Climate Prediction Center Analyses and Monitoring in Support of the Ocean Observing System for Climate

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Table of Contents

1. Project Summary 1
2. Scientific and Observing System Accomplishments 2
3. Outreach and Education 12
4. Publications and Reports 14
   4.1. Publications by Principal Investigators 14
   4.2. Other Relevant Publications 15

1. Project Summary

Ocean plays a crucial role in controlling global climate variability, and thereby, influences various facets of society. The ocean's control on the atmosphere extends from weather to climate on seasonal, decadal and centennial time-scales, and to diverse phenomenon such as weather and climate extremes, droughts, floods. As a consequence, oceans play an important role in influencing societal well-being, e.g., food security, marine transportation, prediction of droughts and floods etc. Due to their large thermal inertia, and a spatial coverage of ~70% of the surface of the globe, ocean monitoring is also a key to understanding and anticipating the potential influence of human induced change in the Earth System, and is the place where such influences would be first detected with confidence.

Given the importance of ocean climate variability, the fundamental outcome of this project - *disseminating a synthesis of the state of the global oceans* – is to deliver ocean information and data sets to the user community to (a) provide a basis to make informed decisions to either mitigate or to take advantage of the consequences resulting from the ocean climate variability (e.g., El Niño-Southern Oscillation), (b) enable science to improve understanding of ocean climate variability and its causes, and (c) keep a pulse of slowly evolving changes in the ocean. The importance of this project is underpinned by the fact that raw ocean observations do not provide a synthesis view of the state of the ocean, and it is the process of converting individual observations into a form that could be easily understood is required for an end-to-end ocean climate information system.

This project is an ongoing partnership between the Office of Climate Observations (OCO) of the Climate Program Office (CPO) and the Climate Prediction Center (CPC) with a focus on the development, maintenance, and dissemination of *real-time ocean monitoring information and products* to the user community. The real-time ocean products disseminated as part of this project rely critically on the ocean climate observing system supported and maintained by the OCO, and provide a *synthesis of the state of the global oceans, together with real-time monitoring of ocean climate variability on different time-scales*. The outcomes of the project are crucial for an end-to-end ocean climate delivery information system that connects gathering of the ocean observations (supported by the OCO) to the dissemination of readily usable ocean products to global user community in real-time. Project outcomes also facilitate NOAA goal to accomplish its societal challenge (a) to mitigate and adapt to vulnerability to weather and climate extremes that are influenced by oceanic variability, and (b) advance understanding and prediction of droughts, floods, and water resources.

2. Scientific and Observing System Accomplishments

2.1. Sub-Task 1: Development and maintenance of a web-site for routine delivery of ocean monitoring and forecast products

The Global Ocean Data Assimilation System (GODAS) website, hosted by the CPC, serves the global user community with real-time ocean monitoring and ocean prediction products. The web-site also provides access to the GODAS data sets that can be used for (a) improved understanding of ocean climate variability, and (b) validating different *in situ* ocean observing systems. Starting from 1979 onwards, the web site contains plots of climatology and anomalous fields of various oceanic variables over different basins of the global ocean, and covers time scales from weekly to interannual to decadal.

Under this sub-task, specific work items and products delivered were:

Maintain the GODAS website and respond to user's requests: We continued to maintain the ocean monitoring website to disseminate the real-time ocean climate information to the user community. Components of ongoing activities included: routine maintenance of the ocean product delivery web-site; monitoring website statistics (Fig. 1); providing responses to the user queries in a timely manner.

Deliverable: Real-time ocean climate information to the global user community, for example, SST, OHC, air-sea exchanges of heat, momentum and fresh water, sea level.

Maintain "Monthly Ocean Briefing: To synthesize available ocean information, we hosted the "Monthly Ocean Briefing" (MOB), which is an expert assessment of the recent evolutions of the state of ocean, and ocean forecasts delivered via a conference call around the 7th day of each month. We solicited feedbacks on the ocean briefing, and included additional analysis as needed to address unique climate events. In addition, we monitored the data return status of the TAO mooring arrays and explored impacts of missing TAO data on the GODAS ocean analysis and discuss potential implications for ENSO prediction.

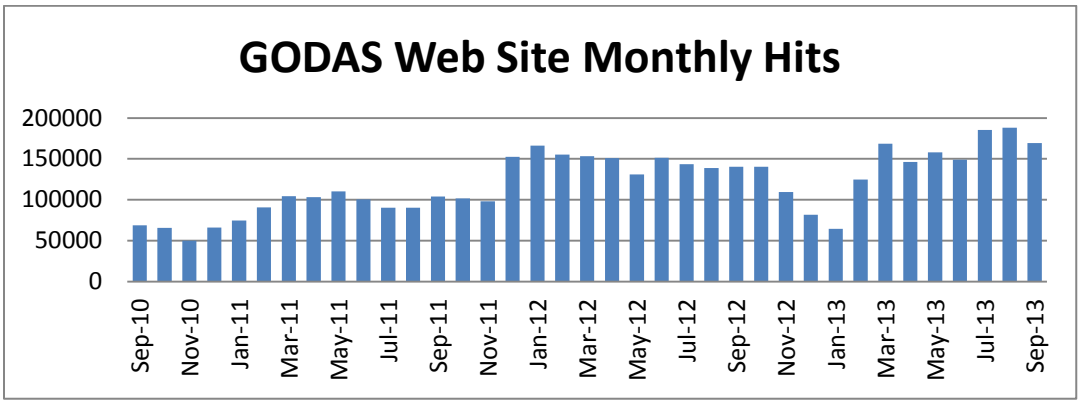

Fig. 1. Number of monthly hits on the GODAS web site from September 2010 to September 2013.

