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Through a Glass Darkly: Envisioning Ocean Heat Budget [1]

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A new model indicates that scientists may be able to gauge atmosphere-ocean heat flux using sea level data.

Since nearly three-quarters of the Earth's surface lie under water, heat flux between atmosphere and ocean significantly impacts global climate. Oceans store heat during summer and release it through the year, so that ocean heat flowing into the atmosphere in late fall and early winter moderates land temperatures. But the amount and rate of heat transfer between atmosphere and ocean, whether from solar radiation, through the effects of evaporation, or by conduction of heat from warm water to cold atmosphere, or vice-versa, have not been comprehensively measured.

If magnitude makes ocean heat budget an important factor in global climate, sheer expanses are a large part of the problem in measuring it. Moored buoy systems, while measuring atmospheric and oceanic variables to depth, are limited to a few hundred locations around the world. Accurate sea surface temperature (SST) measurements from satellites have been calculated globally, but only reflect heat changes near the surface. SSTs do not present a picture of the total amount of heat in the water column, that is the heat available for imminent release to the atmosphere.

A lack of direct measurements with which to address pressing questions is at the heart of much inspired science. It is especially vindicating when, on the brink of discovery researchers turn to theory, stretch the limits of what we know, test relationships we think we understand, and -- having no missing terms -- find once again the stunning simplicity linking theory and fact. In 1996, a University of Texas post-doctoral fellow, Don Chambers, and colleagues, using TOPEX altimeter data, leaned on the relationship between ocean temperature and density to infer annual and long-period heat storage rates over the global oceans.

"Traditionally, researchers compute heat budget terms using bulk formula equations based on in-situ temperature and specific humidity measurements of the atmosphere and the ocean," said Chambers. But besides biases inherent to the formulas, he said "We don't have measurements everywhere, so the heat budget model has errors in it that can be up to 15 to 20 watts per meter squared.

"With errors that big you couldn't measure long-period change," he said. "Is the Pacific cooling off? Is the Atlantic warming?" Gradual changes in ocean heat storage would have consequences for climate, but without a strong record of trends, it is speculation as to whether changes are temporary, ordinary cyclical weather themes, or permanent alterations putting the Earth on track for the next ice age. "That's why we wanted to look at the TOPEX data," Chambers said.

"The TOPEX altimeter measures sea level very precisely. One of the signals in sea level is the heat content," Chambers said. "If you put heat from the atmosphere into the ocean, it causes the water to expand, so the sea level will rise.

"But the TOPEX measurement is not a pure measurement of sea level due to heat. There are other factors in sea level, like rain and evaporation, that are not connected to heat. Sea level changes due to wind forcing aren't connected to heat. We wanted to see how big that heat signal was. Could we compare it with temperature data and get a good agreement? If we could get an error bar on the value, could we infer, for instance, a basin-scale heat flux over the North Atlantic or Pacific?" The researchers' aim, he said, was to get a better idea of the heat exchange between atmosphere and ocean, taking into account the complexities, layered currents, gyres, and circulation patterns that regulate the ocean heat budget.

Testing the relationship between ocean temperature and density meant compensating for sea level fluctuations caused by forces other than heating, such as atmospheric pressure, salinity, and barotropic forcing. The team

estimated annual mean effects for each, modifying the heat-equals-sea-level-rise equation with factors of error for non-heat-induced amplitude changes. From sea level data for November 1992 to April 1996, the researchers derived annual heat storage rates, computed inter-annual changes and averaged data over the Pacific and Atlantic basins.

The moment of truth came in the comparison of estimates of heat content indirectly observed by TOPEX/Poseidon with direct (albeit few) measurements from the Tropical Ocean Global Atmosphere (TOGA) program's Tropical Atmosphere-Ocean (TAO) buoy system and to historical in-situ data contained in NOAA's 1994 World Ocean Atlas (WOA94).

"My comparisons with TOGA-TAO buoy data seem to show that changes agree within two or three watts per meter squared at any particular place," said Chambers. "The annual signal of the variability in the North Pacific and the North Atlantic over the basin agrees well with the mean temperature measurements, and the spatial signal of the heat storage rates is very similar to the spatial signal of the sea surface temperature changes." The result was reassuring, he said, because it indicated that heat changes are the dominant influence in the sea level measurements.

Heat flux determinations from the team's work show the North Atlantic basin to be warming faster than any of those compared, while the northern Pacific seems to be cooling. Chambers plans to further compare the altimeter heat signals with temperature data.

"TOPEX will never replace in-situ measurements of heat storage," Chambers says. "TOGA-TAO is probably one of the best devices out there right now for monitoring heat storage and the long-term heat storage rate." But the key, he says, is global coverage. "TOPEX can supplement things like TOGA-TAO.

"The real strength of TOPEX is that it takes measurements in several hundred thousand locations every 10 days," said Chambers. "Even if TOPEX has a larger error in some places, having a larger error mean value is better than having no mean value at all."

Reference(s)

Chambers, D.P, B. D. Tapley and R. H. Stewart. In Press. Long-period ocean heat storage rates and basin-scale heat fluxes from TOPEX altimetry. Journal of Geophysical Research.

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