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Research Document 2001/113

Document de recherche 2001/113

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Physical Oceanography of Southern Gulf of St. Lawrence and Sydney Bight Areas of Coastal Cape Breton

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ISSN 1480-4883
Ottawa, 2001

ABSTRACT
This document describes some aspects of the physical oceanography of the Southern Gulf of St. Lawrence and Sydney Bight areas of coastal Cape Breton (Fig. 1.). The description is based on previously published information complemented with results from a three-dimensional numerical model of the ocean developed at Bedford Institute of Oceanography. The water column in the Cape Breton Trough is strongly stratified in summer, which isolates cold water (0 – 3 °C) at the bottom. Surface water temperature in summer is between 16–18 °C and the thermocline is sharply defined between 20-40m depth. In Sydney Bight, the maximum stratification is deeper in the water column (30-50 m). The semi-enclosed shape of the Gulf of St. Lawrence favors the formation of a northeastward coastal current, along the west coast of Cape Breton, that is modulated and can be reversed by the action of tide and wind. There are indications that this flow, combined with the morphology of the Cape Breton Channel and the tidal action, generates a pumping mechanism that brings deeper water closer to the surface layer. On a smaller scale, the Cape Breton Trough and Sydney Bight influence the current patterns creating gyres and upwelling. Wind can be an important determinant of the direction and speed of surface water movement. There is a surface outflow within Cabot Strait along the Cape Breton coast that is partly counterbalanced by an inflow in the deep Laurentian Channel. The presence of a clockwise gyre in Sydney Bight could be linked with the outflow at Cabot Strait and the morphology of the Bight itself. Sydney Bight and the west coast of Cape Breton have ice present for 60 to 100 days per year on average, from January to the beginning of April.

RÉSUMÉ
Le présent document décrit certains des aspects de l'océanographie physique des secteurs du sud du golfe du Saint-Laurent et du Sydney Bight, sur la côte du Cap-Breton (fig. 1). La description est fondée sur des renseignements publiés antérieurement, auxquels s'ajoutent les résultats d'un modèle numérique tridimensionnel de l'océan, élaboré à l'Institut océanographique de Bedford. La colonne d'eau dans le chenal du Cap-Breton est fortement stratifiée l'été, ce qui isole les eaux froides (0 – 3 °C) au fond. En été, la température des eaux de surface se situe entre 16 et 18 °C et la thermocline est nettement définie entre 20 et 40 m de profondeur. Dans le Sydney Bight, la stratification maximale est plus profonde dans la colonne d'eau (30-50 m). La forme semi-close du golfe du Saint-Laurent est propice à la formation d'un courant côtier vers le nord-est, le long de la côte ouest du Cap-Breton, qui est modulé et peut être inversé par l'action des marées et du vent. Selon certaines indications, ce courant, combiné à la morphologie du chenal du Cap-Breton et à l'action des marées, crée un effet de pompage qui amène les eaux profondes près de la couche de surface. À plus petite échelle, la dépression du Cap-Breton et le Sydney Bight influent sur les régimes de courant, créant des tourbillons et des remontées d'eau. Le vent peut être un déterminant important de la direction et de la vitesse de la circulation de l'eau de surface. Il y a en surface un transport d'eau sortant par le détroit de Cabot, le long de la côte du Cap-Breton, qui est compensé en partie par un transport entrant dans le chenal Laurentien profond. La présence d'un tourbillon (sens horaire) dans le Sydney Bight pourrait être liée au transport d'eau sortant par le détroit de Cabot et à la morphologie du bight lui-même. Dans le Sydney Bight et sur la côte ouest du Cap-Breton, des glaces sont présentes de 60 à 100 jours par an en moyenne, entre janvier et le début d'avril.

1 TEMPERATURE AND SALINITY

In summer (August) the mean sea surface temperature (SST), offshore of western Cape Breton, is around 17 °C while the salinity is between 28 and 29 $^o/_{oo}$ (Petrie *et al.*, 1996a). In Sydney Bight Area, the mean SST is around 17 to 18 °C and the salinity is between 29.5 to 30.5 $^o/_{oo}$ (Petrie *et al.*, 1996b). The bottom temperature ranges from 3 to 10 °C depending on the depth (the coldest waters are found at depth) and the bottom salinity varies from 30 $^o/_{oo}$ in St. Georges Bay to 32 $^o/_{oo}$ at Cape North and up to 33.5 $^o/_{oo}$ in the deep water of Sydney Bight. In winter (February), the water has less heat with surface temperature close to the freezing point (0 to - 1.7 °C) while the surface salinity increases from 29.5 $^o/_{oo}$ in St. Georges Bay to 31.5 $^o/_{oo}$ around Cape North and Sydney Bight area. At the bottom, temperatures are also less than 0 °C and the salinity is still around 30 $^o/_{oo}$ – 32 $^o/_{oo}$ (Cape Breton Channel, Cape North) to 34 $^o/_{oo}$ (Sydney Bight). Figures 2 and 3 show vertical structure of temperature and salinity in the Cape Breton Channel and Sydney Bight areas, respectively. The maximum stratification is reached in August with a surface temperature of 17 °C and a bottom temperature of 2 °C in the Cape Breton Channel and 5 °C in Sydney Bight. The maximum vertical gradient is located at depths around 25 to 30 m. By the beginning of September, the surface water (first 20 m) starts to cool at a rate close to 4 °C per month. Temperature at depth, greater than 25 m, increases due to the loss of stratification and to an increased mixing during the fall. The minimum sea surface salinity (~ 28-29 $^o/_{oo}$) is also seen at the end of August, when the freshwater pulse reaches the area, and is increasing during the fall at a rate of around 1 $^o/_{oo}$ per month in the Cape Breton Channel and 0.5 $^o/_{oo}$ per month in Sydney Bight area. Salinity at depth decreases during the same period also due to the more intense vertical mixing at that time.

2 CURRENTS

The tides affecting the Gulf of St. Lawrence come mainly from the Atlantic Ocean through Cabot Strait (Godin, 1979). These gravity waves are subjected to reflection and dissipation as they propagate into the region. The propagation pathways generate amphidromic points, located near the Magdalen Islands, for semi-diurnal tidal component (e.g. M_2, S_2, N_2). There is also a second amphidromic point at the western exit of the Northumberland Strait for these semi-diurnal components (Godin, 1979; Lu *et al.*, 2001). Consequently, the amplitude of tidally induced semi-diurnal oscillations increase with the distance away from Magdalen Island and western Northumberland Strait. The diurnal tidal currents are the same order of magnitude as the semi-diurnal ones along the western side of Cape Breton. Figure 4 shows the amplitude of the tidal components M_2 and K_1 around Cape Breton. Tidal current amplitude is around 5-10 cm/s for M_2 and 5-15 cm/s for K_1. Strong amplification of the K_1 signal could be seen around St. Paul Island and east of Louisbourg. There are also tidally generated residual currents around several capes, at the tips of Magdalen Island and Prince Edward Island (PEI).

The sub-tidal water movement in the southern Gulf of St. Lawrence is part of the general cyclonic circulation observed in the Gulf (Trites, 1972; El-Sabh, 1976; Koutitonsky and Bugden, 1991). The freshwater input into the Gulf drives a basic, estuarine like, circulation. Part of the Gaspé Current flushes the Magdalen Shallows before exiting on the southern side of Cabot Strait where it merges with the other part of the Gaspé current that follows the slope of the Laurentian Channel (El-Sabh, 1976). This pattern is present in both summer and winter seasons (Han *et al*., 1999). The quantity of water exiting and entering at Cabot Strait is partly controlled by the runoff, the mixing within the Gulf and the physical properties of the water at Belle-Isle Strait. The outflow at Cabot Strait is partly counterbalanced by an inflow at depth (Trites, 1972; Han *et al.*, 1999). The results of Han *et al*., (1999) show that the mean surface currents are stronger in summer than in winter along the western coast of Cape Breton and in Sydney Bight Area.

