Beyond Topographic Variance

The Need for Accurate High–Resolution Bathymetric Data in Physical Oceanography

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Abstract

It is commonly observed in hydrographic sections crossing mid-ocean ridges that the isopycnals on the ridge flanks slope downward toward the crests, an effect that is presumed to be associated with boundary mixing. The resulting cross-flank pressure gradients are usually inferred to be associated with geostrophic along-flank flows, equatorward on the western flanks and poleward on the eastern flanks of meridional ridge slopes. Model results imply that the transports of the along-flank flows can be of the same order as DWBCs *(Thompson and Johnson,* DSR, 1996, *Huang and Jin,* JPO, 2002), i.e. they are of large-scale significance. The isopycnal surfaces over the Mid-Atlantic Ridge (MAR) in the South Atlantic, where high mixing levels have been calculated from microstructure data *(Polzin et al.,* Science, 1997) and from the evolution of a cloud of deliberately released tracer *(Ledwell et al.,* Nature, 2000), are consistent with this conceptual picture. Observations of southward flow along the western ridge flank near 20°S in the Brazil Basin *(Hogg and Owens,* DSR, 1999, *Ledwell et al.,* Cruise Report, 2001), on the other hand, are not.

We have analyzed hydrographic data from the MAR in the South Atlantic *(Thurnherr and Speer,* JPO, in press). Calculating geostrophic velocities without considering topographic blocking in cross-flank canyons results in erroneous along-ridge transports of up to 3 Sv. In addition, some studies have suggested that mixing extends significantly above the topography (e.g. *Polzin et al.,* Science, 1997), while in reality it is largely confined below the peak depths of the canyon walls. This has potentially important consequences for the processes inferred to be causing the mixing. In particular, we suggest that the topographic organization on the ridge flanks may be related to the high observed dissipation levels, in which case it will not be appropriate to parameterize mixing rates from topographic variance of the sea floor *(St. Laurent et al.,* GRL, in press).

None of these inferences could have been drawn without the availability of high-resolution seafloor topography of the entire South Atlantic *(Smith and Sandwell,* Science, 1997). This study also illustrates some limitations of the topographic data: (i) there are regions of systematic vertical bias exceeding 100 m, (ii) there are large (extending over several 10s of km) false apparent topographic highs rising up to 500 m from the true sea floor, and (iii) some of the first-order topographic structures that control the hydrographic characteristics are too small to be resolved adequately.

1. Seafloor Topography in the South Atlantic

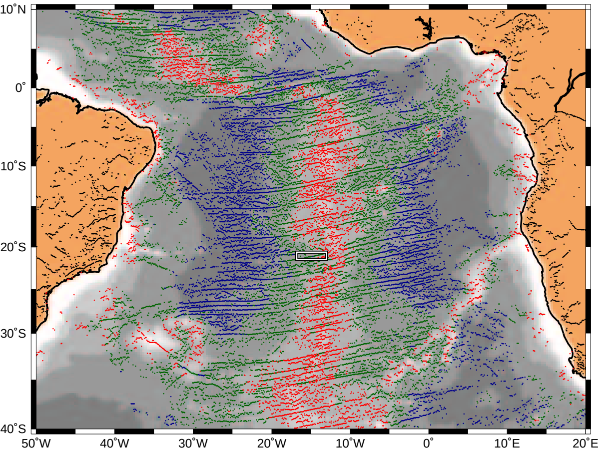

Figure 1: Local depth maxima (red: above 4000 m, green: 4000–5000 m, blue: below 5000 m) in meridional sections of the South Atlantic seafloor topography. Bathymetric contours are derived from 9×9 pixel block-averaged data of *Smith and Sandwell* (1997, version 8.2); contour interval is 1000 m. Depth maxima are taken from full-resolution meridional sections, separated by 5′ of longitude, and subsampled every 5 km; successive maxima at a given longitude are separated by depth minima at least 250 m shallower; frame indicates region shown in Figure 5.

