Hydrographic Circulation Analysis of the Lau Basin

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1 Regional Setting of the Lau Basin

The Lau Basin is a semi-enclosed basin in the tropical South Pacific, located approximately 1500 km north of New Zealand (Figure 1). Below 1000 m it is largely closed to the east, south and west by the Lau and the Tonga Ridges, respectively (top panel). The Zephyr Shoal at 15°S blocks the northern edge of the Lau Basin below 2000 m almost completely. The East Lau Spreading Center (ELSC), which form the "bull's eye" of the Lau Basin Integrated Study Sites (ISS), runs approximately parallel to the Tonga Ridge in the Lau Basin between 19°30′ and 22°45′S. Its depth is shallowest (≈2000 m) near its southern end and deepens northward to ≈2800 m (bottom right panel). The exact focus of the ISS on the ELSC is yet to be determined.

The bathymetry of the Lau Basin is characterized by high roughness compared to the deeper regions to the east and to the west (bottom left panel; bathymetric cross sections further north are similar, e.g. left panel of Figure 2 below). East of the Tonga Ridge lies the very deep Tonga Trench where a Deep Western Boundary Current (DWBC) flows northward along the eastern slope of the Tonga Ridge (e.g. *Banks et al.,* 1995). The South Fiji Basin west of the Lau Ridge is deeper than the Lau Basin as well.

2 Regional Surface Circulation

In the context of the proposed project the regional surface circulation in the upper ocean is primarily relevant for estimating the errors in the float trajectories introduced by the drift away from the target depth, i.e. during ascent, while the floats are transmitting their data back to shore, and during descent. Figure 5a in the analysis of *Reid* (1997) suggests that the Lau Basin lies in a region of relatively weak surface circulation. World Ocean Circulation Experiment (WOCE) surface-drifter trajectories allow quantitative estimates