To improve our understanding and prediction of ENSO, we developed *new ENSO monitoring tools* incorporating recent advances in the understanding of ENSO. For example, we noted that the warm water volume (WWV) index, a measure of warm water pool above the depth of 20 degree isotherm (D20), is no longer a good precursor for ENSO development since 2000. We then examined the relationship between D20 variations and El Niño and La Niña events separately for the period before and after 1999. The analysis suggests that D20 variation in the central tropical Pacific is a good precursor for ENSO events for the two periods, while the WWV index is a good precursor only before 1999. We also found the decadal changes in the relationship between D20 and ENSO to be associated with a strengthening of subtropical cell circulation around 1999..

Deliverable: An expert assessment of the recent evolutions of the state of global oceans and ocean forecasts on a monthly basis.

Maintain "Annual Ocean Review" and lead the SST section in the BAMS Annual Climate Report: In early February 2013, we provided an "Annual Ocean Review" (AOR) summarizing the major features of the state of global oceans in 2012, and led SST section in the Ocean Chapter. The AOR included a set of GODAS-based analysis to mimic the plots in other sections in the Ocean Chapter of the BAMS Annual Climate Report.

Deliverable: Annual contribution to the "Ocean Chapter" of the BAMS Annual Climate Review.

Participation in the CLIVAR GSOP/GODAE OceanView reanalyses intercomparison project: The CLIVAR Global Synthesis and Observations Panel (GSOP) and GODAE OceanView jointly initiated a community effort to conduct inter-comparison among ocean reanalyses and to evaluate uncertainties and consistencies in many physical fields such as ocean heat content, sea surface steric height, mixed layer depth and surface fluxes. We contributed monthly fields from GODAS, Climate Forecast System Reanalysis (CFSR) and NCEP reanalysis 2 (R2) from 1979 to 2011. Detailed intercomparison results for each variable will be presented at the GODAE OceanView Symposium to be held on November 4-6, 2013 in Baltimore, Maryland.

Another goal GSOP/GODAE ocean reanalysis intercomparison project is to explore the possibility to develop climate indices using operational ocean reanalyses for real time ocean monitoring (Xue et al. 2012). We plan to actively participate in the effort led by GSOP/GODAE.

Deliverable: Understand uncertainties in ocean reanalyses and needs for global ocean observing systems in reducing ocean reanalysis uncertainties.

Validating CFSR, NCEP reanalysis 1 (R1) and R2 surface fluxes using the OceanSite data: In FY13, in collaboration with Dr. Meghan Cronin at PMEL, we compared the CFSR, R1 and R2 surface heat flux with data from Kuroshio Extension Observatory (KEO), an ocean reference site. We found that latent heat flux (LHF) and sensible heat flux (SHF) to be substantially improved in the CFSR compared to earlier NCEP reanalysis data R1 & R2 (Fig. 2). Further analysis suggested that improvement in wind speed and specific humidity were the major factors contributing to improved CFSR LHF and SHF.

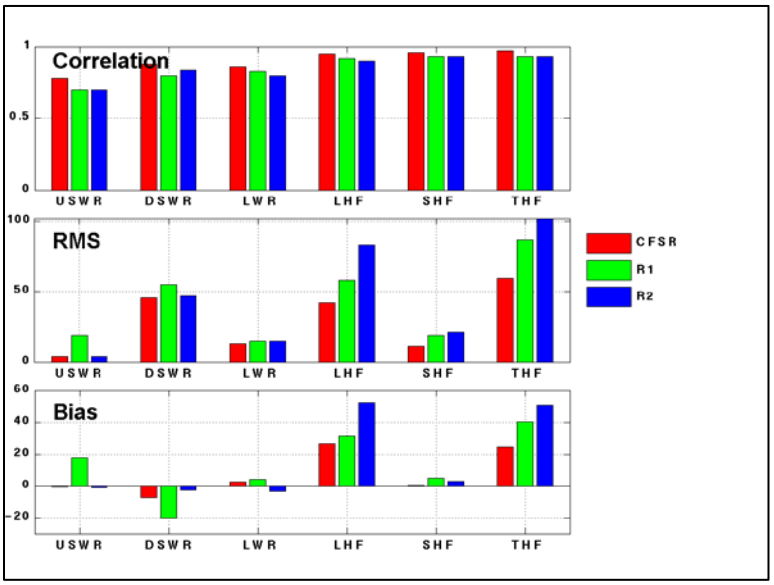

Fig. 2. Anomaly correlation, root-mean-square (RMS) error and bias (W/m^2) of CFSR (red bar), R1 (green bar) and R2 (blue bar) with KEO surface heat fluxes in 2004-2010. Surface fluxes are upperward short wave radiation (USWR), downward short wave radiation (DSWR), long wave radiation (LWR), latent heat flux (LHF), sensible heat flux (SH) and total heat flux (THF).

