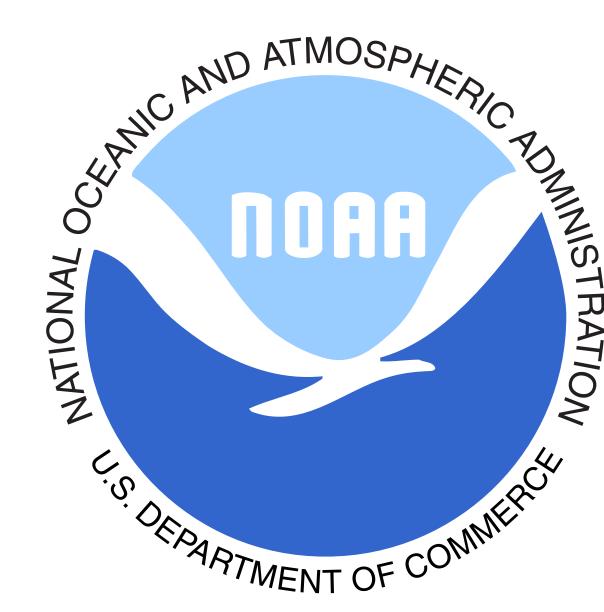


A Numerical Investigation of the Impact of Air-Sea Interaction on Hurricane Intensification

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Summary

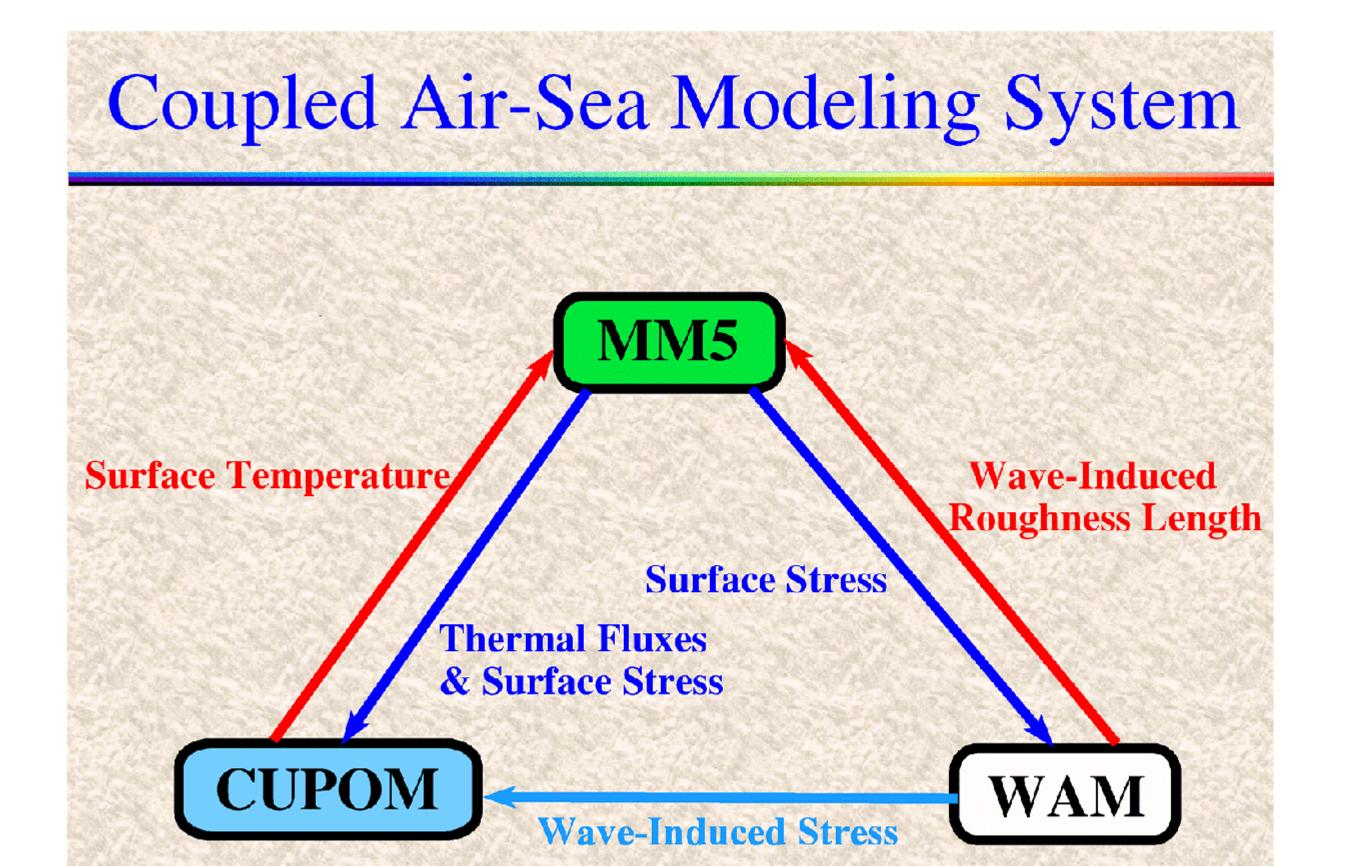
In this study, a coupled atmosphere-ocean-wave modeling system is used to simulate air-sea interaction under high wind conditions. This coupled modeling system is made of three well-tested model components: the Pennsylvania State University/National Center for Atmospheric Research regional atmospheric Mesoscale Model, the University of Colorado version of the Princeton Ocean Model, and the ocean-surface gravity wave model developed by the Wave Model Development and Implementation Group. The ocean model is initialized using a 9 month spin-up simulation forced by 6-hourly wind stresses and with assimilation of satellite sea surface temperature (SST) and altimetric data into the model. The wave model is initialized using a zero wave state. The scenario in which the study is carried out is the intensification of a simulated hurricane passing over the Gulf of Mexico. The atmospheric model is therefore initialized by incorporating a Rankine vortex into a real time analysis, with the center of the vortex at the center of an observed hurricane. The focus of the study is to evaluate the impact of sea spray, mixing in the upper ocean, warm-core oceanic eddies shed by the Gulf Loop Current, and the sea-surface wave field on hurricane development, especially the intensity.

