Year one annual report

Evaluation And Improvement Of Spray-Modified Air-Sea Enthalpy And Momentum Flux Parameterizations For Operational Hurricane Prediction

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1. Results from the Research of Previous Year

During the first year of this project, a bulk parameterization scheme of air-sea sensible and latent heat fluxes developed at NOAA/ESRL was implemented, tested and evaluated in the newly developed hurricane WRF-NMM (HWRF) model. This scheme was developed as an extension of the TOGA-COARE bulk flux model (Fairall et al. 1994), and was refined with observations from new field campaigns (such as the CBLAST experiment) and updated theoretical understanding (Fairall et al. 2008). The objectives of the project for the first year were accomplished with great help from Dr. Naomi Surgi's group at NCEP of NOAA/NWS. The NOAA/ESRL team visited NCEP in July 2007 to coordinate with Naomi Surgi's group. Collaborative effort was also started with Dr. Isaac Ginis' group at the University of Rhode Island to further the physical understanding of the impact of the spray-mediated thermal and momentum fluxes on the marine atmospheric boundary layer dynamics. In addition to the implementation and testing of the sea-spray parameterization scheme in the HWRF model, the explicit sea-spray model of Kepert et al. (1999) coupled with the 1-D Mellor-Yamada turbulence mixing model was also used to investigate the thermal and kinematic feedback effects. This explicit spray model is capable of simulating the evaporation and dispersion of saline water droplets of various sizes. There is full coupling among the spray-droplet microphysics, turbulence mixing, and droplet transport. Results from the investigation using the explicit sea spray model revealed important characteristics of the way in which evaporating droplets of various sizes modify the turbulence mixing near the surface, which in turn affects further droplet evaporation. Based on these results, a parameterization for accounting the kinematic effect of sea spray in the surface thermal and momentum fluxes has been developed.

All the preliminary results from the testing of the sea-spray parameterization scheme can be found in the mid-year report that was submitted to JHT at the end of 2007. A copy of the report can be downloaded from http://www.etl.noaa.gov/~jbao/ESRL-JHT-07-Mid-Year-Report.pdf. The following is the summary of the results that are not included in the above report and related to our work on the parameterization of the effects of sea spray on the surface momentum flux.

The parameterization of the effects of sea spray on the surface momentum flux is motivated by the notion that the same turbulence that transports heat across the air-sea interface is also responsible for the momentum transport and the generation of sea spray. Progress has been made over the past year in using the explicit sea-spray model to understand and parameterize the effects of sea spray on the momentum flux across the air-sea interface. These effects were recognized as significant under high winds in previous studies (see, e.g., Pielke and Lee 1991 and Andreas 2004). The explicit sea-spray model of Kepert et al. (1999), due to its original intention to examine the thermal feedback of sea spray, did not include the effects of sea spray on the surface momentum flux. In order to use the same model to investigate the kinematic feedback of sea spray to the momentum flux, an additional term has been included in the turbulence kinetic energy (TKE) equation to take into account the TKE dissipation due to sea-spray load. Figure 1 compares the differences in the simulated vertical TKE profiles between the runs with and without sea spray that are driven by hurricane winds. The model output is valid at 20 h into

