Climate Variability in Ocean Surface Turbulent Fluxes

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1. Abstract

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), and is critical for ocean transport in both the upper ocean and the deep ocean. The evaporative moisture flux would be the rate, per unit area, at which moisture is transferred from the ocean to the air. Evaporation and precipitation are dominant considerations in studies of moisture change. 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 LHF and SHF contribute to global and local energy budgets, which can be linked to global change. 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. We find that the variability between flux

products is far greater than the variability due to climate variability, 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 found that it is very important to consider high frequency (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. This is very important for the local ecosystem including some important finfish and shellfish. We also found that variability in northern hemisphere tropical cyclone activity is related to large scale sea surface temperatures (SSTs) patterns, with particularly strong correlation to SSTs in the Gulf of Alaska. These studies add to the evidence demonstrating the importance of consider the ocean and the atmosphere as coupled for climate applications.

2. 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. 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.

The FSU activity is motivated by a need to better understand interactions between the ocean and atmosphere on weekly to interdecadal time scales. Air-sea exchanges (fluxes) are sensitive indicators of changes in the climate, with links to floods and droughts[1] and East Coast storm intensity and storm tracks[2]. On smaller spatial and temporal scales they can be related to the storm surge[3], and tropical storm intensity. On longer temporal scales, several well-known climate variations (e.g., El Nino/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[4]. A similar, more recent estimate for the entire U.S.

[1] 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.

[2] 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.

[3] 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.

[4] 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.

agricultural production suggests economic value of non-perfect ENSO predictions to be over $240 million annually[5]. 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.

ENSO, PDO, and NAO (AO) each have atmospheric and oceanic components that are linked through the surface of the ocean. Changes in the upper ocean circulation result in modifications to the SST and near surface wind patterns. Variations in SSTs can be related to ENSO and other climate patterns; however, it is the fluxes of heat and radiation near the ocean surface that transfer energy across the air-sea interface. It is an improved understanding of these turbulent fluxes and their variability that motivates our research (radiative fluxes are difficult to accurately estimate from in situ data; however, satellite-based estimates are available). By constructing high quality fields of surface fluxes we provide the research community the improved capabilities to investigate the energy exchange at the ocean surface.

FSU produces both monthly in-situ based (the FSU3) and hybrid satellite/numerical weather prediction (NWP) fields of fluxes and the flux-related variables. Our long-term monthly fields are well suited for seasonal to decadal studies, and our hybrid satellite/NWP fields are ideal for daily to annual variability and quality assessment of the monthly products. The flux-related variables are useful for ocean forcing in models, testing coupled ocean/atmospheric models, ENSO forecasts, and for understanding climate related variability (e,g., the monthly Atlantic surface pressure is a good indicator of extreme monthly air temperatures over Florida).

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 have recently worked with other members NOAA climate observing team to estimate the importance of using six hourly winds vs. monthly averaged winds on estimates of **Ocean Carbon Uptake**. The FSU flux project also focuses on the task of evaluating operational assimilation systems[6,7] (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems. A related scientific result is that most of the long-term trend in tropical Pacific winds and latent heat fluxes[8] can be

[5] 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.

[6] Smith, S., P. Hughes, and **M. Bourassa**, 2009: A comparison of nine monthly air-sea flux products. *Internat. J. Clim.*, submitted.

[7] **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*. (submitted).

[8] Yu, L., 2007: Global variations in oceanic evaporation (1958-2005): The role of the changing wind speed. *J. Climate*, 20(21), 5376–5390.

explained by slightly different physics in the transition from in situ (dominating the early data record) to satellite observations (dominating the recent decades). We have also found that northern hemisphere and global hurricane activity can be closely linked to large scale ocean variability. All products are distributed in a free and open manner at: http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/.

The FSU fluxes support a broad user community. Our web data portal currently shows 169 registered users from 16 countries. Fifty-seven users are from academic institutions, 35 at governmental agencies, four from public/non-profit entities, and one from 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).

3. Scientific Accomplishments

The tasks pertain to the continued development/production of products and the dissemination of scientific results. Results include a detailed comparison of nine freely available flux products, revealing many differing strengths as weaknesses. This has better enabled the PI to recommend flux products for specific applications.

Deliverables for FY 2009 included:

1. Update Atlantic, Indian, and Pacific Oceans using new ICOADS releases (if available)
2. Complete Equatorial and North Pacific 1˚ winds and fluxes
    - Subtask1: Complete editing of the wind fields
    - Subtask2: Assess the fluxes for problems that can be fixed, and determine the appropriate cautionary notes for users.
3. Publish comparisons of FSU3 fluxes to other available in-situ, satellite, and blended flux products
    - Subtask1: Report results at national and international meetings
    - Subtask2: Publish evaluation of practical applications of FSU3 fluxes
4. Continue production of satellite and NWP hybrid wind fields for the Gulf of Mexico.
    - Begin to develop metrics to assess the usefulness of wind observations for various applications and time scales.