The Gaspé Current, running southeastward over the Magdalen Shallows, drives a coastal jet along the north shore of PEI. This coastal jet then veers southward at the eastern end of PEI to reach the western coast of Cape Breton Island where it merges with the current exiting Northumberland Strait. The current flows northeast along Cape Breton Island due to topographic effects (Fig. 5). Although the information is scarce, the bottom residual currents calculated by Lauzier (1967) have a north-eastward direction close to the shore of Cape Breton while south-westward currents are found on the northern side of the Cape Breton Channel. This has some resemblance to an estuarine circulation and would support the presence of a shear-induced pumping mechanism activated by the surface current and tidal oscillations into the trough. This mechanism would bring deeper water closer to the surface due to the intensified mixing. However more measurements are necessary to confirm this hypothesis. Simulations carried out by Koutitonsky and Bugden (1991) show that northerly winds cause a stronger coastal jet than southwesterly winds along the western shore of Cape Breton. Because the area is relatively shallow, wind and bottom stresses are important factors affecting the mixing and circulation over the Magdalen Shallows. On the other hand, the shallows are deep enough to allow for wind-induced inertial motion; the currents on the Magdalen Shallows show strong oscillations at the inertial frequency with a decay time of 1-3 days (Tang, 1979; Lefaivre *et al*., 1997). These inertial oscillations could contribute up to 20 % of the energy found in the currents.

There is little information about the currents in the Northumberland Strait. Lauzier (1965) inferred the residual circulation by releasing drift bottles in the Strait (Fig. 6). The pattern revealed a southerly movement along the New Brunswick coast and northwesterly movement at some location along the PEI shore. This work also showed the presence of two cyclonic gyres at both entrances of the Strait. There are indications that the residual currents in the Strait are correlated and influenced by non-local forcing from the Gulf. For example a northwesterly wind would setup water along the coast of Cape Breton and this water would partly “relax” into the Strait as the wind diminishes or veers.

3 SCALES OF THE DRIFT

The drift scales were investigated using a three-dimensional numerical ocean model under development at BIO and GFC. The simulations used summer (July) climatological temperature and salinity fields. The freshwater runoff, surface heat flux and tides were also included in the forcing of the model. The simulations cover a month long period. Figures 7 and 8 show the drift of passive particles at 2.5 m in the water column without wind forcing. The effect of the coastal current, along the western side of Cape Breton, is clearly seen in Figure 7. At Cabot Strait, the surface water flows mainly between Cape North and St. Paul Island. Gyres are also visible west of Cape Breton (Fig. 7) and at depth in the Sydney Bight area (Fig. 9). Particles in the Sydney Bight area could follow two different tracks; some particles turn south –westward and follow the coast of Nova

Scotia while others drift more offshore, following the slope of the Laurentian Channel (Fig. 8). Particles along the Newfoundland side have a tendency to drift north-westward into the Gulf of St. Lawrence.

The wind causes a high variability for the surface drift in the area. Figures 10 and 11 show the drift of particles, for years 1992 and 1994, when the wind forcing is also included in the simulations.

4 ICE

The area around Cape Breton has a mean occurrence of ice of 80 to 100 days during an average year (Drinkwater *et al.*, 1999, Figure 12). On average, the ice first appears on the western side of PEI and St. Georges Bay around January 15th (Canadian Ice Service, 2001). By the beginning of February, most of the water around Cape Breton is ice covered (Fig. 13) with an occurrence ranging from 67 to 84 % of the time in the water offshore of western Cape Breton and 16 to 33 % of the time in the Sydney Bight area. In mid-February the Cape Breton Channel is covered with ice 100% of the time. By the beginning of March, the ice has evolved to first-year ice that has a thickness of more than 30 cm. The area usually has ice present until the second week of April. The ice moves out of the Gulf through Cabot Strait and ice movement can be expected around Sydney Bight at this time of the year. Note that by the end of April, ice is still present around the Cape Breton 16 to 33 % of the time.

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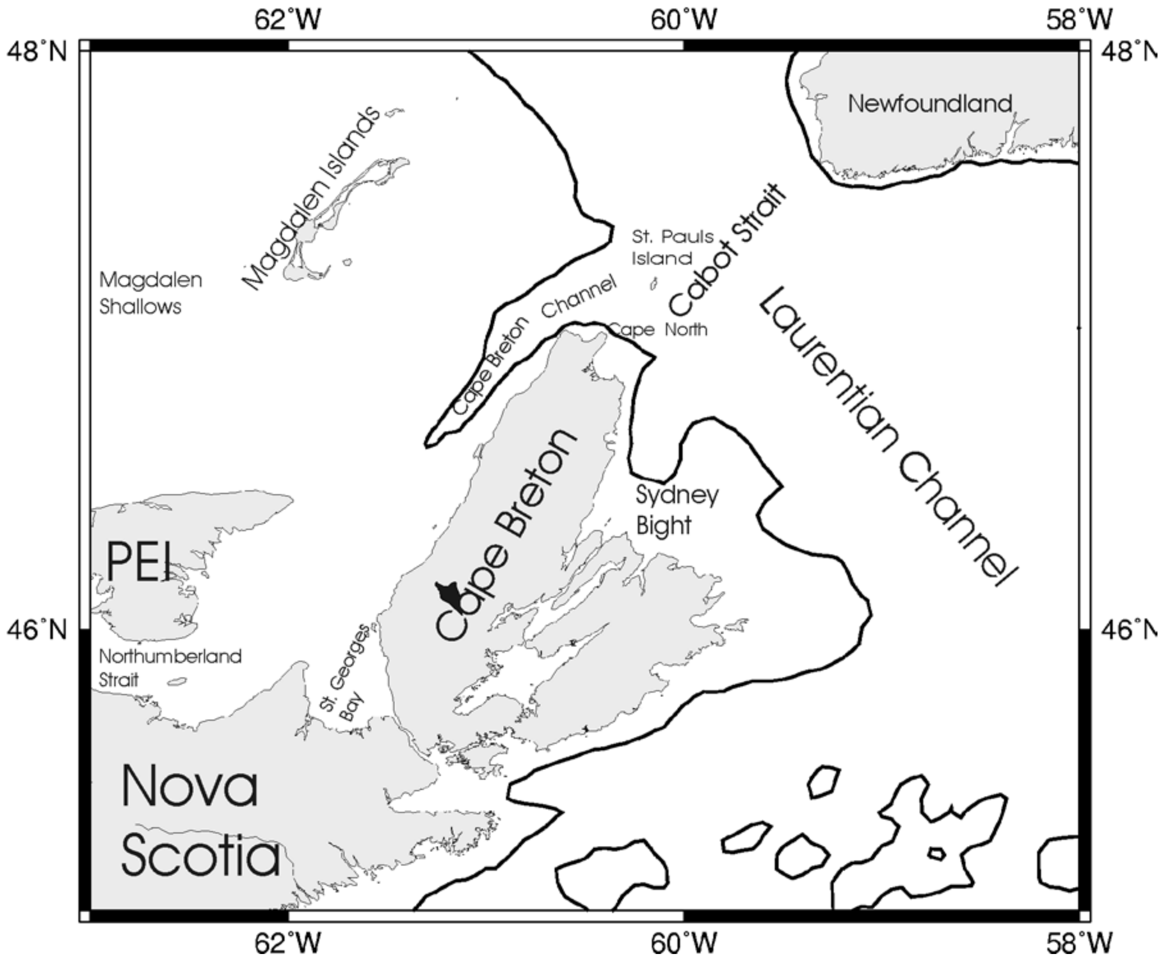

Figure 1. Map of the study area. The heavy line is the 100 m depth contour.