2. Topographic Blocking

Figure 1 shows that the MAR covers more than half of the seafloor in the tropical and subtropical South Atlantic. The "roughness" of the ridge flanks is organized into a large number of deep cross-flank canyons; between the equator and 30°S they extend over at total length of ≈100,000 km. The meridional spacing of the canyons is similar to the distance between neighboring hydrographic stations. Most CTD profiles extend significantly into the canyons (Figure 2) where along-flank flow is topographically blocked ($Nh/U \gtrsim 2$). (The ≈200 km-wide geostrophic along-flank flows are not expected to follow the isobaths into the narrow ridge-flank canyons, consistent with the isopycnal surfaces shown in the figure.) The topographic context is required in order to interpret the hydrographic data correctly.

Plunging of the isopycnal surfaces takes place over both flanks of the MAR (Figure 3). When the ridge-flank canyons are taken into account, the plunging on the western flank is seen to be largely restricted below the topographic blocking depth. The plunging on the eastern flank, on the other hand, extends significantly above the blocking topography but the magnitude of the corresponding horizontal density gradients is significantly smaller because of the reduced stratification in the eastern basin.

In the absence of ridge-flank canyons the cross-flank density gradients would presumably be geostrophically balanced, implying northward transport of nearly 2 Sv along the western flank at this latitude (blue curve in lower panel). The density gradients immediately above the blocking topography are reversed, however, implying southward flow (red curve) consistent with Lagrangian observations *(Hogg and Owens,* DSR, 1999, *Ledwell et al.,* Cruise Report, 2001). Similar observations hold in all analyzed cross-ridge sections between 5° and 30°S with erroneous transports up to 3 Sv.

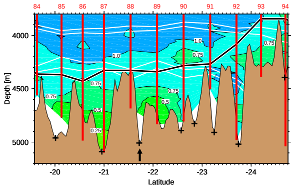

Figure 2: Buoyancy frequencies (shaded, in units of $10^{-3}\,\mathrm{s}^{-1}$) and neutral-density surfaces (white contours) at 19°W. Crosses on the sea floor indicate the locations of local depth maxima (c.f. Figure 1). The heavy topography-following line illustrates the blocking depth for along-flank flow. The red lines show CTD profiles of the WOCE A09 section; station numbers are indicated above the panel. The arrow near 21°45′S marks the canyon shown in Figure 5.

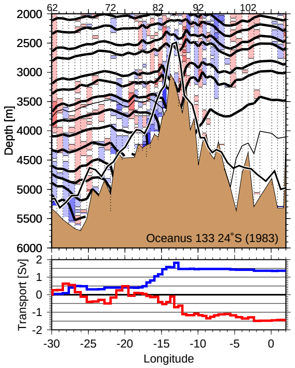

Figure 3: Zonal section across the MAR at 24°S. Upper panel: Neutral-density contours and zonal density gradients (values $\geq 5 \times 10^{-8}\,\mathrm{m}^{-1}$ are shaded; contour interval is $10^{-7}\,\mathrm{m}^{-1}$); topography-following lines indicate blocking depths. Lower panel: West-to-east cumulated apparent geostrophic transports in the canyons (blue), and geostrophic transports immediately above the canyons (red).

From meridional hydrographic sections at 25° and 19°W density-difference profiles can be calculated (Figure 4). Isopycnal plunging takes place along the entire western flank of the MAR and is largely restricted to the canyons. The layer of reverse gradients, consistent with southward flow near 20°S, is restricted to the region south of ≈15°S. The cross-flank density gradients of both signs can be accounted for by bottom-intensified diapycnal mixing acting on water from the interior of the western basin on time scales of years (for details, see *Thurnherr and Speer,* JPO, in press).

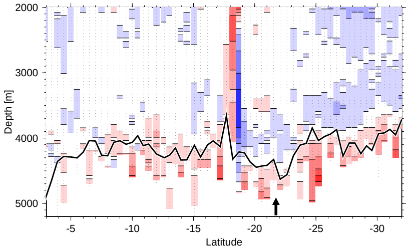

Figure 4 (left): Isobaric neutral-density differences between 25° and 19°W. Positive values (red) indicate densities decreasing toward the crest (plunging); shading indicates density differences $\geq 5 \times 10^{-3}$; contour interval is 10^{-2}. The solid line shows the topographic blocking depth at 19°W; the arrow is the same as in Figure 2.