Deliverable: Utilization of in situ measurements at selected ocean reference sites to validate models

2.2. Sub-Task 2: Development of an Ocean Observing System Evaluation (OSE) capability and assessment of the utility of the TAO array

In FY13, we led a NOAA effort in coordinating an OSE capability based on multi-analysis approach. The requirement for this activity stems from (a) resource limitations on the maintenance of TAO moored array in the equatorial tropical Pacific, and (b) possibility of alternate observing systems that may provide adequate replacement for observational gaps if the

TAO array cannot be sustained. Informed decisions about the observing system need to have a sound scientific basis to ensure that NOAA's monitoring and prediction requirements in the tropical Pacific are maintained. Towards this, a multi-analysis approach OSE capability to gain confidence in OSE is essential.

We conducted coordinated OSEs and hindcast experiments using the NCEP and GFDL ocean data assimilation systems and seasonal forecast models for the post-Argo period 2004-2011. Four OSE runs were made with the NCEP Global Ocean Data Assimilation System (GODAS) and GFDL Ensemble Coupled Data Assimilation (ECDA), in which no observations (CTL), all observations (XBT, moorings, Argo) (ALL), all except the moorings (noTAO), and all except the Argo (noArgo) data are assimilated. We evaluated the mean bias, annual cycle, standard deviation, RMSE and anomaly correlation coefficient (ACC) against observations. The relative importance of Argo and TAO data on simulation of SSHA in ECDA and GODAS was also evaluated.

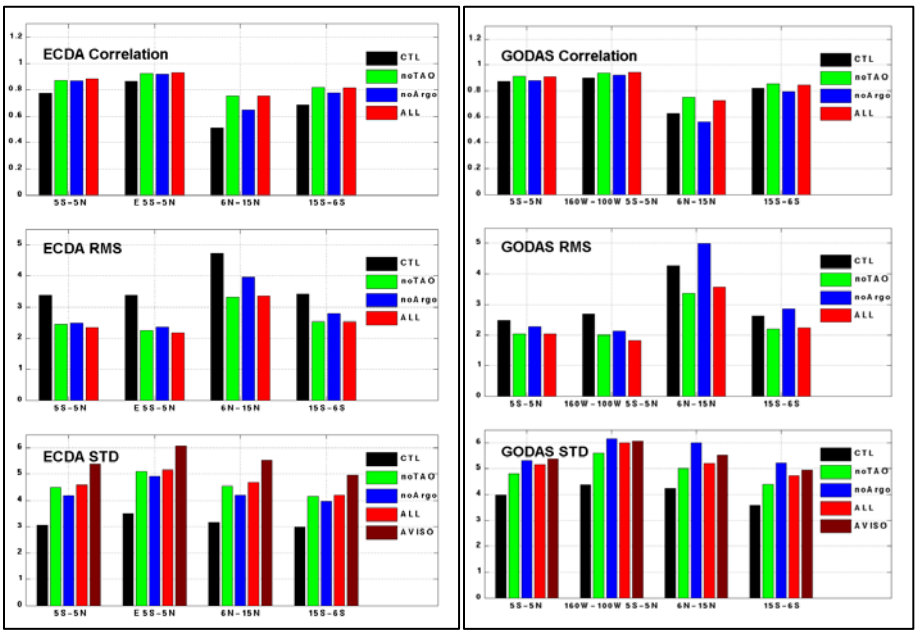

Fig 3. Anomaly correlation coefficient (ACC) (top row) and root-mean-square error (RMSE) (middle row) with Aviso sea surface height anomaly (SSHA) in 2004-2011 for ECDA (left column) and GODAS (right column) OSEs. The bars show the average of ACC and RMSE in each region labeled on the x-axis. The bottom row shows standard deviation (STD) of SSHA from OSEs and Aviso. The bars show the average of STD in each region labeled on the x-axis.

Preliminary analysis of OSE indicates that data assimilation is needed to realistically simulate the amplitude of SSH variability. For example, the mean standard deviation (STD) in the equatorial Pacific was underestimated by 43% in ECDA CTL and 26% in GODAS CTL. Assimilation of TAO while not Argo (noArgo) was particularly helpful in improving STD in

GODAS. However, STD of SSHA is underestimated by 15% in ECDA even when both TAO and Argo are assimilated (ALL, red bars). The situation is similar off the equator except in GODAS in which STD is overestimated in noArgo (blue bars). In summary, data assimilation is necessary to realistically simulate the amplitude of SSH variability, and the TAO data is particularly helpful for a realistic simulation of the amplitude of SSH variability in the eastern tropical Pacific where ENSO variability is the strongest.

