Session Title: **PO34B**
Poster Number: **PO34B-3059**

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Variability of Surface Salinity within the Southeast Asian Seas

Leah E.M. Trafford[1], Arnold L. Gordon[1], Tong Lee[2] and Claudia F. Giulivi[1]
(1)Columbia University, New York, NY, United States and Lamont-Doherty Earth Observatory, Palisades, NY, United States (2)NASA Jet Propulsion Laboratory, Pasadena, CA, United States

Introduction

Sea surface salinity (SSS) variability in the South China Sea (SCS) is described for two eras of available measurements. The first utilizes Aquarius/SAC-D SSS data from August 25, 2011 through June 7, 2015. A second investigates variability over a longer time scale using the Simple Ocean Data Assimilation (SODA) product from 1979 to 2010. Using a number of satellite, model, and merged reanalysis products, freshwater fluxes due to precipitation, river runoff, evaporation, and advection are quantified for both periods using monthly data. The seasonal anomaly of each freshwater flux term is calculated to investigate inter and intra seasonal variability that is potentially associated with ENSO phase [1][2]. We conclude that observed SSS annual and inter-annual variability of the SCS points to the importance of ocean processes, particularly advection, in modulating SSS variability.

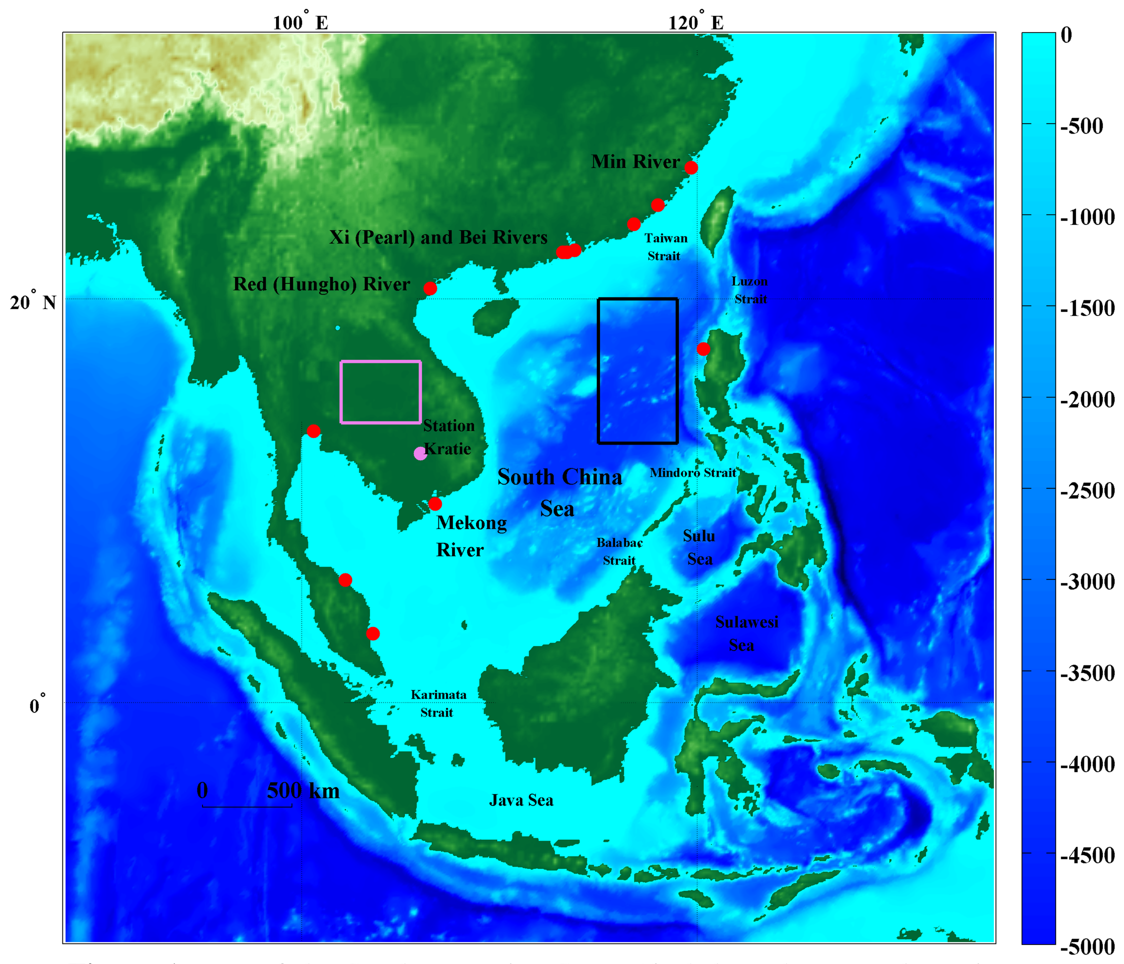

Figure 1 Map of the Southeast Asian Seas. Black box shows study region and red dots show location of largest rivers contributing to the SCS. Station Kratie is shown together with region of integrated precipitation in purple.