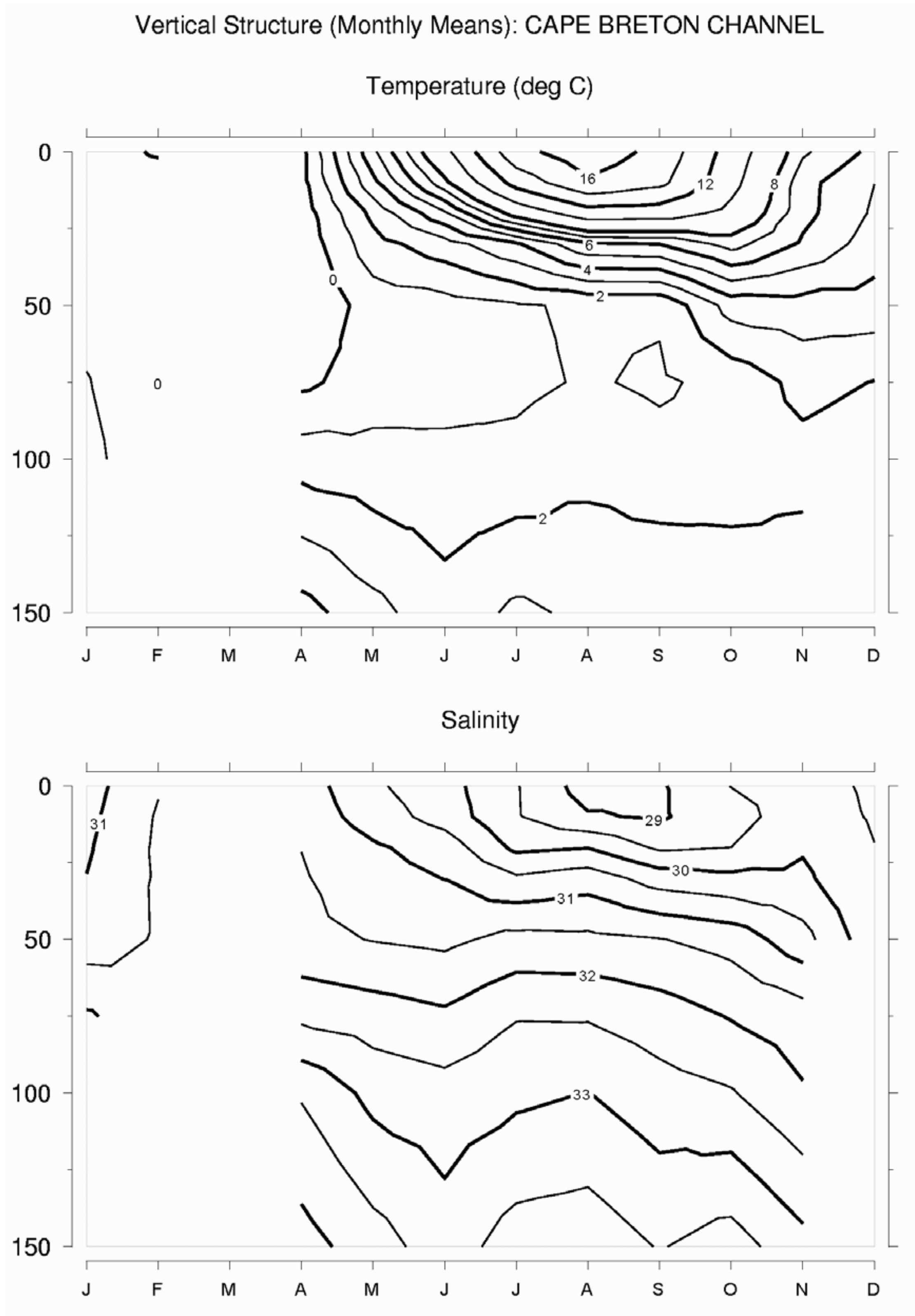

Figure 2. Vertical structure of the temperature and salinity field in the water offshore of western Cape Breton (from Petrie *et al.*, 1996a).

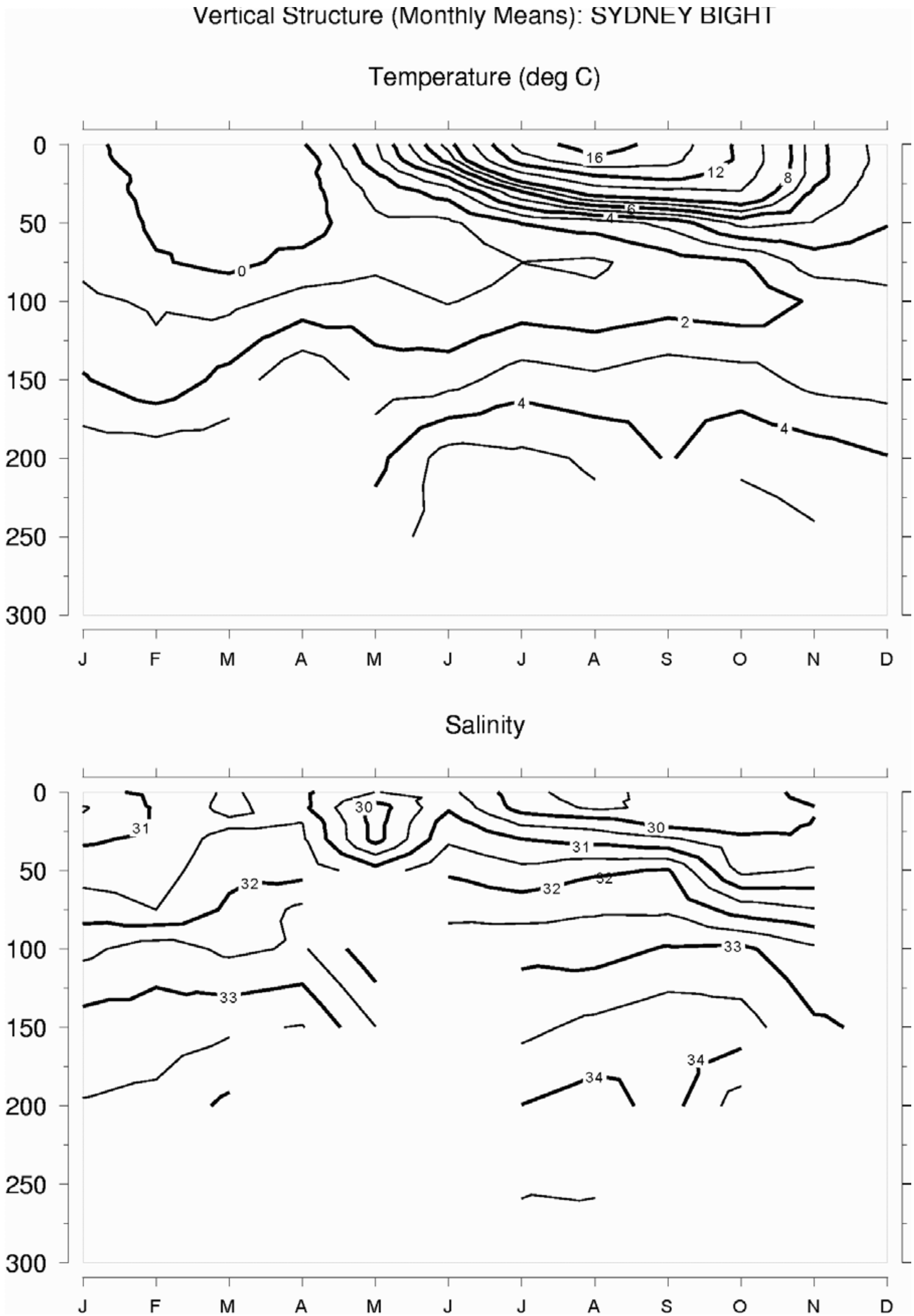

Figure 3. Vertical structure of the temperature and salinity field in the Sydney Bight area (from Petrie *et al.*, 1996b).

