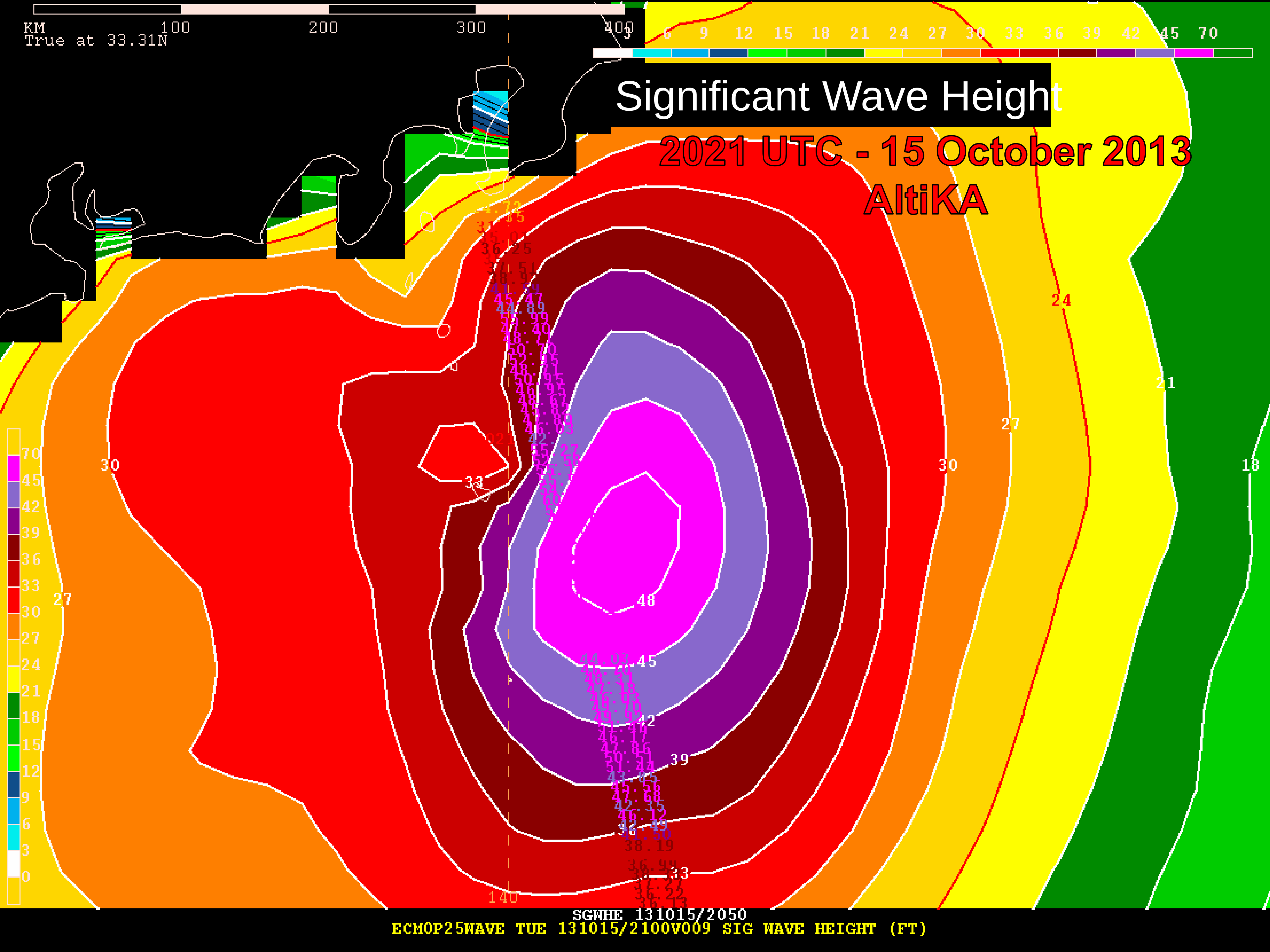


Recent ASCAT passes confirm storm force winds associated with 972 mb low pressure in Labrador Sea over the north Atlantic - Jason-3 altimeter passes support wave heights greater than 30 ft!

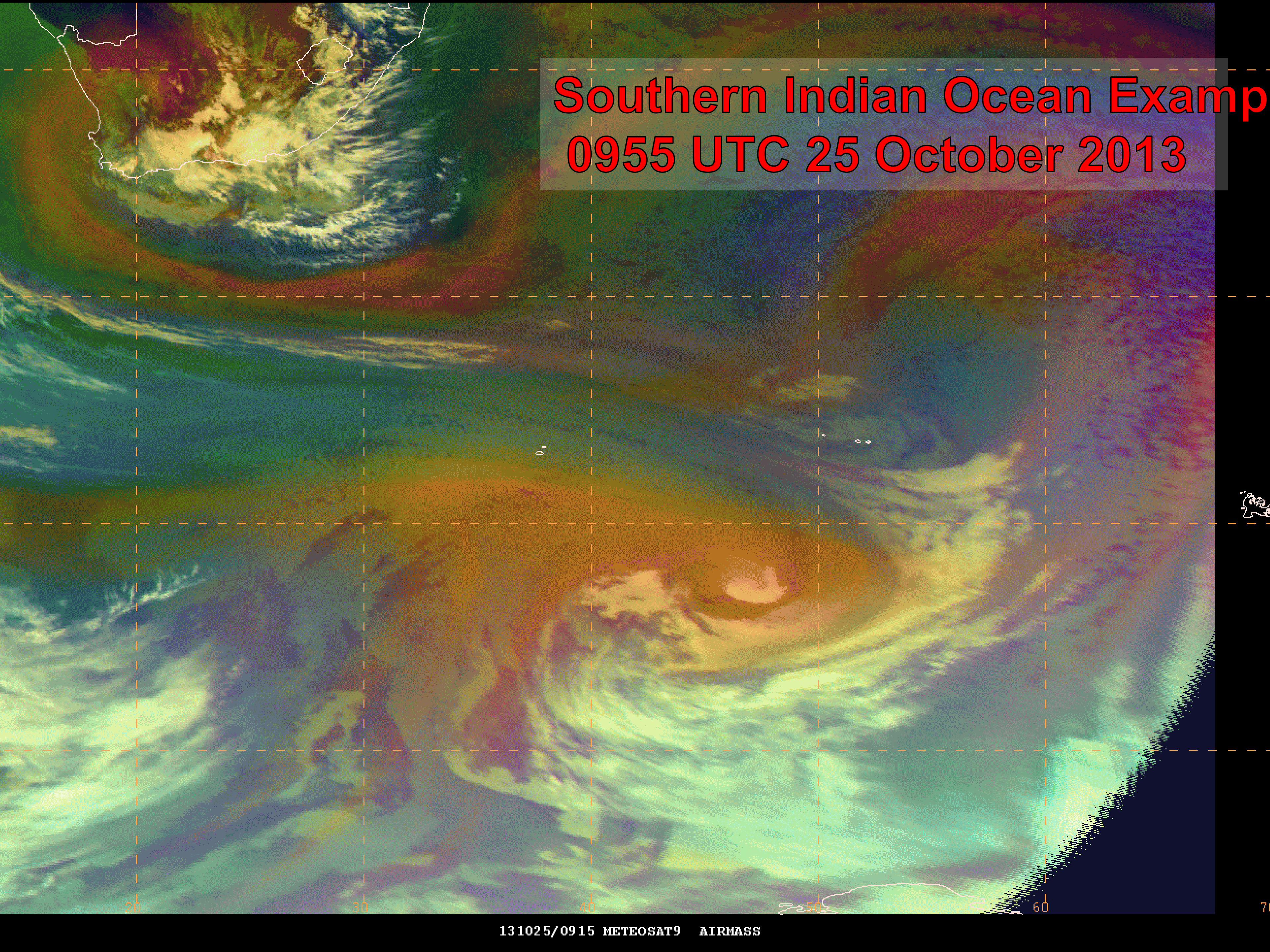


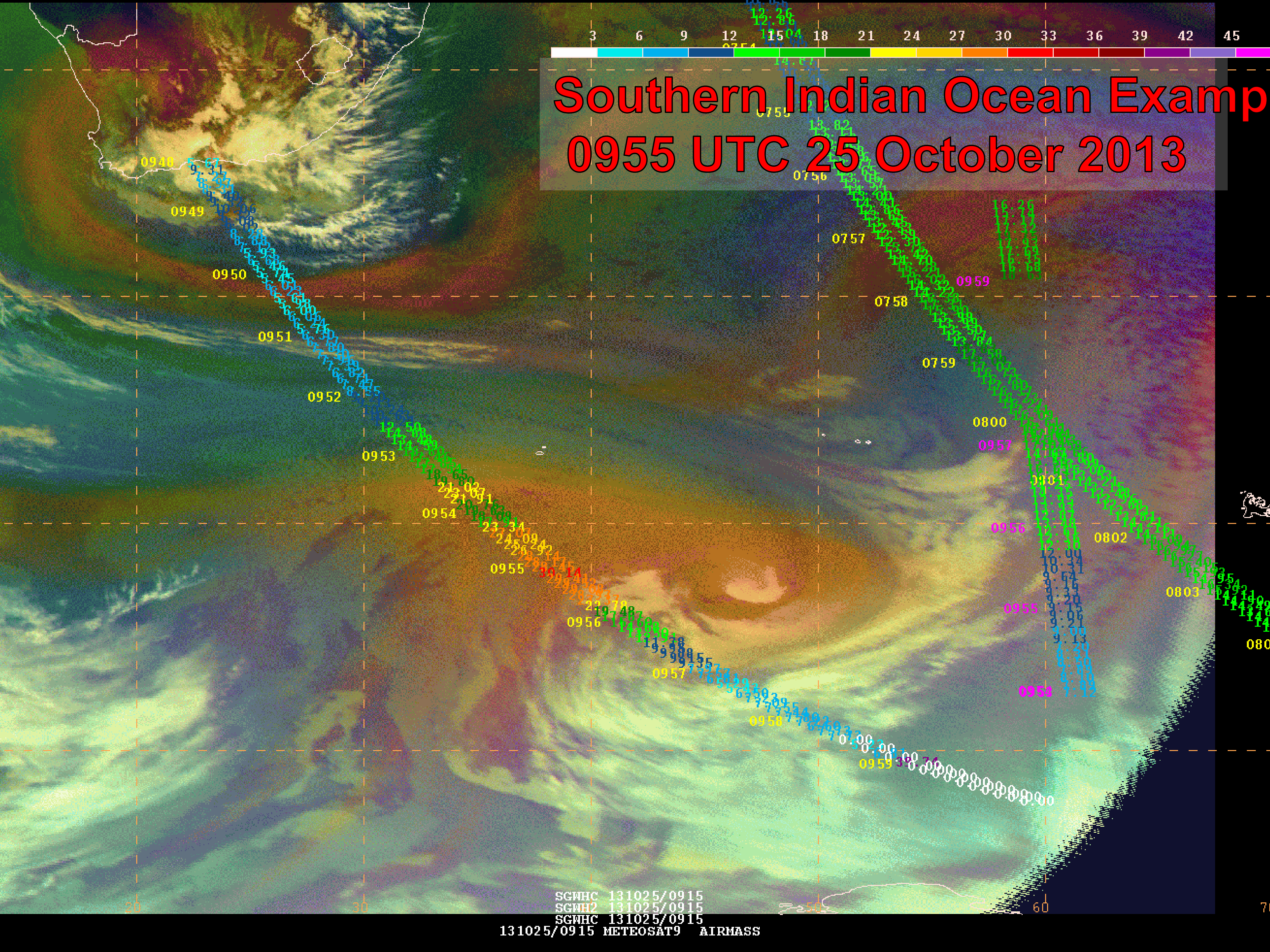
10/15/13 1800Z 25W WIPHA
10/15/13 2032Z MTSAT-2 IR
2021 UTC - 15 October 2013
AltiKA
30 knots
TYPHOON 25W (WIPHA) WARNING #22
*** FINAL WARNING ***
WTPN31 PGTW 152100
151800Z POSIT: NEAR 32.7N 138.9E
MOVING 040 DEGREES TRUE AT 30 KNOTS
MAXIMUM SIGNIFICANT WAVE HEIGHT: 30 FEET
15/18Z, WINDS 065 KTS, GUSTS TO 080 KTS
16/06Z, WINDS 055 KTS, GUSTS TO 070 KTS
16/18Z, WINDS 045 KTS, GUSTS TO 055 KTS
CPA TO: NM DTG
CAMP_FUJI 120 15/20Z
ATSUGI 83 15/22Z
CAMP_ZAMA 83 15/22Z
YOKOSUKA 64 15/22Z
YOKOTA_AB 89 15/22Z
NARITA_AIRPORT 52 15/23Z
MISAWA 178 16/05Z
LESS THAN 34 KNOTS
34-63 KNOTS
MORE THAN 63 KNOTS
PAST 6 HOURLY CYCLONE POSITS IN BLACK
FORECAST CYCLONE POSITS IN COLOR
16/18Z
16/06Z
15/18Z
Vladivostok
Misawa
Seoul
Kunsan
Busan
Kyoto
Sasebo
Iwakuni
Amami Oshima
Kadena
Minami Daito Jima
Iwo To
JTWC
ATCF


ft
m
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 70
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Significant Wave Height in Feet
2021 UTC - 15 October 2013
AltiKA
35
2021
37.51
38.92
41.59
45.47
44.89
55.99
47.40
48.71
50.70
52.95
48.71
50.95
46.95
48.67
45.82
47.80
46.03
42.77
55.27
52.58
55.14
55.99
54.23
60.95
51.56
45.76
46.05
48.22
52.20
52.63
51.38
49.79
55.52
49.21
47.22
46.48
46.49
45.69
50.46
44.03
46.70
48.31
47.18
46.03
49.70
49.92
51.46
46.17
47.86
50.51
51.44
43.85
45.56
47.68
42.35
46.12
42.49
41.50
38.19
35.41
140
True at 33.00N
KM
100
200
SGWHE 131016/0010
400