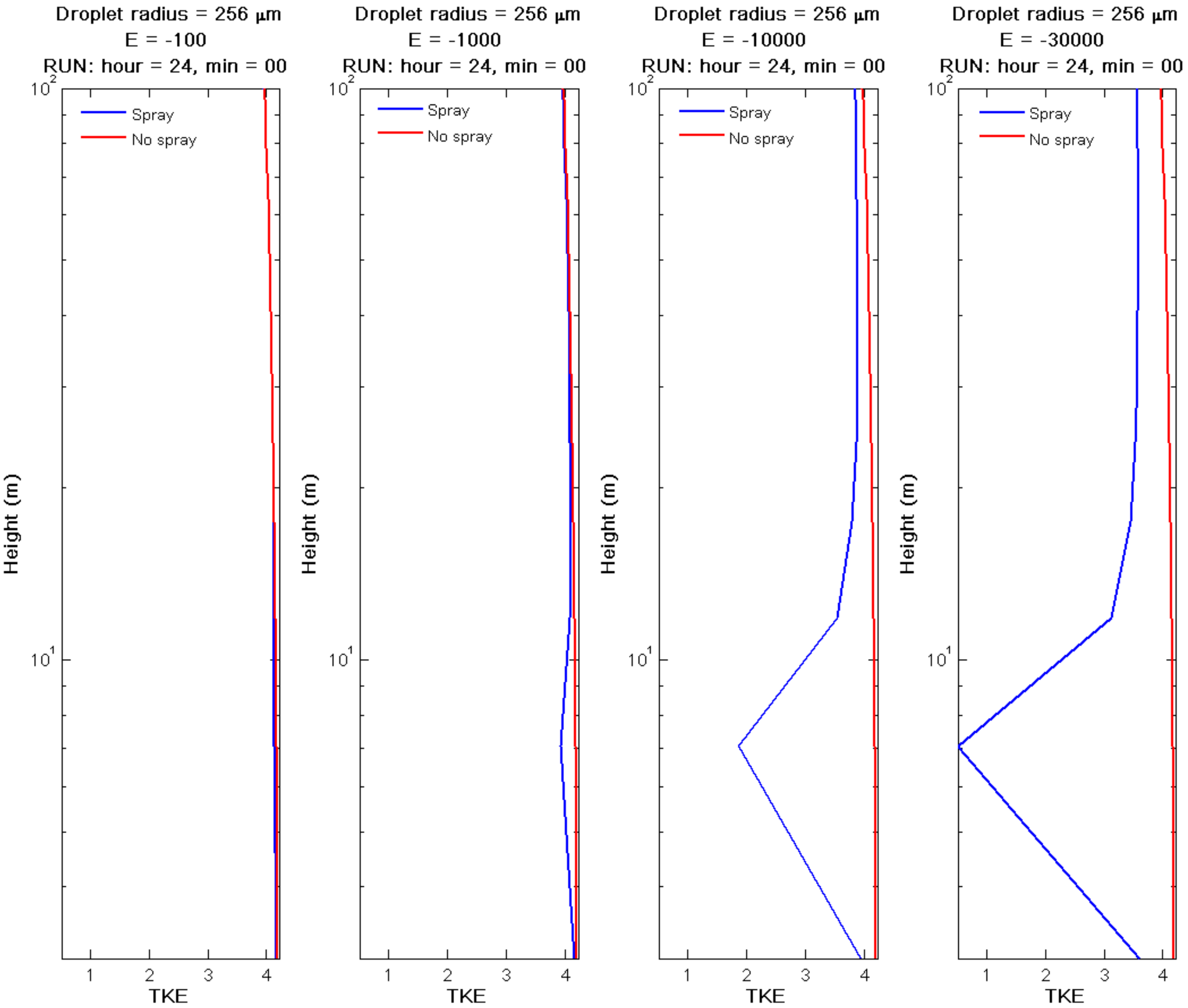

Figure 1: The change of vertical TKE distribution as the total spray mass of large spray droplets (r = 256 μm) increases. The total mass production of the droplets is indicated by the magnitude of E (in watt unit), which equals to the total mass multiplied by the latent heat.

the simulation when the solution becomes quasi-steady. It is seen that as the total mass of large spray droplets (r = 256 μm) increases, the TKE within the lowest 100 m decreases with the minimum at the spray ejection level (~7 m).