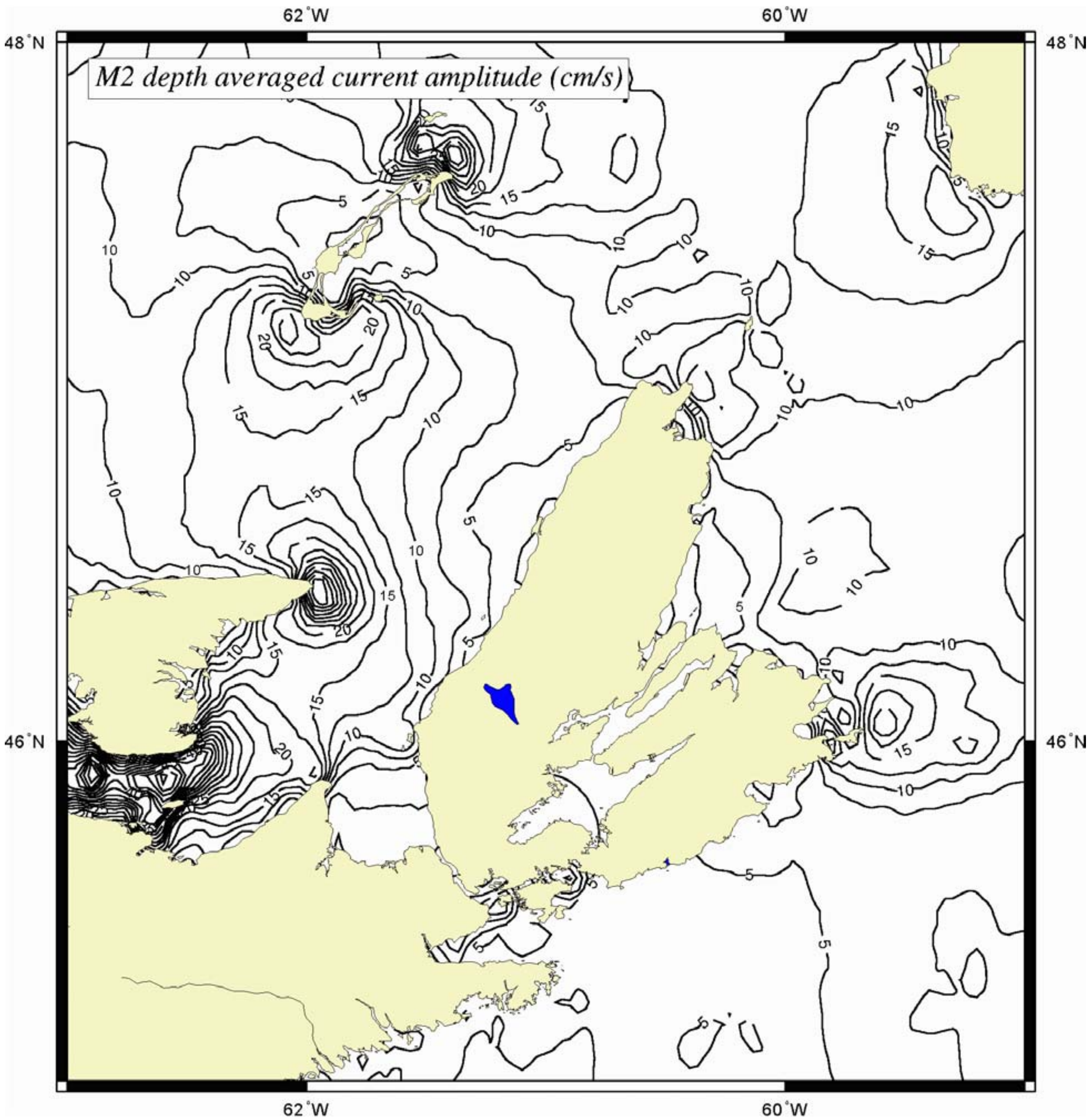

Figure 4a. Depth-averaged current amplitude for tidal component M_2.

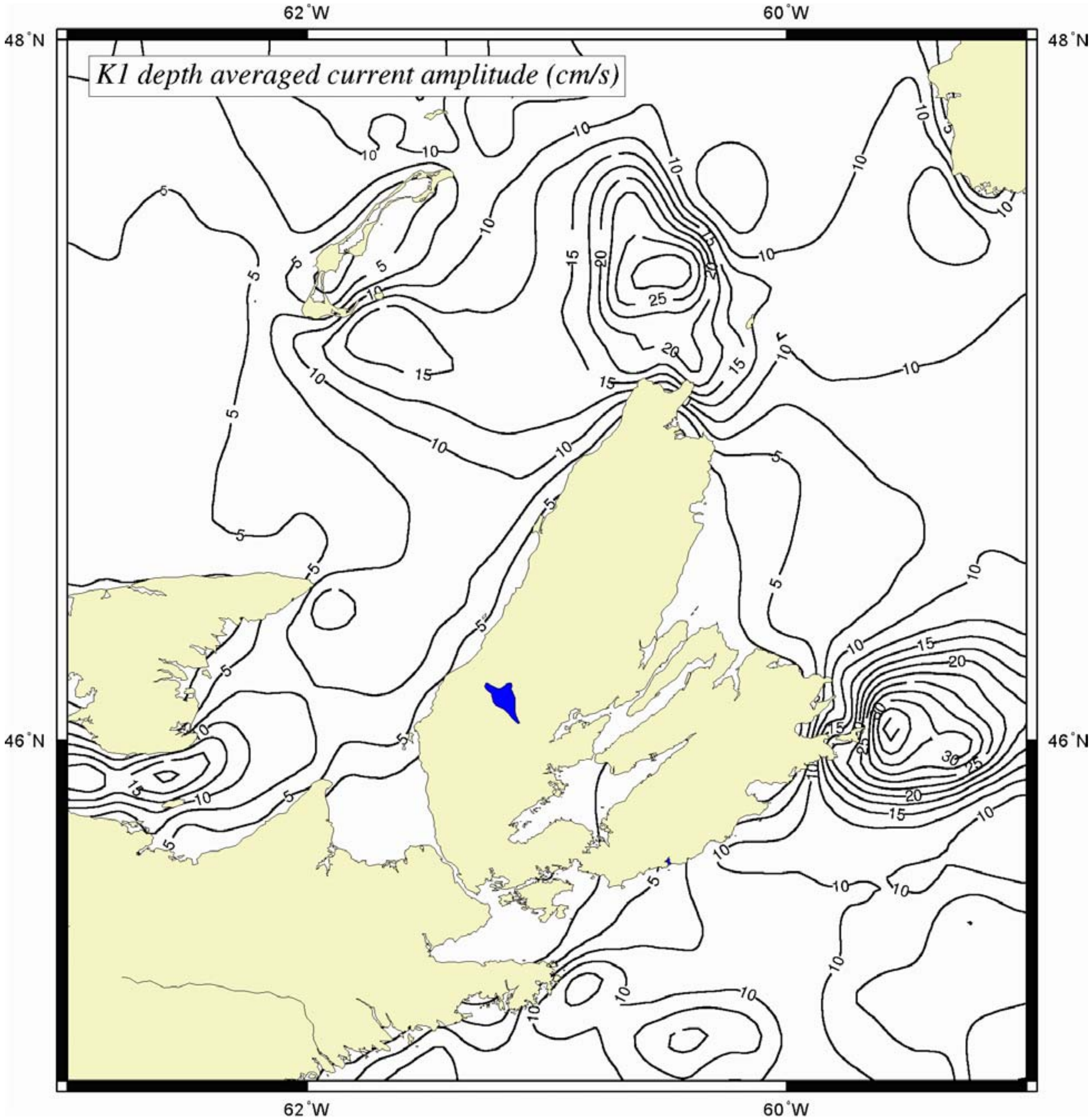

Figure 4b. Depth-averaged current amplitude for tidal component K_1.

