Microphysical-Dynamical Interaction in Tropical Cyclone Intensification

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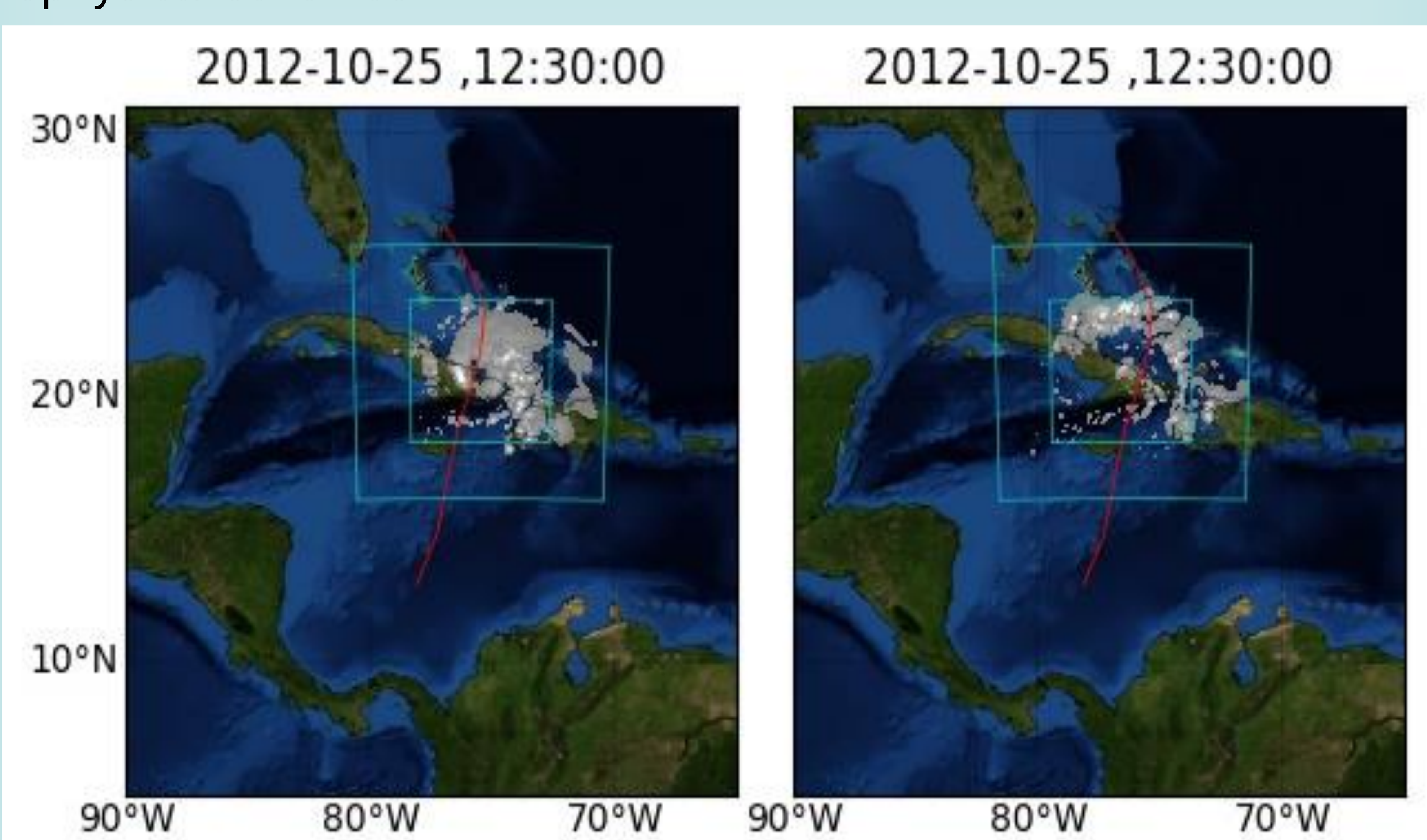
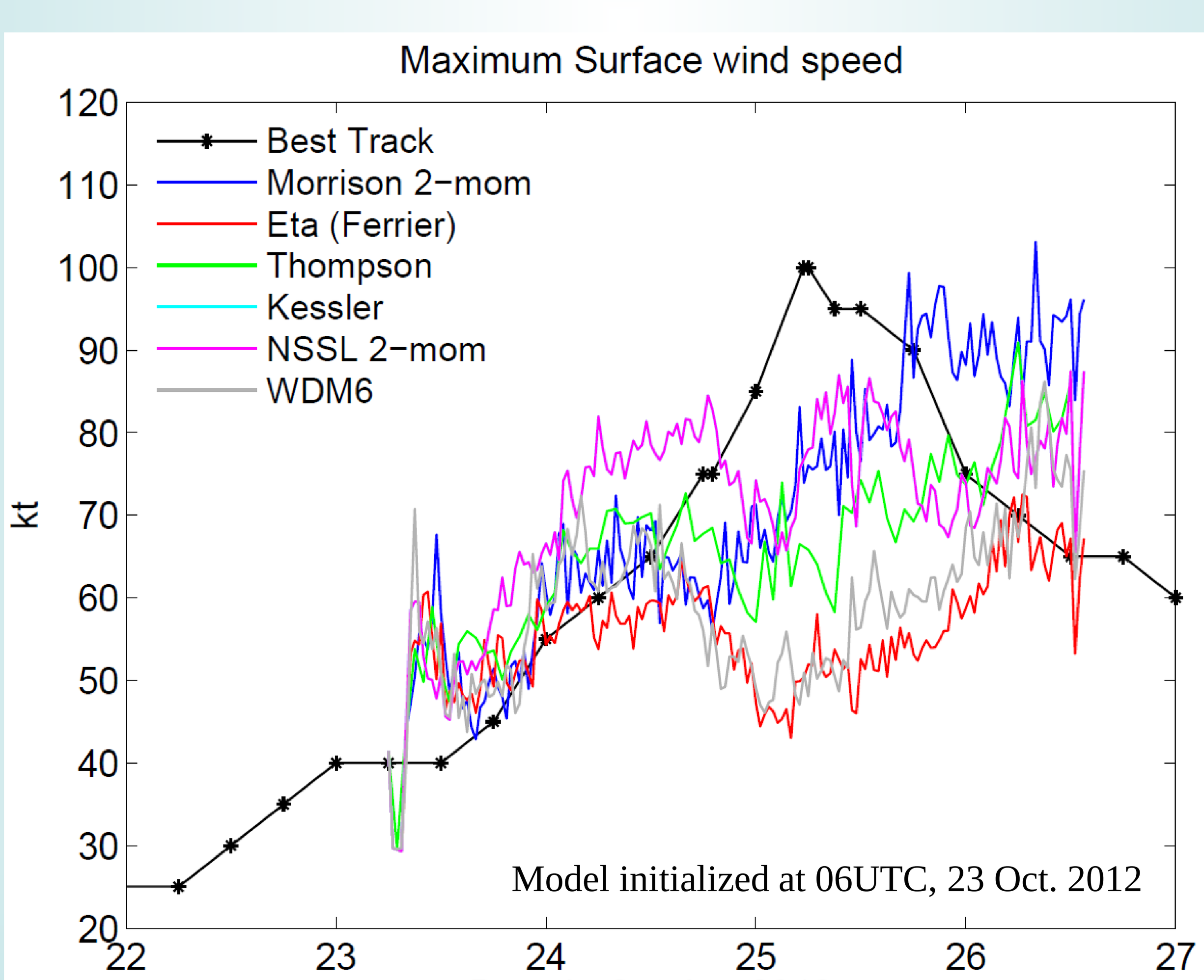
Introduction