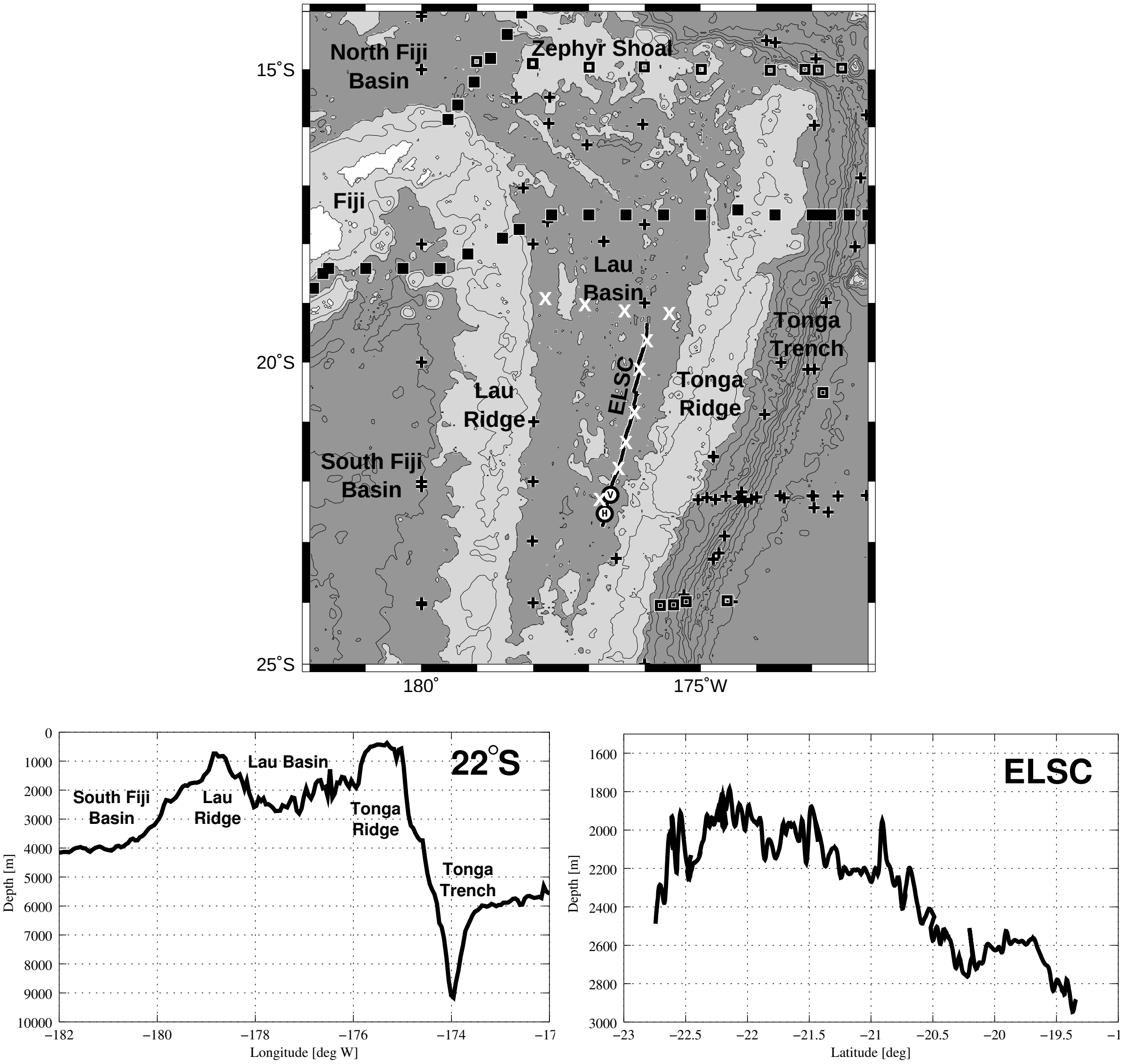

Figure 1: Bathymetry *(Smith and Sandwell,* 1997), hydrothermal vent fields (labeled circles), proposed float-deployment locations (white "x"), and hydrographic stations in the Lau Basin region. Top panel: Lightly shaded areas are less than 2000 m deep; contour level is 1000 m. Labels "V" and "H" indicate the locations of the active Vai Lili and Hine Hina vent fields on the ELSC, respectively. (A third hydrothermal site on the ELSC, the White Church field at 21°56′S, is less active.) Squares indicate CTD stations (open: NODC WOD98; solid: WOCE P21 at 17°S and P31 at 15°S, both occupied in 1994) and black crosses show NODC bottle stations extending below 1500 m. Bottom-left panel: bathymetric section along 22°S. Bottom-right panel: bathymetric section along the ELSC.

of the surface velocities. The WOCE data base[1] contains over 19000 surface-velocity estimates between 1984 and 1999 in the region show in the top panel of Figure 1. While the zonal and meridional RMS speeds are large ($20\,\mathrm{cm \cdot s^{-1}}$ and $17\,\mathrm{cm \cdot s^{-1}}$, respectively) the corresponding mean speeds are $6\,\mathrm{cm \cdot s^{-1}}$ and $3\,\mathrm{cm \cdot s^{-1}}$.

3 Lau Basin Hydrography and Circulation

From the point of view of the deep circulation the Lau Basin should be treated as a single region, because of its relatively small extent (approximately 200–400 km zonally and 1000 km meridionally) and its topographic isolation. By analogy with other enclosed and semi-enclosed regions in the deep ocean we expect the deepest passages between the confining ridges and shoals to act as inflow pathways and, therefore, to determine the end-member properties of the deep water in the Lau Basin *(Saunders and Francis,* 1985; *Thurnherr and Richards,* 2001). The most likely pathways for inflow into the Lau Basin is from the North Fiji Basin via the deep channel between the Zephyr Shoal and the islands of Fiji and perhaps also the passage between Tonga Ridge and Zephyr Shoal.

The deep hydrography of the Lau Basin has been sampled only sparsely. The open squares and the crosses in the top panel of Figure 1 show the available CTD and the bottle stations extending below 1500 m in the NODC World Ocean Data Base 98 (WOD98).[2] During WOCE a zonal hydrographic section crossing the Lau Basin near 17°S (P21) as well as a section across the deep channel east of Fiji (P31) were occupied in 1994 (solid squares). Neither the PIs[3] of these WOCE cruises nor the authors of a recent high-resolution climatology of the southwestern Pacific (CARS 2000)[4] are aware of additional hydrographic stations in the Lau Basin. A literature search has not revealed any publications related to the hydrography or circulation in the Lau Basin. (The Lau Basin portion of the P21 data is not discussed by *Tsimplis et al.* (1998).)

