

# The Global Ocean: A 10-Year Portrait of the Near-Surface Circulation<sup>1</sup>

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Understanding the dynamics controlling Earth's climate requires a thorough knowledge of the ocean mean state, particularly of mean sea level. Sea level, together with Ekman currents, largely defines the surface circulation. Horizontal velocities lend stability to Earth's climate by advecting and mixing the properties of the seawater to compensate for the effects of air-sea fluxes that vary in space and time. Although since 1992 advanced satellite altimetry provides continuous and accurate observations of the time-variable sea level anomaly, determining mean sea level remains a challenge: Spatial variations in mean sea level that maintain the dynamic balances of the ocean do not exceed 3 m, while elevation of the equipotential surface (geoid), used as a reference for mean sea level, varies between about -100 to +100 m, owing to the mass distribution within the Earth. Even the most advanced models of the geoid, based on decades of satellite and ground gravity measurements, contain errors reaching nearly 1 m in some areas. The specially designed twin-satellite NASA mission GRACE, launched in 2002, collects data to correct the geoid models. Unfortunately, the GRACE model of the geoid released last year by the Center for Space Research, University of Texas at Austin, resolves only horizontal scales 500 km or larger, imposing the same low resolution on mean sea level estimates referenced to this geoid. Such coarse resolution significantly distorts the pattern of most oceanic fronts and jets, whose accurate representation is necessary for adequate description of mean ocean circulation.

**Nikolai Maximenko** (International Pacific Research Center) and **Peter Niiler** (Scripps Institution of Oceanography) have managed to increase the spatial resolution of the GRACE-based mean sea level by using information from surface drifters, satellite altimeters, and wind products to estimate the mean sea level tilt. Estimates are made using the momentum equation, which includes terms representing acceleration, the Coriolis force, pressure gradient, and the vertical divergence of the Ekman stress. Values for the first and second terms are computed from trajectories of the Surface Velocity Program drifters that have large drogues attached at 15-m depth. Inter-annual bias in the pressure gradient was corrected using Aviso/Enact Merged Sea Level Anomaly maps derived from

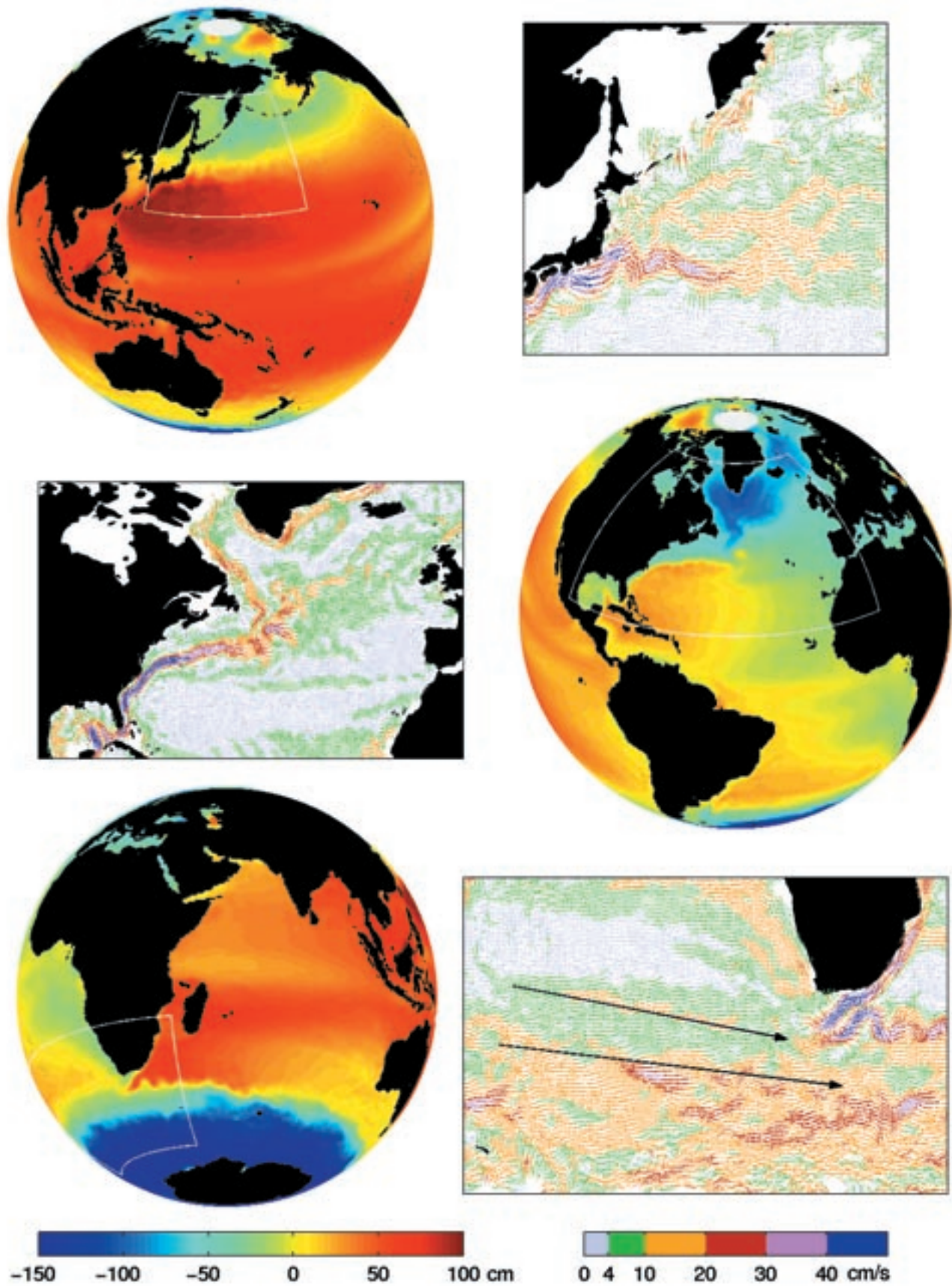
satellite altimetry. Parameterization of Ekman stress divergence to the NCAR/NCEP reanalysis winds was determined by fitting the mean pressure gradient, smoothed to 9° in the zonal and 3° in the meridional direction, to the GRACE-based mean sea level released recently by the NASA Jet Propulsion Laboratory.

