Climate Variability in Ocean Surface Turbulent Fluxes

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1. Project Summary

FSU produces fields of surface turbulent air-sea fluxes and the flux related variables (winds, SST, near surface air temperature, near surface humidity, and surface pressure) for use in global climate studies. Surface fluxes are by definition rates of exchange, per unit surface area, between the ocean and the atmosphere. Stress is the flux of horizontal momentum (imparted by the wind on the ocean). The evaporative moisture flux would be the rate, per unit area, at which moisture is transferred from the ocean to the air. The latent heat flux (LHF) is related to the moisture flux: it is the rate (per unit area) at which energy associated with the phase change of water is transferred from the ocean to the atmosphere. Similarly, the sensible heat flux (SHF) is the rate at which thermal energy (associated with heating, but without a phase change) is transferred from the ocean to the atmosphere. The SHF directly changes the temperature of the air whereas the LHF released energy only after the water vapor condenses. In the tropics, the latent heat flux is typically an order of magnitude greater than the sensible heat flux; however, in the polar regions the SHF can dominate.

We examine these fluxes on the basis of in situ data (funded solely by NOAA) and satellite data (leveraged from several NASA projects and from the PI being the NASA Ocean Vector Winds Science Team Leader). The in situ product is well suited for long time scale studies, and comparisons to reanalyses[1]. We find that the variability between flux products is far greater than the accuracy need to resolve climate variability[2] (e.g., interannual time scales and larger), indicating that a great deal more work is needed to make products that are well suited to ocean process studies where the processes are sensitive to the fluxes (as is often the case). We have also

[1] **Smith, S.**, P. Hughes, and **M. Bourassa**, 2011: A comparison of nine monthly air-sea flux products. *Int. J. Climatology*, **31**, 1002-1027, doi: 10.1002/joc.2225.
[2] **Bourassa, M. A.**, S. Gille, D. L. Jackson, B. J. Roberts, and G. A. Wick: Ocean Winds and Turbulent Air-Sea Fluxes Inferred From Remote Sensing. *Oceanography*, **23**, 36-51.

found that it is very important to consider high frequency variability[3] (e.g., finer scale synoptic variability) in the calculation of longer-term average fluxes (particularly the ocean uptake of CO_2), and in the case of the Gulf of Mexico's West Florida Shelf, for correctly modeling the regional ocean climate[4]. This is very important for the local ecosystem including some important finfish and shellfish. These studies add to the evidence demonstrating the importance of considering the ocean and the atmosphere as coupled for climate applications. The same physics was applied on smaller scale to examine how an oil slick modifies air/sea interaction and thereby modifies its motion.

The FSU activity is motivated by a need to better understand interactions between the ocean and atmosphere on daily to interdecadal time scales. Air-sea exchanges (fluxes) are sensitive indicators of changes in the climate, with links to floods and droughts[5] and East Coast storm intensity and storm tracks[6]. On smaller spatial and temporal scales they can be related to the storm surge[7], and tropical storm intensity. On longer temporal scales, several well-known climate variations (e.g., El Niño/Southern Oscillation (ENSO); North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO)) have been identified as having direct impact on the U.S. economy and its citizens. Improved predictions of ENSO phase and associated impact on regional weather patterns could be extremely useful to the agricultural community. Agricultural decisions in the southeast U.S. sector based on ENSO predictions could benefit the U.S. economy by over $100 million annually[8]. A similar, more recent estimate for the entire U.S. agricultural production suggests economic value of non-perfect ENSO predictions to be over $240 million annually[9]. These impacts could easily be extended to other economic sectors, adding further economic value. Moreover, similar economic value could be foreseen in other world economies, making the present study valuable to the global meteorological community. By

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[3] Hughes, P., and **M. A. Bourassa**, J. Rolph, and **S. R. Smith**, 2011: An Averaging-Related Biases in Monthly Latent Heat Fluxes. *J. Clim.*, **30**, 984 - 986. DOI: 10.1175/JTECH-D-11-00184.1.

[4] Morey, S. L., D. S. Dukhovskoy, and **M. A. Bourassa**, 2009: Connectivity between variability of the Apalachicola River flow and the biophysical oceanic properties of the northern West Florida Shelf. *Continental Shelf Research*, doi:10.1016/j.csr.2009.02.003.

[5] Enfield, D. B., A. M. Metas-Nuñez, and P. J. Trimble, 2001: The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. *Geophy. Res. Let.*, **28**, 2077-2080.