The left panel of Figure 2 shows the WOCE P21 neutral-density section across the Lau Basin near 17°S. Above approximately 1700 m (unshaded) there are no clear density differences between the Lau Basin and the deeper regions on either side. Below that depth the stratification inside the Basin is reduced when compared to the stratifications in the east and in the west. (The stratification in the deep channel east of Fiji, on the other hand, is similar to that outside the Lau Basin (right panel)). This is similar to the situation in other enclosed and semi-enclosed regions of the deep sea floor. The reduced stratification may be a consequence of topographic blocking preventing dense water from entering the Lau Basin (e.g. *Saunders and Francis,* 1985) or it may be the

[1] http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Prog_Int/WOCE/WOCE_SVP/SVP_K_e.html

[2] http://www.nodc.noaa.gov

[3] Harry Bryden <H.Bryden@soc.soton.ac.uk> and Dean Roemmich <droemmich@ucsd.edu>

[4] Jeff Dunn <jeff.dunn@csiro.au>; see http://www.marine.csiro.au/~dunn/eez_data/atlas.html

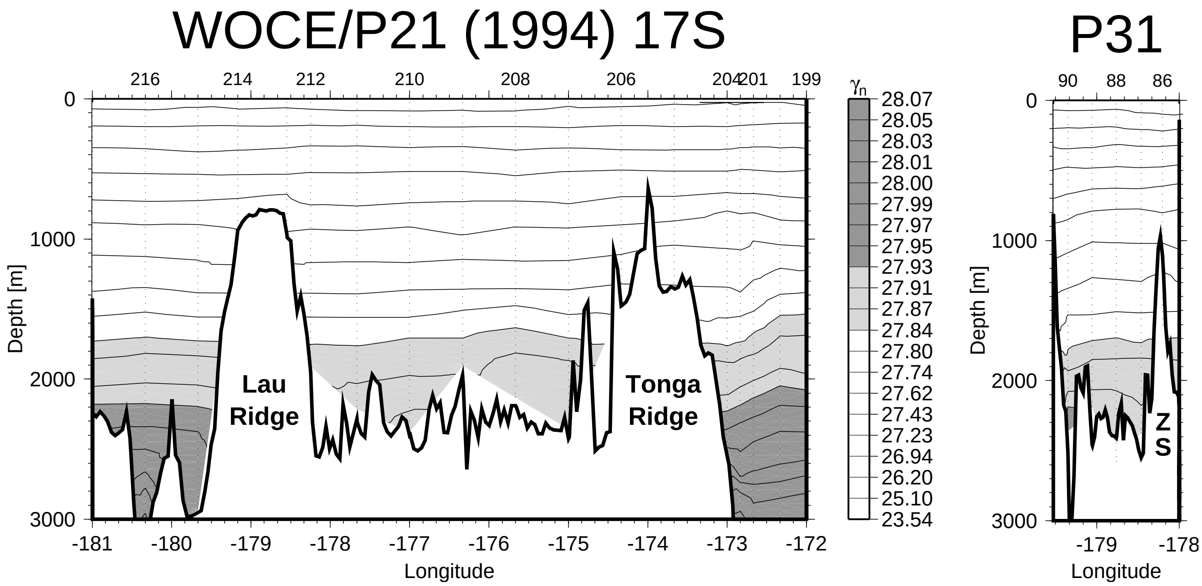

Figure 2: WOCE neutral-density sections. Left panel: P21 section across the Lau Basin near 17°S. Right panel: P31 section across deep channel connecting the North Fiji Basin to the Lau Basin; Zephyr Shoal is labeled "ZS." Station numbers are listed above the panels; see top panel of Figure 1 for station positions.

effect of locally enhanced diapycnal mixing (e.g. *St. Laurent et al.,* 2001; *Thurnherr et al.,* 2002; *Thurnherr and Speer,* 2003). High levels of diapycnal mixing have been observed elsewhere near rough topography *(Polzin et al.,* 1997). From the hydrographic observations we expect topographic effects to dominate the circulation in the Lau Basin below ≈1700 m.

There are reasons to expect either cyclonic or anticyclonic circulations in stratified enclosed basins. *Johnson* (1998) analyze current-meter records from a number of deep oceanic trenches and find primarily cyclonic circulations, consistent with upwelling-related vortex stretching. Boundary mixing on slopes, on the other hand, are known to cause horizontal density gradients consistent with anticyclonic along-slope flows *(Thompson and Johnson,* 1996) but *Thurnherr and Speer* (2003) show that the anticyclonic along-slope flows can be (partially of fully) topographically blocked and that diapycnal mixing can also cause gradients consistent with cyclonic along-slope flows. Hypsometric effects associated with upwelling in basins with sloping sidewalls can also lead to anticyclonic circulations *(Rines and MacCready,* 1989; *Speer and Tziperman,* 1990). The density section at 17°S in Figure 2 shows indications for doming of the isopycnal surfaces in the Lau Basin, suggestive of anticyclonic flow (assuming a level of no motion in the overlying water column); southward in the western part and northward in the eastern