The results from the experiments with and without sea-spray effect show that the inclusion of sea-spray evaporation can significantly increase hurricane

intensity in a coupled air-sea model when the part of the spray that evaporates is only a small fraction of the spray mass so that the heat required for spray evaporation ultimately comes from the ocean. When the fraction of sea spray that evaporates increases so that the evaporation cools the lower atmospheric boundary layer, the impact of sea-spray evaporation on the hurricane intensity decreases.

It is shown that the development of the simulated hurricane is strongly dependent on the location and size of the warm-core anticyclonic eddy shed by the Loop Current. This dependency is also a function of the moving speed of the simulated hurricane. The eddy affects the timing, rate, and duration of hurricane intensification. The feedback from the SST change in the wake of the simulated hurricane is negative in the sense that the reduction of SST results in a weaker simulated hurricane than that produced when SST is held unchanged during the simulation. The degree of surface cooling is strongly dependent on the initial oceanic mixed layer (OML) depth. It is also found in this study that in order to obtain a realistic thermodynamic state of the upper ocean and not distort the evolution of the OML structure during data assimilation, care must be taken in the data assimilation procedure to preserve the physics in the OML.

Compared with the sensitivity to the initial OML depth and the location and intensity of the warm eddy associated with the loop current, the model is found to be less sensitive to the wave-age-dependent roughness length.



Schematic diagram of parameter exchanges between MM5, WAM, and CUPOM when the coupling takes place.

of the warm eddy enclosed by the 15 kcal contour of

upper ocean heat content is modified.

Summary of numerical experiments

Fully coupled with sea spray; CUPOM was initialized with Eddy 2

Fully coupled without sea spray; CUPOM was initialized with Eddy 2

Fully coupled with sea spray; CUPOM was initialized with Eddy 3 and with prescribed 10 m OML

Fully coupled with sea spray; CUPOM was initialized with Eddy 3 and with prescribed 30 m OML

Fully coupled with sea spray; CUPOM was initialized with Eddy 3 and with prescribed 50 m OML

Fully coupled with sea spray; CUPOM was initialized with Eddy 1

Fully coupled with sea spray; CUPOM was initialized with Eddy 3

Fully coupled with sea spray; CUPOM was initialized with Eddy 2 but with modification of the water column of the warm eddy enclosed by the 15 kcal contour of upper ocean heat content

