REFRACTION OF SWELL BY SURFACE CURRENTS

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Using recordings of swell from pitch-and-roll buoys, we have reproduced the classic observations of long-range surface gravity wave propagation between the Southern Ocean and California (Munk et al., 1963). In the modern data, the direction of the incoming swell fluctuates by about $\pm 10^\circ$ on a time scale of one hour. But if the incoming direction is averaged over the duration of an event then, in contrast with the observations by Munk et al. (1963), the sources inferred by great-circle backtracking are most often in good agreement with the location of large storms on weather maps of the Southern Ocean. However there are a few puzzling failures of great-circle backtracking e.g., in one case, the direct great-circle route is blocked by the Tuamoto Islands and the inferred source falls on New Zealand. Mirages like this occur more frequently in the earlier observations of Munk et al. (1963), where several inferred sources fell on the Antarctic continent.

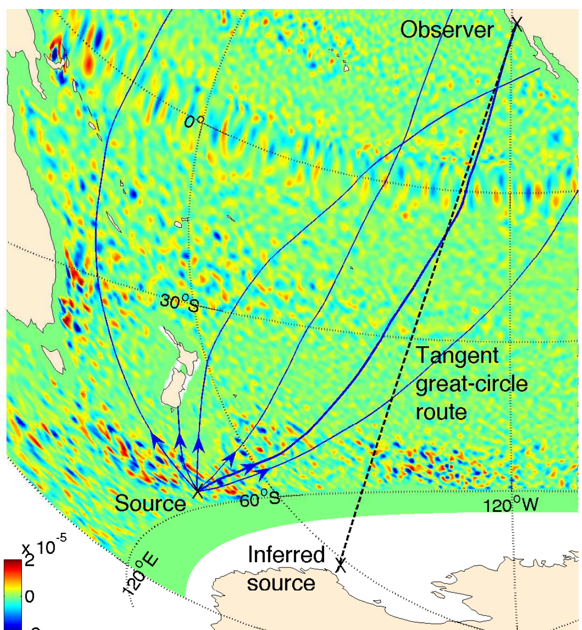

Figure 1. This map uses azimuthal projection centered on a Californian observer at $\times$; great circles passing through the observer are straight lines. The color scale is sea-surface vorticity (s^{-1}) inferred from satellite altimetry and vector wind data by the Ocean Surface Current Analysis in Real-time (OSCAR) dataset (Bonjean & Lagerloef, 2002). A point source in the Southern Ocean emits six rays all of which show significant refraction by ocean currents. The thick ray connects the point source to the receiver; because of ocean surface currents this ray does not follow a great circle. Great-circle backtracking (the dashed great circle) thus infers a source under the ice.
Rays are bent from great circles only where there is strong surface vorticity in localized current systems such as the Antarctic Circumpolar Current, the subtropical frontal zone and the equatorial current system. The thick ray undergoes strong refraction when crossing these three features, and then travels more-or-less on great circles in between. For example, after leaving the Southern Ocean the thick ray is on a great circle headed away from the receiver. But refraction by a large equatorial eddy then bends the ray onto a great circle passing through the receiver.

With spherical ray tracing we investigate the hypothesis that the refraction of surface gravity waves by ocean currents produces the mirages. The group velocity of surface waves is much greater than the typical speed of ocean currents, and in this limit the curvature of a ray is nearly equal to the vertical vorticity of the surface currents divided by the group velocity (Landau & Lifshitz 1987). Thus the vertical vorticity of surface currents is the key environmental variable controlling the departure of rays from great circles. Using observed surface currents we show that mesoscale vorticity is strong enough to produce significant deflections, so that the source and receiver are connected by a bundle of many rays, none of which precisely follow a great circle. The $\pm 10^\circ$ directional fluctuations at the receiver result from the arrival of wave packets that have travelled along the different rays within this multipath. The occasional failure of great-circle backtracking, and the associated mirages, probably results from partial topographic obstruction of the multipath, which biases the directional average at the receiver.

References

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