[6] Hurrell, J.W., and R.R. Dickson, 2004: Climate variability over the North Atlantic. Marine Ecosystems and Climate Variation - the North Atlantic. N.C. Stenseth, G. Ottersen, J.W. Hurrell, and A. Belgrano, Eds. Oxford University Press, 2004.

[7] Morey, S. L., S. Baig, **M. A. Bourassa**, D. S. Dukhovskoy, and J. J. O'Brien, 2006: Remote forcing contribution to storm-induced sea level rise during Hurricane Dennis. *Geophys. Res. Letts.*, 33, L19603–19607, doi:10.1029/2006GL027021.

[8] Adams, R. M., K. J. Bryant, B. A. McCarl, D. M. Legler, J. O'Brien, A. Solow, and R. Weiler, 1995: Value of improved long-range weather information. *Contemporary Economic Policy*, **13**, 10-19.

[9] Solow, A. R., R. F. Adams, K. J. Bryant, D. M. Legler, J. J. O'Brien, B. A. McCarl, W. Nayda, and R. Weiler, 1998: The value of improved ENSO prediction to U. S. agriculture. *Climate Change*, **39**, 47-60.

constructing high quality fields of surface fluxes we provide the research community the improved capabilities to investigate the energy exchange at the ocean surface. We have traditionally examined the distributions of weather, with more emphasis on typical weather conditions. However, recent work on extremes strongly suggests that climate cycles also influence the likelihood and magnitude of extreme events[10].

FSU produces both monthly in-situ based and hybrid satellite/numerical weather prediction (NWP) fields of surface winds (the 'FSU Winds') for the tropical Pacific and Indian Oceans. We are also developing a much higher quality surface flux product that assimilates satellite and in situ data. Our long-term monthly fields are well suited for seasonal to decadal studies. They are available in time for monthly updated ENSO forecasts, within eight days after the end of the month. The flux-related variables are useful for ocean forcing in models, testing coupled ocean/atmospheric models, ENSO forecasts, and for understanding some aspects of climate related variability.

2. Scientific and Observing System Accomplishments

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the **Air-Sea Exchange of Heat, Momentum, and Fresh Water**. These fluxes can be related to **Sea Surface Temperature** and **Ocean Heat Content**. Additional targets are **Ocean Transport** and **Thermohaline Circulation.** Surface winds (stress) contribute to upper ocean and deep ocean transport. The heat and moisture fluxes also contribution to the thermohaline circulation. **Ocean Carbon Uptake** is highly dependent on wind speed. We plan to work with other members NOAA climate observing team to estimate the importance of SST-related variability in surface winds in the context of **Ocean Carbon Uptake** (see related material in accomplishments). The FSU flux project also strives to understand the strengths and weaknesses of our flux product relative to operational assimilation systems[11,12] (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems.

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[10] Vose, R. S. S. Applequist, **M. A. Bourassa**, S. C. Pryor, R. J. Barthelmie, B. Blanton, P. D. Bromirski, H. E. Brooks, A. T. DeGaetano, R. M. Dole, D. R. Easterling, R. E. Jensen, T. R. Karl, K. Klink, R. W. Katz, M. C. Kruk, K. E. Kunkel, M. C. MacCracken, T. C. Peterson, B. R. Thomas, X. L. Wang, J. E. Walsh, M. F. Wehner, D. J. Wuebbles, and R. S. Young, 2013: Monitoring and Understanding Changes in Extremes: Extratropical Storms, Winds, and Waves. *Bull. Amer. Meteor. Soc.* (in press).

[11] **Smith, S.**, P. Hughes, and **M. Bourassa**, 2010: A comparison of nine monthly air-sea flux products. *Internat. J. Climatol*., **30**, 26pp., DOI: 10.1002/joc.2225.

[12] **Bourassa, M**., S. Gille, C. Bitz, D. Carlson, I. Cerovecki, M. Cronin, W. Drennan, C. Fairall, R. Hoffman, G. Magnusdottir, R. Pinker, I. Renfrew, M. Serreze, K. Speer, L. Talley, G. Wick, 2009: High-Latitude Ocean and Sea Ice Surface Fluxes: Requirements and Challenges for Climate Research. *Bull. Amer. Meteor. Soc*. *Bull. Amer. Meteor. Soc*. **94**, 403 - 423. http://dx.doi.org/10.1175/BAMS-D-11-00244.1.

