Global Ocean Surface Heat Flux Analysis

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1. Project Summary

The Objectively Analyzed air-sea Fluxes (OAFlux) project is a research and development project focusing on global air-sea heat, moisture, and momentum fluxes. The project is committed to develop high-quality, long-term, global ocean surface forcing datasets from the late 1950s to the present to serve the needs of the ocean and climate communities on characterization, attribution, modeling, and understanding of variability and long-term change in the atmosphere, and the ocean. Over the years, concerted efforts have lead to the development of an innovative objective analysis approach to improving the quantification of global air-sea flux fields, and to the use of these flux datasets to stimulate advances in our understanding of the role of the ocean in the global energy budget, the global hydrological cycle, and the change and variability of the Earth's climate.

Global air-sea fluxes are commonly constructed from flux bulk parameterizations that require surface meteorological observables (e.g., wind speed, temperature, humidity, cloud cover, etc.) as inputs. However, no surface meteorological observables are free from errors/biases regardless of whether they are ship-based measurements or space-born satellite retrievals. The OAFlux project was established on the basis that quality global flux fields can be obtained by taking into account data errors while combining and synthesizing the existing data sources. To better represent errors in input data sources, a validation data base was created that consists of 120+ flux buoys over the global oceans, including the tropical moored array network in all three tropical oceans (i.e., the Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) in the Pacific, the Prediction and Research Moored Array in the Atlantic (PIRATA), and the Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (RAMA) in the Indian Ocean), and moored surface buoys deployed by the Upper Ocean Processes Group at the Woods Hole Oceanographic Institution. The in situ validation base provides benchmark time series essential for quantifying uncertainties in input data sources and for evaluating the accuracy of the OAFlux analysis.

At present, the OAFlux project has produced global 1° resolution, daily/monthly analysis (1958-to present) of ocean evaporation, air-sea latent and sensible heat fluxes, and related surface meteorological variables. These products are being maintained online (http://oaflux.whoi.edu/

data.html) with twice-per-year updates. The OAFlux new datasets, developed in coordination with other projects, are the global 0.25° and 1° resolution analyses of daily ocean vector wind fields covering the period of satellite passive/active sensors from 1987 to the present. The current effort of the project is directed toward a global net heat flux dataset with reduced biases/errors. The multi-decadal global flux time series contribute to new insights into the fundamental changes in the global climate system when temperature rises. It shows the intensification of ocean evaporation since the late 1970s, providing observation evidence to the Intergovernmental Panel on Climate Change (ICPP) 5th assessment report (AR5) on the acceleration of the global hydrological cycle in the past warm decades. It illustrates the important role of the strengthening ocean surface wind speed in increasing ocean evaporation. It suggests a non-negligible contribution of high-latitude sensible heat flux (i.e. the thermal exchange at the air-sea interface due to air-sea temperature differences) to global energy balance. Steady progress has been made and the project is on track toward achieving its objectives.

The quality and accuracy of the OAFlux time series have gained increasing recognition and appreciation in the community and the OAFlux data user base is growing rapidly. Users of the OAFlux products include but are not limited to: 1) climate modeling groups and centers, including National Centers for Environmental Prediction (NCEP), Global Ocean Data Assimilation System (GODAS), the National Aeronautics and Space Administration (NASA), Modern Era Retrospective-Analysis for Research and Applications (MERRA), and Coupled Model Intercomparison Project (CMIP), using the global OAFlux fields as base reference for validating the performance of the models; 2) investigators and researchers working under the NASA Aquarius mission and the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, and the NASA field experiment of the Salinity Processes in the Upper Ocean Regional Study (SPURS), using OAFlux evaporation time series together with the precipitation time series from the NASA Global Precipitation Climatology Project (GPCP) as freshwater flux forcing to study the cause of the change of ocean salinity; 3) researchers and investigators working to understand the global hydrological change under climate warming, using OAFlux time series to study the intensification of the global ocean cycle in the past three decades; 4) investigators under targeted field programs, including CLIVAR (Climate Variability research program), Mode Water Dynamic Experiment (CLIMODE), and Dynamics of the Madden-Julian Oscillation (DYNAMO), using OAFlux products to identify key air-sea interaction processes and feedback mechanisms; 5) researchers working on the ocean carbon cycle, using OAFlux products to identify global "hot spots" where the ocean releases heat to the atmosphere and absorbs carbon dioxide from the atmosphere to understand the air-sea heat flux as a driver of the air-sea carbon flux; 6) those working to quantify the role of the ocean in climate variability and change, using the OAFlux time series to evaluate the ocean's role as a source or sink of heat and freshwater; 7) those working with ocean models, who use the OAFlux product as the forcing fields for model runs; 8) those developing alternate air-sea flux fields from remote sensing and/or in situ data, who compare their products to the OAFlux fields; 9) those researching new and renewable energy sources, using OAFlux wind and near-surface meteorological parameters to estimate global offshore wind power potential; and 10) educators involved in the Education and Outreach programs, e.g., the education program of the NASA Aquarius mission, the NOAA National Weather Service (NWS) online weather school - JetStream, and the Cooperative Program for Operational Meteorology, Education and Training (COMET) established by the University Corporation for Atmospheric Research (UCAR) and NWS, who use OAFlux climatology as course materials.