Data Products Used

- L3 Version 4, smoothed, and 0.5° gridded SSS data from the Aquarius/SAC-D collaboration between NASA and Argentina's space agency, Comisión Nacional de Actividades Espaciales (CONAE) (Figure 2a)
  - 0.2 PSU global RMS error for monthly data over spatial scales of 150 km.
- 0.25° by 0.4° gridded salinity at 5 m depth from the SODA assimilation product provided by NOAA/OAR/ESRL PSD (Figure 2b)
- 0.25° gridded ground precipitation estimates from the Tropical Rainfall Measuring Mission (TRMM)
- 2.5° gridded ground precipitation from the Global Precipitation Climatology Project (GPCP)
- 1° gridded evaporation estimates from the Woods Hole Oceanographic Objectively Analyzed air-sea Fluxes (OAFlux) product.

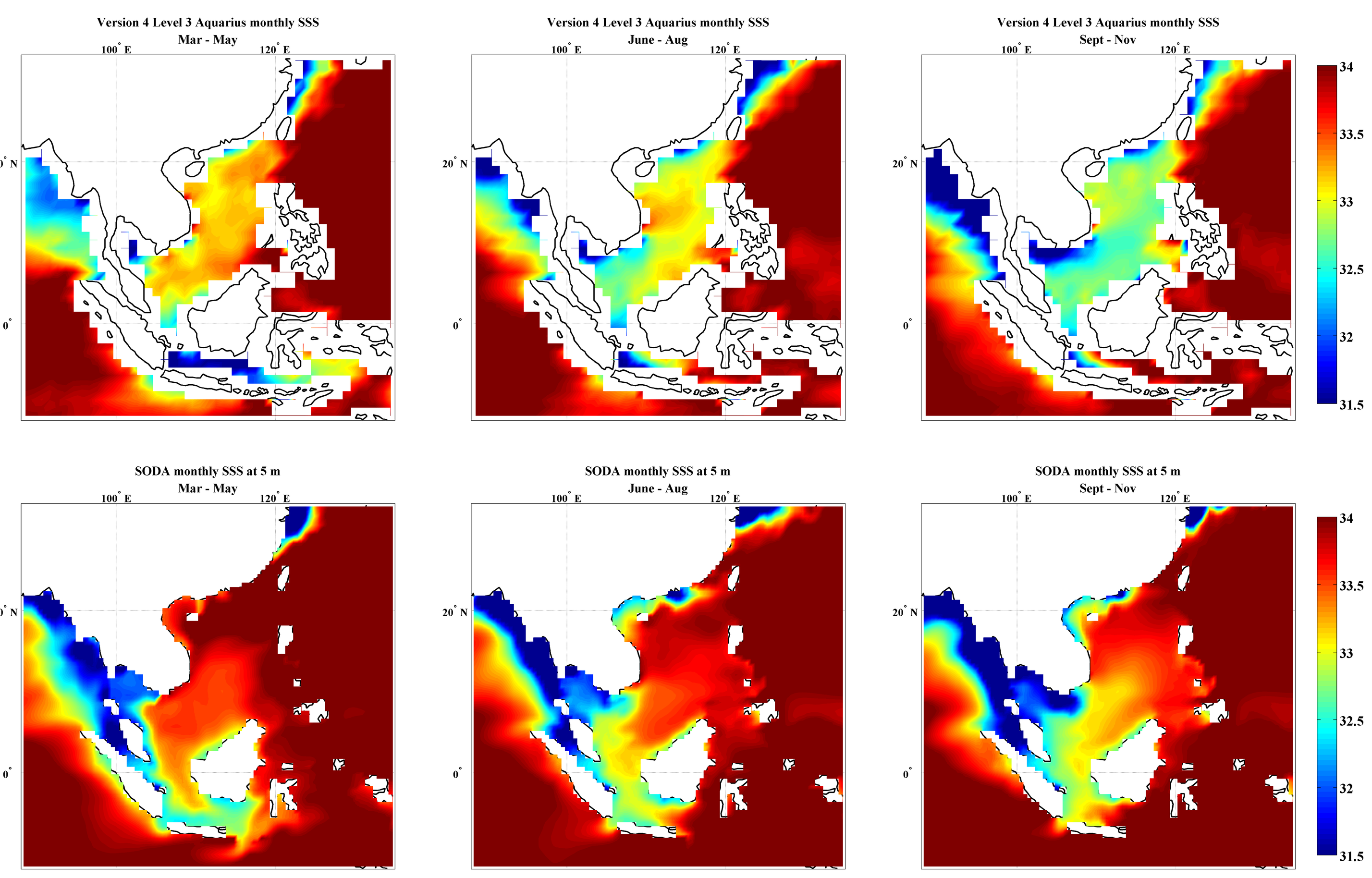

Figure 2 (a) Seasonal variability of SSS within the SCS as measured by Aquarius/SAC-D
(b) Seasonal variability of SSS within the SCS as given by SODA

Sea Surface Salinity Calculations

For both eras of calculations, (Aquarius/SAC-D: 2011 – 2015 and SODA: 1979 – 2010) a deep region within the SCS will be considered as shown in Figure 1. A simplified volume model is assumed using a constant mixed layer depth of 50 m. For a given volume of freshwater added, V_{FW}, a reference salinity, S_0, and a time interval Δt (taken to be one month), the resulting change in salinity of the volume assuming the volume to be well mixed is given by:

$$\frac{\Delta SSS}{\Delta t} = -V_{FW}\frac{S_0}{h} \qquad V_{FW} = V_P + V_E + V_R + V_{AO}$$

Where V_P, V_E, V_R, and V_{AO} represent the absolute volume change of freshwater by precipitation, evaporation, runoff, and advection together with other ocean processes not accounted for such and vertical and horizontal mixing. All salinity calculations using monthly data assume that freshwater fluxes due to each factor are completely mixed within V over the period of one month. Spatially averaged timeseries are generated for each freshwater input term within the bounded regions. Using the Aquarius/SAC-D and SODA data to determine the monthly rate of change in salinity, $\Delta SSS/\Delta t$, the change of SSS due to P, E, and R and the change of SSS due to advection and other ocean processes can be calculated:

