# Modal Variability in the Bellingshausen Basin

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Satellite observations revealed an exceptional circulation pattern in the Bellingshausen Basin in late 2009. Here we study that event using a one-layer ocean model forced by observed winds. We find that the event can be explained as a circulation pattern trapped by the local bathymetry, especially the Bellingshausen Basin and East Pacific Rise. An analysis of the energetics suggests that the mode loses most of its energy at only a few areas, like the Eltanin Fracture Zone and the crest of the East Pacific Rise. These areas might be "hot spots" for abyssal mixing.

During the fourth quarter of 2009 (Q4 2009), exceptionally high sea levels were detected in the southeastern South Pacific Ocean, in an area known as the Bellingshausen Basin [1]. The signal had an amplitude of about 8 cm and persisted for several months. It was found in radar altimetry, as well as in bottom pressure estimates from the Gravity Recovery and Climate Experiment (GRACE) satellite mission.

The Bellingshausen Basin (Fig. 1), together with Mornington and Amundsen Abyssal Plains, form a deep abyssal basin in the southeastern South Pacific Ocean. High sea-surface height (SSH) variability has been detected there before [2], and was interpreted as a circulation pattern trapped by the local bathymetry [3]. In particular, ocean circulation tends to be steered by bathymetry–currents do not like to flow across isobaths since the resulting stretching or squeezing of the water column requires a change in a quantity called vorticity (the continuum-mechanical equivalent of angular momentum). So water preferentially flows along contours of so-called potential vorticity, or f/H (where f is twice the local rotation rate of the Earth and H is ocean depth). These contours are strongly warped by the bathymetric features of the southeastern South Pacific (contours in Fig. 1) and, in fact, many contours are closed or almost closed. This gives rise to the possibility of modal circulation—circulation along such (almost) closed contours decays very slowly, retaining their large-scale spatial structure for days or weeks. Depending on whether the circulation is clockwise or anticlockwise, it is associated with low or high sea level in the center. And it is just such a signal that was recorded in Q4 2009.

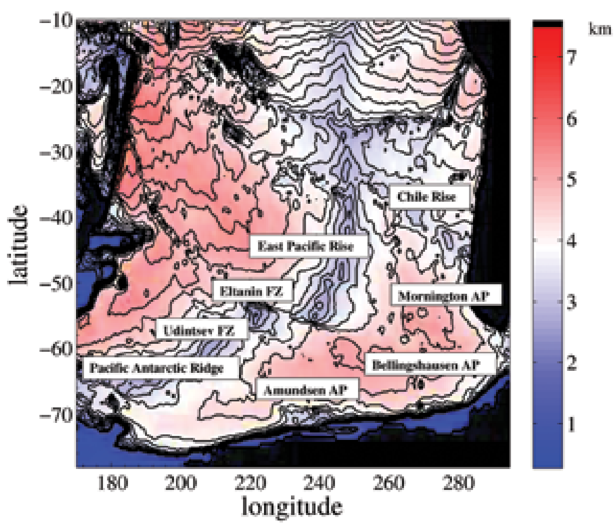


*Fig. 1. Bathymetry of the South Pacific with some relevant geographic features indicated (FZ: Fracture Zone; AP: Abyssal Plain). Contours are isolines of potential vorticity, f/H.*

Here we study the excitation and energetics of this mode in a so-called shallow water model. This model treats the ocean as a single layer of constant density, which is appropriate for the intraseasonal variability that we are interested in [4]. We force the model with wind stress observations from 2008 through 2010. The model displays substantial skill in reproducing the high sea level in late 2009. Figure 2 shows that the SSH in Q4 2009 was significantly positive over the Bellingshausen Basin and East Pacific Rise, and that the anomaly appears to be trapped by the distribution of f/H. The amplitude of the SSH anomalies seems somewhat underestimated (reaching 2 cm instead of 8 cm); however, the Q4 2009 event was clearly anomalous in its amplitude and persistence compared to the rest of the time series. A weaker event is visible during the third quarter of 2008 (Q3 2008).

