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Experimental Validation of the Navy Air-Sea-Wave Coupled Forecasting Models

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LONG-TERM GOALS

Contribute to validation and increased performance of the Navy air-sea-wave coupled forecasting models and air-sea interaction processes.

OBJECTIVES

On the basis of data collected during the DYNAMO project including SeaGlider, R/V Revelle and R/V Mirai flux data and CTD/turbulence measurements contribute to better understanding of oceanic processes responsible for initiation and propagation of Madden–Julian Oscillation (MJO) in the Indian Ocean, contribute to validation and increased performance of the Navy air-sea-wave coupled forecasting models**,** develop and validate a simplified Skin, Warm and Mixed Layer (SWaM) parameterization of the oceanic upper level. On the basis of the Sea Glider observations provide validation data against coupled COAMPS forecasts.

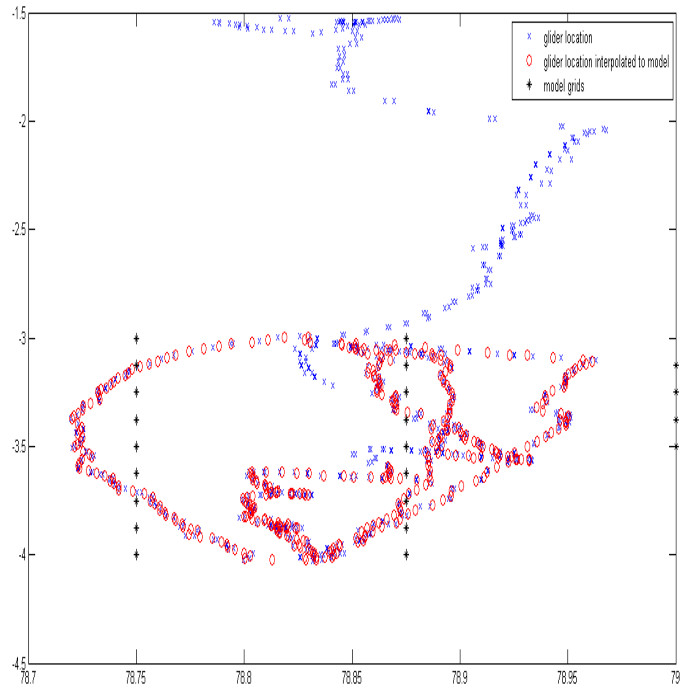
APPROACH

We have participated in the DYNAMO project. We deployed (together with UEA's Andrew Matthews) SeaGlider which had the following characteristics

- Autonomous underwater vehicles
- No propellor
- Oil-filled bladder controls buoyancy
- Shifting internal ballast (battery) controls pitch and roll
- On surface, sends data and receives new instructions through Iridium satellite phone network
- Real-time upload to GTS
- Speed 0.25 m s-1(20 km day-1)
- Maximum depth 1000 m
- Temperature, salinity, chlorophyll, dissolved oxygen sensors

- Vertical resolution 0.25 m

We have collected the following datset

- Active between 14 September 2011 and 23 January 2012
- 1474 profiles of T, S and O2 and Chl
- 6-10 profiles/day
- 10-20km distance/day
- 3S a 4S along 78.85E
- 10 horizontal profiles
- 

Dariusz Baranowski participated in the DYNAMO cruise and subsequently (summer 2012) traveled to the University of East Anglia (England) to prepare data for distrubution. The data is now available for all DYNAMO researchers. Paper was presented during the Air-Sea interaction conference in Boston which summarized the progress and during the incomming AGU conference in San Francisco another conference paper will be presented (see references).

WORK COMPLETED

1. We participated in the DYNAMO project (leg 1 on R/V Revelle) and subsequently we collected several months of data from SeaGlider in collaboration with Dr Adrian Matthews (University of East Anglia). We helped in collection and processing of this dataset which was used in COAMPS and NOGAPS model validation. We studied the role of atmospheric-ocean interaction in triggering convection during the transition from the suppressed to the active state

and importance of diurnal cycle of SST. We looked at the role of rainfall events in the barrier layer formation and upper ocean mixing.

