Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

No 35 (Volume 10 No 4) October 2005

Southern Hemisphere Climate Variability

CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

The CLIVAR Newsletter Exchanges is published by the International CLIVAR Project Office
ISSN No: 1026 - 0471

Editors: Howard Cattle and Mike Sparrow
Layout: Sandy Grapes
Printing: The Print Centre, University of Southampton

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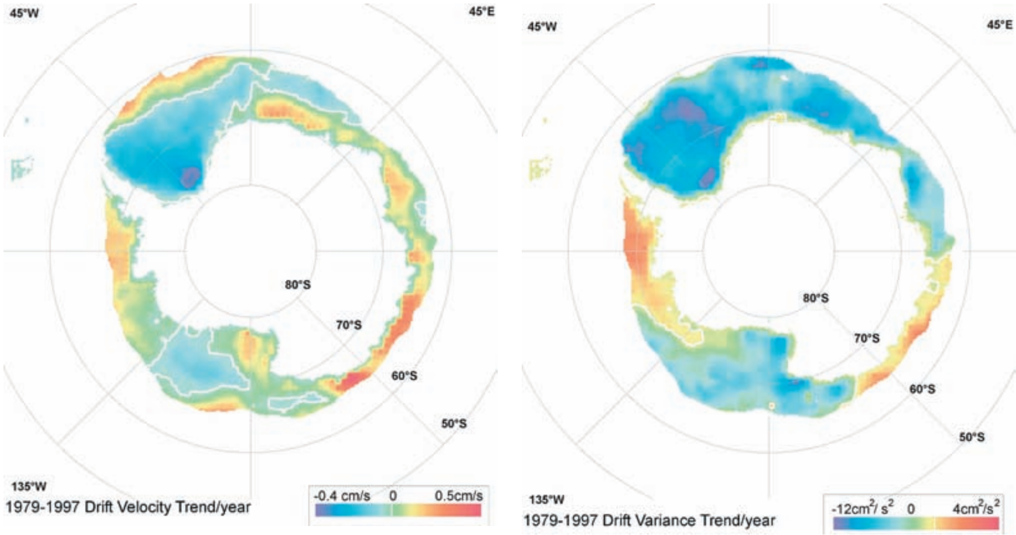

Figure 4. Spatial representation of ice drift speed and ice drift variance trends expressed as a mean trend/year over the interval from 1979-1997. White isolines seperate positive from negative trend values.

References:

Drinkwater, M.R., X. Liu., and S. Harms, Combined Satellite- and ULS-derived Sea-Ice Flux in the Weddell Sea, *Ann. Glaciol*., 33, 125-132, 2001.

Drinkwater, M.R. and S. Venegas, Interannual Variations in Antarctic Atmosphere-Ice-Ocean Coupling, *EOQ*, 69, 14-17, 2001.

Fyfe, J.C., 2003: Extratropical southern hemisphere cyclones: harbingers of climate change? *J. Clim*., 16, 2802-2805.

Hines, K.M., D.H. Bromwich, and G.J. Marshall, 2000: Artificial Surface Pressure Trends in the NCEP/NCAR Reanalysis over the Southern Ocean and Antarctica. *J. Clim*., 13, 3940-3952.

Kwok, R. and J.C. Comiso, 2002: Spatial patterns of variability in Antarctic surface temperature: Connections to the Southern Hemisphere Annular Mode and the Southern Oscillation, *GRL*, 29, 14, 10.1029/2002GL015415.

LeFebvre, W., H. Goose, R. Timmermann, and T. Fichefet, 2004: Influence of the Southern Annular Mode on the Sea-ice-ocean System. *JGR*, 109, C09005, 10.1029/2004JC002403.

Nan, S., and J. Li, 2003: The relationship between summer precipitation in the Yangtze River valley and the previous Southern Hemisphere Annular Mode. *GRL* , 30(24), 2266, doi: 10.1029/2003GL018381.

Simmonds, I., K. Keay, and E.-P. Lim, 2003; Synoptic Activity in the Seas around Antarctica, *Mon. Weather Rev*., 131, 2, 272-288.

Venegas, S., and M.R. Drinkwater, Sea Ice, Atmosphere and Upper Ocean Variability in the Weddell Sea, Antarctica, *JGR*, 106, C8, 16747-16766, 2001.

