Climate Variability in Ocean Surface Turbulent Fluxes

Mark Bourassa and Shawn Smith
Center for Ocean-Atmospheric Prediction Studies, Tallahassee, FL

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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 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.

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[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.

[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.

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 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 fluxes and the flux-related variables. Our long-term monthly fields are well suited for seasonal to decadal studies (available in time for monthly updated ENSO forecasts, within eight days after the end of the month), and our hybrid satellite/NWP fields will be ideal for daily to inter-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). 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 the beta testing, the wind product will be released in near real time for oceanographic applications (we are aiming for release within two days). 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 will soon be moving to integrate these many parts into a 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.

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 worked with other members NOAA climate observing team to estimate the

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[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.

[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).

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[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. 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).

2. Scientific and Observing System Accomplishments

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˚ Legler 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.

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[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.

2.1. Operational Pacific and Indian Ocean Wind Products

In keeping with the GCOS climate monitoring principles, we continue operational production of the quick-look 2˚ tropical Pacific (http://coaps.fsu.edu/RVSMDC/html/pacmonyrq.shtml) and 1˚ tropical Indian (http://coaps.fsu.edu/woce/html/ndnquick.htm) ocean pseudo-wind stress products. These operational products continue to have a large user community, although many users are unknown to our group. We typically receive a half-dozen requests per year via email for more information on the Indian ocean winds from Asian scientists working on topics related to the Indian monsoon cycles. The Pacific wind products continue to be used by operational ENSO forecasters as part of their modeling efforts (e.g., LDEO) and are published monthly in the NOAA Climate Diagnostics Bulletin (http://www.cpc.ncep.noaa.gov/products/CDB/) used widely by the ENSO community. These operational products directly address the NOAA goals of **Prepare for drought and water resource challenges** and **Sustainably manage marine ecosystems** by supporting operational ENSO forecasting and subsequent decision making processes for the agricultural communities (particularly in the Southeastern U.S.). We have been 100% success in meeting our goals for production and timeliness.

Reduced funding could seriously jeopardize the production of these wind products. Reduced support for the VOS program and reduced maintenance of tropical buoy arrays reduces the quality of this product.

2.2. Develop a multi-satellite wind product

We have made great improvements to our gridded satellite product. We now assimilate wind data (speeds and vector components) from many instruments. We also utilize sea surface temperature data (Reynolds OI Satellite data set) and a model (the University of Washington Planetary Boundary-Layer Model) of wind responses to SST patterns to add realistic small scale variability to areas where satellite winds are not available. This is a major improvement, as it allows us to have a much more consistent time series of wind derivations (e.g., curl for ocean forcing, and convergence for links to the atmosphere) than we had in prior years. This adjustment has been tested for impacts on surface **fluxes of momentum, heat, and fresh water**, and found to have a very large influence in the area of western boundary currents (winter average $30W/m^{-2}$ regional changes), and smaller adjustments over the mid-latitude oceans. These changes appear to be larger than the long-term heat imbalance needed to account for observed changes in **Ocean Heat Content**.

The model of wind responses has been shown to be flawed in the tropics. We are working on removing to simplifications of physics that result in this problem.

Interestingly, the processes modeled for this objective are very similar to the processes that couple oil slicks to small scale atmospheric and oceanographic circulations. The slick causes local changes in surface roughness (wave characteristics) and sea surface temperature, which causes changes in surface wind and momentum resulting in atmospheric and oceanographic processes that cause the slick to contract and rotate (Zheng et al. 2013).