* MM5 and CUPOM coupled; CUPOM was initialized with Eddy 2



Yes, but only for the layer of 100-1000 m

WAVE HEIGHT/WAVE DIR

Yes for the entire upper 1000 m

Assimilation of

altimetry data

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5

Summary of CUPOM spin-up runs

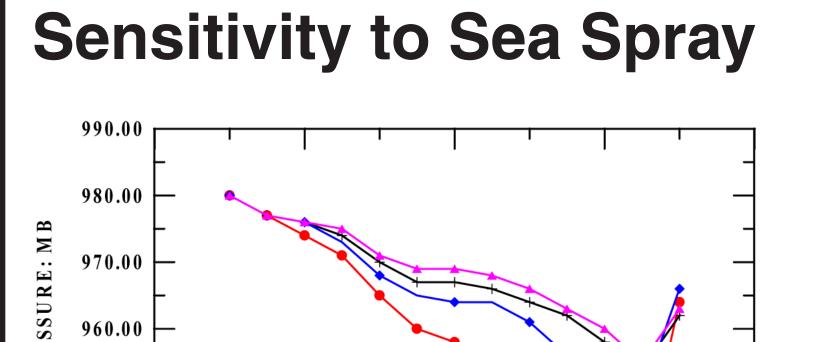
Eddy 1

Eddy 2

Eddy 3

Assimilation of

MCSST



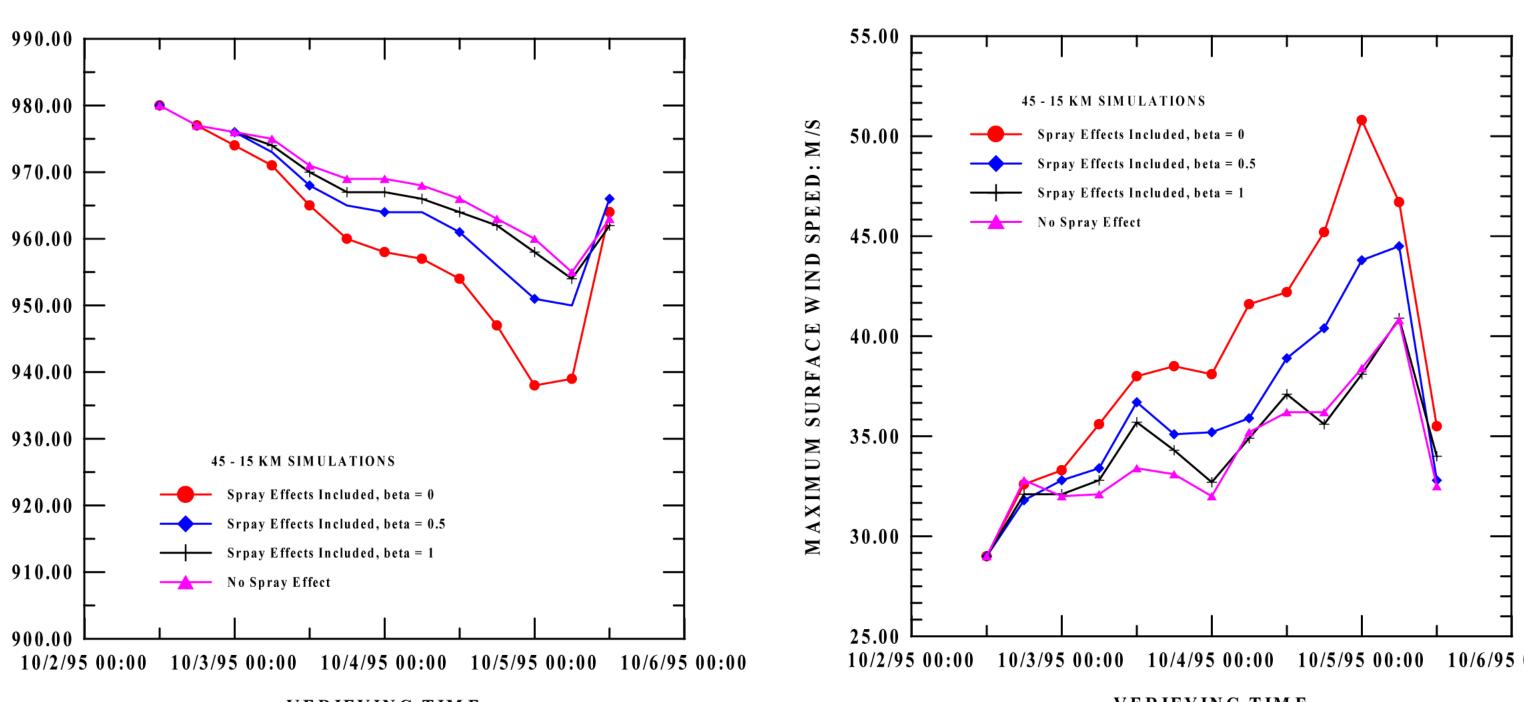
45 - 15 KM SIMULATIONS

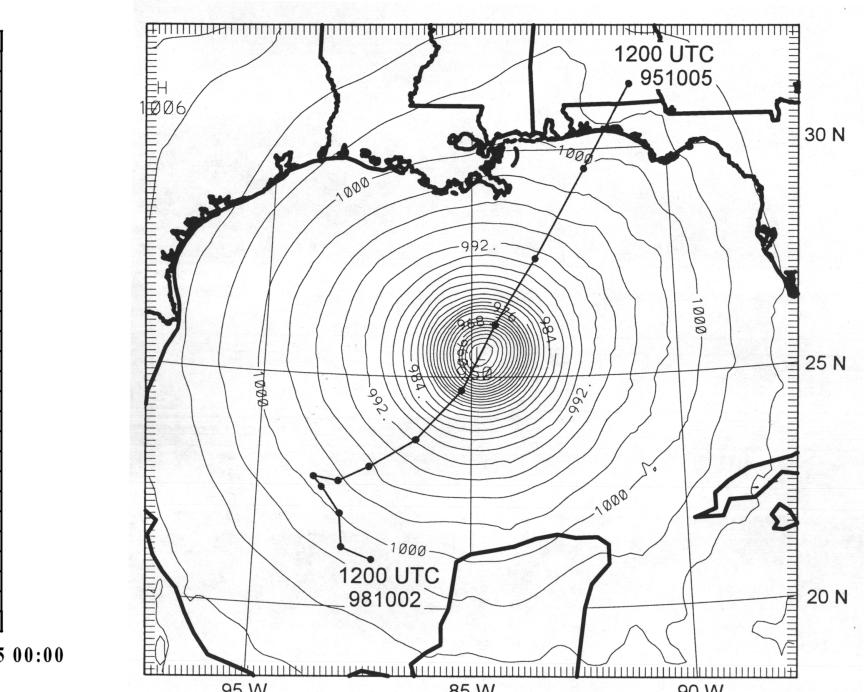
Spray Effects Included, beta = 0

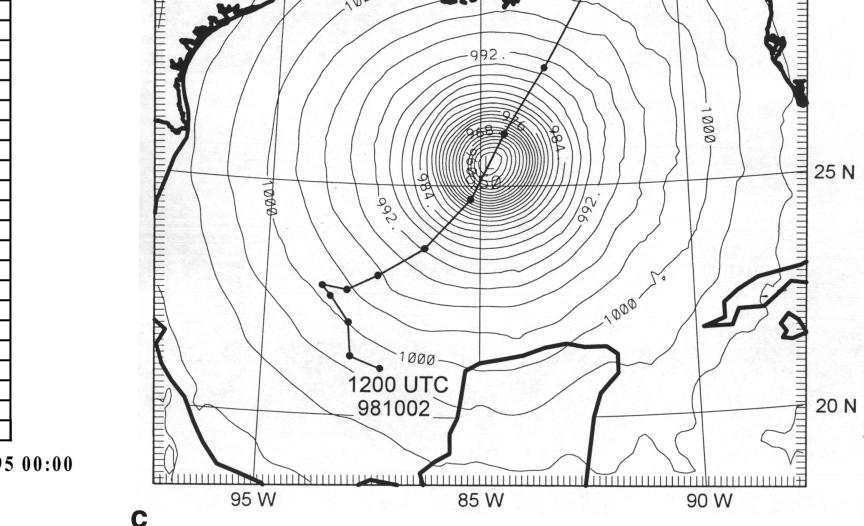
Srpay Effects Included, beta =

Srpay Effects Included, beta = 0.

