TERRA NOVA BAY POLYNYA: A SMALL COASTAL AREA AFFECTING BASIN SCALE OCEANIC CONDITIONS

Giorgio Budillon, Giannetta Fusco, Emanuela Rusciano, Giancarlo Spezie

Dipartimento di Scienze per l'Ambiente, Università degli Studi di Napoli "Parthenope" – Centro Direzionale, Is. C4 – 80143 Napoli, Email: giorgio.budillon@uniparthenope.it

1. ABSTRACT

Terra Nova Bay polynya plays a key role in the formation of the High Salinity Shelf Water (HSSW), the densest water mass of the Southern Ocean which is crucial in the formation of the Antarctic Bottom Water. The short residence time of the HSSW in the Ross Sea represents a rapid conduit to transfer Antarctic atmospheric anomalies, temporal changes and trends in the climatic characteristics to the rest of global ocean making this area a crucial region for multidisciplinary monitoring activity. A long time monitoring program of the polynya, started in 1995 by the Italian CLIMA project, collected thermohaline moored time series in the intermediate-deep layers, meteorological information measured by coastal Automatic Weather Stations; moreover six oceanographic surveys were carried out during the summer periods. Results reveal vigorous interannual variability in the heat fluxes, sea ice conditions, and of water column stratification, which induce significant variability of HSSW production.

2. INTRODUCTION

The Antarctic Ocean supplies dense, cold abyssal water to the world ocean. This dense waters are formed on the continental shelf of the Antarctica. The dense shelf waters entrain surrounding fluid as they descend into the deep ocean to form Antarctic Bottom Water (AABW), which spreads along the sea floor throughout much of the abyssal ocean. AABW is formed in only a small number of locations around Antarctica, where conditions are right to increase the density of surface waters (by decreasing temperature and increasing salinity) to the point where water can sink to the sea floor. It is widely recognized the crucial role of the brine released during the sea ice growth processes for the formation of the AABW. A key element in the formation of the AABW from the Ross Sea is the formation of dense High Salinity Shelf Water (HSSW) by the coastal polynya that form in Terra Nova Bay (TNB) [1, 2, 3]. This very dense water depends critically on the production rates of sea ice, which in turn depend on interplay of the coastal katabatic winds, the large-scale synoptic winds, and on the thermohaline condition of the water column for preconditioning effects. The geometry of the polynya and coastline shape is also important in these processes. The TNB polynya, located in the western sector of the Ross Sea, between the Drygalski Ice Tongue (DIT) and the land, is formed and maintained by the combined of influence of persistent katabatic winds, which advect newly formed bay ice eastward, and by the DIT which prevents northward drifting pack ice from entering in the bay [4, 5, 2, 6, 7, 8].

Intense heat loss from the open water (sea water free by the sea ice) to the atmosphere leads to rapid and persistent ice growth in latent heat polynyas. Brine rejected from growing sea ice forms dense brine-enriched shelf waters that accumulate near the bottom of basins and eventually spill toward the deep sea as dense plumes.

Recent observations along the Antarctic shelves, while discontinuous and sparse, show that Antarctic Bottom Water has declined in salinity in recent decades highlighting the importance to continuously monitor this area, and emphasizing its key role in the global climate system (9, 10, 11, 12, 13). The observational results showed that, during the second half of the 20th century, bottom water formed in the Ross Sea and offshore of Adélie Land has gradually freshened; also the AABW in the Australian Antarctic basin has gradually freshened, likely due to a substantial decline in the salinity of the Ross Sea shelf waters [12, 14, 15, 10, 16, 17, 18]. The causes of this freshening are considered to be the glacial ice melting, an increase in precipitation, or a decrease in sea-ice formation [10, 12]. A freshening of the intermediate and deep layers of the water column was already detected by [19] in the TNB polynya at the end of the 90's.

This study describes the interannual variability in the heat fluxes, sea ice conditions, and of the water column stratification, which induce significant variability of HSSW production in the TNB polynya during Italian CLIMA expeditions between 1994/95 to 2005/06.