2.3. Design a satellite-based flux product, based on (2)

The satellite flux product has moved forward in development, passing several milestones. We have demonstrated that we can produce surface turbulent fluxes in satellite swaths, and we have

demonstrated that the input data used in these calculations are reasonably accurate. We slowed our efforts to assimilate the air temperatures and humidities needed to calculate fluxes because we saw small scale patterns consistent with the wind and momentum variability mentioned in section 2.2). We have verified that these small scale features are important to estimates of **Air-Sea Exchanges of Heat, Momentum, and Fresh Water**. It is worth noting that wind-related changes are underestimated in numerical weather models. We anticipate that better understanding of this process will eventually contribute to improvements in weather models and ocean models. The changes in wind direction have a substantial impact on the **curl of surface stress**, which is very important for ocean forcing. These changes will impact the ocean's mixed layer and the deep ocean transport, hence try are important for the transport of **Ocean Heat Content**.

Currently, NOAA provides the only support for the development of the turbulent heat flux portion of this product; although wind and stress portions are largely supported by NASA. Lack of funding could seriously slow this work.

2.4. Engage new users of (2) and (3)

We have found several users of wind and flux products to engage in testing of our improved wind product. The comments from this group will also improve the satellite-based flux product as that is based on the same core code as the wind and momentum product. This information is also contributing to a proposed satellite-based program to better observe and understand these processes, as well as similar processes closer to coastlines than has been previously examined.

2.5. Continue interaction with national and international satellite and in situ wind groups

We continue to engage and lead the national and international communities in the areas of satellite and in situ wind and flux products. Through leadership of the NASA Ocean Vector Winds Science Team and chairmanship of the International Ocean Vector Winds Science Team we work with national and international partners to improve gridded wind and flux products. We are also co-Is in the ICOADS Value ADded (IVAD) project, which is greatly improving the very long ICOADS record for use in climate applications. In this project, we aid in the removal of biases in winds, which will lead to reduced biases in derived quantities: **Air-Sea Exchanges of Heat, Momentum, and Fresh Water**. The satellite winds continue to be very useful in the forecast of storm surge and wave damage - **managing risks to coastlines and coastal infrastructure**.

2.6. Continue interaction with national and international flux groups

See 2.5

3. Outreach and Education

We continue to provide opportunities for undergraduate students in the fields of meteorology and computer science to learn research and programming skills that will serve them in graduate school and their respective careers. Four undergraduates were employed via this funding over the past year. Two are undergraduate honors students, and one now has a full time job in part because of the training received with us. We also have one graduate student, who has worked on

estimating white capping from satellite data (papers soon to be submitted). White capping is of interest because if its strong connection to wind and to CO_2 fluxes.

We have also developed a flux program that is used in training graduate students about the importance of a wide variety of physical considerations, as well as examining the differences between parameterizations. This tool is freely available on our web site:
http://coaps.fsu.edu/~bourassa/MFT_html/MFT_docs.php
Information developed on the accuracy requirements for surface fluxes on local, regional, and global scales is used to teach students about some the goals of the global observing system. How various parts of the system can be combined to reach these goals is also discussed. The students also learn to process data to examine surface fluxes and the ocean's response.

Results of our research are routinely published in peer reviewed journals and presented at professional meetings. We try to send our students (graduate and undergraduate) to meeting to further their professional growth.

In this year we completed the development and implementation of a NASA funded professional development (PD) or middle school science teachers. The topic of this PD (called ASK-Florida) was Climate and Climate Change. A portion of the development benefitted from our research related to climate variability, ENSO variability and impacts in particular. It also leveraged the PIs participation in the global observing system, informing teachers of carefully observed and verified changes in the Earth system. The program also emphasized that local and regional changes are different than globally averaged changes. This approach could be used to highlight local changes, which were of more interest to the teachers and students, and link them to larger scale climate patterns. Local changes included sea level rise, temperature and precipitation patterns, and mitigation of ENSO changes on agricultural productivity. This activity contributed to improved education and outreach in three Florida counties, and portions of the work are now being used by 4H. Reviews by the county education supervisors were extremely positive, regrettably funding for the NASA program was not usefully continued. Our work has also been used to inform university juniors, seniors and graduate students about the coupled ocean/atmosphere system and the observing system used to study it.