2. Scientific and Observing System Accomplishments

Four tasks were proposed in the Work Statement for FY11: (1) Maintaining and updating the online OAFlux long-term time series to support near-real time delivery of reliable OAFlux data records, (2) Continuing the development of high-resolution heat flux products in coordination with the development of high-resolution vector wind time series supported by NASA, (3) Improving the net heat flux dataset by reducing biases/errors in satellite-based surface radiation estimates toward an eventual globally balanced surface energy budget, and (4) Applying the OAFlux products to climate studies on the global water cycle and ocean salinity. The deliverables and accomplishments for each task are summarized as follows.

(1) Maintenance and update of OAFlux online products

Deliverables: The deliverables from this task are: i) timely online update of the OAFlux products delivered according to the proposed timeframe, ii) the 50-plus year time series of OAFlux fields made available from January 1958 to July 2011, iii) the OAFlux time series as a base data set for NOAA's annual assessment report on the State of Climate 2011, iv) 14 scientific publications in 2011 by the PIs, with 9 in referred journals, and iv) the consistent, long-term OAFlux products as a fundamental data set in approximately 60 papers that were published in refereed journals in 2011 by international researchers.

Accomplishments and discussion:

OAFlux daily analysis of global ocean evaporation, latent heat flux, sensible heat flux, and related surface meteorology currently operates on a regular production mode and is available from the project website at http://oaflux.whoi.edu. In FY11, online dissemination of the OAFlux products was timely delivered according to the proposed timeframe, with one in October 2010 and the other in May 2011. The most recent update was carried out in October 2011 and all time series are available up to July 2011. The next update is scheduled for May 2012.

OAFlux is developed not from a single source, but from an objective synthesis of multi-platform, multi-sensor satellite observations with atmospheric reanalysis outputs to fill in the information that is not observed by satellites. The accuracy of input datasets changes year to year because of changes in the satellite platforms, aging/degrading of some sensors, the changing error characteristics of atmospheric reanalysis products, etc. To ensure the quality of input datasets and to provide the uncertainty estimates to the OAFlux analysis, a validation database was created that consists of moored buoy measurements from more than 120 locations (Figure 1a), including the tropical moored array network in all three tropical oceans (i.e., the TAO/TRITON in the Pacific, the PIRATA in the Atlantic, and the RAMA in the Indian Ocean), and flux reference sites from Stratus, NTAS, WHOTS, KEO, PAPA, etc. During each scheduled update, the validation database is amended to include the most recent buoy time series.

Long-term time series are essential for characterizing the long-term tendency in surface forcing functions. The OAFlux analysis provides a base data set for the NOAA's State of Climate annual assessment report on the changing global surface forcing functions (Figure 1b; Yu et al., 2011 BAMS). The 50-plus year time series suggests a dominance of decadal oscillation on the long-term change of global ocean latent (evaporation) and sensible heat fluxes. There were 14 publications by the PIs in 2011 (see Section 3.1), with 9 in refereed journals and 5 in proceedings from conferences.

The OAFlux analysis is being increasingly used by international researchers in a wide range of applications, including process-oriented studies on atmosphere-ocean interactions, validation reference for model simulations, forcing functions for oceanic models, climate analysis and assessments, etc. It serves as a fundamental data set for approximately 60 papers that were published (by researchers not affiliated with the PIs) in referred journals in 2011 alone (see Section 3.2).