The tasks pertain to the continued development/production of products and the dissemination of scientific results. Results include an evaluation of the sampling and averaging related biases in the FSU3 in-situ flux products which has led to the determination that the FSU3 methods are not ideal for the non-tropical oceans. This, combined with continued funding reductions, resulted in the termination of the FSU3 product development. We continue to routinely produce the operational FSU tropical Pacific and Indian Ocean products in compliance with GCOS climate principles.

Work Plan and Deliverables for the past year include the following:

1. Continue operation production of the 2˚ Tropical Pacific and 1˚ Tropical Indian Ocean FSU wind products.
2. Develop a multi-satellite wind product
3. Design a satellite-based flux product, based on (2)
4. Engage new users of (2) and (3)
5. Continue interaction with national and international satellite and in situ wind groups
6. Continue interaction with national and international flux groups

Progress on these deliverables specifically target the **program deliverables related to sea surface temperature, surface currents (via wind observations), and the air-sea exchanges of heat, momentum, and freshwater.** The DAC strives to make high-quality fields of surface turbulent fluxes readily available to the research and operational marine climate community. We produced the Pacific and Indian Ocean FSU Winds products, with 100% success in meeting our timeliness goal. However, we are deeply concerned that deterioration of the TOA/TRITON array adversely impacted the quality of the tropical Pacific Ocean product, particularly in the eastern Pacific Ocean where data from this array is a very important component of the in situ observing system. The data-related problem in Indian Ocean remains a lack of sampling in the northwestern Indian Ocean due to fears of piracy. Our prior examination of this problem found an enormous impact on the accuracy of in situ-based products in this region[13].

The FSU fluxes support a broad user community. Our web data portal currently shows ~170 registered users from 16 countries. Users are from academic institutions (57), governmental agencies (30), public/non-profit entities, and the military. Although we do not track the users applications, we know that many are using the FSU winds and fluxes to support tropical SST forecast models (e.g., LDEO model; http://rainbow.ldeo.columbia.edu/~dchen/forecast.html).

Our satellite winds are currently undergoing a vast improvement. They were not released during this funding cycle; however, they are expected to be released in at least a beta testing mode during the next funding year. Pending improvements based on this beta testing (and based on a first round of beta testing), the wind product will be released in near real time for oceanographic applications (we are aiming for release within two days of acquisition of the satellite data, which is typically within 12 hours for satellite data). Last year our satellite wind product suffered from the limitation that the technique worked only poleward of 20°. We have now improved the

[13] Smith, R.S., **M.A. Bourassa**, and M. Long, 2011: Pirate attacks affect Indian Ocean climate research. *Eos*, **92**, 225-226.

physics and can produce the winds poleward of 15°. We are now in the process of adding physics that will bring similar capability to the tropics. The satellite sensible and latent heat fluxes will continue to be in a development phase. We have addressed many key issues in producing a high quality product, and we are working towards integrating these many parts into a high resolution surface flux product that can be produced with a two day or less delay provided that collaborators can provide the input data within slightly less than two days.

Specific examples of progress include examination of how small scale sea surface temperature (SST) gradients modify the surface winds (fig. 1), which in turn modify the surface turbulent fluxes and vertical and horizontal ocean transport[14,15]. Our model for assimilating ocean observations accounts for these coupling processes, allowing us to capture the small scale changes in fluxes in the gridded flux product that we are developing. Traditional reanalysis techniques based on weather forecasting greatly smooth features with spatial scale less than six times the grid spacing. These small scale processes result in seasonally and regionally varying systematic errors in **air-sea exchanges of heat, momentum, and freshwater** based on these overly smooth products[15]. In winter months these biases (fig. 2) are sufficiently large to modify the temperature and salinity characteristics of near surface water, which will impact **sea surface temperature** as well as **ocean heat content and transport**.

