Improving Surface Flux Parameterizations in the NRL Coupled Ocean/Atmosphere Mesoscale Prediction System

Shouping Wang
Naval Research Laboratory
Monterey, CA 93943
Phone: (831) 656-4719 Fax: (831) 656-4769 email: wang@nrlmry.navy.mil

Qing Wang
Meteorology Department, Naval Postgraduate School
Monterey, CA 93943
Phone: (831) 656-7716 Fax: (831) 656-3061 email: qwang@nps.edu

Award Numbers: N0001408WX20782 and N0001408WR20137

LONG-TERM GOAL

The long-term goal is to understand the physical processes that critically regulate the coupling between the oceanic and atmospheric boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.

OBJECTIVES

The objective of this research is to improve the surface flux and boundary layer turbulence parameterization in COAMPS™ for low- and high-wind events over the ocean in the context of air-sea interaction. Special emphasis will be placed on flux parameterizations in low-wind regimes in collaboration with the CBLAST **D**efense **R**esearch **I**nitiative (**C**oupled **B**oundary **L**ayer Layers/**A**ir-**S**ea **T**ransfer) community.

APPROACH

There are two complementary and strongly interacted components in our study: modeling and observational efforts. Our first approach is to use COAMPS® as a tool in understanding the physical processes and developing new parameterizations for the surface and boundary layer turbulence mixing. We provide real-time COAMPS weather forecasts for each intensive observational period of the CBLAST-Low field experiments, and therefore establish a focused model dataset, which can be used, with the measurements, to evaluate the model physics and investigate the impacts of the interaction on the mesoscale weather prediction. We also use various single column versions of COAMPS and experiment data to study the detailed turbulence processes, and develop new parameterizations. The second approach is the observational study that included measurements in the boundary layer and upper air at the CBLAST Nantucket site. These measurements are critical in the evaluation of the COAMPS forecast and development of the new parameterizations. They also provide a valuable data source for the process study of the air-sea interaction in that area.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Improving Surface Flux Parameterizations In The NRL Coupled Ocean/Atmosphere Mesoscale Prediction System**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The long-term goal is to understand the physical processes that critically regulate the coupling between the oceanic and atmospheric boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

1. Explore impact of sea spray evaporative cooling on hurricane intensity in COAMPS (Collaborate with Yi Jin of NRL)

One of important issues in spray parameterization is how much evaporative cooling actually occurs in the atmosphere. This question arises from the consideration that the initially cooled large drops re-enter oceans without being sufficiently evaporated. Andreas and Emanuel (2001) argued that the re-entry process would significantly increase the entropy flux. Bao et al (2000) showed that their coupled model simulated hurricane is indeed sensitive to the partitioning of the evaporative cooling. In this work, we evaluated COAMPS hurricane intensity to different partitioning method. Parameter α is used to represent the fraction of evaporation that occurs in the atmosphere. Donelan's z_0 formulation and Fairall's sea spray parameterization are used. We used COAMPS to simulate Hurricane Isabel (2003), and have found relatively strong sensitivity to the parameter α.

2. Observational and modeling study of strong SST variability

High, small-scale, SST variability (6^oC over 5-10 km) observed South of Martha's Vineyard during the low-wind component of the Coupled Boundary Layers Air-Sea Transfer (CBLAST-Low) oceanographic field program in August 2003 is investigated using the Navy Coastal Ocean Model (NCOM) with atmospheric forcing provided by the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®*). The ocean model includes tidal boundary forcing by the eight major tidal constituents, which is superimposed on the non-tidal lateral boundary conditions obtained from the 1/8° global NCOM real-time nowcast/forecast. The simulation is conducted with a high-resolution, 200-m grid, with bathymetry from the NGDC 3-arc-second Coastal Relief Model. The COAMPS fields, tidal forcing and NCOM results are evaluated with the CBLAST-Low observations.

3. Analyses of low-level jet and boundary layer structure from CBLAST Nantucket measurements

While many researches have studied the formation and properties of low-level jets, only a few have focused on low-level jet over the marine atmospheric boundary layer, which was observed during the 2003 CBLAST campaign on Nantucket Island, MA. Using measurements from onshore wind sectors, we identified persistent low-level jets at the top of the marine boundary layer for many days. Measurements from these days from a suite of instruments were analyzed, including those from rawinsonde launches, acoustic radar, and the 20 m flux tower. The objective of the analyses is to characterize the development and evolution of marine boundary layer low-level jets and identify their effects on the vertical turbulent structure of the lower boundary layer. COAMPS-LES was also used to help interpret the observed turbulent structure in relation to the low-level jet.