3. RESULTS AND DISCUSSION

Recent studies [20] showed a relative short residence times of the Ross Sea shelf waters, the 2-4 years seems a reasonable period representative of the time interval between their formation and their ventilation of the deep ocean at the shelf break. Sea-ice remote sensed data (SSM/I) of the last 15 years allowed us to discriminate two different behaviours of the polynya during the summer and winter conditions. The former is peculiar of the period between December-March and the polynya is often completely ice free, while the latter is between April-November when the polynya shows an average dimension of about 1000 km^2 with a maximum extension of about 5000 km^2. The analysis of the meteorological data collected by the Italian AWS network (www.climantartide.it) from 1994 to 2008 allowed us to observed that the katabatic events interesting the polynya area are concentrated during May-October although with a significant interannual variability. Moreover this analysis stressed the importance of the extension in time of the katabatic events. In particular we observed that the persistency of the katabatic regime (mainly in the offshore component (u) of the wind) plays a major role for the maintaining the polynya opened [21].

The "Fig. 1" qualitatively evidences for the year 2000 – considered representative of the "typical" behaviour of the polynya – the relationship between the duration of the katabatic winds and the size of the area free from the sea-ice (open water) "Fig. 1a", and the thermohaline changes in the water column measured at different depths by a mooring located approximately in the middle of the TNB polynya. At the end of February, the open sea rapidly decreases due to the formation of the sea-ice. Until June the salinity freshen along the water column, then it shows a sharp increase between July and October "Fig. 1b". Our data show that the increase in the offshore wind speed, regularly detected in June/July, is strongly correlate with the increase in salinity which appears in the surface layer (120 m depth approx.) and along the water column.

We speculate on the different role of the polynya during the winter season: the period characterized by a considerably sea-ice free area and a salinity increase along the water column, which is proceeded and followed by a period when the polynya is still open but the salinity of the water column decrease. While the former appears related with a maximum efficiency of the TNB polynya in the sea-ice production, the former marks a "partial" functioning of the polynya that may still be open by the presence of relatively intense offshore winds but the production of sea-ice (and the associate release of brine) is not allowed by the shortness or by the infrequency of the katabatic wind regime.

This is confirmed also by the vertical thermal signature: a relatively surface warm layer 150 m deep appears in November producing a thermocline between 150 - 500 m which persists during the austral summer (December - February) and rapidly disappears at the beginning of the winter conditions (March) cause the increase of vertical turbulent mixing provided by the katabatic events "Fig. 1c".

At longer time scales [23], the estimated yearly averaged surface heat budget (using ERA40 meteorological data from European Center for Medium-Range Weather Forecasts) in the TNB polynya "Fig. 2a" remarks a large variability in the last two decades showing higher values between 2001 to 2006 (maximum in 2003 with an average heat loss of -313 Wm^2); the minimum heat loss (-58 Wm^2) occurred in 1996 and the mean value for the entire period was -140 Wm^2. The estimated HSSW mean yearly production span in the same period between 0.7 to 2.0 Sv with an estimated average value of 1.2 Sv. In the deeper layers of the water column "Fig. 2b" a general freshening was detected from 1995 up today (ΔS = -0.06 at 900 m deep) with a short positive anomaly measured in correspondence of the period 2002-03 associated to the maximum of the heat loss at the surface (i.e. maximum in the HSSW estimated formation).

A comparative analysis of the whole data set collected by the Italian CLIMA project [24] focused on the thermohaline variability of the shelf waters at the shelf break of the Ross Sea (which are involved in the deep ventilation processes and in the AABW formation) showed a significant correlation with the TNB thermohaline trends; this aspect underlies the key role of this small area in controlling processes of climatic relevance. Should be also mentioned that a not negligible role in the controlling the thermohaline condition of the TNB water column may be played also by the heat and salt carried by the modified Circumpolar Deep Water which flows along the Ross Sea slope and periodically may reaches the polynya area.

4. CONCLUSIONS

The TNB polynya is key region of the Southern Ocean cause its crucial role for the sea-ice production and for the dense water formation processes which affect the regional ocean properties. In the last decades both meteorological and oceanographic conditions showed relevant changes.

Recent work showed that the meteorological anomalies and the associated thermohaline changes detected in the TNB region can rapidly propagates in the properties of the Ross Sea shelf waters and, cause the relatively short residence time of the shelf waters, may rapidly modify the characteristics of the deep ocean ventilation process and in the composition of the regional AABW. Therefore the Terra Nova Bay polynya represents, not only for the logistic facilities due the proximity of the Italian scientific station, a unique polar environment to realize a relative cost effective multi-disciplinary observing system that will provide the long-term measurements needed to improve understanding of climate change and variability, biogeochemical cycles and the coupling between climate and marine ecosystems in polar environments.