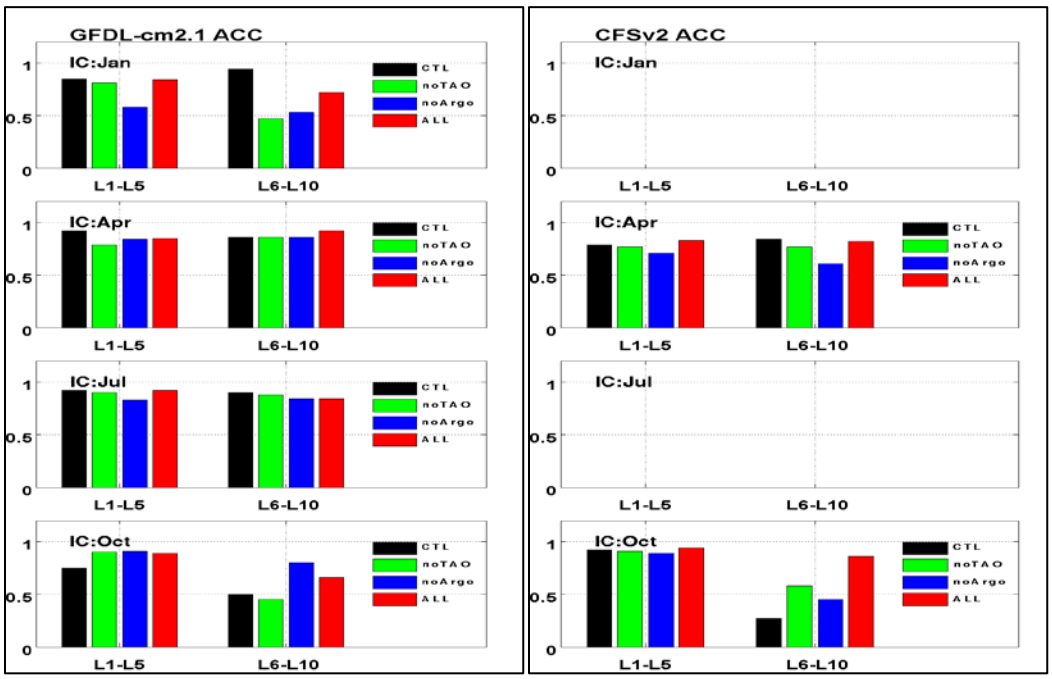

Fig. 4. Anomaly correlation of hindcast NINO3.4 of CM2.1 (left) and CFSv2 (right) starting from January 1, April 1, July 1 and October 1 in 2004-2010 initialized with CTL (black), noTAO (green), noArgo (blue) and ALL (red).

The impacts of ocean initialization on hindcast skill is being investigated using various skill measurements such as ACC, RMSE, absolute error and MSSS. The ACC for seasonal mean SST is calculated for each initial month and averaged over lead months 1-5 and lead months 6-10 (Fig. 4). For GFDL CM2.1, the ACC for January 1 I.C. is highest starting from CTL when both TAO and Argo are not included, particularly at long lead time when spring barrier is crossed. Although this suggests that including more data such as TAO and Argo may not help prediction to across spring barrier, it needs to be investigated further. For April 1 and July 1 I.C., the ACC of CM2.1 is insensitive to ocean initialization. On the other hand, for April 1 I.C., the ACC of CFSv2 is lowest when Argo is excluded. For October 1 I.C., both CM2.1 and CFSv2 suggest that including TAO or Argo help improve prediction skill. CM2.1 suggests that excluding TAO hurts skill more than excluding Argo. On the other hand, CFSv2 suggests that excluding Argo hurts skill more than excluding TAO, and the highest skill is achieved by including both TAO and Argo.

Deliverable: Development of a NOAA capability for Ocean Data Assimilation Experiments for assessing the utility of various oceanic observing system, particularly in the Tropical Pacific.

2.3. Sub-Task 3: Global oceanic precipitation and SSS analyses in support of understanding air-sea exchange of fresh water and its influence on surface salinity

During FY13, we continued our efforts to update and improve our precipitation analyses. We developed a prototype technique and applied it to construct a global oceanic SSS analysis for a three-year period from 2010 to 2012 through blending information from *in situ* measurements and satellite observations, and examined the relationship between SSS and oceanic fresh water flux to evaluate physical consistency among them.

Under this sub-task, specific work items and deliverables were:

CMORPH Global Precipitation Analyses: During FY2013, our efforts on the CMORPH satellite precipitation estimates focused on two major tasks: a) to reprocess CMORPH using input satellite from five additional satellites, and b) to adjust the raw CMORPH satellite estimates against an extended precipitation record of coarser resolution to facilitate long-term climate and oceanic applications.

The CMORPH integrated satellite precipitation estimates are generated on a real-time basis using all input satellite data available at the production time. Due to various technical limitations, input data from five satellites, including NOAA 15, 16, 17, the Chinese FY3B and the Japanese METOP-B, are not available on a real-time basis, and therefore, not included in the CMORPH production. Lack of the sampling from as many as five satellites substantially compromised the quality of the CMORPH precipitation products, especially in quantifying the high-frequency components of the oceanic fresh water flux and its impacts to the sea surface salinity and oceanic circulations. Tremendous efforts were made during FY2013 to collect the satellite data from various satellite centers and to ingest them into the CMORPH for an eight year period from 1995 to the present. As a result, the high-quality, high resolution CMORPH satellite estimates are now available for a 15-year period from 1998 to the present.