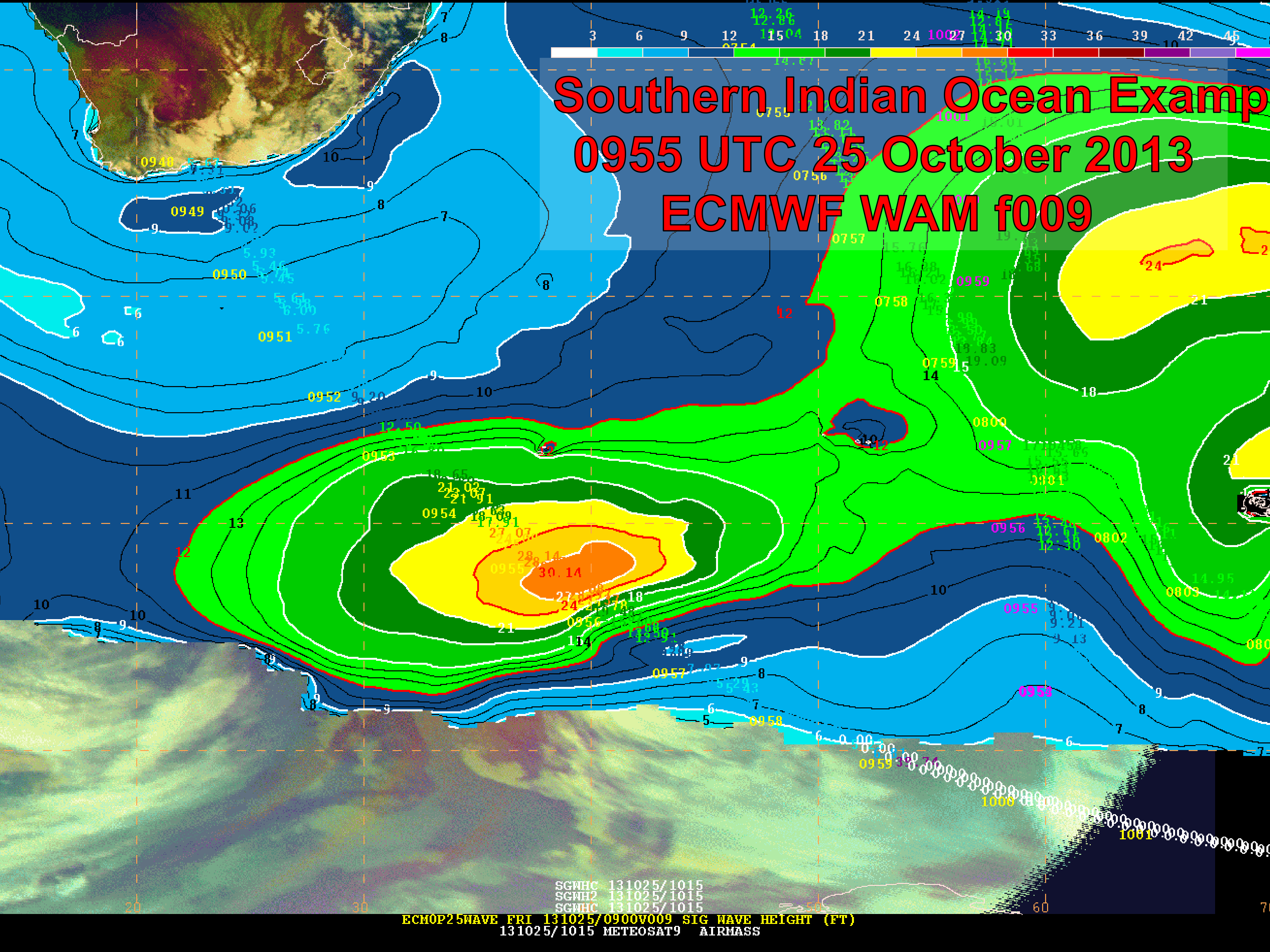


Significant Wave Height
2021 UTC - 15 October 2013
AltiKA
KM 100 200 300 400
True at 33.31N
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 70
SGWHE 131015/2050
ECMOP25WAVE TUE 131015/2100V009 SIG WAVE HEIGHT (FT)

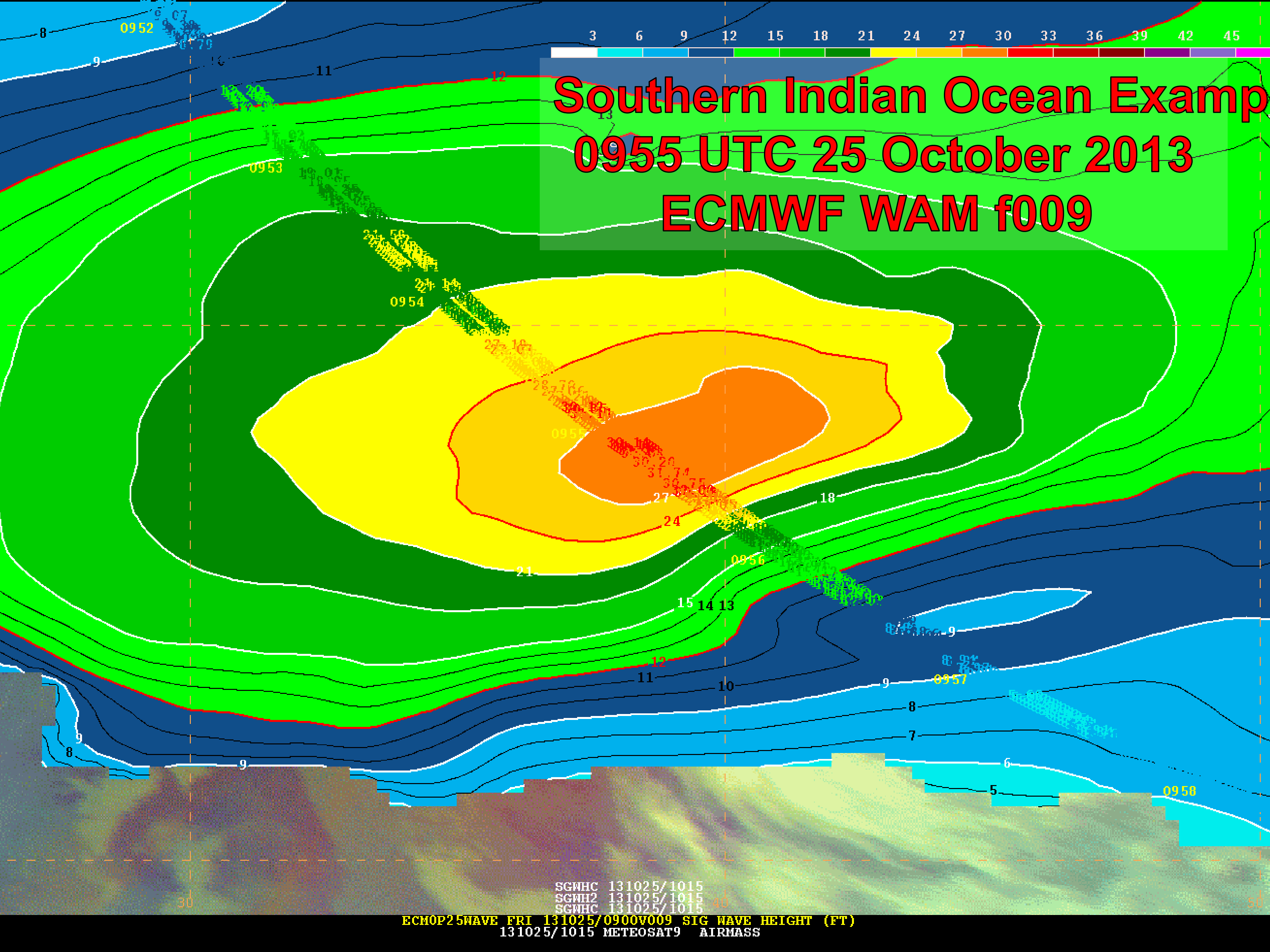

Southern Indian Ocean Examp
0955 UTC 25 October 2013
131025/0915 METEOSAT9 AIRMASS
60



Southern Indian Ocean Examp
0955 UTC 25 October 2013
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
SGWHC 131025/0915
SGWH2 131025/0915
SGWHC 131025/0915
131025/0915 METEOSAT9 AIRMASS



Southern Indian Ocean Examp
0955 UTC 25 October 2013
ECMWF WAM f009
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
SGWHC 131025/1015
SGWH2 131025/1015
SGWHC 131025/1015
ECMOP25WAVE FRI 131025/0900V009 SIG WAVE HEIGHT (FT)
131025/1015 METEOSAT9 AIRMASS



Southern Indian Ocean Examp
0955 UTC 25 October 2013
ECMWF WAM f009
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
0952
0953
0954
0955
0956
0957
0958
SGWHC 131025/1015
SGWH2 131025/1015
SGWHC 131025/1015
ECMOP25WAVE FRI 131025/0900V009 SIG WAVE HEIGHT (FT)
131025/1015 METEOSAT9 AIRMASS

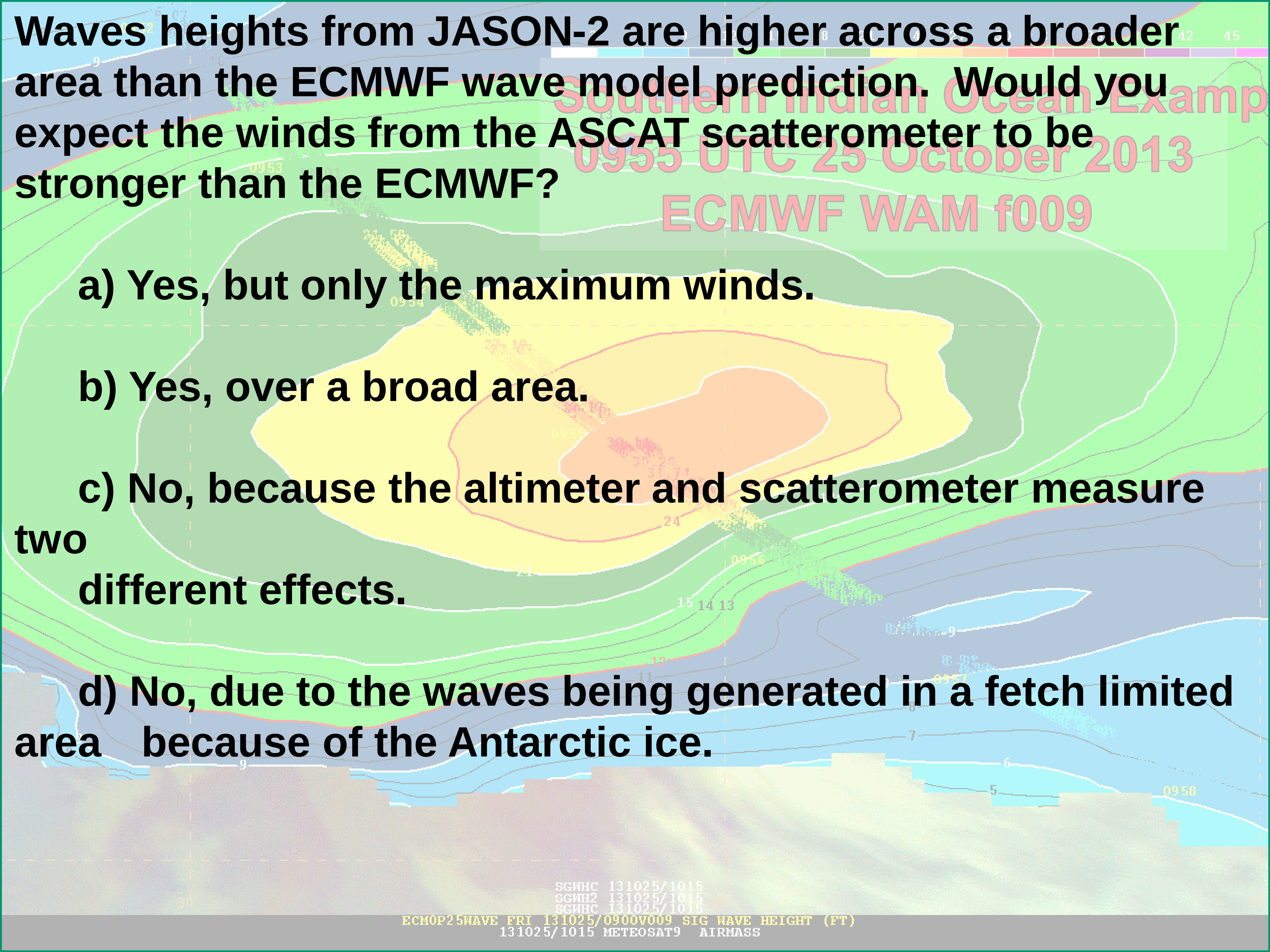
Waves heights from JASON-2 are higher across a broader area than the ECMWF wave model prediction. Would you expect the winds from the ASCAT scatterometer to be stronger than the ECMWF?