2. We have processed SeaGlider data and investigated diurnal cycle observed during 5 months of continuous observations in the DYNAMO region.
3. We have tested and validated oceanic mixing layer mode - Skin, Warm, and Mixed layer (SWaM) parameterization. This is similar to COARE flux algorithm but improves upon it by including mixing processes from within the thermocline. Such model is important for the westerly burst conditions observed during MJOs Current schemes of this type are used in global models such as ECMWF but do not include thermocline interaction. The first version of the model which we are developing is included in research version of NOGAPS and shows promise in better tropical forecasts of convection and precipitation.
4. We collaborated with NRL researchers working on MJO large dynamics and local Wheeler-Hendon type index.

RESULTS

Representation of the SST spatial and temporal variability trough simple mixed layer model

We have developed and validated model new warm layer SST model (Zeng & Beljaars, 2005). The extension of this model includes mixing of colder water below the thermocline (see Figure and equations).

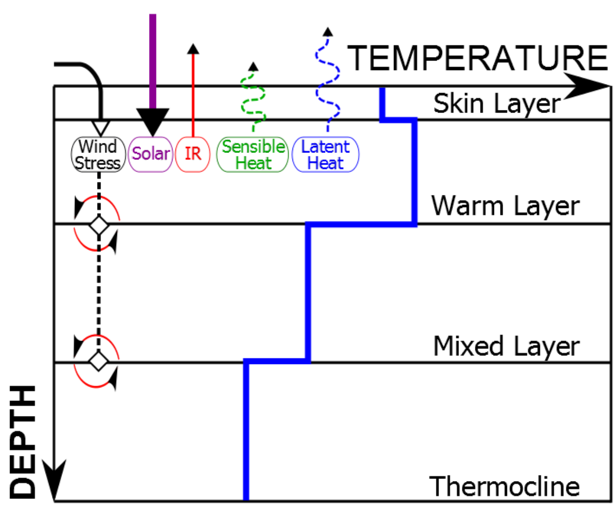


Figure. Extension of (Zeng & Beljaars, 2005) model includes thermocline waters but still keeps the model simple and fast so it can be implemented in models such as NOGAPS.

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}(K_w + k_w)\frac{\partial T}{\partial z} + \frac{1}{\rho_w c_w}\frac{\partial R}{\partial z}$$

$$K_w(z) = -zku_{*w} / \phi(\frac{-z}{L})$$

$$\frac{\partial}{\partial t}\left(T_{SL} - T_{WL}\right) = \frac{Q + R_s - R(d_{WL})}{d_{WL}\rho_w c_w \nu / (\nu + 1)} - \frac{(\nu + 1)ku_{*w}}{d_{WL}\phi_t\left(d_{WL} / L\right)}[T_{SL} - T_{WL}]$$

The model has been validated with the DYNAMO observations to provide temporal (e.g., diurnal) variability. Even though the bulk SST is traditionally observed by ships and buoys, it is the warm layer SST which is directly responsible for many physical processes in the atmosphere such as, for example, occurrence and strength of the deep atmospheric convection. In turn, these convective systems modulate such large scale weather events in tropics such as tropical cyclone genesis and Madden Julian Oscillations (MJO).