3.1 Update fluxes using new ICOADS release [deliverable 1]

Version 2.5 of ICOADS was not released until mid-summer 2009; therefore we are just beginning updates to our products. ICOADS 2.5 uses a new format that requires revisions to our data processing codes. These revisions are underway and should be complete in early FY2010.

3.2 Complete Pacific winds and fluxes [deliverable 2]

The Equatorial and North Pacific 1˚ FSU fluxes have been completed for the period 1978-2004 (using the earlier ICOADS release). With the completion of the Pacific fluxes, we have also created a series of global FSU flux files, which merge the Pacific, Indian, and Atlantic Ocean products for the period 1978-2004. All in-situ products are available via the web, ftp, and a THREDDS server (see below). Satellite products are available through the web and THREDDS.

3.3 Publish and report results of flux comparisons [deliverable 3]

An outcome of the CLIMAR-III meeting in Gydnia, Poland will be the publication of a special edition of the *International Journal of Climatology*. A full manuscript has been submitted to the special edition that compares nine air-sea flux products (Smith et al. 2009; Figs 1, 2), focusing in stress, latent heat flux, and sensible heat flux. The results of this comparison also contributed to OceanObs'09 papers (Hughes et al. 2010, Gille et al. 2010). Leading causes of differences between products have been identified (Smith et al. 2009, Hughes et al. 2010), and consequences of these differences on SST (related to ocean heat content) have been examined (Hughes et al. 2010).

