Propagation of features in the Southern Ocean, using ATSR and altimetry

C. W. Hughes — Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead, Merseyside L43 7RA, U.K.
C.Hughes@pol.ac.uk
http://www.nbi.ac.uk

M. S. Jones — James Rennell Division, Southampton Oceanography Centre, Empress Dock, European Way, Southampton SO14 3ZH, U.K.
msj@mail.soc.soton.ac.uk
http://www.soc.soton.ac.uk/JRD/jrdindex.html

S. Carnochan — Dept. of Civil Engineering, University of Aston, Aston Triangle, Birmingham B4 7ET, U.K.
carnochs@sun.aston.ac.uk
http://www.civ.aston.ac.uk

Abstract

Results from the Fine Resolution Antarctic Model have suggested that the Antarctic Circumpolar Current (ACC) is a region in which the mean eastward flow speed exceeds the intrinsic westward propagation speed of baroclinic Rossby waves. As a result, the modelled ACC shows up as a region in which transient features propagate eastwards. Features of the mean flow on scales as small as 250 km are reflected in the propagation of transient features. In this study, sea surface slopes measured by the ERS1 altimeter, and sea surface temperature gradients measured by the Along-Track Scanning Radiometer (ATSR), are used to map the zonal propagation of transient features. A consistent picture is produced using the two instruments, with eastward propagation confirmed throughout the ACC. Many smaller scale features are visible in both maps, in some cases agreeing with FRAM, but in many cases disagreeing. The dynamic relevance of these features is clear from the fact that they appear in maps made from two independent data sources, and often correspond to features in the mean surface temperature field. In particular, the Tasman Front and the South Atlantic Current can be clearly identified.

Keywords: Rossby waves, Mesoscale, Southern Ocean, Antarctic Circumpolar Current, Altimetry, Surface temperature

Introduction

The ACC is an exceptional feature in the circulation of the World Ocean. It links the Atlantic, Indian and Pacific oceans with a flow of about 135 Sv (1 Sv = 1 million cubic metres per second). Since it has no eastern or western boundary at some latitudes, the standard Sverdrup dynamics which give such a good first order picture of the flow in other ocean basins cannot be applied here, so the basic dynamic balance of the region cannot be said to be understood even to a first approximation. The lack of eastern or western boundary also means that interactions with bottom topography are necessary to balance the input of angular momentum by the mean zonal wind stress, at the latitudes of Drake Passage (Munk and Palmen, 1951). The resulting current is strong, and penetrates to great depths with an equivalent barotropic structure - the direction of currents tends to be the same at almost all levels (Killworth, 1992).

The question of how the current comes to penetrate to such great depths is an interesting one. Anderson and Killworth (1977) showed that, in spin-up experiments, baroclinic Rossby waves propagated across the ocean basin from east to west. The effect of these waves is to shut off the current below the thermocline, permitting the flow to assume a Sverdrup balance, with no interaction with bottom topography over the bulk of the basin. If baroclinic Rossby waves were to do the same in the Southern Ocean, then the flow could not attain a dynamical balance, since deep currents are necessary to allow interaction with the bottom topography. This being the case, something must be preventing the baroclinic Rossby waves from cutting off the deep flow in the Southern Ocean.

Hughes (1996) showed that, in the Fine Resolution Antarctic Model (FRAM), the current is strong enough to advect baroclinic Rossby waves eastwards. This strong advection makes the ACC act as a waveguide, with eastward-propagating waves trapped within a region of strong eastward flow bounded by critical layers, at which strong wave/mean-flow interactions take place. Dynamical processes in this region are analogous to those seen in the stratosphere, at the edge of the polar vortices, where Rossby wave dynamics and critical layers have been shown to play an important role in horizontal mixing.

TOPEX/POSEIDON (T/P) altimetry has been used to map these waves in the southeast Pacific sector of the ACC (Hughes, 1995), where both eastward and westward propagation were seen, but the relatively poor spatial resolution of T/P limited useful results to this high latitude region. Typical observed wavelengths are about 250 km, compared with a cross-track spacing of 2.83 degrees of longitude = 315 km * cos(latitude) for T/P.

In this paper, the improved spatial resolution of the ERS 1 altimeter (cross-track spacing 0.72 degrees of longitude) and the Along-Track Scanning Radiometer (ATSR, used at 0.5 degree resolution) are used to map wave propagation throughout the Southern Ocean.

Data and Processing

Two datasets are considered here: sea surface slopes from the 35 day repeat phase of the ERS 1 altimeter (18 cycles), and sea surface temperature (SST) gradients from ATSR. Sea surface slopes are calculated from 100 km arcs at crossover points. Collocated heights were calculated, and subtracted from a reference arc for which all measurements were present. Slopes were then calculated as a linear fit to the 100 km arcs, and the 18 cycle mean slope subtracted off. At each crossover point, two components of the slope can be calculated, but the shallow angle between ascending and descending passes makes these effectively indistinguishable from meridional gradients (this is confirmed by sampling model and SST measurements the same way), so this is how the slopes are treated. The orbits used were corrected using ERS 1-T/P crossovers (Carnochan 1996). Slopes, rather than heights, are used because of the much higher signal to noise ratio for signals at such short wavelengths.

