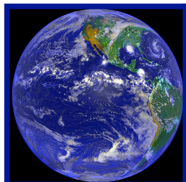

Towards the Simulation of Tropical Cyclones in High-Resolution GCMs: Assessing Uncertainty

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Overview

Using General Circulation Models (GCMs) for tropical cyclone studies is difficult due to the relatively small size of the storms, the intense convection and a host of large-scale small-scale interactions. These are mostly unresolved at typical GCM resolutions of about 50-100 km, and still challenged at high resolutions between 12-30 km. Nevertheless, high-resolution GCMs are becoming a tool of choice to evaluate tropical cyclones in current and future climate conditions. Therefore, the physical and dynamical components of a GCM need to be carefully evaluated to assess their fidelity for tropical cyclone studies.

An idealized tropical cyclone test case for high-resolution GCMs is implemented in aqua-planet mode with constant sea surface temperatures. The initial conditions are based on an initial vortex that is in gradient-wind and hydrostatic balance and intensifies over a 10-day period. The impact of small variations in the initial conditions on the evolution of the tropical cyclone are assessed. In particular, we investigate the role of these uncertainties within the National Center for Atmospheric Research's (NCAR) hydrostatic Community Atmosphere Model CAM 5. In addition, we utilize two different dynamical cores available in CAM 5. These are the default Finite-Volume (FV) and the next-generation Spectral-Element (SE) dynamics package. The dynamical core is the central component of every GCM and determines the numerical methods, diffusion properties and computational mesh for the resolved fluid flow. Therefore, the investigation also sheds light on the role of structural differences within GCMs in tropical cyclone simulations.

Simulation Design

We utilize CAM 5 (Neale et. al., 2010) with two dynamics packages to trigger idealized tropical cyclone-like vortices and track them over ten simulation days. The FV dynamical core is a grid point-based method on a regular latitude-longitude grid and the SE package is an element-based method on a cubed-sphere grid. All simulations are run with 30 vertical levels (L30) in a so-called *aqua-planet configuration* (Neale and Hoskins, 2000) that consists of an ocean-covered Earth with prescribed radiative forcing and sea surface temperatures (SST). A constant SST of 29ºC is utilized to provide favorable conditions for tropical cyclogenesis. All parameters in the physics parameterization suite are fixed and correspond to the settings of a FV 1° simulation for both packages. The following horizontal resolutions are tested:

FV: 1°, 0.5°, 0.25° which corresponds to about 111, 55, 28 km grid spacing near the equator.

SE: n_e=30, n_e=60, n_e=120 which also corresponds to about 111, 55, 28 km grid spacing near the equator.

A total of 54 ensemble model simulations are performed. This corresponds to 9 individual runs at each horizontal resolution and each dynamics package. They are separated into two different sets:

1. The first set is the **control case** with identical idealized initial conditions to those in Reed and Jablonowski (2011) .
2. The next set represents **initial data uncertainty**. The simulations are initialized with random perturbations on the order of ±2% to the zonal and meridional wind speeds, which accounts for at most a change in the wind speeds of ±0.4 m s^{-1}.

The differences between the simulations of varying dynamical packages shed light on the **structural uncertainty.**

Vortex Initialization

The initialization of the idealized vortex (our 'control case') is built upon prescribed 3D moisture, pressure, temperature and velocity fields (Reed and Jablonowski, 2011). These are embedded into tropical environmental conditions that resemble the Jordan (1958) mean tropical sounding. The vortex is centered at 10ºN and 180ºW, has a maximum wind speed of 20 m s^{-1} and a radius of maximum wind (RMW) of 250 km. The relative humidity is about 80% in low levels. The wind in the background environment approaches zero everywhere. The initial fields are in exact hydrostatic and gradient-wind balance in an axisymmetric form.

The weak low-level vortex has a warm-core and triggers the evolution of an intense tropical cyclone-like storm over 10 simulation days. The initialization technique is analytic for GCMs with height-based vertical coordinates. The initial data is analytic and can easily be computed on any GCM computational grid which fosters model intercomparisons (shown here).

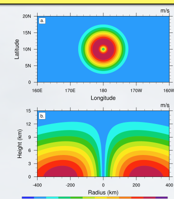

Figure 1: Initial wind speed displayed as (a) a horizontal cross section at a height of 100 m and (b) a longitude-height cross section through the center latitude of the vortex.

