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High-Resolution Coupled Ocean-Wave-Atmosphere Prediction of Typhoons and Their Impact on the Upper Ocean

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LONG-TERM GOAL

The long-term goal is to gain new insight into the atmosphere-ocean-wave interaction within typhoon environments and to advance the development of the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System COAMPS®[1] through integration of new knowledge and technology and collaboration with ONR's Ocean Battlespace Sensing Departmental Research Initiative (DRI).

OBJECTIVES

The objectives of this research are to (1) investigate the impact of air-sea interaction including wave and sea spray effects on typhoon structure and intensity and its impact on the ocean mixed layer characteristics in the Western Pacific; (2) evaluate and validate new atmosphere-ocean-wave model parameterizations and COAMPS simulations of typhoon impacts on the ocean and atmosphere boundary layers; and (3) advance the development and improvement of the high-resolution COAMPS-On Scene (COAMPS-OS®[1]) Coupled Modeling Initiative through systematic evaluation using the DRI field experiment data and other available datasets.

APPROACH

We will implement and evaluate the wave-wind coupling and sea-spray parameterizations in COAMPS; explore the impact of the atmosphere-ocean-wave interaction on the intensity and structure of typhoons and its effect on the ocean mixed layer; develop and improve the COAMPS-TC (tropical cyclone) system by comprehensive evaluation of the coupled system; and provide real-time forecast support for the field program planned in the DRI. The emphasis of the scientific exploration is on the understanding of the physical mechanisms by which the wave-wind and sea spray may significantly change the ocean mixed-layer structure and the sensitivity of these changes to details of the parameterizations. The model development effort is concentrated on the systematic evaluation of the COAMPS-TC system using previous and DRI-collected datasets, emphasizing the ocean-wave-wind coupling. This effort also provides a transition path for the new technology emerging from the scientific exploration effort. Dr. Shouping Wang is responsible for overall progress of the project. He leads efforts in developing, implementing and evaluating new sea-spray parameterization and boundary layer formulations. Dr. Hao Jin conducts COAMPS coupled real-time fore-

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casts and develops interactive website for the Impact of Typhoons on the Ocean in the Pacific (ITOP) field program 2010.

WORK COMPLETED

1. Continue to study evolution of cold wake during Typhoon Fanapi 2010

During ITOP IOP 2010, the coupled COAMPS-TC predicted a realistic evolution of Typhoon Fanapi compared with observations, including its track, intensity, and particularly the development and recovery of the cold wake. In FY11, we compared the predicted ocean and atmospheric boundary layer structure with observations from satellite data, dropsondes and AXBT soundings. For this year, we have derived ocean mixed layer and surface energy budgets from COAMPS-TC prediction and evaluated various forcing terms in the budget. This work was presented in 30th Conference on Hurricane and Tropical Meteoorology. We are currently working on a paper to summarize these results.

2. Evaluation of turbulent fluxes using observations from Isabel 2003.

We continue to study roles of PBL parameterization in simulating TC structure in COAMPS. We used two mixing length formulations and applied them in two simulations of Hurricane Isabel (2003). The standard mixing scheme used in COAMPS is Mellor-Yamada formulation; the other alternative is that by Bougeault (1985). In general, Bougeault formulation gives larger values than the MY. We compared the simulated turbulence fluxes with those computed from observations (Zhang et al., 2009).

RESULTS

1. Further analysis of evolution of cold wake during Typhoon Fanapi 2010

Our focus is on the physical processes that lead to formation of the cold wake and its subsequent recovery. We have chosen two areas for comparative analyses. One of them was located where the cold wake was formed; the other was not significantly impacted by Fanapi and is designated as “environment”. Fig. 1 shows evolution of sea surface temperature, stress, and heat fluxes at the interface for two areas (labeled as “cold” for cold wake and “env” for the environment). The cold wake was created after the stress was significantly increased due to intensive surface wind speed (Fig. 1a and b). The wake started to recover after the minimum SST was reached on Sept. 19. After 5 days, the cold wake recovered by 2.5°C. Increases of SST from both areas are clearly correlated with the daytime solar absorption (Fig. 1c), although the heating rate due to the solar warming is larger for the cold wake area than for the environment. This is in part due to the heat loss for the cold wake that is larger than that for the environment due to the SST difference as indicated in Fig. 1d. Therefore, it is clear that the recovery of cold wake is primarily driven by the greater heat loss that occurs to the environmental area.

