Satellites Are Changing Our View of the World Ocean

The classical view of the ocean circulation at mid-latitudes, away from the sea surface and coastlines, is one of broad, graceful gyre-like flows. Although this view has been modified to include eddying motions that vary with time, it is still one of a broad, time-averaged circulation. Results from ocean models, which typically have had poorly resolved eddying motions and relatively high dissipation rates, have tended to conform to this view. Results from higher resolution models and analyses of data from satellite-borne altimeters are now changing that classical view, according to work by **Kelvin Richards**, professor of oceanography at the University of Hawai'i and leader of the IPRC Regional Ocean Influences Team, and **Nikolai Maximenko**, associate researcher with the team.

Richards and his colleague **Frank Bryan** at the National Center for Atmospheric Research have analyzed the flows in a simulation from a high-resolution global ocean model with a 10-km resolution in the horizontal that was run on the Japanese Earth Simulator. They found an unexpected feature when they studied the eastward velocity component in the deeper ocean. Although the flow shows a signature of the broad mid-latitude gyres, it is dominated by a series of jets that alternate coherently in the east-west direction. Figure 1 shows the eastward component of velocity at 400-m depth in the Pacific, averaged over two years.

Maximenko has been looking at altimeter data relayed from satellites to study ocean currents detectable in sea surface height variations. Remarkably, the altimeter data revealed structures in the surface dynamic topography of the ocean that are similar to those seen by Richards and Bryan.

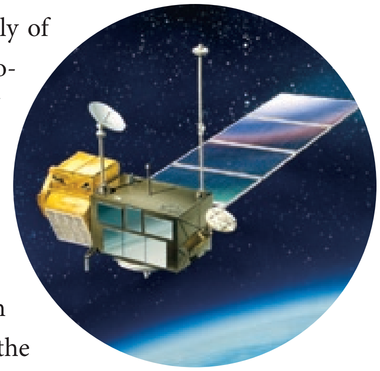
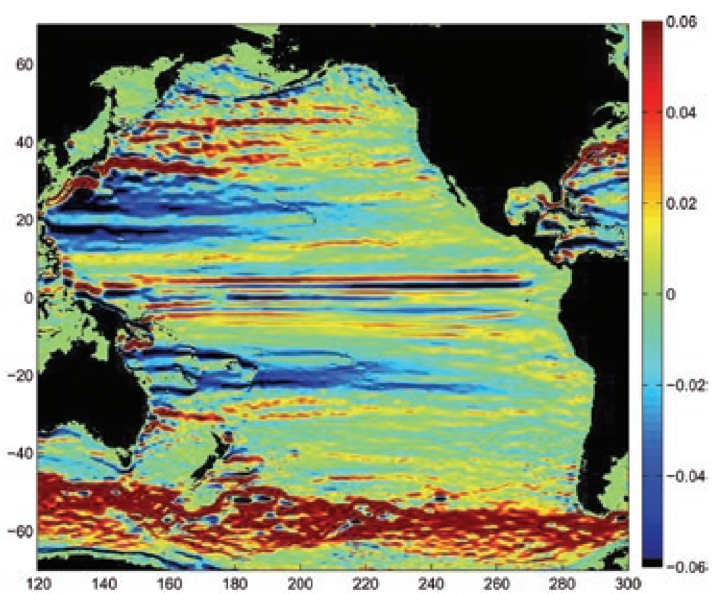


Figure 2 shows the anomaly of the geostrophic zonal velocity derived from maps of altimeter data averaged over 18 weeks. Again, the structures are coherent in the east-west direction and have a north-south scale similar to that in the model results.

Several questions spring to mind. Do such jets really exist in the deep ocean—is the structure seen in the altimeter data only an artifact of the sampling or indeed the surface signature of deeper jets? Why do the jets form? What is the significance of the presence of the jets? At present, only partial answers to these questions can be given.

The most direct observational evidence for the existence of deep multiple jets comes from the equatorial Pacific where measurements with acoustic Doppler current profilers have been taken in several sections across the equator to a depth of about 400 m. The region has multiple jets in addition to the many near-surface zonal flows, such as the Equatorial Undercurrent. The meridional scale of the observed jets is similar to that seen in the model results. Analysis of the high-resolution Ocean Model for the Earth Simulator (OFES) by Maximenko and his colleagues revealed that such deep jets

Figure 1. Zonal component of velocity averaged over two years at 400-m depth from a high-resolution ocean model. Flow speed is given in m/s. (Richards and Bryan, 2005)