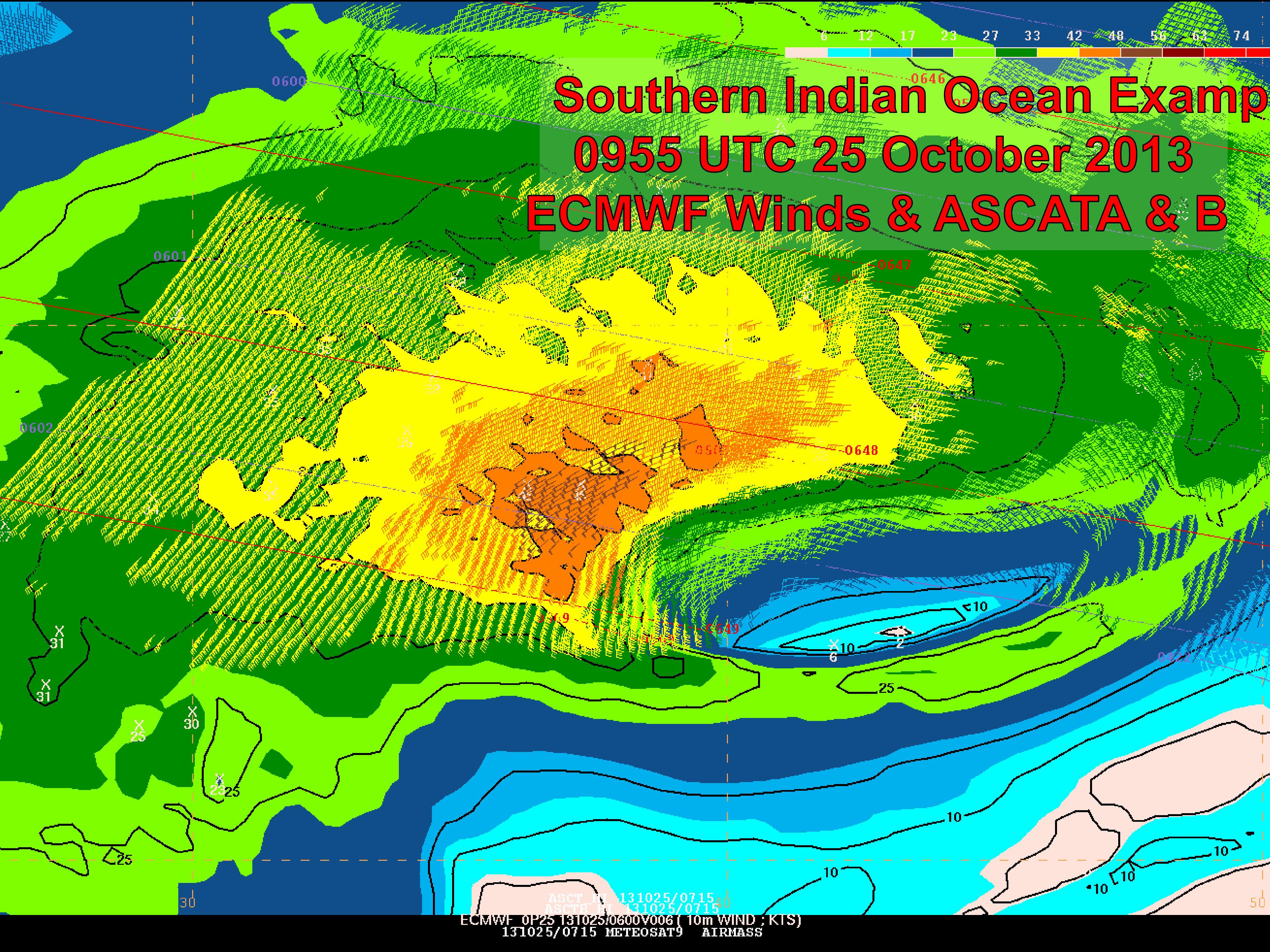
a) Yes, but only the maximum winds.

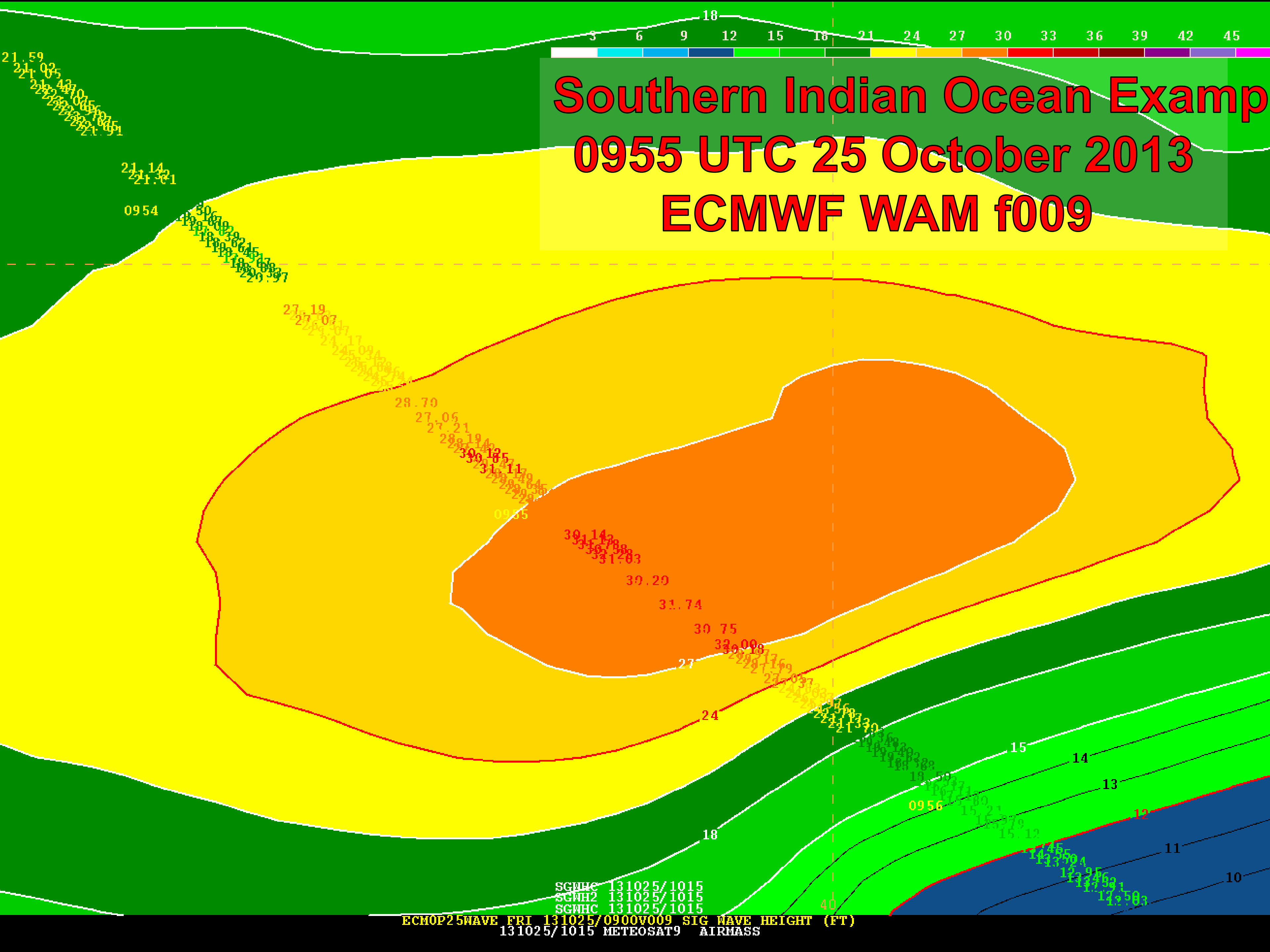
b) Yes, over a broad area.

c) No, because the altimeter and scatterometer measure two different effects.

d) No, due to the waves being generated in a fetch limited area because of the Antarctic ice.

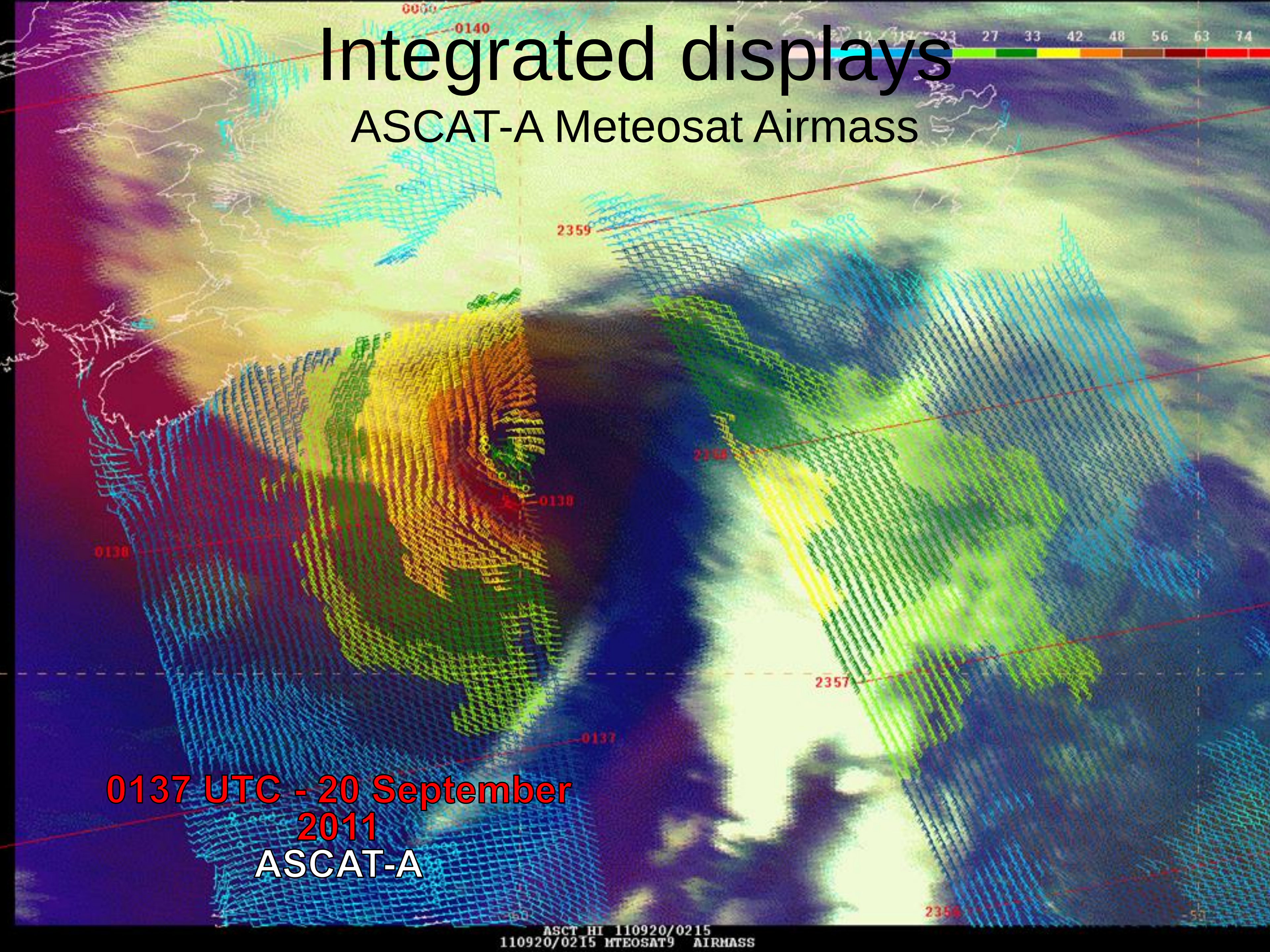



Southern Indian Ocean Examp
0955 UTC 25 October 2013
ECMWF Winds & ASCATA & B
6 12 17 23 27 33 42 48 56 63 74
ASCT HI 131025/0715
ASCTB HI 131025/0715
ECMWF 0P25 131025/0600V006 (10m WIND ; KTS)
131025/0715 METEOSAT9 AIRMASS

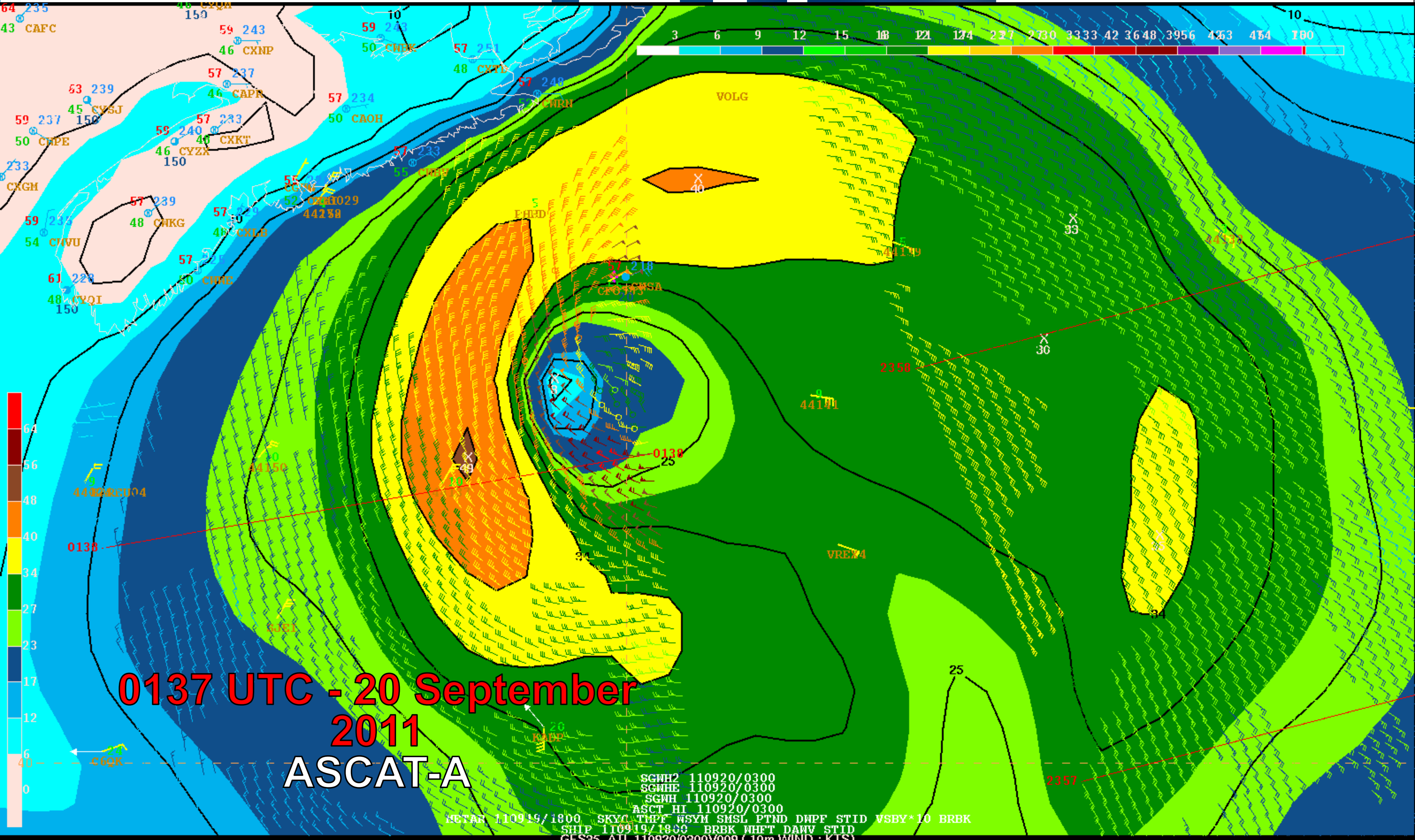

Southern Indian Ocean Examp
0955 UTC 25 October 2013
ECMWF WAM f009
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45
SGWHC 131025/1015
SGWH2 131025/1015
SGWHC 131025/1015
ECMOP25WAVE FRI 131025/0900V009 SIG WAVE HEIGHT (FT)
131025/1015 METEOSAT9 AIRMASS

