“The Three-Dimensional Circulation of the Ocean ”

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ABSTRACT

The global three-dimensional ocean circulation is mapped by combining satellite altimeter data and other observations with numerical models of the ocean. Results help us understand mechanisms of ocean circulation and how the ocean affects the Earth's climate.

The oceans dominate Earth's climate

The oceans cover 70% of the Earth's surface (Fig 1) and can absorb heat 1000 times more than the atmosphere. As a result, the ocean acts as a giant buffer and regulator of the Earth's climate.

Fig 1: Landsat Image of Earth

Combining Observations and Models (Fig 2)

Understanding ocean circulation is not easy because it is difficult to measure its complete flow. Satellite remote sensing provides the only way to measure the global ocean frequently, but satellites cannot directly see the circulation at depth. Observations at sea are sparse due to the oceans' vast and inaccessible environment. The only practical way to describe the complete three-dimensional circulation is to combine the observations with numerical models. This combination is called data assimilation. Because the ocean is a continuum, the models can take the measurements in one place and guess what the ocean is like at another. The resulting description of the ocean provides a testbed for ideas.

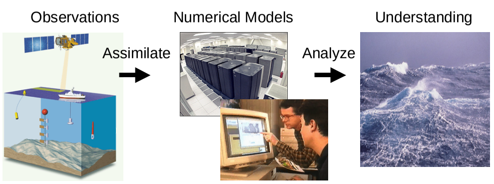

Fig 2: Understanding Ocean Circulation by Combining Observations with Models

Deep Ocean Currents and Long-Term Climate Change

Surface circulation is linked to deeper flow by a global closed circuit, schematically shown as the “global conveyor belt” in Fig 3. Surface waters sink to great depths in the North Atlantic Ocean. The water then flows to the Indian and Pacific Oceans where it rises to upper levels and makes its way back to the Atlantic Ocean. Understanding this global circuit is important in studies of global climate change because this circulation controls the ocean's storage and transport of heat and of green house gasses. Data assimilation determines not only the near surface circulation but also the flow at great depths (Fig 4). While qualitatively similar to the schematic diagram (Fig 3), the actual circulation is much more complicated.

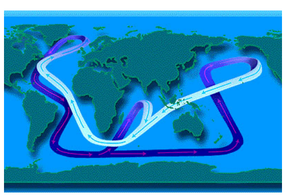

Fig 3: The Global Conveyor Belt

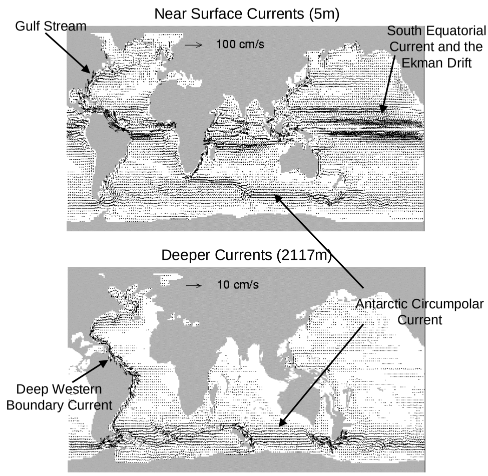

Fig 4: Average Currents Near the Surface and at Greater Depths.
Data assimilation extrapolates surface observations and combines them with other measurements into a continuous description of the complete three-dimensional circulation of the oceans.

Ocean Circulation of El Niño

The early detection of El Niño by TOPEX/Poseidon in 1997 allowed preparations to be made for subsequent weather changes. During El Niño, sea level in the equatorial Pacific rises in the east and drops in the west (Fig 6). Conventional wisdom explains this change as due to warm water flowing eastward near the surface and colder water flowing westward at depth (Fig 5). Such depth dependency cannot be directly measured from a satellite, but a data-assimilated ocean model provides a quantitative confirmation of this circulation (Fig 6). The model also shows warming at the surface in the eastern equatorial Pacific, but cooling at depth in the western Pacific.