$$\frac{\Delta SSS_{P-E+R}}{\Delta t} = -(V_P + V_E + V_R)\frac{S_0}{h} \qquad \frac{\Delta SSS_{AO}}{\Delta t} = \frac{\Delta SSS_{Observed}}{\Delta t} - \frac{\Delta SSS_{P-E+R}}{\Delta t}$$

Calculations together with freshwater volume contributions are shown in Figure 4 with seasonal anomalies in Figure 5. Immediately apparent is the large difference between estimated change in SSS due to P, E, and R and observed change in SSS, particularly during positive changes (saltier) of SSS.

Reconstruction of River Runoff

While datasets exist for discharge of major rivers and deltas that flow into the SCS, finding long-term data that properly describes inter-annual variability for all major rivers in the region proves difficult. It has been shown that river discharge can be well approximated using precipitation [4]. Discharge approximation is investigated here using TRMM precipitation and discharge data from Station Kratie, located on the largest branch of the Mekong River, which was kindly made available by Dr. Heiko Apel of Helmholtz Centre Potsdam/GFZ German Research Centre for Geosciences, Germany. For this method, river discharge is assumed to be a filtered response of precipitation only. Precipitation and discharge are then described by the linear system:

$$\vec{d} = \vec{G}\vec{g}$$

More explicitly, for a 3rd order filter:

$$\begin{bmatrix} d_1 \\ \vdots \\ d_N \end{bmatrix} = \begin{bmatrix} p_1 & 0 & 0 \\ \vdots & p_1 & \vdots \\ p_N & p_{N-1} & p_{N-2} \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \\ g_3 \end{bmatrix}$$

where N represents the number of observations in time and g is a vector or filter coefficients. The system can be solved by generalized least squares for the given filter coefficients using:

$$\vec{g} = \left[\vec{G}^T\vec{G}\right]^{-1}\left[\vec{G}^T\vec{d}\right]$$

Reconstruction of the seasonal anomaly of discharge at Station Kratie is shown in Figure 3. Seasonal anomaly of TRMM precipitation and seasonal anomaly of Kratie discharge have a correlation of 0.71 at a lag close to 1 month for overlapping data. Estimated filter coefficients applied to the seasonal anomaly of spatially averaged TRMM precipitation over the region shows effective in reproducing over half of the variability expressed in the discharge data.