4. Publications and Reports

4.1. Publications by Principal Investigators

4.1.1. Published

Ali, M. M., G. S. Bhat, D. G. Long, S. Bharadwaj, **M. A. Bourassa**, 2013: Estimating wind stress at the Ocean surface from scatterometer observations. *IEEE GRSL*, **10**. 1129 – 1132.

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, and G. Wick, 2013: High-latitude ocean and sea ice surface fluxes: requirements and challenges for climate research. *Bull. Amer. Meteor. Soc*. **94**, 403 - 423. http://dx.doi.org/10.1175/BAMS-D-11-00244.1

Rudzin[13], J. E., S. L. Morey, **M. A. Bourassa**, and S. R. Smith, 2013: The influence of loop current position on winter sea surface temperatures in the Florida Straits. *Earth Interactions*, **17**, 9 pgs. DOI: 10.1175/2013EI000521.1

Zheng, Y., **M. A. Bourassa**, and P. J. Hughes, 2013: Influences of Sea Surface Temperature Gradients and Surface Roughness Changes on the Motion of Surface Oil: A Simple Idealized Study, *J. Appl. Meteor. Clim.*, **52**, 1561 - 1575. DOI: 10.1175/JAMC-D-12-0211.1

Purna Chand Ch, M. V. Rao, I. V. Ramana, M. M. Ali, J. Patoux, and **M. A. Bourassa**, 2013: Estimation of Sea-Level Pressure Fields during Cyclone Nilam from Oceansat-2 Scatterometer Winds, *J. Geophys. Res. (Oceans)*, (in press).

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).

4.1.2. Technical reports

Yu, L., K. Haines, **M. Bourassa**, M. Cronin, S. Gulev, S. Josey, S. Kato, A. Kumar, T. Lee, D. Roemmich, 2013: CLIVAR GSOP WHOI Workshop on Ocean Syntheses and Surface Flux Evaluation. CLIVAR Workshop Summary Report, Woods Hole, Massachusetts

Bourassa, M. A., A. Stoffelen, P. Chang, D. Chelton, R. Edson, Z. Jelenak, T. Lee, W. T. Liu, D. Long, M. Powell, E. Rodriguez, D. Smith, and F. Wentz, 2010: Remotely sensed winds and wind stresses for marine forecasting and ocean modeling. Proceedings of the Integrated Ocean Observing System (IOOS) Summit Workshop, (submitted).

Fairall, C. W., **M. A. Bourassa**, M. F. Cronin, S. R. Smith, R. A. Weller, G. Wick, S. Woodruff, L. Yu, H-M Zhang , 2012: Observations to Quantify Air-Sea Fluxes and Their Role in Gloabal Variability and Predictability. Proceedings of the Integrated Ocean Observing System (IOOS) Summit Workshop, (submitted).

4.2. Other Relevant Publications

This section includes significant publications (published in the past year) in which a project investigator's work (or the project itself) is cited, or the project's data used.

Fangohr, S., E. C. Kent, 2012: An Estimate of Structural Uncertainty in QuikSCAT Wind Vector Retrievals. *J. Appl. Meteor. Climatol.*,**51**, 954–961. doi:10.1175/JAMC-D-11-0183.1.

Fu, W. W., 2012: Altimetric data assimilation by EnOI and 3DVAR in a Tropical Pacific model: Impact on the simulation of variability. *Adv. Atmos. Sci.*, **29**(4), 823–837, doi:10.1007/s00376-011-1022-7.

Gulev, S. K., and K. Belyaev, 2012: Probability Distribution Characteristics for Surface Air–Sea Turbulent Heat Fluxes over the Global Ocean. *J. Climate*, **25**, 184–206. doi:10.1175/2011JCLI4211.1.

