50 Year Global Ocean Surface Heat Flux Analysis

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1. Project Summary

The Objectively Analyzed air-sea Fluxes (OAFlux) is a research and data development project focusing on global air-sea heat, moisture, and momentum fluxes. The project is committed to produce 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 the characterization, attribution, modeling, and understanding of variability and long-term change in the atmosphere and the oceans.

The OAFlux project was established on the basis that quality global flux fields can be obtained only when data errors are properly treated. This is due to the fact that global air-sea flux fields 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. To take into account data errors, the OAFlux project developed an objective synthesis to include error information in the formulation and to improve the flux estimates through synthesizing measurements/estimates from various sources. The error information of input data is determined from air-sea measurements from surface moorings. The OAFlux established a validation database consisting of more than 130 flux buoys from the ocean climate observing system, 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 the OceanSITES Ocean Reference Stations deployed and maintained by the Woods Hole Oceanographic Institution (WHOI) and by the National Oceanography and Atmospheric Administration (NOAA) *Pacific Marine Environmental laboratory (PMEL).*

The OAFlux project has produced the global 1° resolution, daily/monthly analysis (1958-to the present) of ocean evaporation, air-sea latent and sensible heat fluxes, and related surface meteorological variables. The products are distributed online through the project website at http://oaflux.whoi.edu/data.html and updated twice per year. The project continues in efforts to develop a high-resolution (0.25°) global analysis of surface heat fluxes to improve the representation of the coupling between the atmosphere and ocean fronts/eddies, to develop surface radiative fluxes with improved accuracy, and to progress toward a net heat flux dataset. The OAFlux project demonstrates the important role of integrating air-sea measurements from the global ocean climate observing system in constraining the global flux products. At the same time, the OAFlux global products broaden, strengthen, and enrich the use of in situ flux measurements. The buoy-validated, completely global, gridded, and temporally homogeneous products of several-decades long can help the ocean and climate diagnostic and modeling studies in many ways that the irregularly spaced and sparse buoy time series cannot do. The OAFlux user base has been growing rapidly. Since the access counter was installed on 01 May 2013, the project home page has been accessed 2,593 times and the data download page 2,390 times. The products were a base dataset in 146 referred publications in FY2013, compared to 95 in FY2012. A new recent trend shows that OAFlux has emerged as a leading source of verification and validation for climate models and data assimilation models.

The OAFlux global products of 50-years continue to provide new insights into the fundamental changes in the global climate under warm conditions. The evidence yielded from the OAFlux products leads to a wide recognition on the intensification of ocean evaporation since the late 1970s, providing observational support for the Intergovernmental Panel on Climate Change (ICPP) 5th assessment report (AR5) on the acceleration of the global hydrological cycle in the past warm decades. The OAFlux products lead to the finding of the important role of the strengthening ocean surface wind speed in increasing ocean evaporation, providing a thought-provoking addition to the theory based on the Clausius-Clapeyron equation. The OAFlux datasets lead to the identification of the 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 the global energy balance. The OAFlux global products have demonstrated in many ways their value in stimulating 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.

Users of the OAFlux products include but are not limited to: 1) global reanalysis projects, climate modeling groups and centers, including the Coupled Forecast System Reanalysis (CFSR) by NOAA National Centers for Environmental Prediction (NCEP), the Modern Era Retrospective-Analysis for Research and Applications (MERRA) by the National Aeronautics and Space Administration (NASA), the Coupled Model Intercomparison Project (CMIP), and the consortium for Estimating the Circulation & Climate of the Ocean (ECCO),using the global OAFlux fields as a base reference for validating the performance of the models; 2) investigators and researchers working under the NASA SAC-D Aquarius salinity mission, 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, together with the precipitation from the NASA Global Precipitation Climatology Project (GPCP) as freshwater flux forcing for studying ocean salinity change; 3) The satellite surface radiation projects including Global Energy and Water Cycle Experiment – Surface Radiation Budget (GEWEX-SRB) and NASA Clouds and Earth's Radiant Energy Systems (CERES), who collaborate with OAFlux to produce net heat flux products to investigate the global energy balance; 4) 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; 5) 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; 6) those 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; 7) 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; 8) those working with ocean models, who use the OAFlux product as the forcing fields for model runs; 9) those developing alternate air-sea flux fields from remote sensing and/or in situ data, who compare their products to the OAFlux fields; 10) those researching new and renewable energy sources, using OAFlux wind and near-surface meteorological parameters to estimate global offshore wind power potential; and 11) 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, using OAFlux climatology as course materials.