RESULTS

1. Effects of evaporative cooling of sea spray

When the sea spray parameterization is not included and the Charnock formulation is used for the roughness, the storm is weak compared with observed minimum sea level pressure and maximum wind speed. Implementing Donelan's z_0 formulation and sea spray clearly enhances the hurricane intensity. When all the evaporative cooling (α=1) is included, the C_k/C_D ratio is well above 0.7, a theoretical threshold value for development of hurricanes. This value is lower than that derived from the simulation with α being 0.2, because the enthalpy flux is enhanced due to less evaporative cooling in the surface layer. The minimum pressure in the 20% evaporation case is about 18mb lower than that from the full evaporation case; the wind speed is about 9 m/s stronger. The simulation with 20% evaporative cooling produces a significantly stronger storm than that with the full cooling. This clearly demonstrates the importance of correct treatment of the evaporative cooling in sea spray parameterization.

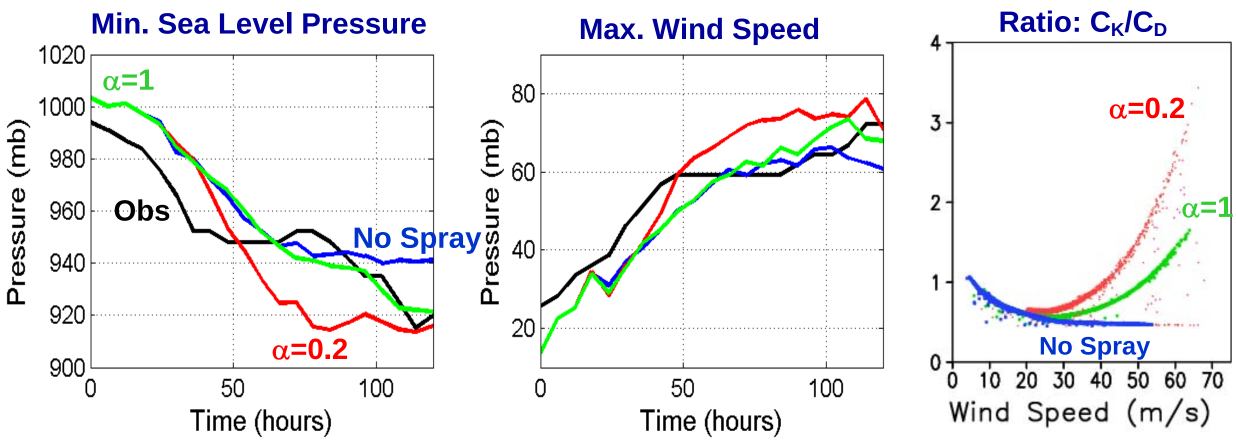

Figure 1. Simulation of Hurricane Isabel (2003) with different sea spray evaporative cooling coefficient. Black line denotes observation; the blue no spray case; the green full evaporative cooling; and the red the 20% evaporative cooling. Left: minimum sea level pressure; Center: maximum wind speed; Right: ratio of enthalpy transfer coefficient to drag coefficient.

2. Study of SST variability

The NCOM results display sustained strong stratification south of Martha's Vineyard during August except during cooling events from August 17 to 18 and from August 24 to 25. High SST variability occurs on August 18 and 25 due to the cold water that appeared in the warm and stratified water (Figure 2).

