Understanding Air-Sea Coupling Processes and Coupled Model Predictions Using GOTEX Measurements and COAMPS/NCOM

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LONG-TERM GOAL

The long-term goal of this project is to improve air-sea coupled model forecast in regions of strong air-sea coupling. We target on understanding the coupled processes, coupled model performance, and improving physical parameterizations in the forecast models to better represent the coupled processes.

OBJECTIVES

The objectives of this project are 1) to explore and test new methods for turbulence flux analyses over inhomogeneous surfaces and generalize the bulk formula; 2) to understand current coupled COAMPS/NCOM model behavior and identify error sources in the coupled model using the improved flux calculations; and 3) to obtain further in-depth understanding of the coupled processes and improve physical parameterizations of the coupled model.

APPROACH

Our approaches are 1) analyzing the GOTEX measurements to understand the observed boundary layer and ocean mixed evolution; 2) calculating turbulence fluxes over heterogeneous surfaces using new methods involving wavelet filtering; 2) performing atmospheric COAMPS and COAMPS/NCOM simulations for all GOTEX cases and evaluate simulations through model-observation intercomparison with the GOTEX measurements and improved flux calculations; and 3) performing model sensitivity tests with the COAMPS/NCOM simulations and test new surface flux and boundary layer parameterizations in coupled COAMPS in high-wind conditions. Although the main cases will be selected from GOTEX due to the availability of concurrent air/ocean measurements, we will also explore other cases/datasets such as those from the recent High-Resolution Wave-air-sea Interaction (HiRes) project.

Qing Wang is involved in all phases of the project including GOTEX data analyses, atmospheric COAMPS simulations, and for analyses of COAMPS/NCOM simulations. Larry Mahrt will be responsible for evaluation of new analysis techniques for improved estimates of fluxes in heterogeneous conditions. He will also evaluate the performance of the bulk formula using the improved flux estimates and generalize the bulk formula for estimation of grid-averaged fluxes over heterogeneous conditions. At the current stage of development, coupled COAMPS/NCOM is not yet

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available to researchers outside NRL. All coupled model simulations will be done at NRL Monterey by the our collaborative NRL team (S. Wang/X. Hong).

WORK COMPLETED

1. Initial coupled NCOM/COAMPS simulations for selected GOTEX cases were setup by Drs. X. Hong and S. Wang (NRL Monterey). The model output flat files were ftp-ed to NPS for analyses. The coupled COAMPS atmosphere component was setup to run in three nested domains with 3 km grid resolution in the inner-most domain. Two-way coupling occurred in the inner-most nest with the coupled NCOM running at the same grid resolution.
2. We have overcome all technical issues in reading and interpreting NCOM model output and developed a full set of MATLAB programs to interpret NCOM model output. This is an important initial step for further model analyses.
3. We have made initial analyses of NCOM results and compared with aircraft AXBT measurements as well as satellite SST measurements.
4. We have analyzed aircraft measurements to explore the heteorogeneous nature of coastal ocean and atmosphere during the Tehuno events of February 2004.
5. Data analyses in year one of the project suffered from administrative difficulties in getting contract to Dr. Mahrt. This is now resolved at the beginning of FY11.
6. As part of the ONR MJO DRI, Qing Wang also worked on coordinating potential aircraft measurements with DYNAMO investigators. This includes attending DYNAMO workshop and presenting aircraft measurement objectives on air-sea interaction as part of the ONR DYNAMO efforts, preparing all information needed for aircraft request to NOAA, and coordinating with other potential aircraft investigators for deep convection studies.