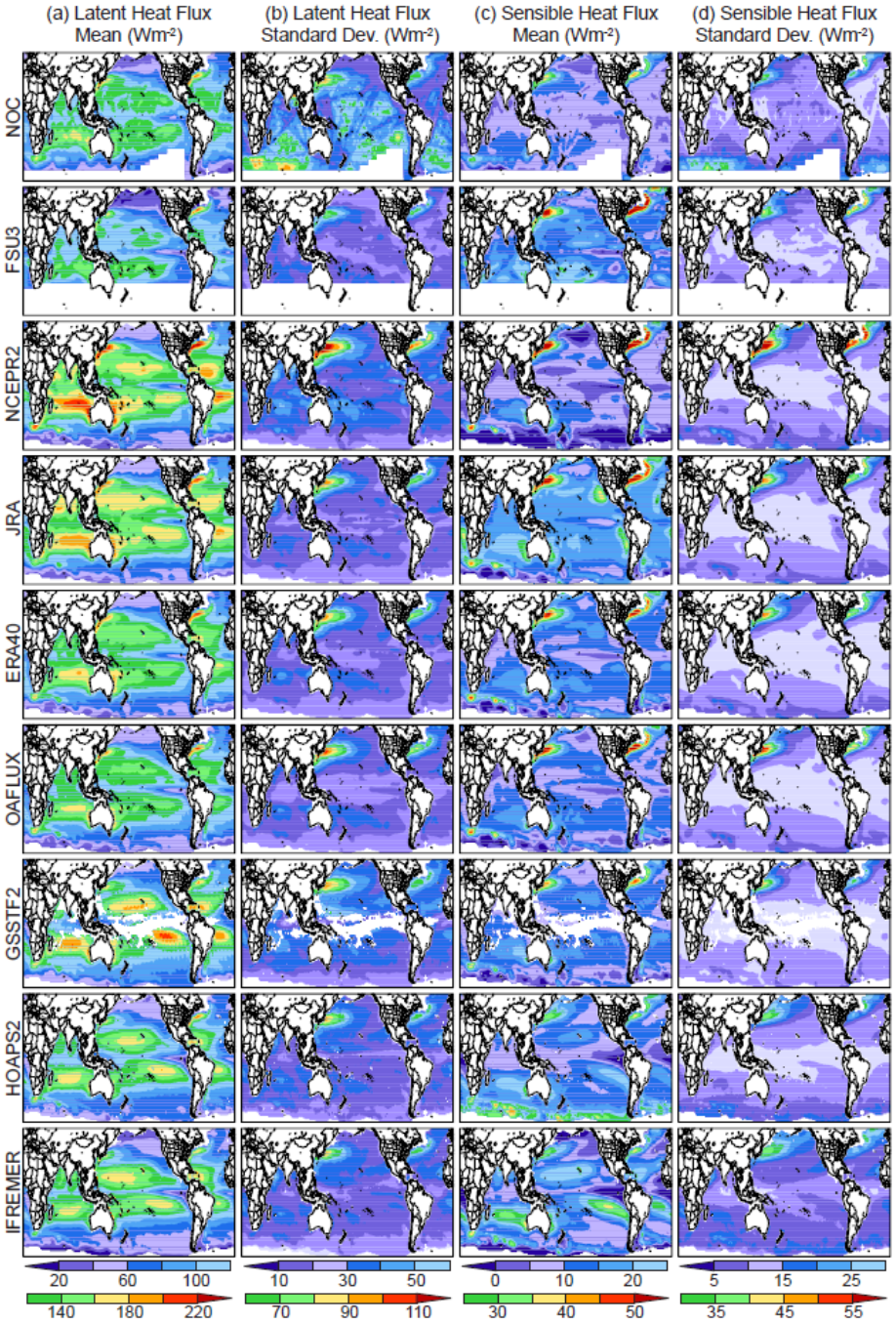

FIG. 1. Average (a) latent and (c) sensible heat flux and their corresponding standard deviations (b and d) for the common period March 1992 through December 2000. The magnitudes (Wm^{-2}) for each of the nine products are shown in the color bars. White areas on the maps represent one-degree grid cells that are either defined as land or had one or more missing months in the common period. The GSSTF2 had several months with missing data near the equator due to variations in satellite coverage and the FSU3 is not produced for the Southern Ocean. The Gibbs phenomena is notable in the GSSTF2 means. The variability between these products is far greater than interannual and decadal variability identified in any of the individual products!

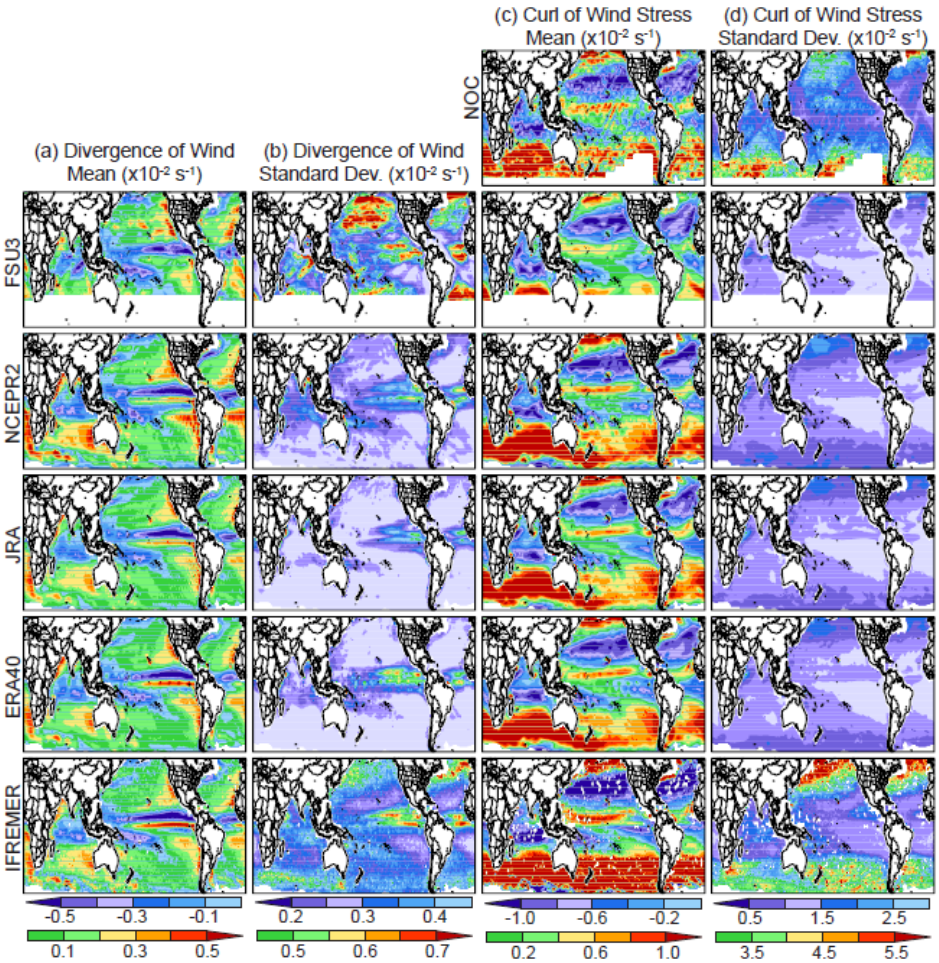

FIG. 2. Same as figure 1, except for the wind divergence (a and b) and wind stress curl (c and d). HOAPS2, OAFLUX, and NOC (divergence only) did not provide the necessary parameters to determine the wind divergence and curl of the wind stress. GSSTF2 was omitted due to the missing data in the tropics. The product to product differences in the mean stress is small compared to the heat fluxes; however, there are very large product to product differences in the distribution of stresses about the mean.

Related activities (supported by NASA) include hosting a meeting on Scatterometry and Climate, which will result in a publication on climate related applications and the accuracy of fluxes and winds estimated to be required for those applications. Following the meeting, collaboration with NOAA experts on CO_2 fluxes resulted in a crude estimate of the importance

of improving temporal resolution of the winds used in calculating CO_2 fluxes, based on two parameterizations of the gas transfer coefficient. One clear conclusion is that much finer than monthly sampling is required, particularly in the regions with strong and variable winds such as the high-latitude storm tracks (Fig. 3). If the cubic parameterization with the cubic is correct (or correct at high latitudes), the wind sampling must accurately capture synoptic scale variability. With the impending loss of QuikSCAT, sampling of high-latitude systems will be inadequate unless ASCAT and the new Indian scatterometer can be accurately calibrated for high-wind conditions.