The ATSR data used are monthly median temperatures calculated from the half degree product. Contamination due mostly to nighttime clouds was filtered out (Jones et al. 1996a, b), and gradients in the zonal and meridional directions were calculated from differences between two values at one degree spacing. Gradients of temperature were thought to be a better measure of geostrophic dynamics on these scales than temperature values themselves.

A small patch of nine grid points in the zonal direction was taken, and, for each instrument, autocovariances (in time) and cross covariances were calculated, the cross covariances being between values at one grid point and those at the next grid point to the east. From these covariances, cross spectra were calculated. From the phases, a wavenumber was then calculated for each frequency. The emphasis here is on propagation direction, which is expected to be quite robust, so results are only shown for one period (4.6 months for altimetry and 4.8 months for ATSR). Positive wavenumbers then correspond to eastward propagation, negative wavenumbers to westward propagation. For the altimetry, the systematic nature of the sampling between one grid point and the next to the east (separated by about 16 + 35*n days, rather than simply 35*n days) requires a substantial correction to this phase.

Results

The wavenumbers resulting from the analysis described above are shown in Fig. 1.

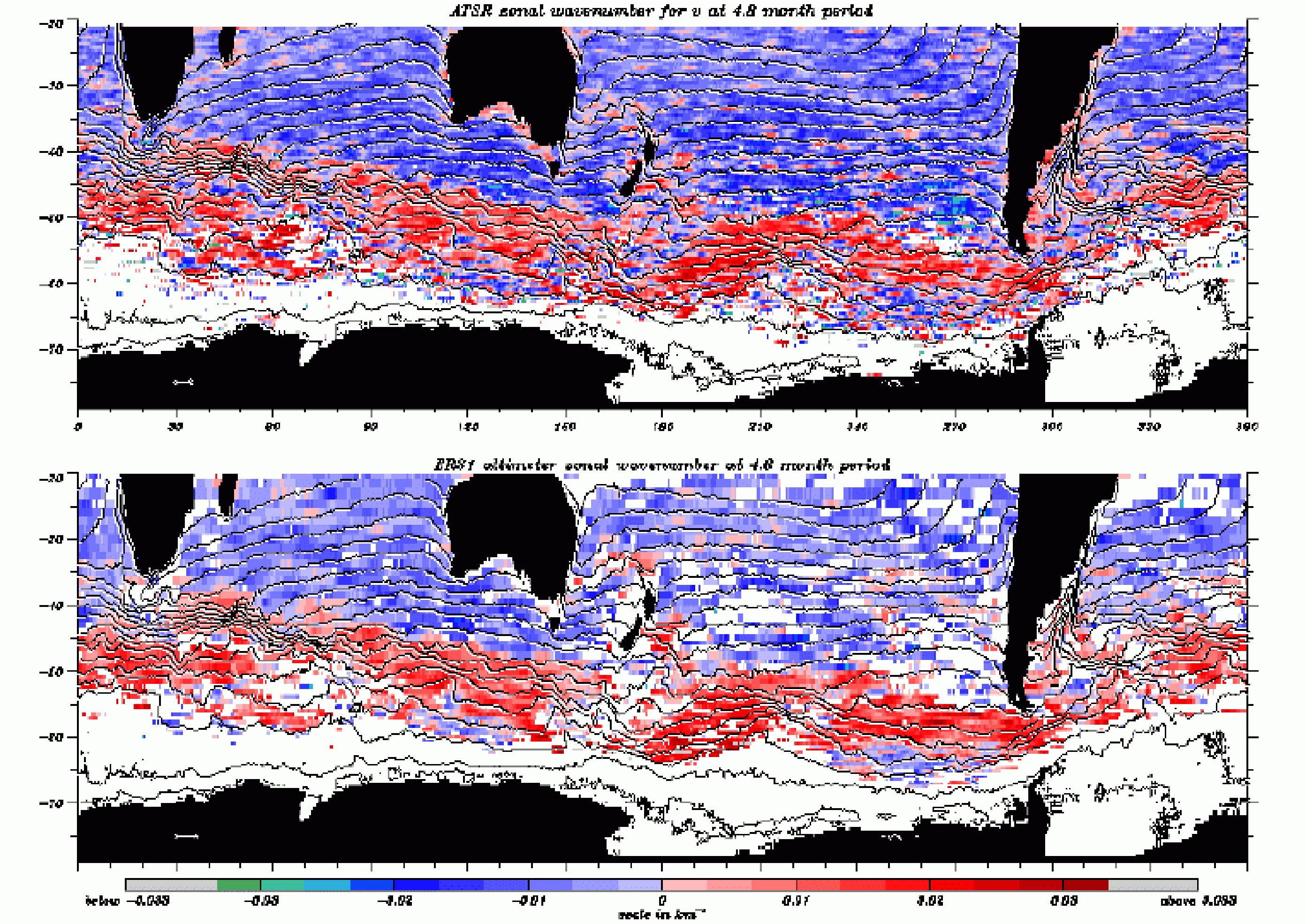

Figure 1: Wavenumbers derived from zonal SST gradients at 4.8 month period (top), and along-track sea surface slopes at 4.6 month period (bottom). Contours of mean SST are superimposed with a contour interval of 1.5 degrees C, and white regions are where the cross spectral coherence is not significant at the 95% level. The zonal smoothing scale of 9 grid points is shown by the white bar at the bottom left of each map.