Venegas, S., M.R. Drinkwater, and G. Schaffer, Coupled Oscillations in the Antarctic Sea-Ice and Atmosphere in the South Pacific Sector, *GRL*, 28, 17, 3301-3304, 2001.

Yuan, X. and D.G. Martinson, 2001: Antarctic sea ice extent variability and its global connectivity. *J. Clim*. 13, 1697-1717.

Did a Prolonged Negative SAM produce the Weddell Polynya of the 1970s?

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With the advent of scanning passive microwave sensors on board polar orbiting satellites in late 1972, the polar community entered the era of viewing sea ice conditions poleward of the outer ice edge with nearly synoptic clarity. The waxing and waning of the seasonal sea ice cover in the Southern Ocean, whose northern ice edge had previously only been observed sporadically from ship, was now exposed in its entirety. The satellite sensors in their second full year of operation revealed a surprisingly large ice free region in winter near the Greenwich Meridian and 65°S that is now referred to as the Weddell Polynya (Zwally and Gloersen, 1977; Carsey, 1980; Gordon and Comiso, 1988; Fig 1a). The Weddell Polynya, averaging 250 x 103 km^2 in size, was present during the entire austral winters of 1974, 1975 and 1976. As the Weddell Polynya was observed near the very start of the satellite based time series one might have reasonably expected that a winter persistent Polynya was the norm, but since 1976 a persistent winter polynya has not been observed. What has been observed are much smaller (10 x 103 km^2), sporadic polynyas with characteristic time scale of 1 week in the vicinity of Maud Rise near 65°S, 2°E [Comiso and Gordon, 1987; Lindsey et al., 2004] induced by circulation-topographic interaction [Gordon and Huber, 1990].

The normal stratification within the Weddell Gyre is that of a thick layer of relatively warm, saline deep water drawn from the lower Circumpolar Deep Water. Along the southern limb of the Weddell cyclonic gyre, in which the Weddell Polynya was situated, the warm deep water is >1.0°C, with salinity >34.7. The warm deep water is capped by the ~100 m thick surface layer of near freezing temperature in the winter, separated from the warmer deep water by a rather weak pycnocline. A

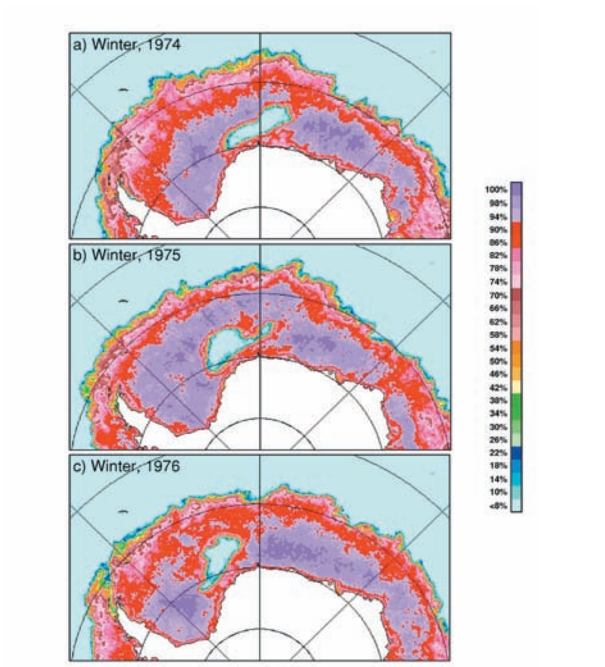

Figure 1a Colour coded sea ice concentration maps derived from passive microwave satellite data in the Weddell Sea region during (a) August 30, 1974, (b) August 30, 1975 and (c) August 29, 1976. The Weddell Polynya is the extensive area of open water (in blue) near the Greenwich Meridian roughly between 65°S and 70°S. [Adapted from Gordon and Comiso, 1988].

breakdown of this normal stratification is the likely cause of the Weddell Polynya [Gordon, 1978, 1982]. The Weddell Polynya was created as sea ice formation was inhibited by deep reaching ocean convection that injected relatively warm deep water into the winter surface layer. The ocean overturning left its mark on the deep water stratification down to 3000 m with significantly cooler and fresher deep water, a sign of massive intrusion of surface layer water into the deep, relative to the pre-polynya stratification (Fig 1b; Gordon, 1978, 1982). The deep water salt delivered into the surface layer by the convection insured a repeat performance of the polynya in the next winter. However the polynya "sensitized" regions slowly advected westward [~ 0.013 m/sec, the approximate barotropic flow within the Weddell Gyre] within the Weddell gyre flow into the western boundary current, where it was destroyed by shear. Estimate of the three-year average winter ocean heat lost to the atmosphere within the Great Weddell Polynya is 130 W/m^2.