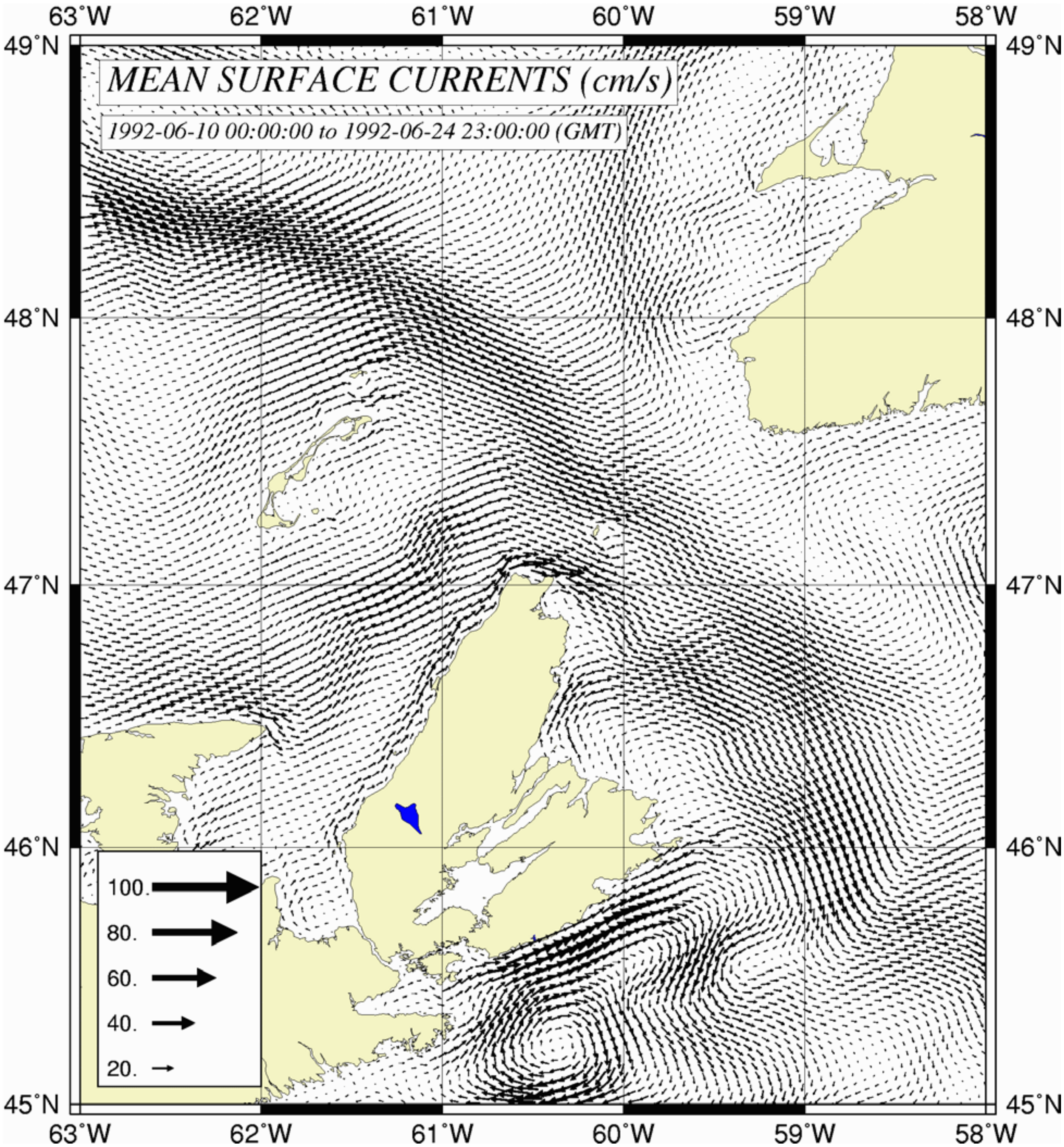

Figure 5. Residual currents around Cape Breton for two weeks in June 1992 including wind forcing.

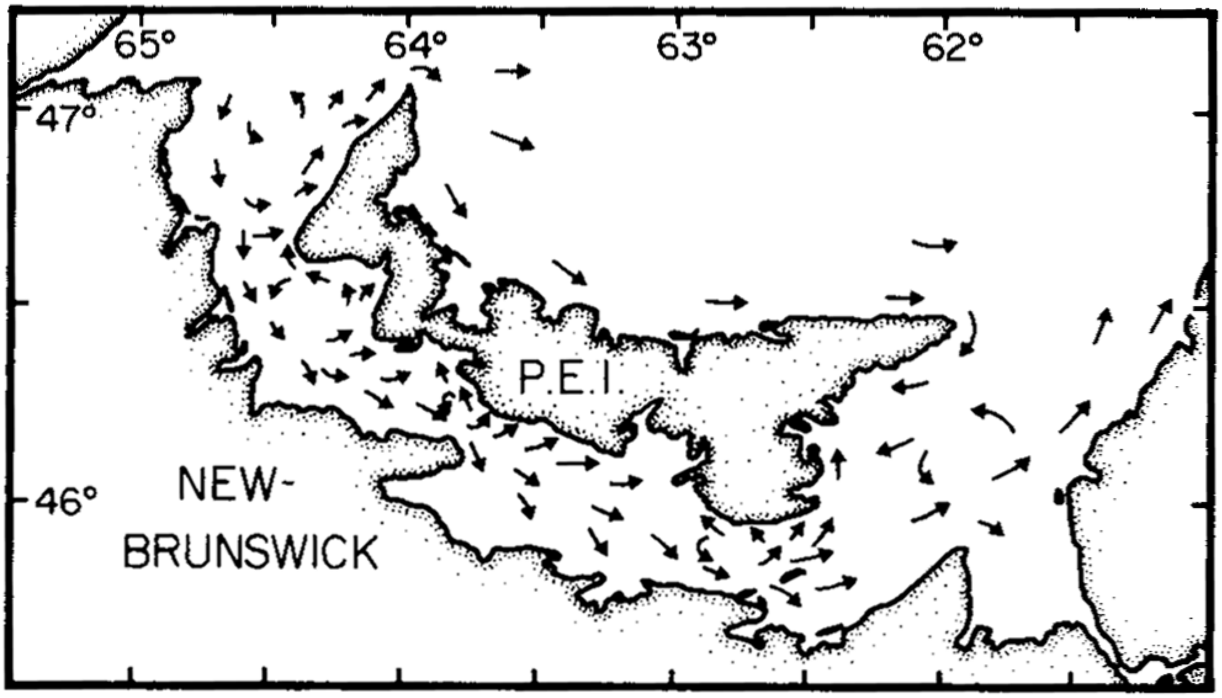

Figure 6. Residual circulation in the Northumberland Strait (from Lauzier, 1965).