RESULTS

GOTEX aircraft data analyses: One of the objectives of this project is to explore new techniques of data analyses for regions of strong heterogeneity. Figure 1 shows an example of the variability in multiple variables from measurements at 30 m above the surface by the NCAR C-130 during flight 9 (RF09) of GOTEX. The two measurement legs were made at different locations relative to the gap outflow jet. Leg S7 (Fig. 1a) intersects the outflow jet towards the west side of the jet core, Leg S39 (Fig. 1b) is upwind of S7 and sampled the center and east of the jet core. The most prominent spatial variation is in wind direction, where the north-south wind component changed from 5 ms^{-1} northerly wind to 20 ms^{-1} northerly wind at the end of the Leg S7 . Similar magnitude of variations are also found in the later flight leg (Fig. 1b). Along the ~80 km path in Fig. 1a, the air potential temperature decreased by more than 2 K following the SST change in nearly the same magnitude. The variation of the wind depicts the fanning of the gap outflow as it expands from the mouth of the gulf to the open ocean, generating mesoscale cyclonic circulation west of the jet core and cyclonic flow east of the jet core. From the u and v wind plot, it is apparent that the increase in northerly wind is accompanied by intensified turbulence field represented by the increasing magnitude of perturbations. This is further explored through spectral analyses (Fig. 2), where power spectra of all three velocity components and the ogives of momentum flux components are compared between the two sections of the measurement leg in Fig. 1a: the warm and relatively weak wind section to the east and the cold and strong wind section towards the jet core. The power spectra from the strong wind section shows a dominant peak in eddy scales between 200 m to 800 m that has considerably more energy than the corresponding wind component in the weak wind section. The ogives of the cospectra indicate that the these most energetic eddies also contribute most to the momentum flux, especially those in the dominant north-south components of the wind. In fact, Fig. 2b shows that in both high wind and low wind sections, the flux contribution from scales greater than 1 km are very limited as the ogives flatten out beyond 1 km eddies. The momentum flux in the strong wind section is nearly three time larger than that in the weak wind section. Interestingly, the water vapor perturbations seem to be larger in the weak wind region (Fig. 1a, panel for q_v). Further analyses are needed to understand the TKE budget of the each section. Although wind shear is likely a contributor, the effects of buoyancy in the energetics of the turbulence eddies should be explored because there is also strong variations in the near surface thermal stability. Furthermore, quantifying the transition from the weak wind to the strong wind section would be a challenge, which is the subject of investigation in our second year effort.