What initiated the Weddell Polynya and why hasn't it occurred since the 1970s? Though observations within the Weddell gyre are sparse, there is convincing enough evidence that prior to the Weddell Polynya the surface water increased in salinity and the pycnocline isolating the cold surface later from the abundant heat of the deep water weakened [Fig 2]. We propose that this was the consequence of a prolonged period of negative Southern Annular Model [SAM]. During –SAM the Weddell gyre experiences colder and drier atmospheric conditions, making for saltier, denser surface water. This eventually led to a breakdown of the pycnocline stability, prompting deep reaching convection. Since the late 1970s SAM has been about neutral or in a positive state, inducing warmer, wetter conditions over the Weddell Sea and forestalling a repeat of the Weddell Polynya.

The weakened pycnocline was primarily a consequence of increased surface salinity. The surface layer [upper 100 m] salinity increases during the late 1960s and through the 1970s, levelled off in the 1980s and decreased in the 1990s, at a reduced rate since year 2000. The surface layer salinity for the decade before the Weddell Polynya is about 0.2, which require a decrease of freshwater input of 0.58 m over the 10 year interval, or about ~10-20% reduction of the estimated annual mean freshwater water input.

The atmospheric conditions associated with the SAM (or Antarctic Oscillation) is described by Gong and Wang (1999) and Thompson and Wallace (2000); and its impact on the ocean and sea ice by Hall and Visbeck (2002). Zonally symmetric fluctuations of the midlatitude westerly winds are caused by changes in the sea level air pressure difference between 40° and 65°S. SAM is the primary mode of atmospheric variability poleward of 30°S (Visbeck and Hall 2004), and may also account for much of the variability in ocean circulation and sea ice in this region. Hall and Visbeck (2002) use a coupled ocean-atmosphere model to explore how SAM influences ocean circulation and sea ice variability on interannual to centennial time scales. They find that the maximum westerlies shift southward during positive SAM and to the north in negative SAM. The atmosphere over the seasonal sea ice zone (between the maximum westerlies and Antarctica) becomes more convergent during the positive SAM, leading to an increase in rising motion within the air column, perhaps associated with poleward migration of cyclonic eddies, which would induce greater precipitation. During negative SAM the opposite condition prevails, that of reduced rising motion and drier conditions. In essence, during negative SAM the drier Antarctic high pressure conditions extend over the adjacent seas, such as the Weddell Sea. The results of Hall and Visbeck (2002) are in general agreement with the model findings of Lefebvre et al. (2004), showing that positive SAM spins up the meridional overturning circulation of the Southern Ocean, and the Weddell Sea experiences decreased sea ice with increased winds from the north (warmer), and negative SAM increases Weddell sea ice cover and induces slightly colder air with an increased southerly wind component.

Visbeck (unpublished) using air pressure records over the southern continents developed a SAM time series based on sea level pressure (SLP) indices for various sectors (Figure 3). An extensive period of negative SAM occurred from 1955 to1980, with a particularly strong period of negative SAM from 1965 to

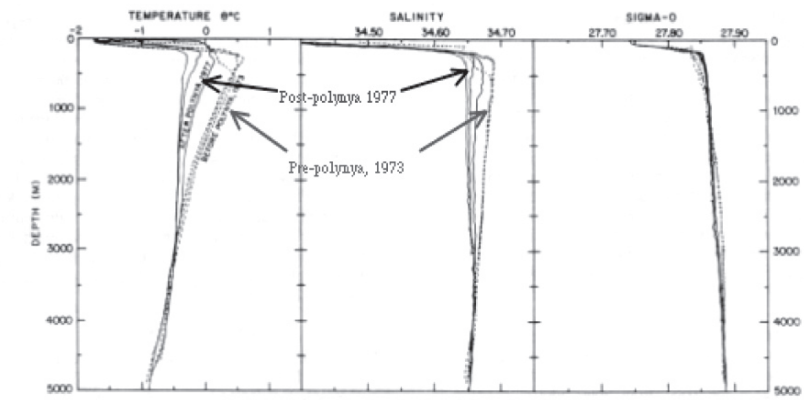

Figure 1b Profiles of potential temperature, salinity and density (sigma-0) within the area of the Weddell Polynya before and after the occurrence of the Polynya (adopted from Gordon, 1982).