2. Scientific and Observing System Accomplishments

In the Work Plan for the FY2013 period from 01 October 2012 to 30 September 2013, three tasks were outlined. In the following, we report our accomplishments and efforts made for each task in the past year.

Task 1. Improving, updating, and maintaining the online OAFlux 50+ year time series

We issued three updates (October 2012, February 2013, and June 2013) in FY2013 to bring the OAFlux time series from 1958 to the near real time. The OAFlux data products from 1958 to the present are freely available from our project website at http://oaflux.whoi.edu. We installed a page access counter on the website in the spring. In the past six months since the access counter started on 01 May 2013, the OAFlux project home page has been accessed 2,593 times and the OAFlux data download page has been accessed 2,390 times.

OAFlux products were a base dataset in 146 referred publications in FY2013, compared to 95 in FY2012. OAFlux products are becoming the leading flux products and are being applied to a broad range of research areas, thanks to the users who have trusted and relied on the quality of our products to do their research. Using OAFlux for evaluation and verification of climate models and data assimilation models is a new, recent trend that is growing in the modeling community. We led the analysis of global ocean surface flux for the NOAA State of Climate annual assessment report since 2005 by using the timely update of OAFlux products.

Ensuring the quality and continuity of data products has been our primary effort during the scheduled updates each year. The updates cannot be taken lightly, as the input datasets used in constructing OAFlux time series have been constantly changing. Two types of changes in the input data need to response during each OAFlux update. The first one is that estimates for flux-related variables with better resolution and better accuracy have been made available from recent atmospheric reanalyses, among which NOAA CFSR and ERA interim are in the forefront. Air temperature and humidity provided by the reanalyses can help improve the accuracy of the flux estimated, if biases in the products can be corrected. One effective way to identify the biases in reanalyses is the evaluation using buoy time series measurements at 130+ buoy sites (this number has been down significantly in recent months due to the lack of service for TAO buoys). OAFlux depended upon NCEP in the past, but has successfully implemented ERAinterim to the online datasets and is currently working toward replacing NCEP with CFSR. The second input data change is made by satellite data producers, who put up new versions once every few years. Every version invokes the change of global mean averages. The decision has to be made whether we correct the mean or embrace the newer version by updating the entire OAFlux time series to avoid spurious jumps. In last year, the Remote Sensing System released the new version 7 for SSMI wind speed, which is the core dataset for OAFlux. We made every effort to revise the entire OAFlux time series from 1987 onward. Although the work is labor intensive and time consuming, it is a necessary step to ensure the high quality of the OAFlux products.

The effort we have put into producing the best possible flux estimates receives recognition and appreciation. Figure 1 was from Robinson et al. (2013), who found major divergence between ocean evaporation products during the satellite era. For instance, OAFlux shows that the increase of ocean evaporation in the 1990s has leveled off after 2000. Yet, GSSTF and SeaFlux both have a major upward trend continuing through the decade of 2000s. Robinson et al. (2013) attempted to use global water balance to check the consistency of three evaporation data products with land data and ocean precipitation. The findings from their study support OAFlux that the ocean evaporation increase has leveled off after the year 2000.

