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ALTIMETER MEASUREMENTS OF THE VOLUME TRANSPORT THROUGH THE DRAKE PASSAGE

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ABSTRACT

From in situ measurements it has been inferred that the variability of flow through the Drake Passage down to 2500m does not depend upon depth (barotropic flow). By making this assumption it is possible to calculate the variability of the volume transport from the surface slope as measured by a radar altimeter. It is shown that it is not possible to use data from individual passes as there is too much noise on the observations. However by averaging all the data in a ten day period in boxes north and south of the Passage an estimate of the variability comparable to the in situ observations is obtained. Using an additional two boxes in the centre of the Passage shows that most of the variability is in the northern half. The variability in the centre is negatively correlated with both the north and south. ©1999 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION AND BACKGROUND

The Southern Ocean is unique among the world's oceans in that it links the other major ocean basins. There are three 'choke' points, south of Australia, South Africa and South America, through which all interchanges between the other oceans must occur. Note that although it is possible for water to flow from the Atlantic to the Pacific via the Arctic Ocean and the Bering Strait, the Bering Strait is so shallow that the total flux is very small compared to the Southern Ocean. The fluxes through the choke points are therefore very important in the global circulation. The Drake Passage (figure 2) is the narrowest of the choke points and was extensively studied during the late 1970's in the ISOS (International Southern Ocean Studies) programme (Whitworth, 1983; Whitworth and Peterson, 1984; Peterson, 1988). As part of ISOS an array of current meters was deployed in the upper 2500m of the Drake Passage. In addition pressure recorders were deployed on either side of the Passage on the shelf slopes. Whitworth and Peterson (1984) compared the geostrophic current from the pressure difference across the Passage to the transports measured by the current meter array. Fitting a linear relationship

$$T=\alpha U+\beta \tag{1}$$

where U is the geostrophic current and T is the volume transport
they found that α was equal to the cross-sectional area across the Passage. Thus the variable part of the flow above 2500m can be considered as barotropic (i.e. the flow does not depend on depth). Note that this does not imply that the mean part of the flow, which is about twelve times the variable part, is independent of depth.

ESTIMATING THE TRANSPORT FROM TOPEX/POSEIDON DATA

Radar altimeters are able to measure the height of the sea surface, relative to a reference ellipsoid, to a few cm accuracy (Fu *et al.*, 1994). Using the geostrophic equation

$$\frac{\partial H}{\partial x} = \frac{fv}{g} \qquad (2)$$

where H is the height difference over the distance x, f is the Coriolis parameter, v is the geostrophic velocity and g is the acceleration due to gravity

we can calculate the geostrophic velocity. However because we do not know the geoid we do not know the shape the sea surface would have if the ocean were at rest. Thus it is impossible to calculate the true geostrophic velocity, but because the geoid is, for the time periods we are interested in, time invariant we can easily calculate the current anomalies, and hence the variability, by subtracting the mean.

Once we have calculated the current anomaly we can use Eq. 1 to work out the volume transport anomaly calculating the constant from a published bathymetry.

Calculating the Transport Using Single Passes

The simplest way to calculate the current anomalies is to use a single pass which crosses the Drake Passage. After correcting the data for atmospheric effects, tides etc. the transport anomaly can be calculated from each pair of altimeter measurements along track. The height difference is calculated, the mean subtracted and a velocity anomaly calculated from Eq. 2. The cross-sectional area between the pair of points is then calculated and the volume transport anomaly derived from the sum of the individual transports. So we have

$$\text{Transport anomaly} = \Sigma\, v' \times \text{depth} \times \text{distance between velocity estimates} \qquad (3)$$

where v' is the velocity anomaly

The advantage of this method is that it should give very good temporal resolution as we can use data from a number of different tracks.