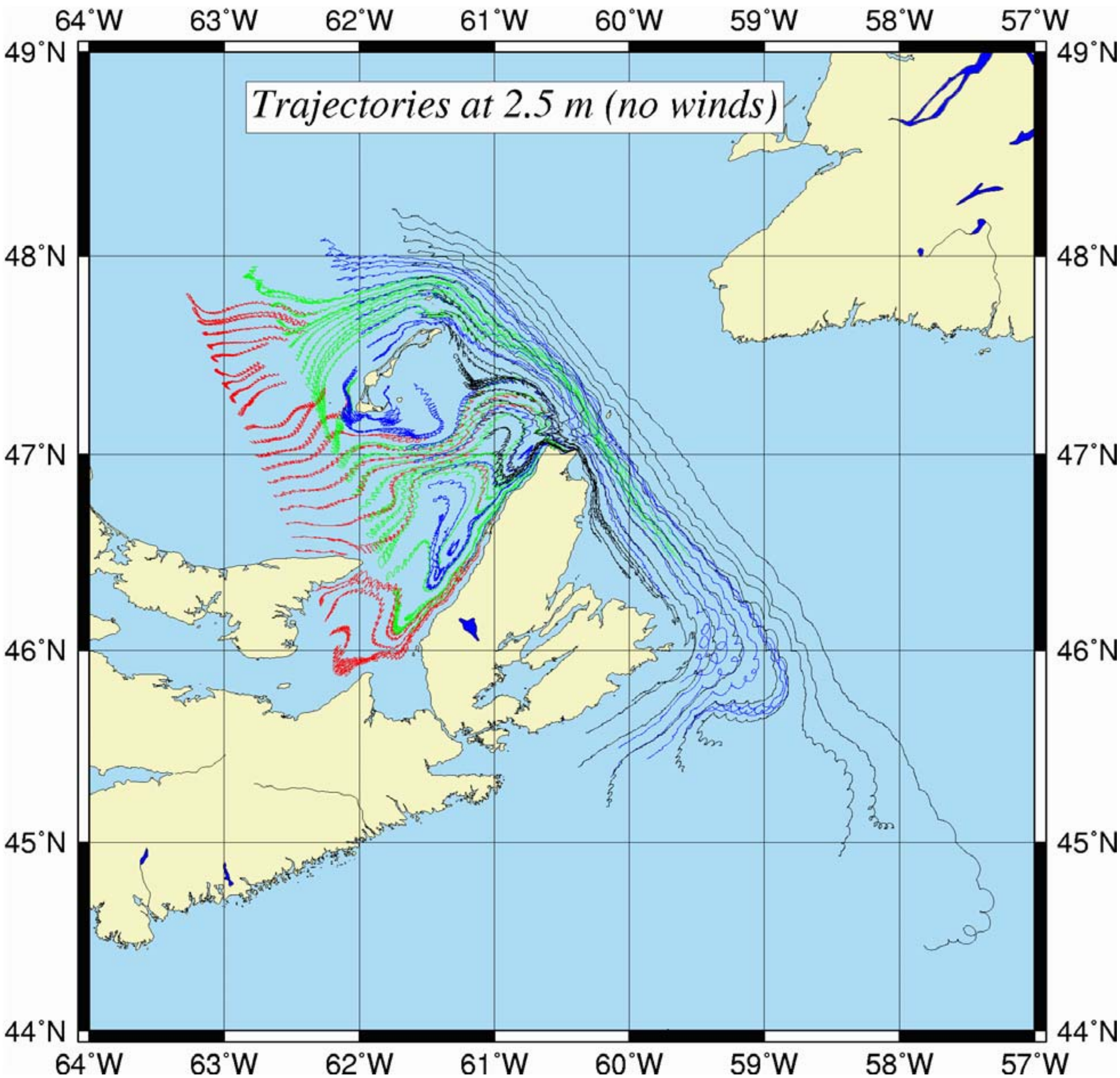

Figure 7. Trajectory of passive particles at 2.5 m using summer climatological temperature and salinity fields without wind forcing. The particles were released in the Southern Gulf. The simulation lasts one month.

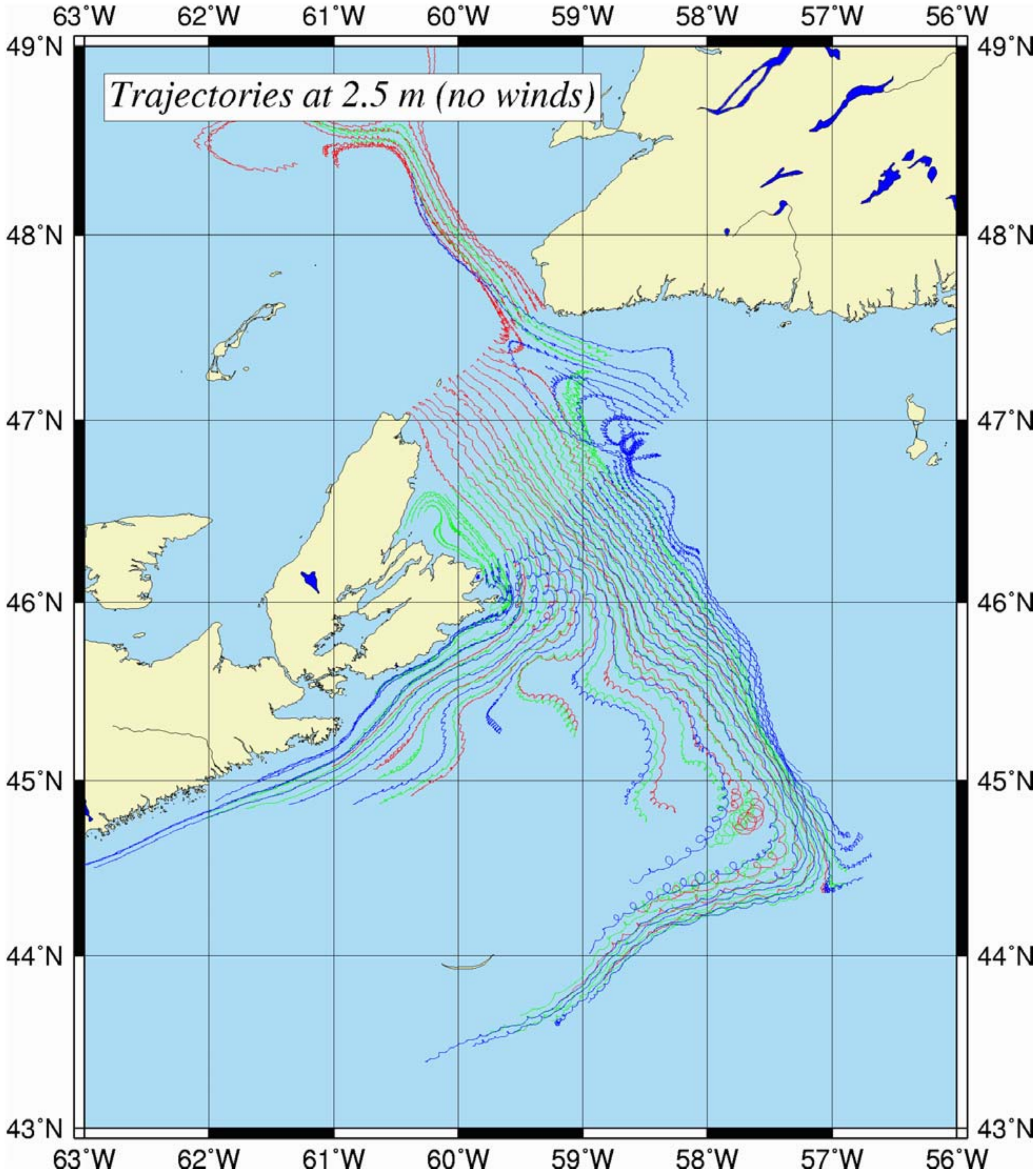

Figure 8. Trajectory of passive particles at 2.5 m using summer climatological temperature and salinity fields without wind forcing. The particles were released in Cabot Strait and Sydney Bight areas. The simulation lasts one month.

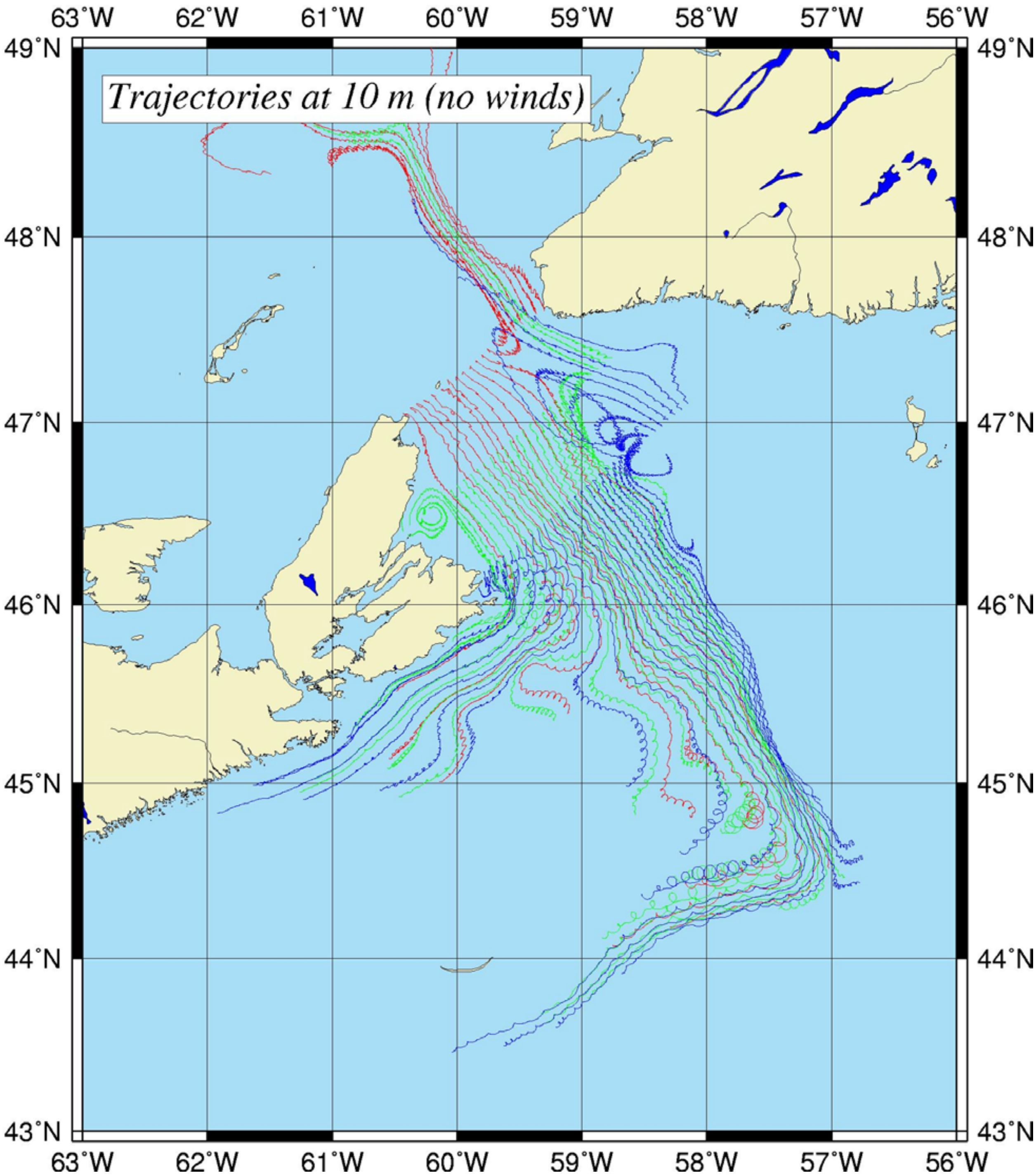

Figure 9. Trajectory of passive particles at 10 m using summer climatological temperature and salinity fields and without wind forcing. The particles were released in Cabot Strait and Sydney Bight areas. The simulation lasts one month.