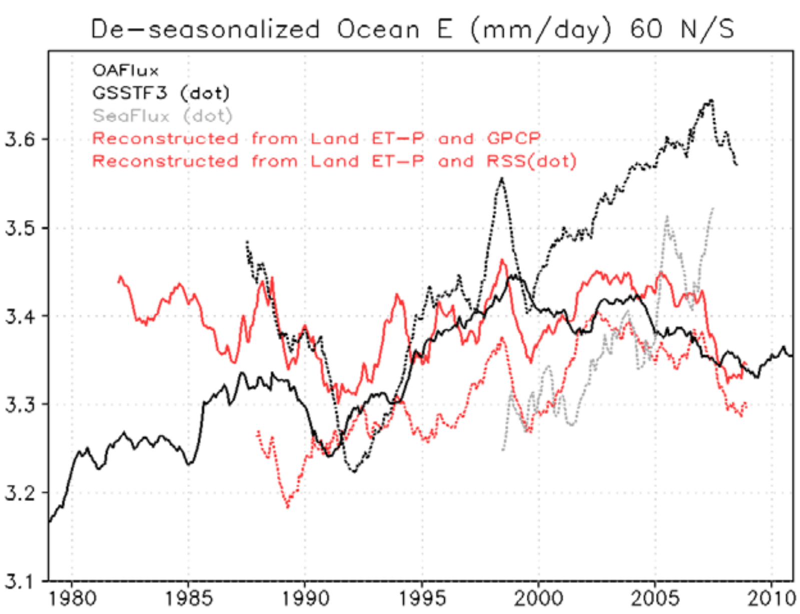

Figure 1. Consistency check for estimates of global ocean evaporation. The red lines denote the evaporation diagnosed from land data assimilation estimates and either GPCP (red solid line) or RSS V7 (red dotted line) precipitation. OAFlux (black thick solid line), GSSTF (black dotted line), and SeaFlux (gray dotted line) ocean E are also shown for comparison. Units are mm d^{-1}. (From Roberson et al. 2013). The good agreement of OAFlux with GPCP based reconstructed E is evident. The other two ocean E products show major upward trends since 2000, which is <u>not</u> consistent with the global water balance.

Task 2. Evaluating the high-resolution OAFlux analysis and progressing toward product dissemination

The task on evaluating the high-resolution (HR) OAFlux analysis was completed with a manuscript in press at the *Journal of Geophysical Research – Oceans* (Jin and Yu 2013). The manuscript used the Gulf Stream as a test bed to investigate the degree of improvement made by the OAFlux 0.25-degree data products that have been developed under the COD funding support. The OAFlux data products that are distributed online are on 1°×1° resolution. Two approaches were applied, one was a point-to-point validation based on six moored buoys in the region, and the other was a basin-scale analysis using wavenumber spectra and probability density functions (PDFs). An intercomparison was carried out between OAFlux-0.25°, OAFlux-1°, and four atmospheric reanalyses (ERAinterim, CFSR, MERRA, and NCEP).

One major advantage of the 0.25° resolution is the improved spatial depiction of the SST modulation on synoptic flux variability near sharp ocean fronts and mesoscale eddies. Ocean fronts are a source of high air-sea fluxes and a region where the oceans are the forcing for the atmospheric variability. Our evaluation indicated that OAFlux-0.25° has the best performance among the six participating products in comparison with buoy measurements. The mean difference between OAFlux and buoy is 7.6 Wm^{-2} (7.7%) for latent heat flux (LHF) and 0.0 Wm^{-2} for sensible heat flux (SHF). The root-mean-square (rms) difference is 44.9 Wm^{-2} for LHF and 19.4 Wm^{-2} for SHF. The length scale for the eddy variability in the Gulf Stream can be as short as 120 km, about four times the grid size for the 0.25° resolution; thus resolving air-sea flux down to the order to 0.25° - a critically important step forward in the description and understanding of frontal-scale air-sea interaction. The wavenumber spectra and decorrelation length scale analysis indicated that OAFlux-0.25° has the best depiction of eddy variability followed by CFSR (~0.31°).

In addition to the study reported in the manuscript, we extended the scope of the tasks outlined in the work plan by two new efforts. One was the extension of the time series of 2000-2010 back to 1988 to take advantage of satellite-derived air humidity constructed by the NASA GSSTF flux group so that the HR fluxes can cover the entire satellite period from 1987 onward. Merging GSSTF and Jackson &Wick air humidity time series requires major corrections on mean bias for each dataset, for which we did extensive evaluation and validation using buoys from the tropical moored array (TAO, PIRATA, and RAMA) and the reference stations from OceanSites. Figure2 shows the buoy-based validation of the newly constructed HR air temperature and humidity.

