GOV Symposium 2013: S3.2-13

Experiments with Satellite Ocean Color Fields in an Operational NCEP Ocean Model

Sudhir Nadiga[1], Eric Bayler[2], David Behringer[3], and Avichal Mehra[3]

[1]IMSG at NOAA/NCEP/EMC, [2]NOAA/NESDIS/STAR, [3]NOAA/NCEP/EMC

Motivation

To understand the impact of satellite ocean color (chlorophyll) fields on the representativeness of ocean modeling with the objective of quasi-near-real-time integration of ocean color (chlorophyll) data.

Abstract

Solar shortwave heating of the upper layers of the ocean is dependent on the wavelength of the incoming radiation and the optical properties of the water column and correlates with chlorophyll concentration, which modulates the absorption of solar insolation in the upper ocean. Through changes in density profiles, differential heating patterns cause baroclinic pressure gradients, which, in turn, impact the three-dimensional circulation patterns of the upper ocean. Thus, we examine changes in upper-ocean heat content, mixed-layer depths, and velocity in the top 300 m of the water column. Anomalous build-up of Equatorial Pacific ocean heat content is an important variable for the recharge-discharge oscillator theory for the evolution of El Niño events. Here, we show that differences in the chlorophyll data inputs cause significant changes in the ocean heat content anomalies in the tropical Pacific. Thus, it is important for seasonal predictions that we study the impact that the ocean color data sets have on the quality of ocean forecasts. Specifically, improvements to ocean initialization of coupled seasonal and weather forecast models, resulting from ingesting more accurate ocean chlorophyll fields, are analyzed and verified against independent data streams.

Satellite Ocean Color Fields

Three different satellite ocean color (chlorophyll) data sets, interpolated to the model grid, are used:

- Current operational data set: 1997-2001 climatological monthly Sea-viewing Wide Field-of-View Sensor (SeaWiFS);
- Visible Infrared Imaging Radiometer Suite (VIIRS), next-generation NOAA operational sensor: 2012 monthly fields;
- VIIRS 2012 daily fields.

Model

NOAA's National Center for Environmental Prediction (NCEP) operational near-global Modular Ocean Model v.4 (MOM4), half-degree resolution, forced with daily NCEP Climate Forecast System Reanalysis (CFSR; Saha *et al*., 2010) and relaxed to daily satellite sea-surface temperature (SST) fields and the climatological annual-mean sea-surface salinity (SSS) field. All runs were initiated from the same ocean initial condition and run for 2012 only. The MOM4 provides the core for NOAA's Global Ocean Data Assimilation System (GODAS) (Behringer, 2007), the ocean component of NOAA's seasonal-interannual coupled Climate Forecast System (CFS).

CASES:

- CONTROL = MOM4 run with the operational 4-year monthly climatological SeaWiFS data
- VIIRSMON = MOM run with Visible Infrared Imager Radiometer Suite (VIIRS) monthly data
- VIIRSDLY = MOM4 run with VIIRS daily data