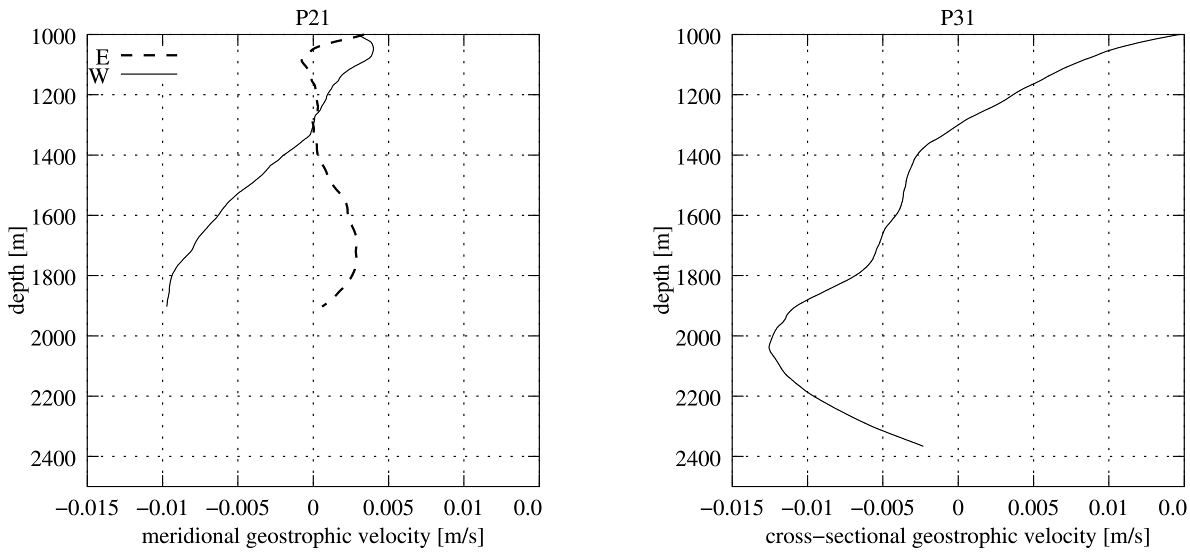

Figure 3: Geostrophic velocity profiles referenced to 1300 m. Left panel: from the eastern ("E", stations 207–209) and from the western part of the Lau Basin ("W", stations 209–211) at 17°S. Right panel: from the deep channel connecting the North Fiji Basin and the Lau Basin at 15°S (stations 87–90).

part of the basin. The left panel Figure 3 shows geostrophic-velocity profiles from the eastern and the western half of the Lau Basin at 17°S. (The density gradients are averaged over 100 km in order to attempt to filter out some of the mesoscale variability.) The velocities are arbitrarily referenced to 1300 m where the isopycnals in the basin are nearly horizontal (Figure 2). With this choice the geostrophic velocities are consistent with anticyclonic flow around the basin; the southward flow in the western half of the basin in particular appears quite robust. Anticyclonic flow in the Lau Basin is consistent with inflow from the North Fiji Basin through the deep channel between Fiji and Zephyr Shoal. The right panel of Figure 3 shows geostrophic velocities from that channel, again referenced to 1300 m. The geostrophic flow in the channel is consistent with inflow (negative velocities are southeastward). Assuming that the geostrophic shears shown in Figure 3 are representative on longer time scales we expect flow velocities of $3\text{–}10 \times 10^{-3}\,\mathrm{m \cdot s^{-1}}$ ($100\text{–}300\,\mathrm{km \cdot year^{-1}}$), which is fairly typical for the deep ocean.

Both T/S properties and the oxygen concentrations (not shown) of the Lau Basin water are consistent (within measurement uncertainties) with water from the Tonga Trench and from the North Fiji Basin while the properties in the South Fiji Basin are significantly different. (The differences are small, however; $\approx$0.005 psu in case of salinity). The bias corrections of *Gouretski and Jancke* (2001) were applied before comparison of the P21 and P31 data.