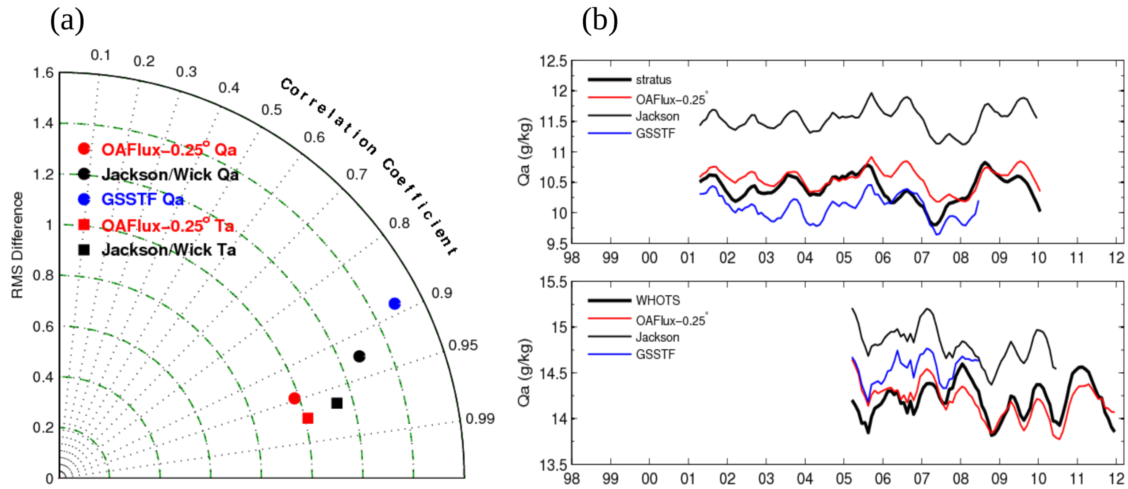

Figure 2. (a) The Taylor diagram based on two statistical properties, correlation coefficients and rms differences between products and buoys, for air humidity (Qa, circles) and air temperature (Ta, squares). A total of 139,053 collocations were used for Qa, and 294,238 collocations for Ta. (b) time series comparison of monthly means with STRATUS (top) and WHOTS (bottom). A 13-month running mean was applied.

The other effort was the scientific investigation of the value of the HR fluxes. The PI had two invited presentations specifically based on the 25-year OAFlux HR flux products. One was entitled “Air-sea fluxes in the Gulf Stream region”, given at the IUGG Joint Assembly, session “North Atlantic and Climate”, Gothenburg, Sweden, July 2013. The other was entitled “Air-sea Interaction in the vicinity of ocean fronts - Insights from OAFlux high-resolution analysis”, given at the NCAR workshop on “Frontal scale air-sea interaction”, Boulder, Colorado, August 2013. One main question in these two presentations was: what new insights can the HR flux products provide in terms of the physical mechanisms governing the atmosphere-ocean front interactions? The presentations focused on one aspect, which is the role of SST in modulating surface heat fluxes. What has been found is striking; that is, the maximum SST modulation on surface heat fluxes is not along the mean position of the Gulf Stream but on the north of the Gulf Stream north wall. This is evident in Figure 3, showing the SST correlation with OAFlux-0.25° and the other five datasets used in Jin and Yu (2013). When examining the structure of the correlation, one further obtained the influence of the ocean topographic feature on the SST modulation of atmospheric fluxes. Figure 4 shows the superposition of the correlation between SST and OAFlux-0.25° onto the ocean topography in the Gulf Stream regime, revealing that the SST modulation is confined between the shelfbreak and the Gulf Stream north wall. The figures are thought provoking: one often presumes that the maximum SST modulation to the atmosphere should occur along the Gulf Stream front because fluxes have the maximum magnitude. We are pursuing the following questions in an ongoing study: (i) what processes governing the SST winter variability and its persistence near and north of the Gulf Stream? (ii) What are the links with the SST variability in the preceding winter and with weather patterns and extreme weather events, and (iii) How does SST impact on the atmosphere? Or, what is more important for mean climate and climate variability, the maximum SST-flux correlation or the maximum heat flux variance along the Gulf Stream front?

