Investigation of ACC transport and variability through Drake Passage using the simple ocean model BARBI

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Introduction

The determination of the transport of the Antarctic Circumpolar Current (hereafter ACC) through Drake Passage is one of the major tasks in studying the ocean climate of the southern hemisphere. Several studies (e.g. ISOS and WOCE) have tried to monitor the ACC transport and its variability. The mechanisms that balance the ACC transport are described e.g. in Olbers et al. (2004) and an overview of the measured transport values is given in Cunningham et al. (2003), who found no significant trend over the time period between 1975 and 2000.

With respect to the variability, Hughes et al. (1999) proposed that for periods between about 10 and 220 days the variability of the transport through Drake Passage is dominated by a barotropic mode that follows *f/h* contours at the rim of Antarctica. Furthermore, bottom pressure in the south of Drake Passage is a good indicator for monitoring the variability of the flow through Drake Passage. This view is supported further by Aoki (2002), Hughes et al. (2003) and Meredith et al. (2004). Additionally, they connected the variability of transport and pressure data with the Southern Annular Mode (hereafter SAM, see e.g. Thompson and Wallace 2000), which seems to be the dominant mode of atmospheric forcing in the southern hemisphere.

Here we investigate what the BARBI model (Olbers and Eden (2003)) yields about these issues of transport variability.

The BARBI model

BARBI is a two-dimensional simplified ocean general circulation model that is based on the vertically integrated primitive equations in Boussinesq form (further details in Olbers and Eden (2003)). The resulting model equation for the integrated velocity U is $\frac{\partial U}{\partial t} + fk \times U = -\nabla E + \tau + F$

where *h* is the depth of the ocean, *P* is the bottom pressure and *E* the baroclinic potential energy associated with the perturbation density. τ represents the surface forcing created by the wind stress (which is the only forcing in the model) and F stands for lateral friction. By using the rigid-lid approximation it is possible to introduce a transport streamfunction ψ for the volume transport with $U=k\times\nabla\psi$. The equations of heat and salt are combined into an equation for the perturbation density about a mean linear background stratification described in the constant Brunt-Väisälä Frequency N. A prognostic equation for the potential energy is derived, which is extended by a dissipation term $-\mu E$. For the sake of simplicity, this equation and the prognostic equation for the velocity moments are omitted in this abstract but can be found in Olbers and Eden (2003).

The following model parameters are used: the horizontal and vertical viscosities are $A_h=5\cdot10^4 m^2/s$ and $A_v=10^{-4} m^2/s$, the horizontal diffusivity is $D_h=2\cdot10^3 m^2/s$, the dissipation factor is $\mu=1.5\cdot10^{-10} s^{-1}$, the stratification frequency is $N=0.0015 s^{-1}$. Only one baroclinic density and velocity moment is used, and the model domain is from 76°S to 20°S with a resolution of $\Delta X\cdot\Delta Y=2°\cdot1°$. Two different kinds of wind forcing are used: the first (type A) is a composition of a mean wind stress provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the anomalies from NCEP/NCAR monthly wind data with a linear interpolation between the monthly values. The second (type B) are daily winds provided by NCEP/NCAR.

A trend in ACC Transport

Figure 1 shows the model transport through Drake Passage for wind forcing scenarios A and B during the time interval of the ISOS and WOCE studies. The time series are low-pass filtered to suppress periods less than 60 days. Furthermore, the estimated transport values from measurements, presented in Cunningham et al. (2003) (table 1), are plotted to compare them with the model transports. It is important to know that these values assume a level of no motion at 3000 dbar. The figure shows that the two time series of the model transports are quite similar and match the values of Cunningham et al. (2003) quite well.

On the basis of these data Cunningham et al. used a t-test with a 95% significance level to prove that the two sample means of the two time series (1975-1980, 1990-2000) are not different, and concluded that there is no trend in the ACC transport. Using the same procedure with the model data, the means of the two time intervals are significantly different. Taking the model data (NCEP daily forcing) only at those dates which are equal to the dates in Cunningham et al., the results are the same: the mean values are not significantly different. Therefore, these model data suggest that there is a trend from the mid 1970s until today, which can be estimated from the time series with NCEP daily forcing to be 0.30 Sv/y.

The model trend, shown in figure 2, is smaller for the NCEP daily forcing, which might be due to inertia of the system under the linear interpolated wind forcing of type A. Furthermore, an increasing trend is seen in the wind forcing which might cause the increasing model transport, because it seems reasonable that increasing the strength of the forcing increases the model response (ACC transport). The increasing wind stress could be related to the increasing SAM index.

Connection with SAM

Two different definitions of SAM indices are used here to relate them with the model transport. The first (hereafter SAM-1) is based on station data provided by Gareth Marshall (www.nerc-bas.ac.uk/icd/gjma/sam. html) and is displayed in the lower panel of figure 2. The second (SAM-2) follows Thompson and Wallace (2000) and has been derived from an EOF analysis of 700hPa geopotential height anomaly south of 20°S (www.cpc.ncep.noaa.gov/products/precip/Cwlink/ ENSO/verf/new.aao.shtml) .