Ocean mixed layer evolution and its heat budget are demonstrated in Fig. 2-4. The thermocline is lifted due to strong upwelling between 16-17 September. The mixed-layer temperature reached minimum by the end of 17 Sept. For the same period, mixed-layer currents are enhanced by strong surface wind stress, leading to the strong current speed shear across the thermocline shown in Fig. 2b. This shear should generate turbulence and enhance the entrainment across thermocline. Fig. 3a-c shows the vertical advection heating rate, the mixing and radiation, and the horizontal advection. The heating rate driven by upwelling clearly follows the pattern of quasi inertial oscillation.

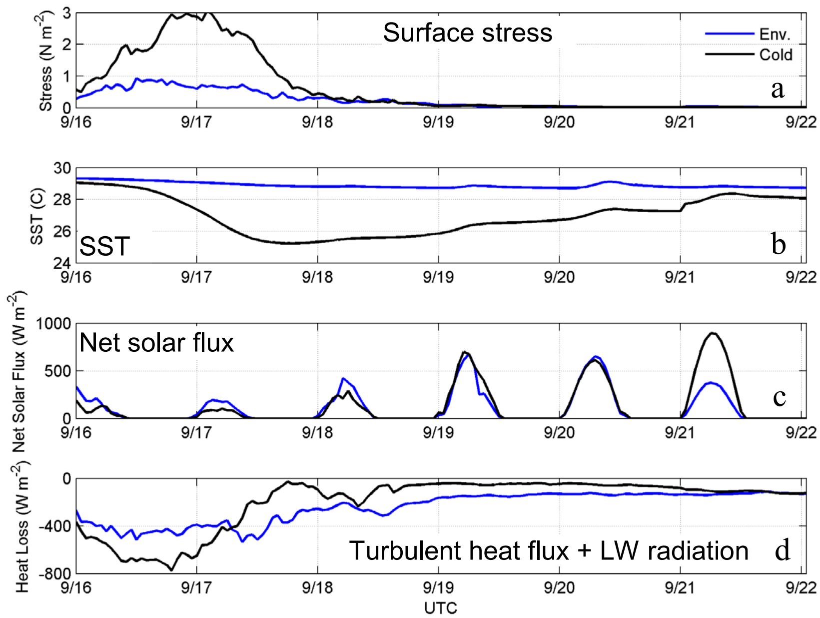

Fig. 1. Evolution of surface flux components for the area of "cold wake" and "env". (a) Surface stress; (b) SST; (c) net solar flux; and (d) heat loss (sum of sensible, latent heat and longwave radiation fluxes). The blue lines denote results for "environment", the black for "cold wake".