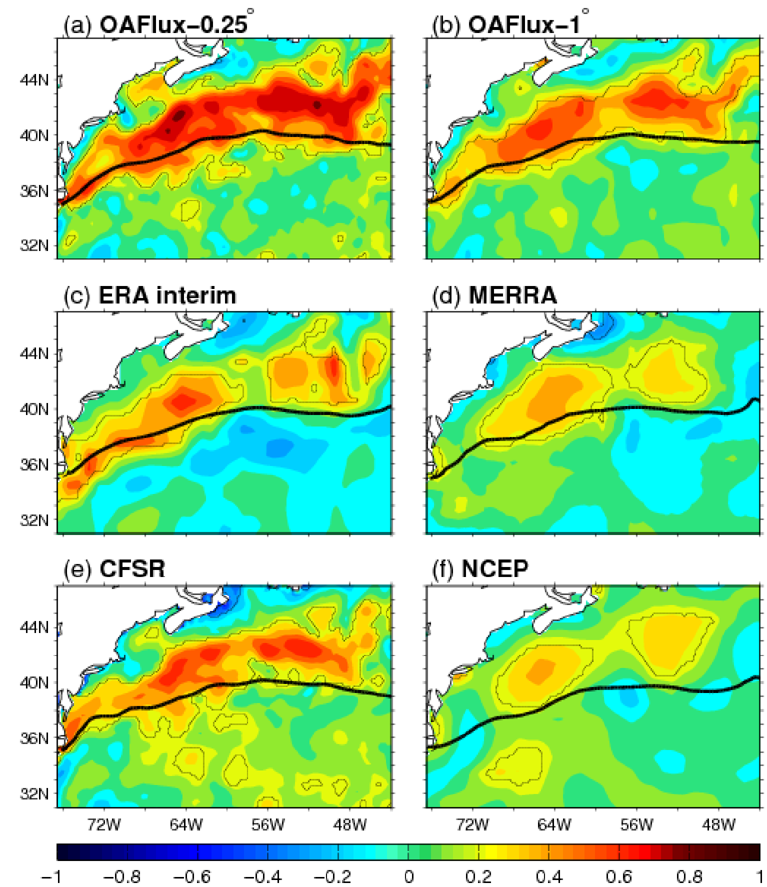

Figure 3. Correlation between wintertime SST and surface latent and sensible heat fluxes from six products during the 25-year period 1988-2012.

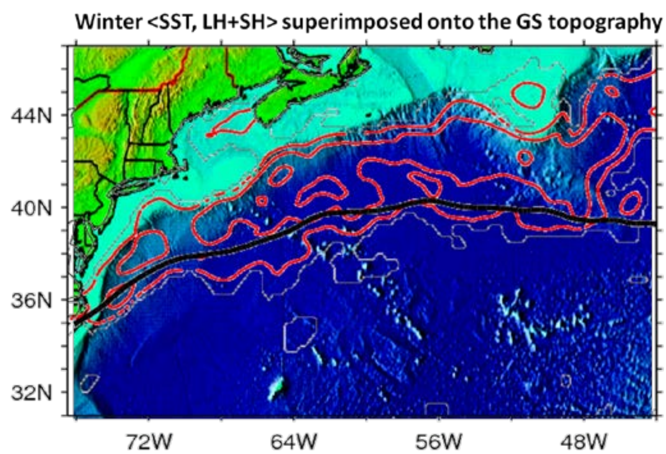

Figure 4. Superposition of the correlation between SST and OAFlux-0.25° onto the Gulf Stream topography. The confinement of the correlation between the shelfbreak and Gulf Stream north wall is clearly displayed, showing the importance of topography on modulating air-sea interactions in the Gulf Stream regime.

Task 3. Identifying and quantifying biases in surface radiation products and investigating the possibility of combining OAFlux and satellite surface radiation for a net heat flux

We have been continuing making efforts toward improving surface radiation estimates for an improved net heat flux product. However, the current funding climate and the budget reduction for a second consecutive year (more than 13.2% down compared to YR2011) limited much of our time and effort to this task, since the technical development required in Tasks 1&2 is demanding and was led by a research associate (Dr. X. Jin), who is the primary hire (9-month time in FY2013) for the project. The PI (two-weeks time in FY2013) has worked diligently to keep the scientific investigations going by means of leveraging available resources and establishing collaborations with international colleagues. Yu accomplished two achievements with regard to this task in the YR2013.