A timely and accurate prediction of storm intensity change is difficult primarily due to the highly convective nature of tropical cyclones (TCs) and the interaction of moist convection with the larger scale processes (Marks and Shay 1998). In real TCs, microphysical processes (e.g., riming, melting, evaporation, sublimation, autoconversion, accretion) interact directly with the convective updrafts/downdrafts and turbulent eddy circulations in the clouds to generate the distribution of diabatic heating and cooling critical to the determination of the rate of TC intensification. In numerical simulations, however, the characteristics of convective elements depend on both the model-resolved fields and the parameterized sub-grid scale (SGS) processes. Parametric representation of SGS processes is a source of major uncertainty for intensity forecast of TCs. How to generate a physical robust interaction between the resolved and SGS processes to yield a correct distribution of diabatic heating and cooling that ultimately determines the changes of TC intensity is not only a difficult forecasting problem but also an important scientific question. This study aims to advance our understanding of the feedback between the parameterized microphysical and turbulent processes and the model-resolved dynamical processes.

Sensitivity of TC simulations to microphysics

Hurricane Sandy (2012) was simulated using WRF-ARW with different microphysical schemes.

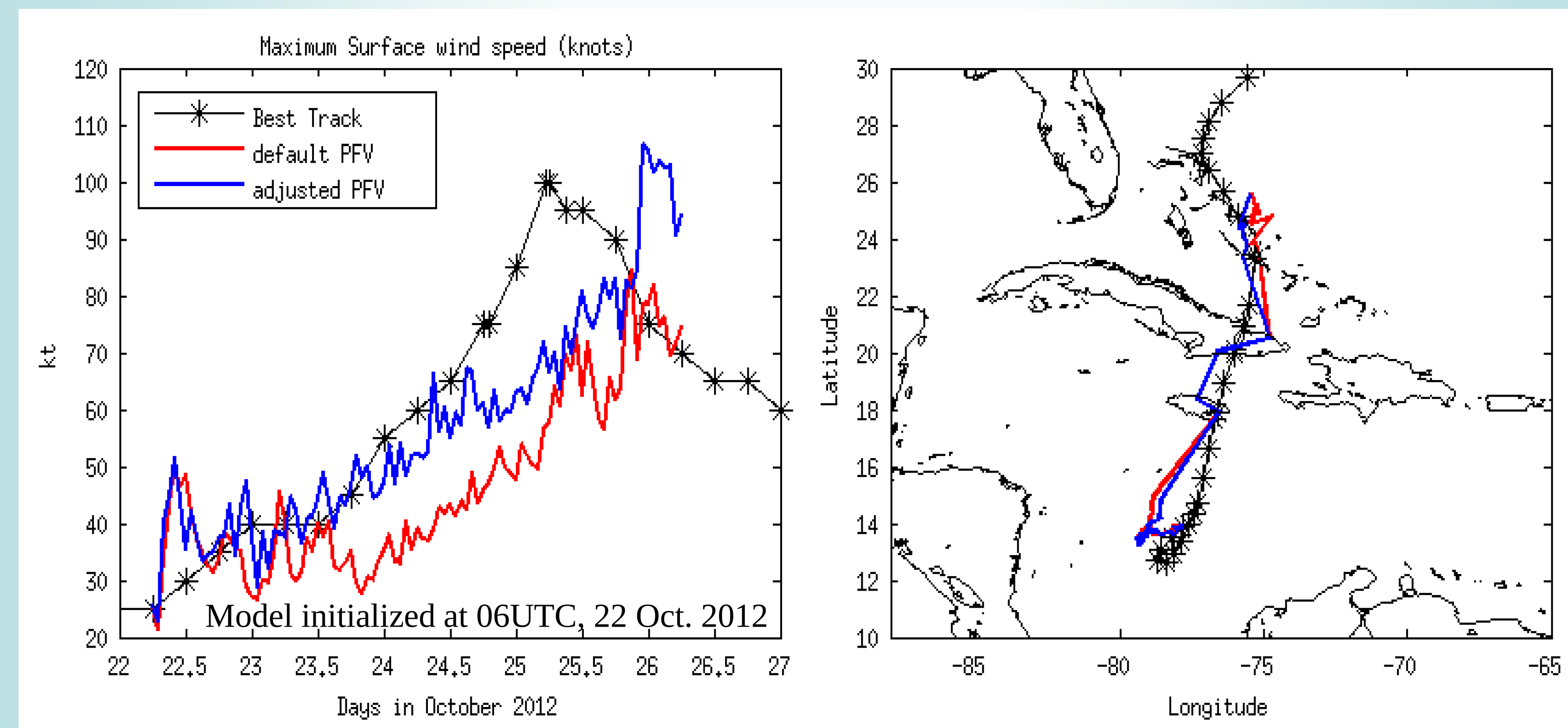




There is a wide spread in the simulated storm intensity, and none of these simulations are capable of reproducing the observed rapid intensification of Sandy. It suggests that microphysical representation has a substantial impact on the simulated storm intensity.