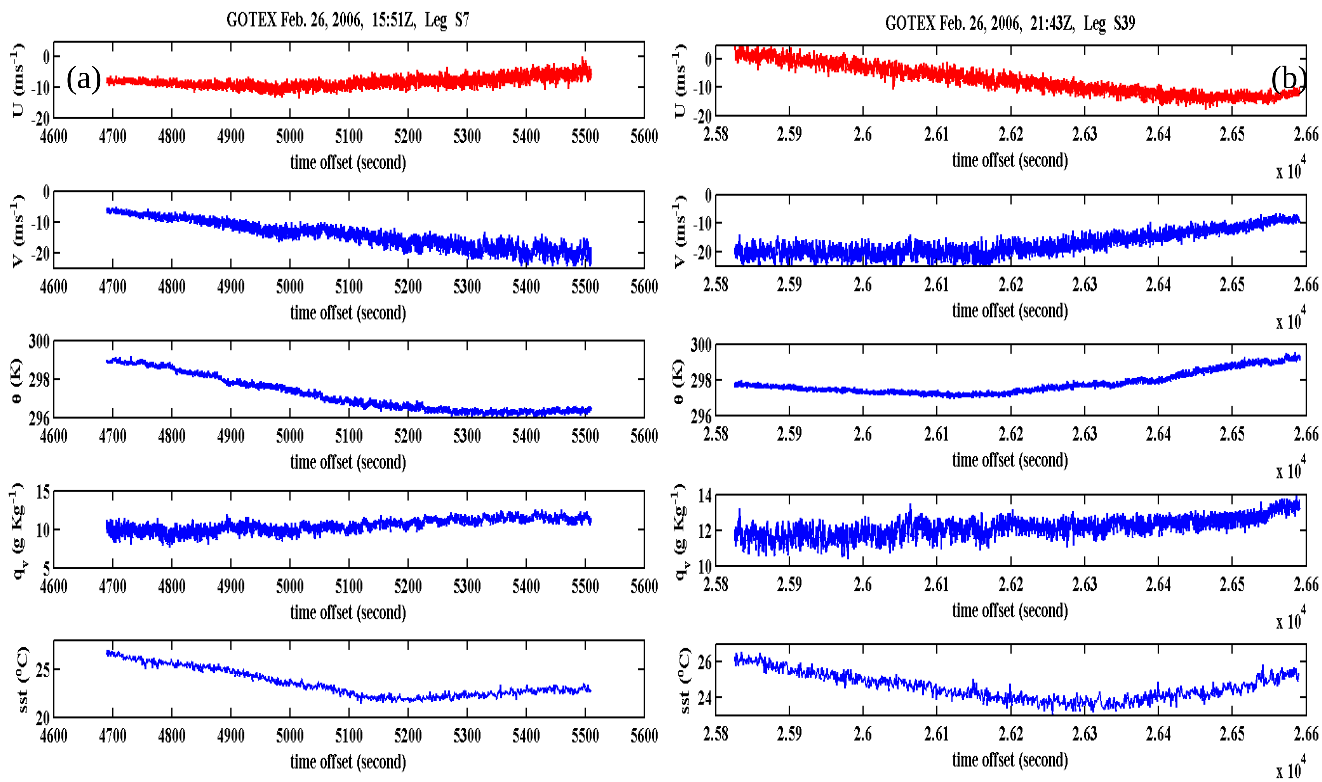

Figure 1. Spatial variations of wind, potential temperature, specific humidity, and sea surface temperature along two low-level measurement legs made by the NCAR C-130 on Flight 9 of GOTEX on February 26, 2004. (a) at around 1551 UTC on the west side of the gap outflow jet core; (b) at around 2143 UTC on the east side of the jet core.

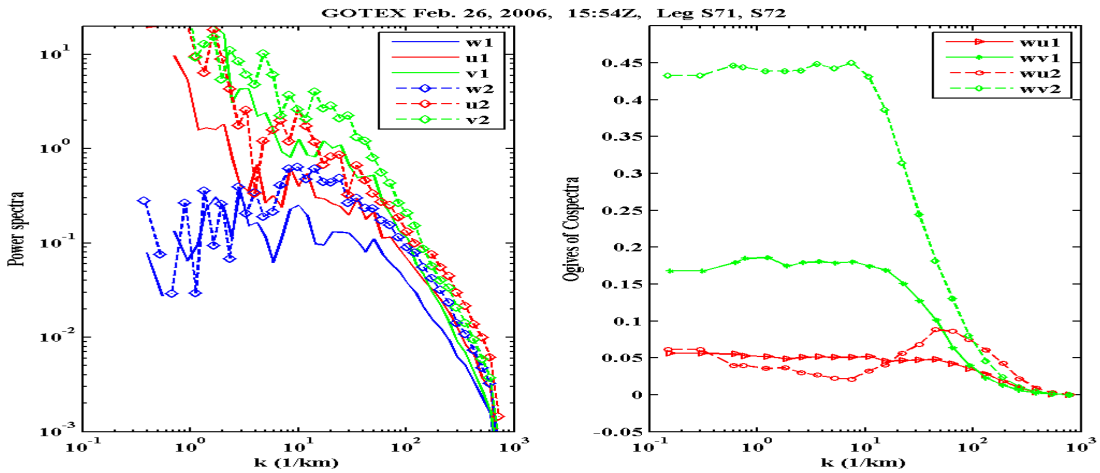

Figure 2. Turbulence power spectra (a) and ogives for components of momentum fluxes (b) from the weak wind (w1, u1, v1) and strong wind (w2,u2,v2) sections. In both regions, flux contributing eddies are between 200 m to 1 km.

