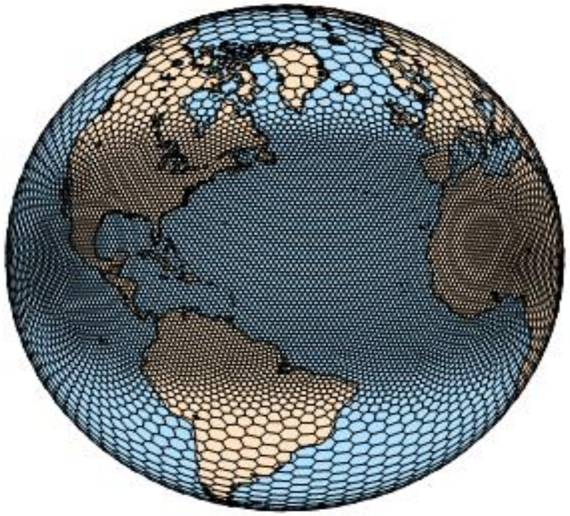
Next Generation Global Prediction System (NGGPS)

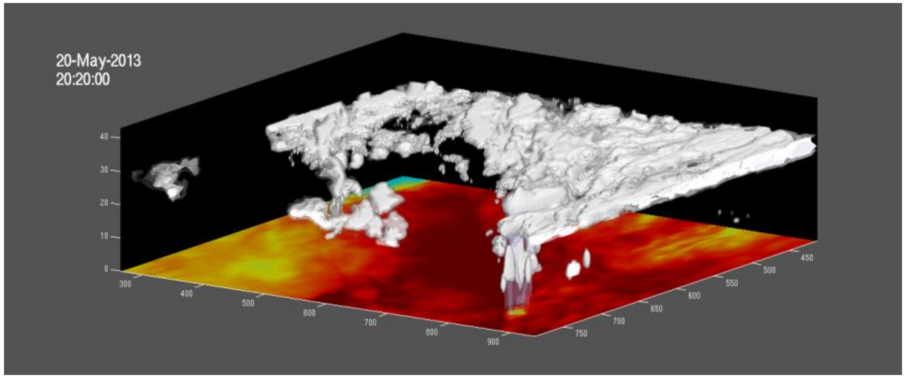


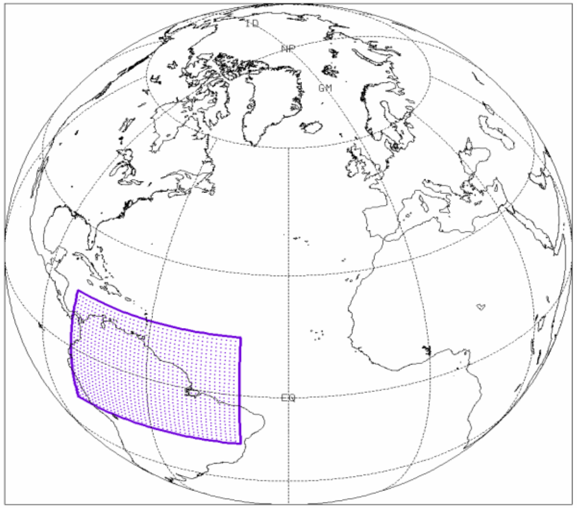
Nesting and Convective Systems

Update on Team Plans and Activities

Vijay Tallapragada

NOAA/NWS/NCEP/EMC





HIWPP/NGGPS Program Status Meeting
February 9-10, 2016

NGGPS Nesting/Convective Systems Team Membership

- Chair: Vijay Tallapragada, EMC
- Members:
  - EMC: Tom Black, Samuel Trahan, Dusan Jovic, Matt Pyle, John Michalakes, Bin Liu
  - AOML: S.G. Gopalakrishnan, Thiago Quirino, Steven Diaz
  - GFDL: S.J. Lin, Lucas Harris, Morris Bender, Tim Marchok
  - ESRL: Stan Benjamin, Jin Lee, Ligia Bernardet
  - NCAR: Bill Skamarock, Chris Davis
  - Navy: Jim Doyle
  - PSU: David Stensrud, Paul Markowski, Yvette Richardson
  - U. Michigan: Christiane Jablonowski, C.M. Zarzycki