The above mentioned reprocessed CMORPH satellite precipitation estimates were also adjusted against the pentad GPCP analysis to facilitate applications in long-term climate and oceanic analysis studies. To this end, CMORPH precipitation estimates at their raw resolution (30-min, 8kmx9km) were up-scaled to the pentad GPCP resolution of 2.5^{o} lat/lon and 5-day. The raw CMORPH precipitation estimates were then adjusted against the pentad GPCP analysis through matching the cumulative probability density function (CPDF) of CMORPH against that of the pentad GPCP (Fig. 5).

CMAP global precipitation analyses: In FY2013, we continued our efforts to update the legacy monthly and pentad CMAP precipitation analyses and developed OLR-based daily precipitation estimates for use as the primary input to the a new version of CMAP merged precipitation products on a higher time and space resolution.

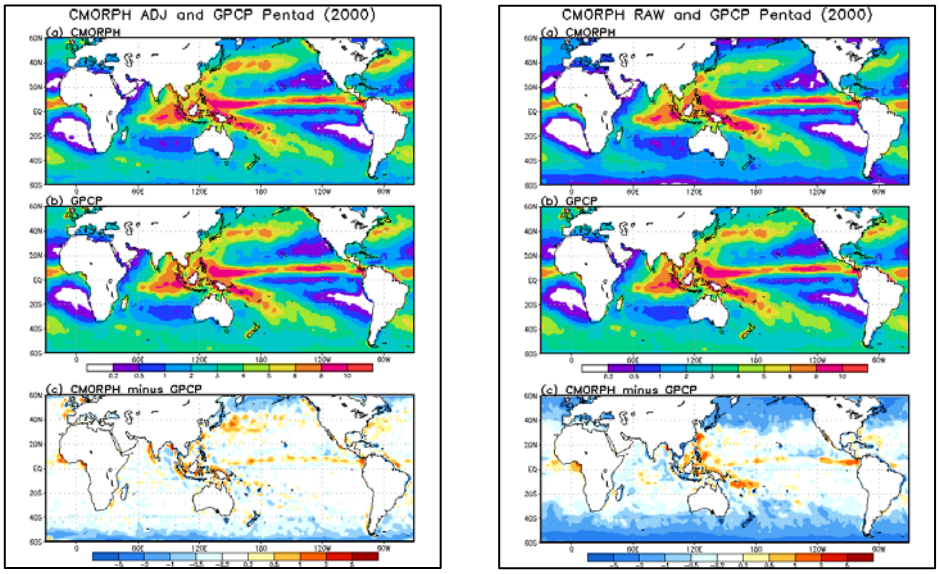

Figure 5: CMORPH (top) and pentad GPCP (middle) annual mean precipitation (mm/day) for 2000 and their differences (bottom). Results for the raw CMORPH satellite estimates and the adjusted CMORPH are presented on the left and right columns, respectively.

Key to the construction of the new CMAP was the development of a long-term satellite precipitation estimates on a finer time and space resolution covering the global regions from 1979 to the present. Our original plan was to develop a precipitation estimate taking advantage of the infrared (IR) data from geostationary satellites collected and edited through the Climate Data Record Program (CDR) of National Climatic Data Center (NCDC). Preliminary investigation, however, revealed some problems in association with incomplete spatial coverage and less-than-desirable calibration. We therefore revised our plan to develop a satellite-based precipitation estimates from the HIRS OLR data homogenized by Dr. H.-T. Lee of University of Maryland.

Instantaneous observations of HIRS are first binned onto a 0.25^{o} lat/lon grid over the globe. A regionally dependent and seasonally changing OLR – precipitation relationship was then established through matching the CPDF of the instantaneous OLR against that for the CMORPH precipitation using co-located HIRS OLR and CMORPH precipitation over a 15-year period from 1998 to the present. The OLR – precipitation relationship was then applied to estimate instantaneous precipitation rate from the HIRS OLR from individual satellite observations. The precipitation estimates for individual satellite scans were then integrated to form an analysis of satellite OLR based daily precipitation on a 0.25^{o} lat/lon grid over the globe for a 35-year period from 1979 to 2012. As illustrated in Fig. 6, the HIRS OLR based precipitation estimates exhibit good skill in capturing and quantifying precipitation over the global oceans and land. Although precipitation estimates taking advantage of passive microwave observations such as the CMORPH have superior quantitative accuracy and refined spatial resolution, they were available only for recent years from 1988. Development of the OLR-based daily precipitation estimates

extended the record of high resolution precipitation back to 1979, enabling a variety of climate research and applications in the fresh water flux and its interaction with ocean and atmosphere.

The HIRS OLR based global daily precipitation estimates developed at NOAA Climate Prediction Center (CPC) under support from the NOAA Climate Program Office (CPO) is the very *first* daily precipitation product that covers a 35-year time period from 1979. This data set will be used as the primary input to the construction of the new version CMAP that is the ultimate goal of this part of our project.