Correlating the model transport under forcing B with SAM-1 results in r=0.55 and with SAM-2 results in r=0.60. These are quite similar but explain only about 36% of the observed variance. Therefore, these model results suggest that the SAM index might not be the best proxy for the transport variability through Drake Passage. The objection could be raised that the SAM isn't likely to be well characterised in the model, because only wind stress is used as forcing, which might not completely represent the SAM index. Using a linear regression model a change of SAM index of 1 standard deviation produces a transport change of 5.7 Sv for SAM-1 and 6.0 Sv for SAM-2 (for

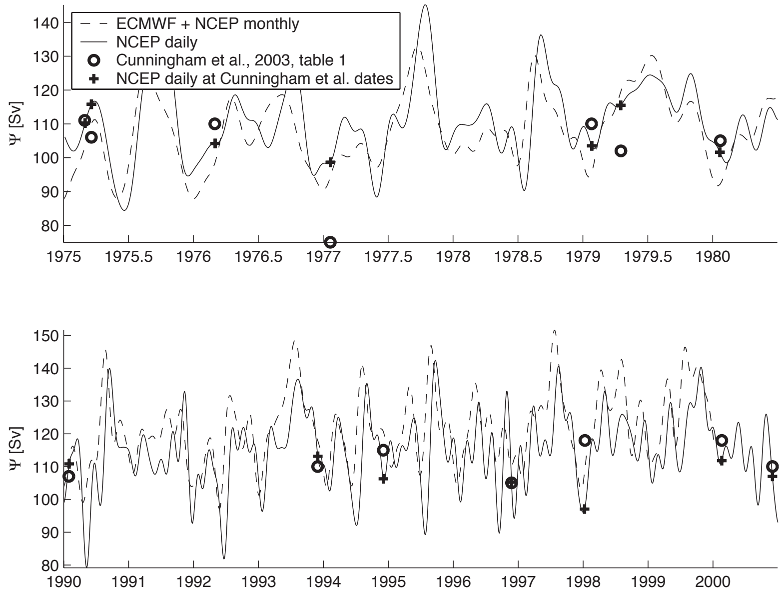

Figure 1: Comparison of model transport through Drake Passage with measurements listed in Cunningham et al. 2003.

comparison Hughes et al. (2003) find 3.5 Sv).

The bottom pressure as proxy

As mentioned in the introduction a good indicator of transport variability might be the bottom pressure around the rim of Antarctica. In figure 3 the correlation between transport through Drake Passage and bottom pressure at every grid point is plotted, showing the highest correlations along the *f/h* contours around Antarctica.

Borowski et al. (2002) and others showed the importance of the gradient of potential energy forcing the flow over the blocked *f/h* contours at Drake Passage. Therefore it seems interesting to investigate on which time scale potential energy comes into play. Figure 4 displays the coherence of transport through Drake Passage with the difference of potential energy across, and the bottom pressure in, the south of Drake Passage using the longer time series with forcing A. As can be seen, for periods up to four years the variability is dominated by bottom pressure peaking between 0.25 and 0.5 years.

Summary

From these results of the BARBI model it is suggested that for time scales of up to 4 years bottom pressure in the south of Drake Passage is a good proxy of ACC transport, whereas SAM index does not seem to be quite suitable.

Additionally, relying in the accuracy of the wind forcing a positive trend in transport through Drake Passage since the late 1970s seems plausible.

Acknowledgement

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References

Aoki S., 2002: Coherent sea level response to the Antarctic Oscillation. *Geophysical Research Letters*, 29(20), doi:10.1029/2002GL015733

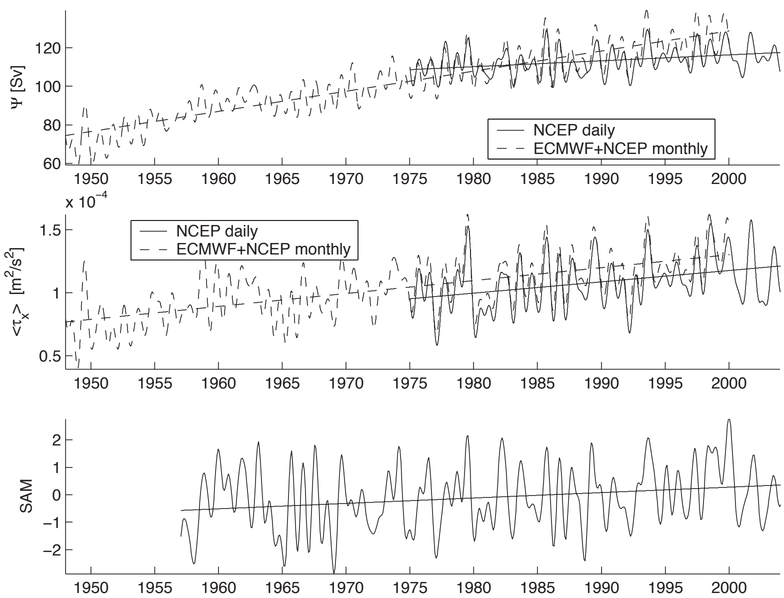

Figure 2: Upper panel: model transport through Drake Passage for wind forcing A and B. Middle panel: mean zonal wind stress between 68°S and 47°S. Lower panel: SAM index after Gareth Marshall