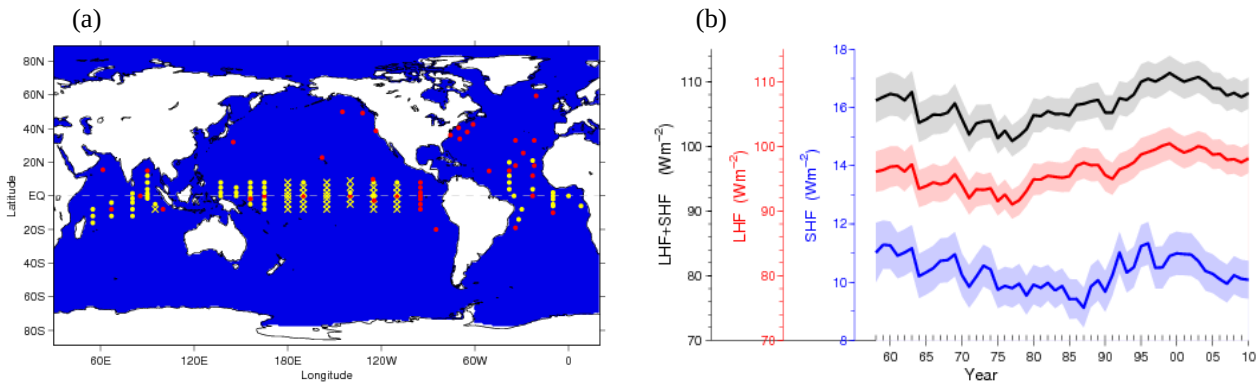

Figure 1. a. The moored-buoy based validate database used in OAFlux analysis. b. Annual-mean time series of latent heat flux (red), sensible heat flux (blue), and the sum of the two heat flux components (black) from the OAFlux analysis. Adapted from Yu et al., 2011.

(2) Continuing the development of high-resolution heat flux products

Deliverables: The basic deliverable from this task is the development of a 0.25-degree gridded global analysis of heat fluxes from 1999 to the present. The high-resolution (HR) dataset has undergone extensive validation using buoy measurements and cross-evaluation with recent atmospheric reanalyses. The dataset has been examined in the Gulf Stream region to examine the benefits of the HR analysis in studying mid-latitude atmosphere-ocean coupled interactions.

Accomplishments and discussion:

The development of a high-resolution (0.25-degree) analysis of global heat flux products takes advantage of three new satellite-derived products. The first is our newly developed vector wind analysis on 0.25-degree from 1987 to the present under the auspices of NASA vector wind science team activities (Yu and Jin 2012). The second product is the SST measurements from microwave (MW) radiometers from 1997 to the present. In contrast to AVHRR, MW is transparent to clouds so that SST can be retrieved in nearly all weather conditions except for rains. Merging AVHRR SST with MW SST remains a technical challenge for the SST community, and so only one type SST can be chosen to ensure the consistency of the OAFlux analysis. The SST product used for the current 1-degree product is the AVHRR SST from NOAA Optimum Interpolated SST (OISST) analysis, which is known for its poor representation in ocean frontal regions on a daily basis. The third product is the near-surface air temperature and humidity produced by Jackson and Wick at the NOAA Environmental System Research Laboratory. The products were derived from satellite SSMI sensors and AMSU sounding profiles with in situ observations as a training background. These three datasets improve the

representation of spatial variability of air-sea variables, especially in the ocean frontal regions such as the western boundary currents.

In FY2011, efforts were made to fix technical issues (data gaps, mean bias in humidity and air temperature), to validate the accuracy of the HR OAFlux analysis, and to gain in-depth understanding of the benefits of the HR analysis through applications to mid-latitude air-sea interaction. We collaborated with the CLIMODE project in the Gulf Stream and cross-evaluated the HR analysis with the recent atmospheric reanalysis from ECMWF reanalysis (ERA) interim, NASA Modern Era Retrospective-analysis for Research and Applications (MERRA), and NOAA coupled forecasting system reanalysis (CFSR) (Figure 2). The benefits of the OAFlux HR wind stress and heat fluxes are clearly displayed. A high degree of covariability between the HR fluxes and MW SST retrievals suggests a strong ocean thermal modulation on the air-sea heat and momentum fluxes when cold air mass passed by. Figure 2 also shows that CFSR fluxes are better than ERA-interim and MERRA in that CFSR is a coupled system and can do better than the atmosphere-only models in case of strong air-sea coupling. Presentation of the analysis was given at several meetings, including the CLIMODE PI meeting, the WCRP open science conference, and the NASA SST science team meetings.