Integrated displays

ASCAT-A Meteosat Airmass



Integrated displays
ASCAT-A vs. GFS 201009191800 f009



Integrated displays
ASCAT-A vs. GFS 201009191800 f009

The winds from ASCAT are stronger than the GFS model 9 hour forecast, should we expect the waves to be higher than the GFS forced wave model?

a) **Yes, but by only one or two feet**

b) **Yes, by a significant number of feet**

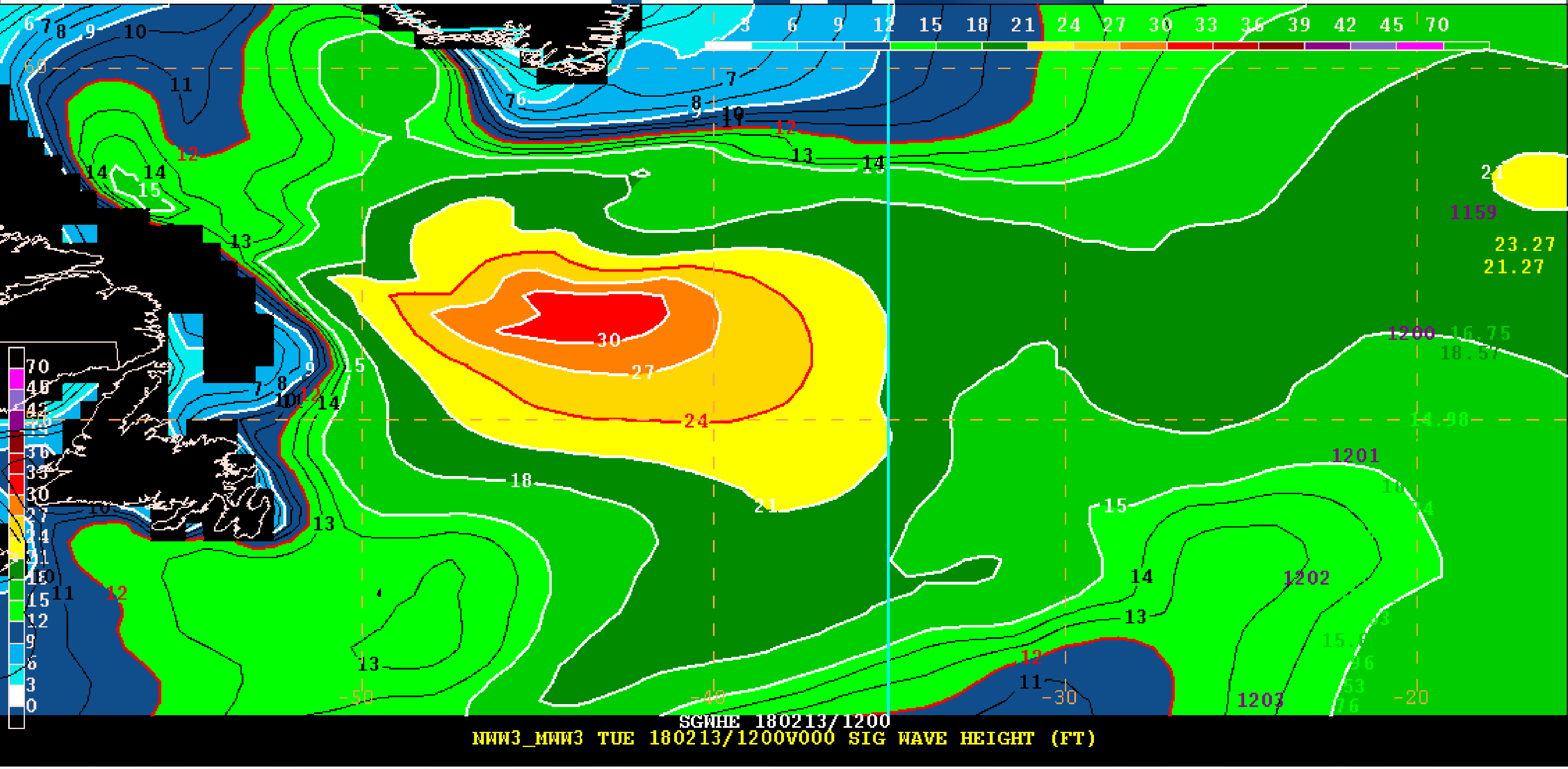
c) **No, as it takes time to build waves**