In order to apply this method to multiple rivers in the region, the Global River Inflow climatology from the Navy Coastal Ocean Model (NCOM) [5] was used to investigate river contributions to the SCS. Climatologies from the 12 largest rivers contributing to the SCS were used together with integrated TRMM and GPCP rainfall timeseries in the following calculations.

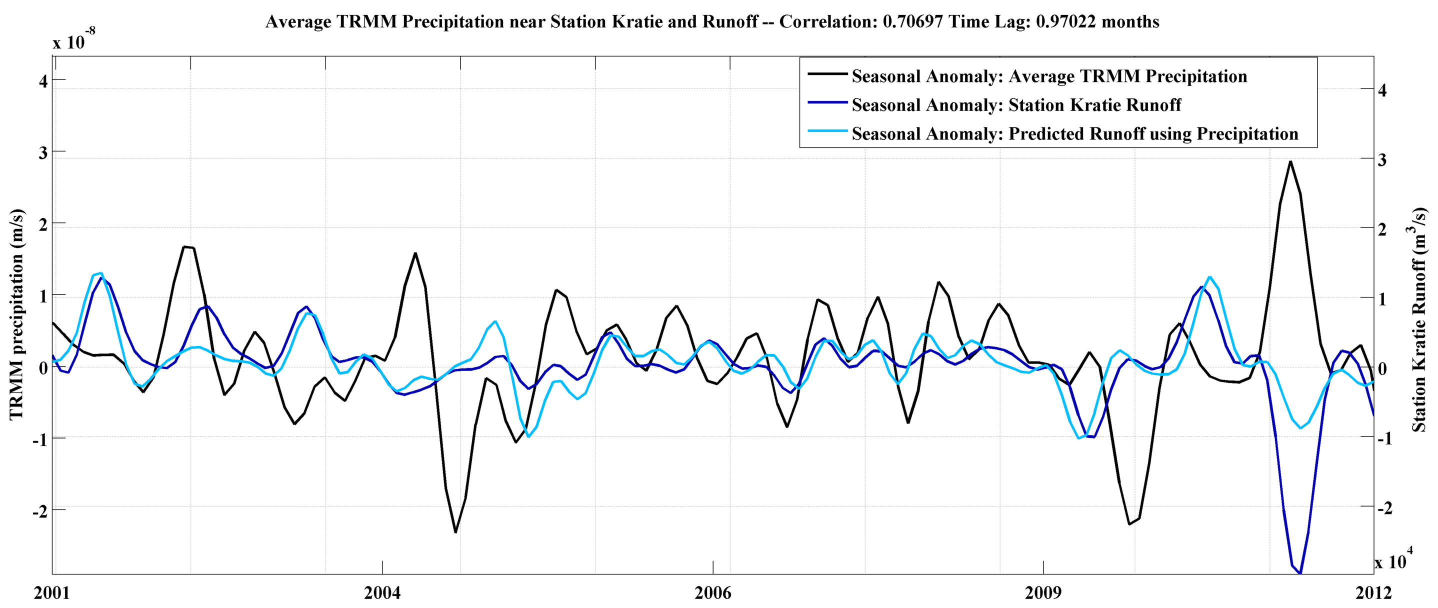

Figure 3 Reconstruction of the seasonal anomaly of discharge at Station Kratie using integrated TRMM precipitation over the Mekong catchment basin.

Sea Surface Salinity and Advection

Western Pacific water enters the SCS primarily via the Luzon Strait [1][2][3]. Given that surface water entering the SCS via the Luzon Strait is relatively warm and saline with respect to the SCS interior, advection of water through the Luzon Strait is a mechanism through which the SCS can become saltier. Calculated and observed changes in SSS are compared with available HYCOM transports through the Luzon Strait in Figures 6 and 7. In both seasonal and seasonal anomaly data there exists a strong link between Luzon Strait transport and measured SSS by Aquarius/SAC-D and SODA. Further, the sign of calculated monthly change of salinity due to advection and other ocean processes $\Delta SSS_{AO}/\Delta t$ shows a correlation with Aquarius-SAC-D and SODA measurements, while $\Delta SSS_{P-E+R}/\Delta t$ does not.