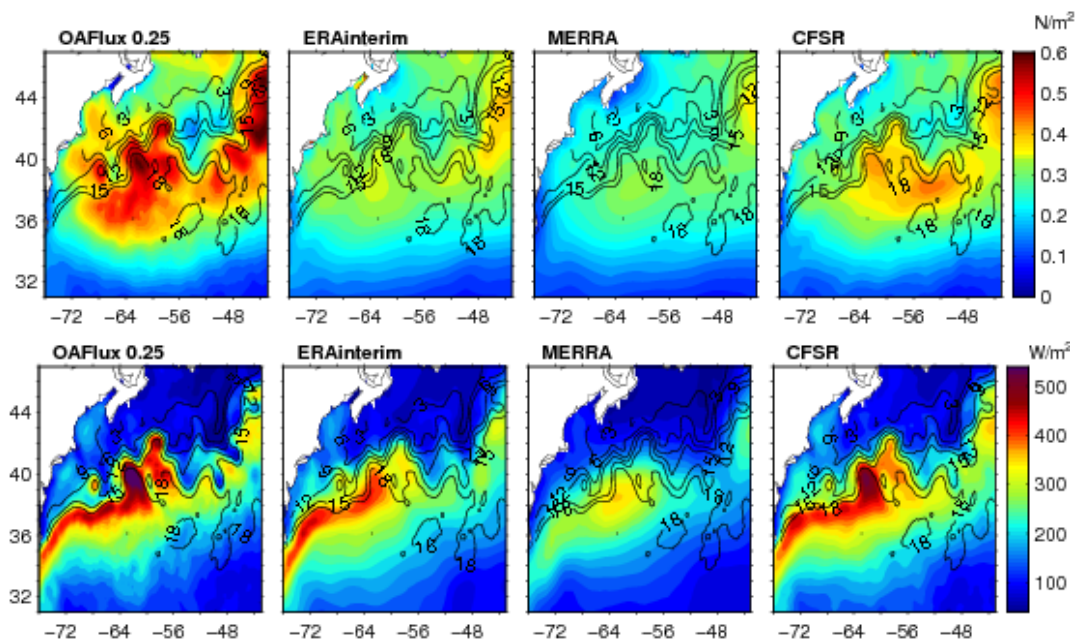

Figure 2. Comparison of OAFlux HR (0.25-degree) analysis of wind stress (top panel) and latent-plus-sensible heat fluxes) with three recent atmospheric reanalyses (ERA interim, MERRA, and CFSR) during a cold air outbreak event in February 2007. OAFlux HR fluxes show a high-degree of covariability with SST.

(3) Improving surface radiation and the net heat flux estimates

<u>Deliverables:</u> The deliverables from this task include i) quantifying the uncertainties in current satellite surface radiation products through buoy validation, and ii) providing guidance on improving global net heat flux estimates.

Accomplishments and discussion:

Achieving a globally balanced net heat budget remains a leading issue for all flux products despite many significant progresses made in the past 20 years. The OAFlux analysis faces the same challenge. When combining the OAFlux global latent and sensible heat fluxes with the state-of-art satellite derived surface radiation products (such as ISCCP (International Satellite Cloud Climatology Project, Zhang et al. 2004) and SRB (Surface Radiation Budget, Stackhouse et al. 2004), the global heat budget is not balanced and the residual is as large as 29-33 W/m^2. Having a globally balanced heat budget is of paramount importance for climate studies, because it is the forcing term in the long-term change of global ocean temperatures.

Efforts in YR2011 were made to evaluate ISCCP and SRB products using all available buoys. We also introduced three recent reanalyses, three older reanalyses (NCEP1, NCEP2, ERA40), and the ship-based climatology from the National Oceanographic Centre at Southampton (NOCS) in the analysis. The mean and standard deviations between the 9 products for shortwave (SW) and longwave (LW) components are shown in Figure 3, suggesting that errors in SW products are confined mostly in the tropical oceans and that errors in LW are comparable to the errors in SW, though the magnitude of LW is about one-fifth of that of SW. The time series at the STRATUS site further indicates the biases in LW, particularly ISCCP LW.