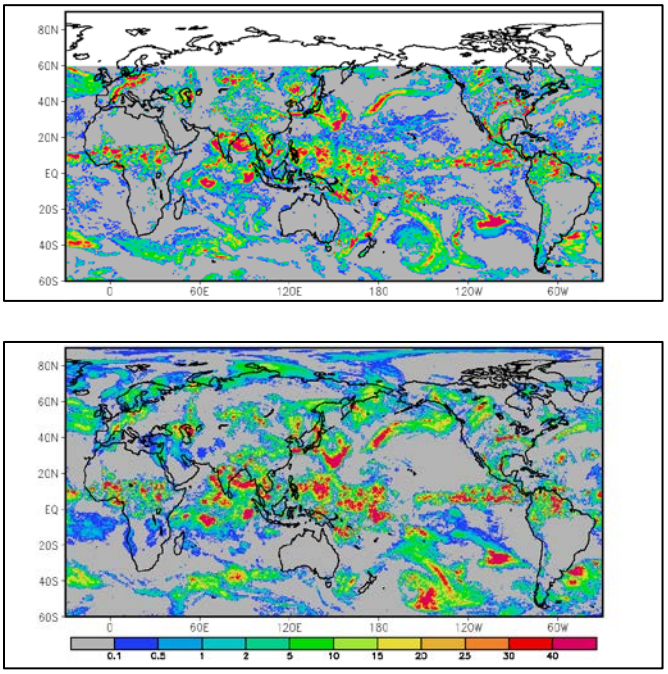

Figure 6: Daily precipitation (mm/day) for July 1, 2012, derived from, (top) the CMORPH satellite precipitation estimates, and (bottom) the HIRS OLR-based estimates.

Construction of a blended analysis of sea surface salinity (SSS) over the global oceans: In FY2103, we completed the development of the prototype blending technique and constructed a blended sea surface salinity (SSS) analysis on a 1° lat/lon grid over the global ocean over a three year period from 2010 to 2012. The prototype blending algorithm produces the global SSS analysis in two steps. First, bias in the satellite retrievals is removed by matching the cumulative probability density function (CPDF) of the satellite retrievals against that of the co-located *in situ* measurements. The blended SSS analysis is then defined through an optimal interpolation (OI) approach, in which the analysis for the last time step is used as the first guess while the in situ buoy measurements and the bias–corrected satellite retrievals are employed as the observations to update the first guess.

The input data we take include the *in situ* measurements of SSS collected and edited at National Oceanographic Data Center (NODC) and the SSS satellite retrievals derived from the Soil Moisture and Oceanic Salinity (SMOS) of European Space Agency (ESA) and the Aquarius

satellite of National Aeronautics and Space Agency (NASA). A set of procedures were developed to identify and remove suspicious input data from the satellite SSS retrievals through comparisons with the medians of the SSS retrievals from the individual satellites and against concurrent observations of SST and in situ SSS measurements. Bias in the quality controlled satellite SSS retrievals are then removed through matching the cumulative probability density function (CPDF) of the satellite retrievals against the *in situ* measurements. The bias correction is performed for each of the two satellite retrievals (SMOS and Aquarius), for each grid box of 1° lat/lon and for each month using co-located satellite and in situ data over a 5-month period centering at the target month and over a spatial domain centering at the target grid box. The spatial domain was expanded until sufficient number of *in situ* – satellite data pairs were secured for stable CPDF tables.

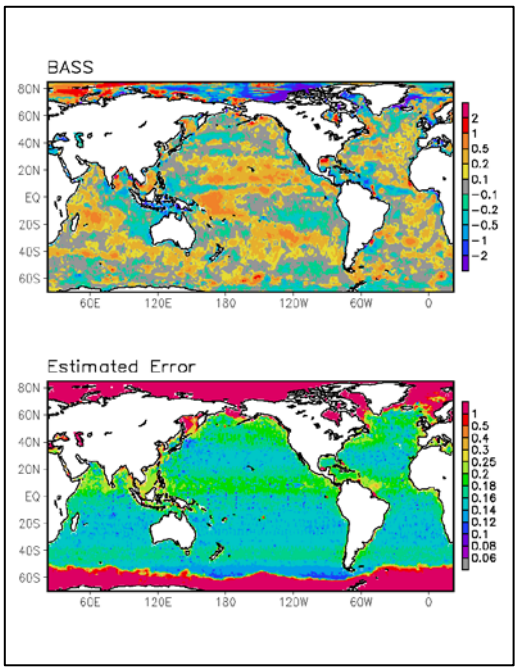

Figure 7: Anomaly of global sea surface salinity (SSS, psu) for October 2011, derived from the prototype NOAA Blended Analysis of Surface Salinity (BASS, top), as well as estimation of the analysis error for the month (bottom, psu).