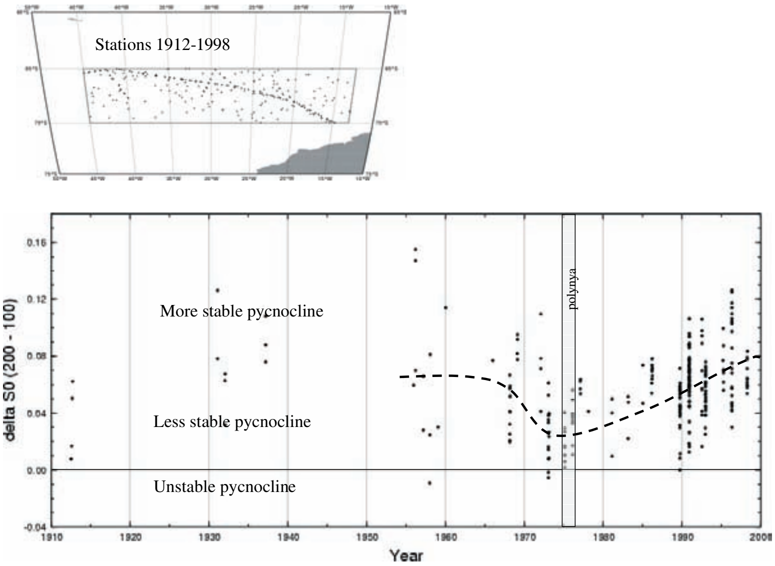

Figure 2 The pycnocline strength within the Weddell Polynya region of the Weddell Gyre (see map insert for data positions). "Delta S0 (200 m –100 m)" is the difference in sigma-0 density between 100 and 200 meters depth. The period of the Great Weddell Polynya is marked. Decreased pycnocline stability is observed in the early 1970s leading to the Weddell Polynya, since then the pycnocline strength has increased.

1978, represented by higher than normal SLP along the Antarctic margin and lower than normal SLP over both the African and South American sector, maximizing the response in the area of the Weddell Gyre. During the 1980s SAM was slightly positive, with a more substantial period of positive SAM since the late 1980s. In more recent years the strong SAM positive appears to be waning.

The relationship of SAM to precipitation since 1979, based on the CPC merged analysis of precipitation based on station observations and satellite estimates (CMAP, version 2, November 2004; Xie and Arkin, 1997) over the Weddell Sea reveals a positive, albeit weak, correlation of precipitation with SAM. For the central Weddell Gyre the regression imples 0.05 to 0.10 mm/day or 1.8 to 3.7 cm/yr less precipitation for a SAM index of –1. Over a decadal negative SAM period, as experienced in the mid-1960 into the mid-1970s, this could result in a deficit of freshwater of 20 to 40 cm. This is smaller, but probably not significantly so from the calculated decadal deficit of freshwater input of 58 cm, discussed above. Therefore it is reasonable to deduce that the negative SAM from the mid-1960s to the mid-1970s reduced the freshwater input to the Weddell surface water making the surface water saltier and denser, weakening the pycnocline, leading to deep reaching convection, and the Great Weddell Polynya.

We present the hypothesis that the Weddell Polynya of the mid-1970s resulted from a prolonged period of negative SAM. The –SAM starved the Weddell surface water of freshwater through a reduction of precipitation, making for a saltier surface layer. Winter cooling and increased sea ice production of this now saltier surface layer, destabilized the ocean pycnocline allowing the development of deep reaching ocean convection that delivered into the sea surface layer the "heat" of the Weddell deep water, thus inhibiting winter sea ice formation, resulting in the polynya state. ENSO may also have played a supporting role in that the strong La Niña of the 1970s produced a colder period over the Maud Rise region, allowing the destabilizing effect of more sea ice formation. We base our conjecture on observational data, which admittedly are sparse within the remote Weddell Sea, but we think sufficiently convincing to warrant further [most likely model based] research.