Satellite Ocean Color: Chlorophyll-a Fields

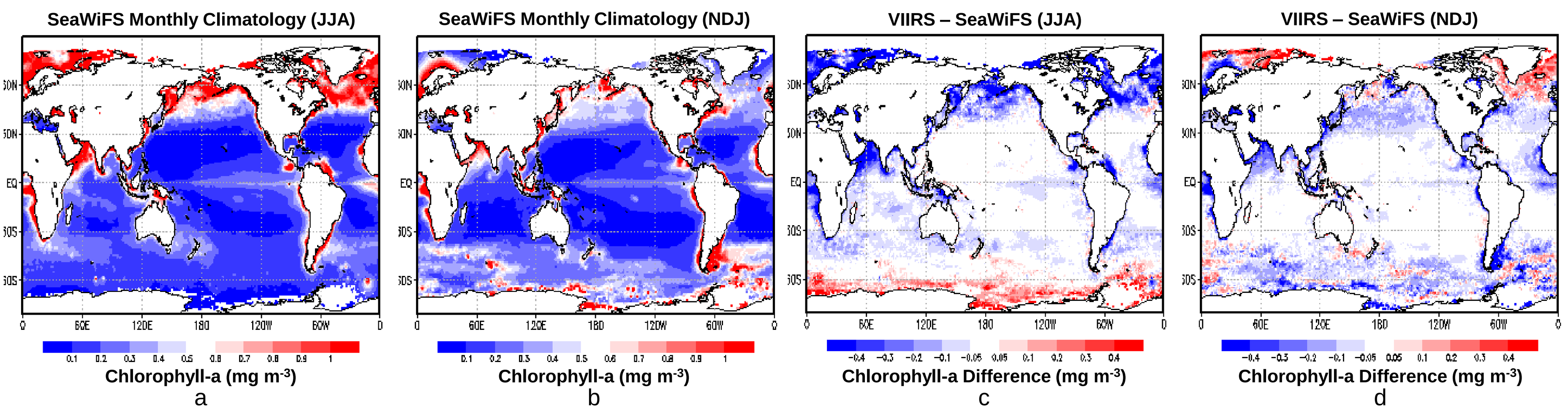

Fig. 1. Operational (1997-2001) SeaWiFS chlorophyll climatology (mg m-3) for Jun-Jul-Aug (a), Nov-Dec-Jan (b). Chlorophyll difference (mg m-3), VIIRS monthly climatology minus SeaWiFS climatology (1997-2010), for Jun-Jul-Aug (c), Nov-Dec-Jan (d).

Figure 1 highlights summer/winter differences between the first year of VIIRS observations and the MOM4's operational SeaWiFS climatology. These differences are due, in part, to the operational SeaWiFS climatology (1997-2001) being significantly influenced by the intense 1997-1998 El Niño, as well as any differences between 2012 (minimal El Niño/La Niña index) and climatological values. NOAA's VIIRS (Nov 2011 to present) replaces SeaWiFS, which ceased functioning in 2010.

Model impacts from employing the VIIRS monthly and daily chlorophyll-a data, seen in temperature and salinity time-depth plots for the eastern Pacific equatorial cold tongue region (Figure 2), are likely due to vertical mixing due to differences in stability induced by differences in chlorophyll absorption of the solar radiation. Note that the temperature differences appear to precede the salinity differences. The scales for both panels reflect similar contributions to density changes.

Model Sensitivity to Ocean Color (Chlorophyll-a) Reference

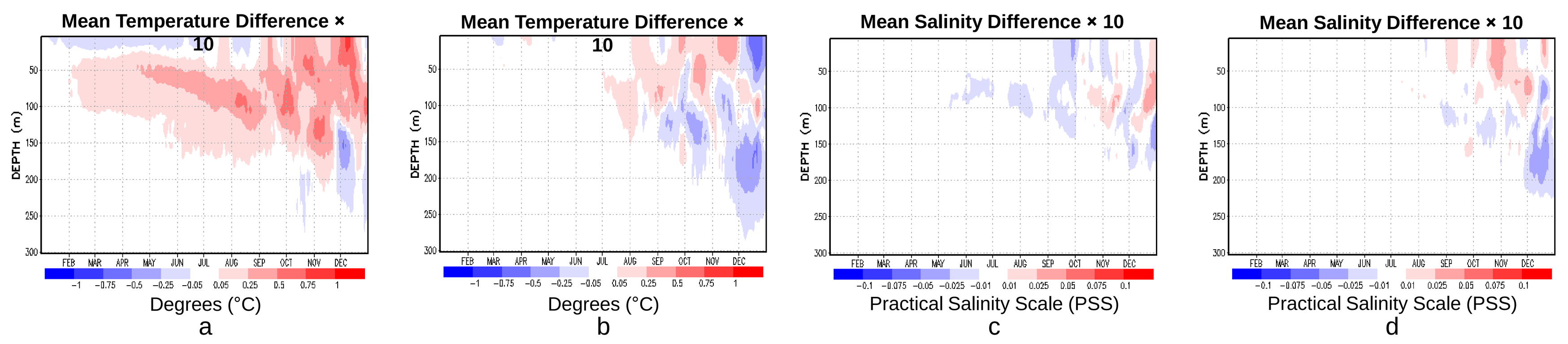

Fig. 2. Average differences, (5°S-5°N, 170°W-120°W) (time-depth evolution): Temperature difference × 10 (°C) a) VIIRSMON minus CONTROL; b) VIIRSDLY minus VIIRS monthly; Salinity difference × 10 (PSS) c) VIIRSMON minus CONTROL; d) VIIRSDLY minus VIIRS monthly.