The PI hosted and co-chaired a WCRP/CLIVAR/GSOP/WHOI workshop, which was sponsored by NOAA COD and NASA PO, on "Ocean Syntheses and Surface Flux Evaluation", held on November 2012 at Woods Hole, MA. The workshop convened ~60 experts on air-sea fluxes and ocean synthesis around the world to review the current state of surface fluxes (heat, freshwater, & momentum) obtained from synthesis and observation-based products, to discuss gaps and limitations in products with particular reference to balancing global budgets, and to develop requirements for future global/regional synthesis activities. Given the gaps in present-day knowledge and understanding, a consensus was reached during the workshop that achieving globally balanced energy and freshwater budgets is a long- term challenge, and should be broken down into incremental steps with achievable targets at each stage. The PI led the workshop report on "Towards achieving global closure of ocean heat and freshwater budgets: Recommendations for advancing research in air-sea fluxes through collaborative activities " (WCRP Informal/Series Rep. No. 13/2013, ICPO Informal Rep. 189/13, 42 pp., 2013).

The PI supervised a visiting student, Mr. Xiangzhou Song, for his Ph.D thesis work. The paper entitled "How much net surface heat flux should go into the Western Pacific Warm Pool?" (Song and Yu 2013) was published in the *Journal of Geophysical Research*. The study examined the questions: whether and how much the tropical warm pool waters can be used to quantify net heat flux products from different sources. The idea is to consider the heat budget of the 3-D warm pool volume bounded by the sea surface and a specified isotherm (i.e. a "bubble"), and to use the energy budget equation to test the physical consistency of a given Qnet with temperature observations within the bubble. By using the world ocean atlas from Levitus et al., what we found was that none of existing 11 Qnet heat flux climatologies can satisfy the energy budget constraint in the warm pool. The 11 products include atmospheric reanalyses, satellite-based, ship-based, and satellite-reanalysis blended, showing that they have either excessive downward Qnet (i.e., excessive warming to the oceans) or insufficient downward Qnet (i.e., excessive cooling to the oceans) (Figure 5). It appears that there is a need for persistent, concerted, and collaborative efforts to improve the understanding of, and the ability to obtain, a balanced global net heat flux product. This work was one of the tasks outlined in YR2012 workplan.

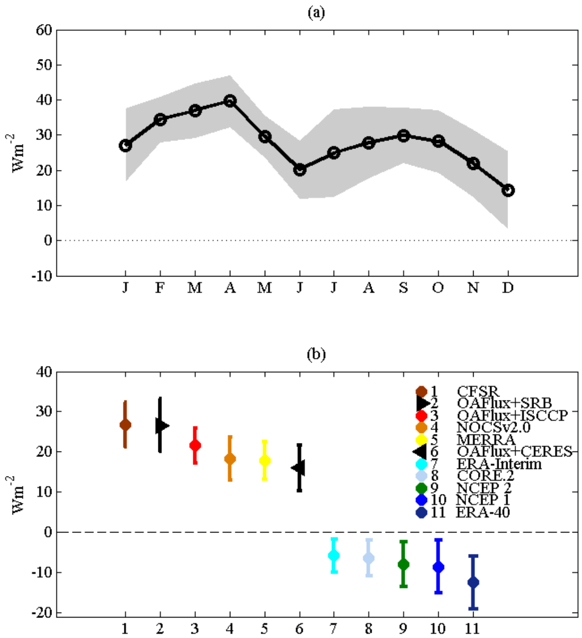

Figure 5. (a) The constructed seasonal Qnet (unit: Wm-2) over the Western Pacific warm pool from the energy budget equation based on temperature fields from WOA09. The shaded error bars show the analysis uncertainty based on WOA09 & TAO/TRITON data. (b) Annual mean difference between the Qnet (Wm-2) from 11 climatology and the constructed Qnet. Error bars represent seasonal deviations. (from Song and Yu (2013))

3. Outreach and Education

Lisan Yu

Dr. Yu routinely presents research results at national and international scientific meetings. Yu 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. Yu serves on the CLIVAR Global Synthesis and Observations Panel, and is a member of the NASA Sea Surface Temperature Science Team, NASA Ocean Surface Salinity Science Team, and NASA Ocean Vector Wind Science Team.

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 started during this year a term as chair of US CLIVAR SSC and will encourage clivar to increase use of new contexts provided by flux products, Ocean Reference Sites time series, and Argo floats etc.

