UPPER OCEAN HEAT CONTENT SIMULATED BY NCEP GODAS

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ABSTRACT

Upper ocean heat content (UOHC) is one of the key indicators of climate variability on many time-scales extending from interannual to long-term anthropogenic trends. Since UOHC variability is also associated with SST variability, a better understanding and monitoring of UOHC variability can help us understand, monitor, and forecast, other SST modes such as Indian Ocean Dipole (IOD), Pacific Decadal Oscillation (PDO), Tropical Atlantic Variability (TAV) and Atlantic Multidecadal Oscillation (AMO). An accurate ocean initialization of UOHC variability in coupled climate models will also play a crucial role in emerging decadal climate prediction efforts.

To quantify uncertainty in the UOHC estimates, a comparison of UOHC in the top 300m using multiple ocean reanalysis products, which include the operational GODAS based on the GFDL MOM.v3 model forced by the NCEP Reanalysis 2 (R2) surface fluxes (GODAS_MOM3), its control simulation (MOM3_CTL), the experimental GODAS that is identical to the GODAS_MOM3 except the GFDL MOM.v4 was used (GODAS_MOM4), and the National Oceanographic Data Center (NODC) objective ocean reanalysis based on in situ observations only, was made.

1. INTRODUCTION

Upper ocean heat content (UOHC) is one of the key indicators of climate variability on many time-scales extending from interannual to long-term anthropogenic trends. For example, UOHC in the tropical Pacific provides the ocean memory that is critical for the long-lead forecast skill of ENSO. Since UOHC variability is also associated with SST variability, a better understanding and monitoring of UOHC variability can help us understand, monitor, and forecast, other SST modes such as Indian Ocean Dipole (IOD), Pacific Decadal Oscillation (PDO), Tropical Atlantic Variability (TAV) and Atlantic Multidecadal Oscillation (AMO) [1]. An accurate ocean initialization of UOHC variability in coupled climate models will also play a crucial role in emerging decadal climate prediction efforts [2].

The NCEP operational global ocean data assimilation system (GODAS) (http://www.cpc.ncep.noaa.gov/products/GODAS) provides a historical ocean reanalysis from 1979 onward, and maintains a continuous update in near real time (1 day delay). The operational GODAS is based on the GFDL Modular Ocean Model version 3 (MOM.v3) forced by the NCEP Reanalysis 2 (R2) surface fluxes, and a three-dimensional variational scheme that assimilates observed temperature, synthetic salinity and Altimetry sea level. Temperature observations include data from XBTs, TAO/TRITON/PIRATA and Argo profiling floats [3].

Estimations of UOHC variability can be affected by many factors including analysis and assimilation produces, and changes in the input data. For example, the coverage of in situ temperature data was poor at the beginning of the reanalysis, but gradually increased with time and reached a near global coverage since 2005. To quantify uncertainty in the UOHC estimates, a comparison of UOHC in the top 300m and 700m using multiple ocean reanalysis products, which include the operational GODAS (GODAS3), its control simulation (CTL), the experimental GODAS that is identical to the operational GODAS except MOM.v4 was used (GODAS4), and the NODC objective ocean reanalysis based on in situ observations only (NODC) [4], was made.

2. TOTAL UPPER OCEAN HEAT CONTENT

We compared the basin average of the top 300m heat content from the four ocean reanalysis products (Figure 1). In the tropical Pacific, CTL was much warmer than GODAS3 and GODAS4, both of which were close to NODC except during 1979-1985 when the initial adjustment was still taking place, and during 1998-1999 when the discharge of heat content following the 1997/98 El Nino was underestimated.

In the tropical Indian Ocean, CTL was much warmer than GODAS3 and GODAS4, and had an erroneous warming trend. GODAS3 and GODAS4 agreed well with NODC except during 1979-1984 and 1996-2001. In the tropical Atlantic, CTL was also much warmer than GODAS3 and GODAS4, both of which were somewhat warmer than NODC before 2002, but became close to NODC afterwards. In the North Pacific, both GODAS3 and GODAS4 agreed very well with NODC prior to 2005, but started to have cold biases afterwards. Note that all the little bumps in the time series around spring 2007 were due to errors in the R2 winds, which have been corrected retrospectively and reflected in GODAS3.