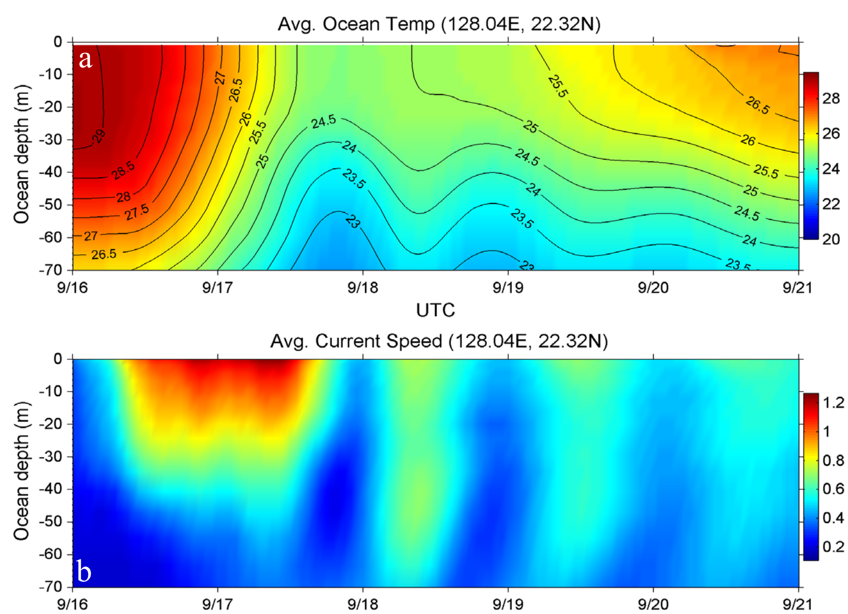

Fig. 2. Evolution of ocean mixed layer for cold wake. (a) Temperature; and (b) current speed.

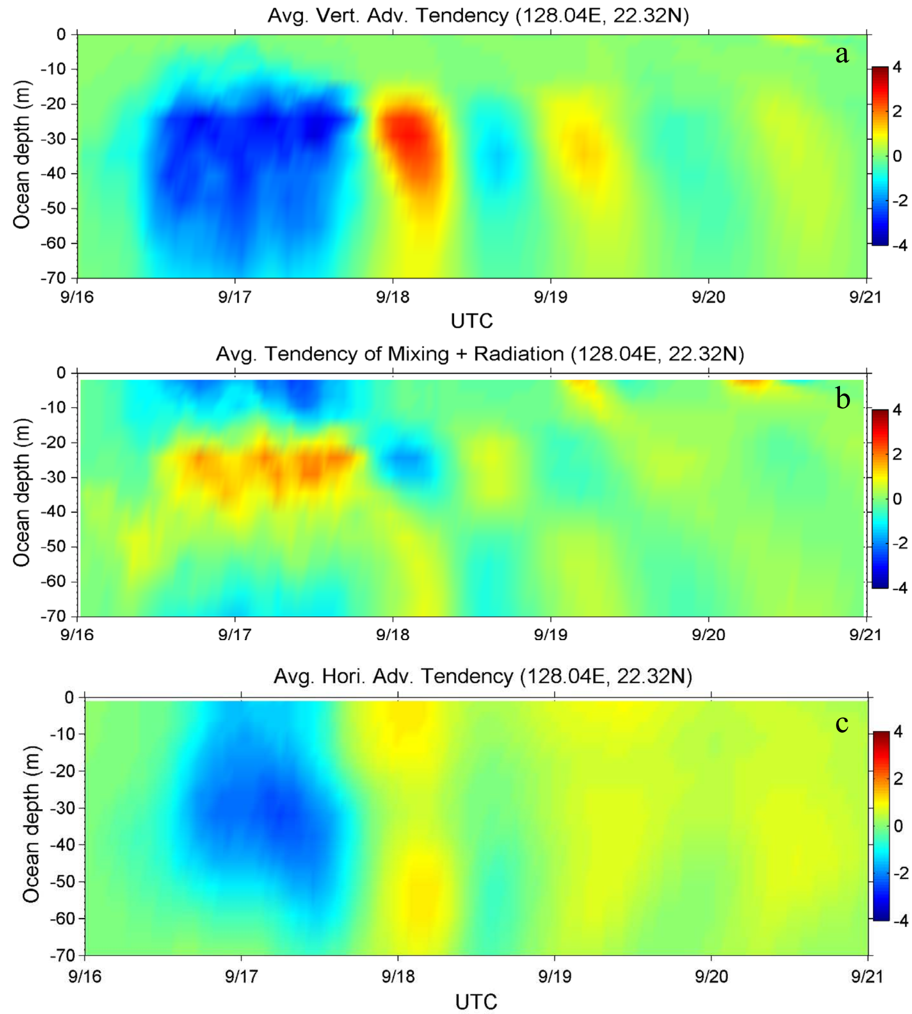

Fig. 3. Evolution of heat budget for cold wake. (a) Vertical advection heating rate; (b) sum of the mixing and radiation; (c) horizontal advection heating rate.