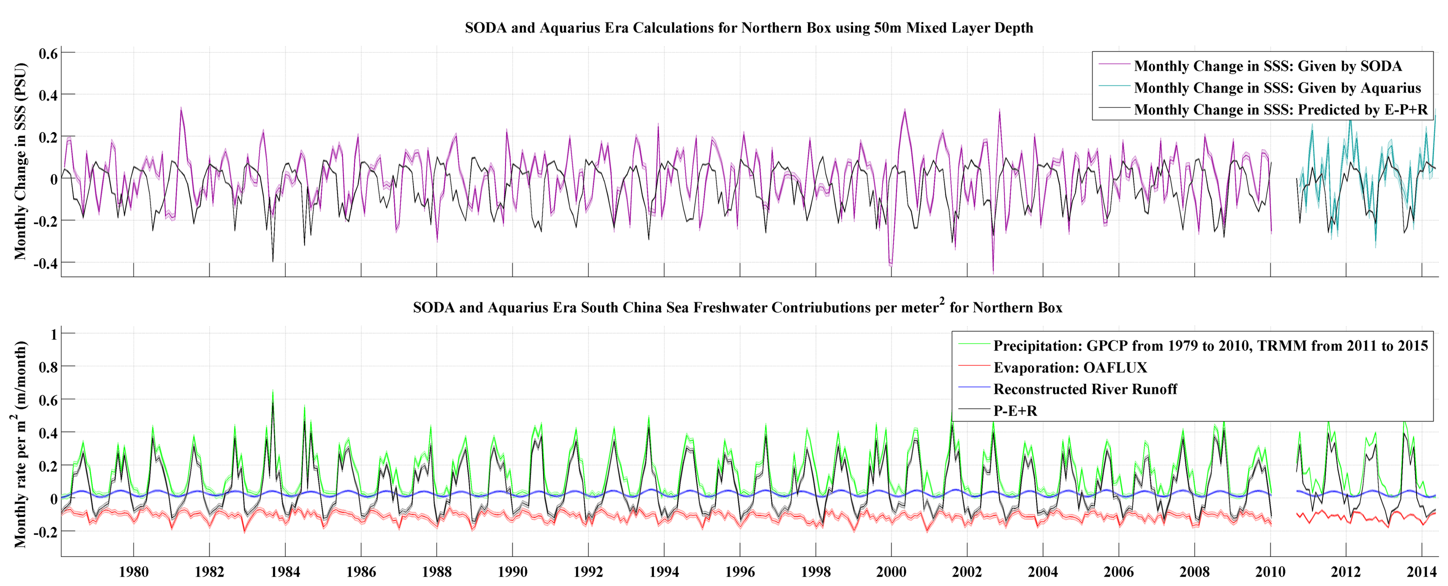

Figure 4 Monthly changes in SSS as given by SODA and Aquarius/SAC-D compared with the monthly change in salinity expected from P, E, and R.