What we are mainly concerned with is what the excitation of the mode means for the energy balance of the ocean. Wind forcing is the main source of energy for the ocean. The question is where this energy ends up. In recent years it has become clear that interaction of the ocean circulation with bathymetry may lead to the generation of small-scale turbulence, which can mix water masses upwards through the ocean column. Thus, it is believed that abyssal mixing plays an important role in the global thermohaline circulation. Figure 3 shows the energetics of the mode, compared to the non-modal circulation. Clearly, both the modal (solid lines) and non-modal (dashed) circulation receive most of their kinetic energy from the wind forcing (blue), and lose a lot through friction (black). However, there is a significant transfer of energy from the modal to the non-modal circulation through the work done by pressure forces (red). This indicates that the mode is decelerated (loses energy) through the emission of planetary waves wherever it encounters discontinuities in the contours of f/H. Additional analysis shows that such discontinuities are encountered in only a few places, in particular in the Eltanin Fracture Zone and on top of the East Pacific Rise. So in these

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locations the mode loses most of its energy and thus may be considered hot spots for abyssal mixing.

An interesting observation is that the wind input into the mode was apparently stronger during Q3 2008 than Q4 2009. Although Fig. 3 does show a persistent anomalous event during that period as well, it was not as strong as during Q4 2009, and is absent in the observations. The reason for this discrepancy is not clear.

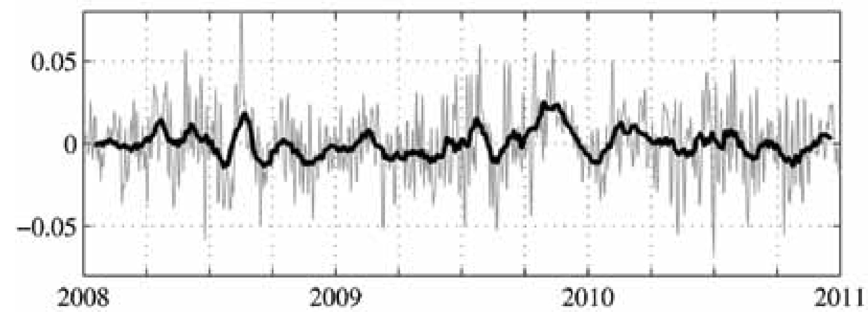


*Fig. 3. SSH anomalies averaged over the region 90°W –140°W, 55°S –35°S.*

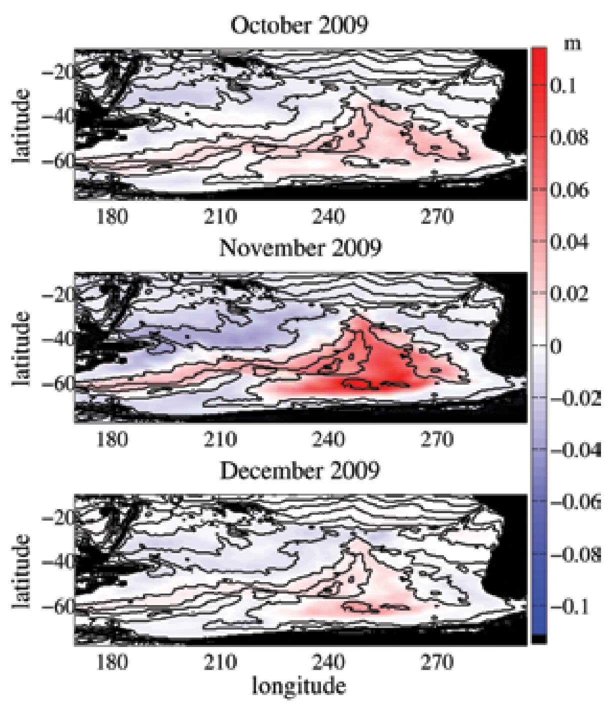


*Fig. 2. Average SSH (m) for the months of October, November, and December 2009.*

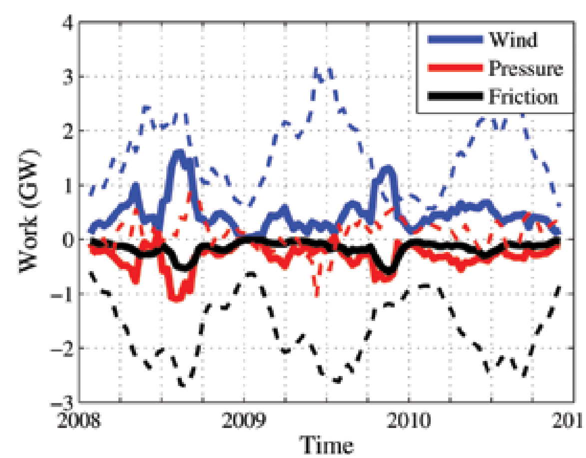


*Fig. 4. Energy balance of the modal (solid lines) and non-modal, residual (dashed lines) circulation. Time series are 50-day moving averages.*

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