[13] Underlined authors are students

Kent, E. C., S. Fangohr, and D. I. Berry, 2013: A comparative assessment of monthly mean wind speed products over the global ocean. *Int. J. Climatol.*, **33**: 2520–2541. doi:10.1002/joc.3606

Kent, E. C., D. I. Berry, J. Prytherch, and J. B. Roberts, 2013: A comparison of global marine surface-specific humidity datasets from *in situ* observations and atmospheric reanalysis. *Int. J. Climatol*. doi:10.1002/joc.3691.

Kessler, W. S., and S. Cravatte, 2013: ENSO and Short-Term Variability of the South Equatorial Current Entering the Coral Sea. *J. Phys. Oceanogr.*, **43**, 956–969. doi:10.1175/JPO-D-12-0113.1.

Lee, T., D. E. Waliser, J.-L. F. Li, F. W. Landerer, and M. M. Gierach, 2013: Evaluation of CMIP3 and CMIP5 Wind Stress Climatology Using Satellite Measurements and Atmospheric Reanalysis Products. *J. Climate*, **26**, 5810–5826. doi:10.1175/JCLI-D-12-00591.1.

Li, M., J. Liu, Z. Wang, H. Wang, Z. Zhang, L. Zhang, and Q. Yang, 2013: Assessment of Sea Surface Wind from NWP Reanalyses and Satellites in the Southern Ocean. *J. Atmos. Oceanic Technol.*, **30**, 1842–1853. doi:10.1175/JTECH-D-12-00240.1.

Nyadjro, E. S., B. Subrahmanyam, V. S. N. Murty, and J. F. Shriver, 2012: The role of salinity on the dynamics of the Arabian Sea mini warm pool, *J. Geophys. Res*., **117**, C09002, doi:10.1029/2012JC007978.

Reineman, B. D., L. Lenain, N. M. Statom, and W. K. Melville, 2013: Development and Testing of Instrumentation for UAV-Based Flux Measurements within Terrestrial and Marine Atmospheric Boundary Layers. *J. Atmos. Oceanic Technol.*, **30**, 1295–1319. doi:10.1175/JTECH-D-12-00176.1.

Roberts, J. B., F. R. Robertson, C. A. Clayson, M. G. Bosilovich, 2012: Characterization of Turbulent Latent and Sensible Heat Flux Exchange between the Atmosphere and Ocean in MERRA. *J. Climate*, **25**, 821–838. doi:10.1175/JCLI-D-11-00029.1.

Schulz, E. W., S. A. Josey, and R. Verein, 2012: First air-sea flux mooring measurements in the Southern Ocean, *Geophys. Res. Lett*., **39**, L16606, doi:10.1029/2012GL052290.

Shi, L., G. Peng, J. J. Bates, 2012: Surface Air Temperature and Humidity from Intersatellite-Calibrated HIRS Measurements in High Latitudes. *J. Atmos. Oceanic Technol.*, **29**, 3–13. doi:10.1175/JTECH-D-11-00024.1.

Song, X., L. Yu, 2012: High-Latitude Contribution to Global Variability of Air–Sea Sensible Heat Flux. *J. Climate*, **25**, 3515–3531. doi:10.1175/JCLI-D-11-00028.1.

Thomas, R. M., K. Lehmann, H. Nguyen, D. L. Jackson, D. Wolfe, and V. Ramanathan, 2012: Measurement of turbulent water vapor fluxes using a lightweight unmanned aerial vehicle system, *Atmos. Meas. Tech*., **5**, 243-257, doi:10.5194/amt-5-243-2012.

Yu, L., and X. Jin, 2012: Buoy perspective of a high-resolution global ocean vector wind analysis constructed from passive radiometers and active scatterometers (1987–present), *J. Geophys. Res*.,**117**, C11013, doi:10.1029/2012JC008069.

Zhu X. Y., Y. M. Liu, and G. X. Wu, 2012: An assessment of summer sensible heat flux on the Tibetan Plateau from eight data sets. *Sci China Earth Sci*, **55**: 779–786, doi:10.1007/s11430-012-4379-2.