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The Switchover from NOGAPS to NAVGEM 1.1 Atmospheric Forcing in GOFS and ACNFS

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14. ABSTRACT

The Navy Operational Global Atmospheric Prediction System (NOGAPS) has recently (13 March 2013 12Z) been replaced by the NAVy Global Environmental Model (NAVGEM) as the U.S. Navy's operational atmospheric forecast system. NOGAPS will be decommissioned on 31 August 2013 but before that date both the Global Ocean Forecast System 3.01 and Arctic Cap Nowcast/Forecast System must switch from using NOGAPS to NAVGEM atmospheric forcing. Calibrations to the wind velocities and net heat flux are performed. Wind velocities are calibrated against satellite scatterometer data whereas heat flux is calibrated using 5-day forecast SST error. The sequence of hindcasts and forecast simulations are described with the net impact of reducing 5-day forecast SST error and ice concentration error in the NAVGEM 1.1-forced system, compared to the NOGAPS-forced system. Overall, the methodology is shown to be effective in minimizing upper ocean discontinuities when switching from one atmospheric product to another.

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1.0 Background:

The Naval Research Laboratory (NRL) – Monterey developed a new atmospheric forecast model, the NAVy Global Environmental Model (NAVGEM) to replace the existing Navy Operational Global Atmospheric Prediction System (NOGAPS). It is initially configured to run at T359L50 resolution (with planned horizontal/vertical resolution upgrades) and has a new and improved dynamical core. NAVGEM 1.1 was transitioned to the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and completed its Operational Test in January 2013 (Pauley et al., 2013). The results show an across the board improvement in forecast skill over NOGAPS and it became the US Navy's new operational atmospheric forecast system on 13 March 2013 12Z.

The Global Ocean Forecast System (GOFS) 3.01 (Metzger et al., 2008, 2010) and the Arctic Cap Nowcast/Forecast System (ACNFS) (Posey et al., 2010) run daily at the Navy DoD Supercomputing Resource Center (DSRC) and presently use NOGAPS forcing. Initial comparisons of NOGAPS and NAVGEM 1.1 surface fields indicate large differences in some variables such that GOFS/ACNFS cannot simply switch to NAVGEM 1.1 with the expectation that the ocean/ice model response will be unchanged. Therefore, FNMOC continues to run NOGAPS until 31 August 2013 but will provide only to the Naval Oceanographic Office (NAVOCEANO) that output required for their ocean/ice models. In the interim, NRL – Stennis Space Center (SSC) will perform the needed calibrations to assure the ocean/ice model response will be consistent across the NOGAPS decommission time boundary. The calibration work and subsequent hindcasts/forecasts are the subject of this report.

2.0 NAVGEM 1.1 wind velocity calibration:

Two calibrations of NAVGEM 1.1 output are required to make it more consistent with the calibrated NOGAPS used in GOFS and ACNFS. The first is to calibrate NAVGEM 1.1 wind velocities to contemporaneous scatterometer output. In general, oceanic wind velocities from numerical weather prediction systems are weaker than that observed by scatterometers and so a calibration of the speed (but not direction) is needed. NAVGEM 1.1 is no different than NOGAPS (and products from other centers), which also need this scaling. The second calibration is to the net surface heat flux in an effort to reduce 5-day forecast SST error (see section 4).

A minimum of one year (a complete season cycle) of NAVGEM 1.1 output is needed to perform these calibrations. NRL-MRY provided NAVGEM 1.1 hindcast output that started on 1 June 2012 and ran through the end of 2012. NRL-SSC began receiving pre-operational NAVGEM 1.1 output on 8 December 2012 and this continues daily with the operational output. Thus, a one year period spanning 1 June 2012 – 31 May 2013 uses a combination of hindcast/pre-operational/operational model output.

Contemporaneous wind velocity from scatterometers is obtained from the Remote Sensing Systems (RSS) website: http://www.remss.com. Daily observations from two Special Sensor Microwave Imager/Sounder (SSMIS) satellites (F16 and F17) and the WindSAT satellite are used. Monthly mean wind speed from the scatterometers and NAVGEM 1.1 are used and a regression analysis is computed. An offset and a scaling factor (Figure 1) are then applied to the NAVGEM 1.1 wind velocities. Figure 2 shows NAVGEM 1.1 wind speed before and after the scaling along with a comparison against the scatterometers.

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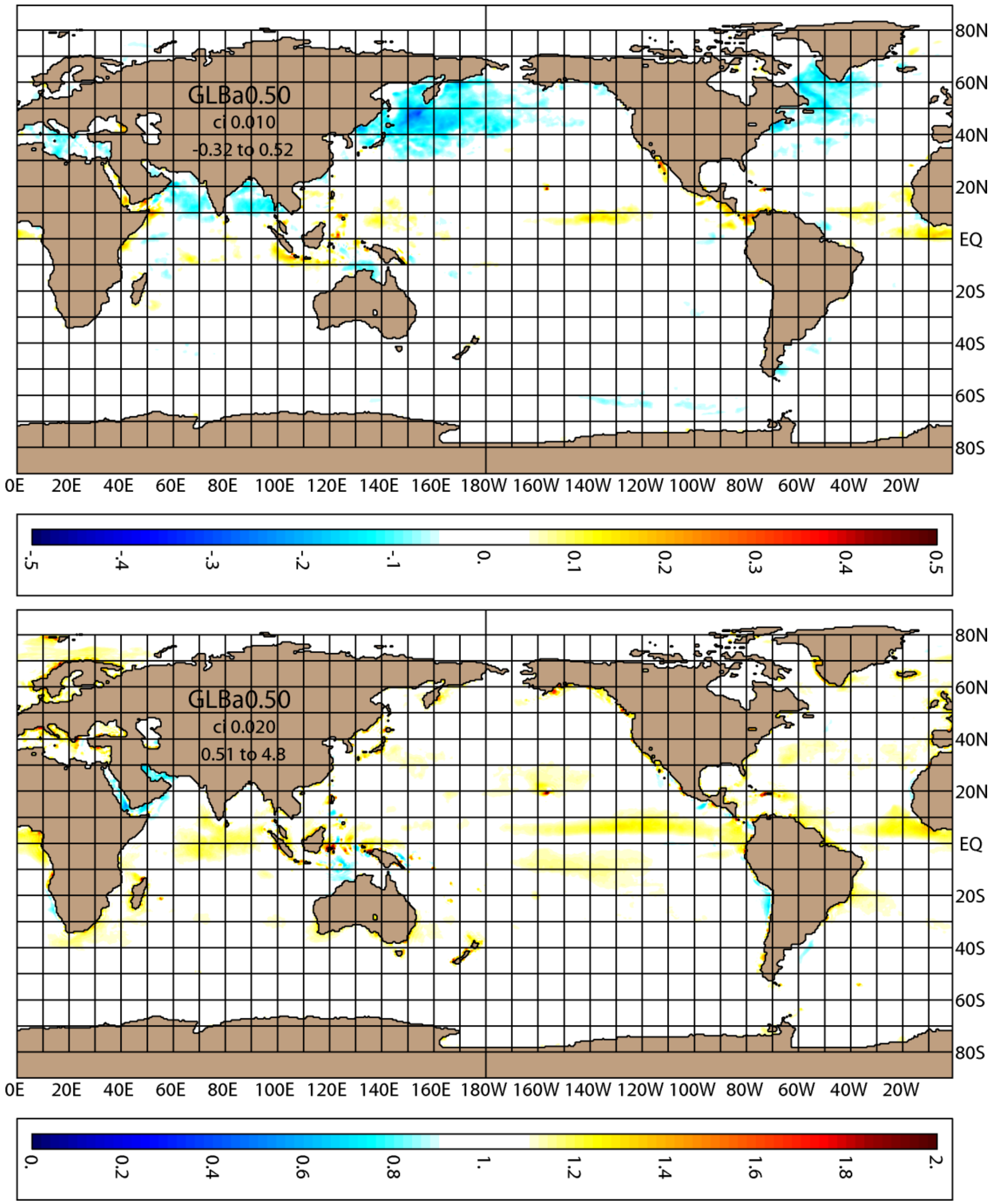