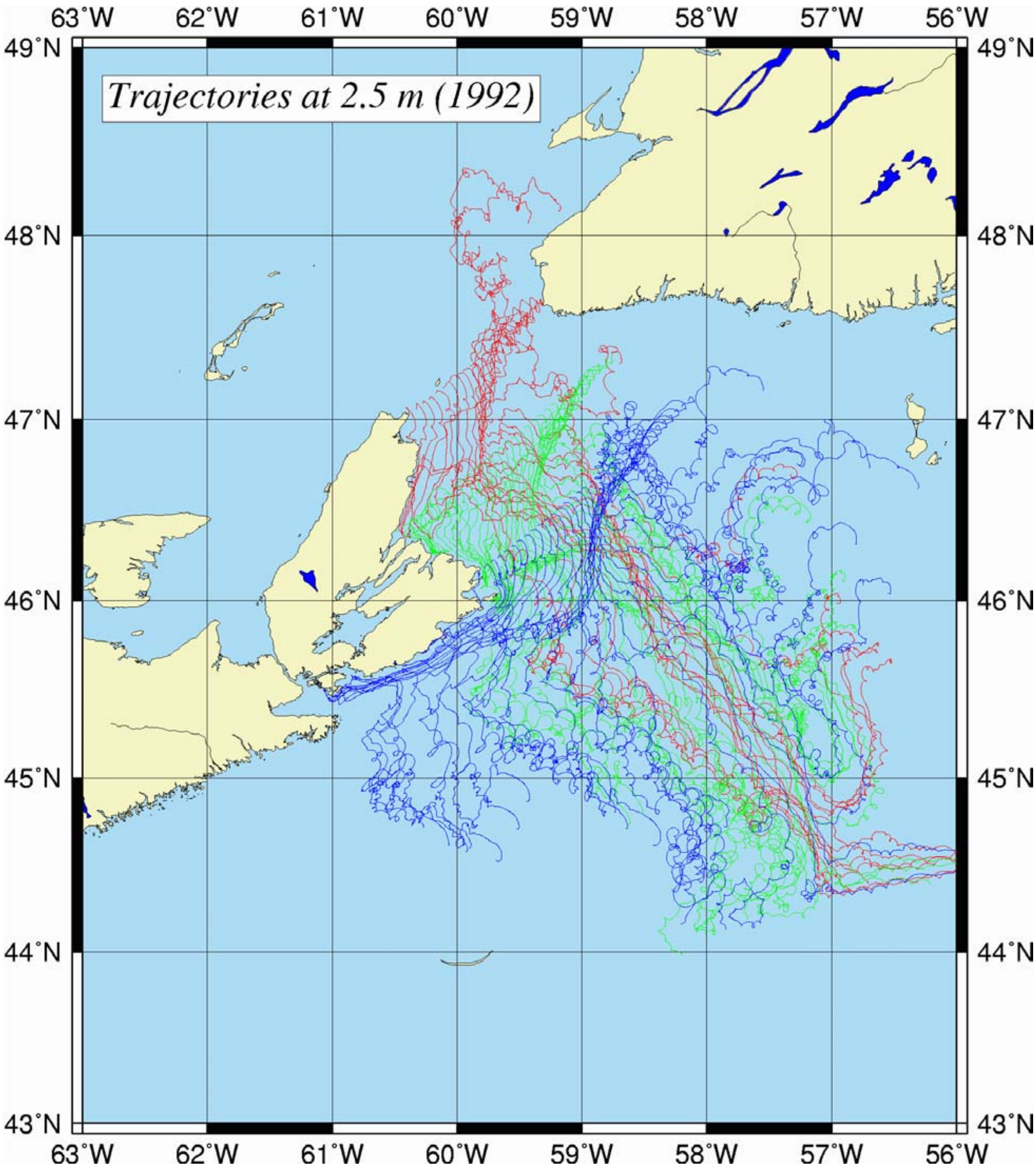

Figure 10. Same as Figure 8 but with wind forcing for the summer of 1992.

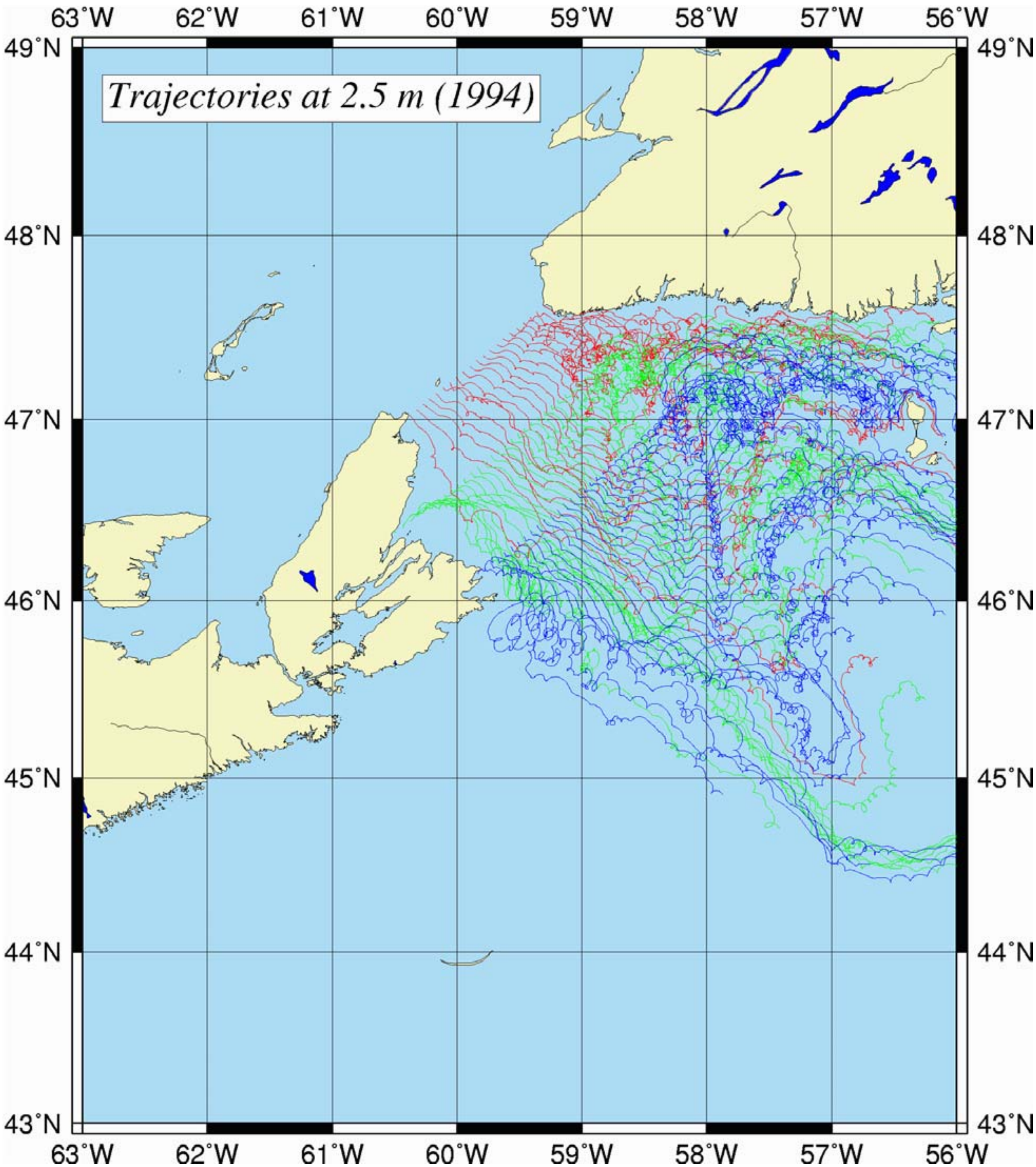

Figure 11. Same as Figure 8 but with wind forcing for the summer of 1994.