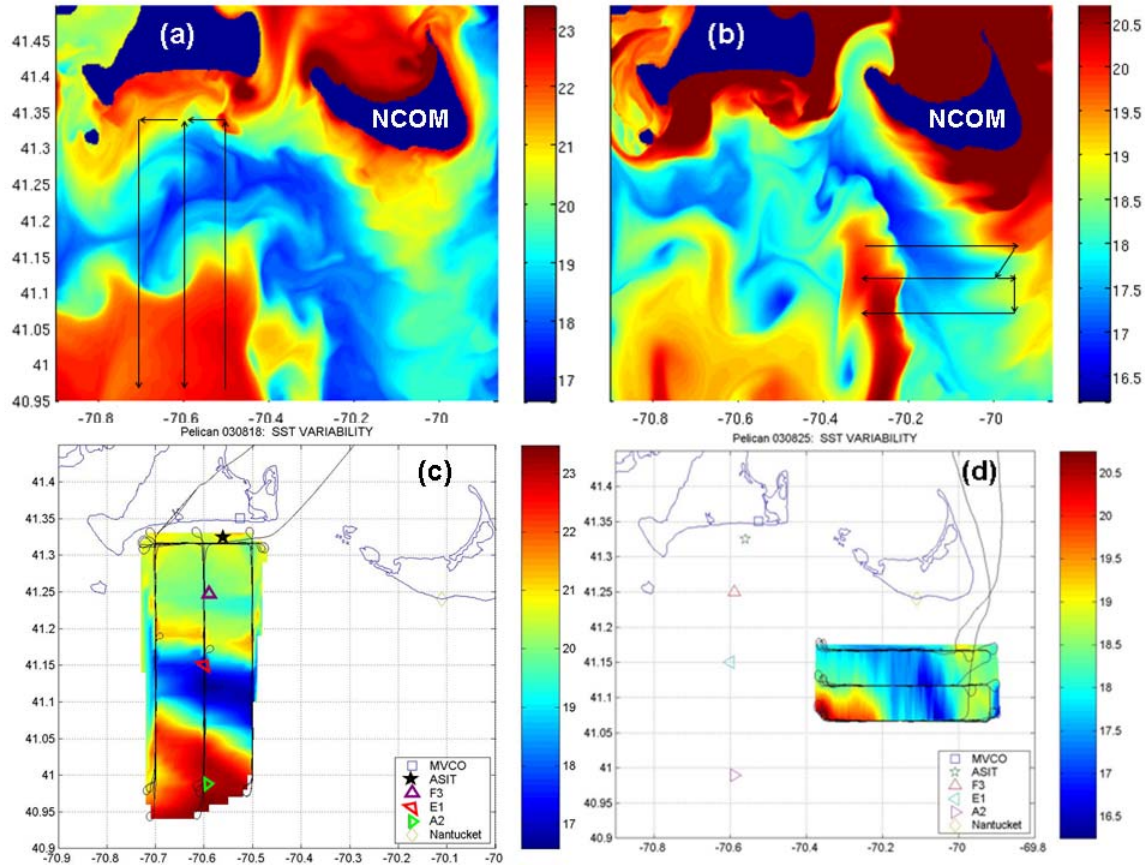

Figure 2. NCOM simulated SST variability on August (a) 18, and (b) 25 and observation as measured by the CIRPAS Pelican aircraft IR pyrometer in CBLAST-Low on (c) August 18, and (d) August 25, 2003.

The NCOM simulation suggests that the high SST variability observed on August 18 is strongly related to the surface winds and heat fluxes (Figure 3a). Gap-type northeast winds accelerate through Muskeget Channel and generate a heat loss that spreads over a larger area to the southwest. The northeast winds expedite the westward advection of cold water originating from the cold water on the east flank of Nantucket Shoals and form a narrow tongue of cool water. The heat loss further induces vertical mixing and upwelling along the cool tongue and enhances the local decrease of the SST.

The cooling event on August 24 to 25 is due to somewhat different processes. The local winds, which are northwest (Figure 2b), show no major effect on the cooling of the local SST since the horizontal transport induced by these winds is eastward, moving warmer water into the area south of Martha's Vineyard and reducing the cooling of the surface layer. The cooling occurs over a broad area corresponding to extent of the surface heat flux and is more related to vertical mixing induced by surface cooling. Even though stronger winds and greater heat loss occur, the surface waters are less dense, indicating weaker response to the surface cooling on August 25 than on August 18.