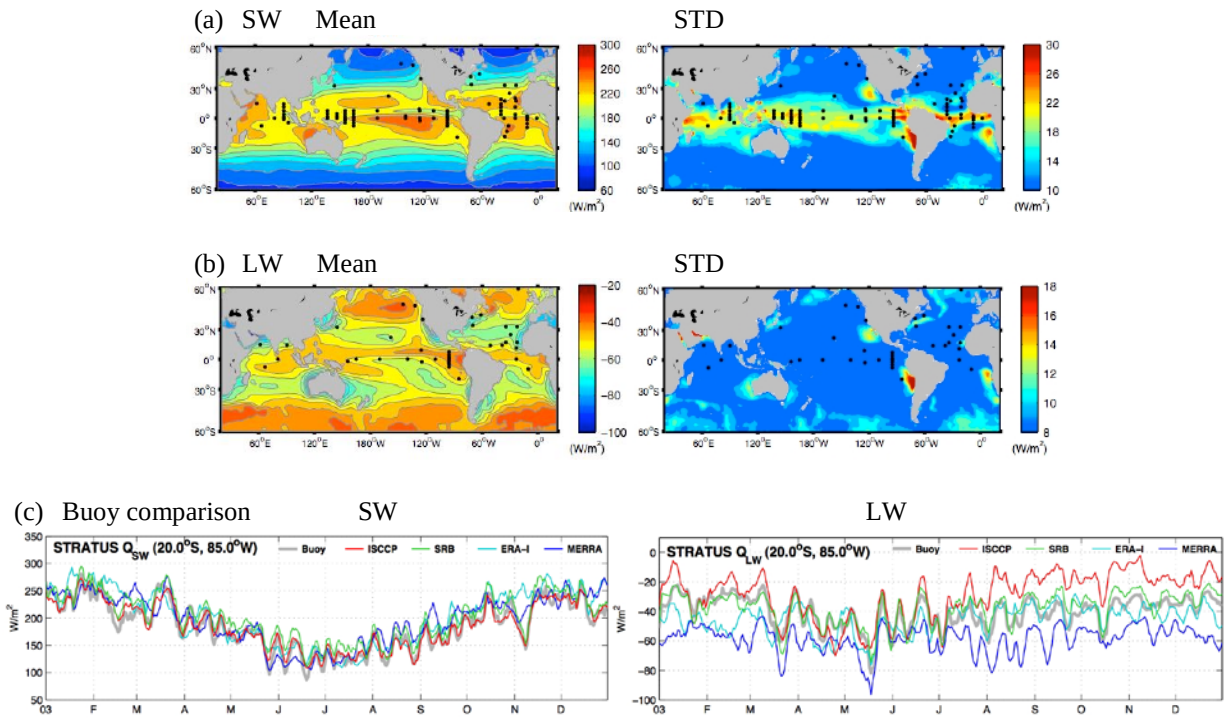

Figure 3. Mean and standard deviation (STD) of (a) 9 annual-mean SW products, and (b) 9 annual-mean LW products. The dots denote available SW and LW buoy locations in the respective plots. (c) Evaluation of SW and LW from 4 products at the STRATUS location.

(4) Climate Applications of OAFlux long-term time series

Deliverables: The deliverables from this task are: i) quantification of the physical representation of OAFlux evaporation and GPCP precipitation time series in ascribing the observed change in salinity, ii) identification of the high-latitude contribution to global sensible flux variability, and iii) publications and presentations based on findings of the study.

Accomplishments and discussion:
In YR2011, the OAFlux time series were applied to address two specific questions. One is the relationship between the ocean water cycle and salinity (Yu 2011) and the other is the cause of decadal variability of sensible heat flux since the 1980s (Song and Yu 2011).

The underlying issue in studying the relationship between the ocean water cycle and salinity is whether and where the oceans can be a rain gauge. Ocean salinity is consequential to the change of the water cycle because evaporation-minus-precipitation (E-P) is the freshwater flux forcing for the open oceans. The concept of using the oceans as a rain gauge has long been proposed, but implementing this concept is complicated owing to the fact that the two variables are related through complex upper ocean dynamics. As a first step toward an advanced understanding, we derived a global map of the leading forcing for seasonal variability of the mixed-layer salinity (MLS), using a lower-order MLS dynamics that allows key balance terms (e.g. *E-P*, the Ekman and geostrophic advection, vertical entrainment, and horizontal diffusion) to be computed from satellite-derived datasets and MLS climatology. The covariance contribution of each process to MLS is ranked according to the magnitude, leading to the construction of the leading dominance over the global domain (Figure 4). This study was also conducted in coordination with support from NASA remote sensing and climate program.

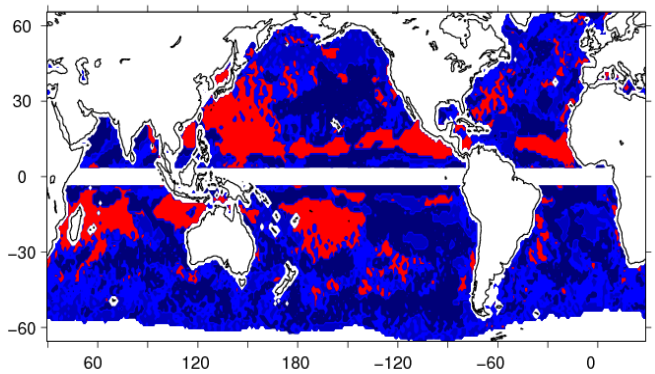

Figure 4. A rain-gauge regime (red colored area) determined from a covariance analysis of seasonal mixed-layer salinity and E-P. The blue (red) colored area denotes the leading process for the change of salinity is governed by ocean dynamics (E-P).

