Global Modeling with NASA Supercomputing Technology:

When Sandy Meets Lorenz

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Over 50 years ago, Prof. Lorenz of MIT discovered the sensitive dependence of numerical results on initial conditions in an idealized nonlinear model (Lorenz, 1963), describing a two-dimensional forced dissipative Rayleigh-Benard convection. Subsequent to his follow-up presentation in 1972 (Lorenz 1972), the term "butterfly effect" was introduced to describe the sensitive dependence on ICs; later this became a metaphor for indicating that small-scale perturbations can make a huge impact on large-scale flows. In this study, the former and latter definitions are referred to as the butterfly effect of the first and second kind, respectively. The pioneering modeling studies by Lorenz laid the foundation for chaos theory, which was viewed as the third scientific revolution of the twentieth century after relativity and quantum mechanics and is being applied in various fields including earth science, mathematics, philosophy, and physics (e.g., Gleick 1987; Anthes 2011).It is now well accepted that perfect (weather/climate) prediction is impossible, and a tiny error in initial conditions may "quickly" contaminate the simulations of large-scale flows. Hence the outlook on extending the lead time beyond 5-7 days has not yet been optimistic (see details in Anthes, 2011). Recently, extreme weather events such as Hurricane Katrina (2005), Tropical Cyclone Nargis (2008) and Hurricane Sandy (2012), causing tremendous damage and numerous facilities, raised an urgent need for improving predictions of high-impact tropical cyclones (TCs). To improve the prediction of TC's formation, movement and intensification with a numerical model, it is crucial to improve the model's nonlinear interactions across a wide range of scales, from the large-scale environment (deterministic), to mesoscale flows, down to convective-scale motions (stochastic). The increased complexities in numerical models demand tremendous computing power.

During the past decade, the quantum jump in computing power enabled by NASA supercomputers (e.g., Columbia and Pleiades; Biswas et al., 2007 and Shen et al., 2011, 2013b) has provided unprecedented opportunities for advancing weather and climate modeling, and has shown a great potential for extending the lead time of predictions for extreme weather events. For example, simulations with the NASA high-resolution global model (Shen et al., 2010a,b; 2012a; 2013c) were conducted to understand to what extent the high intrinsic predictability (of TC genesis) may exist and how realistic the corresponding practical predictability (of a model) can be obtained. It is suggested that a large-scale system (e.g., tropical waves) can provide determinism on the prediction of TC genesis, making it possible to extend the lead time of genesis predictions. Selected cases in our recent studies include the relationship between (i) TC

Nargis (2008) and an Equatorial Rossby (ER) wave; (ii) Hurricane Helene (2006) and an intensifying African Easterly Wave (AEW); (iii) Twin TCs (2002) and a mixed Rossby-gravity wave (MRG, e.g., Silva-Dias et al. 1983) during an active phase of the Madden Julian Oscillation (MJO; Madden and Julian, 1971).

In 2012, Sandy made an unusual northwestward turn at 00Z Oct. 29 prior to its landfall at 2330Z Oct. 29 near Brigantine, New Jersey, devastating surrounding areas and causing tremendous economic loss (Blake et al., 2013). There have been heated debates on this event, including to what extent Sandy's unique features, such as its extraordinarily large scale, and its track, with that sharp turn during Oct. 29-30, may be affected by the current climate; and whether we can extend further the lead time for predicting severe storms such as Sandy (e.g., Emanuel 2012). In this talk, I will present the real-world model simulations of Hurricane Sandy to illustrate how the multiscale processes associated with large-scale tropical waves and an MJO may contribute to the predictability of Sandy. I will then discuss theoretical results with modified Lorenz models to examine the role of nonlinearity and the appearance of a saddle point in producing chaotic responses (i.e., diverged trajectories), suggesting the possible reasons why some models failed to capture the northwestward turn for Sandy. The enabling roles played by the parallel computing and concurrent visualization technology will be also discussed.