Sensitivity to hydrometeor particle fall velocity

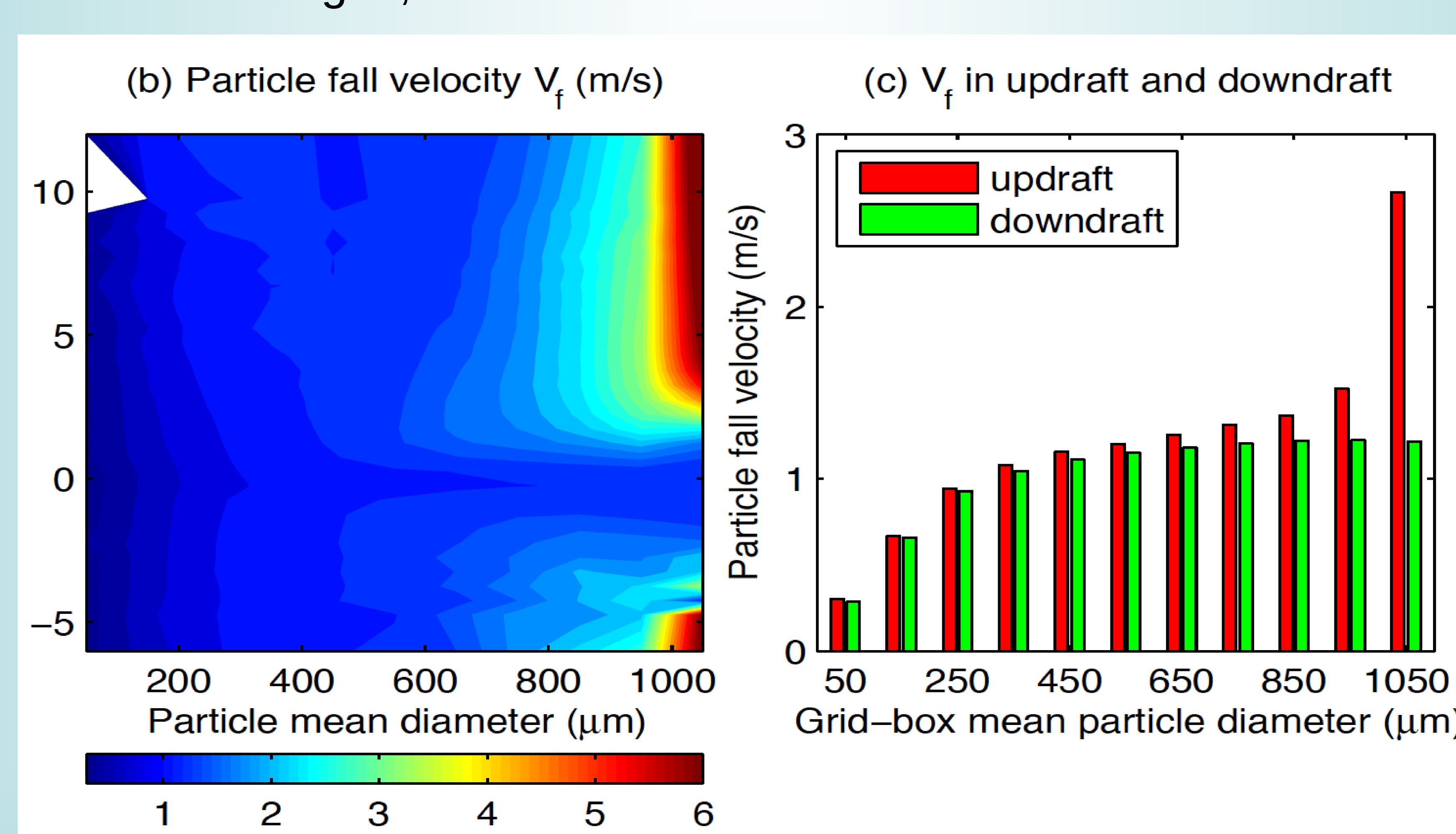
A key microphysical process that depends strongly on microphysical-dynamical interaction is the hydrometeor sedimentation. A sensitivity test of Sandy (2012) was performed in which the particle fall velocity was reduced to 40% of the default value in the Morrison scheme. The storm intensity changed substantially due to the reduction of particle fall velocity.



Parameterization of particle fall velocity

In real clouds, the particle fall velocity is determined by both particle properties (e.g., mass density, size, and shape) and the cloudy turbulent flow in which particles are embedded. It is apparent that the same hydrometeor particle will have a different fall velocity when it resides in convective updraft and downdraft. In microphysical schemes, however, particle fall velocities are often simply parameterized based on the particle properties only, e.g., in the form of $V_t(D) = aD^b$, where D is the particle diameter. The influence of convective currents and turbulent flow on particles is not considered.

To examine if numerical models can generate robust microphysical-dynamical interaction, we outputted the microphysical variables from one of our HWRF simulations of Hurricane Harvey (2017) and sorted the particle fall velocities in terms of grid-box mean particle diameter and model-resolved vertical velocity. The results show that the particle fall velocities in the updraft are greater than those in the downdraft for particles with the same diameters in all diameter ranges, which is unrealistic.



Summary

Simulated TC intensity shows a great sensitivity to cloud microphysics. The oversimplified scheme of particle fall velocity generates unrealistic statistical relationship among fall velocity, particle diameter, and convective currents. To capture robust microphysical-dynamical interaction occurring in real TCs, the effects of convective currents and in-cloud turbulence on hydrometeor particles needs to be included in the particle fall velocity parameterization.