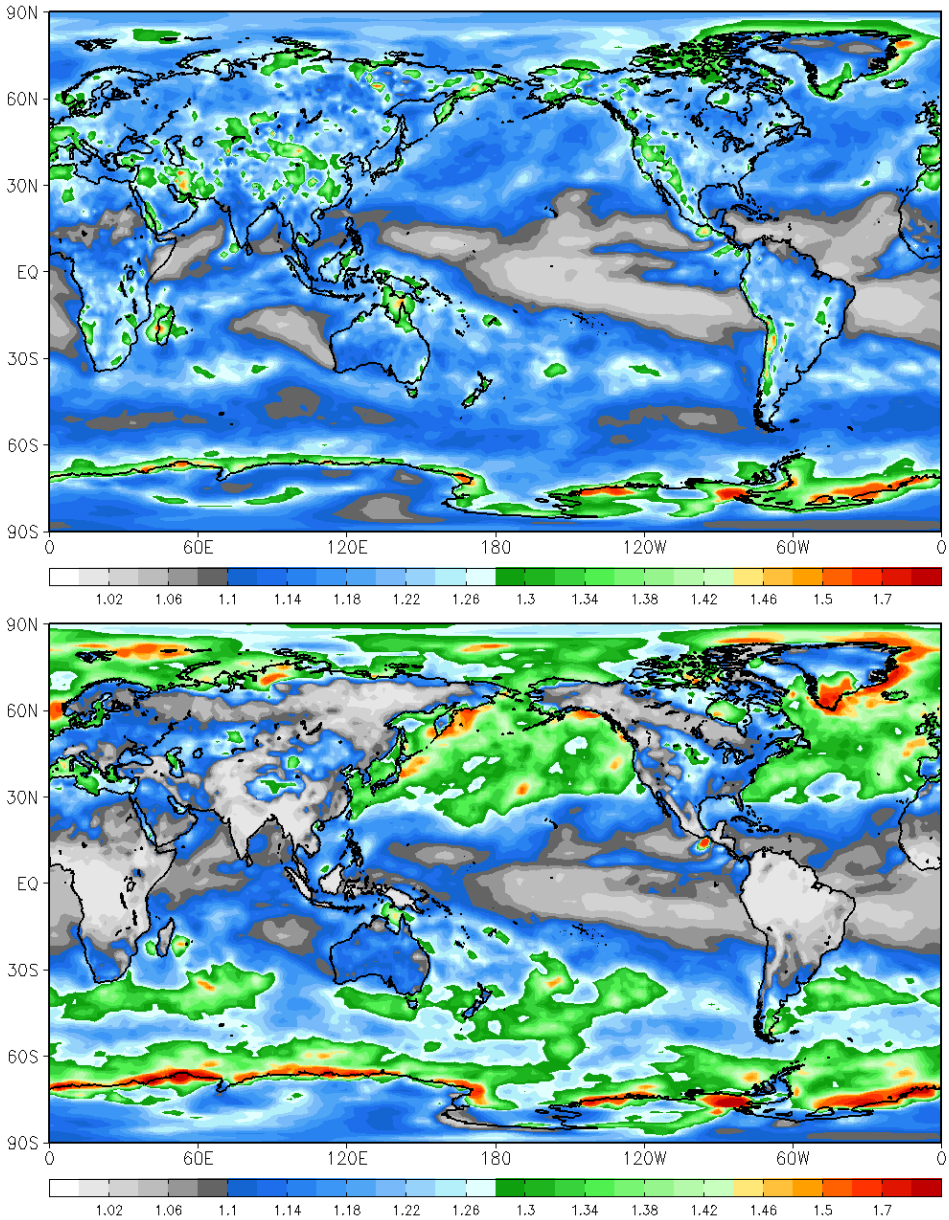

Fig. 3. Ratio of CO_2 flux based on six hourly winds to CO2 flux based on monthly averaged winds for two algorithms: (top) dependent on wind speed squared, and (bottom) dependent on wind speed cubed. The time period is Dec. 2009 through Feb.

2009. If the cubic dependency is correct (or correct in high latitudes) it will be vitally important to use high frequency winds in the calculation of ocean uptake of CO_2. We thank Ryan Maue for producing these plots.

3.4 Continue production of satellite and NWP hybrid products [deliverable 4]

The pseudostress fields are routinely produced, resulting in a 10+ year data set. This dataset has recently been used for forcing of a regional ocean model. The data set is more typically used to verify the high resolution NWP analyses capture the placement and timing of atmospheric fronts, which have been found to be very important in the ocean climatology of the West Florida Shelf (Morey et al. 2009). Leveraging from NASA support, we found that the smaller scale synoptic wind forcing and the river outflow were critical to correctly modeling this region's the ocean transport.