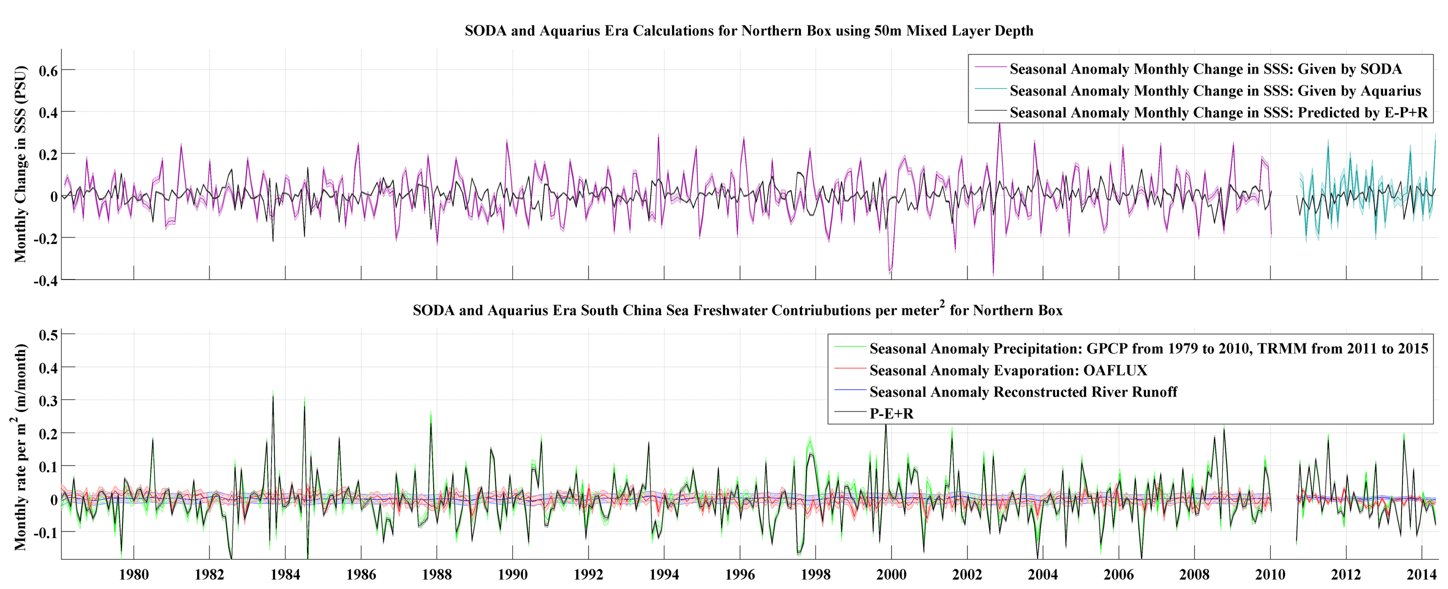

Figure 5 Seasonal anomalies of monthly changes in SSS as given by SODA and Aquarius/SAC-D compared with the monthly change in salinity expected from P, E, and R.