NGGPS Nesting/Convective Systems Team Objectives

- Incorporate more sophisticated nesting or mesh refinement capabilities in the NEMS framework
- Development of generalized nesting or mesh refinement techniques
- Implement multiple static and moving nests globally, with one- and two-way interaction and coupled to other (ocean, wave, sea ice, land, etc.) models using NEMS infrastructure
- Implement scale-aware physics appropriate for the high-resolution nests
- Post-processing, product development and verification of high-resolution model output

NGGPS Nesting/Convective Systems Team Approach

- Strategic development approach
  - Are the generalized nesting techniques truly independent of choice of NGGPS dycore(s)?
  - How scalable and efficient will be the global models with two-way interactive nests for operational considerations? (interactions with overarching system/software architecture and engineering teams)
  - Need for developing appropriate physics and initialization techniques (interactions with atmospheric physics and data assimilation teams)
  - Need for developing advanced diagnostic and verification tools for evaluating truly non-hydrostatic model forecasts at cloud resolving scales

Near term Challenges

– Take advantage of already developed (and ongoing developmental) work in the HWRF and NMMB/NEMS systems

– Accelerate design and development of efficient two-way interactive nests using generalized nesting framework using ESMF/NUOPC coupler functionality in NEMS

– Design of Adaptive Nests that can be activated, terminated, (or re-activated) during model integration

General Requirements for Operational Nesting or Grid Enhancement

- Static/moving
- 1-way/2-way interactive (nests)
- Multiple nests run simultaneously
- Bit reproducible and restartable (static/moving/ 1-way/2-way)
- *Very fast and efficient!*
- Dynamics, physics and initialization appropriate and applicable for high-resolution nests within the global model

Generalized Nesting By Coupling

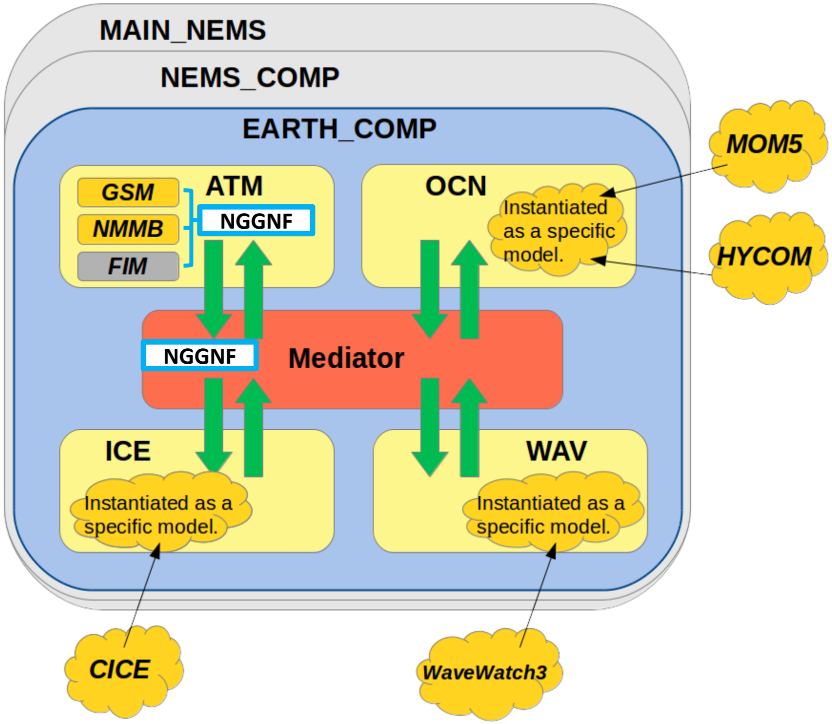
AOML in partnership with EMC and other OAR labs is building the Next Generation Generalized Nesting Framework (NGGNF) within NEMS to advance global-2-local scale modeling for hurricanes