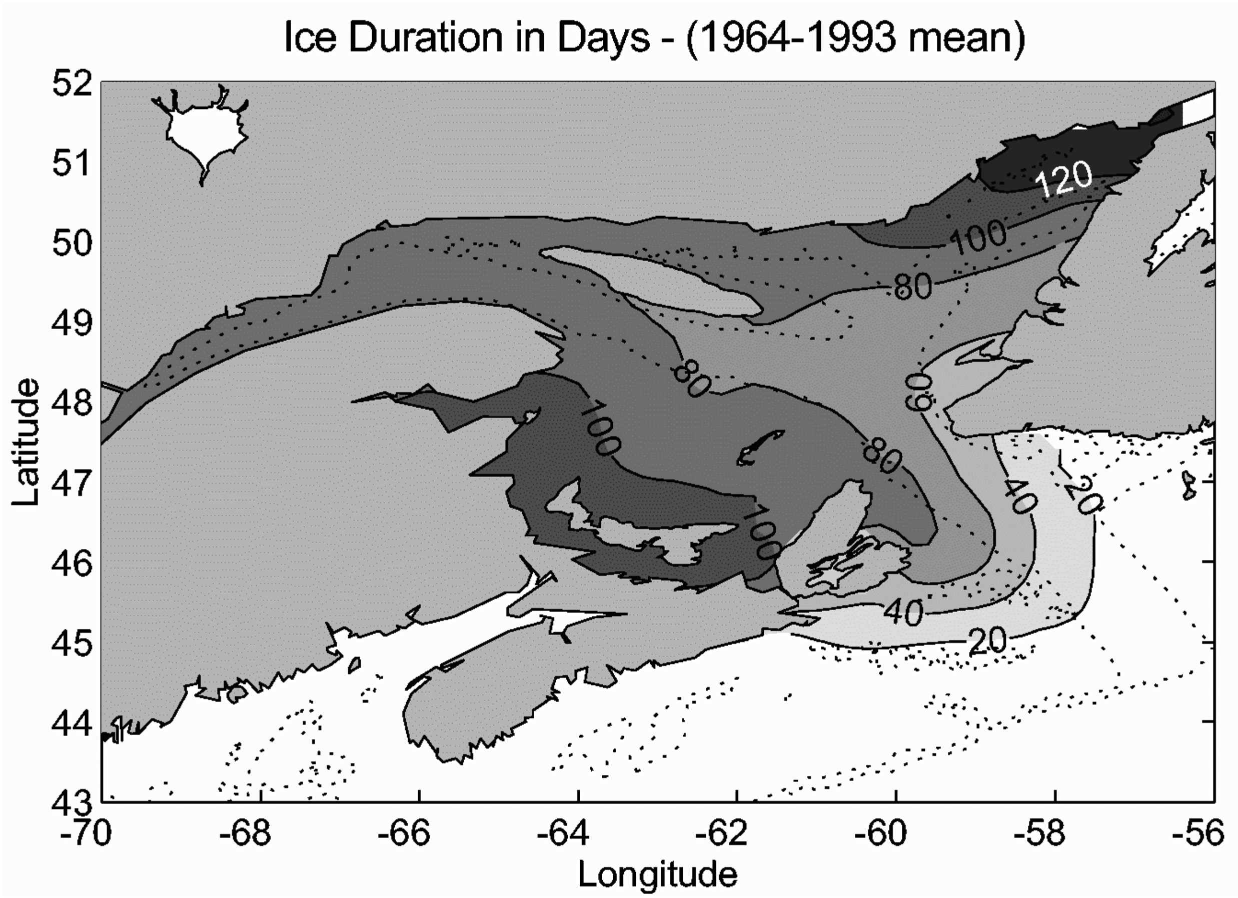

Figure 12. Average number of days for the presence of ice (from Drinkwater *et al.*, 1999).

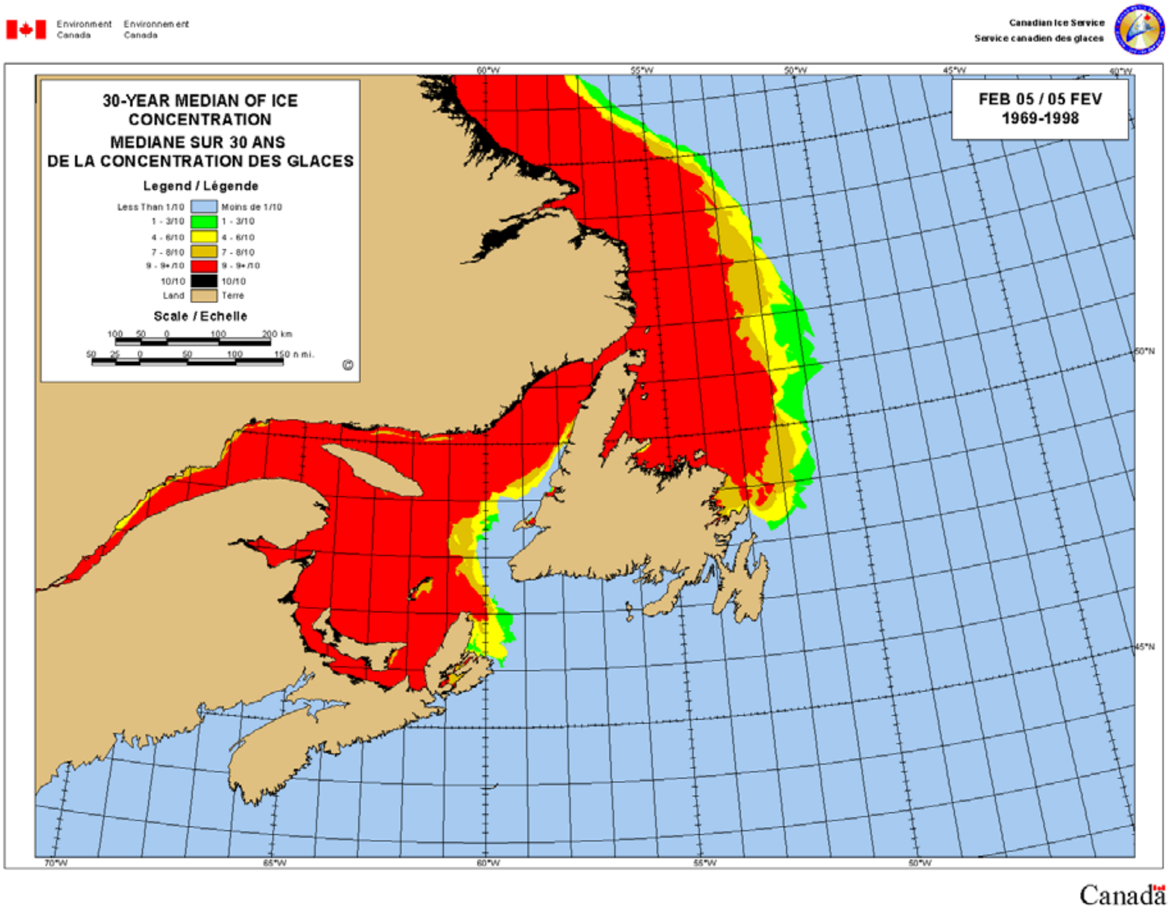

Figure 13. Climatic median of ice concentration for February 05th (from Canadian Ice Service, 2001).