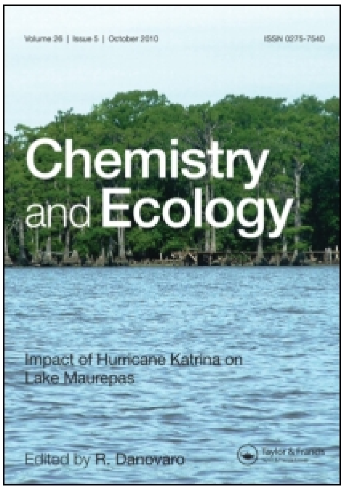

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WHY A POLAR REGION CAN BE CONSIDERED 'AN EXTREME ENVIRONMENT' FOR AN OCEANOGRAPHER

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Recent years have seen a growing awareness of the environment and of the potential impacts of human activities on our climatic system.

Mankind is comparing the possibility of catastrophic events associated with an increase in sea level and the melting of a small, but significant, fraction of the Antarctic ice coverage. Even though controversy remains over the realities of these often-modelled and presented scenarios of global change, it is certain by now that the polar regions, and particularly that of the south, represent the most sensitive indicators of these climatic changes because of their characteristically extreme environments. In particular, the growth and evolution of the sea ice have a profound influence on the albedo and radioactive balance of the planet. This can be clearly seen by the positive temperature trend recorded for the Antarctic peninsula and the associated collapse of the ice platforms.

The sea ice covers 7% of the global ocean surface. During the winter season, the sea surface of the Antarctic oceans is covered by a thin layer of 2–3 m of ice that extends over 20 million km^2 (a larger surface than the total area of the whole Antarctic continent) and reaches as far as 55–60° of southern latitude. In the summer period, the ice pack decreases to 4 million km^2, and thus the major proportion of the sea ice never exceeds 1 yr in age.

Within the Italian National Program for Antarctic Research (PNRA), the researchers of the Climatic Long-Term Interaction and Mass Balance in Antarctica (CLIMA) project have calculated the average weekly values for all the components of the total surface heat budget for the entire Ross Sea from 1994 to 1997. The annual values varied from -87 to $-102\,W\,m^{-2}$, with a mean of $-96\,W\,m^{-2}$. In examining the individual components of this total budget, it was seen that the most significant inter-annual fluctuations are linked to the maximum solar radiation level at the surface and are dependent upon the cloud covering. The long-wave radiation varied between -110 and $-40\,W\,m^{-2}$, with a mean of $-55\,W\,m^{-2}$ and a standard deviation of $4\,W\,m^{-2}$, and was lowest generally during the first few months of the year.

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Of particular interest, there is an abrupt variation in the loss of heat, as sensible heat, at the end of each January when the meteorological forcing runs from summer to winter, and the ice layer is still thin, with a mean of $-45\,\mathrm{W\,m^{-2}}$ and a standard deviation of $3\,\mathrm{W\,m^{-2}}$. In terms of the latent heat, a very regular pattern was noted, the lowest values being in the summer season, with a mean of $-50\,\mathrm{W\,m^{-2}}$ and a standard deviation of $2\,\mathrm{W\,m^{-2}}$. Finally, the conducted-heat flux had a mean value of $-20\,\mathrm{W\,m^{-2}}$ and represents the least significant contribution to the entire budget.

Altogether, it can be deduced that the mean annual value of $-96\,\mathrm{W\,m^{-2}}$ obtained as the total heat budget for the period 1994–1997 can be considered as the reference point for the heat loss in this crucial region of the surface of our planet. This loss can only be compensated for by the heat transported by the deep marine currents and by the mixing processes along the continental slope between the shelf waters and the Antarctic circumpolar waters. Indeed, the circumpolar deep waters (CDW), which arise from the Antarctic circumpolar current, are the main suppliers of heat and salt in this continental slope area when they penetrate into the shelf area and mix with the waters of the shelf itself. A scheme of the circulation of the various water masses in the Ross Sea is shown in Figure 1, according to our reconstruction and as reported by Budillon *et al.* (2003) in *Antarctic Science*.

We have estimated the flux of the CDW that needs to penetrate the Ross Sea shelf to balance the loss of heat in the global budget. Assuming an average temperature of $-1.6\,^{\circ}\mathrm{C}$ for the shelf waters and $+1.5\,^{\circ}\mathrm{C}$ for the CDW, a value of $3978\,\mathrm{J\,kg^{-1}\,K^{-1}}$ for the specific heat and an average sea-water density of $1028\,\mathrm{kg\,m^{-3}}$, we obtain a mean CDW transport of around 2.9 Sv. This value represents a significant fraction of the total baroclinic transport of the Ross Sea, which was estimated by Gouretski (1999) to be around 8.5 Sv.

In this specific area of our planet, emphasis needs to be focused on the polynya processes that are responsible for the transfer of latent and sensible heat to the atmosphere. The polynya

