Impact of Precipitation on the Tropical Cyclone Induced Upper Ocean Cooling in the Couple Atmosphere-Ocean System

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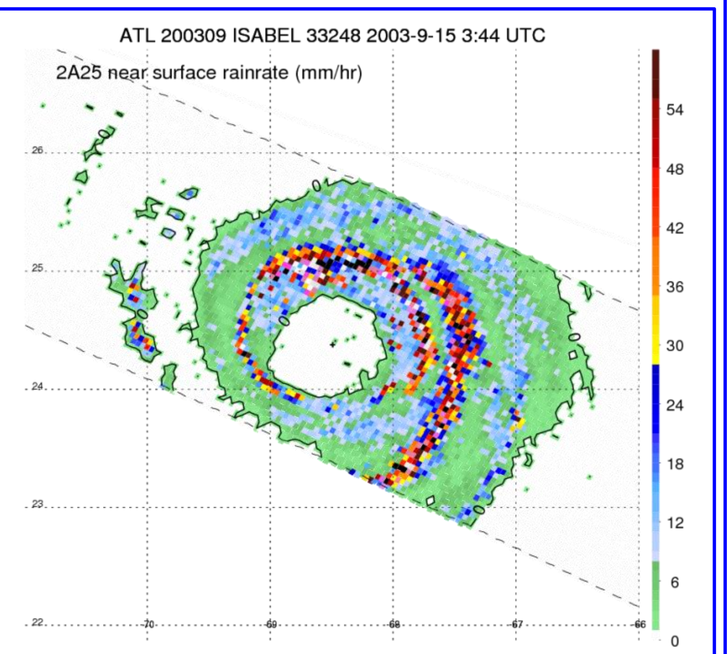
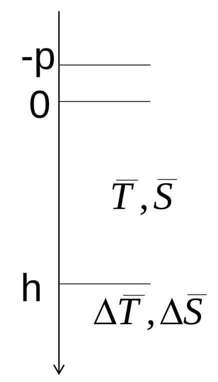
Motivation

Hurricanes are capable of producing extremely heavy rainfall. But the impact of precipitation on the air-sea interaction occurring under the storm is not well understood and the effect has not been included in the coupled state-of-the-art numerical models. This study investigates how to incorporate the precipitation effects in in the atmosphere-ocean coupling and its impact on the storm-induced upper ocean cooling in a coupled modeling system.



Methodology

In current coupling, an atmospheric model is coupled to an ocean model via surface fluxes, which are commonly determined by the bulk transfer model $QFX = \overline{w'q'}_s = C_q \bar{u}(q_a - q_s)$, $HFX = \overline{w'\theta'}_s = C_\theta \bar{u}(\theta_a - \theta_s)$. The precipitation effect is not considered. In this study, we developed a method to include the precipitation in the coupling based on an ocean mixed layer (ML) model.



The budget equations of temperature and salinity may be written as,

$$\frac{\partial \bar{T}}{\partial t} = \frac{\delta T_r \frac{\partial p}{\partial t}}{h+p} + \frac{(\overline{w't'})_{-p}}{h+p} - \frac{(\overline{w't'})_h}{h+p}; \qquad \frac{\partial \bar{s}}{\partial t} = -\frac{\bar{s}\frac{\partial p}{\partial t}}{h+p} + \frac{(\overline{w's'})_{-p}}{h+p} - \frac{(\overline{w's'})_h}{h+p};$$

$$s(-p,t) = 0; \qquad (\overline{w's'})_{-p} = \bar{s}Q = \bar{s}C_q \bar{u}(q_a - q_s); \qquad (\overline{w's'})_h = -W_e \Delta s;$$

$$\delta T_r = T(-p,t) - \bar{T}; \qquad (\overline{w't'})_{-p} = H = C_\theta \bar{u}(\theta_a - \theta_s) + R_s^{\downarrow} + R_l^{\downarrow} \qquad (\overline{w't'})_h = -W_e \Delta T;$$

where p is the precipitation, h is the ML depth, and Δ is the jump across the bottom of ML.