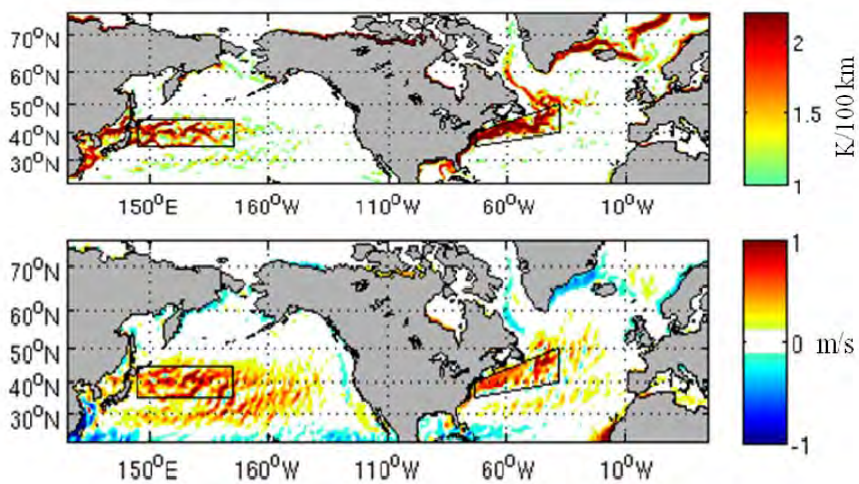

Figure 1. (Top) winter (DJF) seasonal SST gradients (> 1 K/100 km) and data subset regions located over the Gulf Stream and the Kuroshio Extension, and the associated seasonally averaged changes in wind speed (bottom) associated with these small spatial scale SST gradients

These same changes in surface winds modify currents in the upper ocean including the **surface currents** and wind forced vertical motion[14] (fig. 3). This extra vertical mixing will also impact the thickness of the mixed layer and hence presumably modify the **ocean heat content** in that layer and the **surface temperature**. We have found that the magnitude of these changes in motion at the bottom of the ocean's mixed layer is larger for smaller spatial scales (fig. 4).

[14] Hughes, P. J., 2014: The Influence of Small-Scale Sea Surface Temperature Gradients on Surface Vector Winds and Subsequent Impacts on Oceanic Ekman Pumping. Ph.D dissertation, Florida State University, Tallahassee, FL 32306
[15] Steffen, J. 2014: The Effects of Sea Surface Temperature Gradients On Surface Turbulent Fluxes. MS Thesis, Florida State University, Tallahassee, FL 32306

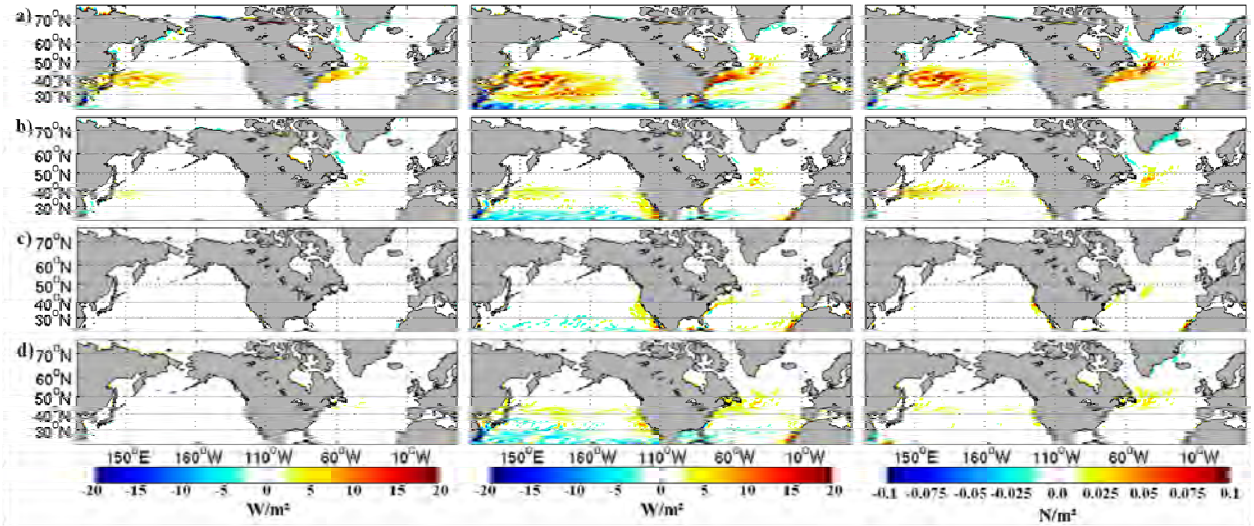

Figure 2. Seasonal biases in sensible heat flux (left), latent heat flux (center) and stress (right). From top to bottom seasons are winter, spring, summer and fall. On daily or six-hourly time scales the changes can by roughly a factor of ten greater.