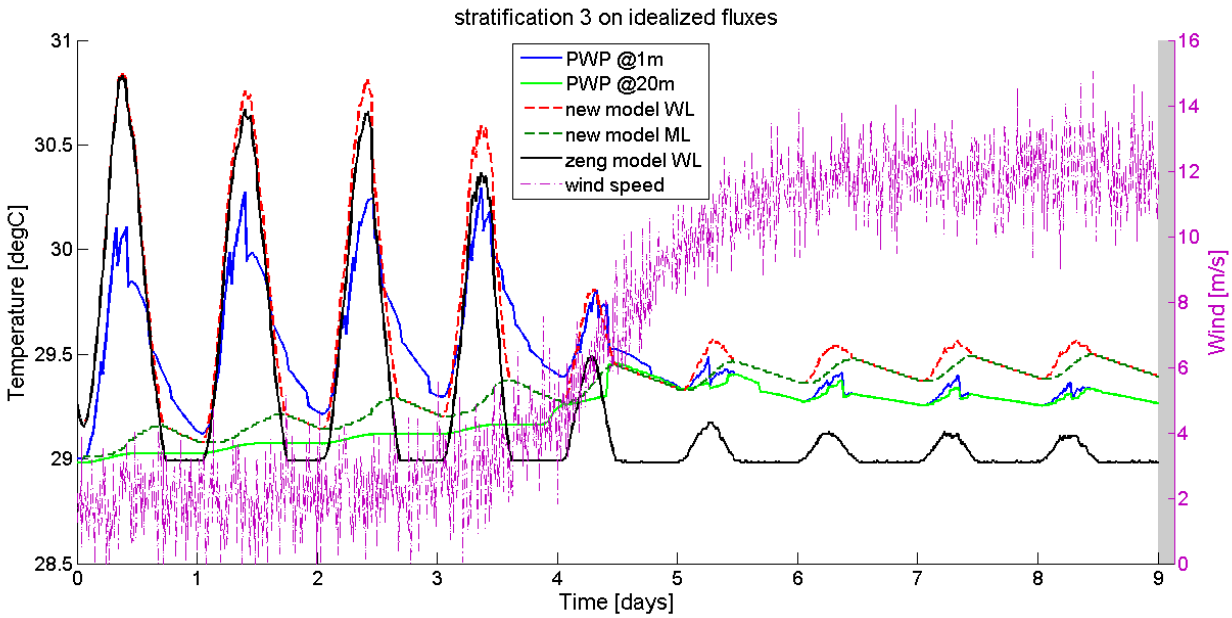


Figure. Initial validation of the model against the DYNAMO dataset shows good fidelity of the model in comparison with more complex schemes and observations.

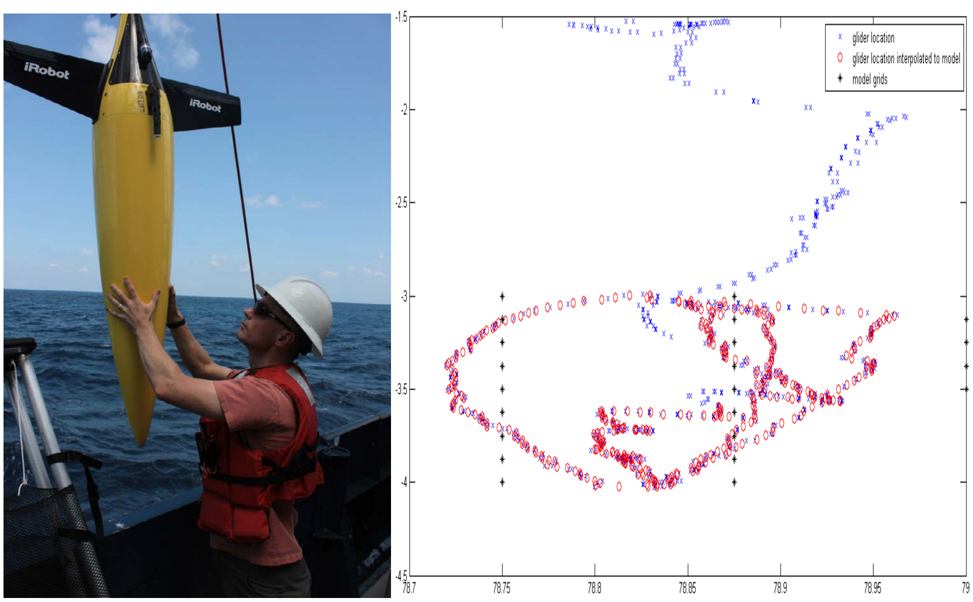
The original model considers skin, sub-skin, warm-layer, and foundation (bulk) ocean temperatures and predicts their evolution in response to evolving surface atmospheric and oceanic conditions (such as wind, surface radiative as well as sensible and latent heat fluxes) - see Figure. Such a model provides increased fidelity of SST prediction over fixed SST assumption, especially from the point of view of small-scale and mesoscale processes that this proposal focuses upon. Various parameters of the model (e.g., the foundation SST) are to be parameterized by applying oceanic DYNAMO observations.

