FV3 and the Next Generation Global Prediction System

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Introduction

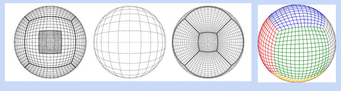
The non-hydrostatic finite volume dynamical core (FV3) at the Geophysical Fluid Dynamics Laboratory (GFDL) is a participant in NOAA's Next Generation Global Prediction System (NGGPS) project. This inter-agency effort is part of the NWS Research to Operations (R20) initiative and will replace the current Global Spectral Model (GSM) with a non-hydrostatic core to improve operational forecasting skill for the next several decades.

In Phase I of the NGGPS project, five dynamical cores (dycores) were tested for suitability and efficiency. The FV3 results from Phase I are presented, with a focus on the high resolution real data Hurricane Sandy test.

The FV3 Dynamical Core

The GFDL finite-volume cubed-sphere dycore is a scalable and flexible core capable of both hydrostatic and non-hydrostatic simulation. It evolved from FV, the latitude-longitude finite volume core that began at NASA/Goddard in the mid-90s. FV3 was designed to be computationally efficient and to have discretization guided by physical principles as much as possible.

- Superior speed and efficiency
- Full finite-volume discretization
  - Finite-volume pressure gradient evaluation has errors an order of magnitude smaller than other schemes
  - Finite-volume vertically-lagrangian discretization is the key to efficiency for cloud-resolving applications
  - The transport algorithm conserves mass and has no false vorticity generation
- Prognostic winds on D-grid allow for consistent transport of Potential Vorticity, air mass, and all tracers
- High--order monotonic advection is used consistently for momentum and all other prognostic variables
- A gnomonic cubed-sphere grid is used with grid-stretching and two-way nesting capabilities
- No spatial or temporal scale restrictions



Nested Grid | Stretched Grid (front and back) | Uniform Grid

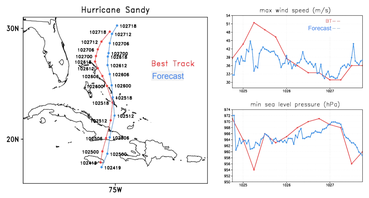
FV3 is used in many advanced weather, climate, and chemistry models:

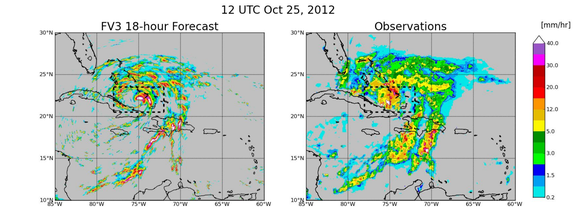
At GFDL
- CM2.1/AM2.1
- ESM2
- HIRAM
- CM2.5/FLOR
- CM3/AM3
- CM4/AM4
- ESM4

Outside of GFDL
- NASA's GEOS-5
- GEOS-CHEM (Harvard U)
- GCM ModelE
- NCAR/DOE CESM
- Academia Sinica, Taiwan
- LASG/IAP, China
- Souel National University

Hurricane Sandy

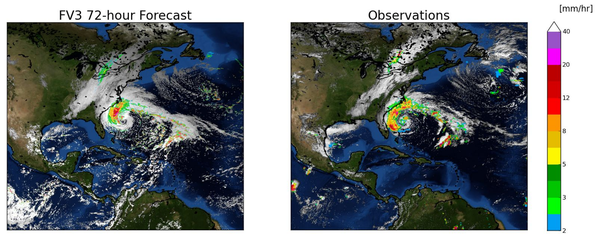
- 3-km globally-uniform 72-hour forecast started 18 UTC October 24, 2012
- The High Resolution Atmospheric Model (HIRAM) was used for this test. The physics package was from GFDL AM2, except:
  - New GFDL double-plume convective parameterization
  - Stable PBL parameterization turned off
  - Six- category cloud microphysics





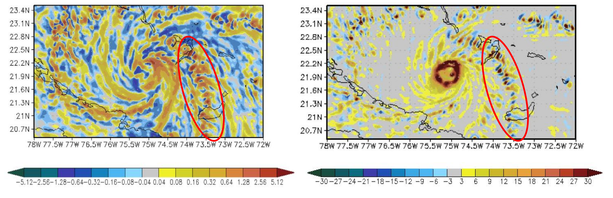
18-hr forecast 1-hr precipitation accumulation (left) 1-hr precipitation accumulation observations from CMORPH dataset (right). Black dashed box shows region in figures below.

18 UTC Oct 27, 2012



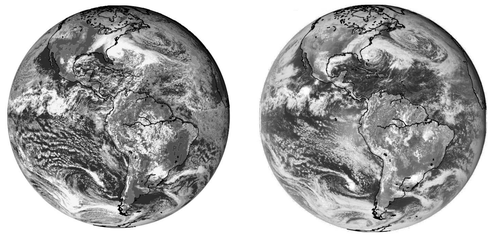
Hurricane Sandy forecast outgoing shortwave radiation TOA with 1-hr accumulated precipitation (left), MODIS visible imagery with CMORPH (NOAA CPC Morphing Technique) precipitation (right).