NGGNF can be considered as a subset of the *"Coupled NEMS" project. While "Coupled NEMS" focuses on coupling various earth system models through surface interactions, NGGNF is a dynamic interface for nesting that couples one or more atmospheric models at the dynamic level by providing several required numerical transformations across the interface, including 3D interpolations.*

NGGNF addresses the shortcomings of the current generation of nesting technology:

1. **Offers a high degree of portability and abstraction**
   - A complete, stand-alone nesting algorithm
   - Built into NEMS framework
   - No dependence on dynamical core, grid shape, grid projection, or vertical coordinate
2. **Offers advanced inter-domain interaction features**
   - Nests can interact with scale spanning resolution of the parent domain
   - Nests can move across domain edges and poles without distortions
   - Supports sequential/parallel, 1 and 2-way interactive, domain integration
3. **Offers novel features**
   - *Generalized IO*: eliminates custom model IO code and performs post-processing

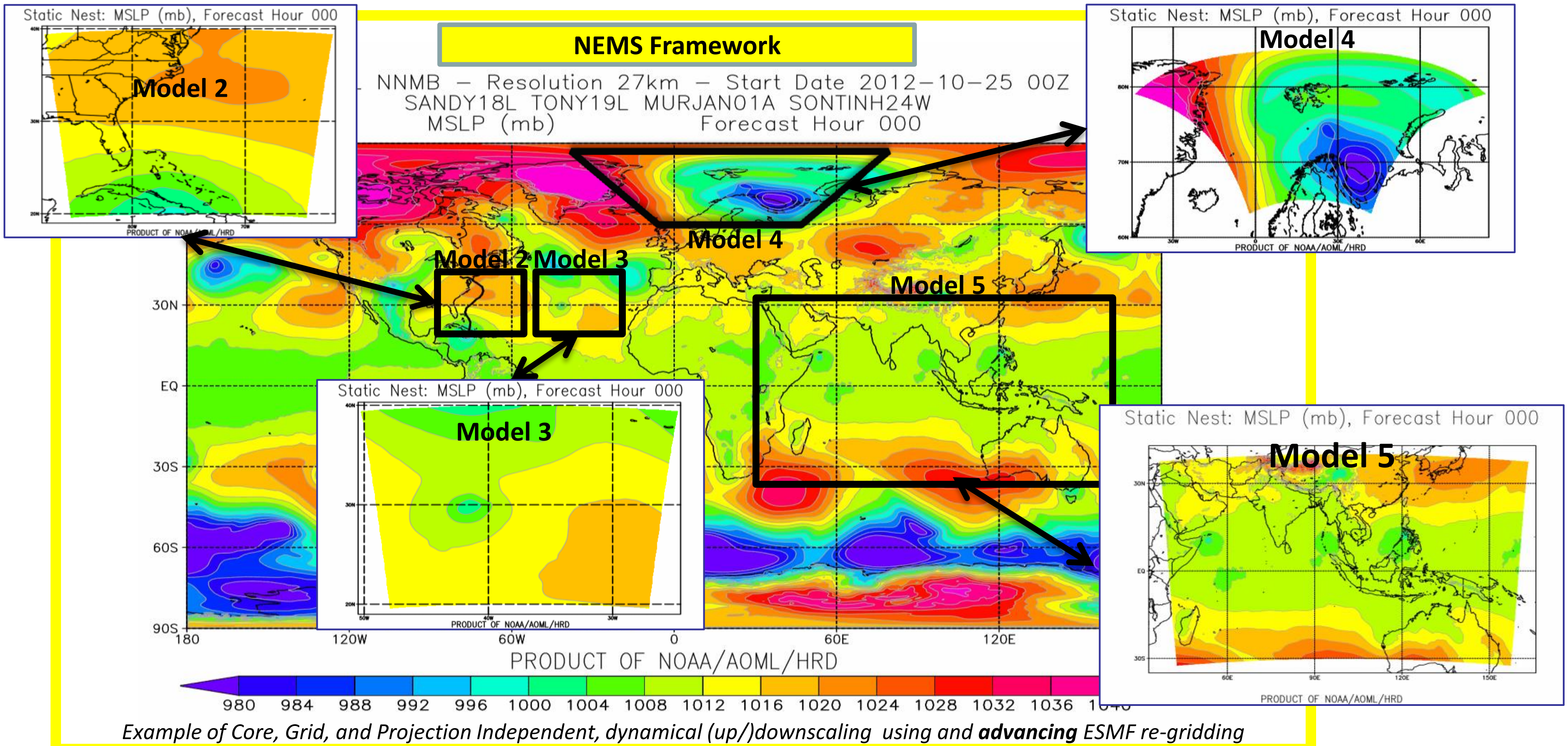
The Coupled NEMS Project



Architecture of the NEMS NUOPC "mediator" with the NGGNF dynamic layer

Example: Generalized Nesting By Coupling

Project Statement: “The current nesting techniques in HWRF and NMMB are based on the projection center of the parent grid, limiting their applications to a confined region in the tropics, and limiting their ability to scale well at higher resolutions and pole-ward locations. A generalized nesting, core independent nesting technique that can work independent of the parent model’s grid structure as well as map projections will advance the state-of-the-art in nesting techniques (one-way as well as two-way).



Example of Core, Grid, and Projection Independent, dynamical (up/)downscaling using and ***advancing*** *ESMF re-gridding*

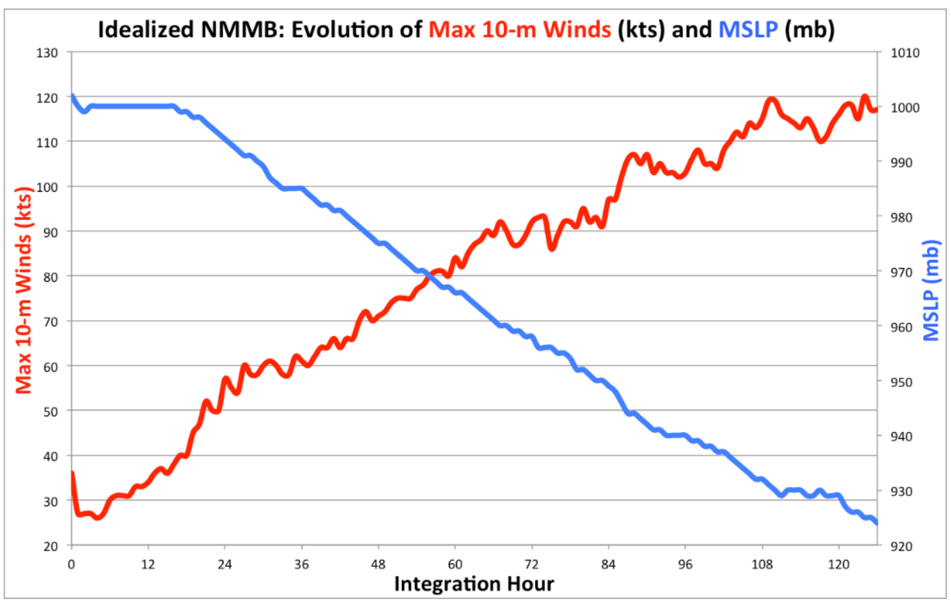
SVN Repository path: https://svnemc.ncep.noaa.gov/projects/hnmmb/branches/AOML-HRD/NGGNF