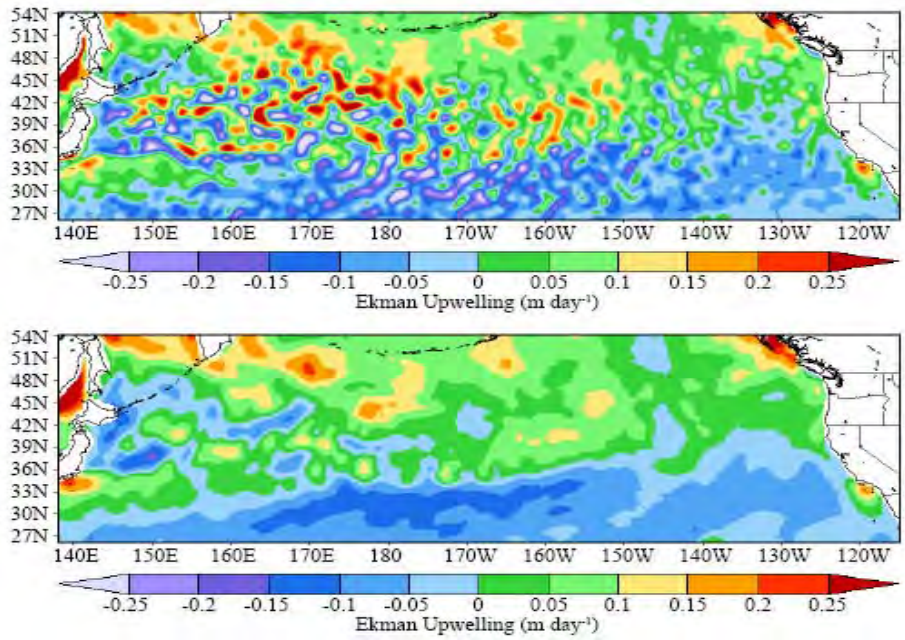

Figure 3. The Ekman upwelling (the wind-induced vertical motion at the bottom of the ocean's mixed layer) calculated for one winter day when surface winds respond to SST gradients (top) and this small scale wind variability is ignored (bottom). Changes are often greater than 30%.

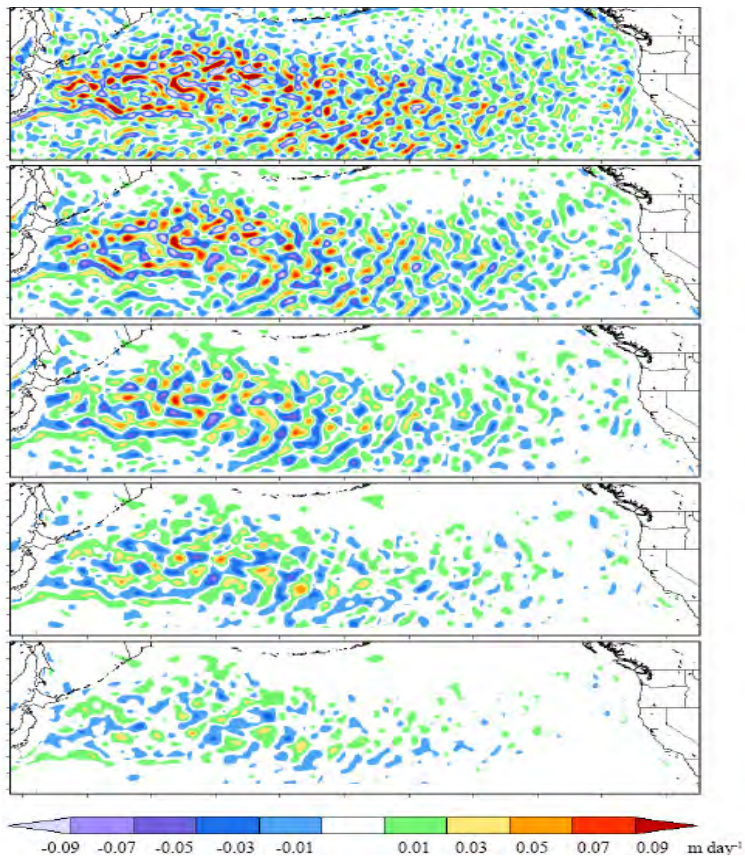

Figure 4. Changes in Ekman upwelling filtered by spatial scale. The greatest changes occur on smaller spatial scales (top). The top scales are between 1 and 2 degrees, 2nd from 2 to 3 degrees, and so on to the bottom image at 5 to 6 degrees

The results shown in the above figures are based on observed sea surface temperatures combined with reanalysis surface pressures, near surface air temperature and near surface humidities. The winds are determined through the physical model used in our data assimilation technique. In one case the SST-gradient influence on winds is removed, and in a second case it is included. These images show the differences in fluxes and Ekman upwelling due to ignoring the small scale variability. This approach is done on the same grid we will use to assimilate winds and other flux-related variables. These numbers are expected to be qualitatively consistent to what we will find when our data assimilation system is fully functional.