Examining the broader equatorial Pacific Ocean response at the end of the model runs, representative of 2012 (Figure 3), the greatest temperature differences due to the chlorophyll differences were typically not found at the surface, but rather just above or below the average depth of the 20°C isotherm. With respect to variability in the control run, the most significant differences were clustered along the 20°C isotherm in the eastern half of the equatorial Pacific Ocean.

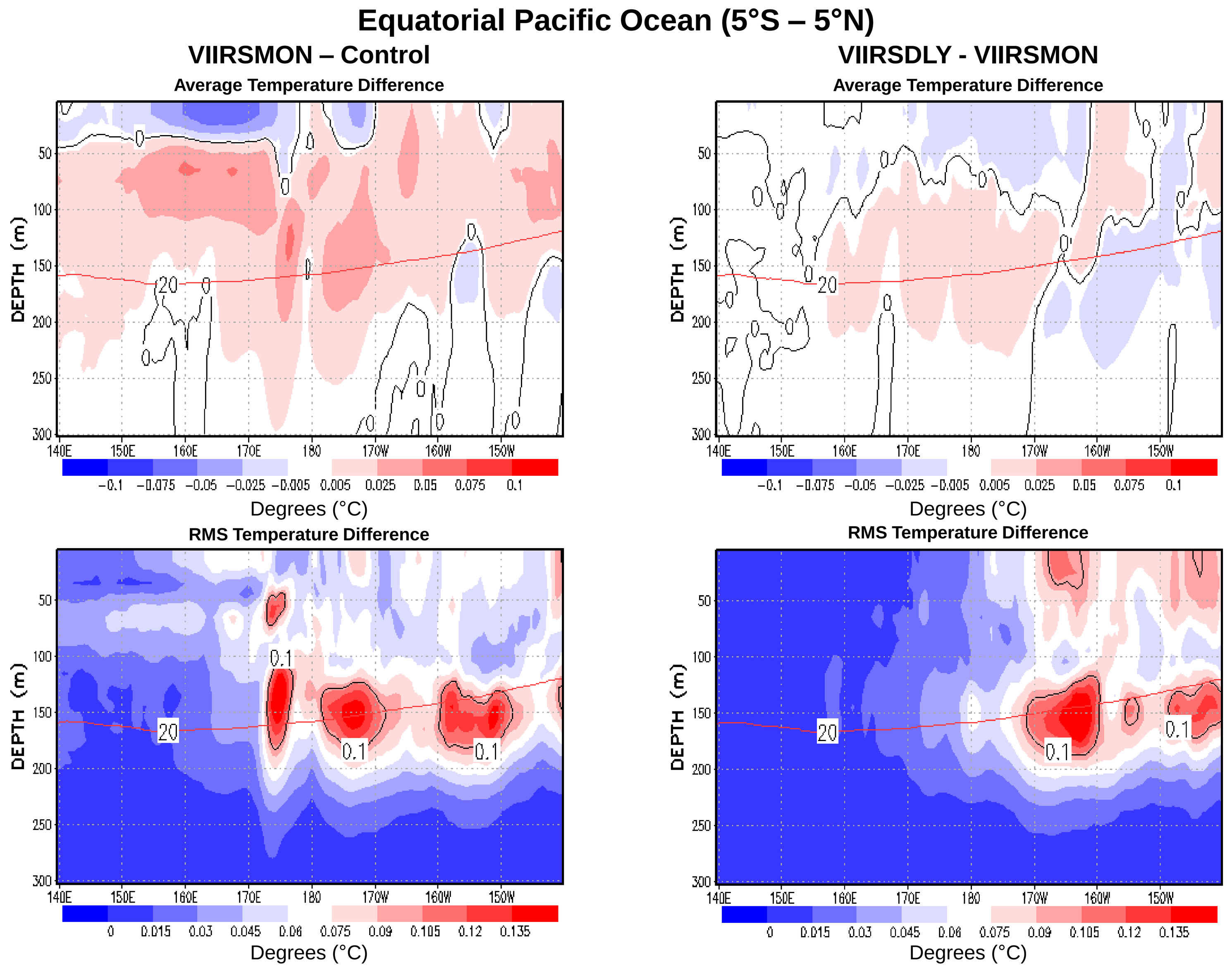

Fig. 3. Temperature differences (°C) for the equatorial Pacific Ocean: VIIRSMON minus CONTROL (average, upper left; RMS, lower left); VIIRSDLY minus VIIRSMON (average, upper right; RMS, lower right). The red line depicts the average depth of the 20°C isotherm in the CONTROL run.

Model sensitivity to changes in chlorophyll is also reflected in the model's sea-surface height (SSH), an indicator of heat content changes. Figure 4 highlights SSH differences for the equatorial Pacific Ocean (5°S-5°N) resulting from differences between the VIIRS data and the SeaWiFS climatology, as well as additional differences from increasing temporal resolution from monthly to daily. The additional differences attributed to daily chlorophyll increments are roughly half as large as those due to the differences between the VIIRS monthly-mean data and the control case's SeaWiFS climatology.