Will a winter-long Weddell Polynya happen again? One can say with a high degree of confidence that the answer is "yes". The conditions recorded at the beginning of the passive microwave data time series could not have been so unique that it caught a one time feature. The Weddell Polynya must have formed before the mid 1970s and will occur again, but when? According to our proposed mechanism, it will happen once the SAM enters into a period of prolonged negative phase, so as to build up the salinity of the surface layer. Coincidence with a strong La Niña event may help, or perhaps of significant is the interplay of the sequencing and relative strengthens of SAMS and ENSO. The Maud Rise forcing upwelling of warm deep water is the trigger, but the regional surface layer salinity needs to be high enough for the local trigger to produce a winter long persistent Weddell Polynya. So our advise to Maud Rise: Keep trying!

If the proposed link between SAM and the Great Weddell Polynya proves to be robust, then one can consider the consequences of the exposure to the polar winter atmosphere of the polynya's 250 x 103 km^2 surface ocean "hot" spot, to the regional synoptic scale meteorology or on the larger scale climate system.

References:

Carsey, F. D., 1980: Microwave observations of the Weddell Polynya. *Monthly Weather Rev*. 108: 2032-2044.

Comiso, J. C. and A. L. Gordon, 1987: Recurring Polynyas over the Cosmonaut Sea and the Maud Rise. *Journal of Geophysical Research-Oceans* 92(C3): 2819-2833.

Gong, D. and S. Wang, 1999: Definition of Antarctic Oscillation Index. *Geop. Res. Lett*. 26(4):459-462.

Gordon, A. L., 1978: Deep Antarctic Convection West of Maud Rise. *J. Physical Oceanography* 8(4): 600-612.

Gordon, A.L., 1982: Weddell Deep Water Variability. *J. Mar. Res*., 40: 199-217.

Gordon, A.L., and J. C. Comiso (1988: Polynyas in the Southern Ocean. *Scientific American*, 256(6): 90-97

Gordon, A.L., and B. Huber, 1990: Southern Ocean winter mixed layer. *J. Geophys. Res*., 95(C7): 11655-11672.

Hall, A. and M. Visbeck, 2002: Synchronous Variability in the Southern Hemisphere, Sea Ice, and Ocean Resulting from the Annular Mode. *J. Climate* 15(21): 3043-3057.

Lefebvre, W., H. Goosse, R. Timmermann, and T. Fichefet, 2004: Influence of the Southern Annular Mode on the sea ice-ocean system (DOI 10.1029/2004JC002403). *Journal of Geophysical Research*, 109, C09005.

Visbeck M. and A. Hall, 2004: Comments on ''Synchronous variability in the southern hemisphere atmosphere, sea ice, and ocean resulting from the annular mode'' - Reply *J. Climate* 17 (11): 2255-2258

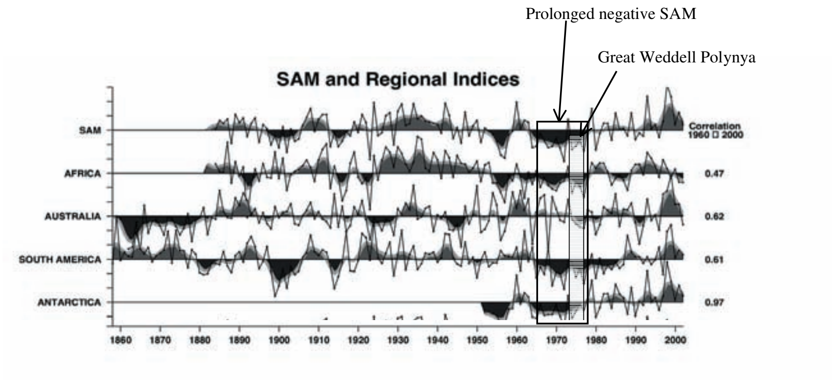

Figure 3. Southern Annular Mode, SAM, time series based on sea level air pressure (SLP) indices for various sectors of the southern ocean (Visbeck, unpublished). An extensive period of negative SAM occurred from 1955 to 1980, with a particularly prolonged period of negative SAM from 1965 to 1978 (marked on the figure, as is the period of the Weddell Polynya).

Lindsay, R. W., D. M. Holland, and Woodgate, R.A. , 2004: "Halo of low ice concentration observed over the Maud Rise seamount (DOI 10.1029/2004GLO19831)." *Geophysical Research Letters* 31(13): L13302.