We also examined the importance of differences between in situ winds and satellite winds. Satellite winds are related to stress (Bourassa 2006, Bourassa et al. 2009). Stress is related to near surface wind shear, rather than near surface wind. That is, satellite winds are relative to the ocean surface (accounting for motions due to waves and currents), whereas in situ winds are relative to the fixed earth. Numerical Weather Prediction (NWP) products treat satellite winds as earth relative. A colleague at the ECMWF recently verified this type of bias in comparison to buoy data (Hans Hersbach, personal communication, 2009). The consequences of this error are likely very small on short-term forecasts; however, for the tropical Pacific Ocean, they results in physically important biases in turbulent heat fluxes on multi-year scales. The change in LHF in the western Pacific region (Fig. 4) is roughly $3Wm^{-2}$ ($5Wm^{-2}$ across the tropical Pacific Ocean). This change is remarkably similar to prior estimates of the change in LHF associated with climate change.

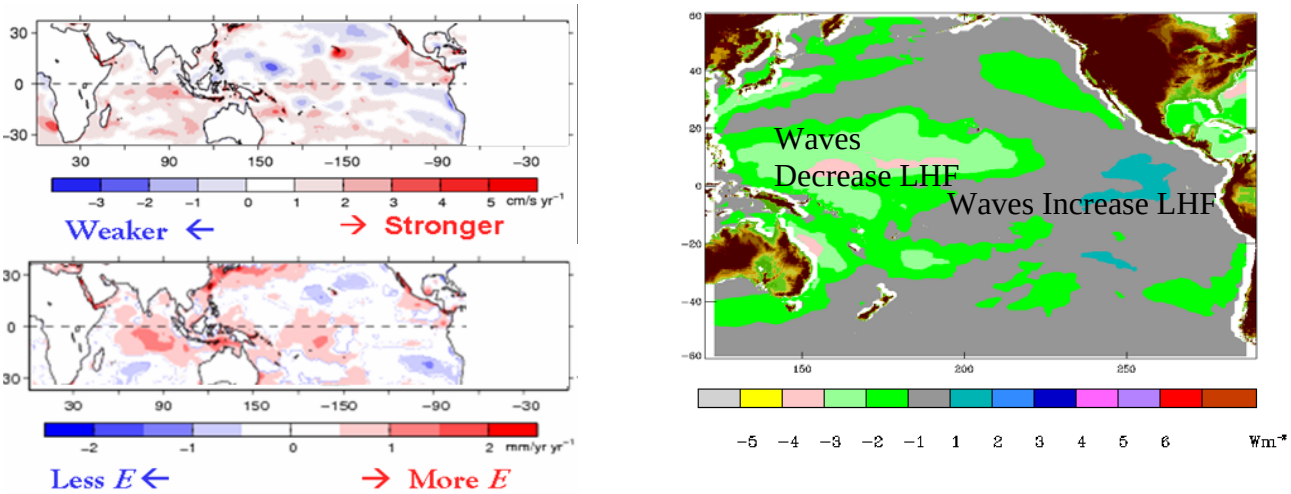

Fig. 4. Multidecadal trends in wind (upper left) and LHF (lower left) based on the OAFLUX product (Lisan Yu, personal communication, 2008), and a loosely similar patter in the apparent change in LHF due changes in the observing system. Much of the long term trend in LHF for this part of the world can be explained in terms of the evolving observing system rather than climate change.

In the past year the PI has been very active with NASA and EUMETSAT groups working on improving the understanding and intercalibration of satellite winds. These activities are critical to climate studies and useful for operations. The PI had a leadership role in related activities at OceanObs09: satellite winds (Bourassa et al. 2010), altimetry (Scott et al. 2010), surface fluxes (Fairall et al. 2010, Gulev et al. 2010, and Gille et al. 2010), data assimilation (Rienecker 2010), and validation of satellite data (Smith et al. 2010a,b, Gille et al. 2010). In these processes, we learned that there is considerable work to be done in modeling fluxes for very high wind speed conditions (e.g., hurricanes, strong mid-latitude storms, and strong cold air outbreaks), that improvements to atmospheric NWP boundary-layer parameterizations are like to positively impact data assimilation of ocean surface observations and increase the benefit of satellite data, calculation of surface fluxes in current NWP products is poor, and the a constellation of satellites is highly desirable for ocean vector winds (ideally with collocated passive microwave observations). There is great concern that the US contribution to the constellation of vector wind observations (NASA's QuikSCAT) will fail soon, and there might not be a timely replacement. The National Research Council's decadal review tasked NOAA to develop a replacement (ideally a greatly improved replacement) mission. A remarkably common theme in OceanObs09 community white papers was the need for a constellation of ocean vector winds observations. Furthermore, as leader of the International Ocean Vector Winds Science Team (IOVWST) meetings, I strongly encourage more participation of climate observers and researchers within NOAA.