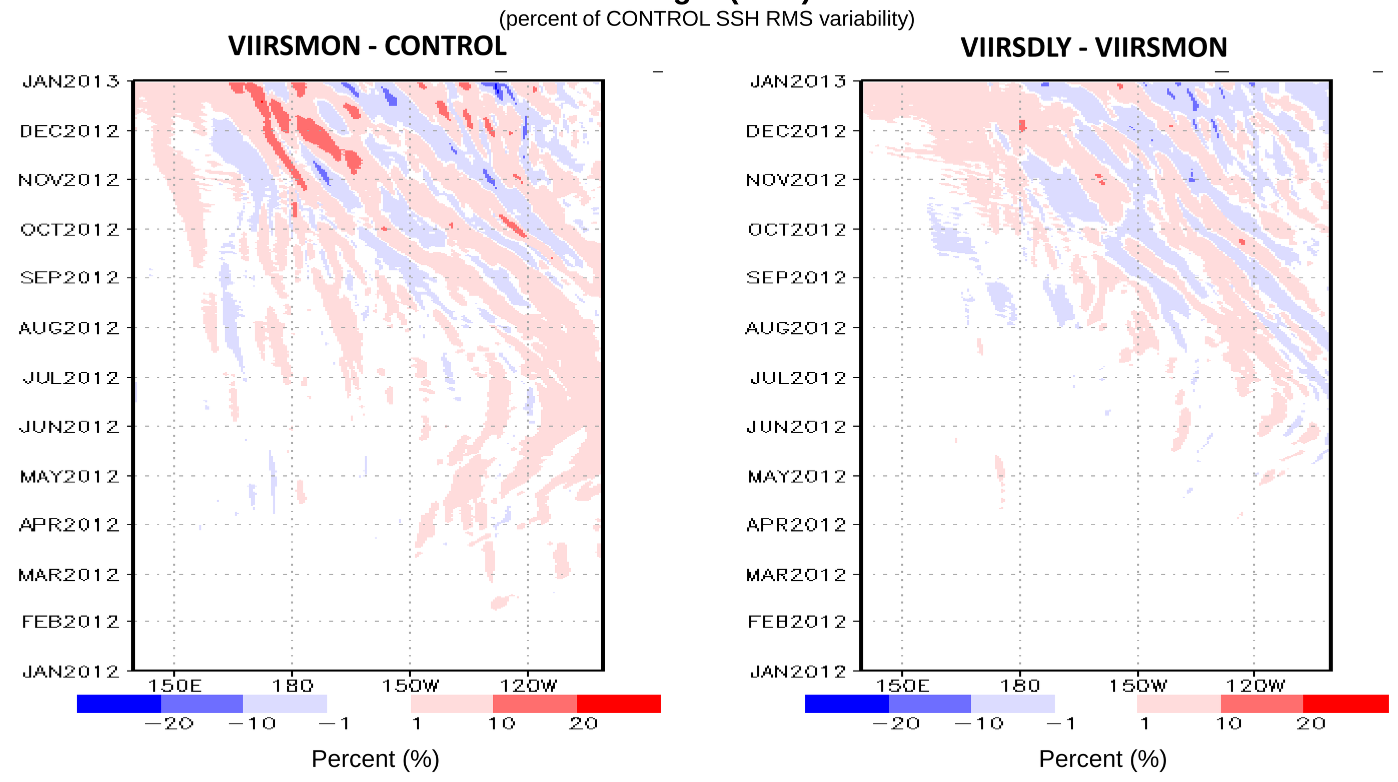

Fig. 4. Sea-surface height (SSH) differences for the equatorial Pacific Ocean (5°S-5°N), expressed as percentages of the RMS of SSH variability in the CONTROL run: VIIRSMON minus CONTROL (left); VIIRSDLY minus VIIRSMON (right).

Verification: Model SSH RMS Differences Referenced to Altimeter Data

For verification, the basic sea-surface height (SSH) structure for the CONTROL case is first compared to satellite altimetry data. Figure 5 depicts, in terms of RMS differences, the SSH variability of the model CONTROL case alongside altimetry data variability. The simulation appears to generally capture the major spatial patterns shown in altimetry, with the altimetric data showing more small-scale features. Model resolution contributes to the smoothing of small-scale features. Figure 6 further compares the VIIRSMON and VIIRSDLY cases by subtracting the relevant RMSE fields to depict differences, between the VIIRSMON and CONTROL cases and the additional differences between the VIIRSDLY and VIIRSMON cases. The use of VIIRS chlorophyll data reduces RMSE in the equatorial wave guide region by about 5%, which is important for seasonal forecasts.