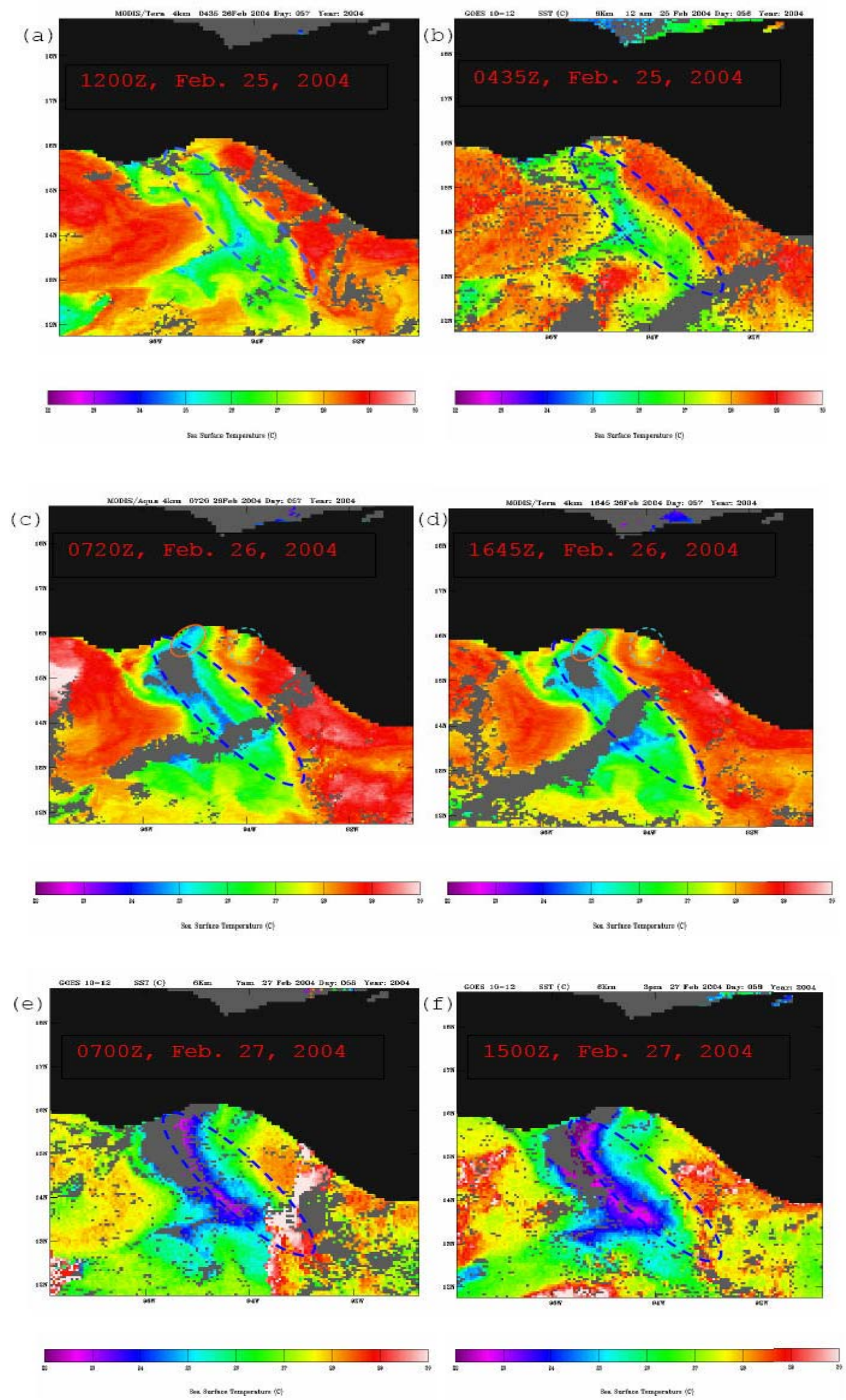

Figure 3. Satellite sea surface temperature from GOES-12, MODIS/Aqua, MODIS/Terra on (a) 25 Feb. 12Z, (b) 26 Feb. 04:35Z, (c) 26 Feb. 07:20Z, (d) 26 Feb. 16:45Z, (e) 27 Feb. 07Z, and (f) 27 Feb. 15Z. The blue oval denotes the location of the cool strip on (a).