Decadal variability of sensible heat flux (SHF; Figure 1b) was examined using the OAFlux analysis in coordination with funding from the WHOI Arctic Ocean Initiative program. We found that global SHF anomalies are strongly modulated by SHF at high latitudes (poleward of 45°) during winter seasons. Decadal variability of global wintertime SHF can be reasonably represented by the sum of two leading EOF modes, namely, the boreal wintertime SHF in the

northern oceans and the austral wintertime SHF in the southern oceans. The increase of global SHF in the 1990s is attributable to the strengthening of the Southern Annular Mode index, while the decrease of global SHF after 2000 is due primarily to the downward trend of the Arctic Oscillation index. This study identified the important effects of wind direction and speed on SHF variability. This finding is in tune with the study of Yu (2007) that shows the important role of winds in enhancing global evaporation in the past 50 years. Taken together, winds are a critical player in the observed global variability of air-sea turbulent latent and sensible heat exchange.

2.1. Outreach and Education

Lisan Yu

Dr. Lisan routinely presents research results at national and international scientific meetings. She serves on the NOAA Ocean Observing System Team of Experts and has led the analysis of global ocean surface flux for the NOAA State of Climate annual assessment report since 2005. She is a contributing author to the IPCC Fifth Assessment report. She serves on the CLIVAR Global Synthesis and Observations Panel. She is a member of NASA Sea Surface Temperature Science Team, NASA Ocean Surface Salinity Science Team, and NASA Ocean Vector Wind Science Team. She routinely reviews research papers and proposals. She presents science talks at the WHOI summer student program. She has advised or co-advised 3 postdoctoral investigators, 1 Ph.D. WHOI-MIT joint program student, 3 guest Ph.D. students, and 2 Summer Student Fellows.

Robert A. Weller

Dr. Weller's outreach and education on air-sea fluxes is closely linked to these same activities on the Ocean Reference Station project that provides some of the high quality validation of the OAFlux. The cruises to the moorings invite participation by the NOAA Teacher at Sea program, and an important teaching topic is air-sea flux. Ten Teachers at Sea have been hosted. A video of one of these cruises and the work to collect air-sea fluxes from surface moorings was produced by volunteer Diane Suhm. This video was recently provided to the Climate Observation Division. A shorter version has run on cable TV in Massachusetts and will be used at public lectures in Woods Hole. These cruises, whenever possible, offer space to undergraduate and graduate students to provide hands on experience at sea and about air-sea fluxes. Weller has used opportunities derived from sailing from different Central and South American ports for regional outreach. Staff from INOCAR (Institute of Naval Oceanography) in Ecuador, the Hydrographic Division of the Peruvian Navy (DHN), the Institute of Marine Sciences of Peru (IMARPE), and the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) have joined Stratus cruises. Weller now advises 2 postdoctoral investigators.

3. Publications and Reports

3.1. Publications by Principal Investigators

Publications in refereed journals:

Cronin, M. F., **R.A. Weller**, and R.S. Lampitt, 2012: Ocean Reference Stations. IN: *Earth Observation, INTERCH*, in press.

Duennebier, F. K., R. Lukas, E.-M. Nosal, J. Aucan, and **R. A. Weller**, 2012: Wind, waves, and acoustic background levels at Station ALOHA. *J. Geophys. Res.*, doi:10.1029/2011JC007267, in press.

Song*, X., and **L. Yu**, 2011: High latitude contribution to global variability of sensible heat flux at the air-sea interface. *Journal of Climate*, special collection on "CLIVAR/SeaFlux High Latitude Surface Fluxes". http://dx.doi.org/10.1175/JCLI-D-11-00028.1. In press.

* Visiting student

Yu, L., 2011: A global relationship between the ocean water cycle and near-surface salinity. *Journal of Geophysical Research – Oceans*. **116**, C10025, 17pp, doi:10.1029/2010JC006937.

Yu, L., X. Jin, and **R. A. Weller**, 2011: Global ocean heat fluxes [in "State of the Climate in 2010"]. *Bull. Amer. Meteor. Soc.*, **92**(6), S1-S266.