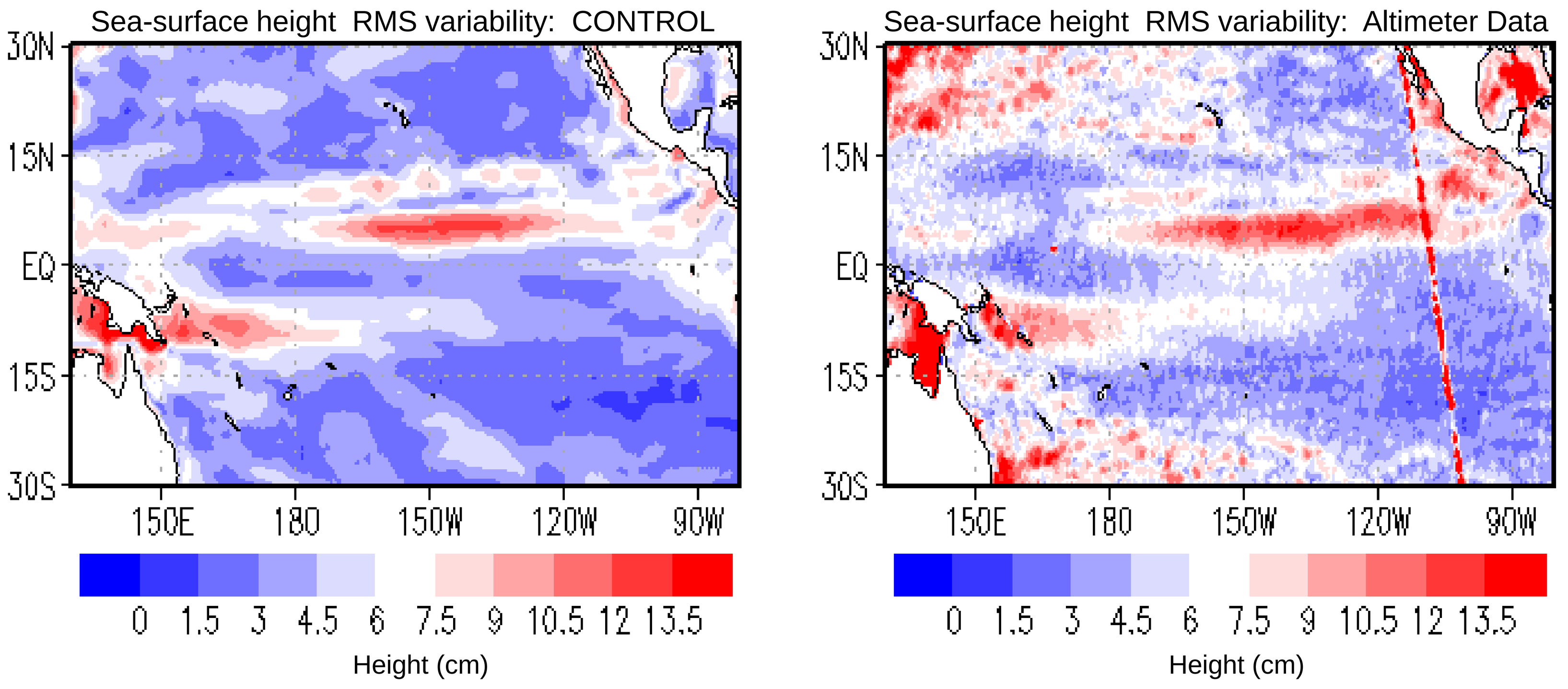

Fig. 5. Sea-surface height (SSH) RMS variability (cm) for the tropical Pacific ocean: CONTROL (left); altimeter data (right).

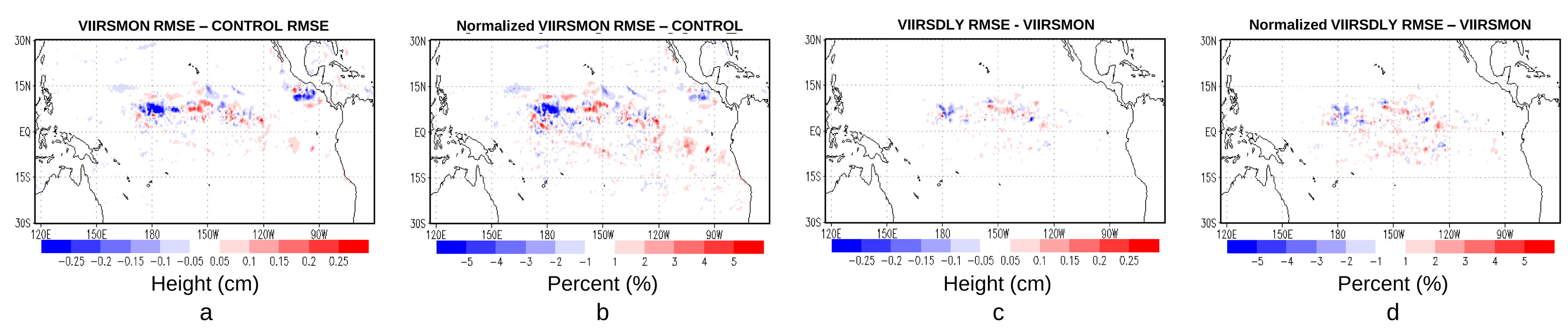

Fig. 6. Difference between model case SSH RMSE, referenced to altimetry data: VIIRSMON RMSE, referenced to altimetry data, minus CONTROL RMSE, referenced to altimetry data: a) centimeters, b) percentage, normalized by CONTRL RMSE referenced to altimetry data; VIIRSDLY RMSE, referenced to altimetry data, minus VIIRSMON, referenced to altimetry data c) centimeters, d) percentage, normalized by CONTRL RMSE referenced to altimetry data. Blue represents reduction in RMS error.

Sea-surface height changes are the surface manifestation of changes in both dynamics and heat content; consequently, examining upper-ocean heat content further focuses on the impact of chlorophyll differences and provides insight on changes in the interior of the ocean. The ocean heat content resulting from full assimilation of *in situ* and remotely-sensed observations provided NOAA's operational GODAS served as the reference state. Figure 7 depicts the percent heat, referenced to CONTROL case RMS differences with respect to the GODAS.