The bias-corrected satellite SSS retrievals were further combined with the *in situ* measurements through the optimal interpolation (OI) framework to produce the final blended analysis of oceanic salinity. In this procedure, the SSS analysis for the previous time step was used as the first guess, while the in situ measurements and the bias-corrected satellite retrievals were employed as the observations to update the first guess. Error estimation was defined for the in situ measurements and the satellite retrievals as a function of sampling size, season and location. Cross validation tests were conducted for the bias correction and the OI blending procedures, respectively, through comparisons of the bias correction and the blending results against in situ measurements withdrawn from the procedures. The results showed that the bias corrected satellite retrievals with substantially reduced mean bias and close agreement in the PDF against the in situ measurements, while the OI blending procedure improves the quality of the resulting SSS analysis, with reduced random error and refined correlation (Fig. 7; Table 1).

a) Tropics (20°S-20°N)

Statistics	SMOS	Aquarius	Blended Analysis
Bias (PSU)	0.005	0.014	0.008
RMS Error (PSU)	0.323	0.289	0.216
Correlation	0.507	0.586	0.686

b) Globe (90°S-90°N)

Statistics	SMOS	Aquarius	Blended Analysis
Bias (PSU)	-0.001	0.010	0.006
RMS Error (PSU)	0.315	0.290	0.205
Correlation	0.407	0.495	0.628

Table 1: Cross-validation Statistics for the Satellite Retrievals and the *In situ*–Satellite Blended Value

The prototype algorithm described above was applied to construct blended analysis of sea surface salinity on a 1° lat/lon grid over the ocean for a three year period from January 2010 to December 2012. The SSS analysis, called NOAA Blended Analysis of Surface Salinity (BASS), is now available through ftp at the NOAA Climate Prediction Center (CPC) server. An automatic processing system is being developed at NOAA/CPC to produce the blended SSS analysis on a real-time basis.

Diagnostic study of SSS - fresh water flux relationship: Construction of the blended analysis of SSS provides a unique opportunity to examine the SSS – fresh water flux relationship over the global ocean. During FY2013, we examined the co-variability among SSS evaporation and precipitation in association with the evolution of ENSO using the SSS data from our blended analysis, precipitation from CMORPH and the evaporation data from OAFlux for the three year period from 2010 to 2012. As shown in Figure 8, SSS variation is dominated largely by precipitation over tropical and sub-tropical oceans. In particular, SSS–precipitation correlation is the strongest (approximately -0.8) over the equatorial western Pacific Ocean, suggesting the dominance of fresh water flux in determining the SSS in this region. Evaporation anomalies exhibit much weaker correlation with the SSS anomalies (Fig. 8, bottom).

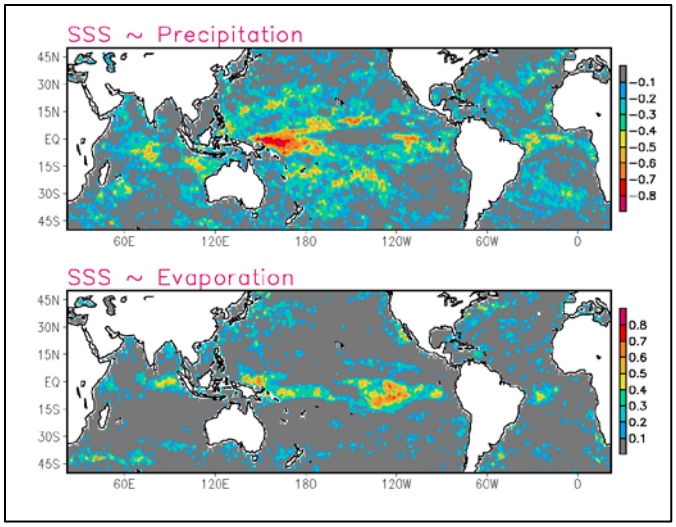

Figure 8: Anomaly correlation between the monthly SSS and precipitation anomaly (top) and that between the monthly SSS and evaporation anomaly (bottom) computed for a 36-month period from January 2010 to December 2012. Monthly SSS, precipitation and evaporation data are from BASS, CMORPH and OAFlux, respectively.

A combined EOF analysis was performed for the standardized SSS, precipitation, and evaporation anomaly fields for the 36-month period January 2010 through December 2012. Despite the relatively short time period, the first mode of the EOF reveals a physically coherent pattern of SSS and fresh water flux variations in association with the evolution of ENSO -- a decrease in precipitation, coupled with enhanced evaporation, increases the SSS in the equatorial western Pacific and tropical Indian Oceans. Over the equatorial Atlantic Ocean, excessive precipitation overwhelmed increased evaporation, resulting in a net decrease in the SSS. Reduced evaporation over the southeast Pacific dry zone, however, did not yield freshened sea water over the entire region, suggesting importance of other freshwater components and oceanic processes in determining the surface salinity there.

3. Outreach and Education

3.1. Ocean Products

We served a broad user community for our global ocean monitoring products. Through our "Monthly Ocean Briefing" we continued to maintain a relationship with users. Following are a few examples signifying the impact of deliverables under this project:

- The ocean briefing was attended by many colleagues from NOAA and academia (the ocean expert team of NOAA, Dr. David Legler, Dr. Diane Stanitski, Dr. Klaus Weickmann, Dr. Frank Schwing, Dr. Mike McPhaden, Dr. David Enfield, Dr. Nick Bond, Dr. Kevin Trenberth, Dr. Tim Boyer, Dr. Syd Levitus, Dr. Dick Crout, Dr. Richard Bouchard, Dr. Jame Kinter, Dr. Bohua Huang, Dr. Ed Schneider, Dr. David Dewitt, Dr. Tony Rosati, Dr. Gabriel Vecchi, Dr. Andrew Wittenberg, Dr. Charles Stock, Dr. Marty

Hoeling, Dr. Mike Alexander, Dr. Lisa Goddard, Dr. Tony Barnston, Dr. Michele Rienecker , Dr. Shanping Xie, Dr. Chunzai Wang, Dr. Weidong Yu).