Entrainment rate W_e is parameterized using the budget equations derived by Jourdian et al. (2013) from a linear model,

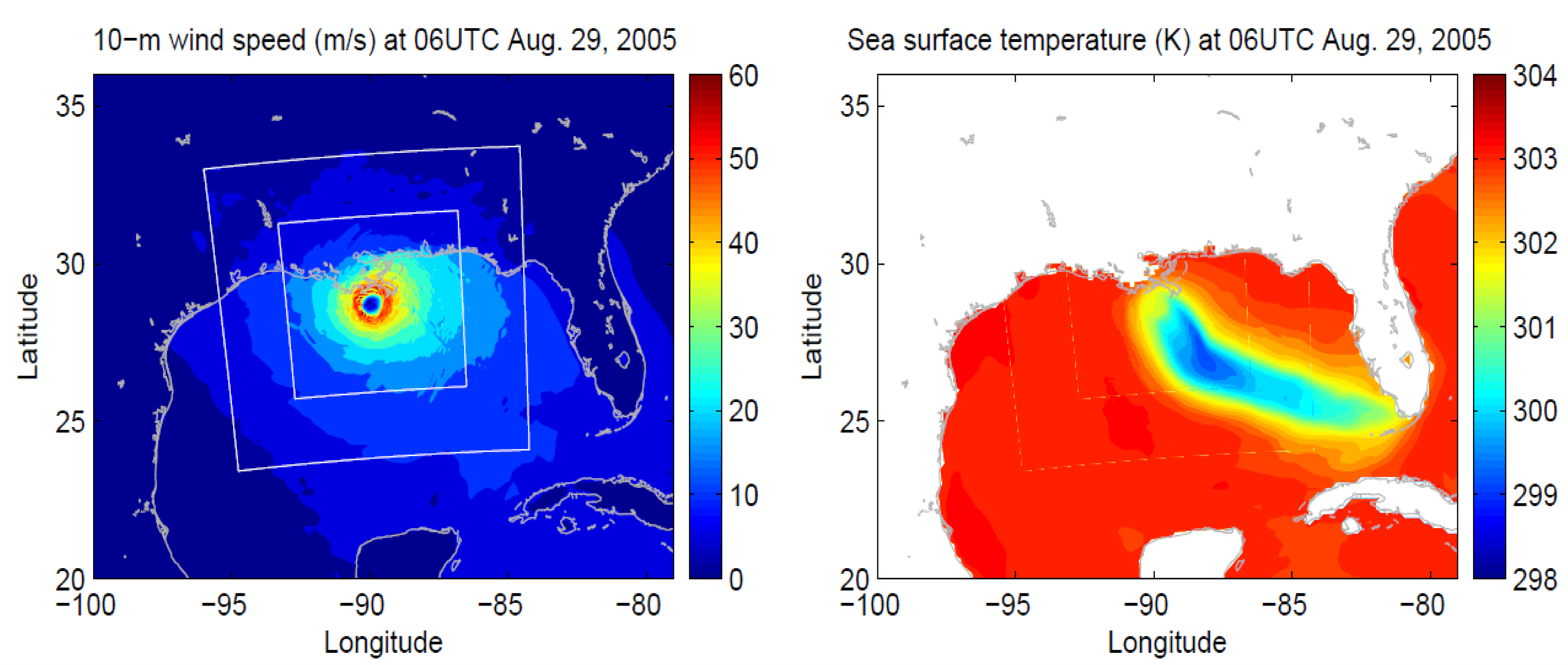
$$\Delta SST(h+p) + \delta T_r p + \frac{a}{2}h^2 = 0;$$

$$\frac{\Delta E_p}{\rho_0 g} = -\frac{2}{3}\tilde{N}^2\left(\frac{\Delta SST}{a}\right)^3 - \left(\frac{b}{a}\delta T_r + S_i^0\right)\beta p \frac{\Delta SST}{a}; \quad \xrightarrow{\text{Without precipitation}} \quad \frac{\Delta E_p}{\rho_0 g} = \frac{\tilde{N}^2}{12}h_0^3;$$

$$W_e = \frac{\partial h_m}{\partial t} = \frac{1}{A}\frac{\partial h_{m0}}{\partial t} + \frac{B}{A}\frac{\partial p}{\partial t} = \frac{1}{A}W_{e0} + \frac{B}{A}\frac{\partial p}{\partial t}; \qquad \frac{W_{e0}}{\Delta V} = f(R_v); \quad R_v \text{: Bulk Richardson Number}$$