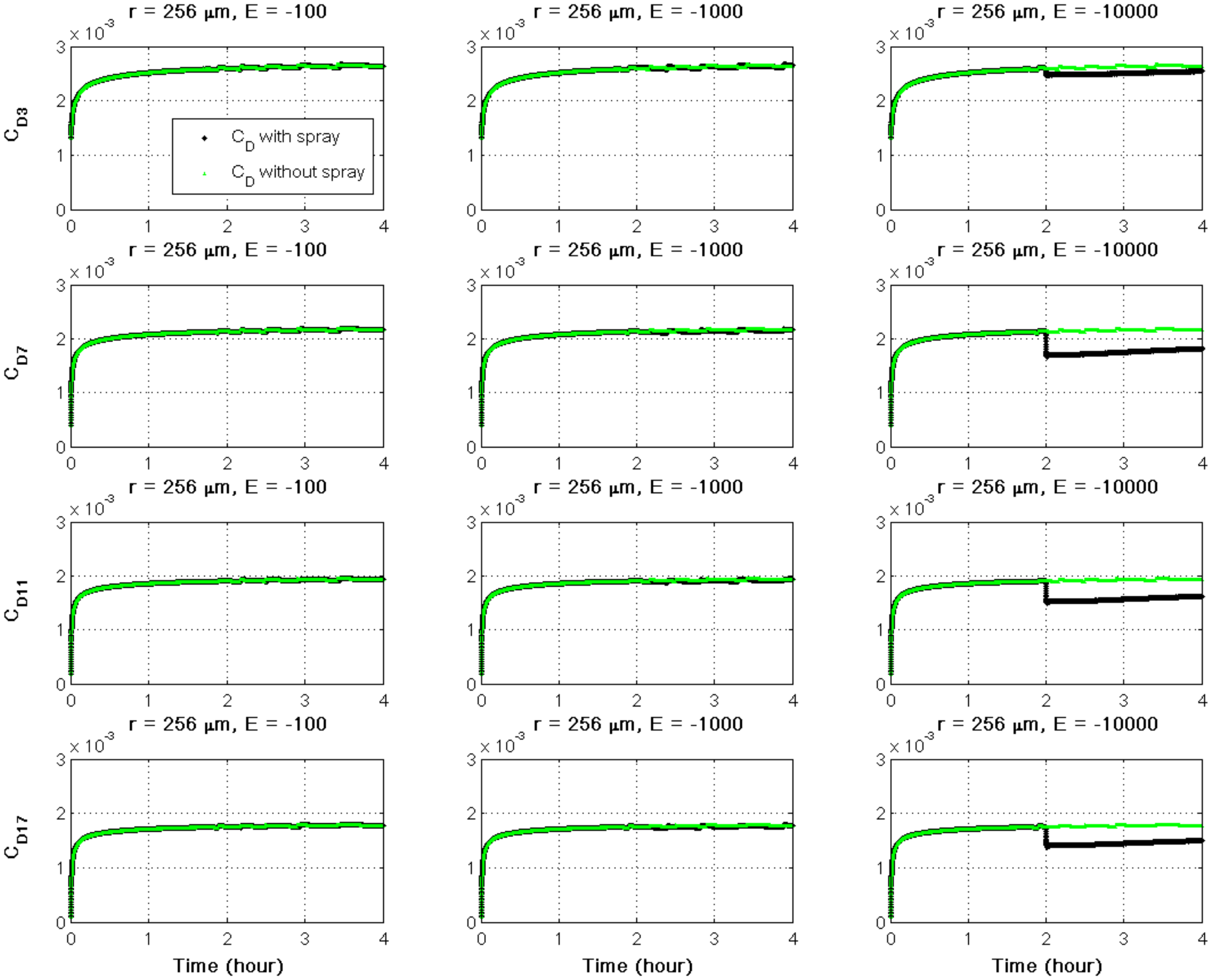

Figure 2: The drag coefficients at 3 m (1st row), 7 m (2nd row), 11 m (3rd row) and 17 m (4th row) above the surface, corresponding to the run without sea spray (black) and the runs with various total mass of large droplets (r = 256 μm) large spray droplets (green): |E| = 100 W, 1000 W, 10000W. The spray generation takes place at z = 7 m, and does not start until 2 h into the simulation. The total mass production of the droplets is indicated by the magnitude of E (in watt unit), which equals to the total mass multiplied by the latent heat.

Changes in the drag coefficient at z = 3 m, 7 m, 11 m and 17 m corresponding the changes in the TKE profile are shown in Fig, 2 for |E| = 100 W, 1000 W, 10000 W. Since the spray droplets are ejected into the air at z = 7 m starting at 2 h into the simulation, the results shown in Fig. 2 indicate that the net effects of large spray droplets on the spray-filled surface layer are to decrease the drag coefficient and thus to accelerate the flow within the surface layer. This is no surprise because (1) the free fall of spray suppresses turbulence and (2) the spray mass increases the effective density of the air, leading to more stable stratification within the surface layer. Consequently, the vertical momentum transport by turbulence is reduced in the surface layer by sea spray.