We conclude that observations of fine scale surface vector winds and SST are both vital to the ocean observing system. The result that variability on small spatial scale cause quite substantial changes to the ocean system is new in the contexts shown above. Even smaller scales are very likely to be important. The limiting space and time scale where changes have little impact because the ocean and atmosphere do not have time to adjust are yet to be determined, but it seems clear that the current observing system is not yet near this boundary. We point out that high temporal observations from research vessels appear to provide a practical approach to furthering such an investigation without modifying the observing system.

A further implication is that small spatial scales are very important to the coupling of the ocean and atmosphere systems. Since SST changes are associated with Ekman upwelling as well as the horizontal transport due to these wind changes, there will be considerable two way coupling that is currently missed in weather and climate models.

Through alternative funding we will examine how these small scale changes in SSTs and winds modify ocean carbon uptake. The **Carbon uptake** is a function of wind (or surface stress) and temperature, therefore we expect that the systematic patterns of winds and SST changes will also cause systematic changes in **Carbon uptake**.

The key impediments to moving forward in better understanding two way atmospheric and oceanic coupling have been:
1) Ability to realistically model and observe small scale variability,
2) The need for a constellation of observing systems and the consequent need to for very carefully intercalibrated data to avoid spurious small scale variability,
3) Satellite observations for near surface air temperature and humidity have vastly improved in the last five years, however, they are not yet planned for near real time production, and
4) An appropriate mechanism for assimilating the observations and retaining the small scale features in a realistic fashion.

We have made great strides with (1) as can be seen in the referenced work by two graduate students, which will soon be submitted for peer review. Intercalibration was still an issue during this reporting period, but the intercalibration of winds is currently being greatly improved through the RapidSCAT mission. Validation of SST gradients is an ongoing concern that the SST community is beginning to appreciate. We continue to improve our data assimilation technique, but models that work well in mid-latitudes have failed in the tropics. Weather forecasting centers (e.g., NCEP and ECMWF) have similar problems as can be seen in impact statistics for data assimilation.

Website:
http://coaps.fsu.edu/RVSMDC/FSUFluxes/index.php

3. Outreach and Education

Activities related to the Ocean Observing System:
1) Co-Chair, GCOS/GOOS/WCRP Ocean Observation Panel for Climate (OOPC)
GCOS (Global Climate Observing System) sets the climate-related observational requirements and goals for the earth observing system. The Ocean Observation Panel for Climate (OOPC) focuses on the ocean observations. Over the last year the panel has gathered information for a report on the status of the observing system, sponsored a very necessary and urgently needed workshop on the future of the Tropical Pacific Observing system, and begun to work on the approach for the next Implementation Plan. Part of these tasks have been working with the Atmospheric Panel to convey the importance of the ocean for their work, and to push surface fluxes forward as nominees for status as Essential Climate Variables. I have also been closely involved in developing metrics for assessing if the observing system is 'fit to purpose' and key identifying purposes.

2) NASA Ocean Vector Winds Science Team Leader (funded through NASA)

Activities most closely tied to the Climate Observing System are pushing forward the RapidSCAT mission, which is extremely well suited to address calibration differences between North American and Asian instruments with European instruments, which operate at different frequencies and resolve different spatial scales. Another NASA funded activity that is relevant to COD is the development of a global over-ocean gridded fields for surface vector winds.

3) Co-chair or organizer of meetings and session on topics closely tied to the observing system.

Work with students and schools
I have advised two graduate students, John Steffen (MS, 2014) and Paul Hughes (Ph.D 2014) on projects that are tied to the ocean observing system and closely related to our longer-term goals for improving the use of this observing system. I have support several local middle school teachers with climate related information and been interviewed by middle school and high school students.

4. Publications and Reports

4.1. Publications by Principal Investigators

Published

Holbach, H. M.[16], and **M. A. Bourassa**, 2014: The effects of gap–wind–induced vorticity, the monsoon trough, and the ITCZ on tropical cyclogenesis. *Mon. Wea. Rev*., **142**, 1312-1325. doi: 10.1175/MWR-D-13-00218.1

Nedbor-Gross, R., D. S. Dukhovskoy, **M. A. Bourassa**, S. L. Morey, E. P. Chassignet, 2014: Investigation of the relationship between the Yucatan Channel transport and the Loop Current area in a multi-decadal numerical simulation. *Marine Technology Society Journal*, **48**, 15 - 26.