3.5 Additional Scientific Accomplishments

Interannual variability in cyclone activity was examined and strongly linked to ocean variability (Maue 2009). The activity metric used in this study was accumulated cyclone energy (ACE), which temporally integrates the square of the time dependent maximum wind speed. The ACE is calculated for a hurricane season (for each ocean-related region) then a 1-2-1 filter is applied to reduce some ENSO dependency and to better deal with the offset in northern and southern hemisphere hurricane seasons. The filtered ACE was shown to be poorly related to ENSO variability as seen in the Hadley Centre SST[9]. The low frequency North Atlantic and South Atlantic SST variability are well correlated with the low frequency ACE (Fig. 5), and have upward trends consistent with the North Atlantic ACE from 1981 to 2007, which is consistent other findings[10] for the North Atlantic main development region (MDR). The similarly strong correlation with South Pacific Ocean SSTs argues against forcing entirely from local SSTs[11,12,13]. A correlation map of northern hemisphere ACE and SST (Fig. 5) shows a very large scale pattern. This strongly suggest that the large longer-term variability (decadal variability) in northern hemisphere hurricane activity is linked to variability in the SSTs. The high correlation

[9] Rayner, N.A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent, and A. Kaplan, 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century *J. Geophys. Res.*, **108**, 4407.

[10] Emanuel, K.A., 2005: Increasing Destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686-688.

[11] Kossin, J.P. and D.J. Vimont, 2007: A more general framework for understanding Atlantic hurricane variability and trends. *Bull. Amer. Met. Soc.*, **88**, 1767-1781.

[12] Vecchi, G.A., and B.J. Soden, 2007:, Effect of remote sea surface temperature change on TC potential intensity. *Nature*, **450**, 1066-1070

[13] Swanson, K. L., 2008: Nonlocality of Atlantic tropical cyclone intensities, *Geochem. Geophys. Geosyst.*, **9**, Q04V01.

(>0.95) in the Gulf of Alaska exists irrespective of the low frequency filtering. The physical processes (both oceanic and atmospheric) behind this extremely high correlation remain to be determined, as does the use of this information for prediction. One problem with prediction of regional hurricane activity is that changes in activity in the Atlantic basin is usually compensate for by equal and opposite changes in the Eastern Pacific Basin. Similarly, changes in the sum of Atlantic and Eastern Pacific Basins are usually compensated for by changes in the Western Pacific Basin. All these connections between regional hurricane activity and the ocean suggest important ties between oceanic and atmospheric climate.