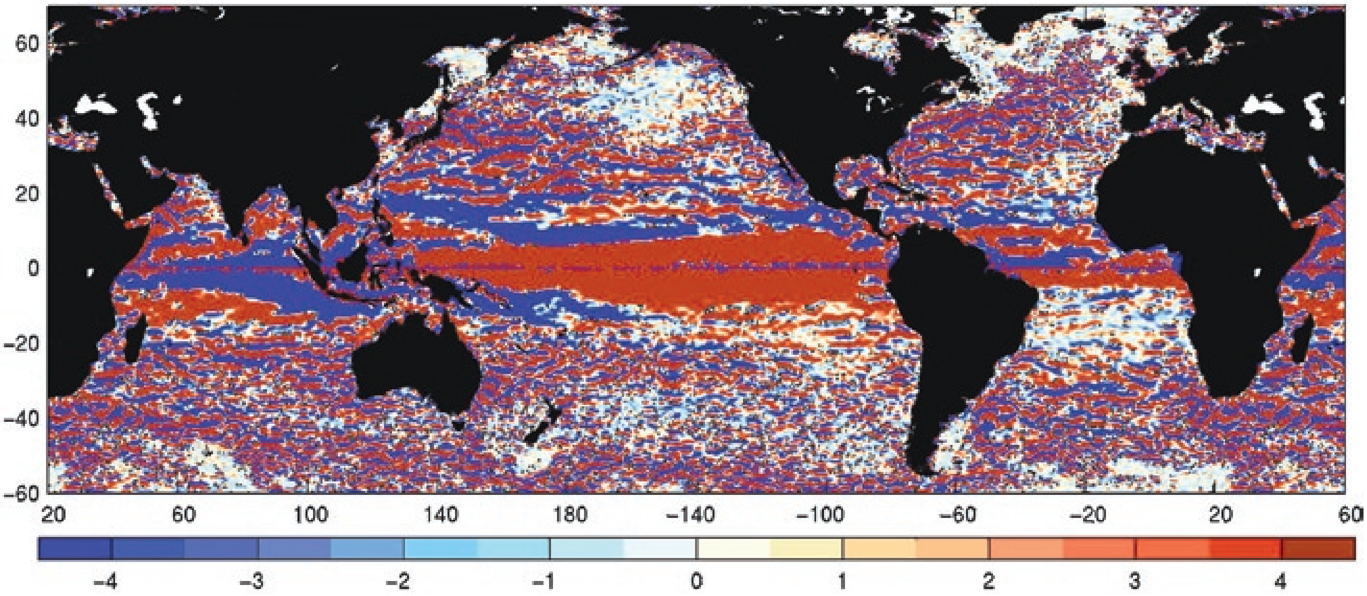


Figure 2. 18-week average of anomalies of geostrophic zonal velocity (cm/s), derived from the Aviso altimeter dataset. (Maximenko et al., 2005)

do indeed have a surface signature in sea surface height that is detectable by satellite altimeters.

The zonal jet structure brings to mind similar banded structures seen in the atmospheres of Jupiter and Saturn. The alternating jets on these giant planets are thought to result from the evolution of quasi two-dimensional turbulence, in which the turbulent energy cascades from smaller to larger eddies, which are eventually halted in their meridional expansion by the fact that the vertical component of the planet's rotation rate increases towards the poles. The resultant jets are often referred to as Rhines jets, whose latitudinal scale is set by the strength of the eddying motions and the rate of change in the Coriolis parameter with latitude. Earth's oceans show large spatial variations in the level of eddy activity and this activity is greatest in regions of intense currents such as the Kuroshio and the Antarctic Circumpolar Current. In the model results, the spatial variation in the meridional scale of the jets (Figure 1) is consistent with the variation in the model's eddy energy, with the latitudinal scale being close to that given by the Rhines scale. This suggests that, in the model at least, the jets may well be formed by the same mechanism as the cloud bands on Jupiter and Saturn.

But what are the implications of the existence of the jets for other aspects of ocean circulation? There are at least two. The zonal velocity of the jets varies much more in the meridional direction than the broader-scale gyre flow does. This increased shear will increase the zonal dispersion of tracers. An estimate suggests this zonal dispersion is many times greater than the meridional dispersion rate and is large enough to influence the large-scale distributions of salinity, temperature, and other properties of the deep ocean. The second reason why

the jets may be important relates to the ultimate fate of energy in the ocean. If the eddying action in the ocean tends towards zonal jets rather than more isotropic chaotic flow, then scientists need to rethink the way unresolved motions are parameterized in coarser-resolution ocean models used in climate studies.

iprc