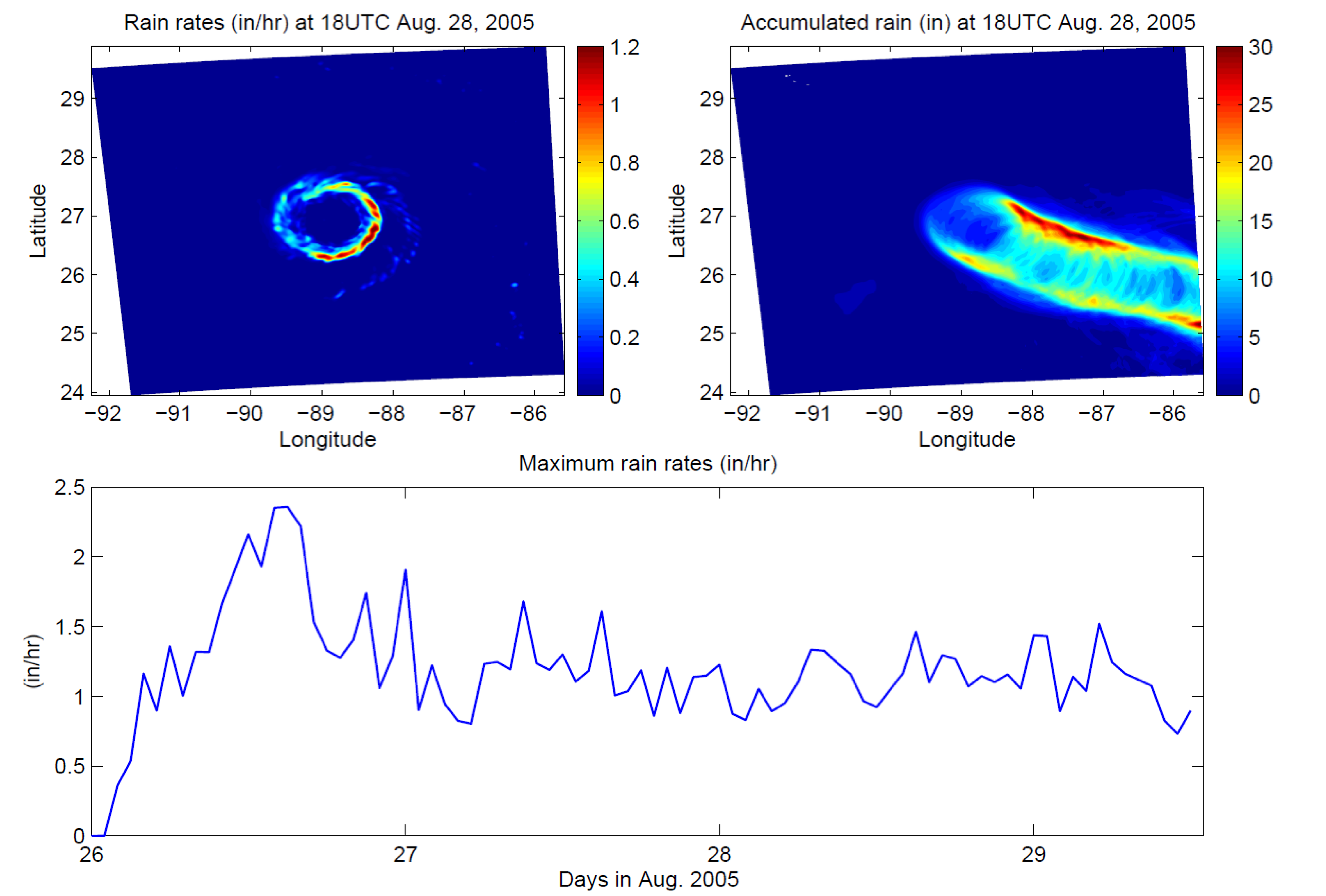
We implemented the parameterization of precipitation effect in a WRF model coupled with the 3DPWP upper ocean circulation model.