d) **No, as the wave model takes into account the weaker winds from the GFS**

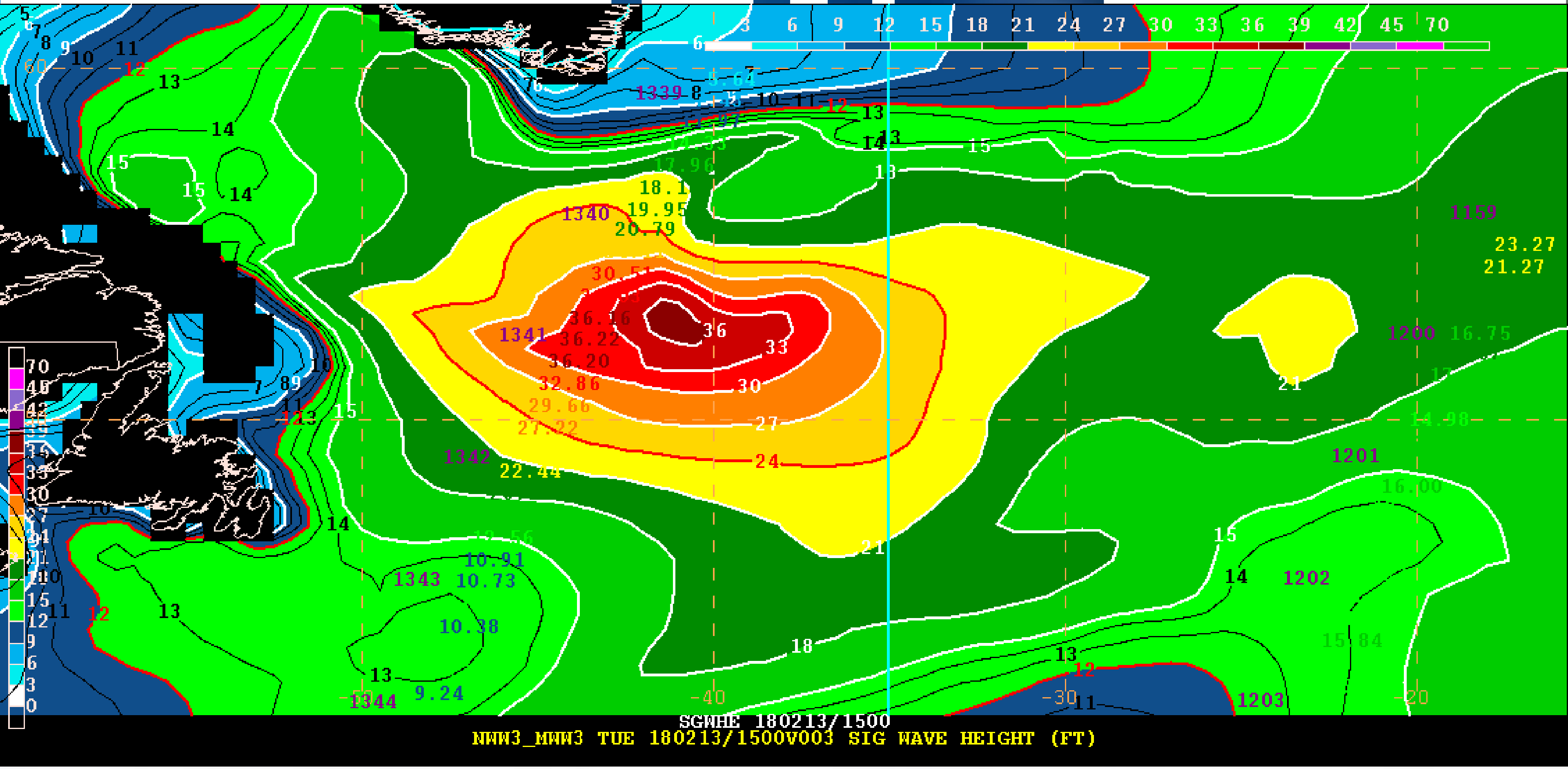
Integrated displays

JASON1 vs. Multi-grid WAVEWATCH3

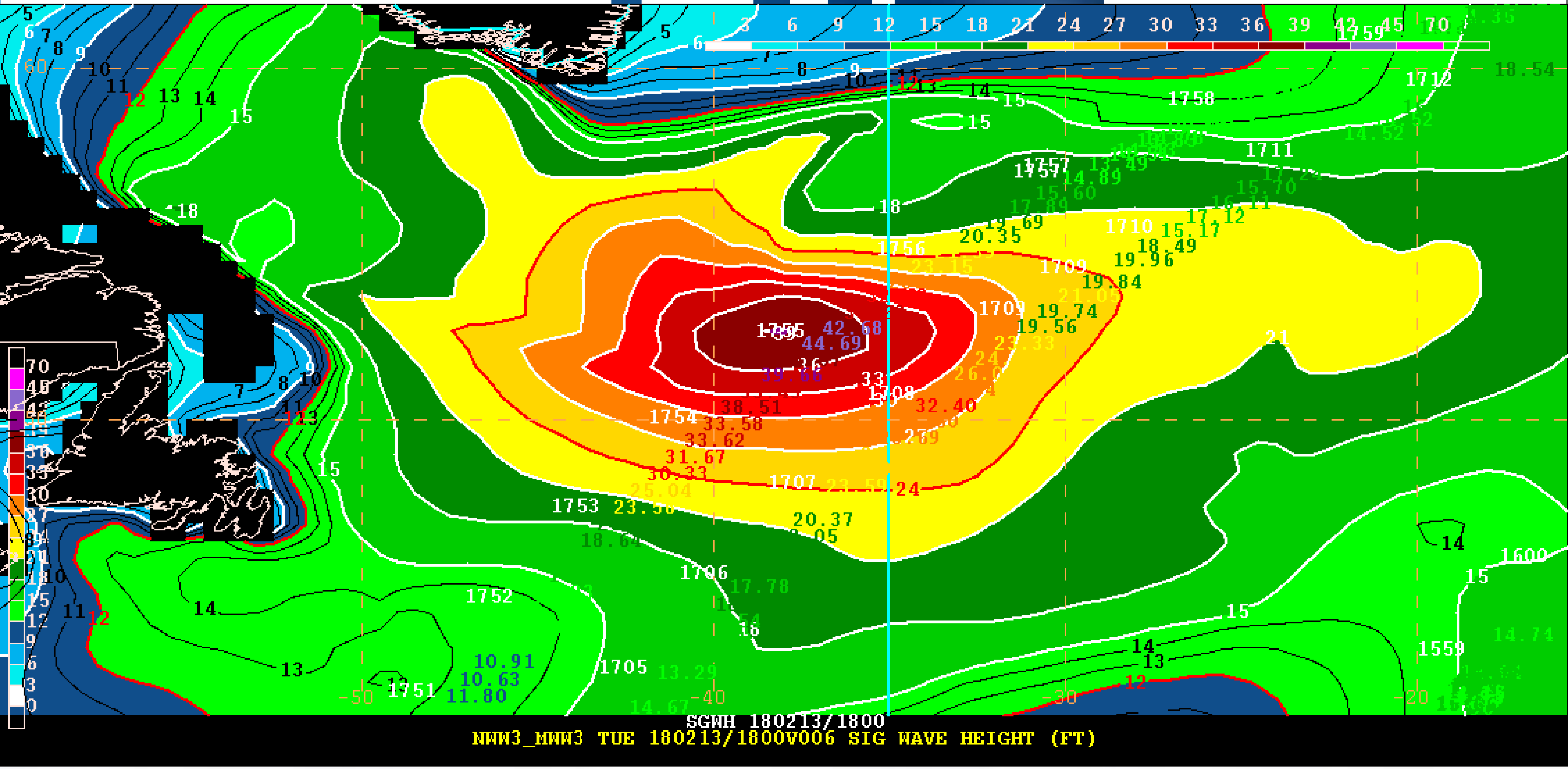
13th December 2017
Wave Watch 3 12Z



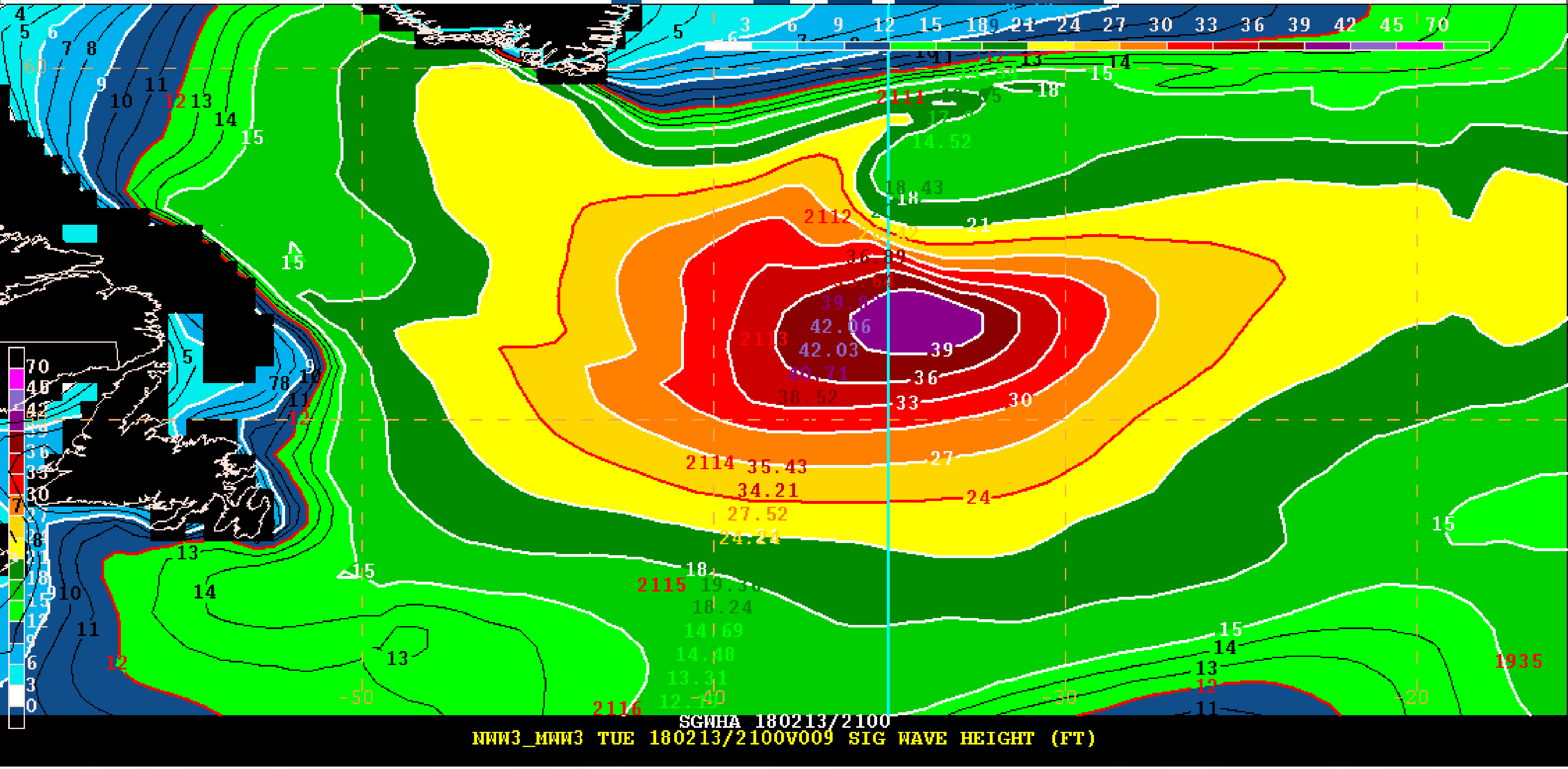
13th December 2017
Wave Watch 3 15Z



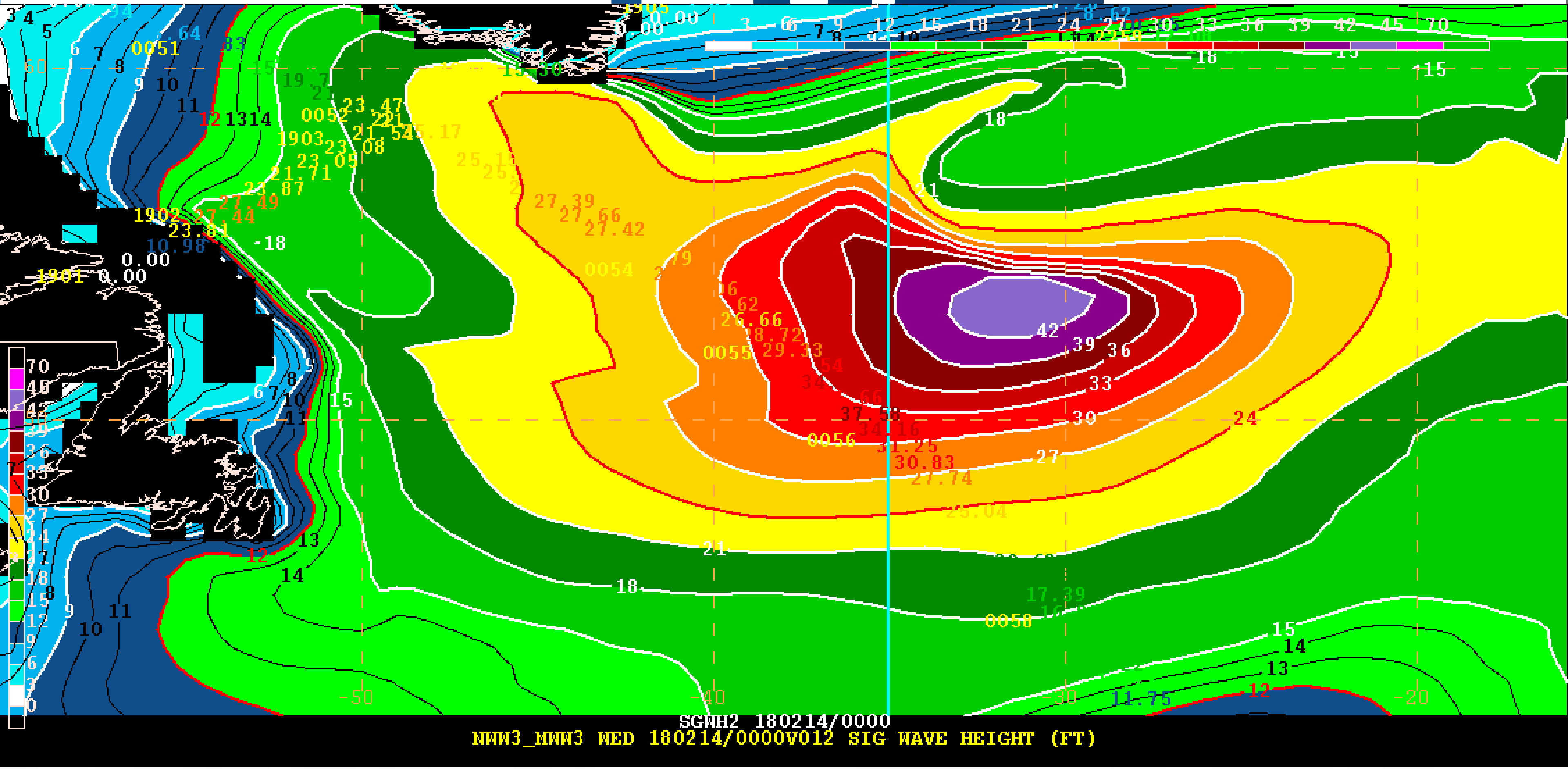
13th December 2017 Wave Watch 3 18Z