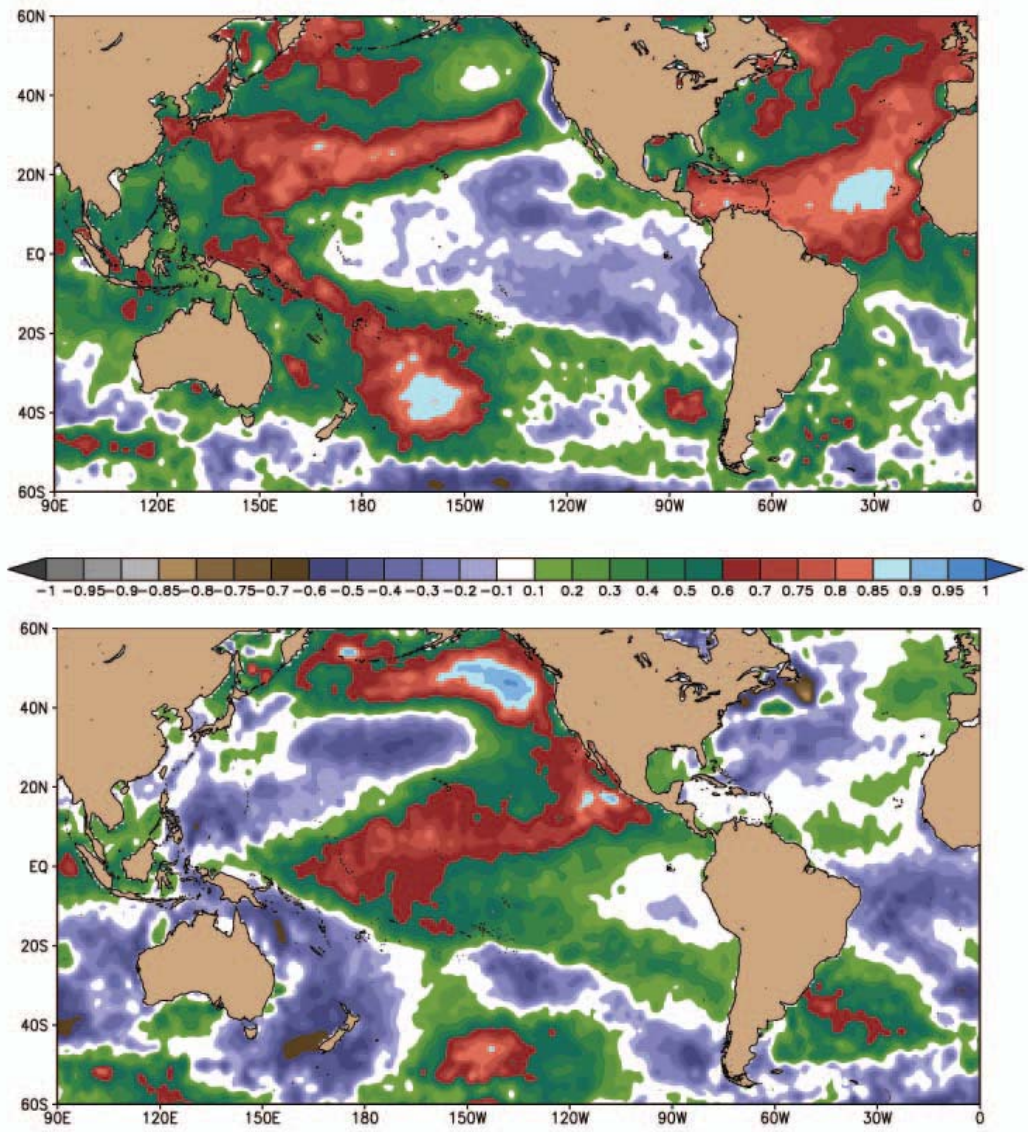

Fig. 5. (top) Correlation map between NA ACE and August-October monthly mean SST for 1981-2007 with a 1-2-1 filter applied once. (bottom) Correlation map between NH ACE and April-June SST (1981-2007). Graphic by Ryan Maue.

3.6 Data distribution and user community

The research quality 1˚ in-situ FSU flux products are available via:

- Web: http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/
- FTP: ftp://www.coaps.fsu.edu/pub/fsu3/research/
- THREDDS: http://coaps.fsu.edu/thredds.php

The THREDDS catalog server was established in FY2009 to support a broader user community.

In addition to the 1˚ fluxes, we continue to create an older version (the FSU2) 2˚ tropical Pacific Ocean wind (pseudo-stress) fields based on near-real time in-situ data. Quick-look 2˚ gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data (received from NOAA NCEP). In addition to the Pacific, COAPS continues to produce one-degree pseudo-stress fields for the tropical Indian Ocean using the method of Legler et al.[14] We have not updated the FSU2 and Legler research products as we had anticipated switching to the near real time version of the FSU3 technique. Resource limitations continue to slow the push towards a real-time FSU3 product. Access to both the two-degree fields for the Pacific Ocean and one-degree fields for the Indian Ocean FSU winds are available via the THREDDS catalog (with embedded links to FTP and Web access points).

As part of our continued production of the FSU2 for the tropical Pacific Ocean, we now produce additional monthly graphics for inclusion into the on-line version of the NOAA Climate Diagnostics Bulletin (http://www.cpc.ncep.noaa.gov/products/CDB/).

Limited tracking of in-situ flux data users is completed via a web registration and may include some users of SAMOS (vs. FSU Flux) data. Our limited information on international use is shown in Table 1. The breakdown by type of user is shown in table 2.

Table 1. Users of FSU data sets by country

2	Australia	15	India	1	South Korea
1	Botswana	3	Ireland	1	Taiwan
3	Brazil	1	Israel	3	United Kingdom
15	China	1	Mexico	43	United States
3	France	1	Portugal		
2	Germany	2	Russia		

Table 2. Users Sorted by Organization

35	Government
1	Military
3	Other Educational
4	Public/Non-profit
54	University/College

[14] Legler, D. M, I. M. Navon, and J.J. O'Brien, 1989: Objective analysis of pseudostress over the Indian Ocean using a direct-minimization approach. *Mon. Wea. Rev.*, **117,** 709-720.

The user community for our gridded satellite products (which are largely supported by NASA) is not well tracked. It include the operational Ocean Surface Current Analysis – Real time (OSCAR) product and their many users (ocean transport science, fisheries, search and rescue); ENSO forecasters; ocean modelers (our global product is used in many countries); and contributes to surface flux analyses.

4. Education and Outreach

Our activities were included in two larger public events and web pages. These events and the web pages help link weather and climate to the ocean. WeatherFest was held at Florida State University on January 17, 2009. It was organized by The National Weather Service in Tallahassee, Florida State University Department of Meteorology and North Florida Chapter of the AMS. An estimated 500-700 people attended (all ages). The FSU Coastal & Marine Lab Open House was held on April 18, 2009. An estimated 1,200 people attended (all ages).

Issues related to the ocean and climate are also taught in undergraduate and graduate classes, reaching roughly 60 students in the previous year. The PI also advises nine graduate students, all but one of which have gained a great deal of knowledge about the ocean and climate, and will contribute to the future workforce. The PI visited a local elementary school to discuss weather and satellites, some of which are tied to oceans and climate. The PI also interacts with local cub scouts and boy scouts regarding weather, ocean observations, and climate.