Figure 1 shows the transport anomalies calculated this way for a single TOPEX/POSEIDON track. The x axis is given in TOPEX cycles, each is equal to 10 days and cycle 10 is the start of 1993. The standard deviation of these points is 55 Sv (1 Sv = 10^6 m^3s^{-1}) and the maximum anomaly is about 123 Sv. From the ISOS experiment we know that the mean volume transport is about 150 Sv and the standard deviation should be between about 10.3 to 12.6Sv (Whitworth and Peterson, 1984). The results in figure 1 are therefore clearly wrong. The reason why this method does not produce good results is unclear, however it will be shown in the next section that averaging the data solves the problem so we can assume that the error is due to noise of some sort in the data or the corrections.

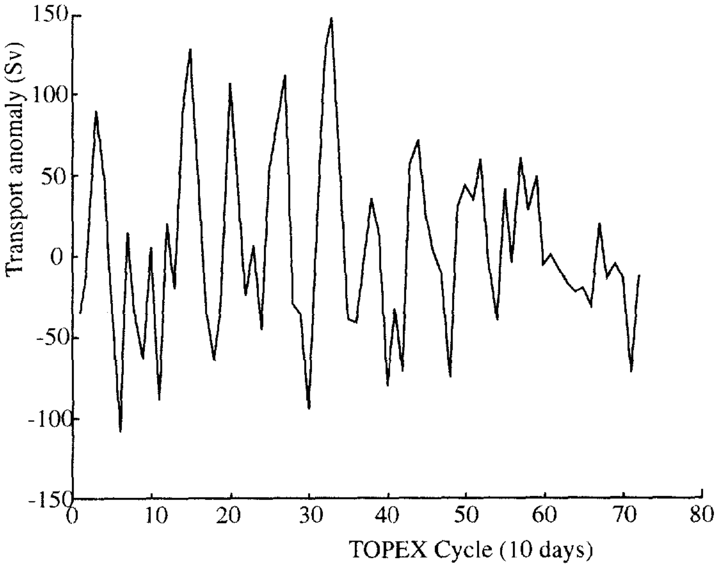

Fig 1. The transport anomaly through the Drake Passage calculated from a single TOPEX track.

Calculating the Transport by Averaging

As an alternative to using single passes to calculate the transport anomaly we can average the data over a number of passes. To do this we average all the data from each TOPEX/POSEIDON cycle in the boxes shown in figure 2. There is one box to the north of the Passage, two in the middle and one at the south. The background to the figure shows the sea surface height variability. Note that there is much more variability, and hence eddy activity, in the northern half of the Passage.

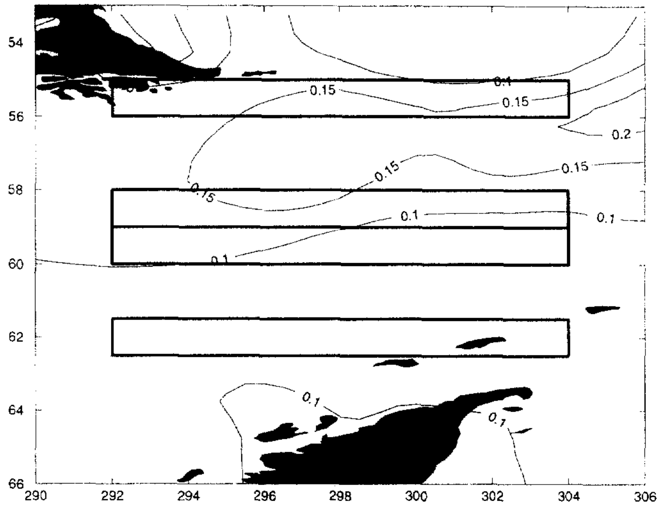

Fig 2. A map of the Drake Passage showing the positions of the boxes used for averaging the TOPEX data. The contours show the sea surface height variability. Note the region of higher variability in the north.

To calculate the transport anomaly values we remove the mean height difference between the boxes, calculate the geostrophic current using equation 2 and finally multiply by the cross-sectional area between the centres of the boxes. The transport anomalies between the north and south boxes are shown in figure 3. The standard deviation is 11.4 Sv which compares very well with the ISOS value of 12.6 SV (Whitworth and Peterson, 1984).