Thompson, D. and J. M. Wallace, 2000 Annular modes in the extratropical circulation. Part I: month-to-month variability. *J. Climate* 13, 1000-1016.

Xie, P. and Arkin, P.A., 1997: Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates, and Numerical Model Outputs. *Bulletin of the American Meteorological Society*, 78, pp.2539-2558

Zwally, H. J. and P. Gloersen, 1977: Passive Microwave images of the polar regions and research applications, *Polar Rec.* 18, 431-450.

Response of the Antarctic Circumpolar Transport to Forcing by the Southern Annular Mode.

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The Southern Ocean is unique in being zonally unbounded, and is home to the world's largest current system, the Antarctic Circumpolar Current (ACC). ACC transports from hydrographic sections are of order 130-140 Sv [e.g. Cunningham et al., 2003; García et al., 2002], and it is believed that this strong circumpolar flow (and associated transports of heat, salt etc) exerts a profound influence on global circulation and climate. Of interest to us is how the circumpolar transport around Antarctica changes over a range of timescales, and what impact these changes might have.

It is now well-established that the higher-frequency (subseasonal) circumpolar transport variability is dominated by a barotropic mode that follows contours of f/H almost everywhere, and that bottom pressure and sea level (corrected for the inverse barometer effect) close to the Antarctic continent provide good measures of the variability of this mode [Hughes et al., 1999]. Recently it was observed that sea level and bottom pressure around the entire instrumented part of Antarctica show high levels of coherence, with negligible lag [Aoki, 2002; Hughes et al., 2003], indicating the synchronous acceleration/deceleration of the circumpolar transport around the continent.

The different measures of sea level and bottom pressure at subseasonal timescales are strongly coherent with an index of the Southern Annular Mode (SAM) [Aoki, 2002; Hughes et al., 2003]. This is the dominant mode of atmospheric variability in the extra-tropical Southern Hemisphere, and is characterised by shifting of mass between a node centred over the Antarctic and an annulus encircling lower latitudes [Thompson and Wallace, 2000]. The changes in surface atmospheric pressure associated with variations in the SAM are also manifested as variations in the circumpolar eastward wind over the Southern Ocean. The lag between changes in forcing by the SAM and changes in bottom pressure / sea level around Antarctica is negligible, indicating a near-instantaneous response of the circumpolar transport (Figure 1; [Hughes et al., 2003]). That the changes in sea level are genuinely reflecting changes in ocean transport is further indicated by analysis of output from the Ocean Circulation and Climate Advanced Model (OCCAM). This is a global OGCM, run at 1/4^{o} resolution and forced with ECMWF reanalysis winds [Webb, 1998]. Transport estimates from OCCAM on subseasonal timescales are also coherent with sea level and the SAM, again with negligible lag (Figure 1).

The seasonality in the SAM has received significant interest recently. The SAM has shown a marked trend toward a higher-index state (stronger circumpolar winds) over the past 30 years [Thompson et al., 2000], however this trend is not purely monotonic but is strongly modulated by season. It has been argued that anthropogenic processes such as greenhouse gas emissions and ozone depletion are important to this trend [e.g. Marshall, 2003; Thompson and Solomon, 2002]. Whilst we cannot examine directly the impact of the trend in the SAM on the circumpolar transport, we can investigate the impact of the changing seasonality of the SAM. Figure 2 shows the month-by-month trends in bottom pressure, as measured at the south side of Drake Passage during the 1990s [Meredith et al., 2004]. Also shown are the corresponding trends from the SAM index, plotted inverted and with their mean subtracted for comparison with the bottom pressure data. The similarity is striking, indicating that the changing seasonality of the SAM has indeed influenced the seasonality in the oceanic circumpolar transport. This also suggests a mechanism whereby humankind's activities can influence the large-scale ocean circulation [Meredith et al., 2004].

At longer (interannual) periods, simple barotropic dynamics are no longer applicable and significant baroclinic variability is expected. For these periods, there are few tide gauge records of sufficient length and of sufficiently high quality to be very useful. The most useful is Faraday/Vernadsky on the Antarctic Peninsula (Figure 1). Annual means of sea level from Faraday are significantly correlated with annual means of the SAM index, and also annual means of the total Antarctic circumpolar transport from OCCAM (Figure 3 [Meredith et al., 2004]), thus