In the North Atlantic, GODAS4 agreed with NODC much better than GODAS3 did. This suggests that including the Arctic Ocean in the ocean model is important for realistically simulating the North Atlantic heat content. In the South Pacific, GODAS4 agreed with NODC much better than GODAS3 and CTL did, both of which had large warm biases prior to 1986. It is comforting to see that the erroneous upward trend in CTL since 1995 was significantly reduced in GODAS3 and GODAS4 due to data assimilation. In the South Indian Ocean, the

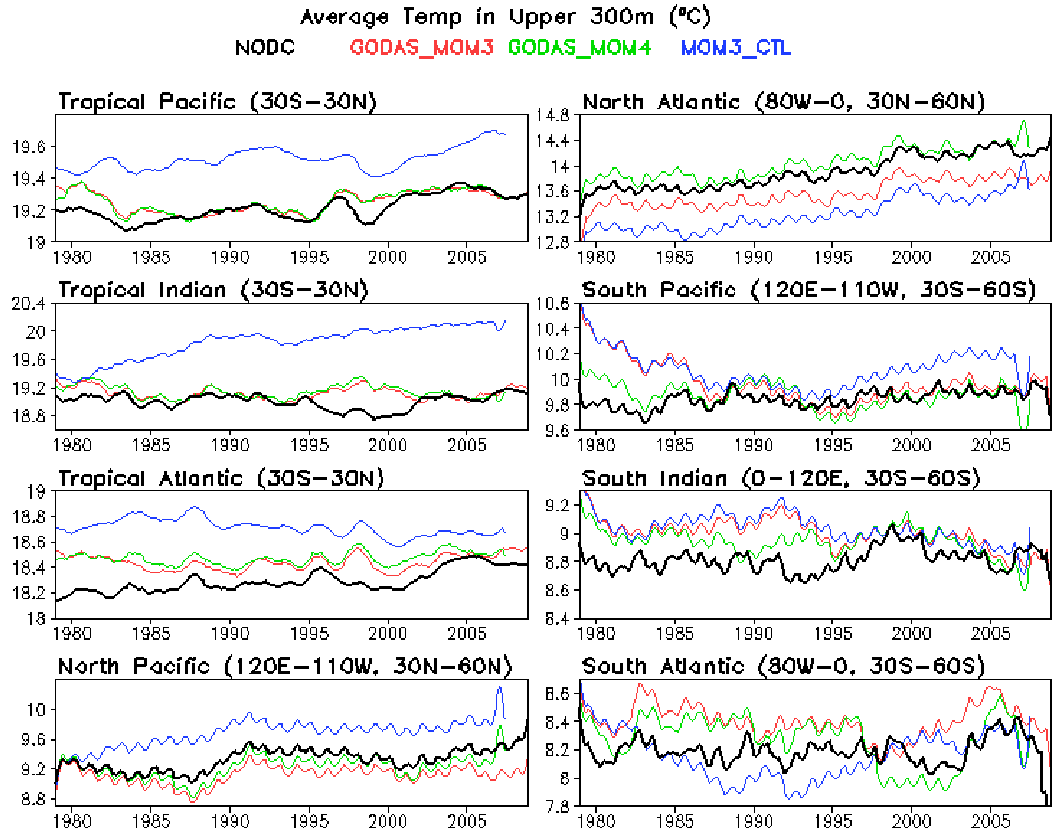

Figure 1. Upper 300m temperature averaged in different ocean basins for the NODC objective ocean analysis (black), the operational GODAS (red), its control simulation (blue) and the experimental GODAS that is identical to the operational GODAS except MOM.v4 was used (green). A one year running mean has been applied to the monthly time series.

downward trend in CTL, GODAS3 and GODAS4 was largely due to the warm biases prior to 1995. In the South Atlantic, large discrepancies existed among the four ocean reanalysis products prior to 2005, and since then they started to converge.