Figure 1: Offset (m/s) (top) and scaling factor (unitless) (bottom) derived from the linear regression analysis between monthly SSMI/S and WindSAT scatterometer data and NAVGEM 1.1 wind velocities over the period 1 June 2012 – 31 May 2013.

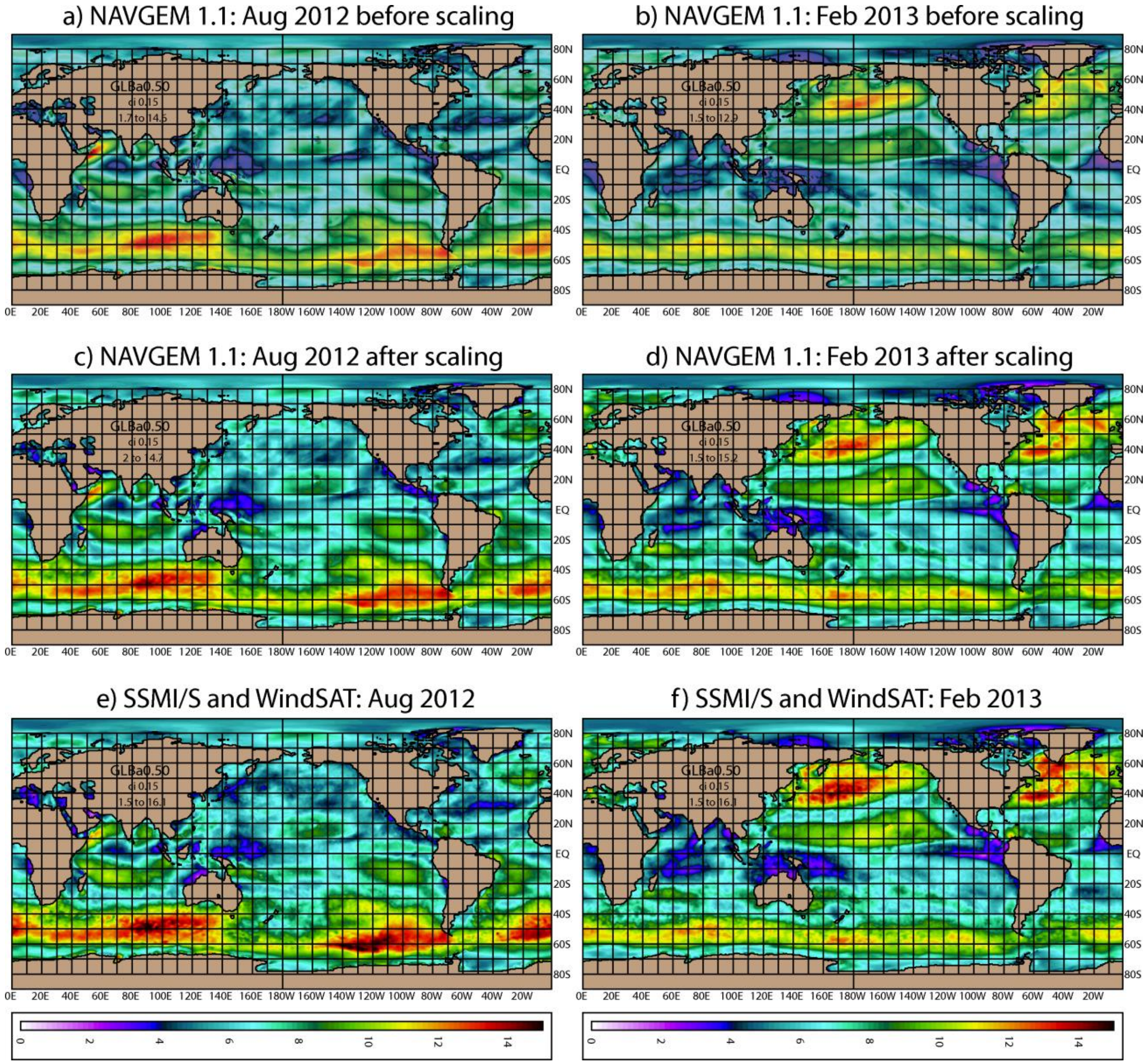

Figure 2: Monthly mean wind speed (m/s) for August 2012 (a,c,e) and February 2013 (b,d,f) for NAVGEM 1.1 before scatterometer calibration (a,b), after calibration (c,d) and for SSMI/S and WindSAT satellite scatterometers (e,f).