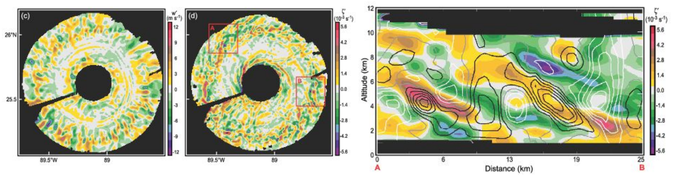
Vertical velocity/vorticity couplets, indicate high helicity, which studies have suggested may be important for hurricane intensification.



18-hr forecast 850hPa vertical velocity (ms^{-1}) (left) 850hPa relative vorticity ($x10^4$) (right) valid 12 UTC October 25, 2012. Figures from the HIWPP report.

Which one is GOES satellite imagery and which one is the 3-day HIRAM forecast?





Hurricane Rita's concentric eyewalls at 4-km altitude from the ELDORA radar (a) vertical velocity. (b) vertical vorticity. The azimuthal-averaged and wavenumber-1 fields have been removed. (c) North-south vertical cross section of vertical vorticity (shading) and vertical velocity (contours, interval 1.5 m/s, black is upward) of wave-like feature in domain B from figure (b). From Didlake and Houze (2011).

Hurricane Rainbands

Strong convective elements were captured in hurricane rainbands, with organized wave-like features, a few grid-cell-widths in length. Are these convective features real or are they numerical artifacts?

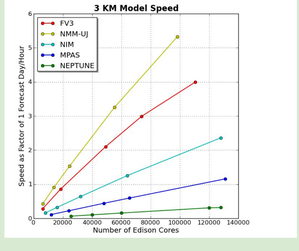
- Similar ~10 km structures were observed in hurricanes Katrina and Rita during the RAINEX in 2005 (Didlake and Houze: 2009, 2011, 2013).
- If the couplets are real, it implies that FV3 has a high effective resolution.
- It cannot be claimed that these features exist universally in hurricane rainbands or eyewalls due to the small sample of observations
- This project has highlighted the need for more field projects with a dense network of hurricane observations. In order to judge which simulation is more realistic, we must have more evidence with which to base comparison.

Conclusion

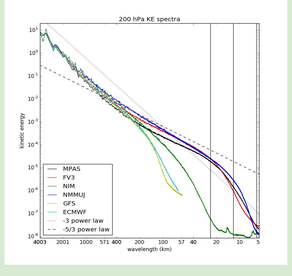
- Phase 1 of the NGGPS project revealed FV3 as a top contender. FV3 is the only dycore to excel at all tests and is one of two dycores that have continued on to Phase 2.
- The final NGGPS model must predict high-impact weather events from the smallest to the largest scales, a new breed of "seamless" weather-climate model.

Computational Performance and Effective Resolution

FV3 is 4x faster than models of similar quality, saving ~$10 million per year in HPC costs!



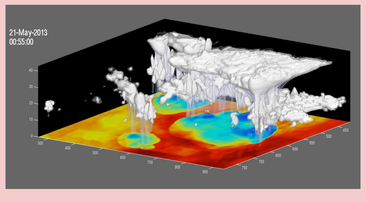
Speed is shown as a function of number of cores, normalized to forecast integration rate of 1 day/hr (3 km workload, higher is better metric). Data from HIWPP report.



200 hPa global kinetic energy spectra (m^2/s^2) for 72 hour forecast of Hurricane Sandy. X-axis ranges from wavenumber 10-7200 with a log-scale in total wavenumber. Vertical lines represent wavelengths corresponding to 2, 4, and 8 times the nominal grid resolution (6, 12, and 24 km). From HIWPP report.

More FV3 Applications

Supercells



FV3 is being used in research aimed at extending supercell and tornado forecasts out to several days. Variable resolution configurations, such as grid nesting and stretching, are crucial to tornado/supercell prediction in a global model. For more on the FV3 grid configurations see the talk by Lucas Harris 2:30 April 18, *Subseasonal hurricane prediction using Nested-Grid HiRAM.*

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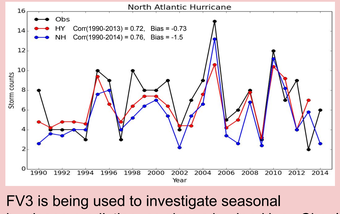
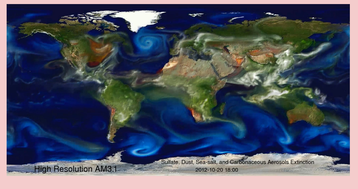
Seasonal Hurricane Prediction



FV3 is being used to investigate seasonal hurricane prediction, as shown by Jan-Huey Chen's presentation at 2:00 April 18, *Seasonal Prediction of Tropical Cyclones in a New Non-hydrostatic GFDL HiRAM*

Chemistry Transport Models



Main References

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