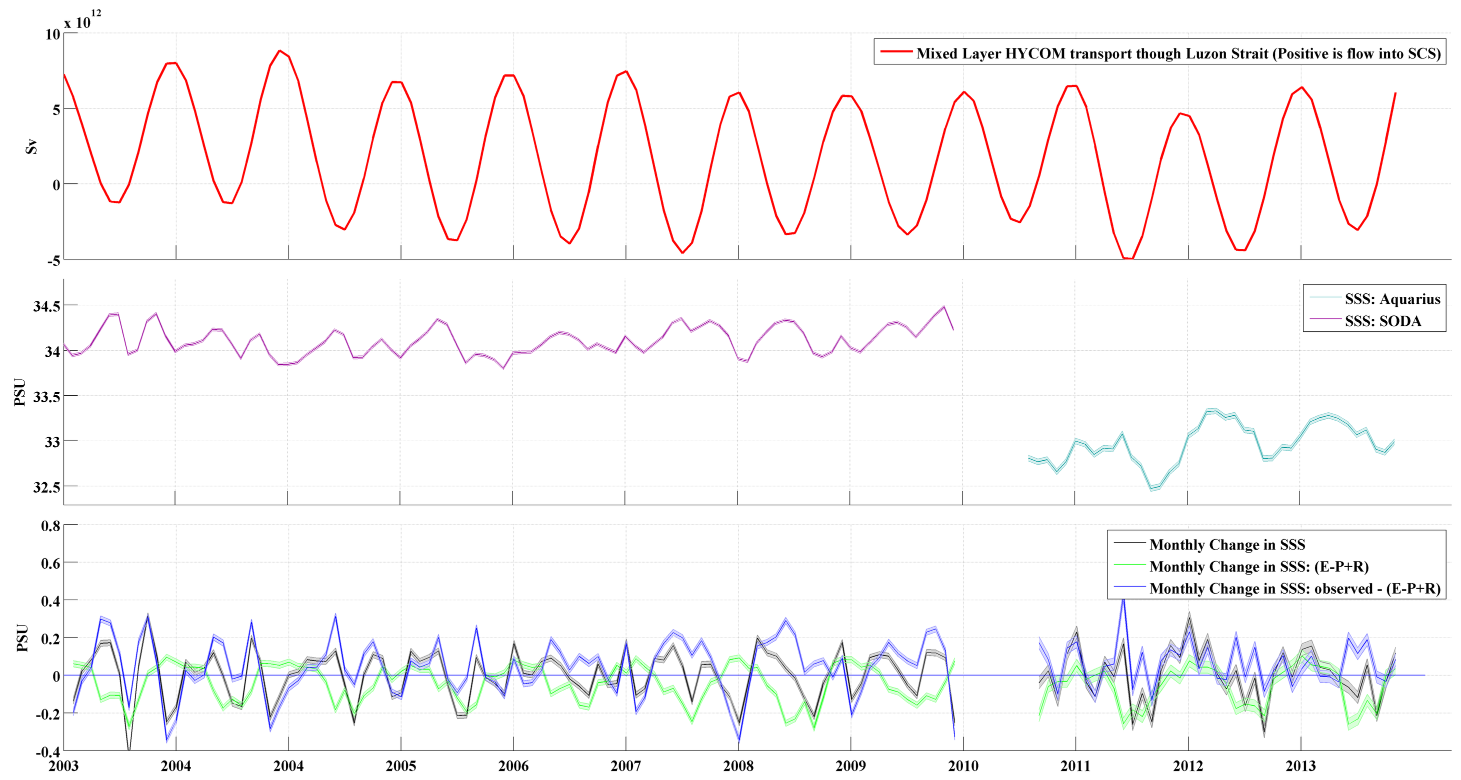

Figure 6 Mixed layer HYCOM transport through the Luzon Strait shown with Soda and Aquarius/SAC-D SSS data and calculated monthly changes in SSS.

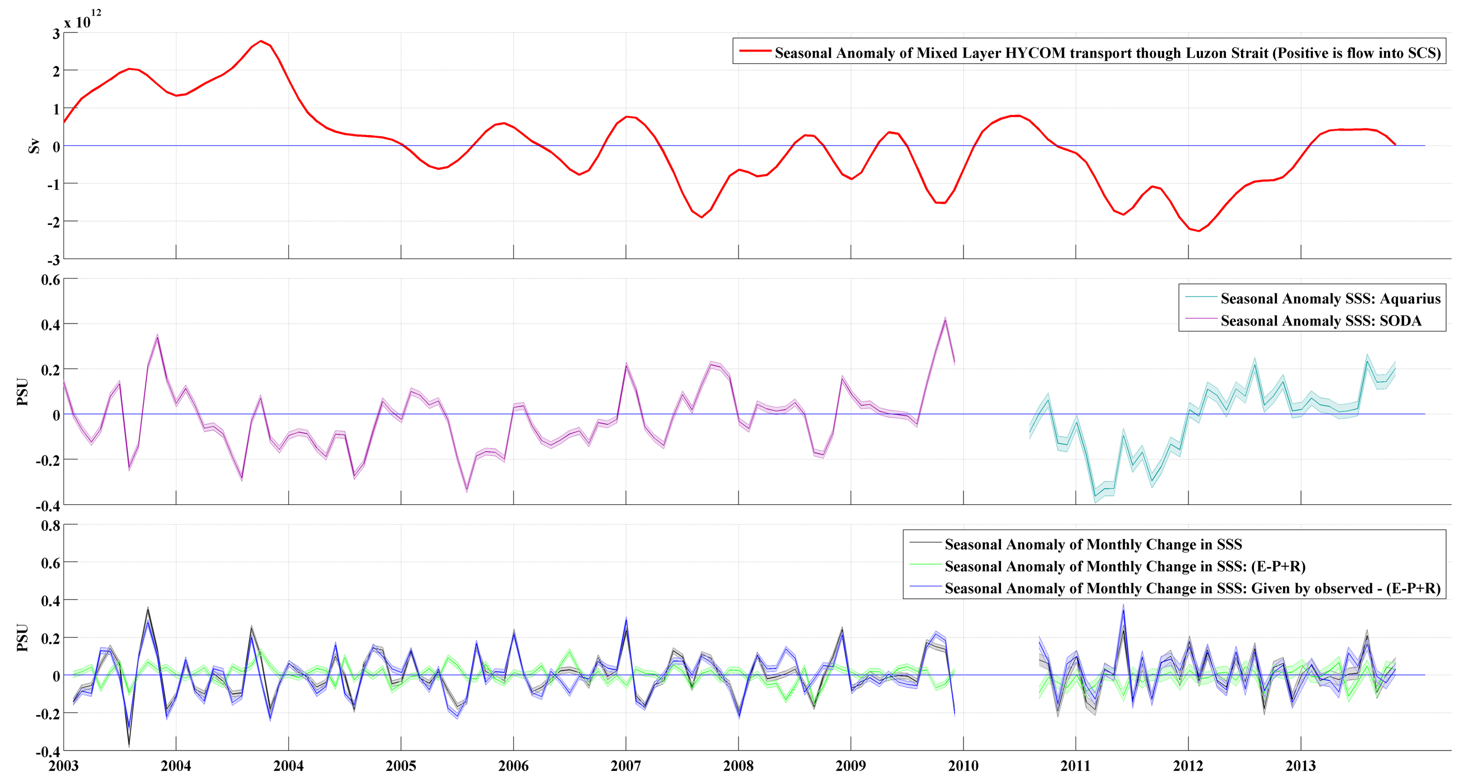

Figure 7 Seasonal anomalies: mixed layer HYCOM transport through the Luzon Strait shown with Soda and Aquarius/SAC-D SSS data and calculated monthly changes in SSS.