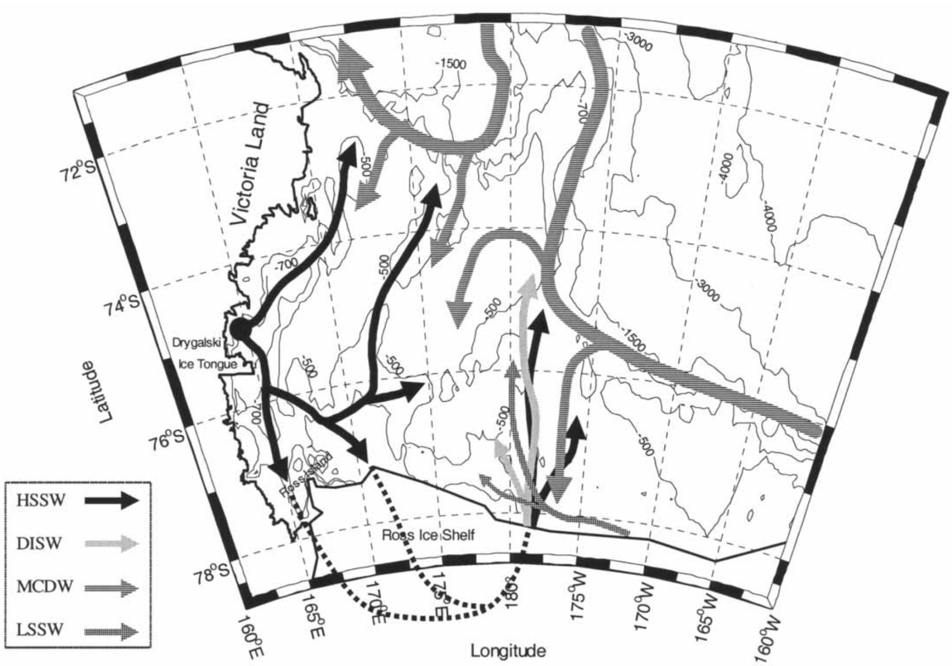

FIGURE 1 Scheme of the circulation of the various water masses in the Ross Sea.

are relatively large sea areas (from 10 to 10^5 km^2) that are free of ice, in which the polar atmosphere and the ocean can freely exchange heat, momentum, water and matter, thus playing a very important role in the biogeochemical and physical characteristics of both the fluids.

According to their mechanism of formation, the polynya can be divided into those of sensible heat and those of latent heat. The former are activated by a water dynamics that carries heat towards the surface, thus preventing the formation of ice, and their form is determined by the size of the associated warm water anomaly. The latent heat polynya develop in areas where the ice movement diverges due to the influence of strong, mainly katabatic, winds. These areas have a higher production of ice, and their extent is determined by the balance between the ice movement out of the polynya and the ice production within the polynya itself.

One polynya of particular interest, specifically for the PNRA researchers, is that of Terra Nova Bay, between the coast and the Drygalski Ice Tongue (Budillon and Spezie, 2000), that is activated and maintained by the katabatic winds. The area of this polynya varies with a periodicity of 15–20 d; its average area is 1000 km^2, with a maximum of 5000 km^2. Its estimated ice production for the whole winter is around 50–80 km^3, which represents 10% of the annual ice production of the entire Ross Sea shelf.

The role of the polynya in the climatic system can be summarized as follows:

(1) They are areas with a strong air–water interaction with heat losses (of up to a few hundreds of W m^{-2}) that lead to rapid heating of the above air column and, consequently, to rapid modifications in the mesoscale atmospheric movements. In winter, about 50% of the total heat exchange between the ocean and the atmosphere of the Antarctic oceans occurs through these areas of polynya, while in summer the polynya receive large amounts of short-wave radiation in the oceanic mixed layer, thus affecting the mass and heat budgets.

(2) The release of salt that accompanies the formation of the frazil ice in the polynya area increases the salinity of the superficial layer (up to a few tens of parts per thousand) and strongly influences the barocline circulation in the areas surrounding the polynya itself. This effect results in the sinking of the dense waters that spreads towards the continental shelf break, activating important water ventilation and deep-water formation mechanisms. In the polynya of Terra Nova Bay, these high-salt plumes released during ice formation 'salinize' about 1 Sv of high-salinity shelf water that moves out of the polynya itself. Between 1995 and 2001, in the deep layer of the Terra Nova Bay area, at around 900 dbar, a progressive decrease in salinity was observed (Fig. 2). This went from

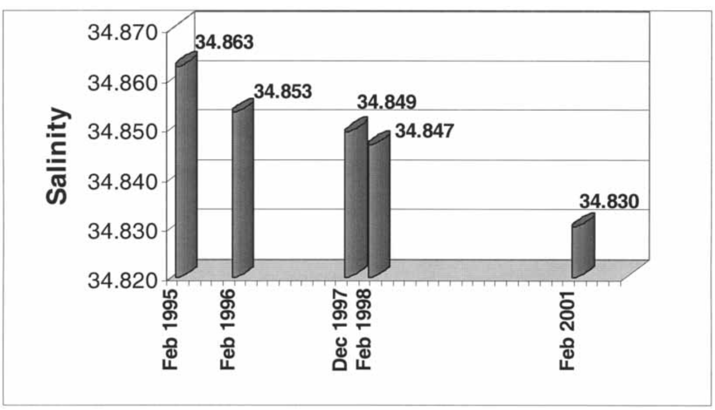

FIGURE 2 Temporal trend of the highest salinity in the Terra Nova Bay polynya.

34.863 to 34.830, consistent with a freshening of the HSSW equivalent to -0.3 per decade, attributed by Jacobs and Giulivi (1998) to the reduction in the formation of ice and/or in the residence time of the shelf waters.

(3) The polynya have relevant effects on the biogeochemical fluxes at the air–water interface and on the transport of tracers as a result of vertical and convectional mixing.

(4) The recurring polynya can be considered as true oases in the polar deserts that allow the survival of various species (mammals and birds) that live there during the winter period.

Finally, the numerous atmosphere–ocean feedback processes mediated through the polynya mean that the polynya themselves can be both affected and influenced by the atmospheric and oceanic characteristics of the planet; *e.g.* by the El Niño southern oscillation, by the North Atlantic and Arctic oscillation, and by the thermohaline circulation.

In conclusion, the predictions of climatic models suggest that if we are experiencing global warming, the polar regions present temperature variations that are greater than those of other areas of the planet. Variations in the frequency and size of the polynya areas can be useful indicators of ongoing climatic alterations. The interactions between the polynya and their environments are thus important in determining the role of these high latitudes.

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