DYNAMO observations of the ocean state trough SeaGlider data

We have been using the DYNAMO oceanic observations to derive diurnal oceanic temperature structure under varying wind, cloudiness, and ocean state conditions. To this end we have at our disposal iRobot Seaglider. This is an autonomous underwater vehicle that glides up and down to measure vertical profiles in the ocean to a depth of 1000 m, with a working vertical resolution of ~25 cm. These gliders are equipped with the standard temperature and conductivity (salinity) sensors. During the DYNAMO we obtained the following dataset

- Active between 14 September 2011 and 23 January 2012
- 1474 profiles of T, S and O2 and Chl
- 6-10 profiles/day
- 10-20km distance/day
- 3S a 4S along 78.85E

We have developed satellite algorithm to derive surface fluxes at iRobot Seaglider lat/lon position. We used PWP (Price-Weller-Pinkel) high resolution model to check if such derived temperature profiles driven in terms of atmospheric forcing such as sensible and latent heat fluxes, radiative fluxes (solar and infrared), stress, wind state, cloud coverage, etc. agree with the SeaGlider data.



Figures. SeaGlider which operated during the DYNAMO and position of all the observations it made.

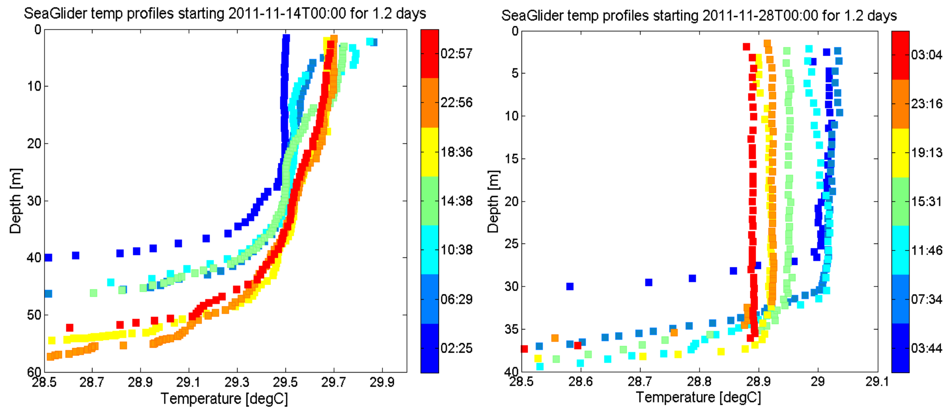


Figure. Glider derived profiles during the DYNAMO are different for different MJO phases.