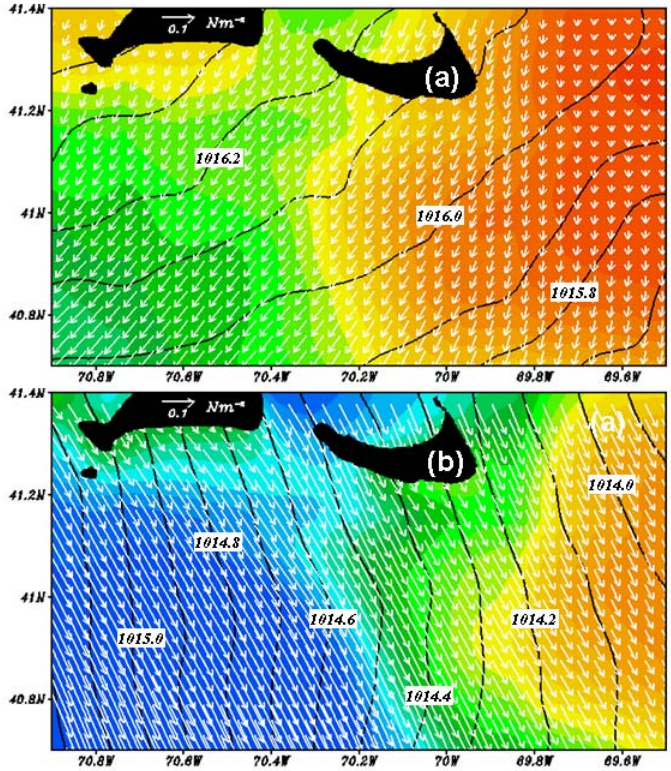

Figure 3. Daily mean surface heat flux (W m^{-2}, color contours), sea-level pressure (mb, black contour lines) and wind stress (N m^{-2}, white vectors) from the COAMPS forecast are plotted for (a) August 18, and (b) August 24.

This study reveals the complex processes causing the high SST variability south of Martha's Vineyard. The processes include tidal currents, tidal and wind-driven advection, air-sea fluxes, vertical mixing, and upwelling. Strong tidal currents generate a perpetual cool pool on the east flank of Nantucket Shoals by vertical mixing. This cold water is advected westward by the tidal residual flow. Surface winds can either accelerate (on August 18) or decelerate (on August 25) this transport, depending on the wind direction and can also generate upwelling (on August 18) when the local stratification is weak. In addition, vertical mixing induced cooling can be caused by the ocean surface heat loss to the atmosphere as occurred on August 18.

3. Low-level jet and boundary layer turbulence

We found three major results from this study. 1) The generation of the LLJ is the result of frictional decoupling due to the strong stability of the lower part of the marine ABL and the subsequent inertial oscillation. Our observations revealed that prior to the development of the LLJ, a high dynamically stable surface layer (see Fig. 4c below, high Richardson number) associated with increased static stability (Fig. 4b) was capable to suppress the turbulence and provide a favorable environment for the emergence of frictional decoupling.