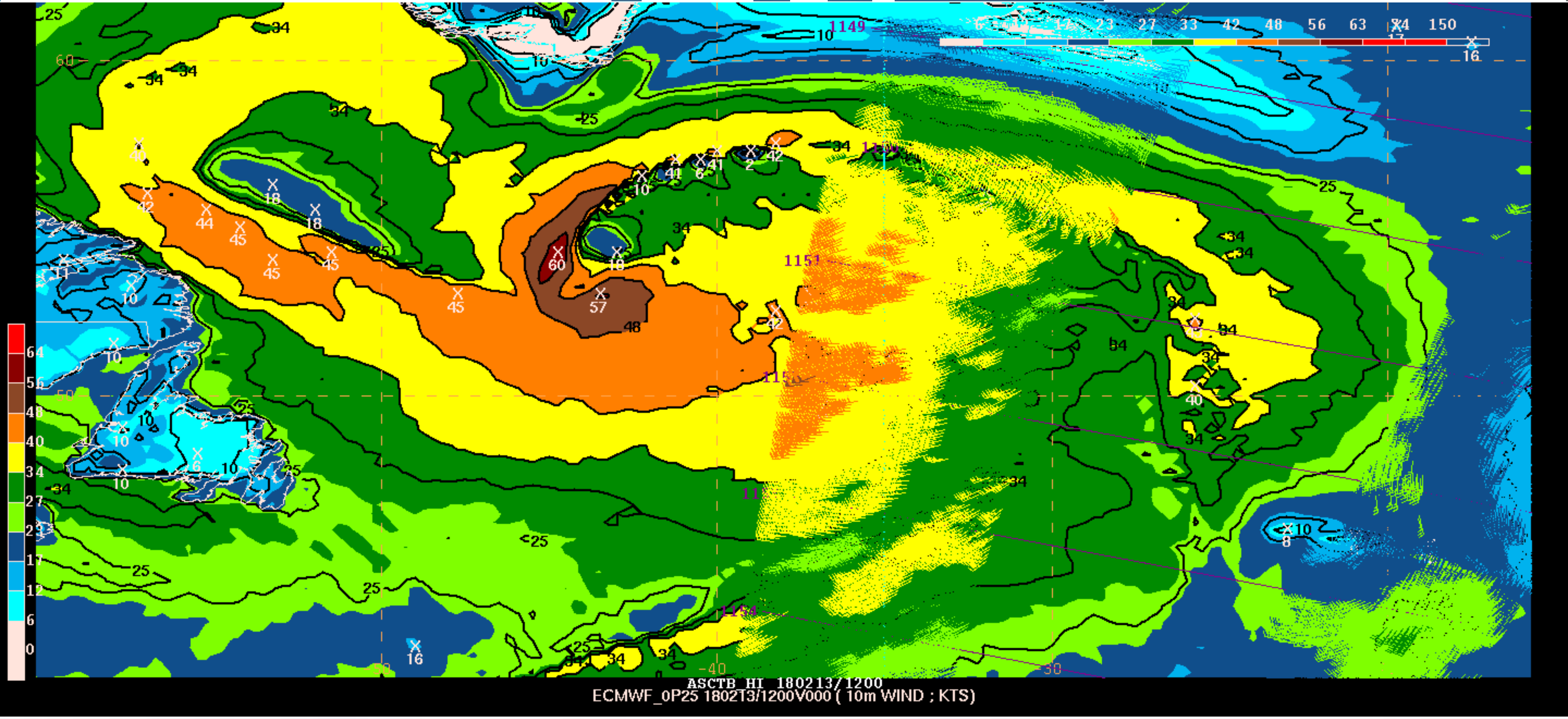
13th December 2017
Wave Watch 3 21Z



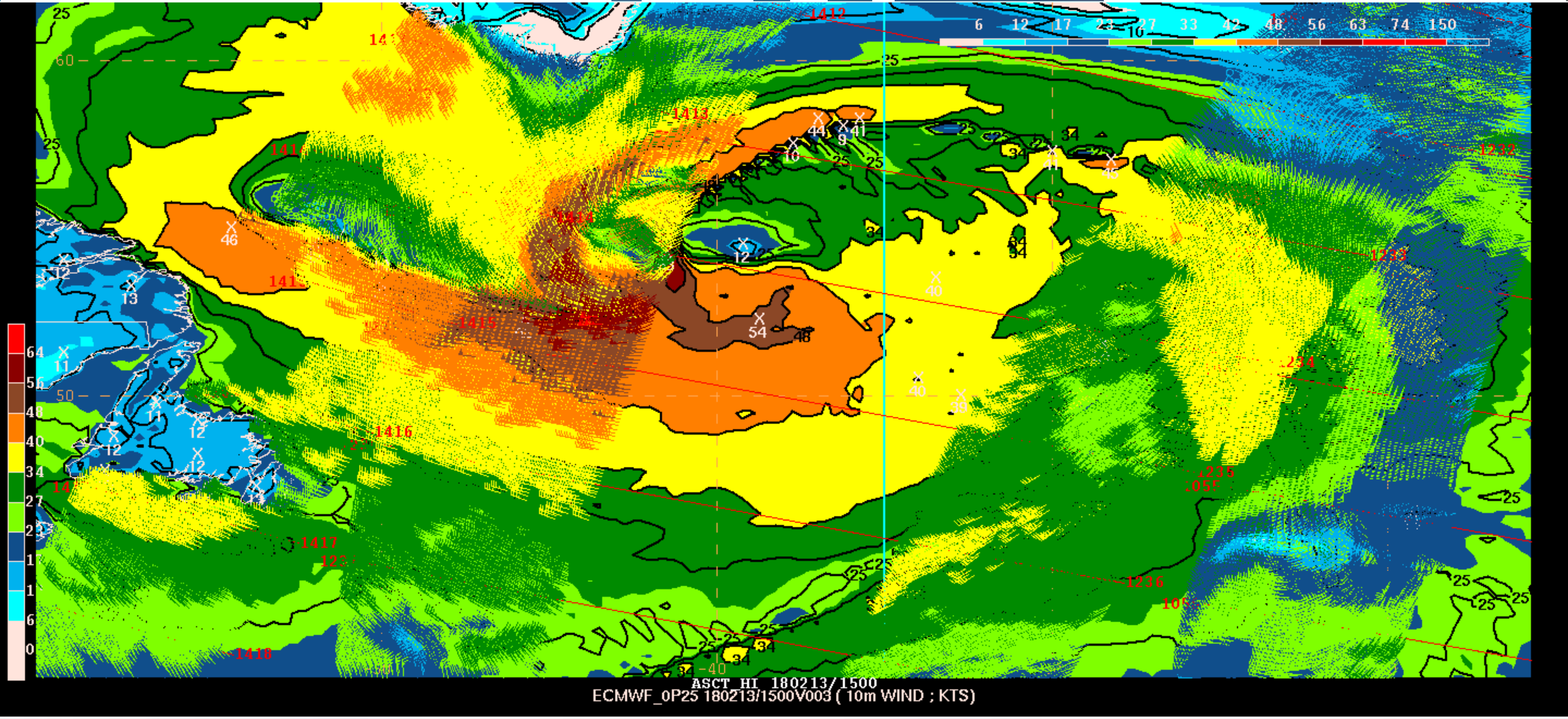
14th December 2017
Wave Watch 3 00Z



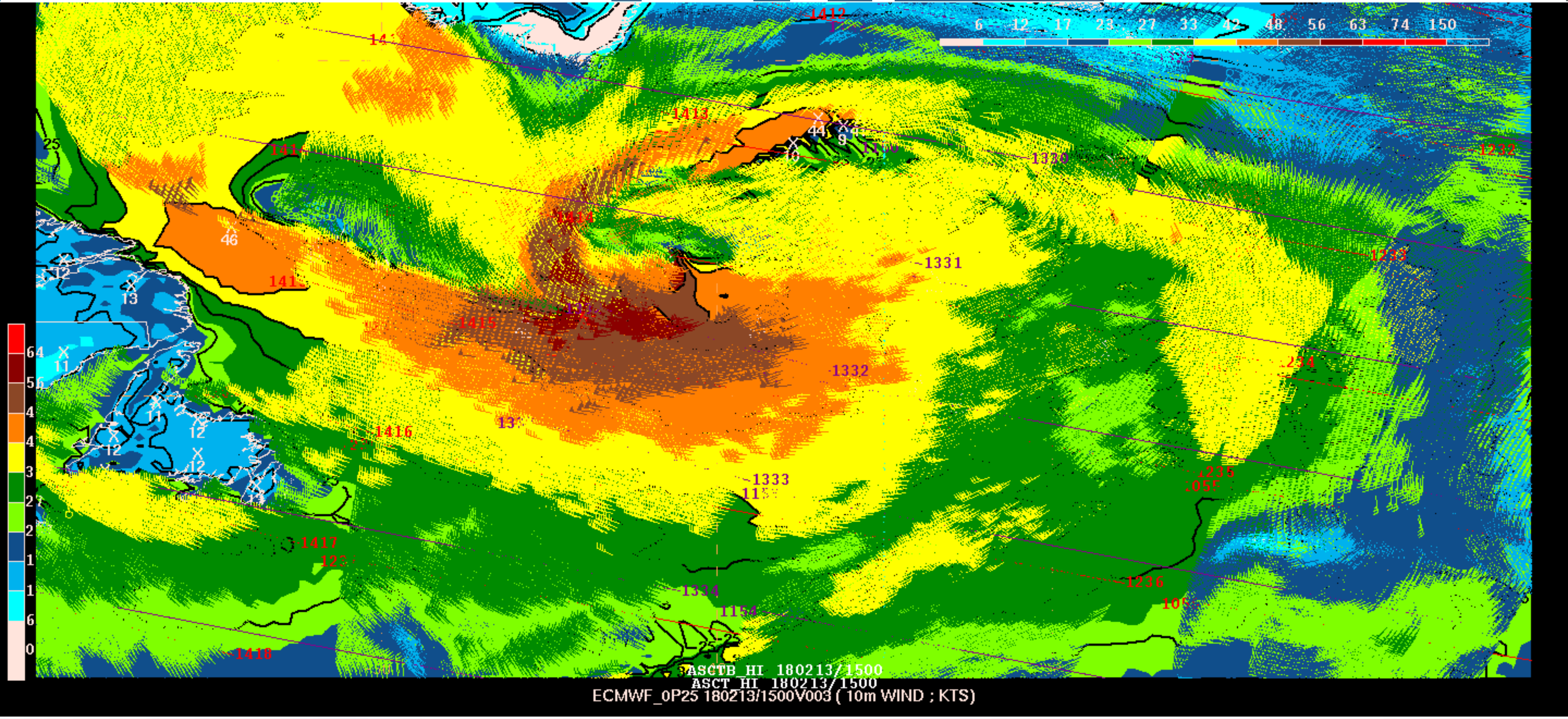
13th December 2017
ECMWF 12Z + ASCAT-B



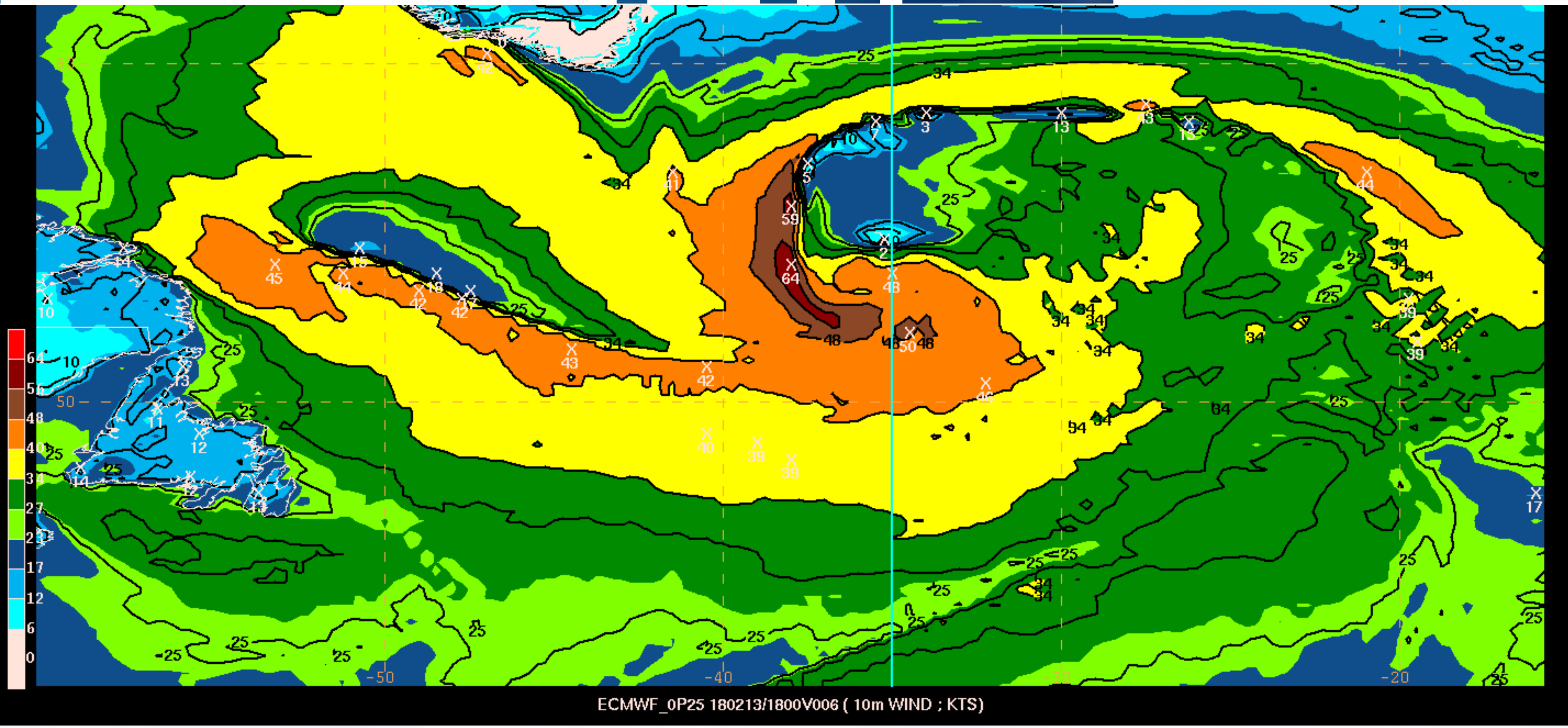
13th December 2017
ECMWF 15Z + ASCAT-A



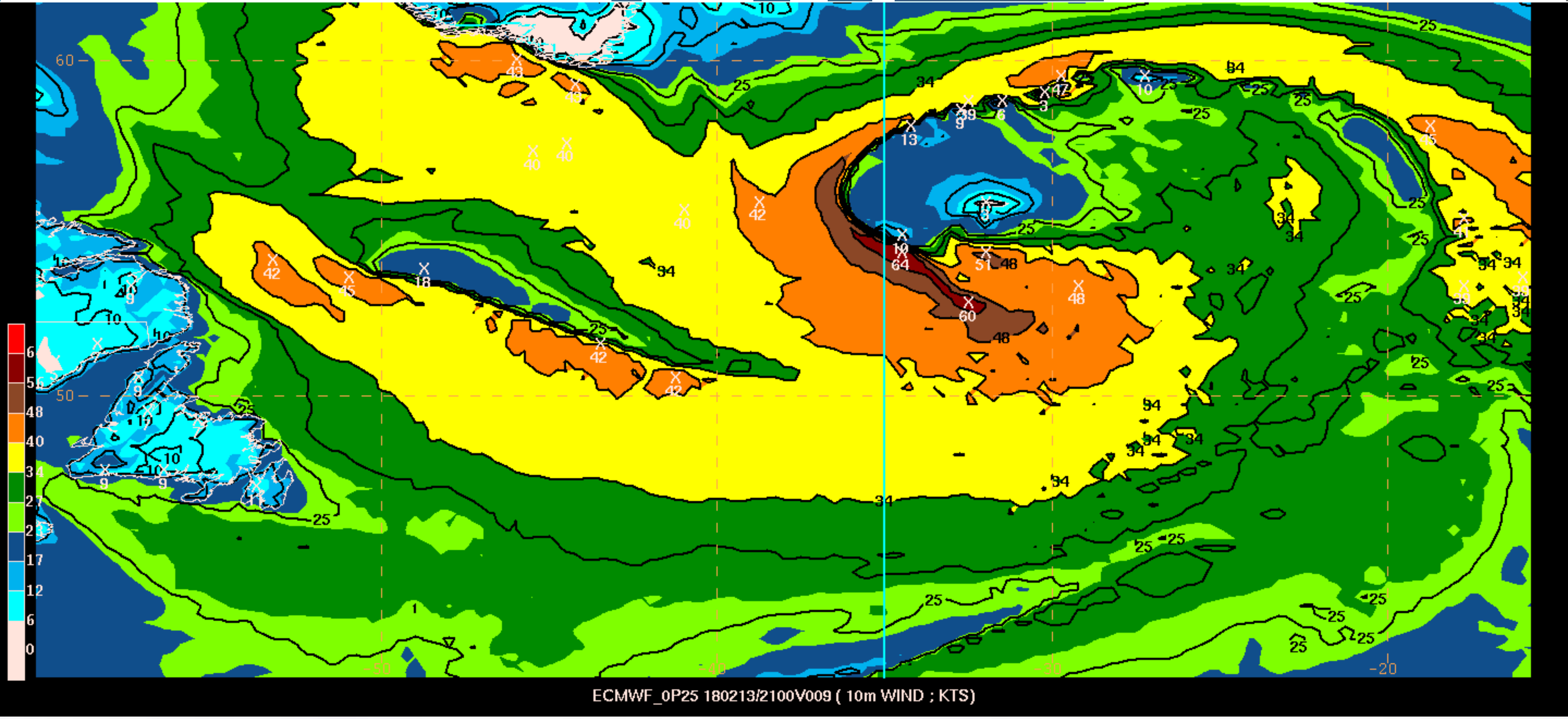
13th December 2017
ECMWF 15Z + ASCAT-A+ASCAT-B