3.0 Comparison of NAVGEM 1.1 and NOGAPS surface fields:

As mentioned previously, substantial differences exist between NAVGEM 1.1 and NOGAPS surface fields, thus a different upper ocean model response is expected. This section highlights differences of the following fields: 2 m height air temperature, 2 m height specific humidity and net surface shortwave radiation. Extensive ground truth observational comparisons have not been undertaken for all the fields because of the short time fuse for switching to NAVGEM 1.1 forcing. Thus the following plots simply show the differences, rather than determine which product is closest to the truth. Figure 3 shows monthly mean 2 m height air temperature differences between NAVGEM 1.1 minus NOGAPS. For the two months shown here (and throughout the year) NAVGEM 1.1 is generally colder than NOGAPS over oceanic regions, but the opposite is true over the polar regions. Polar latitude differences are largest in the winter hemisphere. While the winter-time differences at high latitude are large, it should be noted that these temperatures are already well below freezing, and probably won't have a huge impact on ice formation or melting. Comparisons were also made against NAVGEM 1.1 and the National Centers for Environmental Prediction (NCEP) Climate Forecast System Version 2 (CFSV2). These are not shown but the same basic tendencies exist.

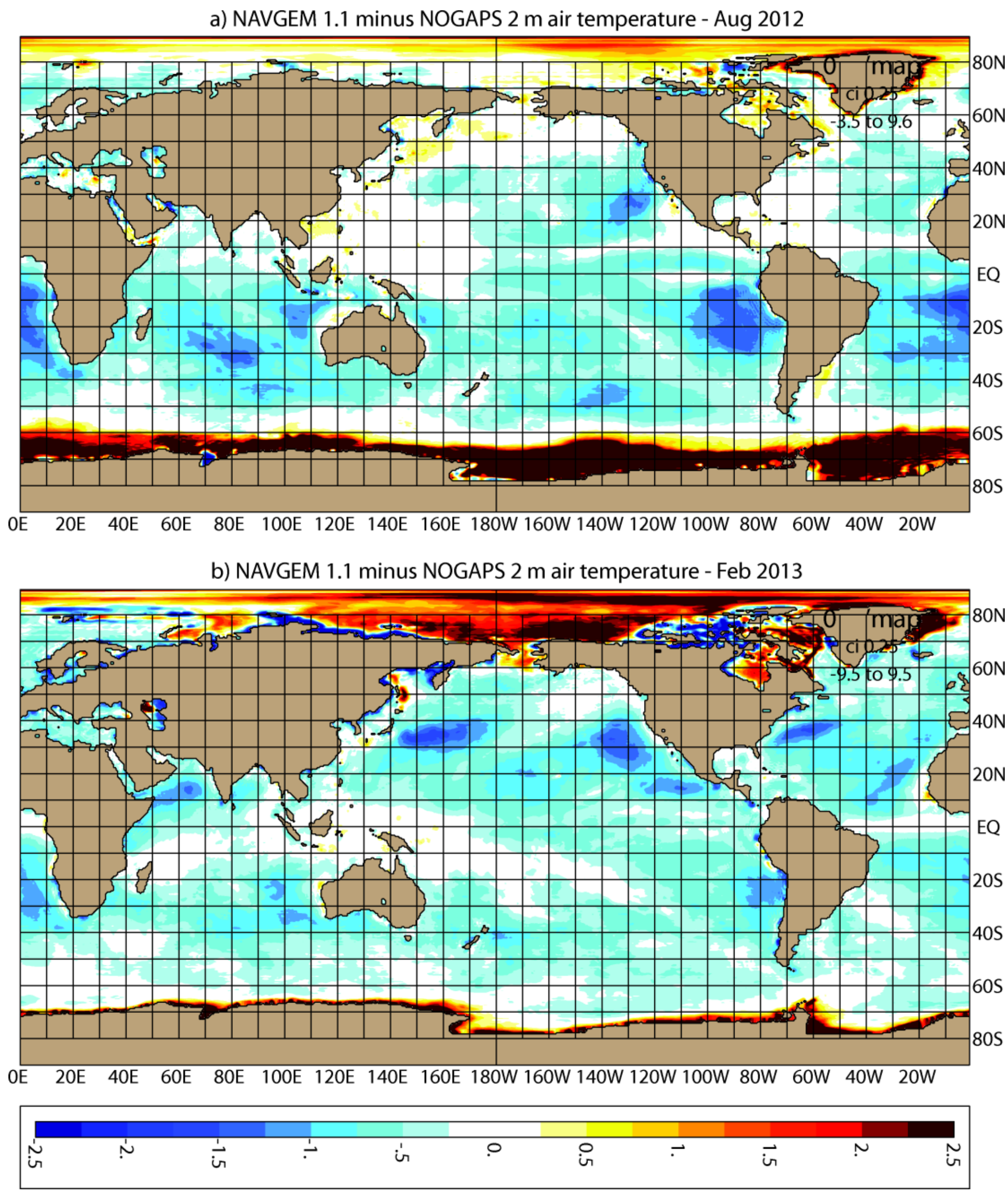

Figure 3: NAVGEM 1.1 minus NOGAPS monthly mean differences of 2 m height air temperature (°C) for a) August 2012 and b) February 2013.

The 2 m height specific humidity differences are shown in Figure 4. Across the tropics and mid-latitudes, NAVGEM 1.1 has a moister lower atmosphere than NOGAPS. A difference of 1 g/kg is approximately 10% of the total signal.