- The ocean briefing plots have been used by a broad user community in private sectors, operational centers, and academic institutions. Particularly, those plots have been used as teaching materials for high school, college and graduate students, according to Dr. Bohua Huang and Dr. Ed Schneider.
- The ocean briefing plots are also routinely used by CPC's operational predictions, e.g. ENSO prediction, Atlantic hurricane seasonal prediction and seasonal predictions for U.S. temperature and precipitation, and they are also used by the Intra-Americas Study of Climate Processes (IASCLiP) Forecast Forum (http://www.eol.ucar.edu/projects/iasclip).
- The "Annual Ocean Review" plots are used by the ocean expert team of NOAA in the preparation of the Ocean Chapter in the BAMS Annual Climate Report.

The research works supported by this project has been reported in various peer reviewed journals, conferences, and workshops. The well-known works include studies of the mixed layer heat budget and AMOC variations using GODAS, an assessment of the CFSR ocean component, a comparative analysis of ensemble operational ocean reanalyses, and studies of prediction skill and predictability of ENSO and PDO.

3.2. Precipitation Products

Two primary deliverables of this component are the CMAP and CMORPH precipitation analyses. The low-resolution, long-term (from 1979) CMAP data set is widely used in operations for the monitoring of global precipitation and in research to examine climate variability and air-sea interactions, and to force oceanic models. Two papers describing the CMAP data set have been cited by more than 3500 papers. Mean climatology of global precipitation derived from CMAP has been used in text books for graduate and college students.

The new version CMAP being developed as part of the project will further improve the quantitative accuracy and refine the time/space resolution to enable improved climate and oceanic applications. The HIRS-OLR based precipitation estimates developed in FY2013 are the very first product of global daily precipitation estimates that extend back from 1979. The HIRS OLR precipitation estimates will be used as a key input to the construction of the new CMAP and released to general users for their long-term climate and oceanic applications.

The CMORPH precipitation data set for modern era (from 1998) provides critical information for precipitation variations on high spatial and temporal resolution. It is utilized by forecasters to monitor and predict severe weather systems over both land and coastal regions and by managers in both public and private sectors around the world for the monitoring of potential coastal hazards. The CMORPH data set is also used by colleges as educational materials for weather and climate. As demonstrated in our preliminary work with the Aquarius SSS data, the high-resolution CMORPH satellite precipitation data enables the investigation of global ocean and its interaction with climate from a spectrum of new perspectives.

The in situ – satellite blended analysis is capable of documenting SSS distribution and variations with superior quality upon its individual inputs. In particular, the blended analysis is expected to

help the monitoring of SSS over regions with sparse in situ network, effectively mitigate the adverse impacts caused by the reduction of in situ networks.

The research work supported by this project provides refined oceanic precipitation analyses and improved understanding of air-sea fresh water exchanges and their relation to salinity that are important components of the ocean – climate connections. Verification of the fresh water fluxes produced by NOAA climate models and reanalyses using observation data sets leads to the improvements of these operational tools.

3.3. Relevant websites for dissemination of information

Ocean Products and Monthly Ocean Briefings:
http://www.cpc.ncep.noaa.gov/products/GODAS

Preciptation data:
ftp://ftp.cpc.ncep.noaa.gov/precip/

Test products of blended salinity analysis:
ftp://ftp.cpc/ncep.noaa.gov/precip/BASS

4. Publications and Reports

4.1. Publications by Principal Investigators

Xue, Y., Z.-Z. Hu, **A. Kumar**, V. Banzon, T. Smith, and N. Rayner, 2013: Global oceans: Sea surface temperature. *In State of the Climate in 2012, Bull. Amer. Meteorol. Soc.*. J. Blunden and D.S. Arndt, eds., *Bull. Amer. Meteorol. Soc.*. 94, S47-S51..

Howard et al. 2013. Oceans and Marine Resources in a Changing Climate. *Oceanography and Marine Biology*: *An Annual Review*, *51*, 71-192.

Wang, H., **A. Kumar**, and W. Wang, 2013: Characteristics of oceanic response to ENSO estimated from simulations with the NCEP Climate Forecast System. *J. Climate*, 26, 8065-8083.

Xue. Y., M. Chen, A. Kumar, Z.-Z. Hu, and W. Wang, 2013: Prediction skill and bias of tropical Pacific sea surface temperature in the NCEP Climate Forecast System Version 2. *J. Climate*, 26, 5358-5378.

Hu, Z.-Z., A. Kumar, B. Huang, and J. Zhu, 2013: Leading Modes of the Upper Ocean Temperature Interannual Variability along the Equatorial Atlantic Ocean in NCEP GODAS. *J. Climate*, **26**, 4649-4663.

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4.2. Other Relevant Publications