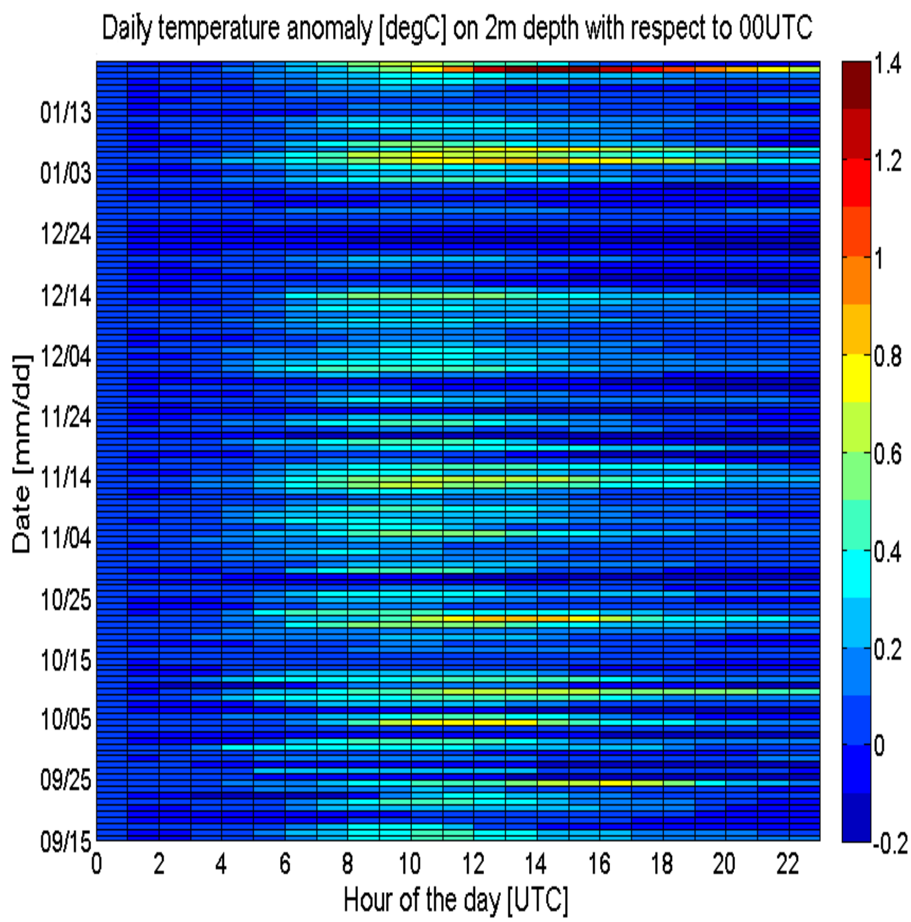


Figure. SeaGlider dataset showing daily temperature changes.

The development of the diurnal warm layer and the ocean mixed layer during different phases of MJO, as observed by the iRobot Sea Glider.

Using glider data, R/V Revelle data, ARGO floast, atmospheric sounding data, satellite data we are developing better understanding of MJO and oceanic-atmospheric interaction processes during the MJO passages. In particiular we studied precipitation patterns vs. glider observations and COAMPS winds. We have developed dataset based on glider observations which was directly used against COAMPS model runs.We observed recharge mechanism, diurnal cycle, and amplitude of diurnal variability. We have noticed that COAMPS underestimated sharp changes in the upper layer but provides good simulation of the evolution of the warm layer. Coupled COAMPS represents well the development the warm layer, but the mixed layer is shallower and warmer than glider observations