Vose, R. S. S. Applequist, **M. A. Bourassa**, S. C. Pryor, R. J. Barthelmie, B. Blanton, P. D. Bromirski, H. E. Brooks, A. T. DeGaetano, R. M. Dole, D. R. Easterling, R. E. Jensen, T. R. Karl, K. Klink, R. W. Katz, M. C. Kruk, K. E. Kunkel, M. C. MacCracken, T. C. Peterson, B. R. Thomas, X. L. Wang, J. E. Walsh, M. F. Wehner, D. J. Wuebbles, and R. S. Young, 2014: Monitoring and Understanding Changes in Extremes: Extratropical Storms, Winds, and Waves. *Bull. Amer. Meteor. Soc*., **95**, 377 - 386. DOI: http://dx.doi.org/10.1175/BAMS-D-12-00162.1

Weihs, R., and **M. A. Bourassa**, 2014: Modeled diurnally varying sea surface temperatures and their influence on surface heat fluxes. *J. Geophys. Res*., **119**, 4101–4123, doi:10.1002/2013JC009489.

Zheng, Y., R. Zhang, and **M. A. Bourassa**, 2014: Impact of east Asian winter and Australian summer monsoons on the enhanced surface westerlies over the western tropical Pacific preceding the El Niño onset. *J. Clim*., **27**, 1928–1944. doi: http://dx.doi.org/10.1175/JCLI-D-13-00369.1

In press

[16] Underlined authors are students whose research pertinent to this publication was supervised by Mark Bourassa

None

Proceedings from conferences (if peer-reviewed)

None

Technical reports

Hughes, P. J., 2014: The Influence of Small-Scale Sea Surface Temperature Gradients on Surface Vector Winds and Subsequent Impacts on Oceanic Ekman Pumping. Ph.D dissertation, Florida State University, Tallahassee, FL 32306

Steffen, J. 2014: The Effects of Sea Surface Temperature Gradients On Surface Turbulent Fluxes. MS Thesis, Florida State University, Tallahassee, FL 32306

Data reports

None

4.2. Other Relevant Publications

References Specific to the FSU Winds

Note that few users explicitly acknowledge the use of the FSU winds, making this impractical to track through normal referencing tools.

Choi, Kit-Yan, Gabriel A. Vecchi, and Andrew T. Wittenberg, 2013: ENSO Transition, Duration, and Amplitude Asymmetries: Role of the Nonlinear Wind Stress Coupling in a Conceptual Model. *Journal of Climate,* **26**, 9462-76.

Duan, Wansuo, Ben Tian, and Hui Xu. 2013: Simulations of two types of El Niño events by an optimal forcing vector approach. *Climate Dynamics*, 1-16. DOI: 10.1007/s00382-013-1993-4

Kent, Elizabeth C., et al. 2014: A Comparison of Global Marine Surface-Specific Humidity Datasets from in Situ Observations and Atmospheric Reanalysis. *International Journal of Climatology,* **34.2**, 355-76.

References to the PI's work with the Ocean Observing System

Abe, Hiroto, et al., 2014: Oceanic Rossby waves induced by the meridional shift of the ITCZ in association with ENSO events. *Journal of Oceanography,* **70.2**, 165-174.

Alsweiss, Suleiman, et al., 2014: A Non-MLE Approach for Satellite Scatterometer Wind Vector Retrievals in Tropical Cyclones. *Remote Sensing,* **6.5**, 4133-4148.

Andersen, Theresa K., David E. Radcliffe, and J. Marshall Shepherd, 2013: Quantifying Surface Energy Fluxes in the Vicinity of Inland-Tracking Tropical Cyclones. *Journal of Applied Meteorology and Climatology,* **52.12**, 2797-2808.

Barthelmie, R. J., and S. C. Pryor., 2014: Potential contribution of wind energy to climate change mitigation. *Nature Climate Change,* **4**, 684-688.

Bridhikitti, Arika, 2013: Connections of ENSO/IOD and Aerosols with Thai Rainfall Anomalies and Associated Implications for Local Rainfall Forecasts. *International Journal of Climatology,* **33.13**, 2836-45.