Hurricane Developments in NMMB

(EMC-HRD Collaborations supported by HIWPP and R2O/NGGPS)

- Developed a Hurricane NMMB repository at EMC
  - Transitioned HIWPP funded Idealized TC framework to repository
    https://svnemc.ncep.noaa.gov/projects/hnmmb
  - Currently transitioning Basin-scale HWRF multi-storm initialization into NMMB

Idealized TC Framework in NMMB



Configuration

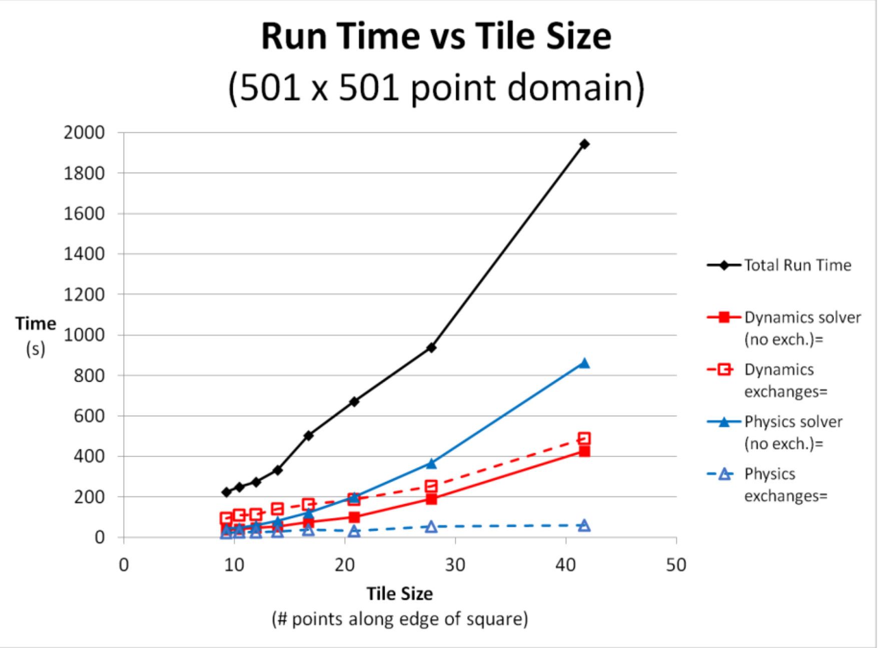
1) Resolution: 18:06:02km, 61 levels, 2mb model top.
2) Initial TC intensity: 20 m/s at 1002 mb.
3) Physics package: HWRF with high-frequency calls

Slide courtesy: Thiago Quirino, HRD/AOML

Efficiency and Scalability of NMMB

(EMC-HRD Collaborations supported by HIWPP and R2O/NGGPS)

- Evaluating NMMB scalability with 2-way nest interaction
  - Performed various *timing* experiments: 1-way and 2-way interaction, varying grid sizes, multiple nests, and HWRF physics package
  - Determined that scalability limitations are similar to those of HWRF:
    - Scalability efficiency levels-off as tile size reaches ~ 12x12 points
    - Halo exchanges and collective MPI calls in solver are costly
    - Frequent physics calls (for high resolution forecasts) are costly
    - Forcing and feedback costs are small when compared to solver costs (low cost of adding nests)
    - *Model code must be further optimized and physics calls must be reduced to attain further speed-up beyond the saturation point*
  - Investigating ways to further reduce cost of 2-way interaction