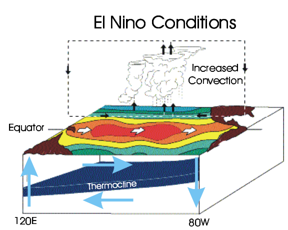

Fig 5: A Schematic Diagram of El Niño Conditions (http://www.pmel.noaa.gov)

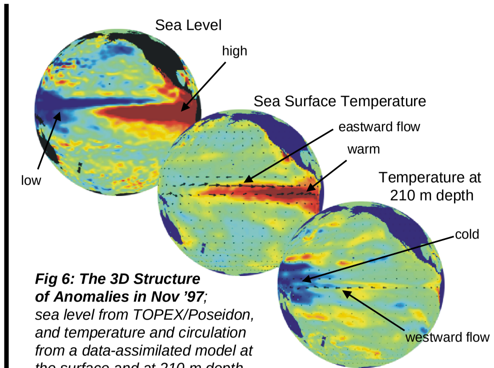

Fig 6: The 3D Structure of Anomalies in Nov '97;
sea level from TOPEX/Poseidon, and temperature and circulation from a data-assimilated model at the surface and at 210 m depth.

Cause of El Niño Warming

The model's complete description of the ocean provides a way to understand how ocean circulation works. For instance, Fig 7 illustrates mechanisms of the warming of the eastern equatorial Pacific during El Niño. Together, circulation and mixing act to warm the ocean, while the atmosphere cools the ocean. Effects of the circulation is larger than that of mixing, and vertical circulation plays a larger role than horizontal circulation in regulating the year-to-year temperature change.

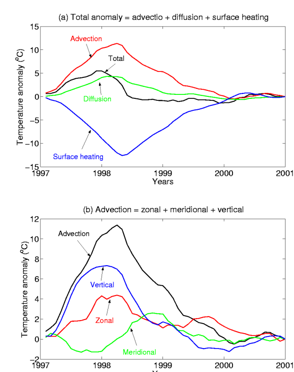

Fig 7: Diagnosing Year-to-year Temperature Change
Contribution of various processes to the year-to-year change of near-surface temperature in the eastern equatorial Pacific Ocean (5°S~5°N, 150°W~90°W).

Biogeochemical Cycle

The new models can also be applied to studies of the carbon cycle. The ocean on the whole is a sink for green house gasses (Fig 8). Describing how the ocean absorbs, transports, and stores carbon dioxide will help understand the global carbon cycle.

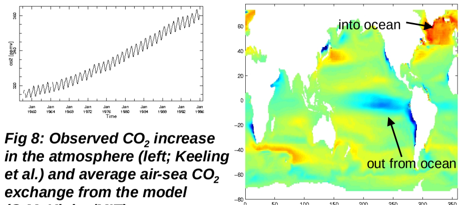

Fig 8: Observed CO_2 increase in the atmosphere (left; Keeling et al.) and average air-sea CO_2 exchange from the model (G.McKinley/MIT).

Earth Rotation

Changes in ocean circulation affect the Earth's rotation. Knowledge of the Earth's orientation is important for satellite navigation. Studies show observed polar motion (i.e., movement of the Earth's rotation axes) can be explained well by the new models (Fig 9).

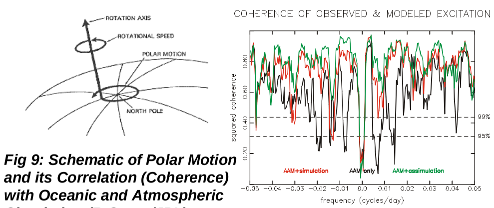

Fig 9: Schematic of Polar Motion and its Correlation (Coherence) with Oceanic and Atmospheric Circulation (R.Gross/JPL).

ECCO data server

The general oceanographic community is invited to further exploit the assimilation through the ECCO data server (Fig 10), where results can be plotted and downloaded for analyses and applications.

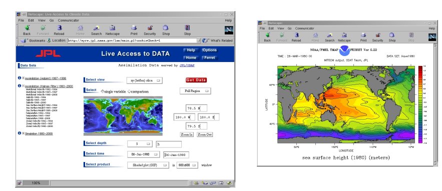

Fig 10: ECCO Data Server at http://www.ecco-group.org/las (alternate http://eyre.jpl.nasa.gov/las)

SUMMARY AND OUTLOOK

Tools have been established that combine observations with numerical models to map the “weather” of the oceans. Results are being analyzed to study mechanisms of ocean circulation and are applied to problems in biogeochemistry and in geodesy. The new Jason-1 observations will be incorporated with others to expand the present analysis to a routine description of the ocean. Such analysis will contribute directly to planned international science initiatives including the Global Ocean Data Assimilation Experiment (GODAE) and the Program on Climate Variability and Predictability (CLIVAR). The routine analyses of the complete state of the ocean will also be useful for weather forecasting, shipping, fishing, ocean exploration, search and rescue, and naval applications.