Estimates of the Global Oceanic Heat Budget from Assimilation Models on Interannual to Decadal Time Scales

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Motivation

As the Earth's climate system has warmed over the past half-century, most of the excess heat has accumulated in the World's oceans (see Figure 1). Furthermore, because of their enormous heat capacity, the oceans will likely continue to take up most of the excess heat as the climate continues to warm. Closure of the global oceanic heat budget is therefore pivotal to understanding and characterizing climate change. Recent estimates of ocean thermal variability have achieved sufficient accuracy that the net thermal energy stored in the World's oceans can now be estimated with some degree of certainty (Levitus et al., *Science*, 2000; Ishii et al., *MWR*, 2003; Willis et al., *JGR*, in press). Despite the improvements in estimates of oceanic heat content, however, global surface heat flux estimates do not yet have sufficient accuracy to close the oceanic heat budget. Here, we consider the heat content variability implied by estimates of net surface heat flux over the oceans from two commonly used atmospheric assimilation models—the NCEP Reanalysis and the ECMWF 40-year Reanalysis, as well as a new estimate based on adjusted surface fluxes from the ECCO global ocean data assimilation model.

Estimating the Earth's Heat Balance

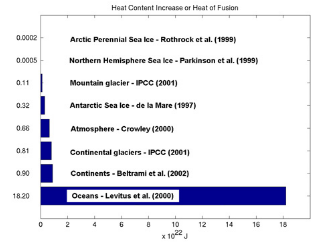

Figure 1. Heat balance of the Earth's climate system from 1955 to 1996. Adapted from *Levitus et al.* (2001). Note that the oceans by far account for the largest portion of the warming.

Implication

Estimates of ocean heat content over decadal time-scales place a strong constraint on the long-term heat balance of the Earth's climate system.

Current Atmospheric Reanalyses

At present, neither the ECMWF nor the NCEP (I or II) Reanalyses imply realistic variability in global oceanic heat content on interannual to decadal time scales. The net surface fluxes from these products contain imbalances in the global average that imply large exchanges of heat between ocean and atmosphere. This is illustrated in Figure 2.

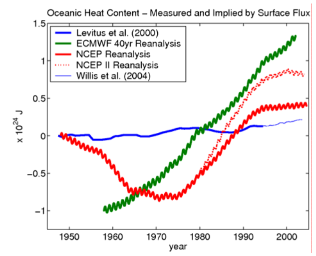

Figure 2. Measured and implied oceanic heat content. The blue curves show estimates of ocean heat content calculated from oceanographic data. The red and green curves show the heat content variability implied by integrating surface heat flux estimates from several commonly used atmospheric reanalysis models. The surface flux estimates were integrated over the oceans only—surface fluxes over land were excluded.

Time Averaged Net Surface Flux

Figures 3 and 4 show time averaged net surface fluxes from the reanalyses along with a surface flux estimate from the ECCO (Estimating the Circulation and Climate of the Ocean) ocean data assimilation model. The ECCO model uses surface forcing from the NCEP Reanalysis, but then adjusts the forcing fields (including surface heat flux) to improve the model's agreement with oceanographic data. Note that the time-mean for NCEP is broken in to two periods to reflect the reflect the sudden change in NCEP fluxes that occurred around 1994 as illustrated in Figure 2.

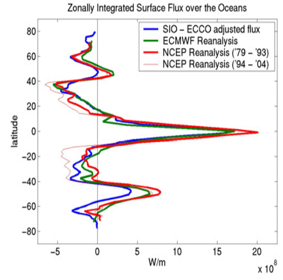

Figure 3. Zonal integral of time-mean surface fluxes over the oceans for several different heat flux products as a function of latitude. Units are Watts per meter of latitude. Note that this curve must average to zero to within about 0.1 W/m to imply realistic heat content variability.

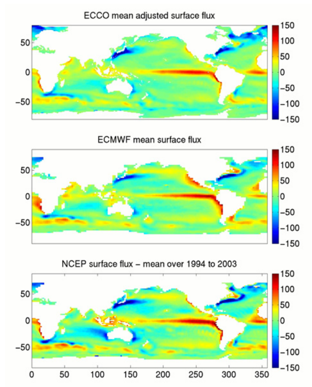

Figure 4. Time-mean net surface flux estimates.

ECCO Oceanographic Assimilation Model

Figures 5 and 6 show ocean heat content and storage variability implied by the ECCO adjusted surface heat flux fields.

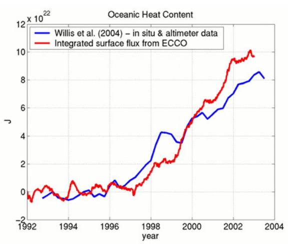

Figure 5. Oceanic heat content variability as estimated by *Willis et al.* (2004) and implied by ECCO adjusted net surface flux estimate.

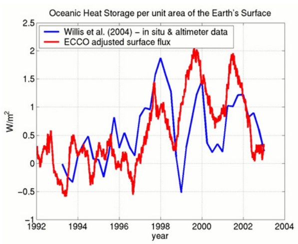

Figure 6. Oceanic heat storage from *Willis et al.* (2004) and implied by ECCO adjusted surface fluxes. Both estimates have been smoothed using a 1-year boxcar average, and normalized by the Earth's total surface area.

References

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Satellite Observations of the Earth's Heat Balance

Satellite observations of the net radiation balance at the top of the atmosphere show some agreement with oceanographic heat storage as estimated by *Willis et al.* (2004).

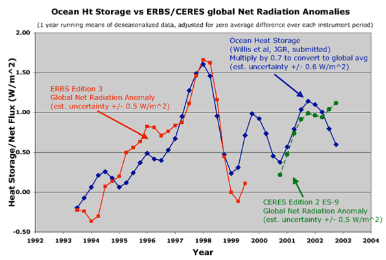

Figure 7. Oceanic heat storage from *Willis et al.* (2004) compared with satellite estimates of global net radiation anomaly. Figure provided by B. Wielicki (personal communication).

Summary

Currently available surface heat flux products from atmospheric reanalyses imply unrealistic transfer of heat into the oceans. This presents a problem for ocean models that use these surface flux fields to force the ocean on climate-related time scales. Left untreated, globally averaged ocean temperature will drift in response to the unrealistic amounts of heat that are forced into or out of the ocean by the surface flux products. Recent results from the ECCO model, however, suggest that surface flux fields can be substantially improved using an oceanographic data assimilation model.