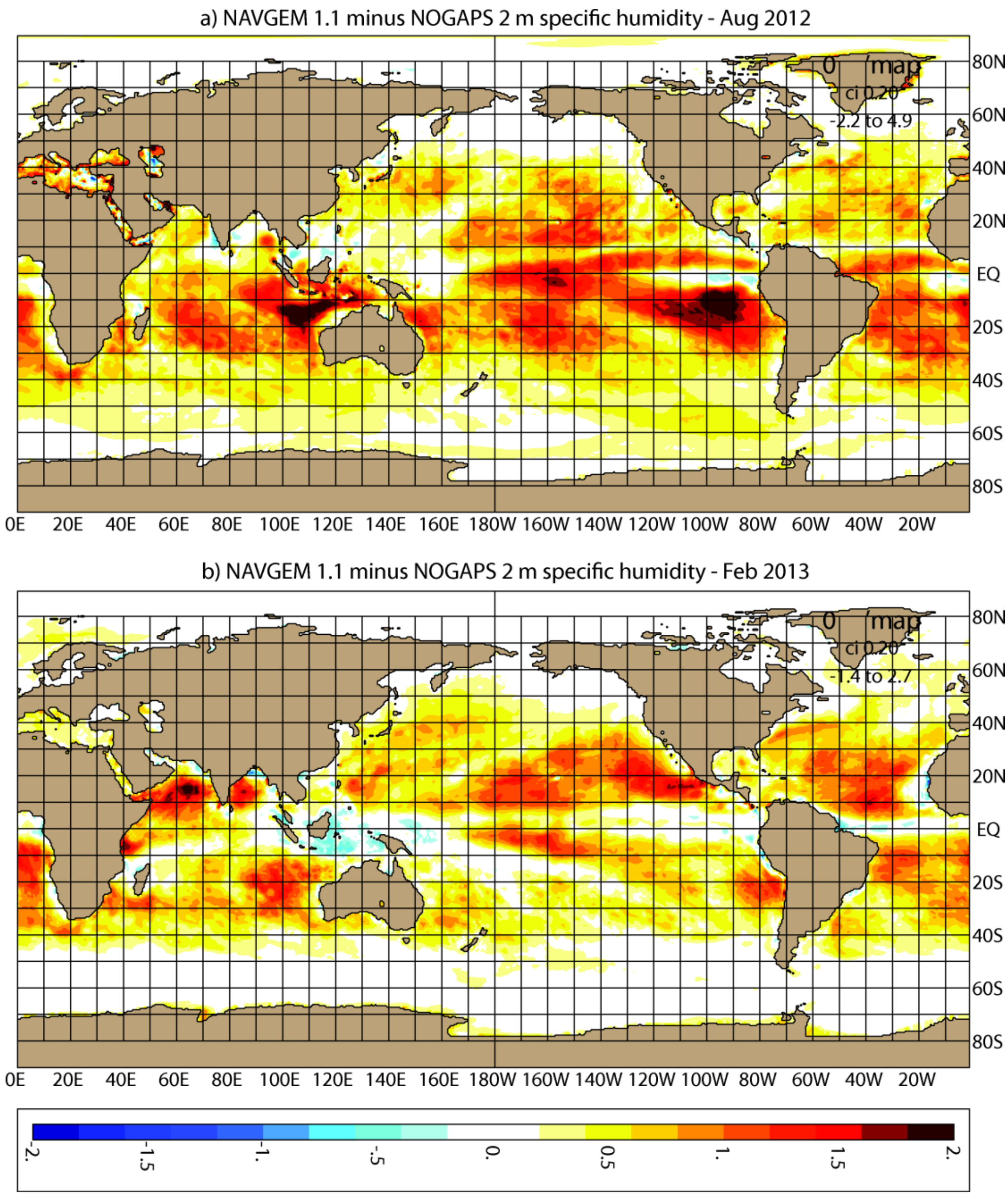

Figure 4: NAVGEM 1.1 minus NOGAPS monthly mean differences of 2 m height specific humidity (g/kg) for a) August 2012 and b) February 2013.

Lastly, net surface shortwave radiation differences are shown in Figure 5. Regional differences can be seen with NAVGEM 1.1 having higher shortwave radiation along the Inter-Tropical Convergence Zone (ITCZ) and tropical Indian and west Pacific Oceans. However, across much of the rest of the global ocean, NAVGEM 1.1 has weaker solar radiation. Difference plots of NCEP CFSV2 versus NOGAPS show very similar patterns (not shown), suggesting too weak radiation in the tropics and ITCZ and too much radiation elsewhere in NOGAPS.

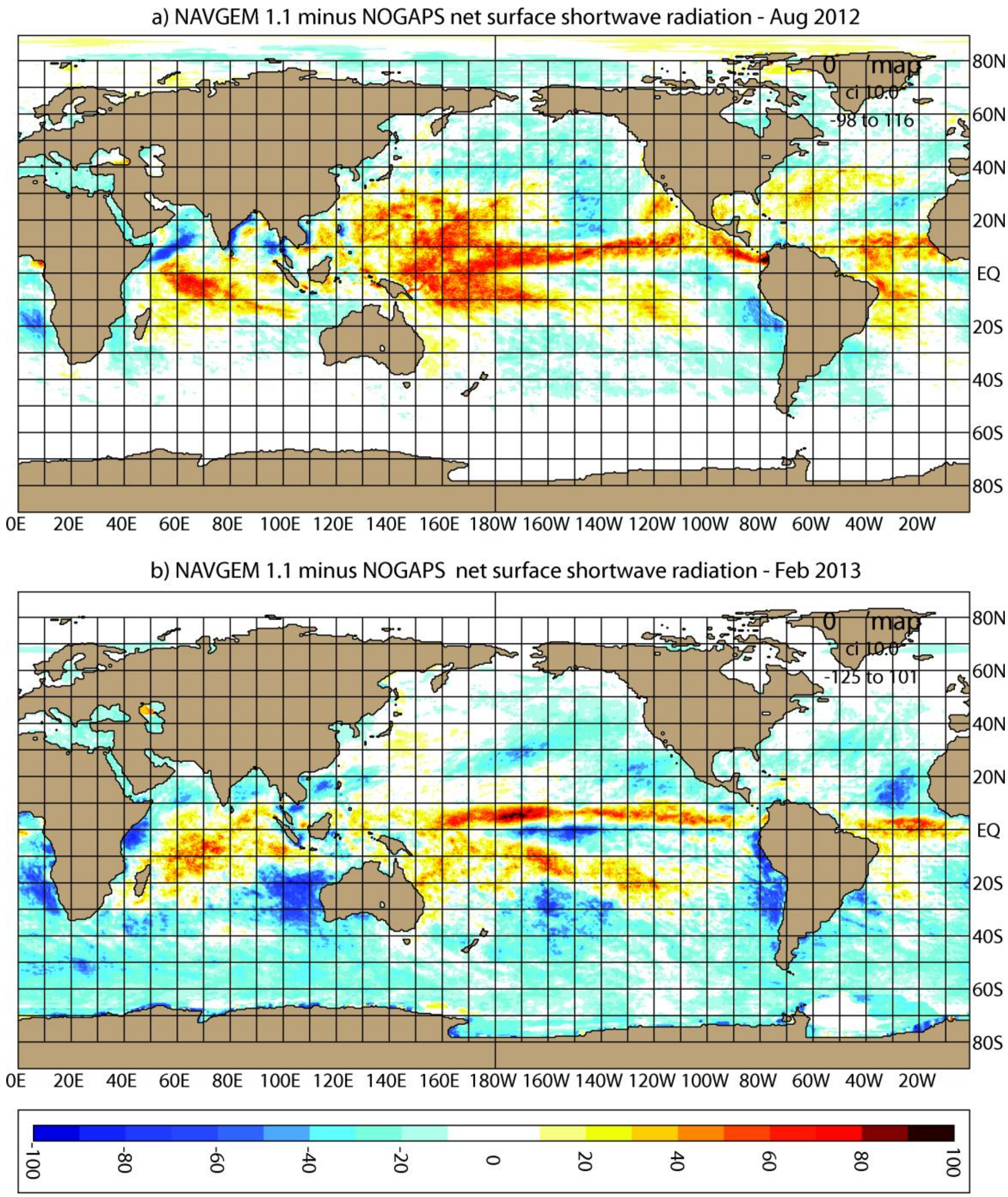

Figure 5: NAVGEM 1.1 minus NOGAPS monthly mean differences of net surface shortwave radiation (W/m^2) for a) August 2012 and b) February 2013.