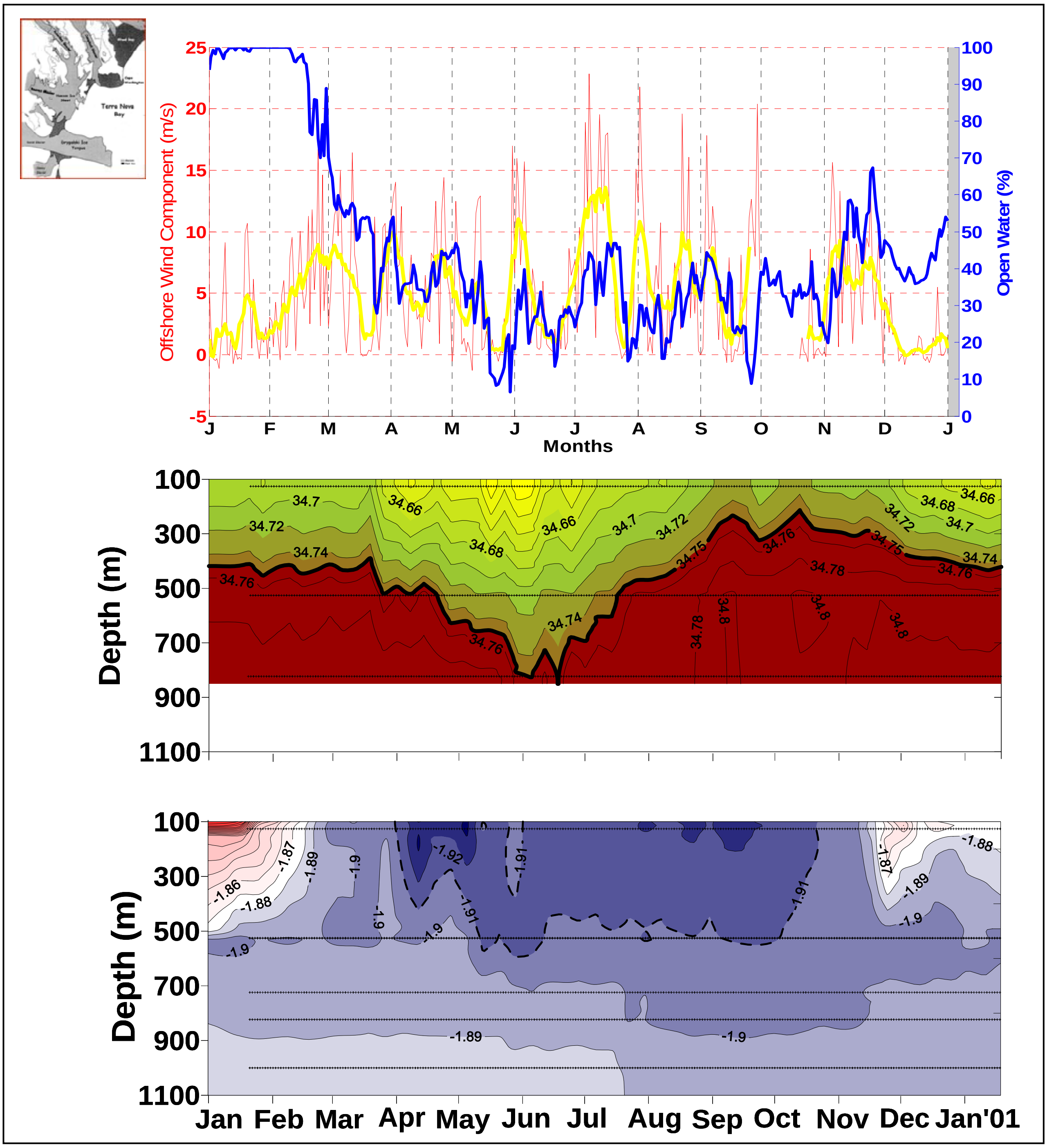

Figure 1. Terra Nova Bay polynya, year 2000; panel a) fraction of the open sea area (i.e. percentage of sea surface free by the sea ice) (blue line) and offshore wind component measured by the AWS Eneide (74°41'S; 164°05'E), daily (red line) and low-pass filtered (yellow line) offshore wind component data; vertical distribution of b) salinity and c) potential temperature along the water column (mooring location: 75°08.206'S; 164°31.627'E). Figure modified by [22].