Comparison of the Wind Speeds

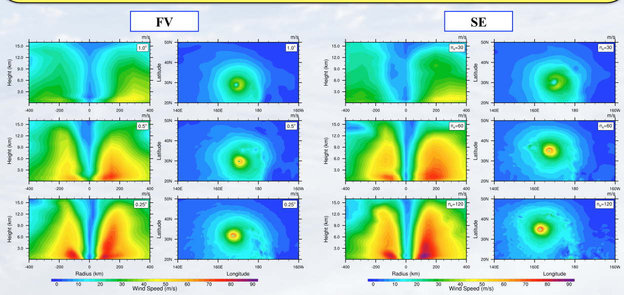

Figure 2: Snapshots of the idealized cyclone simulations at day 10. Results from CAM 5 **control case** simulations for each dynamical core are shown (see labels). **Left Column of each figure:** wind magnitude for a vertical cross section through the center latitude of the vortex as a function of the radius from the vortex center. **Right column of each figure:** magnitude of the wind at 100 m. The SE simulations produce more intense storms than the FV simulation.

Ensemble Spread: Comparison of Resolution and Model Variant

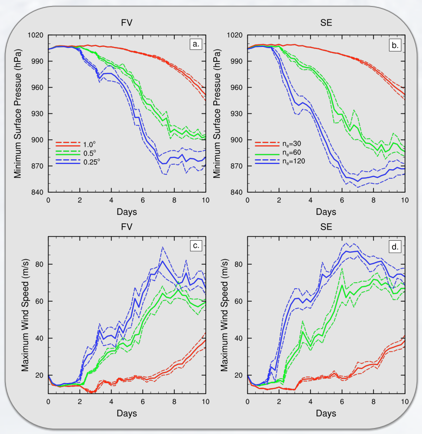

Figure 3. Time evolution of the **control case** (solid line) and the ensemble root-mean-square-difference (RMSD) from the control case of the **initial data uncertainty** (dashed line) at each resolution. **Left:** (a) minimum surface pressure and (c) maximum wind speed at a height of 100 m as a function of day for FV simulations. **Right:** same but for the SE simulations. Note, the vortex strength increases with increasing resolution and varies from FV to SE.

Sensitivity of SE to Physics: Role of Time Scale

Physics time scale: Time interval over which the physics tendencies are computed. The physics-dynamics coupling frequency stays constant (here 450 s). The variation of the physics time scale is a tentative feature of SE and will require more testing.

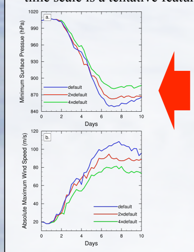

Figure 4: Time evolution of (a) the minimum surface pressure and (b) the absolute maximum wind speed and of the SE dynamical core at n_e=120 for three different physics timescales. The timescales are (1) the default (450 s) (2) two times the default (900 s) and (3) four times the default (1800 s). As the timescale is increased the extreme intensity of the storm decreases, probably becoming more physical.

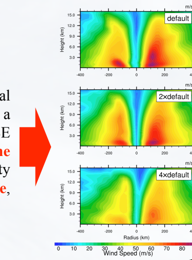

Figure 5: Snapshots of the wind magnitude for a vertical cross section through the center latitude of the vortex as a function of the radius from the center for n_e=120 SE simulations at day 10. The three different **physics time scale** shown in Figure 5 are presented. While the intensity of the storms decreases with increasing **physics time scale**, the structure of the storms remains rather consistent.

Results/Conclusions

- Figure 2 shows that there are intensity and structural differences between the **control case** simulations with the FV and SE dynamics packages.
- The simulated intensities of the SE storms are greater than those of the FV storms at all horizontal resolutions, except the lowest.
- Figure 3 shows that as the resolution increases in the FV and SE dynamical cores the intensity of the storm increases at day 10. The extreme intensities of the n_e=120 SE simulations probably become unrealistic. There is no convergence with resolution.
- The **initial data uncertainties** result in an ensemble RMSD from the control simulation on the order of 1-5 m s^{-1} and 2-8 hPa for the maximum wind speed and for the minimum surface pressure at day 10, respectively (Figure 3).
- The differences in the development, intensity and structure of the tropical cyclone when using FV compared to SE represents **structural uncertainty**.
- Figures 4 and 5 show the sensitivity of the n_e=120 SE simulation to the **physics time scale**. As the **physics time scale** is increased the storm intensity weakens, leading to (most likely) more realistic storms.

References

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