Because shortwave radiation can have a significant impact on the upper ocean thermal structure, a preliminarily comparison is made between NAVGEM 1.1 output and observational data, namely the

National Aeronautics and Space Administration (NASA) Fast Longwave And SHortwave Radiative Fluxes (FLASHFlux) satellites. The single month that is examined indicates NAVGEM 1.1 surface radiation is generally weaker than observed by the satellites (Figure 6), often by 50+ W/m^2 over large regions of the global oceans.

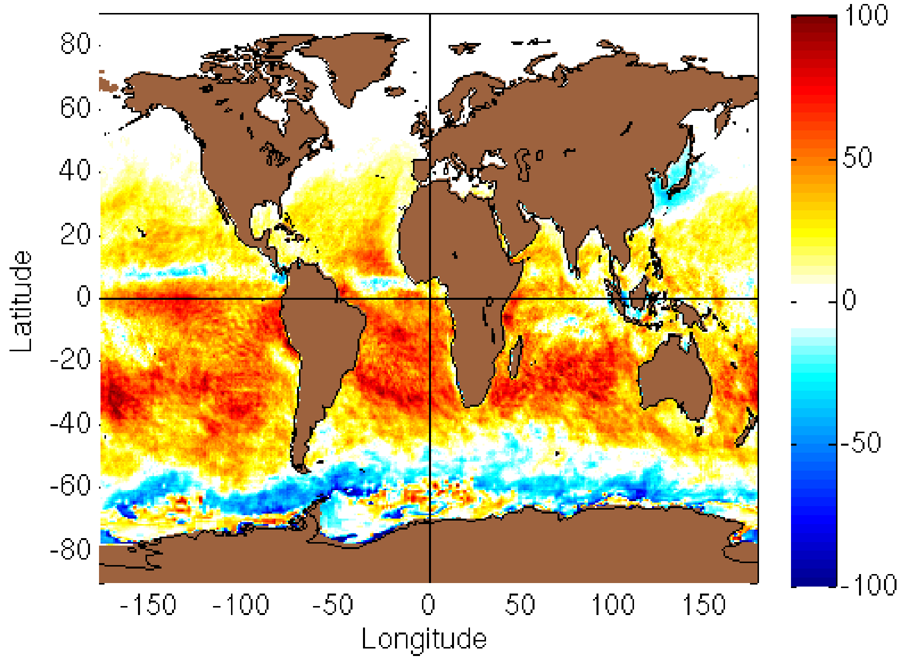

Figure 6: NASA FLASHFlux minus NAVGEM 1.1 net surface shortwave radiation (W/m^2) averaged over the period 8-31 December 2012.

4.0 NAVGEM 1.1-forced GOFS hindcasts and heat flux calibration:

Given a complete year of scatterometer calibrated NAVGEM 1.1 wind forcing, a GOFS 3.01 hindcast (experiment GLBa0.08-27.0) is integrated over the period 1 June 2012 – 31 May 2013; the heat fluxes in this first hindcast are not modified in any way. As this hindcast moves forward, a series of 5-day forecasts is integrated every second day (GLBa0.08-27.1). No forecast NAVGEM 1.1 output is available during the hindcast period, so analysis quality output is used as the forcing. This produces approximately 15 forecast per month. The 5-day forecast sea surface temperature (SST) is compared against the GOFS verifying SST analysis and a heat flux offset is computed in which a 1°C SST error translates into a 250 W/m^2 heat loss or gain. This offset is averaged over each month and additionally a 1-2-1 temporal filter is applied to smooth the fields.

A second GOFS hindcast (GLBa0.08-27.2) then began using the NAVGEM 1.1 scatterometer calibrated winds and net heat flux modified by the temporally smoothed monthly varying offsets described above. It is this second hindcast that will be transitioned to NAVOCEANO to eventually become NAVGEM 1.1-forced GOFS. The timeline to complete the second hindcast is 15 August 2013 since NAVOCEANO plans to run dual operations of NAVGEM 1.1-forced GOFS and NOGAPS-forced GOFS for at least two weeks before the NOGAPS decommission date. To determine the impact of the heat flux calibration, additional 5-day forecasts (GLBa0.08-27.3) are integrated every third month and SST error is compared against the forecasts that used no heat flux corrections. A schematic of the hindcasts is shown in Figure 7.