Katrina Simulation

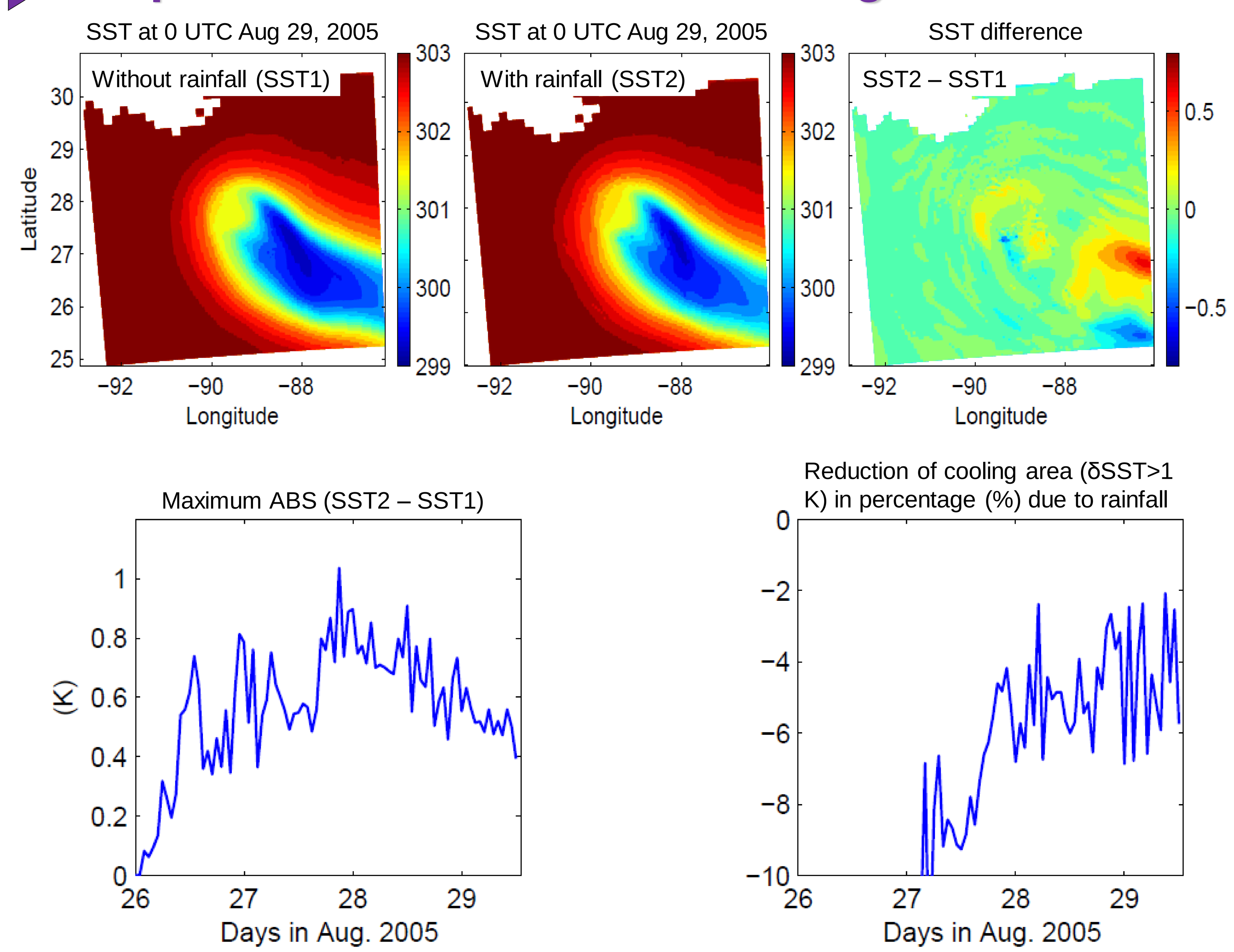


Simulated rainfall rates

- Surface rainfall rates are around 1.2 in/hr, ignoring the model spin-up peak.