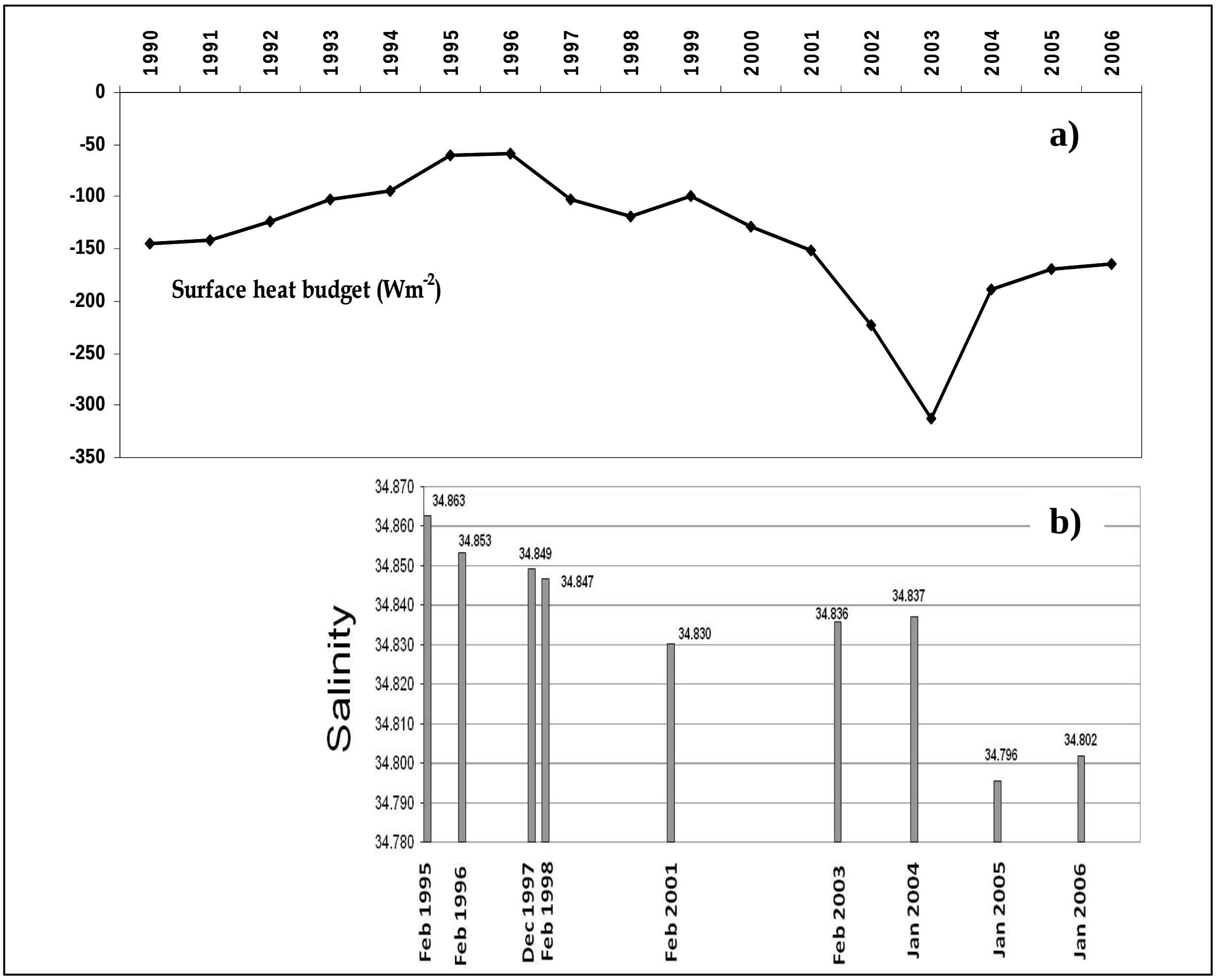

Figure 2. Terra Nova Bay polynya; a) interannual changes in the air-sea heat fluxes between 1990–2006 and b) Salinity changes at 900 m depth measured during the Italian CLIMA cruises. Figure modified by [24].

5. REFERENCES

1. Jacobs, S.S. & Comiso, J.C. (1989). Sea ice and oceanic processes on the Ross Sea continental shelf. *Journal of Geophysical Research*. **94**, 18195-18211.

2. Kurtz, D.D. & Bromwich, D.H. (1985). A recurring atmospherically-forced polynya in Terra Nova Bay. *Antarctic Research Series*. **43**, 177-201.

3. Van Woert, M.L. (1999). Wintertime expansion and contraction of the Terra Nova Bay polynya. In: Spezie G. and Manzella G.M.R. (Eds.), *Oceanography of the Ross Sea*, Springer-Verlag, Milano, pp145-164.