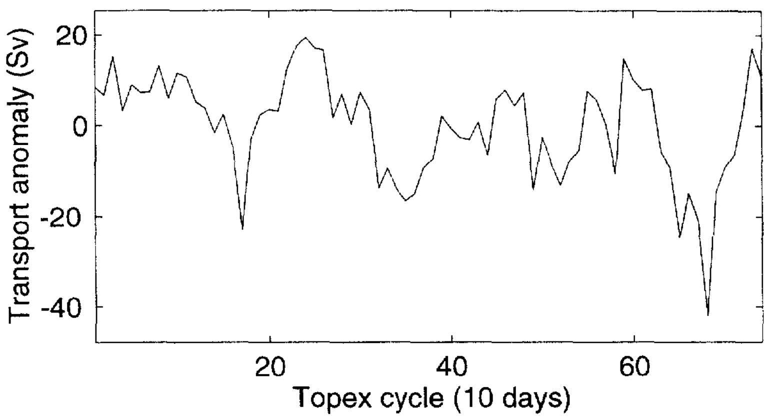

Fig 3. Volume transport anomaly through the Drake Passage calculated between the boxes to the north and south of the Passage in figure 2.

If we include the boxes in the centre of Passage as well we can divide the Passage into three regions: north, mid and south. Figure 4 shows the transport anomalies in these regions. The standard deviations are shown in table 1. Note that the standard deviation in the northern part is in fact larger than that for the total Passage. This is possible because the flows in each region are correlated. The correlation matrix is also shown in table 1. It is noticeable that there are negative correlations between both the north and south regions and the mid region. This may imply some reverse flow as shown by Challenor *et al.* (1996).

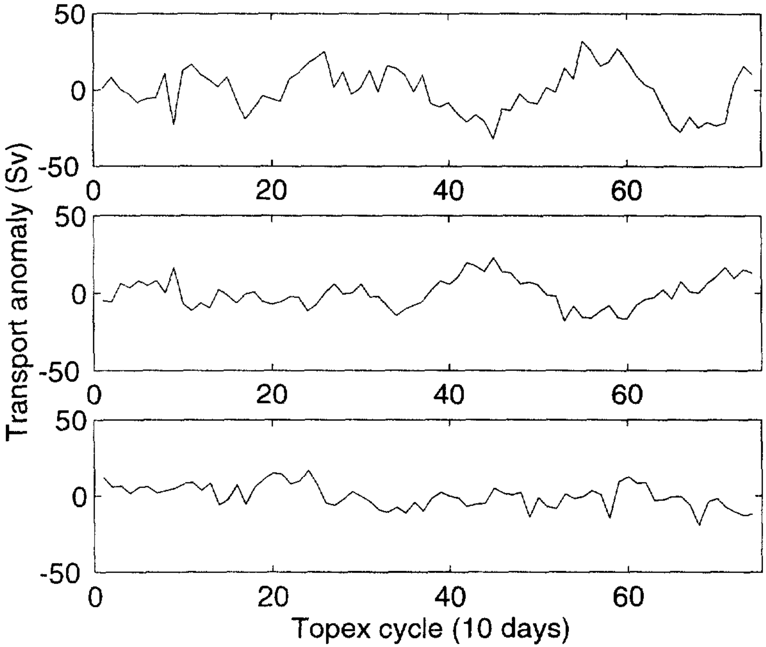

Fig 4. Transport anomaly calculated between (a) the northern two boxes, (b) the middle two and (c) the southern two.

	Whole Passage	North	Mid	South
Standard Dev. (Sv)	11.44	14.7	9.5	7.7
Whole Passage	1	0.49	0.003	0.61
North	-	1	-0.70	0.13
Mid	-	-	1	-0.30
South	-	-	-	1

Table 1. The standard deviations of transport anomaly and the correlation matrix for flow between the boxes shown in figure 2

CONCLUSIONS

We have shown that by averaging the data in both space and time it is possible to measure the anomaly of volume transport through the Drake Passage. The standard deviation of the transport compares well with previous estimates. By using additional boxes for averaging in the centre of the Passage we can obtain information on the structure of the flow across the Drake Passage.

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