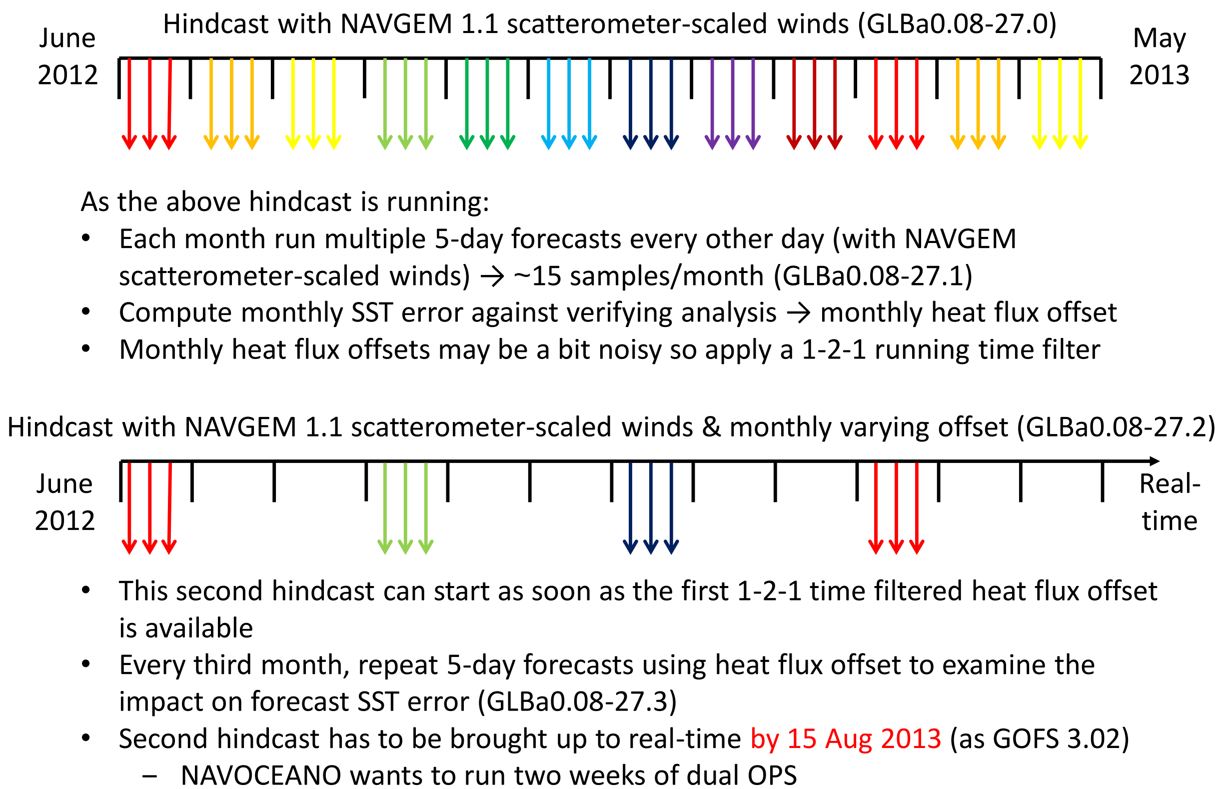

Figure 7: Schematic and description of the hindcast and forecast simulations used to bring the NAVGEM 1.1-forced GOFS up to real-time.

Using NAVGEM 1.1 scatterometer calibrated winds, but unmodified heat fluxes, the 5-day forecast SST is generally colder than the verifying analysis (Figure 8). This would be consistent with cooler 2 m air temperatures (Figure 3) and weaker than observed surface shortwave radiation (Figure 6). These SST error plots show both spatial and seasonal variability. The corresponding heat flux offsets are shown in Figure 9 and in general, positive heat flux is added across most of the global ocean.

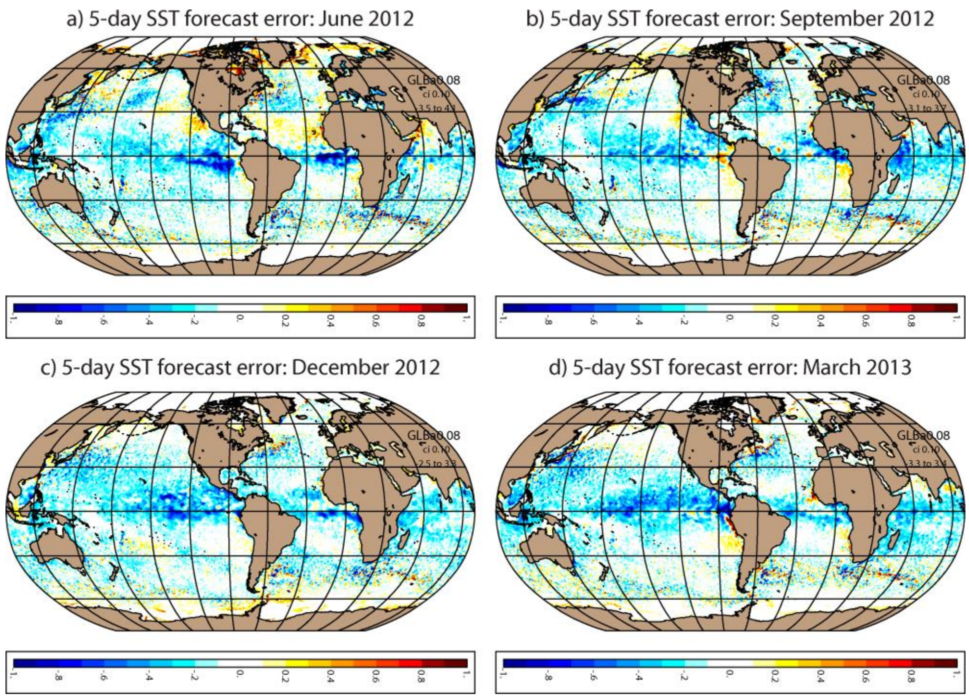

Figure 8: Five-day forecast SST error (°C) between the forecasts (GLBa0.08-27.1) and the verifying analysis (GLBa0.08-27.0) averaged for a) June 2012, b) September 2012, c) December 2012 and d) March 2013. No heat flux offset is applied to the hindcast or the forecasts.