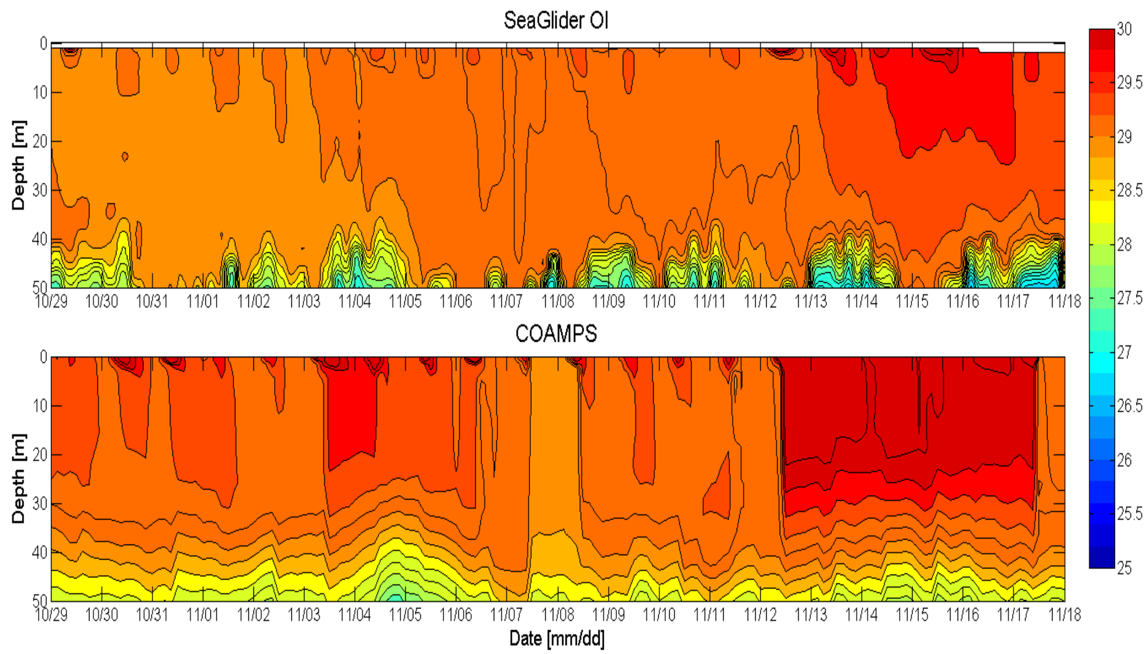


Figure. Temperature in upper 50m of the ocean. Comparison between in-situ SeaGlider observations (upper panel) and COAMPS simulation (lowe panel)

In addition to validation of COAMPS with SeaGlider data, we created unique 4-months long, high temporal and vertical resolution dataset of upper ocean observations. For better understanding of physical processes that force observed variability, satellite and reanalysis derived surface fluxes were added. Based on this comprehensive dataset we are studying diurnal ocean response to large scale, organized atmosheric forcing with particular interest in atmosheric Kelvin Waves and MJO. Our focus is on development of efficient parameterization of observed upper ocean temperature and salinity variability based on variables by default calculated by weather forecast models and thus improving representation of air-sea interactions in these models.