It is noticed that vertical advection does not contribute significantly to the cold wake formation due to nearly constant temperature profile of the ocean mixed layer. The upwelling suppresses the mixed layer depth, which enhances the cooling driven by the mixing. During the wake formation period, the turbulence mixing cooling dominates the radiation effect. Although the horizontal advection cooling rate is smaller than that from the turbulence mixing, it is not insignificant. Even though the turbulence mixing plays a dominant role in the cold wake formation, it is still not clear from the above analysis which part of the mixing is more important: surface flux or entrainment mixing. Furthermore, is the turbulence mixing driven primarily by the wind stress or the current shear across the thermocline? We continue to investigate these issues.

The recovery of the ocean mixed layer of this area mainly results from horizontal advection warming, which occurs for most of the period. The solar warming occurs in a very thin surface layer. When the warming dominates the cooling by surface turbulent heat flux and LW radiation during the day, turbulence is significantly suppressed, leading to a very thin surface warm layer. The solar warming is mixed downward by turbulence mixing as shown in Fig 3c. Even though SST of the cold wake recovered to 27.4°C from 26°C after 4 days, the oceanic upper boundary layer is still significantly more stratified and colder than the environment as shown in Fig. 4. This occurs because weak wind prevents the development of strong turbulence that is a main mechanism to mix down the solar warming which is concentrated in the top layer. Consequently, although SST of a cold wake may recover to the environment temperature, the ocean mixed layer may still maintain stratified and cold temperature profiles for much longer time period. Currently, we are working on a paper to summarize these results.

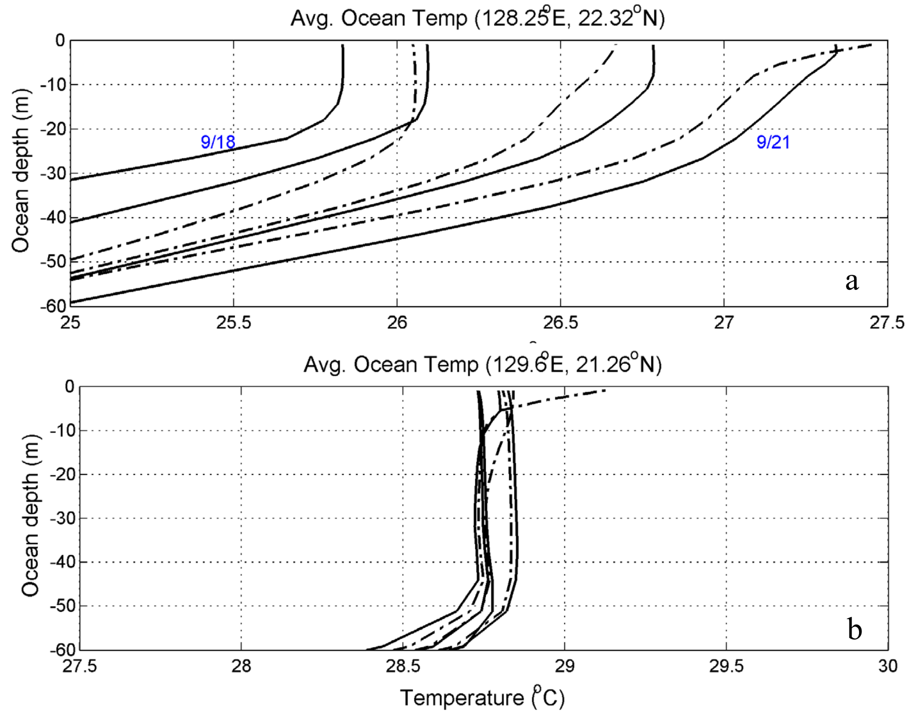

Fig. 4 Comparison between the mixed layer for the cold wake area (a) and for the environment (b). The mixed layer profiles are shown every 12 hours from 1200UTC 18 September 2010. Note the different values for x axis for two figures.