4. Publications and Reports

4.1. Publications by Principal Investigators

- Published

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.

Gimeno, L., A. Stohl, R. Trigo, F. Dominguez, K. Yoshimura, **L. Yu**, A. Drumond, A. Duran-Quesada, and R. Nieto, 2012. Oceanic and Terrestrial Sources of Continental Precipitation. *Rev.Geophys*., **50**, RG4003, doi:10.1029/2012RG000389.

Seiji, K., N. G. Loeb, F. G. Rose, D. R. Doelling, D. A. Rutan, T. E. Caldwell, **L. Yu**, and R. A. Weller, 2013. Surface irradiances consistent with CERES-derived top-of-atmosphere shortwave and longwave irradiances. *Journal of Climate*, **26**, 2719–2740, doi:http://dx.doi.org/10.1175/JCLI-D-12-00436.1.

Song*, X., and **L. Yu**, 2013. How much net surface heat flux should go into the Western Pacific Warm Pool? *J. Geophys. Res.*, **118**, 3569-3585, doi: 10.1002/jgrc.20246.
* visiting Ph.D student under my supervision.

- In press

Jin, X., and **L. Yu**, 2013. Assessing high-resolution analysis of surface heat fluxes in the Gulf Stream region. *J. Geophys. Res.*, DOI: 10.1002/jgrc.20386. In press.

Josey, S., S. Gulev, and **L. Yu**, 2013. Exchange Through the Ocean Surface. In *Ocean Circulation and Climate*, 2nd Edition. G. Siedler, J. Church, J. Gould, and S. Griffies. Eds. In press.

- Meeting report

Yu, L., K. Haines, M. Bourassa, M. Cronin, S. Gulev, S. Josey, S. Kato, A. Kumar, T. Lee, and D. Roemmich, 2013. *Towards achieving global closure of ocean heat and freshwater budgets: Recommendations for advancing research in air-sea fluxes through collaborative activities.* In Report of the CLIVAR/GSOP/WHOI Workshop on Ocean Syntheses and Surface Flux Evaluation, Woods Hole, Massachusetts, 27-30 November

2012, WCRP Informal/Series Rep. No. 13/2013, ICPO Informal Rep. 189/13, 42 pp., 2013.

Fairall, C.W., M.A. Bourassa, M.F. Cronin, S.R. Smith, R.A. Weller, G. Wick, S. Woodruff, **L. Yu**, and H.-M. Zhang, 2012. Observations to quantify air-sea fluxes and their role in global variability and predictability. In Proceedings of the IOOS Summit, Interagency Ocean Observation Committee (IOOC), Herndon, Virginia, 13-16, November 2012, http://www.iooc.us/summit/white-paper-submissions/community-white-paper-submissions/.b.

4.2. Other Relevant Publications

The OAFlux products described by Yu and Weller (2007, BAMS) and Yu et al. (2008, WHOI technical report) have received 529 citations by refereed publications through 9/30/2013, compared to a total of 386 citations reported last year. During 2012-2013, the OAFlux products were a base dataset in 146 referred publications, compared to 95 last year.

The following list contains 42 publications assembled from the 146 citations in 2013. An electronic copy for the two publications marked with * is attached to the package. These papers show that OAFlux datasets are used in a wide range of research topics, including the global water cycle, the ocean salinity change and variability, the basin-scale climate mode variability, the global energy transfer, the atmosphere-ocean feedback mechanisms, the subtropical mode water formation, climate model assessments, and verification of coupled data assimilation. In recent years, the OAFlux datasets have gained popularity in the data assimilation and climate modeling communities for evaluation and verification of climate simulations. The two papers marked with * are a sample of the recent trend of using OAFlux in climate models.

Achyuthan, H., R. D. Deshpande, M. S. Rao, B. Kumar, T. Nallathambi, K. Shashi Kumar,... and S. K. Gupta, 2013. Stable isotopes and salinity in the surface waters of the Bay of Bengal: Implications for water dynamics and palaeoclimate. *Marine Chemistry*, **149**, 51-62.