In summary, the hydrographic measurements taken during the WOCE P21 and P31 cruises are consistent with anticyclonic flow around the Lau Basin, fed from the North Fiji Basin through the deep passage east of Fiji. Both the dipping of the isopycnal surfaces into the slopes of the Lau and Tonga ridges, and the reduced stratification in the Lau Basin are suggestive of high levels of diapycnal mixing, probably associated with the rough topography of the Lau Basin floor. While this is a consistent picture the available data do not allow determination of the southern limit of the inferred anticyclonic circulation. In particular no information on the flow field near the ELSC is available.

4 Rationale for using Floats

The question whether there is a mean circulation, with in- and outflows, in the Lau Basin is of great importance to hydrothermal dispersal and biogeography. In contrast to better-known hydrothermal sites elsewhere, the vent fields on the ELSC are not located on a major ridge. Since the slopes of mid-ocean ridges tend to be associated with comparatively strong but narrow flows (e.g. *Warren and Speer,* 1991; *Thompson and Johnson,* 1996; *Cannon and Pashinski,* 1997; *Thurnherr and Speer,* 2003) the currents dispersing the hydrothermal products in the Lau Basin are expected to be more difficult to measure than those on the Juan de Fuca Ridge, for example. In order to determine the mean circulation with current meters a large array of long-term moorings would be required. We therefore propose to investigate the deep circulation in the Lau Basin with isobaric floats.

References

Banks, H., J. Bullister, S. Bacon, and H. Bryden (1995). The Deep Western Boundary Current at 17°S in the Pacific Ocean. *Int. WOCE Newsl. 19*, 3–5.

Cannon, G. A. and D. J. Pashinski (1997). Variations in mean currents affecting hydrothermal plumes on the Juan de Fuca Ridge. *J. Geophys. Res. 102*, 24965–24976.

Gouretski, V. V. and K. Jancke (2001). Systematic errors as the cause for an apparent deep water property variability: global analysis of the WOCE and historical hydrographic data. *Prog. Oceanogr. 48*, 337–402.

Johnson, G. C. (1998). Deep water properties, velocities, and dynamics over ocean trenches. *J. Mar. Res. 56*, 329–347.

Polzin, K. L., J. M. Toole, J. R. Ledwell, and R. W. Schmitt (1997). Spatial variability of turbulent mixing in the abyssal ocean. *Science 276*, 93–96.

Reid, J. L. (1997). On the total geostrophic circulation of the Pacific Ocean: flow patterns, tracers, and transports. *Progr. Oceanogr. 39*, 263–352.

Rines, P. and P. MacCready (1989). Boundary control over the large-scale circulation. *Parameterization of Small-Scale Processes, 'Aha Huliko'a Winter Workshop, University of Hawaii*, 75–97.

Saunders, P. M. and T. J. Francis (1985). The search for hydrothermal sources on the Mid-Atlantic Ridge. *Prog. Oceanogr. 14*, 527–536.

Smith, W. H. F. and D. T. Sandwell (1997). Global seafloor topography from satellite altimetry and ship depth soundings. *Science 277*, 1956–1962.

Speer, K. and E. Tziperman (1990). Convection from a source in an ocean-basin. *Deep Sea Res. 37*, 431–446.

St. Laurent, L. C., J. M. Toole, and R. W. Schmitt (2001). Buoyancy forcing by turbulence above rough topography in the abyssal Brazil Basin. *J. Phys. Oceanogr. 31*, 3476–3495.

Thompson, L. and G. C. Johnson (1996). Abyssal currents generated by diffusion and geothermal heating over rises. *Deep Sea Res. 43*, 193–211.

Thurnherr, A. M. and K. J. Richards (2001). Hydrography and high-temperature heat flux of the Rainbow hydrothermal site (36°14′N, Mid-Atlantic Ridge). *J. Geophys. Res. 106*, 9411–9426.

Thurnherr, A. M., K. J. Richards, C. R. German, G. F. Lane-Serff, and K. G. Speer (2002). Flow and mixing in the rift valley of the Mid-Atlantic Ridge. *J. Phys. Oceanogr. 32*, 1763–1778.

Thurnherr, A. M. and K. G. Speer (2003). Boundary mixing and topographic blocking on the Mid-Atlantic Ridge in the South Atlantic. *J. Phys. Oceanogr. 33*, 848–862.

Tsimplis, M. N., S. Bacon, and H. L. Bryden (1998). The circulation of the subtropical South Pacific derived from hydrographic data. *J. Geophys. Res. 103*, 21443–21468.

Warren, B. A. and K. G. Speer (1991). Deep circulation in the eastern South Atlantic Ocean. *Deep Sea Res. 38*, 281–322.