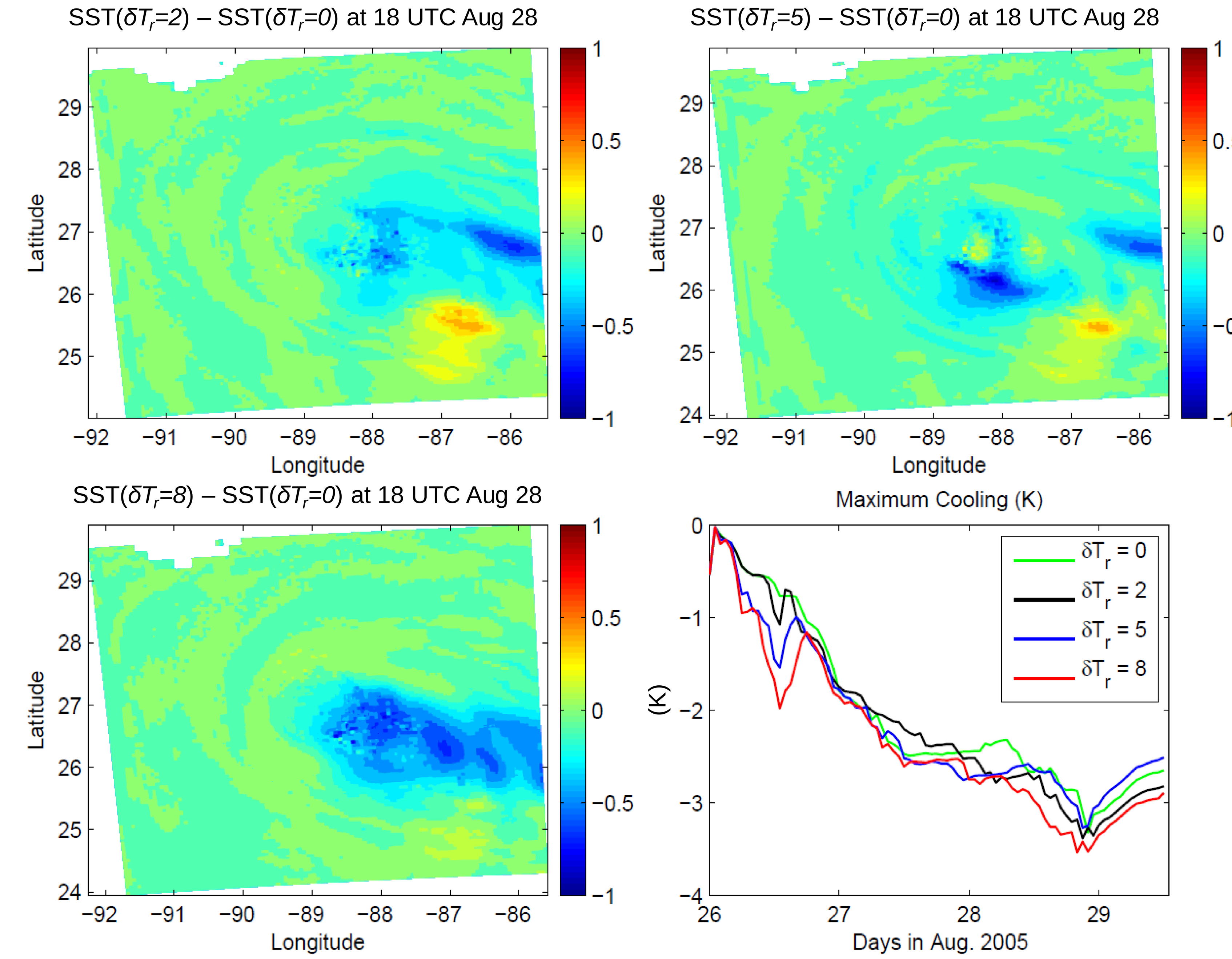


Impact of Rainfall on SST Cooling



- Precipitation causes uneven changes in Sea Surface temperatures.
- Change in sea surface temperatures due to precipitation is about 15-20%.

Experiments on thermal difference between rain water and SST (δT_r)



- Currently there is no observations on the temperature of rain water and this temperature does not exist in numerical simulations.
- Three sensitivity tests were performed to examine the SST change in response to the temperature difference between rain water and sea SST.
- Average change in maximum cooling is about 0.5K, which is not large, but is not negligible.

Summary

- In this study, we investigated in the impact of heavy tropical cyclone rainfall on the storm induced upper ocean cooling.
- Precipitation effects were included in the coupled WRF-3DPWP modeling system based on a simple mixed layer model.
- Simulations of Hurricane Katrina (2005) show that the weakening of upper ocean cooling by precipitation is non-negligible. The results suggest that precipitation should be considered in the coupling of the atmosphere-ocean modeling systems used for prediction of tropical cyclones

Future work

- Our treatment of precipitation in the coupling is very crude. More advanced methods need to be developed.
- Ocean wave model now has been included in the atmosphere-ocean coupling. It remains unknown how precipitation affects the wave dynamics. For example, rain droplets carry large horizontal and vertical momentum. How the impinging of rain droplets on wavy ocean surface to affect air-sea interaction is an unanswered question.

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