4. Bromwich, D.H. & Kurtz, D.D. (1984). Katabatic wind forcing of the Terra Nova Bay polynya. *Journal of Geophysical Research*. **89**, 3561-3572.

5. Kurtz, D.D. & Bromwich, D.H. (1983). Satellite observed behaviour of the Terra Nova Bay polynya. *Journal of Geophysical Research*. **88**, 9717-9722.

6. Parish, T.R. & Bromwich, D.H. (1989). Instrumental aircraft observations of the katabatic wind regime near Terra Nova Bay, Antarctica. *Monthly Weather Review*. 117, 1570-1585.

7. Bromwich, D.H. & Geer, G.K. (1991). Satellite analyses of katabatic winds near Terra Nova Bay. *Antarctic Journal of the United States*. **26**, 268-271.

8. Frezzotti, M. & Mabin, M.C.G. (1994). 20"' century behaviour of Drygalski Ice Tongue, Ross Sea, Antarctica. *Annals of Glaciology*. **20**, 397-400.

9. Robertson, R., Visbeck, M., Gordon, A.L. & Fahrbach, E. (2002). Long-term temperature trends in the deep waters of the Weddell Sea. *Deep-Sea Research II* **49**, 4791–4806.

10. Jacobs, S.S (2004). Bottom water production and its links with the thermohaline circulation. *Antarctic Science* **16**(4), 427-437.

11. Smedsrud, L.H. (2005). Warming of the deep water in the Weddell Sea along the Greenwich meridian: 1977–2001. *Deep-Sea Research I* **52**, 241–258

12. Rintoul, S.R. (2007). Rapid freshening of Antarctic Bottom Water formed in the Indian and Pacific Oceans. *Geophysical Research Letters*. **34**, L06606, doi:10.1029/2006GL028550.

13. Ozaki, H., Obata, H., Naganobu, M. & Gamo, T. (2009). Long-term bottom water warming in the north Ross Sea, *Journal of Oceanography*. **65**(2), 235, doi:10.1007/s10872-009-0022-z.

14. Whitworth, T. (2002). Two modes of bottom water in the Australian Antarctic basin. *Geophysical Research Letter* **29**(5), 1073. doi: 10.1029/2001GL014282.

15. Jacobs, S.S., Giulivi, C.F. & Mele, P.A. (2002). Freshening of the Ross Sea during the late 20th century. *Science*. **297**, 386-389.

16. Jacobs, S.S. (2006). Observations of change in the Southern Ocean. *Philosophical Transactions of the Royal Society*. **364**, 1657-1681. doi:10.1098/rsta.2006.1794.

17. Aoki, S. Rintoul, S.R., Ushio, S. & Watanabe, S. (2005). Freshening of the Adélie Land Bottom Water along 140E. *Geophysical Research Letters*. **32**, L23601, doi: 10.1029/2005GL024246.

18. Bergamasco, A., Defendi, V., Budillon, G. & Spezie G. (2004). Downslope flow observations near Cape Adare shelf-break. *Antarctic Science*. **16**, 199-204.

19. Budillon, G. & Spezie G. (2000). Thermohaline structure and variability in the Terra Nova Bay polynya, Ross Sea. *Antarctic Science*. **12**(4), 501-516.

20. Orsi, A.H. & Wiederwohl, C.L. (2009). A recount of Ross Sea waters. In: Gordon, A., Padman, L., Bergamasco, A. (Eds.*), Deep-Sea Research PartII*, Southern Ocean Shelf Slope Exchange.

21. Rusciano, E., Budillon, G., Spezie, G., Bergamasco, A., Aliani, S.& Capello, M. (2008). Interannual variability of high salinity shelf water production from Terra Nova Bay polynya. *Biennial SCAR Meeting*, 8-12 July, San Petersburg, Russia

22. Rusciano, E. (2009). Variabilità termoalina nella Polynya di Baia terra Nova in relazione alla copertura di ghiaccio ed al forzamento atmosferico. *PhD Thesis*.

23. Fusco, G., Budillon, G., Spezie G. (2009). Surface heat fluxes and thermohaline variability in the Ross Sea and in Terra Nova Bay polynya. *Continental Shelf Research* **29**, 1887–1895. doi:10.1016/j.csr.2009.07.006.

24. Budillon, G., Castagno, P., Aliani, S. & Spezie, G. (2009). Mixing processes and thermohaline variability at the Ross Sea shelf break. *Deep Sea Research*, submitted.