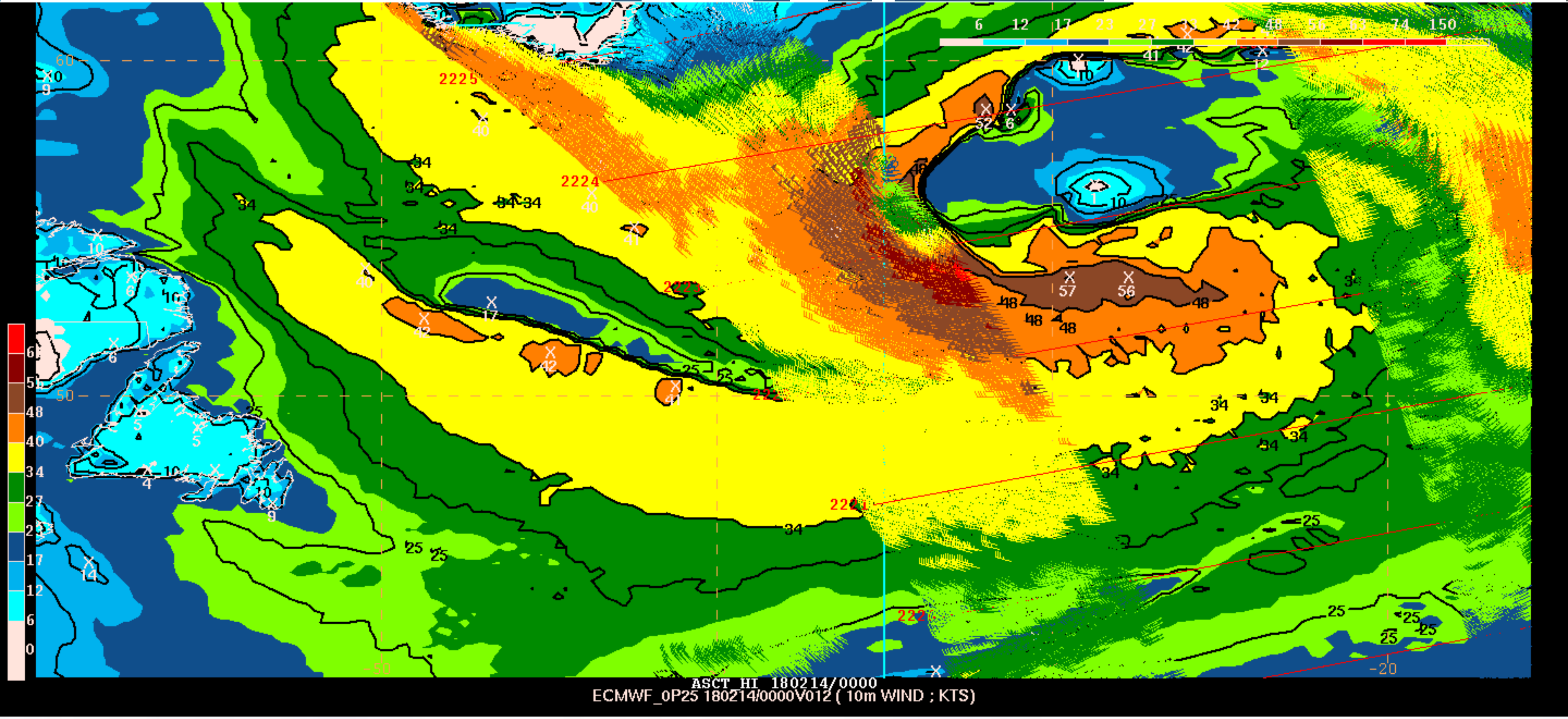
13th December 2017
ECMWF 18Z



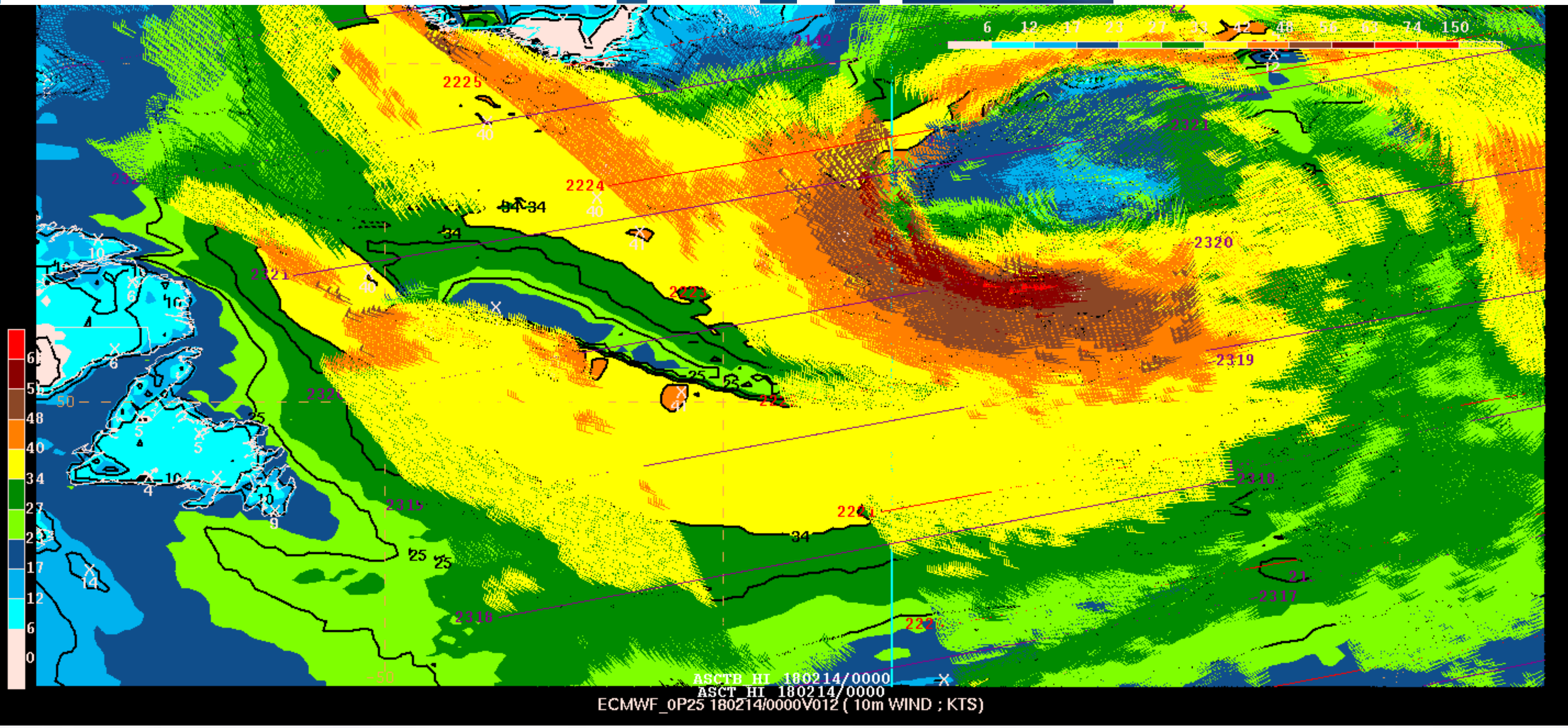
13th December 2017
ECMWF 21Z



14th December 2017
ECMWF 00Z + ASCAT-A



14th December 2017
ECMWF 00Z + ASCAT-A+ASCAT-B



Summary

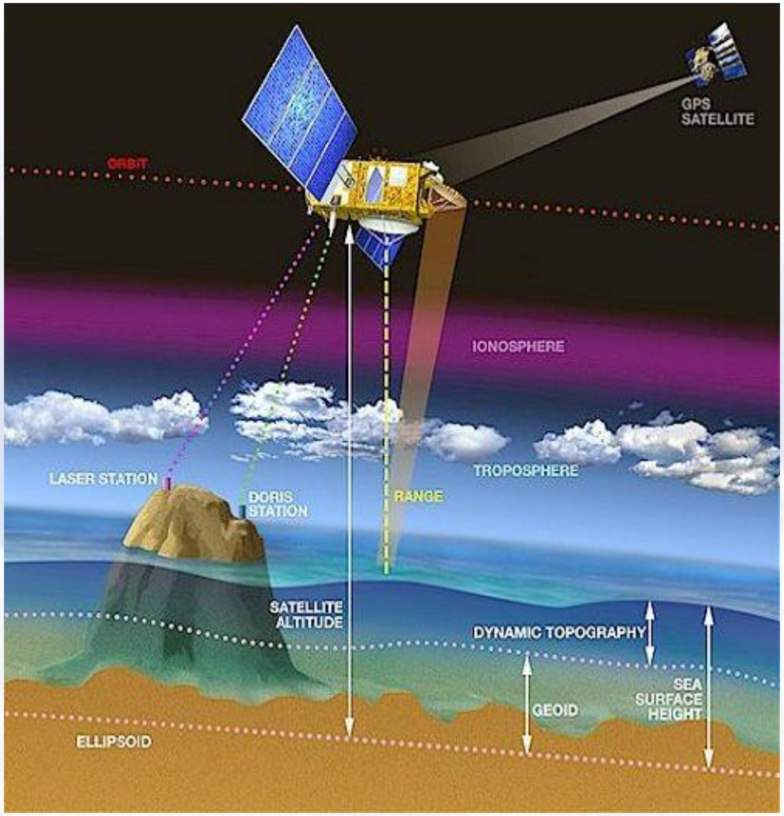
- Satellite altimeters provide near global coverage of significant wave height over varying repeat cycles

- Altimeters derive significant wave height over a 6 to 7 km length

- Altimeter wave heights are an excellent source to be used to :
  - Determine if a specific weather system is behaving as models have predicted
  - Observe conditions over data sparse areas
  - As a means to bias correct large scale biases in wave models
  - Complement other data sources such as
    - Buoy winds and waves
    - Scatterometer winds
    - Satellite imagery

  - Integrated displays with complimentary observations, imagery, and numerical model output are a very powerful tool to enhance forecaster awareness

Sea Surface Heights from Altimeters



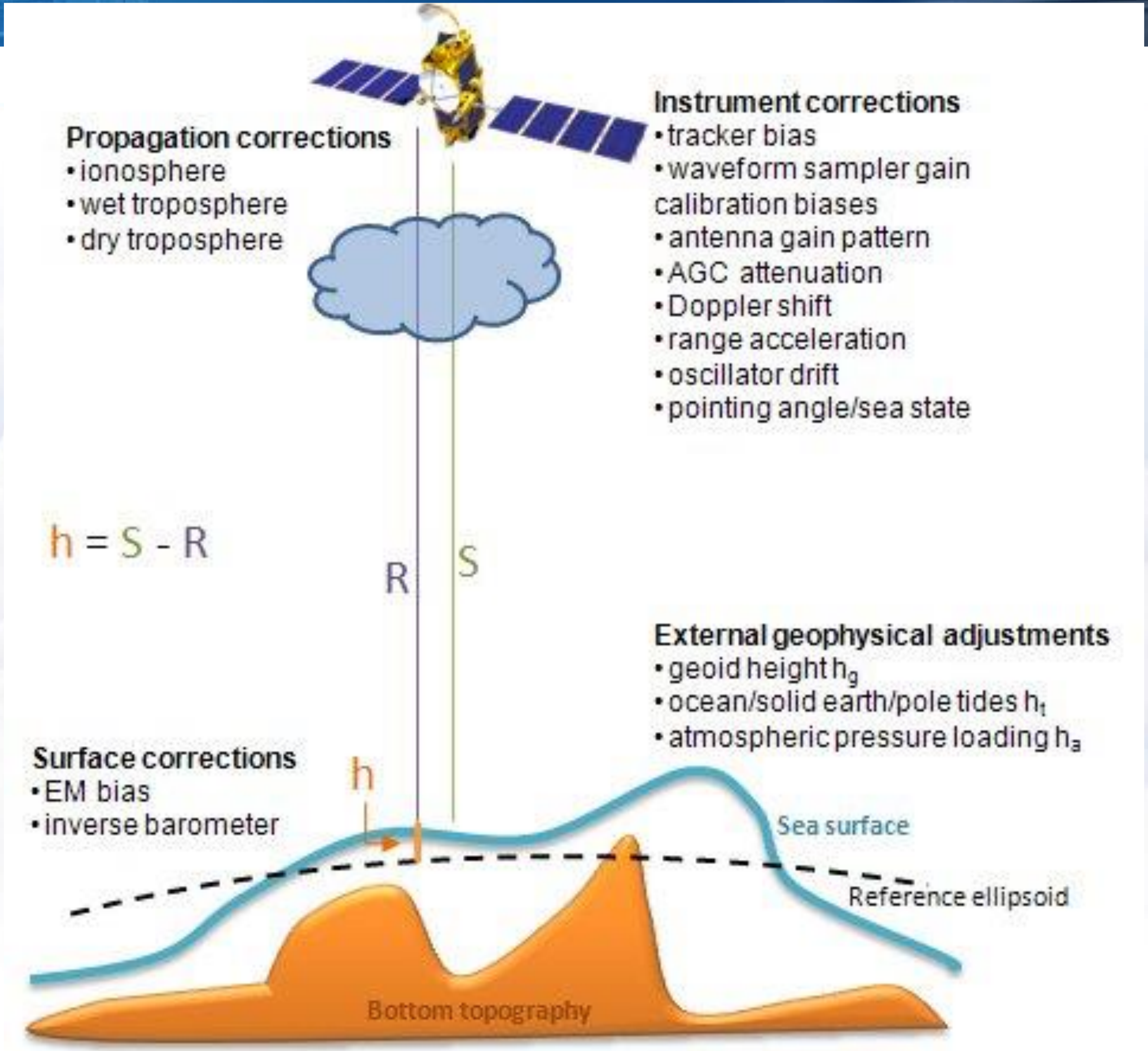
Distance from the satellite to a target surface (**altimeter range**) by measuring the satellite-to-surface round-trip time of a radar pulse:

$$t = 2d/c$$

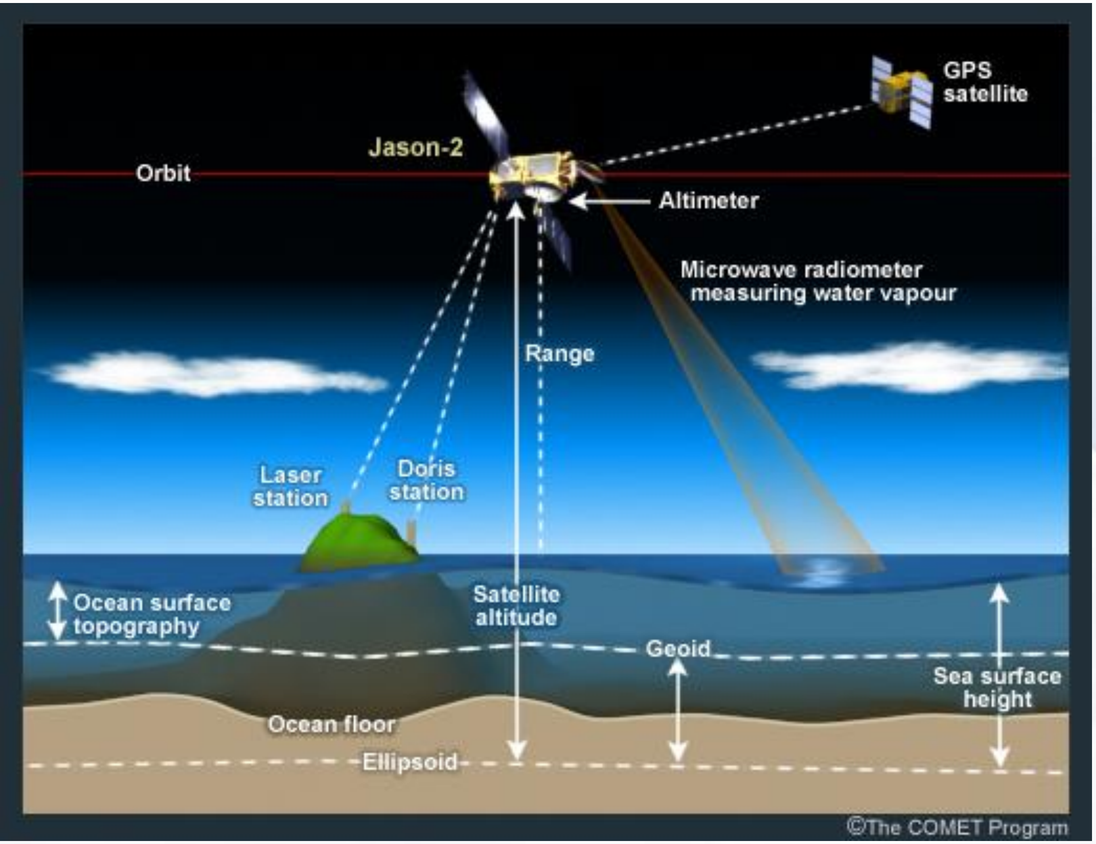
SSH=Orbit Altitude-Range'