3. ANOMALOUS UPPER OCEAN HEAT CONTENT

Once the climatological mean differences were removed, the agreement among the ocean reanalysis products was significantly improved (Figure 2). The data assimilation products (GODAS3 and GODAS4) were superior to CTL in the tropical oceans, particularly in the tropical Indian and Atlantic Ocean. Note that the anomalous UOHC in the North Pacific and North Atlantic was very well simulated by CTL. This suggests that the UOHC variability in the Northern Oceans was largely driven by surface fluxes (obtained from the R2). However, it is puzzling that all the NCEP products started to deviate from NODC significantly since 2005 in the North Pacific where observations were generally plentiful. In the Southern Oceans, there was generally a poor agreement among the NCEP products and NODC. However, the agreement was slightly improved when the MOM.v4 was used.

Another way to quantify the uncertainty of UOHC variability is to compare the dominant EOF patterns and their time series in the ocean reanalysis products. Separate EOF analysis will be done in each ocean basin in order to isolate mode of variability associated with the PDO, IOD, TAV and AMO. A consistency among the dominant EOF patterns and time series would be an indication of their robustness in representing the climate signal.

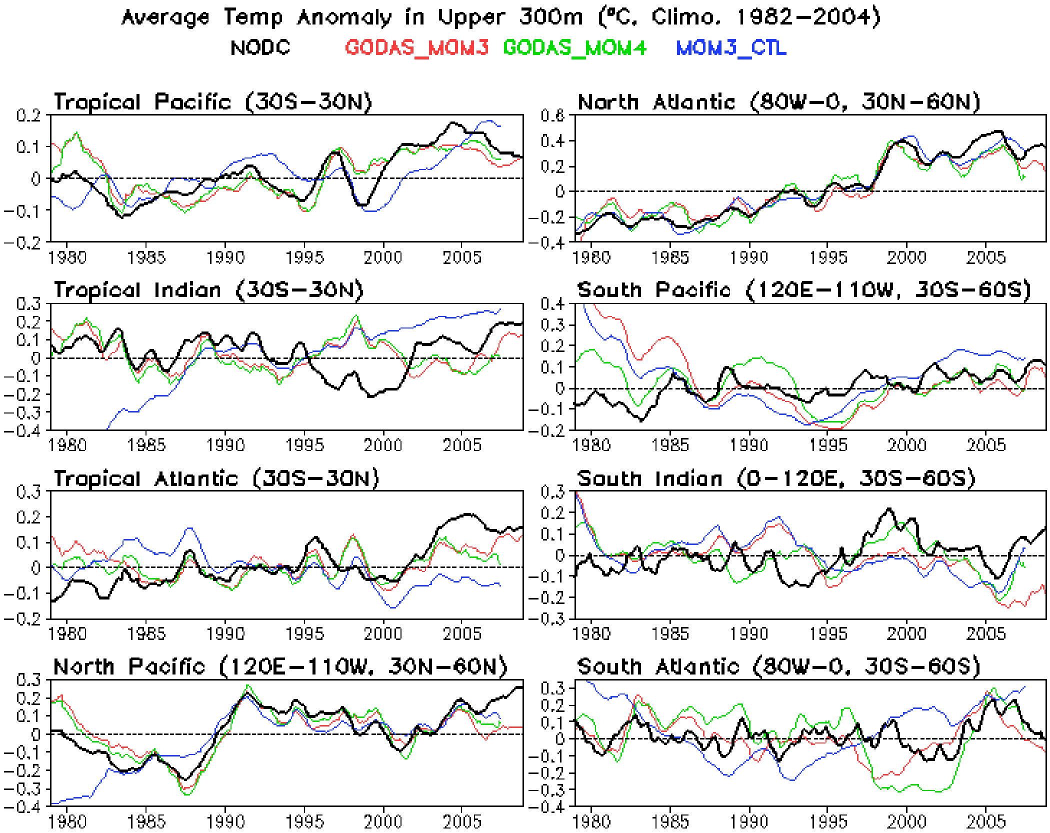

Figure 2. Same as Figure 1 except the upper 300m temperature anomalies were shown.

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