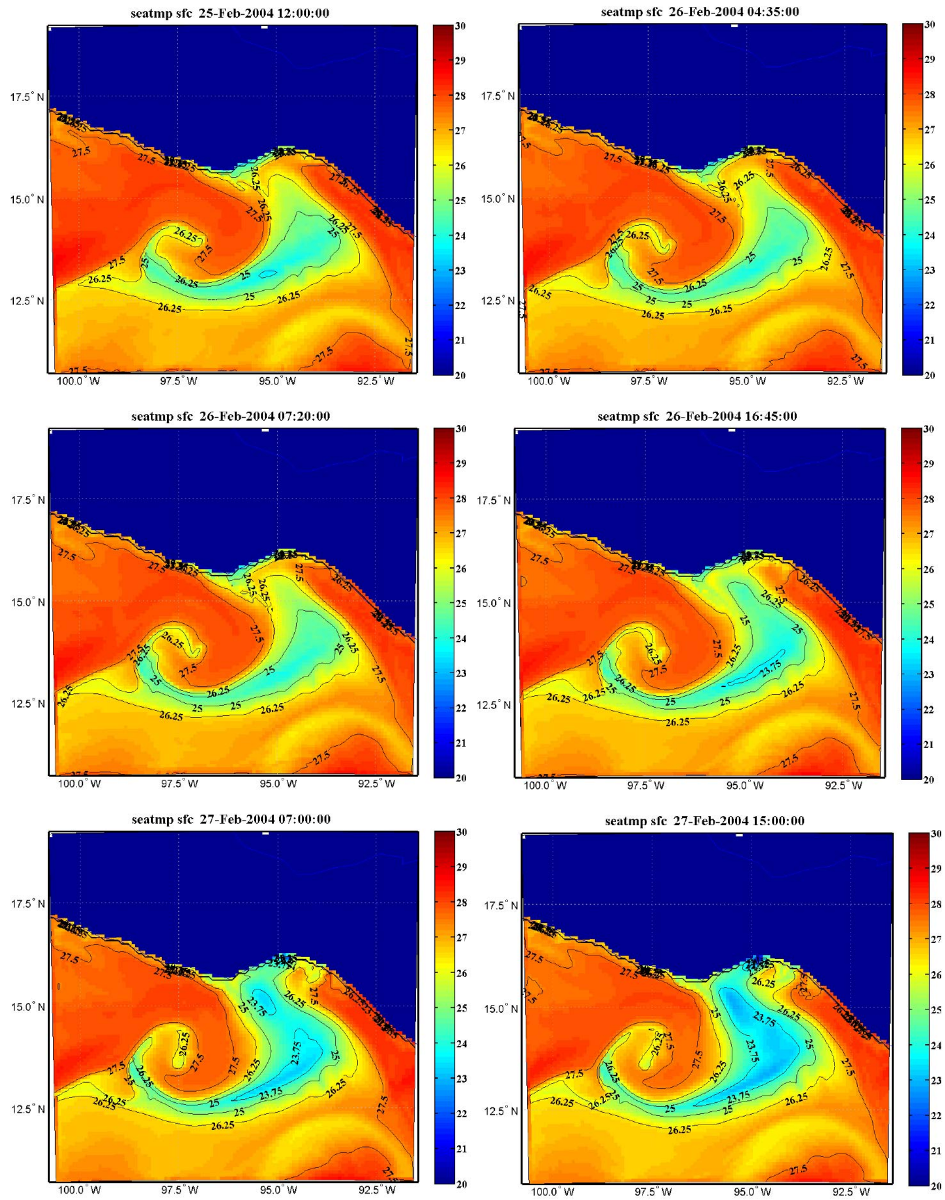

Figure 4. Sea surface temperature evolution from the coupled NCOM simulation. The time of each panel is the same as the corresponding panels in Fig. 3.

NCOM simulated SST evolution: Coupled COAMPS-NCOM simulations were made for about 10 days starting on Feb 20, 2004. During this period, one gap wind event occurred over the GOT region starting at about 00Z on February 26. Figure 3 depicts the SST evolution during this event observed from multiple satellites. The basic feature of the SST field is the cool strip oriented in the northwest-southeast direction as outlined by the blue oval. The coolest water is located at (14^{o}N, 94.4^{o}W) at 25.3^{o}C, whereas the mouth of the GoT near (16.1^{o}N, 95^{o}W) was relatively warm at about 28^{o}C. Warm water of about 29^{o}C is observed in most of the GoT region, particularly along the coastline to the east and west of the cool strip. The SST image in Fig. 3b corresponds to about 4 hours after the gap front moved over water. The SST field at this hour is very similar to that 16 hours ago (Fig. 3a) except for some cooling further off the coast near 14N latitude. Significant SST changes occurred between 04:45Z (Fig. 3b) and 07:30Z

(Fig. 3c). Figure 3c shows further cooling along the previous cool strip (blue oval), although the orientation remains nearly the same. The largest change occurs near the mouth of the gulf where a new cool strip exits along the northeast-southwest direction (orange oval) with the north-most tip at (16.1^{o}N, 95^{o}W). SST at the mouth of the gulf decreased from 28^{o}C to 24.5^{o}C during this three-hour period.