VERIFYING TIME







Time series of (a) minimum sea level pressure (in hPa) and (b) maximum surface wind speed (in ms-1) sampled every 6 hours for the numerical experiments with (dot for $\beta = 0$, diamond for β = 0.5, and cross for β = 1) and without (triangle) sea-spray effect; (c) shows the track of the simulated hurricane along with sea level pressure at 51 hours into the simulation for the experiment with sea-spray effect and β = 0.

From Fairall et al. (1994), droplet-mediated evaporation and sensible fluxes, Q_l and $Q_{\rm S}$ are described by

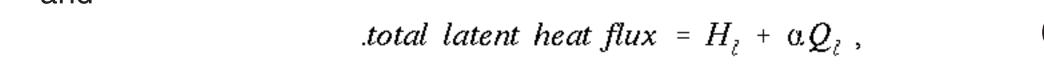
$$Q_{\ell} = 3.0 \times 10^{-6} u^{4.4} B(T_{\alpha}) H_{\ell}[q_{s}(T_{\alpha}) - q] / [q_{s}(T_{s}) - q] , \qquad (1)$$

$$Q_{s} = 2.7 \times 10^{-5} u^{2.4} H_{s} , \qquad (2)$$

where u is the 10-m wind speed (approximated by the wind speed at the lowest level of MM5). B is a parameter that is related to the fact that the sea spray droplets are at the wet bulb temperature (B varies from 0.59 at 273 K to 0.21 at 303 K), q the specific humidity, q_s the saturation specific humidity, H_l the turbulent-latent heat flux, H_s the turbulent-sensible heat flux, and $Q_{l} = Q_{l1} + Q_{l2}$ is the total latent heat flux generated by droplet evaporation. We note that Q_s and Q_l are the droplet mediated fluxes that would occur if the sea spray does not alter the normal logarithmic profile of mean q and T in the droplet evaporation zone. Fairall et al (1994) argue that (1) and (2) represent upper limits, and that the actual spray dependent fluxes will be reduced by a factor a due to the fact that mean profiles of g and T in the droplet zone do not remain logarithmic, but are modified by the presence of the spray. Based on Andreas (1998) re-analysis of his 1992 results, (1) and (2) are a factor of two smaller than as given by Fairall et al. (1994) (Fairall, personal communication).

Since sea spray droplets evaporate at the expense of the sensible heat that they carry, and the sensible heat available in the surrounding air, the flux boundary conditions at the air-sea interface become

total sensible heat flux = $H_s + \alpha Q_s - \alpha \beta Q_l$



where, α is the profile-change feedback parameter, and β is the evaporation partitioning parameter. Equations (3) and (4) are the same as given by Fairall etl al. (1994), except for the inclusion of β , which is described below. Because the sea spray parameterization is derived from data with wind speed less than 30 m s-1 Fairall et al. (1994) suggest that an upper bound of 30 m s-1 should be used in numerical model simulations of weather and climate.

In this study, a simple ad hoc parameterization for α (see Kepert et al. 1998) is

$$\alpha = \frac{H_{tot}}{(H_{tot} + Q_{tot})},$$

where $H_{tot} = H_S + H_I$ and $Q_{tot} = Q_S + Q_I$. The profile-change feedback parameter thus defined varies from 0 to 1. It limits the total production of water vapor from sea spray, reflecting the feedback effect of sea spray to reduce the evaporation. The evaporation partitioning parameter β is defined as the ratio

$$\beta = \frac{Q_{i2}}{Q_{i1} + Q_{i2}}$$

For the range of wind speeds and droplet sizes considered by Fairall et al. (1994) it is assumed that $Q_{1/2} >> Q_{1/1}$, and $\beta = 1$. However, for extremely high wind speeds, the droplet size may be so large that they fall back to the ocean before further evaporation can extract heat from the atmosphere, in which case Q_{12} and β approach zero.