To parameterize the kinematic effects of spray in operational models where the spray-filled surface layer is not resolved, one must appeal to the first principles of the Monin-Obukhov similarity theory. Basically our parameterization scheme takes into account the kinematic effects of spray in the friction velocity calculation. Following the procedure summarized in Lykossov (2001), the application of the steady TKE and spray-droplet transport equations in the spray-filled surface layer leads to the similarity formulation for the friction velocity, in which the kinematic effects of sea spray are described by an additional logarithmic term in the mean wind profile. It is assumed in the derivation of the formulation that the thermal stratification is neutral, and droplets are ejected at z = 10 m above the mean surface. Figure 3 presents that spray- modified drag coefficient and heat exchange coefficient at z = 25 m above the mean sea surface (regarded as the lowest model level). The results shown in Fig. 3 are consistent with the results shown in Figs. 1 and 2: under the same background mean conditions the flow in the surface layer accelerates by the consumption of TKE for spray suspension. In other words, the suspended spray droplets decrease the turbulent drag. The variation of the drag coefficient with wind speed agrees well qualitatively with those revealed by Andreas (2004) and Kudryavtsev (2006).

The implementation and testing of the parameterization scheme in the HWRF model requires taking into account the thermal stratification as expressed in the Monin-Obukhov stability parameters. Figure 4 compares the best track estimate of the maximum wind speed and the minimum sea level pressure of Hurricane Katrina (2005) with those from 4 HWRF model forecast runs. The four HWRF runs shown in Fig. 4 include**:** one run with sea spray, two runs including only the thermal effects of sea spray with different values of source strength parameter (ss =1 and 10)**,** and one run including both the thermal and kinematic effects of sea spray with the source strength parameter of 1. The impact of the kinematic effects on the forecasted track is negligible.

It should be noted that although the qualitative explanation of the kinematic effects of spray is based on the physics of turbulence in the spray-filled surface layer, the quantitative aspect of our parameterization requires further evaluation. Particularly, the relationship between the wave-induced drag on the spray-modified drag should be investigated.

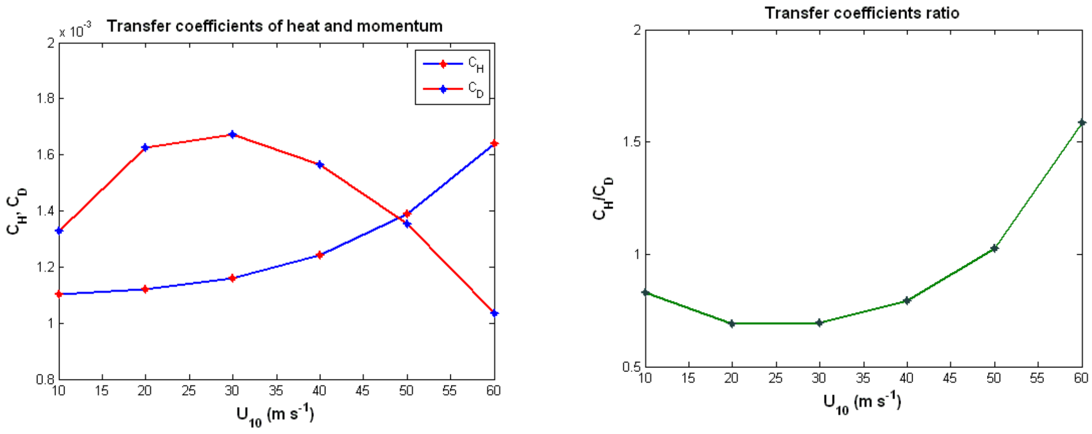

Figure 3: The left panel shows the drag coefficient (C_D) and the heat exchange coefficient (C_H) at z = 25 m above the mean sea surface. The right panel is the ratio of C_H / C_D. It is assumed that spray droplets are ejected at z = 10 m above the mean surface.