The web pages of one of our Ph.D. students Ryan Maue, particularly the pages related to the tropical work mentioned above, receive hundreds of thousands of hits each year. On two occasions in previous year, these pages received over 100,000 hits in a day. These pages are highly readable and contain a great deal of easily digested information (e.g., Fig. 6) in comparison to other tropical pages. This kind of outreach is highly visible and has been noticed by the researchers and the general public. The tropical web page is
http://coaps.fsu.edu/~maue/tropical/

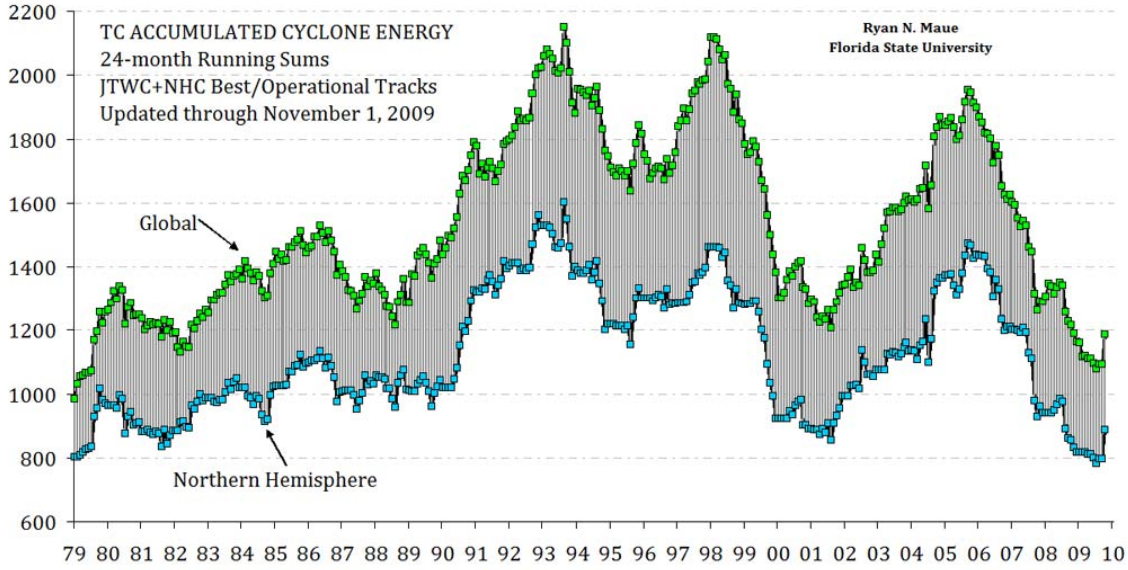

Fig. 6. 24-month running sum of tropical cyclone accumulated cyclone energy for the entire globe (top black squares / time series) and the Northern Hemisphere only (bottom green squares / time series). The difference between the two time series is the Southern Hemisphere total. Data is shown from January 1979 - October 29, 2009 mainly because intensity estimates of SH cyclones are often missing in the JTWC best-tracks prior to 1980. Graphic by Ryan Maue.

5. Publications and Reports

5.1. Publications by Principal Investigators

Bourassa, M. A., H. Bonekamp, P. Chang, D. Chelton, J. Courtney, R. Edson, J. Figa, Y. He, H. Hersbach, K. Hilburn, T. Lee, W. T. Liu, D. Long, K. Kelly, R. Knabb, E. Lindstorm, W. Perrie, M. Portabella, M. Powell, E. Rodriguez, D. Smith, A. Stoffelen, V. Swail, F. Wentz, 2010: Remotely sensed winds and wind stresses for marine forecasting and ocean modeling. *Proceedings of the OceanObs'09: Sustained Ocean Observations and Information for Society Conference (Vol. 2)*, Venice, Italy, eds. J. Hall, D.E. Harrison and D. Stammer, ESA Publication WPP-306. (in press).

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*. (submitted).

Fairall, C. W., B. Barnier, D. I. Berry, **M. A. Bourassa**, E. F. Bradley, C. A. Clayson, G. de Leeuw, W. H. Drennan, S. T. Gille, S. K. Gulev, E. C. Kent, W. R. McGillis, G. D. Quartly, V. Ryabinin, **S. R. Smith**, R. A. Weller, M. J. Yelland, H.-M. Zhang, 2010: Observations to quantify air-sea fluxes and their role in climate variability and predictability. In *Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2)*, Venice, Italy, 21-25 September 2010, Hall, J., Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306. (in press).

Gille, S., **M. Bourassa**, 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, 2010: Surface Fluxes in High Latitude Regions. *Proceedings of the OceanObs'09: Sustained Ocean Observations and Information for Society Conference (Vol. 2)*, Venice, Italy, eds. J. Hall, D.E. Harrison and D. Stammer, ESA Publication WPP-306. (in press).

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[15] Hughes is a Ph.D. student advised by the PI, formerly partially supported by NOAA.

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5.2. Other Relevant Publications

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[16] Maue is a Ph.D. student supervised by the PI, and he is partially supported by this grant.