Multiple jets of the Antarctic Circumpolar Current

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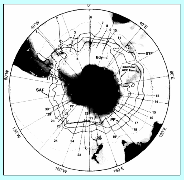
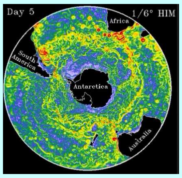
The Antarctic Circumpolar Current (ACC) consists of three circumpolar fronts, according to traditional analyses of hydrographic sections. High resolution simulations and geophysical fluid dynamics theory suggest a more complicated web of discontinuous filaments.

Can these two views by reconciled?



Orsi et al. 1995

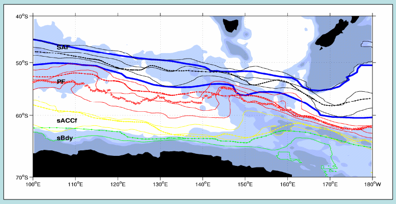
← ? →



Hallberg and Gnanadesikan 2006

Previous studies placed the same fronts 100's of kms apart. For example, the Belkin and Gordon (1996) SAF is always north of that of Orsi et al. (1995) in this sector, sometimes by as much as 500 km (for example south of the Campbell Plateau).

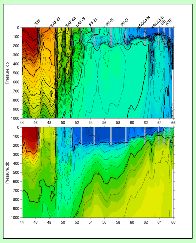
An appreciation of the multiple branches of the Southern Ocean fronts helps to explain many of these discrepancies. For example, the Belkin and Gordon front corresponds to the northern branch of the SAF, the Orsi et al SAF corresponds to the middle or southern brach of the SAF.



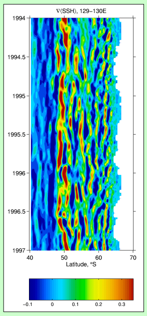
Comparison between Southern Ocean front positions mapped using SSH and positions reported by Belkin and Gordon (1996, thick blue line), Orsi et al. (1995, solid lines with solid symbols) and Moore et al. (1999, solid lines with open triangles). The Southern Ocean fronts (except Belkin and Gordon) are color-coded: SAF – black, PF – red, sACCf – yellow, Bdy – green, SAZ/STF – blue. The bathymetry is shaded grey (the 4000, 3000, and 2500 m contours are shown).

High resolution observations from ships and satellites indicate the frontal structure of the ACC is more complex than the 3-front structure inferred from measurements with coarser sampling.

Each of the ACC fronts consist of multiple branches or filaments that merge and diverge along the circumpolar path.



Potential temperature (top) and salinity (bottom) in the upper 1000 m along the WOCE/CLIVAR SR3 line at 140E in November 2001. Each of the major ACC fronts is split into multiple filaments.



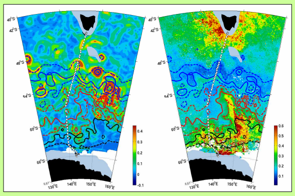
Meridional SSH gradient (m/100 km) at 130°E between 1994 and 1997. The ACC consists of multiple filaments that merge and diverge, but the jets also persist for many months.

Southern Ocean fronts strongly influence biological distributions, from phytoplankton to whales. Numerous previous studies have concluded surface chlorophyll is elevated at Southern Ocean fronts.

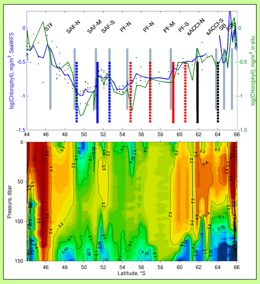
In contrast, we find the fronts generally coincide with boundaries between regions of similar chl *a* concentrations and are not themselves generally associated with enhanced phytoplankton biomass. We believe the discrepancy with previous work disappears when the multiple jets of the ACC are accounted for.

The correspondence between fronts and chlorophyll is even more clear in the subsurface distribution. The chl *a* distribution in the upper 100 m is dominated by columns of similar concentration, bounded by sharp transitions. In each case, the shift from high to low chlorophyll corresponds to one of the branches of the ACC fronts.