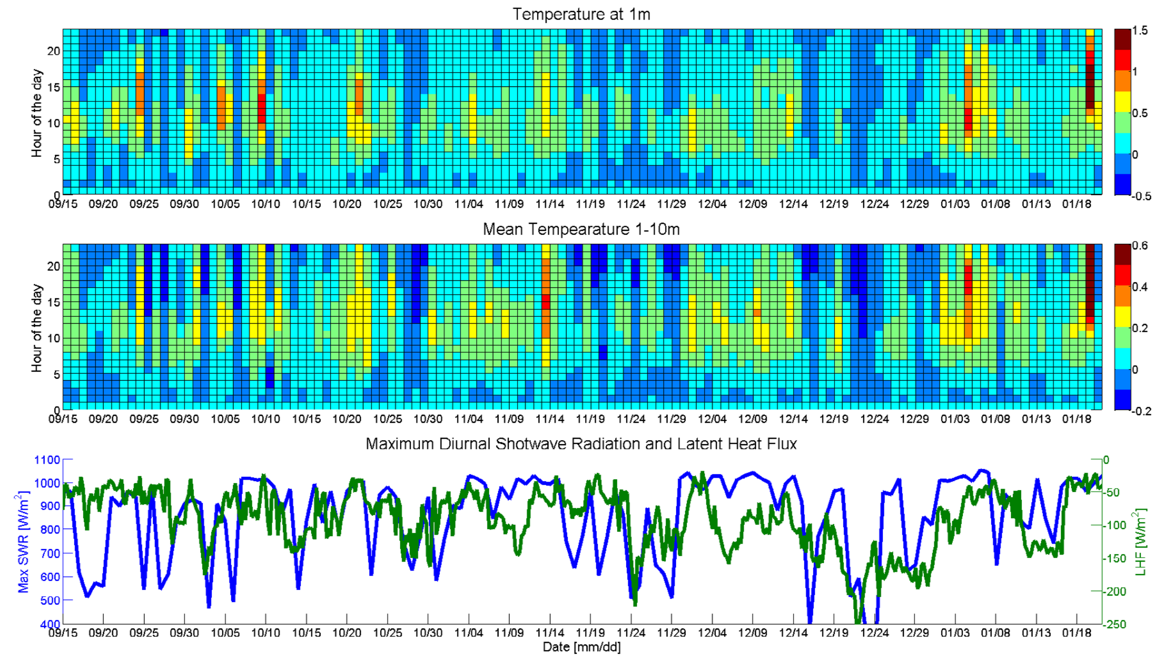


Figure. Diurnal Temperature anomaly at 1m (top panel), 1-10m (middle panel) and corresponding satellite derived solar radiation and latent heat flux (bottom panel)

Understanding of large scale dynamics

We asked a question if glider observations reflect the changes during the Kelvin wave passage? We noticed that development of the warm layer observed in glider measurements is consistent with atmospheric surface fluxes observed during DYNAMO. Sharp temperature gradient in the upper 5 m is observed at noon during the pre-MJO dry period. In the active MJO phase the mixed layer cools and deepens but the diurnal cycle is observed during the breaks between the passage of atmospheric tropical waves. Figure shows the synthesis of the ocean and atmosphere behavior during the 3 MJOs observed during DYNAMO, based on different observational platforms. The top panel illustrates principal components of eastward moving TRMM precipitation modes with the solid line indicating precipitation maximum over the DYNAMO area and the dashed line indicating the precipitation anomaly west of Sumatra. The difference between the three episodes is clearly seen, with the large magnitude and rapid development characterizing the November episode, relatively weaker October episode and convection situated in the eastern part of the Indian Ocean basin in December. Further studies indicated strong Kelvin wave anomaly during the November event. Middle panel illustrates daily means for temperature (solid) and salinity (dashed). Variability due to organized atmospheric forcing is clear, and particularly strong for November event. Bottom panel shows maximum and minimum for diurnal anomaly for temperature (black) and salinity (grey). Clearly during suppressed phase of MJO temperature anomaly minimum is negligible, though during active phase both diurnal maximum and minimum of diurnal temperature anomaly have significant magnitude. This illustrates that even though during this phase there is diurnal heating absorbed by the upper ocean (diurnal temperature cycle), energy stored in the ocean is decreasing. The salinity shows the response to the individual precipitation events preceding the active phase (prior to November 24^{th}); followed by increase caused by mixing associated by the strong winds once the active MJO phase is developed.