Alpert, P., D. Hemming, F. Jin, G. Kay, A. Kitoh, and A. Mariotti, 2013. The hydrological cycle of the Mediterranean. In *Regional Assessment of Climate Change in the Mediterranean* (pp. 201-239). Springer Netherlands.

Bellenger, H., E. Guilyardi, J. Leloup, M. Lengaigne, and J. Vialard, 2013. ENSO representation in climate models: from CMIP3 to CMIP5. *Climate Dynamics*, 1-20.

Cai, W., and Y. Qiu, 2013. An observation-based assessment of nonlinear feedback processes associated with the Indian Ocean Dipole. *Journal of Climate*, **26**(9), 2880-2890.

Chang, Y. S., S. Zhang, A. Rosati, T. L. Delworth, and W. F. Stern, 2013. An assessment of oceanic variability for 1960–2010 from the GFDL ensemble coupled data assimilation. *Climate Dynamics*, **40**(3-4), 775-803.

Clark, R., 2013. A Dynamic, Coupled Thermal Reservoir Approach to Atmospheric Energy Transfer Part I: Concepts. *Energy & Environment*, **24**(3), 319-340.

Chiu, L. S., S. Gao, and C. L. Shie, 2013. Satellite-based ocean surface turbulent fluxes. In *Satellite-based Applications on Climate Change* (pp. 165-181). Springer Netherlands.

Davis, X. J., R. A. Weller, S. Bigorre, and A. J. Plueddemann, 2013. Local oceanic response to atmospheric forcing in the Gulf Stream region. *Deep Sea Research Part II: Topical Studies in Oceanography*, **91**, 71-83.

Deremble, B., N. Wienders, and W. K. Dewar, 2013. Cheap AML: A Simple, Atmospheric Boundary Layer Model for Use in Ocean-Only Model Calculations. *Monthly Weather Review*, **141**(2), 809-821.

Francis, P. A., P. N. Vinayachandran, and S. S. C. Shenoi, 2013. The Indian Ocean Forecast System. *Current Science*, **104**(10), 1354-1368.

Gao, S., L. S. Chiu, and C. L. Shie, 2013. Trends and variations of ocean surface latent heat flux: Results from GSSTF2c data set. *Geophysical Research Letters*, 40, 380–385.

Garcés-Vargas, J., M. Ruiz, L. M. Pardo, S. Nuñez, and I. Pérez-Santos, 2013. Caracterización hidrográfica del estuario del río Valdivia, centro-sur de Chile. *Lat. Am. J. Aquat. Res*, **41**(1), 113-125.

Gimeno, L., R. Nieto, A. Drumond, and A. M. Durán-Quesada, 2013. Ocean Evaporation and Precipitation. In *Earth System Monitoring* (pp. 291-318). Springer New York.

Gleick, P. H., H. Cooley, J. S. Famiglietti, D. P. Lettenmaier, T. Oki, C. J. Vörösmarty, and E. F. Wood, 2013. Improving Understanding of the Global Hydrologic Cycle. In *Climate Science for Serving Society* (pp. 151-184). Springer Netherlands.

Haghroosta, T., and W. R. Ismail, 2013. Influence of Noul Typhoon on Sea Surface Temperature, Heat Fluxes and Precipitation Rate. International Journal of Scientific and Research Publications, **3**(6), 1-14.

Horii, T., I. Ueki, K. Ando, and K. Mizuno, 2013. Eastern Indian Ocean warming associated with the negative Indian Ocean dipole: A case study of the 2010 event. *Journal of Geophysical Research: Oceans*, **118**(1), 535-549.

Johnson, R. H., and P. E. Ciesielski, 2013. Structure and Properties of Madden-Julian Oscillations Deduced from DYNAMO Sounding Arrays. *Journal of the Atmospheric Sciences*, **70**, 3157–3179.

Joyce, T. M., L. N. Thomas, W. K. Dewar, and J. B. Girton, 2013. Eighteen Degree Water Formation within the Gulf Stream during CLIMODE. *Deep Sea Research Part II: Topical Studies in Oceanography*, **91**, 1-10.

Kelly, K. A., and S. Dong, 2013. The contributions of atmosphere and ocean to North Atlantic Subtropical Mode Water volume anomalies. *Deep Sea Research Part II: Topical Studies in Oceanography*, **91**, 111-127.

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