Range'=Range+corrections

Geographical Corrections



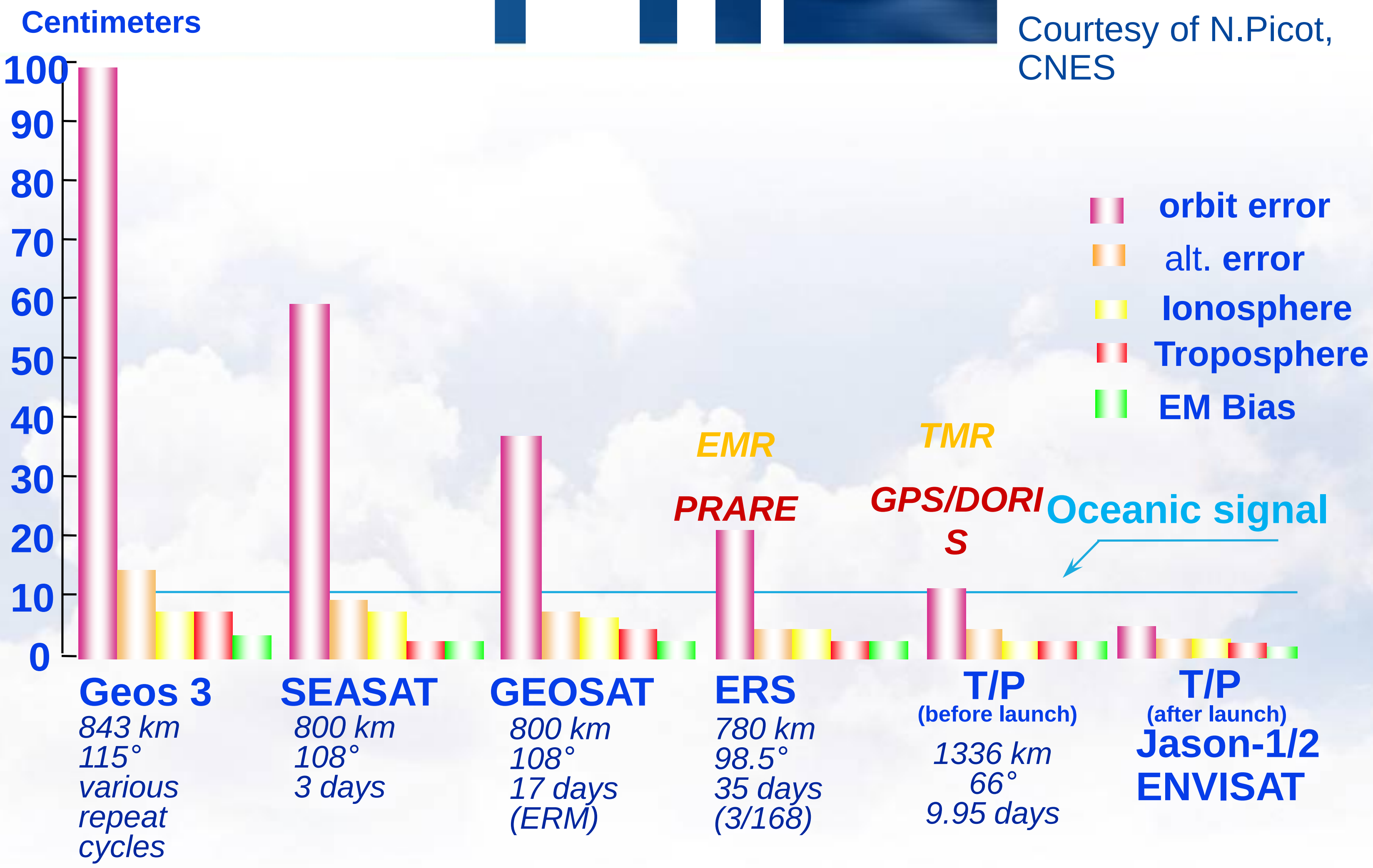
The main components in the satellite altimetry system

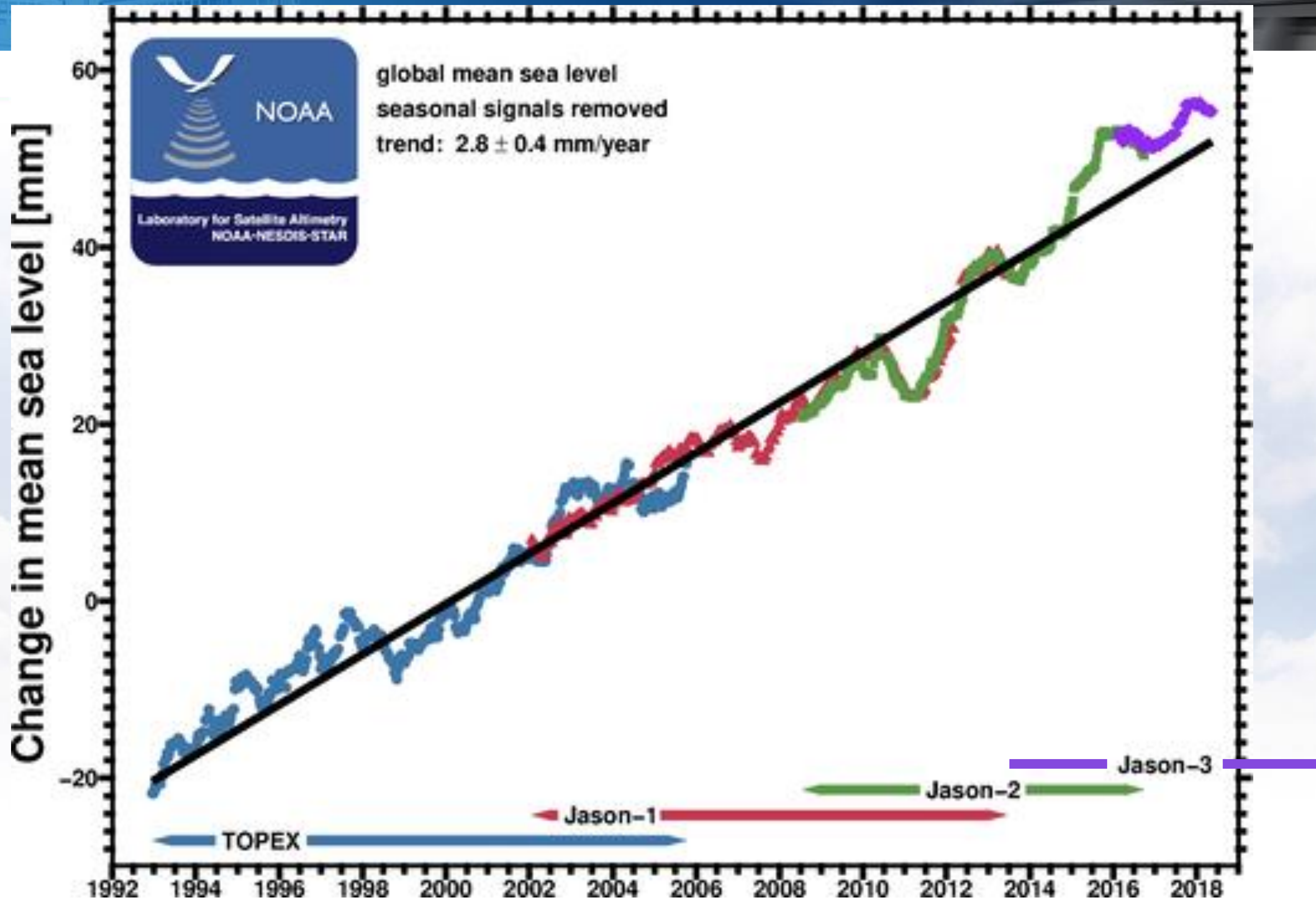


- **The radar altimeter and antenna for surface parameters**
- **The radiometer, which measures atmospheric disturbances**
- **The systems for determining the satellite's precise location in orbit**

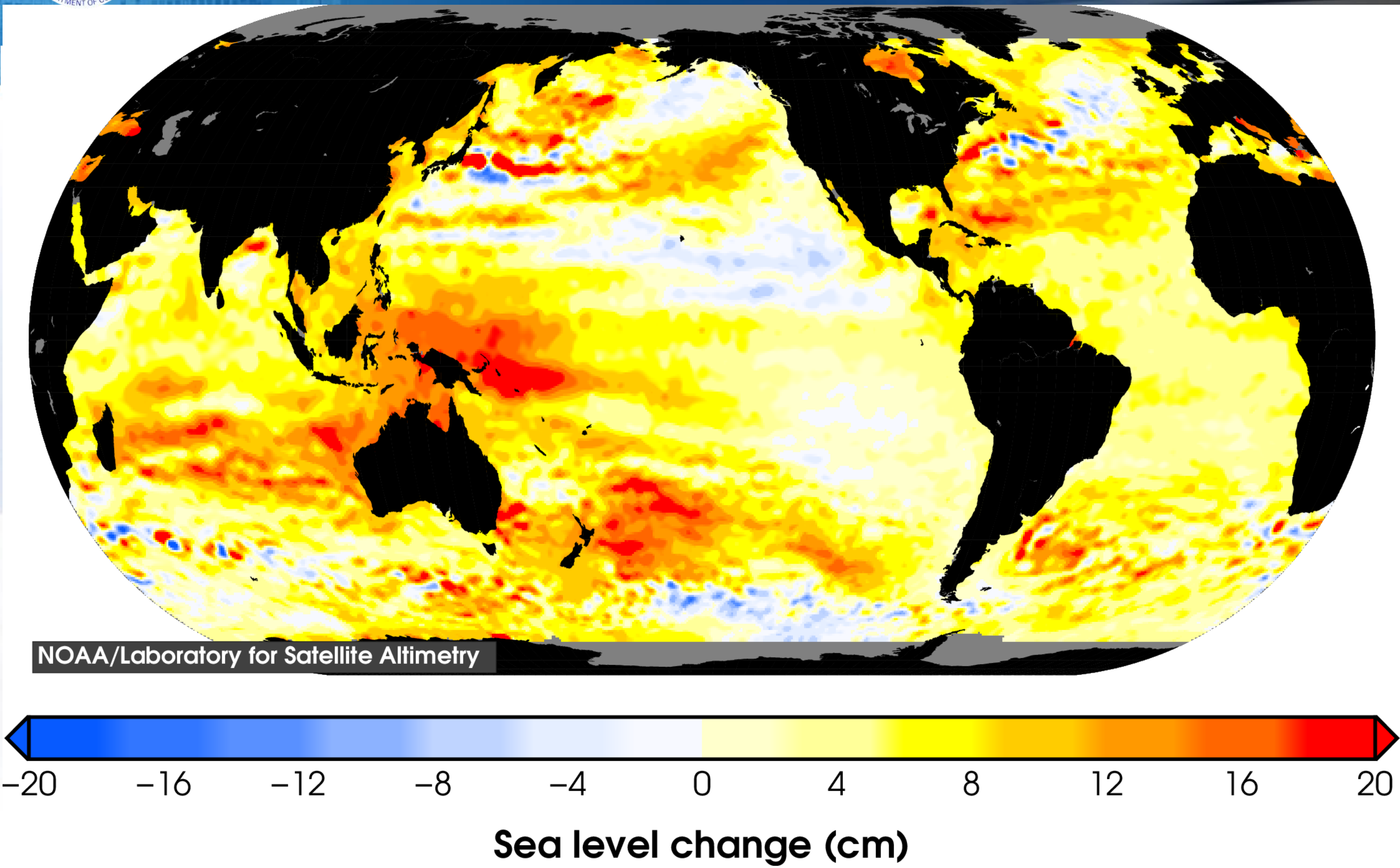
SSH accuracy evolution over time

Courtesy of N.Picot, CNES




NOAA
Laboratory for Satellite Altimetry
NOAA-NESDIS-STAR
global mean sea level
seasonal signals removed
trend: 2.8 ± 0.4 mm/year
Change in mean sea level [mm]
60
40
20
0
-20
Jason-3
Jason-2
Jason-1
TOPEX
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018

Total Sea Level Change Since 1993



http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/