The Role of Oceans in Climate Change

Paola M. Rizzoli and Peter H. Stone

The crucial issues of climate change and global warming involve all the components of the earth system, atmosphere, oceans, land, biosphere, and cryosphere. The oceans are among the most poorly known and understood, because of the enormous difficulty of probing the deep layers which are still basically void of observations, and the sparseness of data in the southern ocean. There are numerous ways in which the oceans affect the Earth's climate, but we will discuss only those two that, in our opinion, are of the utmost importance.

The first crucial role played by the oceans involves the mixing of heat anomalies into the deep layers.

Within the context of global warming scenarios, strong mixing of surface heat anomalies will retard surface warming rates (Hansen et al, 1985). Mixing is primarily performed by small-scale oceanic processes, generally decomposed into multiple components: diapycnal and isopycnal diffusion (i.e., diffusion across and along constant density surfaces); mesoscale and submesoscale eddies, with scales < ~ 100 Km.; and convection. Diapycnal diffusion in particular is crucial in determining the ocean's circulation, since it is the diapycnal mixing of heat and salinity from the ocean's surface to its depths that gives rise to the density gradients which drive the large-scale circulation and its horizontal heat transports (Munk and Wunsch, 1998).

Vertical mixing by the other diffusion processes is strongest in high latitudes (Huang et al., 2003 a, b). There the strong cooling of surface waters favors static instability of the water column and a vertical alignment of the isopycnal surfaces. The former leads to penetrative convection; the latter to isopycnal diffusion being predominantly vertical and large amounts of potential energy becoming available for mesoscale processes. In particular, the convective cell(s) of the polar North Atlantic determine the bottom water mass that from its northern source spreads through the abyssal layers of the global ocean.

All these sub-scale mixing processes, with the possible exception of mesoscale eddies, are extremely difficult to measure in the field and, furthermore, are not resolved by the ocean general circulation models currently used for climate studies. Hence the necessity of stimulating research into process studies, both theoretical and observational, leading to improved or new parameterizations of ocean mixing in its different forms, and their related effects on the heat and, in general, water properties transports by the large-scale circulation at all depths.

The second most important role the oceans play in climate occurs in the regions where they are strongly coupled to the atmosphere. By and large, the ocean is driven by the atmosphere and the ocean circulation is a response to atmospheric forcing, i.e., wind stress, heat, and moisture fluxes. In the tropical/equatorial regions, however, the ocean exerts the strongest feedback on atmospheric motions thanks to the intense sea surface heat exchanges.

Thus in the tropical regions the interannual to decadal modes of climate variability are coupled ocean-atmosphere modes. The most famous of all is the Pacific El Niño/Southern Oscillation (ENSO) mode that has been extensively studied since the early ’80s.

El Niño is the appearance in the Pacific interior of an anomalously warm tongue of water that changes the convective atmospheric cell above it. In normal conditions, the atmospheric convective loop involves upwelling of warm air over the western Pacific which moves eastward at height and downwells over the eastern Pacific.

During El Niño, due to the warm water pool in the basin interior, two convective loops are produced, with upwelling of warm air over the pool, and two branches moving at height both westward and eastward, finally downwelling over the western Pacific and Central America. El Nino is succeeded by its opposite phase, La Niña, in which the warm pool is replaced by a cold one. This coupled oscillation of the atmosphere-ocean system has an irregular periodicity of a few years and has profound consequences on the fisheries and the economy of central/southern America. A major observational effort, the Tropical Atmosphere Ocean (TAO) array, has been in place since 1994, becoming the Triton/TAO array in 2000 with Japan participating in the western part. It comprises 11 arrays of multiple instrumentation moorings regularly distributed all along the equatorial band on both sides of the equator (**www.pmel.noaa.gov/tao/**). The TAO array has produced an incredibly rich time series of observations that have improved both the theoretical understanding and the modeling and prediction of ENSO.

Nothing analogous exists in the Atlantic and even less in the Indian Ocean.

In the tropical Atlantic, in the last decade, the Prediction and Research Moored Array in the Atlantic (PIRATA) has been put in place, through cooperation mostly involving France, the U.S., and Brazil. The PIRATA array, however, is much more irregular, sparse, and limited, coarsely spanning the equatorial band and not resolving well the most important mode of variability. This is the interhemispheric dipole or meridional sea surface temperature (SST) gradient mode. The SST north-south gradient in fact controls the position of the InterTropical Convergence Zone (ITCZ) where the northern and southern trade winds converge (Jochum et al., 2004). The ITCZ in its seasonal north-south migration is responsible for rainfalls or droughts over Brazil and West Africa and related epidemics of tropical diseases.

In the Indian Ocean, only in 2008 has a proposal been put forward for a multinational collaboration leading to RAMA: the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (McPhaden et al., 2009). In the Indian Ocean the most important coupled mode of variability is the Indian Ocean Dipole (IOD), consisting of east-west anomalies of SST and precipitation/drought. The IOD is similar to ENSO in its mechanism but is much more short lived.

The paucity of observations in the tropical Atlantic and Indian oceans have considerably retarded our understanding, modeling, and prediction of these coupled modes, which are extremely important not only because of their societal consequences but because it is through them that the ocean actually drives the atmosphere. These regions and coupled mechanisms should constitute a priority of observational and theoretical research.

References

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