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Coupled Atmosphere-Wave-Ocean Modeling of Tropical Cyclones: Progress, Challenges, and Ways Forward

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It has long been recognized that air-sea interaction plays an important role in tropical cyclones (TC) intensity change. However, most current numerical weather prediction (NWP) models are deficient in predicting TC intensity. The extreme high winds, intense rainfall, large ocean waves, and copious sea spray in TCs push the surface-exchange parameters for temperature, water vapor, and momentum into untested regimes. Parameterizations of air-sea fluxes in NWP models are often crude and create “manmade” energy source/sink that does not exist, especially in the absence of a fully interactive ocean in the model. The erroneous surface heat, moisture, and momentum fluxes can cause compounding errors in the model (e.g., precipitation, water vapor, boundary layer properties). The energy source (heat and moisture fluxes from the ocean) and sink (surface friction and wind-induced upper ocean cooling) are critical to TC intensity. However, observations of air-sea fluxes in TCs are very limited, especially in extreme high wind conditions underneath of the eyewall region.

The Coupled Boundary Layer Air-Sea Transfer (CBLAST) program was designed to better understand the air-sea interaction, especially in high wind conditions, which included laboratory and coupled model experiments and field campaign in 2003-04 hurricane seasons. Significant progress has been made in better understanding of air-sea exchange coefficients up to 30 m/s, i.e. a leveling off in drag coefficient and relatively invariant exchange coefficient of enthalpy with wind speed. More recently, the Impact of Typhoon on the Ocean in the Pacific (ITOP) field campaign in 2010 has provided an unprecedented data set to study the air-sea fluxes in TCs and their impact on TC structure and intensity. More than 800 GPS dropsondes and 900 AXBTs/AXCTs as well as drifters, floats, and moorings were deployed in TCs, including Typhoons Fanapi and Malakas, and Supertyphoon Megi with a record peak wind speed of more than 80 m/s. It is found that the air-sea fluxes are quite asymmetric around a storm with complex features representing various air-sea interaction processes in TCs. A unique observation in Typhoon Fanapi is the development of a stable boundary layer in the near-storm cold wake region, which has a direct impact on TC inner core structure and intensity.

Despite of the progress, challenges remain. Air-sea momentum exchange in wind speed greater than 30-40 m/s is largely unresolved. Directional wind-wave stress and wave-current stress are difficult to determine from observations. Effects of sea spray on the air-sea fluxes are still not well understood. This talk will provide an overview on progress made in recent years, challenges we are facing, and ways forward. An integrated coupled observational and atmosphere-wave-ocean modeling system is urgently needed, in which coupled model development and targeted observations from field campaign and lab measurements together form the core of the research and prediction system. Another important aspect is that fully coupled models provide explicit, integrated impact forecasts of wind, rain, waves, ocean currents and surges in TCs and winter storms, which are missing in most current NWP models. It requires a new strategy for model development, evaluation, and verification. Ensemble forecasts using high-resolution coupled atmosphere-wave-ocean models can provide probabilistic forecasts and quantitative uncertainty estimates, which also allow us to explore new methodologies to verify probabilistic impact forecasts and evaluate model physics using a stochastic approach. Examples of such approach in TCs including Superstorm Sandy will be presented.