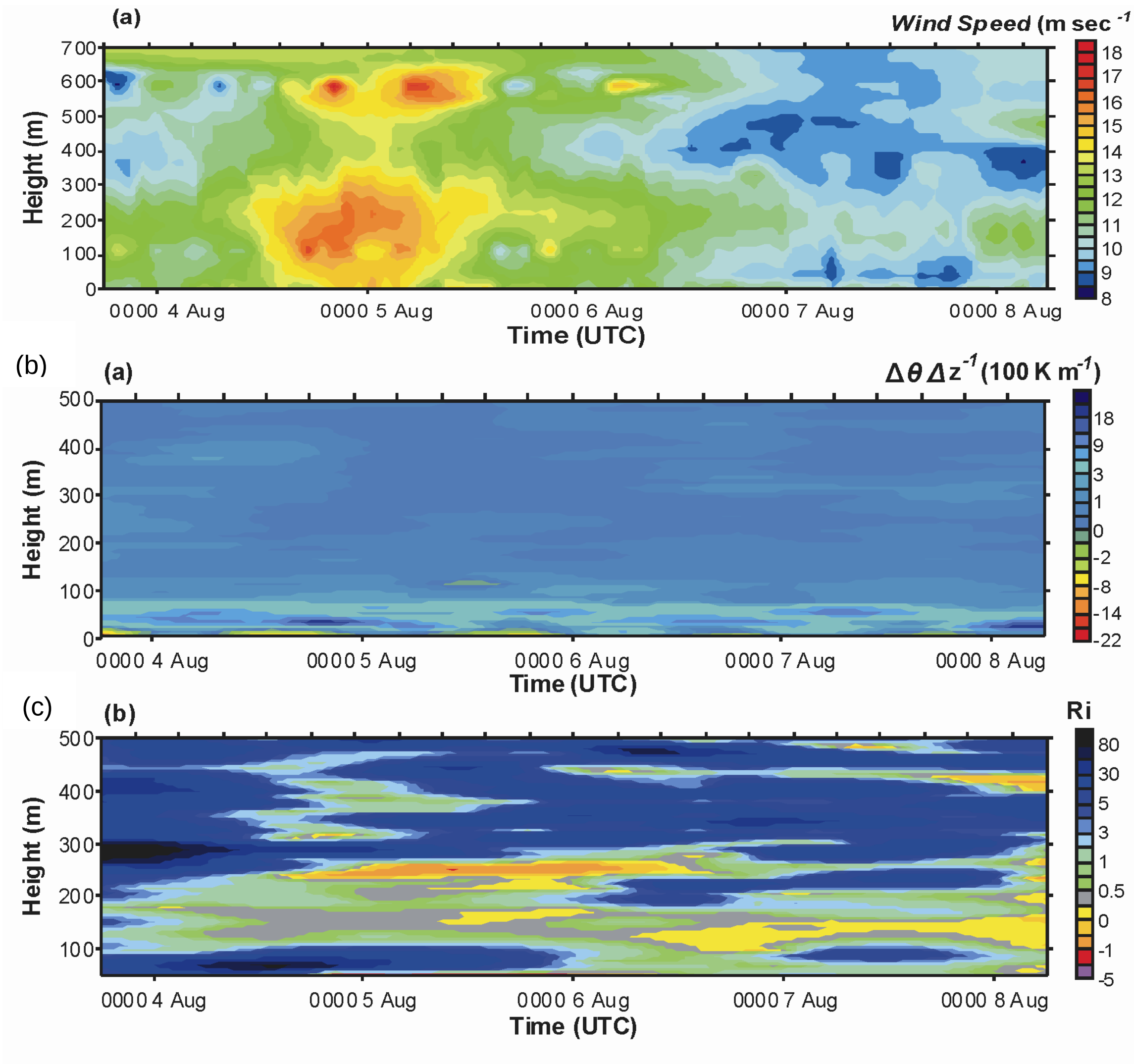

Figure 4. The time-height cross sections from 1800 UTC August 3 to 0600 UTC August 8, 2003. (a) The horizontal wind speed from SODAR measurements; (b) Static and (c) dynamic stability calculated from 18 successive radiosonde launches.

The increase in depth and intensity of the not turbulent stable surface layer decoupled the higher layers from the effect of surface drag leading to the LLJ development. 2) Above and below the LLJ core, turbulent layers were formed indicating strong mixing due to the intense wind shear. The LLJ was preserved until the destruction of the non-turbulent surface stable layer from turbulence events generated by the increased wind shear above the surface. 3) The application of the COAMPS-LES model revealed the modification of the characteristics of the vertical turbulent structure of the MABL due to the developed LLJ. The LLJ strengthens the momentum flux in the stable marine boundary layer so that the stress maxima are not at the surface but rather well above. The jet core separates a positive momentum flux maximum above and the negative one below and may produce a maximum TKE just below the jet core level due to the maximum shear production of the turbulence at this layer.

IMPACT/APPLICATIONS

The turbulent momentum, heat, moisture exchange between ocean and atmosphere at their interface represents the most important interaction between these two fluids. Correct modeling of these transfer coefficients is essential for mesoscale model prediction capability. Current studies have improved the surface flux parameterization in COAMPS at both high- and low-wind conditions. The continued research on this issue will significantly enhance COAMPS prediction capability for both atmosphere and oceans.

TRANSITIONS

The new parameterization of the heat and moisture transfer coefficients under high winds developed in connection with this project will be transitioned to 6.4 projects within PE 0603207N (SPAWAR, PMW-180).

RELATED PROJECTS

Related projects are 6.2 Next Generation COAMPS and 6.2 Coupled TC.

REFERENCES

Andreas, E. L. and K. Emanuel, 2001: Effects of Sea Spray on Tropical Cyclone Intensity. *J. Atmos. Sci.*, **58**, 3741-3751.

Bao, J.-W., J. M. Wilczak, J.-K. Choi, and L. H. Kantha, 2000: Numerical simulations of air–sea interaction under high wind conditions using a coupled model: A study of hurricane development. *Mon. Wea. Rev.*, **128,** 2190–2210.

PUBLICATIONS

Vickers, D., L. Mahrt, and S. Wang, 2008: Sea-surface roughness lengths in the mid-latitude Atlantic coastal zone Submitted to *Geophy. Res. Letter*.

Helmis, C.G., Q. Wang, G. Sgouros, S. Wang, and Ch. Halios, 2008: Inertial Oscillation and vertical turbulent structure of the marine atmospheric boundary layer under the development of a LLJ,. Submitted to *J. Atmos. Sci*.