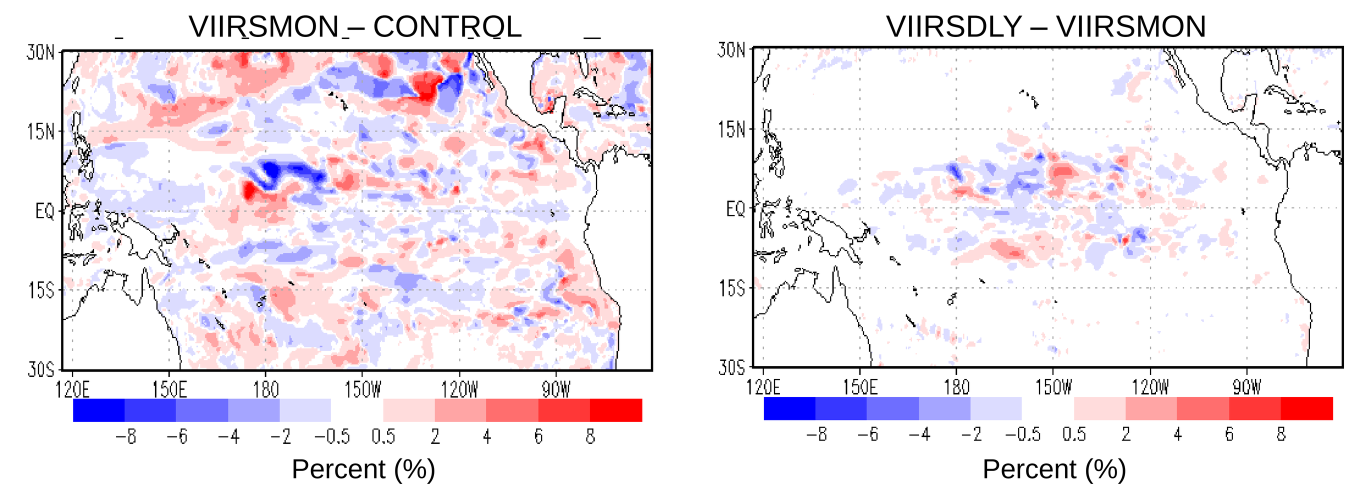

Fig. 7. Ocean Heat Content (OHC), computed from 0-300m, normalized RMS Error differences referenced to GODAS ocean heat content (GODAS_OHC): VIIRSMON RMSE minus CONTROL RMSE (left); VIIRSDLY RMSE minus VIIRSMON RMSE (right). Normalized by CONTROL RMSE referenced to GODAS_OHC. Blue represents reduction in RMS error.

Summary and Conclusions

- The model simulations respond to which ocean color fields are employed.
- The limited duration of VIIRS data (2012 only) limits making firm conclusions, complicated by an inadequate number of Tropical Atmosphere-Ocean (TAO) array buoys being operational during 2012, limiting *in situ* verification.
- The RMSE differences show that the VIIRSDLY modestly outperforms the other cases in the tropical Pacific ocean.
- These cases demonstrate that employing sequential VIIRS chlorophyll-a data improves model performance with respect to using the current limited-duration SeaWiFS monthly-mean climatology
- Employing monthly sequential VIIRS chlorophyll-a data provides about a 5 percent reduction in RMS error, with daily sequential VIIRS chlorophyll-a data providing an additional 2 to 3 percent decrease in RMS error.

References:

- Behringer, D.W., 2007, "*The global ocean data assimlation system at NCEP,*" in 11th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, American Meteorological Society 87th Annual Meeting, San Antonio, TX.
- Saha, et al., 2010, "The NCEP Climate Forecast System Reanalysis," *Bull. Amer. Meteor. Soc. (19) 1015-1057*.
- Joint Polar Satellite System (JPSS) Ground Project 474-00035, *"Joint Polar Satellite Systems (JPSS) VIIRS Ocean Coilor/Chlorophyll Algorithm TheorteticalBasis Document ATBD,"* Goddard Space flight Center, Greenbelt, Maryland, 22 April 2011.
- Leuliette, E., and R. Scharroo, 2010, "Integrating Jason-2 into a Multiple-Altimeter Climate Data Record," *Marine Geodesy* 33(S1): 504-517.

Email: sudhir.nadiga@noaa.gov, (301) 683-3751