A remarkably consistent picture is presented by results from the two instruments. The ACC is clearly visible as a band of eastward propagation, with westward propagation to the north and also, in places, to the south. A number of dynamical features can be clearly seen. The South Atlantic Current (Stramma and Peterson 1990) shows up as a region of eastward propagation at about 37 degrees S. Separating this from the ACC is a region of westward propagation which extends into the Indian Ocean as far as the Kerguelan Plateau at about 60 degrees E. To the northwest of New Zealand there is a region of eastward propagation, associated with the Tasman Front (Stanton, 1976; Stramma *et al.*, 1995). Almost everywhere, ATSR and altimeter produce the same propagation direction.

Although the wavenumber values shown above are quite similar between the two instruments, this is something of a coincidence. The ATSR plot is for zonal SST gradients, rather than along-track gradients. In fact, meridional or along-track gradients give wavenumbers smaller than zonal gradients by a factor of between 2 and 3, for both ATSR SST and FRAM sea surface height. The actual values obtained are thus quite sensitive to direction, and also to resolution; subsampling at 1 degree resolution can produce a similar change. The variation in values which may be obtained using different sampling strategies is enough to say that the ATSR and altimeter results are not incompatible, but there are clearly aspects of the data which demand further investigation. Unfortunately, the relatively short time series available mean the spectral information cannot be dissected much further with any confidence. The results on propagation direction, however, are quite robust.

Conclusions

ERS 1 altimetry and ATSR SSTs have been used to demonstrate that mesoscale disturbances in the Southern Ocean propagate eastwards in the ACC and other strong eastward currents, and westwards elsewhere. Propagation directions determined from the two independent data sources are remarkably consistent and clearly show dynamical features such as the South Atlantic Current and the Tasman Front. This is in accord with the picture derived from FRAM, of a fast ACC acting as a waveguide for eastward propagating Rossby waves. This supercritical flow speed also allows the ACC to penetrate to great enough depths to interact with the bottom topography.

Although it is possible to reconcile the wavenumber values from the two data sources, there are complications which suggest that the spectra involved must be quite complicated. Since dynamical information is clearly contained in the robust parameter of propagation direction, it seems likely that investigation of more subtle aspects of the spectra will prove profitable as longer time series become available.

Acknowledgements

We are grateful to ESA for provision of the altimeter data, and to both ESA and the ATSR team at Rutherford Appleton Laboratory for provision of the ATSR data. This work was funded by the U.K. Natural Environment Research Council and the U.K. Defence Research Agency.

References

Anderson, D.L.T., and P.D. Killworth, 1977:
Spin-up of a stratified ocean, with topography. *Deep-Sea Research*, **24**, pp. 709-732.
Carnochan, S., 1996:
Orbit and Altimeter Corrections for the ERS Satellites Through Analysis of Single and Dual Satellite Crossovers. *Submitted Ph.D. Thesis*, Aston University, Birmingham, U.K.
Hughes, C.W., 1995:

Rossby Waves in the Southern Ocean: A Comparison of TOPEX/POSEIDON Altimetry with Model Predictions. *J. Geophys. Res.*, **100**, pp. 15933-15950.
Hughes, C.W., 1996:
The Antarctic Circumpolar Current as a Waveguide for Rossby Waves. *J. Phys. Oceanogr.*, **26**, pp. 1375-1387.
Jones, M.S., M.A. Saunders, and T.H. Guymer, 1996a:
Reducing cloud contamination in ATSR averaged sea surface temperature data. *J. Atmos. Oceanic Tech.*, **13**, pp. 492-506.
Jones, M.S., M.A. Saunders, and T.H. Guymer, 1996b:
Global remnant cloud contamination in the along-track scanning radiometer data: Source and removal. *J. Geophys. Res.*, **101**, pp. 12141-12147.
Killworth, P.D., 1992:
An Equivalent-Barotropic mode in the Fine Resolution Antarctic Model. *J. Phys. Oceanogr.*, **22**, pp. 1379-1387.
Munk, W.H. and E. Palmen, 1951:
Note on the dynamics of the Antarctic Circumpolar Current. *Tellus*, **3**, pp. 53-55.
Stanton, B.R., 1976:
An oceanic frontal jet near the Norfolk Ridge northwest of New Zealand. *Deep-Sea Research*, **23**, pp. 821-829.
Stramma, L. and R.G. Peterson, 1990:
The South Atlantic Current. *J. Phys. Oceanogr.*, **20**, pp. 846-859.
Stramma, L., R.G. Peterson, and M. Tomczak 1995:
The South Pacific Current. *J. Phys. Oceanogr.*, **25**, pp. 77-91.