3. The Need for Improved Seafloor Topography

In the *Smith and Sandwell* topography the ridge-flank canyons, which cover most of the seafloor of the South Atlantic (Figure 1), are adequately resolved. The fact that many of the CTD profiles apparently extend below the seafloor (Figure 2) implies that there are inaccuracies. Some of the problems may be related to navigational uncertainties but others (e.g. station 94) most likely indicate inaccuracies in the bathymetric data.

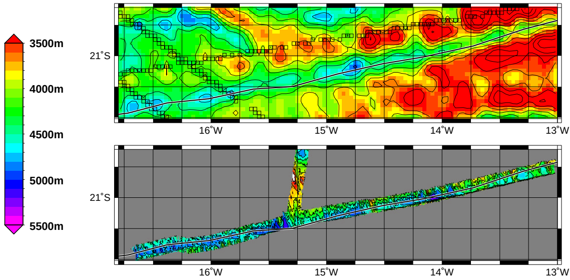

Figure 5: Seafloor topography of a canyon on the western flank of the MAR (framed in Figure 1). Upper panel: *Smith and Sandwell* data; ship-constrained pixels are marked. Lower panel: SeaBeam bathymetry. Solid lines show axial path used for Figures 6 & 7.

SeaBeam data from the western ridge flank near 21°S illustrate some of the limitations of the *Smith and Sandwell* topography (Figures 5 & 6). As expected *(Smith and Sandwell,* JGR, 1994), the vertical extent of small-scale topographic structures is underestimated in the satellite-derived topography. Of particular relevance is the narrow topographic high blocking the ridge-flank canyon below 4000 m near 14.6°W. On the basis of observations elsewhere *(Thurnherr and Richards,* JGR, 2001; *Thurnherr et al.,* JPO, 2002) we expect strong mixing associated with flow across this sill; an examination of available microstructure data from this canyon does support this inference.

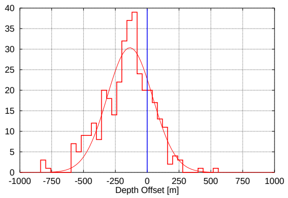

Figure 7: Histogram of depth differences between *Smith and Sandwell* seafloor topography and SeaBeam data along the axis of the canyon shown in Figure 5.

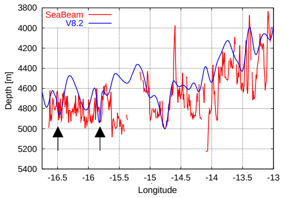

Figure 6: *Smith and Sandwell* seafloor topography and SeaBeam bathymetry along the axis of the canyon shown in Figure 5; arrows indicate the ship-constrained regions.

Less expected are the erroneous hills apparently rising ≈200–500 m above the true canyon floor in the vicinity of the ship soundings constraining the satellite data near 15.8° and 16.5°W (Figure 6). The horizontal scale of these features is similar to the width of the canyon, i.e. well above the nominal resolution of the satellite-derived topography. In addition to these false bathymetric hills there appears to be a systematic shallow bias in the *Smith and Sandwell* data in this region. The mean bias along the canyon axis is ≈150 m (Figure 7). Such systematic errors are potentially important because they introduce corresponding biases in the magnitude of the blocked apparent along-flank flows.

4. Summary & Conclusions

Accurate, high-resolution seafloor topography is important for physical oceanography. Even large-scale hydrographic and circulation studies depend on topographic structure on surprisingly small horizontal scales. The currently available global topographic data sets are extremely helpful, but for process-oriented studies (e.g. to determine the dominant processes responsible for the high rates of diapycnal mixing observed on the ridge flank in the South Atlantic) unbiased bathymetric data of higher resolution are required.