Results

- While the accuracy of SSS given by SODA and Aquarius/SAC-D data do not agree well, both appear to exhibit sufficient precision for describing SSS variability in this study. Observed monthly changes in SSS show a clearer seasonal cycle in the Aquarius data and smaller seasonal anomaly variability than with SODA data.
- The case study using Station Kratie river discharge shows promise for an inverse-filter reconstruction approach in approximating the river runoff contribution to the SCS.
- Overall, the estimation of total river runoff into the SCS needs to be improved and further validated. Currently, integrated estimated river discharge is evenly spread across the entire SCS mixed layer on a monthly basis. Regional advective timescales will be further addressed in future studies in order to consider improvements.
- Changes in SSS estimated from precipitation, evaporation, and river runoff are often much smaller than observed and modeled values. In particular, it is evident that salty events within the region considered are not fully described by precipitation, evaporation, and river runoff.
- There is evidence that changes in SODA SSS, and $\Delta SSS_{AO}/\Delta t$, were affected by large ENSO events, specifically of note: the 1982 El Niño, the 2010 La Niña, and the 2002 El Niño.
- In both seasonal and seasonal anomaly data there exists a strong link between Luzon Strait transport and measured SSS by Aquarius/SAC-D and SODA. Seasonal anomalies are perhaps better captured due to advection in the Aquarius/SAC-D data.

Future Work

- Calculated changes in SSS and observed SSS point to the importance of advection and identifying the advective timescales in the region. Future work will focus on multiple smaller regions for calculations, the use of upper ocean surface current products, and SSS changes due to Luzon Strait transport.
- Estimates of the effect of horizontal and vertical mixing will be calculated.
- A seasonal mixed layer will be defined using available ARGO data.
- The connection of coastal upwelling with the mixed layer will be investigated as an additional mechanism to add salt to the mixed layer.

References

[1] Sprintall, J., A.L. Gordon, A. Koch-Larrouy, T. Lee, J.T. Potemra, K. Pujiana, and S.E. Wijffels (2014) The Indonesian seas and their role in the coupled ocean–climate system, Nat. Geosci. DOI: 10.1038/NGEO2188.

[2] Gordon, A. L., B. A. Huber, E. J. Metzger, R. D. Susanto, H. E. Hurlburt, and T. R. Adi (2012), South China Sea throughflow impact on the Indonesian throughflow, Geophys. Res. Lett., 39, L11602, doi: 10.1029/2012GL052021.

[3] Gordon, A. L., J. Sprintall, H.M. Van Aken, D. Susanto, S. Wijffels, R. Molcard, A. Ffield, W. Pranowo, and S. Wirasantosa (2010), The Indonesian throughflow during 2004–2006 as observed by the INSTANT program, Dyn. of Atmos. and Oceans, 50, 115-128, DOI:10.1016/j.dynatmoce.2009.12.002.

[4] Zeng, L., W.T. Liu, H. Xue, P. Xiu, D. Wang (2014), Freshening in the South China Sea during 2012 revealed by Aquarius and in-situ data, J. Geophys. Res. Oceans, 119, 8296-8314, DOI: 10.1002/2014JC010108.

[5] Barron, C.N. and L.F. Smedstad, (2002). Global River Inflow within the Navy Coastal Ocean Model, Proceedings of the Oceans 2002 MTS/IEEE Meeting, 29-31 October 2002.

Acknowledgements

- The authors would like to thank Joe Metzger of NRL for his assistance with HYCOM data and for providing the NCOM river discharge climatologies used in this study.
- The authors would also like to thank Dr. Heiko Apel of Helmholtz Centre Potsdam/GFZ German Research Centre for Geosciences, Germany for providing river discharge data at Station Kratie.
- This material is based upon work supported by the National Aeronautics and Space Administration under Grant No. NNX14AI90G