Results from the coupled NCOM simulation are shown in Fig. 4 where each panel were taken from the same time of the corresponding panel in Fig. 3. Although NCOM shows the cooling of the region following the onset of the Tehuano, the magnitude of cooling is significantly smaller than those observed SST (Fig. 3). Preliminary comparison of the coupled model results with those from aircraft observation does not reveal a general trend. The deviation of NCOM from observations seem to vary depending on the location relative to the jet core. Figure 5 shows two examples, one close to the mouth of the gulf (S1), one further downwind (S7). At the mouth of the gulf, the coupled model SST compares better compared to further downwind, a trend also shown by other measurement legs. This is also an improvement over the SST field in the uncoupled COAMPS simulations where SST is fixed for every 12 hours of simulation. Further diagnostic study is needed to identify the cause of such 'improvement' in the coupled model. On the other hand, the surface stress from the coupled and uncoupled model result do not seem to differ substantially and both deviates significantly from the aircraft observations. Similar situation is seen in Leg S7 further downwind where the coupled model does not seem to make any difference in both SST and wind stress. Apparently, these initial model-observation intercomparisons raised more questions than providing answers. However, they are helpful in defining issues for further investigations.

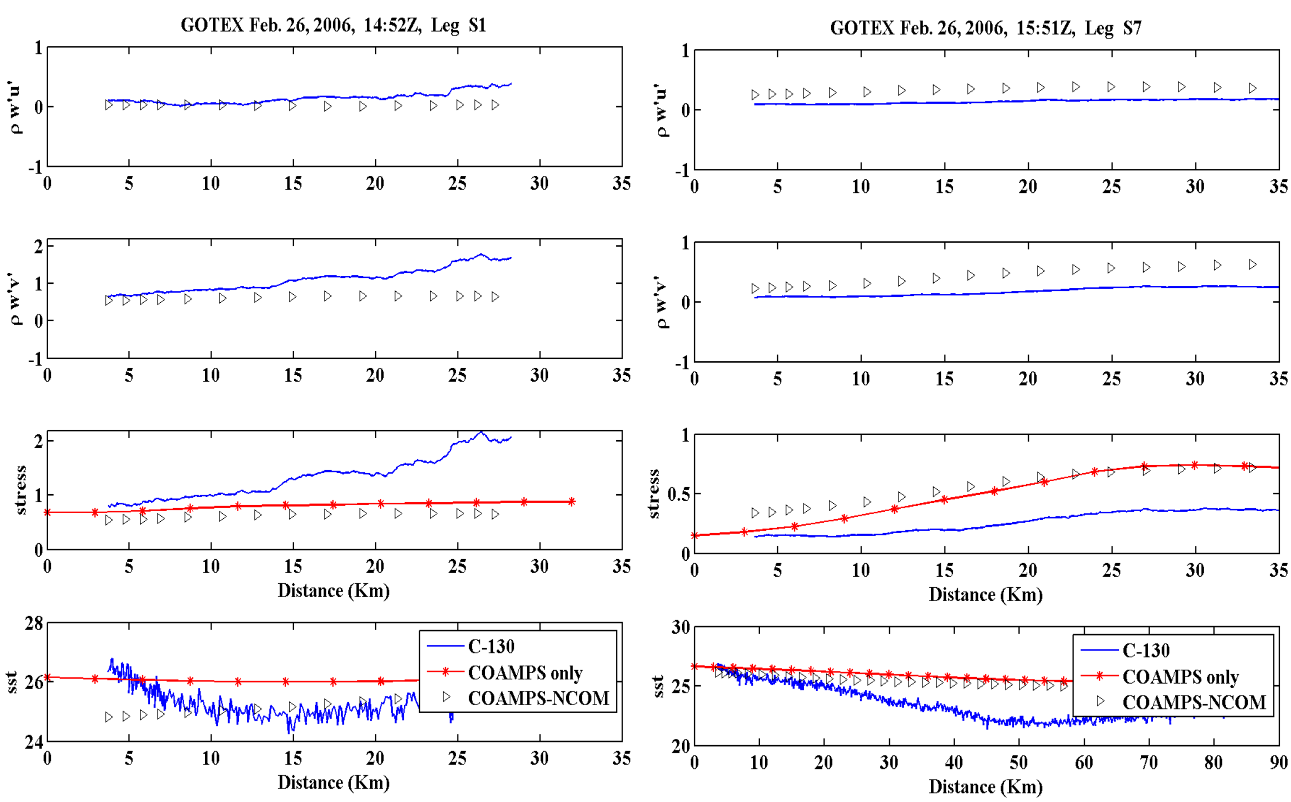

Figure 5. Comparison among observed, uncoupled COAMPS, and Coupled COAMPS results for two different locations. (a) Leg S1 near the mouth of the Bay; (2) Leg S7 downwind away from the Bay.