2. Evaluation of turbulent fluxes using observations from ISABEL 2003.

The comparison in this study demonstrates that the mixing length has important impacts on the turbulence mixing of sensible and latent heat. Fig. 5a shows two significantly different mixing lengths used in this study. The larger mixing length produces very strong entrainment near the mixed-layer top, resulting in a warmer and drier boundary layer compared with observations (not shown here). Although the simulated sensible heat flux from the MY mixing length appears to agree more with the observations, the latent heat flux is relatively small compared to the observations. One of important effects of larger mixing lengths is that it significantly enhances the mixing in the deep cloud layer, which may intensify the convective updrafts/downdrafts (results not shown here). Currently, we are carefully evaluating a series of simulations using observations and sensitivity tests.

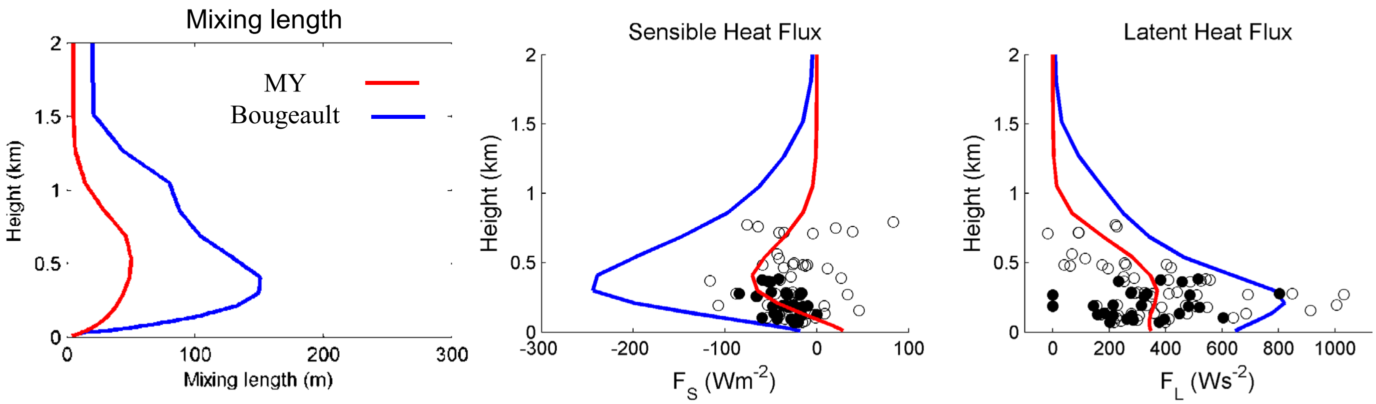

Fig. 5: Comparison of simulated turbulence variables with those derived from measurements of Isabel 2003. (a) Mixing length from MY and Bougeault; (b) sensible heat flux; and (c) latent heat flux

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IMPACT/APPLICATIONS

Study of formation and recovery of TC induced cold wake has important impact on the understanding of air-sea interaction. Our study shows that recovery of the ocean mixed layer takes much longer time than the sea surface temperature. Therefore, not only the cold wake may have important impact on the subsequent TC development, but also it may have implications on intra-seasonal variations of upper oceans.

RELATED PROJECTS

The current project is strongly interacted to NRL's Prediction of Tropical Cyclone Track and Intensity Using COAMPS-TC (James Doyle), whose objective is to develop a robust high-resolution air-ocean coupled tropical cyclone data assimilation and prediction system.