Zhang, L-P., L-X. Wu, and **L. Yu**, 2011: Oceanic origin of recent La-Niña like warming. *Advances in Atmospheric Sciences*, doi: 10.1007/s00376-010-0129-6.

Yu, L., and M. J. McPhaden, 2011: Ocean pre-conditioning of Cyclone Nargis in the Bay of Bengal: Interaction between Rossby waves, surface fresh waters, and sea surface temperatures. *Journal of Physical Oceanography*, **41**(9), 1741-1755. doi:10.1175/2011JPO4437.1.

Nof, D., S. Gorder, and **L. Yu**, 2011: Thoughts on a variable meridional overturning cell and a variable heat-flux to the atmosphere. *Geophysical & Astrophysical Fluid Dynamics*, **105**, 1-22, doi:10.1080/03091929.2010.481383.

Yu, L., 2011: Sea surface exchanges of momentum, heat, and freshwater determined by satellite remote sensing. *Climate and Oceans: A Derivative of the Encyclopedia of Ocean Sciences*. J. Steele, S. A. Thorpe, K. K. Turekian, (Eds). Academic Press, London, UK. 636pp. 110-119.

Abstracts and proceedings from conferences:

Yu, L., 2010: Using the tropical warm water pools to quantify air-sea net heat flux - Rationale, concept, and ongoing work. Proceedings of the NASA SST Science Team meeting. Seattle, Washington, November 2010.

Yu, L., 2010: Long-term variations in the global oceans: Evidence from OAFlux surface forcing datasets. STAREPS Symposium on "Climate Prediction and Information for the Society", JAMSTEC and University of Aizu. Aizu, Japan, December 2010.

Yu., L., and X. Jin, 2011: High-resolution ocean vector wind and heat flux analysis: Example from Feb 2007. The CLIMODE PI workshop. Woods Hole, MA, July 2011.

Yu, L., X. Jin, and R. A. Weller, 2011: Sustained Observations to Address Climate Research Needs Observations for Climate: Sustained air-sea flux buoy observations for quantifying/ characterizing the changes in global ocean surface fluxes in a changing climate. Proceedings of the WCRP open science conference, Denver, CO, October, 2011.

Yu, L., X. Jin, and R. A. Weller, 2011: Observations for Climate: Sustained air-sea flux buoy observations for quantifying/characterizing the changes in global ocean surface fluxes in a changing climate. Proceedings of the WCRP open science conference, Denver, CO, October, 2011.

3.2. Other Relevant Publications

The OAFlux products were a fundamental data set in the following publications that appeared in 2011. All these publications were from investigators other than the PIs.

Allan, R. P., and I. I. Zveryaev, 2011: Variability in the summer season hydrological cycle over the Atlantic-Europe region 1979–2007. *International Journal of Climatology*, 31(3), 337–348.
Alton, P. B., and P. E. Bodin, 2011: Model Estimates of the Land and Ocean Contributions to Biospheric Carbon and Water Fluxes Using MODIS Satellite Data. *Journal of Climate* **24**:14, 3558-3574.

Andersson, A., K. Christian, K. Fennig, S. Bakan, H. Grassl, and J. Schulz, 2011: Evaluation of HOAPS-3 Ocean Surface Freshwater Flux Components. *Journal of Applied Meteorology and Climatology* **50**:2, 379-398.

Berry, D., and E. C. Kent, (2011), Air–Sea fluxes from ICOADS: the construction of a new gridded dataset with uncertainty estimates. International Journal of Climatology, 31(7), 987-1001.

Bosilovich, M. G., F. R. Robertson, and J. Chen,2011. Global Energy and Water Budgets in MERRA. *Journal of Climate,* **24**:22, 5721-5739.

Brunke, M. A., Z. Wang, X. Zeng, M. Bosilovich, and C-L. Shie,2011. An Assessment of the Uncertainties in Ocean Surface Turbulent Fluxes in 11 Reanalysis, Satellite-Derived, and Combined Global Datasets. *Journal of Climate,* **24**:21, 5469-5493.

Cerovečki,I., L. D. Talley, and M. R. Mazloff,2011: A Comparison of Southern Ocean Air–Sea Buoyancy Flux from an Ocean State Estimate with Five Other Products. *Journal of Climate,* **24**:24, 6283-6306.

Chang, P. H., Chun-Ho Cho, and Sang-Boom Ryoo, 2011: Recent changes of Mixed Layer Depth in the East/Japan Sea: 1994–2007. *Asia-Pacific Journal of Atmospheric Sciences*,**47**(5), 497-501, DOI: 10.1007/s13143-011-0034-7.