Ocean mixed layer structure: The upper ocean mixed layer structure is examined along the AXBT drop trajectory which was designed to go downwind and follow the jet core. A comparison of the vertical cross-section on water temperature along the trajectory is shown in Fig. 6b in comparison with those from AXBT dropsonde measurements (Fig. 6a). Comparison of the two figures indicate relatively good representation of the ocean temperature below the thermocline. The observed and modeled variations of the mixed layer depth are also similar with shallower mixed layer to the coast and deeper further away. However, the strong thermocline temperature gradient near the coast is not represented in NCOM. Overall, NCOM shows the trend of mixed layer temperature increase from the coast, but NCOM water temperature is warmer by ~2°C near the coast and slightly colder further downwind.

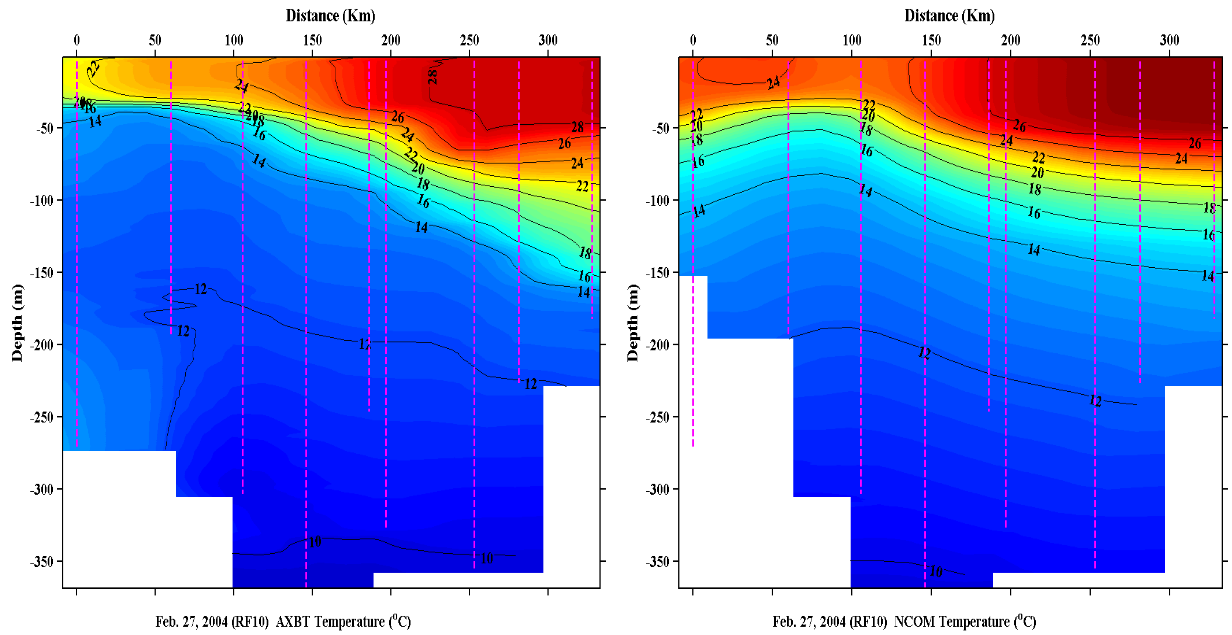

Figure 6. Mixed layer temperature profiles from AXBT measurements (a) and from NCOM simulations. The x axis is the distance to the reference location defined by the AXBT drop location of the group that is the closest to the coast.

IMPACT/APPLICATIONS

Coupled atmosphere-ocean modeling has been developed by several large forecast model groups including the Navy's research labs. However, coupled model simulations have not been examined in great details mainly due to the lack of concurrent and adequate measurements on both side of the air-sea interface. THis research project takes advantage of the existing dataset from GOTEX experiment and intend to examine the coupled model performance and identify issues in coupled model forecast. Results should help improve the model setup and physical parameterizations in the Navy's coupled forecast model.

TRANSITIONS

The results from this project will potentially help to evaluate and improve the surface flux and turbulence parameterizations of the Navy's coupled models.