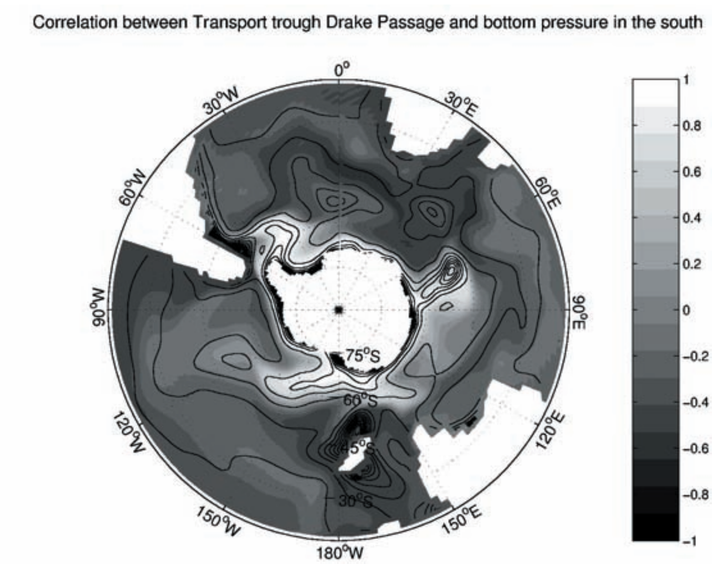

Figure 3: Correlation of transport through Drake Passage with bottom pressure at each grid point and geostrophic (f/h) contours in the model domain

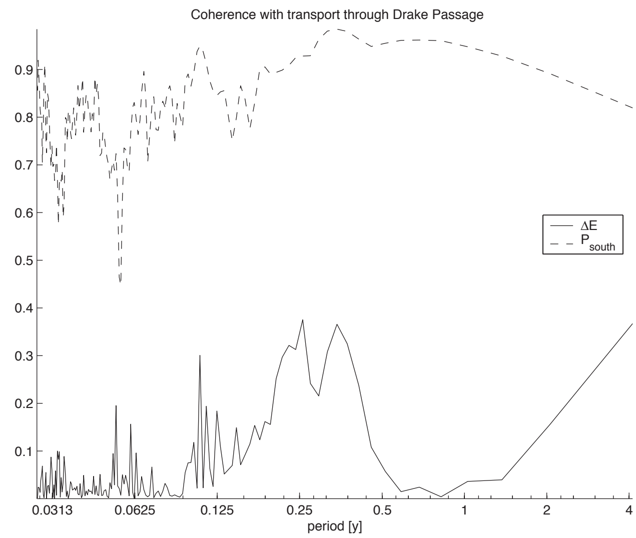

Figure 4: Coherence of transport through Drake Passage with bottom pressure in the south and with difference of potential energy across Drake Passage.

Borowski D., R. Gerdes , D.J. Olbers, 2002: Thermohaline and Wind Forcing of a Circumpolar Channel with blocked Geostrophic Contours. *Journal of Physical Oceanography*, 32, 2520-2540

Cunningham S.A., S.G. Alderson, B.A. King, M.A. Brandon, 2003: Transport and variability of the Antarctic Circumpolar Current in Drake Passage. *Journal of Geophysical Research*, 108, doi:10.1029/2001JC001147

Hughes C.W., M.P. Meredith, K. Heywood, 1999: Wind-Driven Transport Fluctuations through Drake Passage: A Southern Mode. *Journal of Physical Oceanography*, 29, 1971-1992

Hughes C.W., P.L. Woodworth, M.P. Meredith, V. Stepanov, T. Whitworth, A.R. Pyne, 2003: Coherence of Antarctic sea levels, Southern Hemisphere Annular Mode, and flow through Drake Passage. *Geophysical Research Letters*, 30(9), doi:10.1029/2003GL017240

Meredith M.P., P.L. Woodworth, C.W. Hughes, V. Stepanov, 2004: Changes in the ocean transport through Drake Passage during the 1980s and 1990s, forced by changes in Southern Annular Mode. *Geophysical Research Letters*, 31, doi:10.1029/2004GL021169

Olbers D., C. Eden, 2003: A simplified General Circulation Model for a Baroclinic Ocean with Topography. Part I: Theory, Waves and Wind-Driven Circulations. *Journal of Physical Oceanography*, 33, 2719-2737

Olbers D.J., D. Borowski, C. Völker, J.O. Wolff, 2004: The dynamical balance, transport and circulation of the Antarctic Circumpolar Current, *Antarctic science*, 16(4), 439-470.

doi:10.1017/S0954102004002251

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