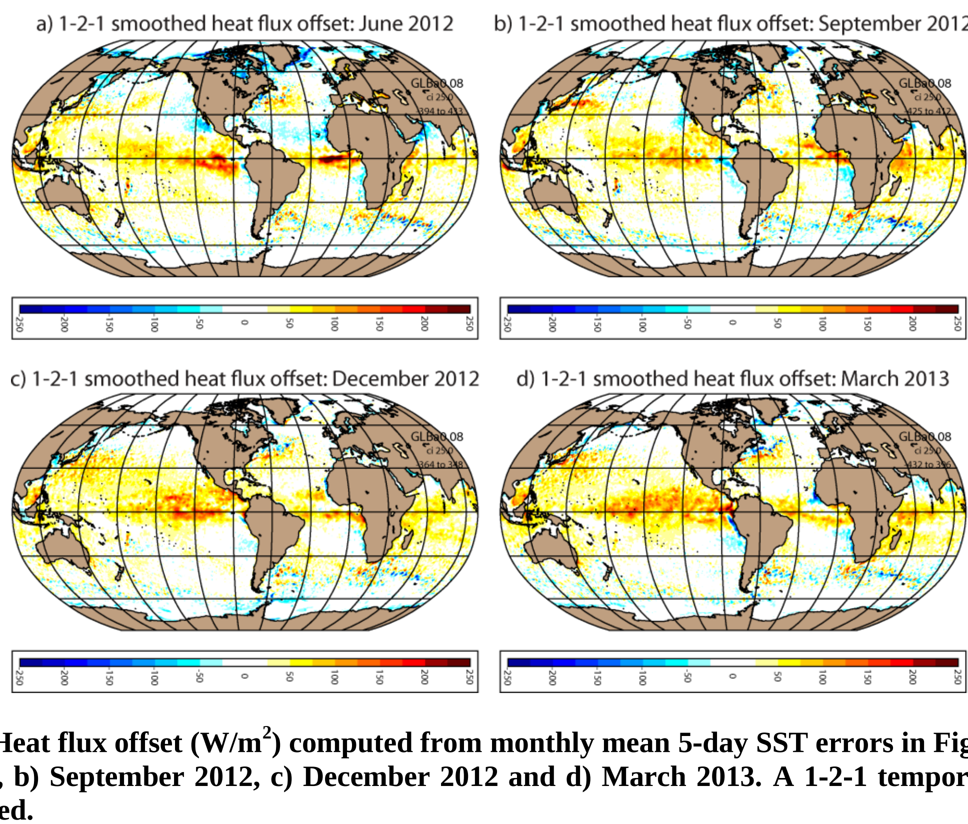

Figure 9: Heat flux offset (W/m^2) computed from monthly mean 5-day SST errors in Figure 8 for a) June 2012, b) September 2012, c) December 2012 and d) March 2013. A 1-2-1 temporal filter has been applied.

With the temporally smoothed heat flux offsets computed, the second hindcast (GLBa0.08-27.2) has started and is presently being integrated forward to real time to be delivered to NAVOCEANO as GOFS 3.02. As this is proceeding, a second set of 5-day forecasts (GLBa0.08-27.3) examine the impact of the computed heat flux offset on SST. A comparison of Figures 10a vs. 10b shows a significant reduction in 5-day forecast SST error after the application of the heat flux offset, thus the methodology is shown to be successful. However, Figure 10b is during the period of "training" output while Figure 10c is the first month outside that period. The higher error in Figure 10c may be due to interannual variability not taken into account in the computation of the heat flux offset. Lastly, Figure 10d is included for comparison with the existing NOGAPS-forced GOFS 3.01. The lower SST error in the NAVGEM 1.1-forced hindcast (Figure 10c vs. 10d) may not be entirely attributed to the change in atmospheric forcing, but rather to a difference in how the heat flux offset is applied. This is done as an annual mean correction in NOGAPS-forced GOFS 3.01 but is done as a monthly varying correction in these new hindcasts. Figure 9 clearly indicates seasonal variability in the heat flux offset that should be taken into account, but this is not done in NOGAPS-forced GOFS 3.01.

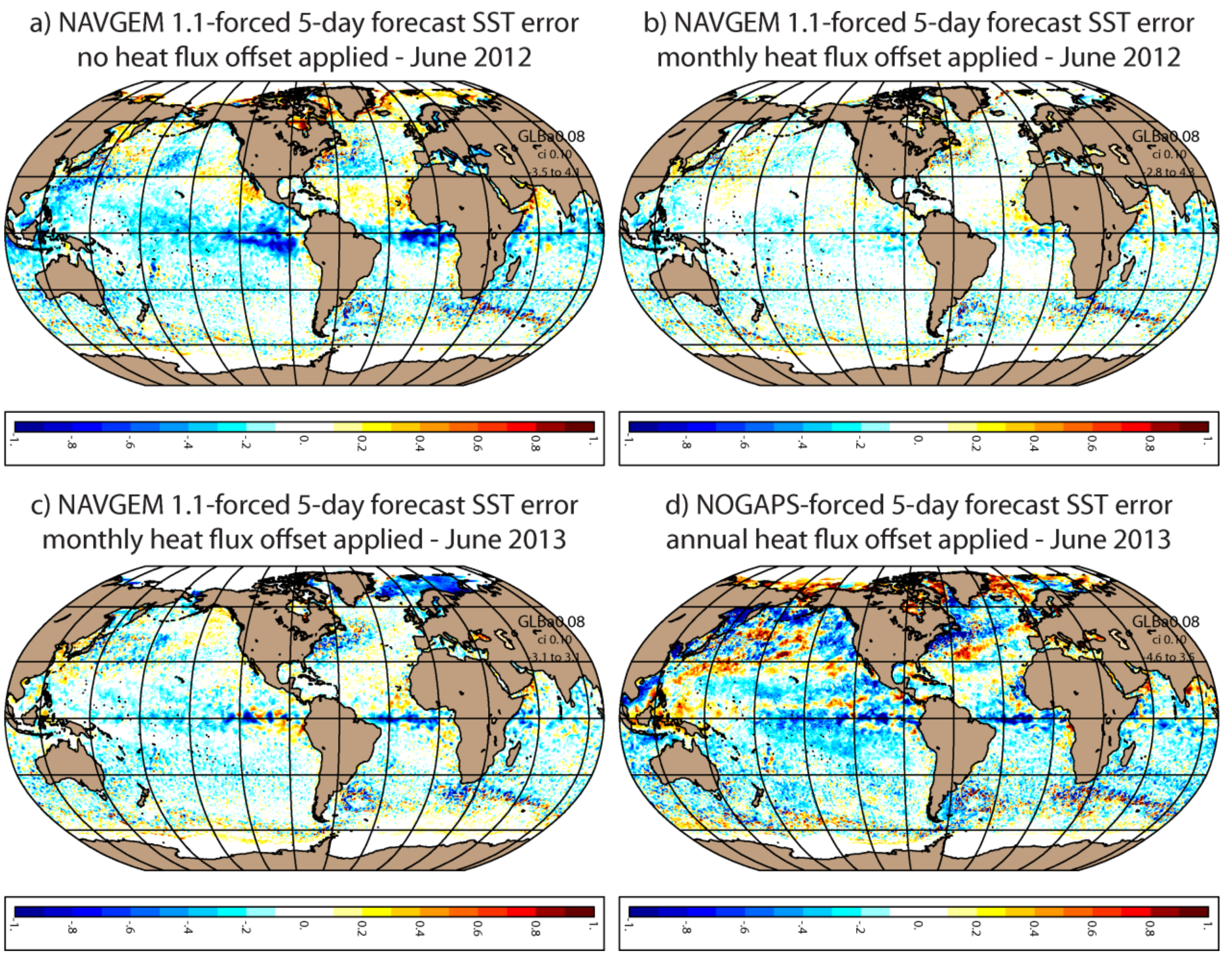

Figure 10: Five-day forecast SST error (°C) between the forecasts and the verifying analysis averaged over June 2012 (a,b) and June 2013 (c,d) with a) NAVGEM 1.1 forcing and no heat flux offset applied, b) NAVGEM 1.1 forcing and the monthly varying heat flux offset applied, c) NAVGEM 1.1 forcing and the monthly varying heat flux offset applied, and d) NOGAPS forcing and an annual mean heat flux offset applied.