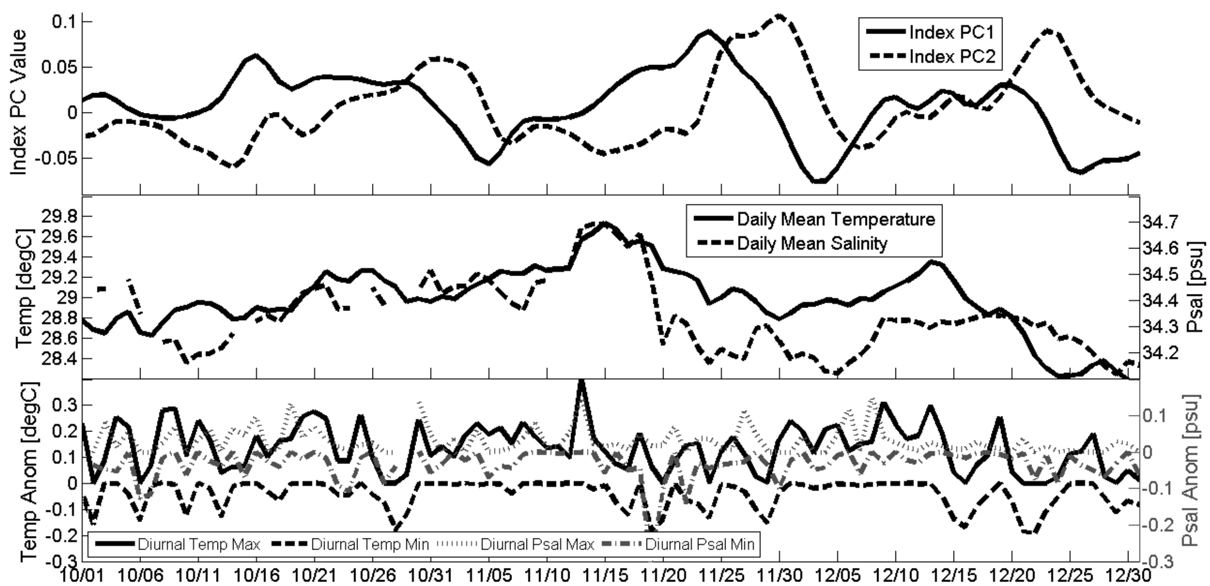


Figure. Top panel is TRMM precipitation first two EOFs principal components; middle panel shows daily mean temperature (solid) and salinity (dashed); bottom panel shows daily anomaly maximum and minimum for temperature (black) and salinity (grey).

IMPACT/APPLICATIONS

The project will contribute to the better understanding of feedbacks between convection and atmospheric and oceanic mixed layer. The knowledge gained in this project will allow us to formulate and test more accurate parameterizations, the variance/co variance of coupling, and to improve the forecasting capability of COAMPS® and NAVGEM. For example, in our recently published paper "Inclusion of sea-surface temperature variation in the U. S. Navy ensemble-transform global ensemble prediction system" (JGR, 2012) we used the local ensemble transform (ET) analysis perturbation scheme to generate perturbations to both atmospheric variables and sea surface temperature (SST). The adapted local ET scheme is used in conjunction with a prognostic model of SST diurnal variation and the Navy Operational Global Atmospheric Prediction System (NOGAPS) global spectral model to generate a medium-range forecast ensemble. Thus, research supported by this grant has potential to be transitioned to operational NAVGEM model.

RELATED PROJECTS

1. Ph. D. student Dariusz Baranowski, who participated as NCAR researcher in the DYNAMO project, works with NRL researchers Maria Flatau and Sue Chen to study Kelvin waves and the role of oceanic warm layer on atmospheric Kelvin waves observed on 2-3 day scale ("cold pool Kelvin wave dancing"). He combines oceanic and atmospheric information about Kelvin waves. He uses our SWaM model to model the warm layer cycle and contributes to Maria K. Flatau "local Hendon-Wheeler" index. In the fall and winter 2012 he is visiting NRL Monterey.

2. Our plans include collaboration with Chris Zappa to investigate aircraft observations to include EDMF (eddy diffusivity – mass flux) type parameterization to include the role of Langmuir mixing. With Chris Fairall and Jim Edson we will improve warm layer and add mixed layer scheme in COARE algorithm. We will use R/V Revelle fluxes (Chris Fairall) and CTD (Jim Moum). With Masaki Katumata we will work on R/V Mirai data (flux, CTD) validation of our newly developed SWaM (skin-warm-mixed layer parameterization). We contribute to November 24, 2012 case study of MJO passage as observed in the DYNAMO region.

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Chen S., M. Flatau, J. M. Schmidt, T. Jensen, T. Shinoda, D Baranowski: Initation of November 24 2011 MJO DYNAMO event, as modeled by coupled COAMPS. To be submitted to *Mon Wea Rev* in Oct. 2012. [IN PREPARATION]

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