Highest chlorophyll values are found north of the STF and south of the sACCf, with particularly high values found near the Antarctic shelf; lower values are found in the vicinity of the PF; and the lowest values are found between the northern and middle branches of the SAF.



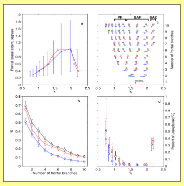
Synoptic maps of SSH (a) and chlorophyll *a* (b) south of Australia during the occupation of along WOCE SR3 section in November 2001. Positions of ACC fronts are show and color-coded as in the figure below.



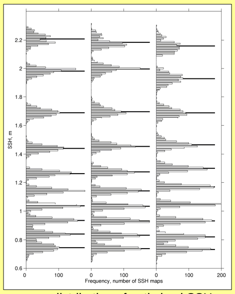
Chlorophyll along WOCE SR3 section in November 2001. Top panel: interpolated (blue line) chl *a* measured from satellite (SeaWiFS) vs in situ chl *a* (green line) averaged in top 50 m. Front positions using traditional front indicators and SSH satellite observations are shown. Bottom panel: Vertical distribution of in situ chl *a* in the top 150 m.

To test how robust the multi-jet structure of the ACC was, we fit contours of absolute SSH to a 12 year sequence of weekly maps of the gradient of SSH. We found that the distribution of maxima in ∇SSH was sharply peaked at particular values of SSH, demonstrating that each frontal jet was associated with a narrow range of SSH values over the 12 year period. Ten SSH contours are sufficient to account for 92% of all enhanced ∇SSH values (Figure 2).

We conclude that contours of absolute SSH can be used to map the filaments of the ACC with very high resolution in space and time.



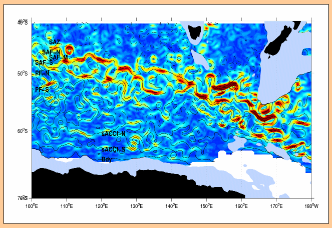
Fitting SSH contours to the ∇SSH field. (a) Width of each frontal branch, (b) Mean reduction in error as the number of frontal branches used in the optimization is increased. (c) Optimal SSH contours as the number of frontal branches used in the optimization is increased. (d) Fraction of the enhanced SSH gradient that is unexplained by optimal contours.



Frequency distribution of optimized SSH contours obtained for frontal branches in three sectors of the Southern Ocean: left panel - sector 100-130E; middle panel - sector 130-160E; right panel - sector 160-180E. Frequency is the number of SSH maps for which that value of SSH coincided with a maximum in ∇SSH. Mean SSH values for each frontal branch are indicated by solid horizontal lines.

A typical synoptic ∇SSH field shows a large number of discontinuous filaments of elevated ∇SSH. The best-fit SSH contours derived from the 12-year sequence of weekly maps pass through essentially all the regions where the gradient is enhanced. While the patchy distribution of ∇SSH maxima suggests little in the way of continuous fronts, the fact that the optimized SSH contours do a good job of tracking the high ∇SSH regions indicates that the frontal structure of the ACC is persistent and robust. While the fronts weaken and strengthen along their path, they remain aligned with a particular streamline.

Using different mean fields to construct absolute SSH does not change the conclusion that the jets are aligned with streamlines.



A typical SSH gradient field south of Australia and New Zealand overlaid with the mean best-fit SSH contours optimized for the whole period of observations. The contours corresponding to the SAZ feature and the middle branch of the PF are dashed, for clarity. Depths shallower than 2500 m are shaded in grey.

Conclusions:

1. The ACC consists of multiple, robust filaments or jets.
2. The jets are consistently aligned with particular streamlines, throughout the circumpolar path of the current.
3. Maps of absolute SSH can be used to map the ACC jets with high resolution in space and time.
4. These results act as a bridge between the traditional view of the ACC derived from coarse resolution hydrographic sections and the theory explaining how geophysical turbulence organises the flow into multiple zonal jets.
5. The jets strongly influence Southern Ocean biological distributions.

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References:

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