5.0 ACNFS:

The ACNFS must also switch to NAVGEM 1.1 forcing and a hindcast starting at June 2012 has begun using the scatterometer calibrated winds and the monthly varying heat flux offset derived from the global system. These heat flux offsets are applied to both the ocean (HYCOM) and ice (CICE). Five-day ice concentration forecasts from NAVGEM 1.1-forced ACNFS and NOGAPS-forced ACNFS are shown in Figure 11 and both are performing very similarly. Thus, ice forecasts appear to be less sensitive to the magnitude of the heat flux offset and/or its frequency of application. This result holds throughout both the summer/spring melt and fall/winter growth seasons.

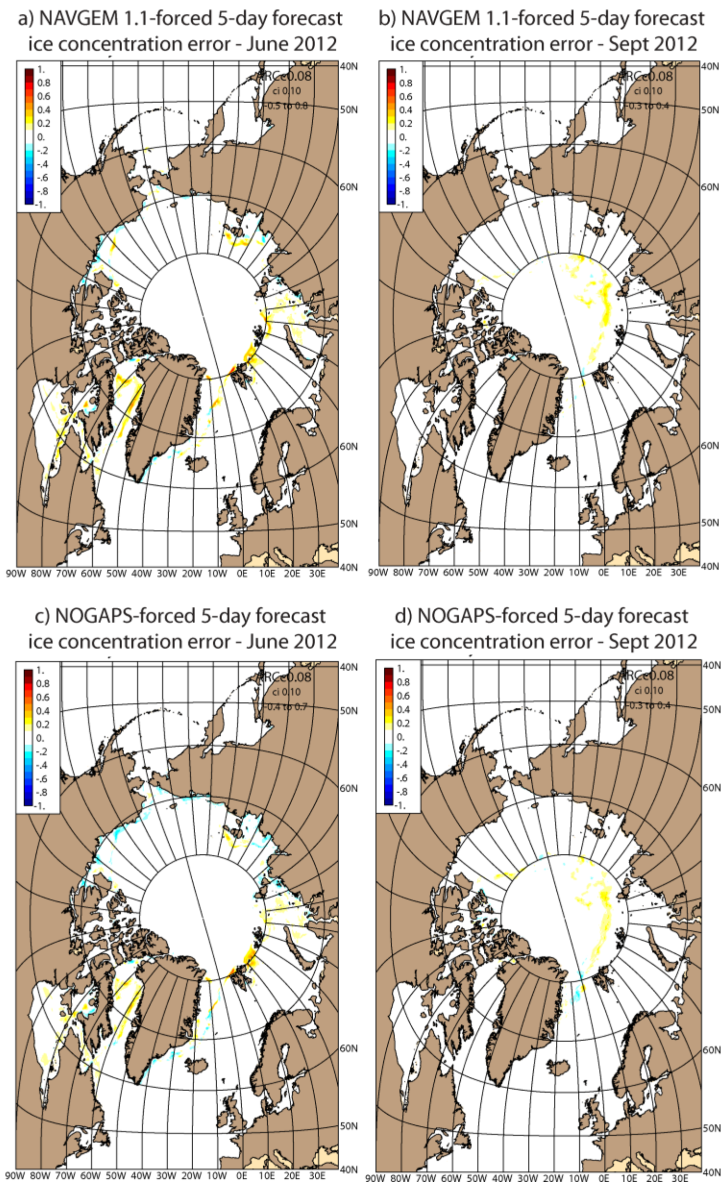

Figure 11: Five-day ice concentration (fraction of 1.0) between the forecast and verifying analysis averaged over June 2012 (a,c) and September 2012 (b,d) with a,b) NAVGEM 1.1 forcing and the monthly varying heat flux offset applied, and c,d) NOGAPS forcing and an annual mean heat flux offset applied.

6.0 Summary:

With the pending decommissioning of the Navy Operational Global Atmospheric Prediction System, both the Global Ocean Forecast System 3.01 and Arctic Cap Nowcast/Forecast System must transition to NAVy Global Environmental Model atmospheric forcing. Differences between these two atmospheric models require a calibration of both the wind velocities and the net heat flux at the air/ocean interface. Wind velocities are calibrated against satellite scatterometer data whereas heat flux is calibrated using 5-day forecast SST error. The sequence of hindcasts and forecast simulations is described above with the net impact of reduced 5-day forecast SST error and comparable ice concentration error in the NAVGEM 1.1-forced system, compared to the NOGAPS-forced system. Overall, the methodology is shown to be effective in minimizing upper ocean discontinuities when switching from one atmospheric product to another.

7.0 Acknowledgments:

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Posey, P.G., Metzger, E.J., Wallcraft, A.J., Preller, R.H., Smedstad, O.M., Phelps, M.W., 2010. Validation of the 1/12° Arctic Cap Nowcast/Forecast System (ACNFS). *NRL Memo. Report,* NRL/MR/7320--10-9287. (Available at http://www7320.nrlssc.navy.mil/pubs.php)

9.0 Table of Acronyms

ACNFS	Arctic Cap Nowcast/Forecast System
CICE	Community Ice CodE

CSFV2	Climate Forecast System Version 2
DSRC	DoD Supercomputing Resource Center
FLASHFlux	Fast Longwave And SHortwave Radiative Fluxes
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GOFS	Global Ocean Forecast System
HYCOM	HYbrid Coordinate Ocean Model
ITCZ	Inter-Tropical Convergence Zone
NASA	National Aeronautics and Space Administration
NAVGEM	NAVy Global Environmental Model
NAVOCEANO	Naval Oceanographic Office
NCEP	National Centers for Environmental Prediction
NOGAPS	Navy Operational Global Atmospheric Prediction System
NRL	Naval Research Laboratory
SSC	Stennis Space Center
SSMI/S	Special Sensor Microwave Imager/Sounder
SST	Sea Surface Temperature