Brown, Paula J., and Christian D. Kummerow. An Assessment of Atmospheric Water Budget Components Over Tropical Oceans. *Journal of Climate,* **27.5**, 2054-71.

Cannizzaro, Jennifer P., et al., 2013: On the Accuracy of SeaWiFS Ocean Color Data Products on the West Florida Shelf. *Journal of Coastal Research,* **29.6**, 1257-72.

Carvalho, D., et al., 2014: Offshore Wind Energy Resource Simulation Forced by Different Reanalyses: Comparison with Observed Data in the Iberian Peninsula. *Applied Energy,* **134**, 57-64.

Carvalho, D., et al., 2014: Comparison of Reanalyzed, Analyzed, Satellite-Retrieved and NWP Modelled Winds with Buoy Data Along the Iberian Peninsula Coast. *Remote Sensing of Environment,* **152**, 480-92.

Chakraborty, Abhisek, et al., 2014: An OGCM Assessment of Blended OSCAT Winds." *Journal of Geophysical Research-Oceans,* **119.1**, 173-86.

Chamberlain, J. M., et al., 2014: Forecasting storms over Lake Victoria using a high resolution model. *Meteorological Applications,* **21.2**, 419-430.

Clarke, Allan J., 2014: El Nino Physics and El Nino Predictability. *Annual Review of Marine Science,* **6**, 79-99.

Cook, Duncan, and Sally Garrett, 2013: Somali Piracy and the Monsoon. *Weather, Climate, and Society,* **5**, 309-316.

Davidson, Noel E., et al. 2014: ACCESS-TC: Vortex Specification, 4DVAR Initialization, Verification, and Structure Diagnostics. *Monthly Weather Review,* **142.3**, 1265-1289.

Drennan, W. M., et al. 2014: EASI: An air-sea interaction buoy for high winds. *Journal ofAtmospheric and Oceanic Technology*.

Dunstone, Nick J., 2014: A perspective on sustained marine observations for climate modelling and prediction. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* **372**, 20130340.

Forzieri, G., E. R. Vivoni, and L. Feyen, 2013: Ecosystem Biophysical Memory in the Southwestern North America Climate System. *Environmental Research Letters.* **8.4**, 044016.

Gairola, R. M., et al., 2014: Rainfall estimation from Kalpana-1 satellite data over Indian land and oceanic regions. *CURRENT SCIENCE,* **107,** 1.

Gilford, Daniel M., et al., 2013: Southeastern U.S. Daily Temperature Ranges Associated with the El Nino-Southern Oscillation. *Journal of Applied Meteorology and Climatology,* **52.11**, 2434-49.

Goldstein, Miriam C., Andrew J. Titmus, and Michael Ford, 2013: Scales of Spatial Heterogeneity of Plastic Marine Debris in the Northeast Pacific Ocean. *Plos One,* **8**.

Ghosh, Arindam, et al., 2014: Rain Identification and Measurement using Oceansat-II Scatterometer Observations. *Remote Sensing of Environment,* **142**, 20-32.

Huang, Wan-Ru, and Kuan-Chieh Chen, 2014: Trends in pre-summer frontal and diurnal rainfall activities during 1982–2012 over Taiwan and Southeast China: characteristics and possible causes. *International Journal of Climatology*.

Jackson, Scott I., Terry D. Prowse, and Barrie R. Bonsai, 2014: Linkages between Snow Ablation and Atmospheric Boundary-Layer Conditions in a Semi-Arid Basin of Western Canada. *Journal of Hydrology*, **517**, 949-62.

Jiang, ChuanLi, et al., 2014: Drake Passage Oceanic pCO_2: Evaluating CMIP5 Coupled Carbon-Climate Models using in Situ Observations. *Journal of Climate*, **27**, 76-100.

Josey, Simon A., et al., 2014: Unexpected impacts of the Tropical Pacific array on reanalysis surface meteorology and heat fluxes. *Geophysical Research Letters*, **41**, 6213-6220.

Karagali, Ioanna, et al., 2014: Wind Characteristics in the North and Baltic Seas from the QuikSCAT Satellite. *Wind Energy*, **17.1**, 123-40.

Kerr, P. C., et al., 2013: US IOOS Coastal and Ocean Modeling Testbed: Inter-Model Evaluation of Tides, Waves, and Hurricane Surge in the Gulf of Mexico. *Journal of Geophysical Research-Oceans*, **118**, 5129-72

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5. Slides

See attachment.