Ciasto, L. M., and M. H. England, 2011: Observed ENSO teleconnections to Southern Ocean SST anomalies diagnosed from a surface mixed layer heat budget. *Geophysical Research Letters*, **38**, L09701, doi:10.1029/2011GL046895.

Colas, F., J. C. McWilliams, X. Capet, and J. Kurian, 2011; Heat balance and eddies in the Peru-Chile current system. *Climate Dynamics*,DOI: 10.1007/s00382-011-1170-6.

Faure, V., M. Arhan, S. Speich, and S. Gladyshev, 2011: Heat budget of the surface mixed layer south of Africa. *Ocean Dynamics*, **61**(10), 1441-1458, DOI: 10.1007/s10236-011-0444-1.

Girishkumar, M. S., M. Ravichandran, and V. Pant, 2011: An intelligent wavelet transform-based framework to detect subsurface fires with NOAA–AVHRR images. *International Journal of Remote Sensing*, **33**(4), 1276-1295.

Gulev, S. K., and K. Belyaev,2012: Probability Distribution Characteristics for Surface Air–Sea Turbulent Heat Fluxes over the Global Ocean. *Journal of Climate*, **25**:1, 184-206.

Iwasaki, S., and M. Kubota,2011: Increasing trends for the surface heat flux and fresh water flux in the North Pacific eastern subtropical region. *Geophysical Research Letters*, **38**, L10604, 6pp., doi:10.1029/2011GL047128.

Kim, D., A. H. Sobel, and I.-S. Kang,2011: A mechanism denial study on the Madden-Julian Oscillation. *J. Adv. Model. Earth Syst.*, **3**, M12007, doi:10.1029/2011MS000081.

Katsaros, K. B., A. Bentamy, M. Bourassa, N. Ebuchi, J. Gower, W. T. Liu, and S. Vignudelli, 2011. Climate data issues from an oceanographic remote sensing perspective. In "Remote Sensing of the Changing Oceans", Ed. L. Tang, pp7-32. Springer.

Kumar, A., and Z-Z. Hu, 2011. Uncertainty in the ocean–atmosphere feedbacks associated with ENSO in the reanalysis products. *Climate Dynamics*, DOI: 10.1007/s00382-011-1104-3.

Lagerloef, G., R. Schmitt, J. Schanze, and H.-Y. Kao. 2010. The ocean and the global water cycle. *Oceanography*, **23**(4):82–93.

Li, G., B. Ren, J. Zheng, and C. Yang,2011: Trend Singular Value Decomposition Analysis and Its Application to the Global Ocean Surface Latent Heat Flux and SST Anomalies. *Journal of Climate*, **24**:12, 2931-2948.

Lee, E., C. C. Barford, C. J. Kucharik, B. S. Felzer, and J. A. Foley, 2011. Role of Turbulent Heat Fluxes over Land in the Monsoon over East Asia. *International Journal of Geosciences*, **2**(4),420-431.

Li, G., B. Ren, C. Yang, and J. Zheng,2011: Revisiting the trend of the tropical and subtropical Pacific surface latent heat flux during 1977–2006. *Journal of Geophysical Research*, **116**:D10.

Li, G., B. Ren, J. Zheng, and C. Yang, 2011:Net air–sea surface heat flux during 1984–2004 over the North Pacific and North Atlantic oceans (10°N–50°N): annual mean climatology and trend. *Theoretical and Applied Climatology*, **104**(3-4), 387-401, DOI: 10.1007/s00704-010-0351-2.

Lin, P., H. Liu, Y. Yu, and X. Zhang, 2011: Response of sea surface temperature to chlorophyll-a concentration in the tropical Pacific: Annual mean, seasonal cycle, and interannual variability. *Advances in Atmospheric Sciences*,**28**(3), 492-510, DOI: 10.1007/s00376-010-0015-2.

Liu, J., J. A. Curry, C. A. Clayson, and M. A. Bourassa, 2011: High-Resolution Satellite Surface Latent Heat Fluxes in North Atlantic Hurricanes. *Monthly Weather Review*, **139**:9, 2735-2747.

Liu, J., T. Xiao, and L. Chen, 2011: Intercomparisons of Air–Sea Heat Fluxes over the Southern Ocean. *Journal of Climate*, **24**:4, 1198-1211.

Lloyd, I. D., and G. A. Vecchi,2011: Observational Evidence for Oceanic Controls on Hurricane Intensity. *Journal of Climate*, **24**:4, 1138-1153.

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