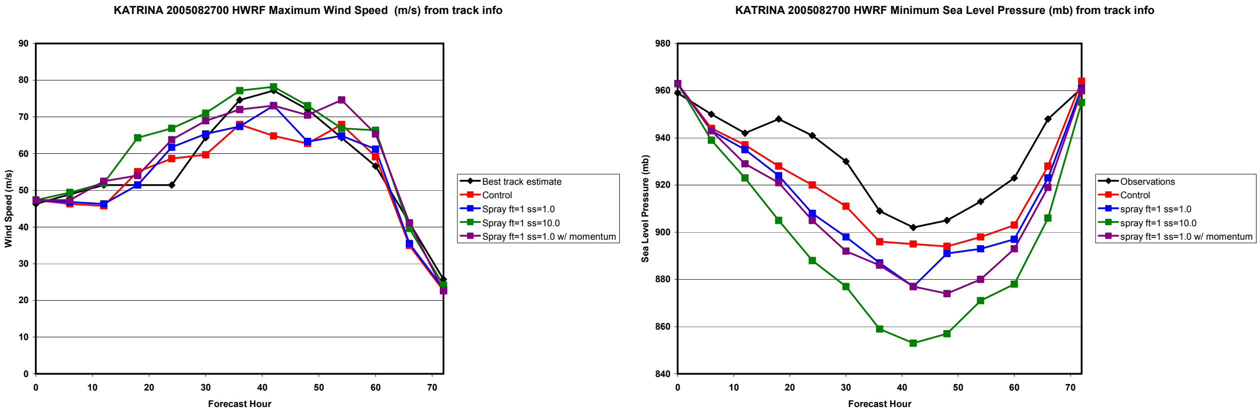

Figure 4: The maximum wind speed (left panel) and minimum sea level pressure (right panel) from the best track estimate (back) and four HWRF forecast runs of Hurricane Katrina (2005). The four HWRF model runs are: a run without sea spray (red) , two runs including only the thermal effects of seas spray with the source strength parameter of 1 (blue) and 10 (green) and one run including both the thermal and kinematic effects of seas pray with the source strength parameter of 1 (purple).

In summary, with the physical understanding of the kinematic effects of sea spray on the surface momentum flux, we have developed a parameterizations scheme for the HWRF model that includes both the kinematic and thermal effects of sea spray on the momentum and thermal fluxes. Preliminary results from running the HWRF model with the sea-spray scheme with both kinematic and thermal are a potentially promising option in operational modes to improve hurricane intensity forecasts.

2. Objectives of the Second-Year Research

Despite the success of our first-year research, our results are still inconclusive due the limited number of case studies. We propose to carry the research into the second year to further test and improve the current scheme. The proposed second-year work will be focused the following 2 tasks:

1. Evaluate and refine the parameterization of the kinematic effects of spray with the HWRF model through multiple case studies.

2. Finalize the NOAA/ESRL sea spray scheme in the HWRF model to include the Fairall-Banner parameterization for the sea spray droplet source term (which predicts the size spectrum of sea spray produced by the ocean in terms of wind speed, surface stress, and wave properties).

To accomplish these objectives, we will work closely with our NCEP colleagues to analyze the quantitative information obtained from running a significant number of case studies. We will iterate the evaluation procedure used in the aforementioned tasks to provide a working set of parameters used in the NOAA/ ESRL air-sea heat flux parameterization scheme.

3. Work Statement and Deliverables of the Second Year

* Further investigate the combined effects of the kinematic and thermodynamic feedbacks of sea spray on the air-sea fluxes using the 1-D explicit sea-spray model, and use the results from this investigation to refine the parameterization of the effects in the revised NOAA/ESRL scheme (delivery date: July 31, 2008).

* Evaluate and calibrate the revised NOAA/ESRL scheme with the parameterized momentum feedback in the coupled HWRF model, and perform enough number of case studies to evaluate its performance in the operational setup of the HWRF model (delivery date: November 30, 2008).

* Publish the results from the second-year work (delivery date: March 31, 2009).