The best parameterization reveals remarkable seasonal differences in the relationship between Ekman velocity and local wind and, in summer, it corresponds well to the parameterization suggested by Ralph and Niiler in 1999. In winter, the angle between Ekman velocity and wind vectors as well as the ratio of their magnitudes decreases markedly. Although this tendency agrees with the expected effect of known greater mixing due to winter-time convection, traditional models of the mixed layer, such as the KPP model, are unable to reproduce the observed Ekman velocity at 15-m depth. Maximenko and Niiler are now using NASA QuikSCAT satellite data to validate their results with more direct measurements of the wind stress.

When the values of mean sea level tilt obtained with the momentum equation are combined with the NASA-JPL large-scale sea level data within a single cost function to form a "hybrid" mean sea level data set, a precise description of mesoscale structures of the global upper ocean emerges. Several structures are amazingly complex even after averaging over ten years of observations. The fine mesoscale resolution maps of global mean sea level and mean surface velocities show all known currents and reveal some new features. For example, they show that the South Atlantic Current, thought by Stramma and Peterson (1990) to close the subtropical gyre, actually consists of two separate eastward jets. The first, the South Atlantic Current proper, is a continuation of the Brazil Current, shifting gradually southward and eventually merging with the Antarctic Circumpolar Current around 20°E. The second, newly discovered jet is weaker. Appearing around 35°N, 40°W, it flows parallel to the South Atlantic Current and merges with the reflected Agulhas Current south of Africa. Possibly this jet, analogous to the Azores Current in the North Atlantic, is induced by a local sink that may be part of the Agulhas eddy-formation or it may result from an interaction between the Agulhas Current with the Southern Ocean.

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<sup>1</sup> This work supplied the data for the Natural World Plate #9, *National Geographic Atlas of the World*, 8<sup>th</sup> Edition, in press.



**Figure 3.** Maps of hybrid 1992–2002 mean sea level (globes) and mean surface velocity (rectangles) in the three strongest western boundary currents: Kuroshio, Gulf Stream, and Agulhas. Black arrows show branches of the South Atlantic Current. Velocity vectors in color are proportional to their magnitude and shown only where drifter data are available.