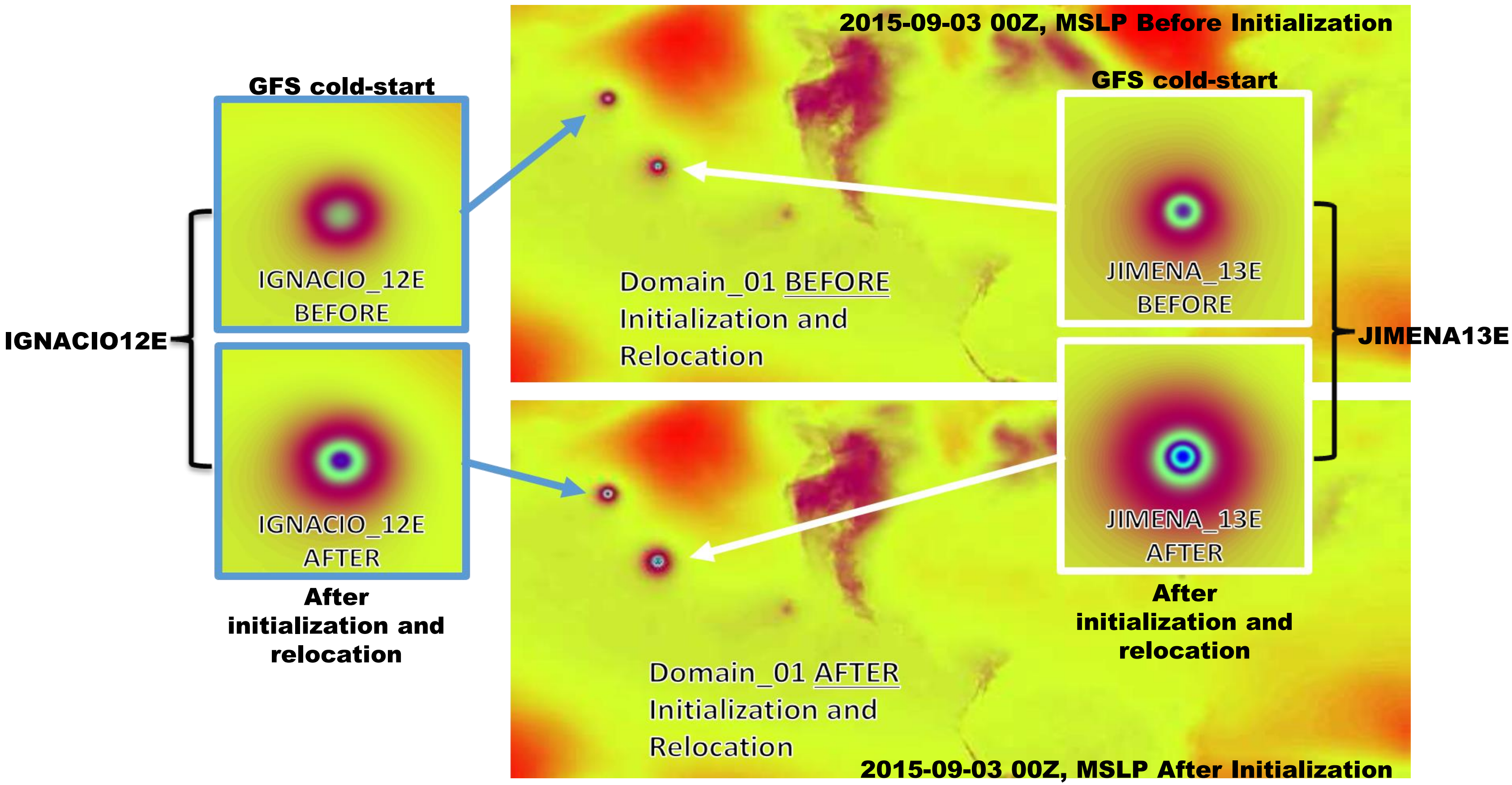


Slide courtesy: Thiago Quirino, HRD/AOML

Multi-Storm Vortex Initialization and Cycling in NMMB

(EMC-HRD Collaborations supported by HIWPP and R2O/NGGPS)

Project Statement: "Test and evaluate the Basin-scale HWRF's multi-storm initialization capabilities in the NMMB/NEMS framework and assess potential for demonstrating the initialization real-time in FY16 and implementing it in FY17."



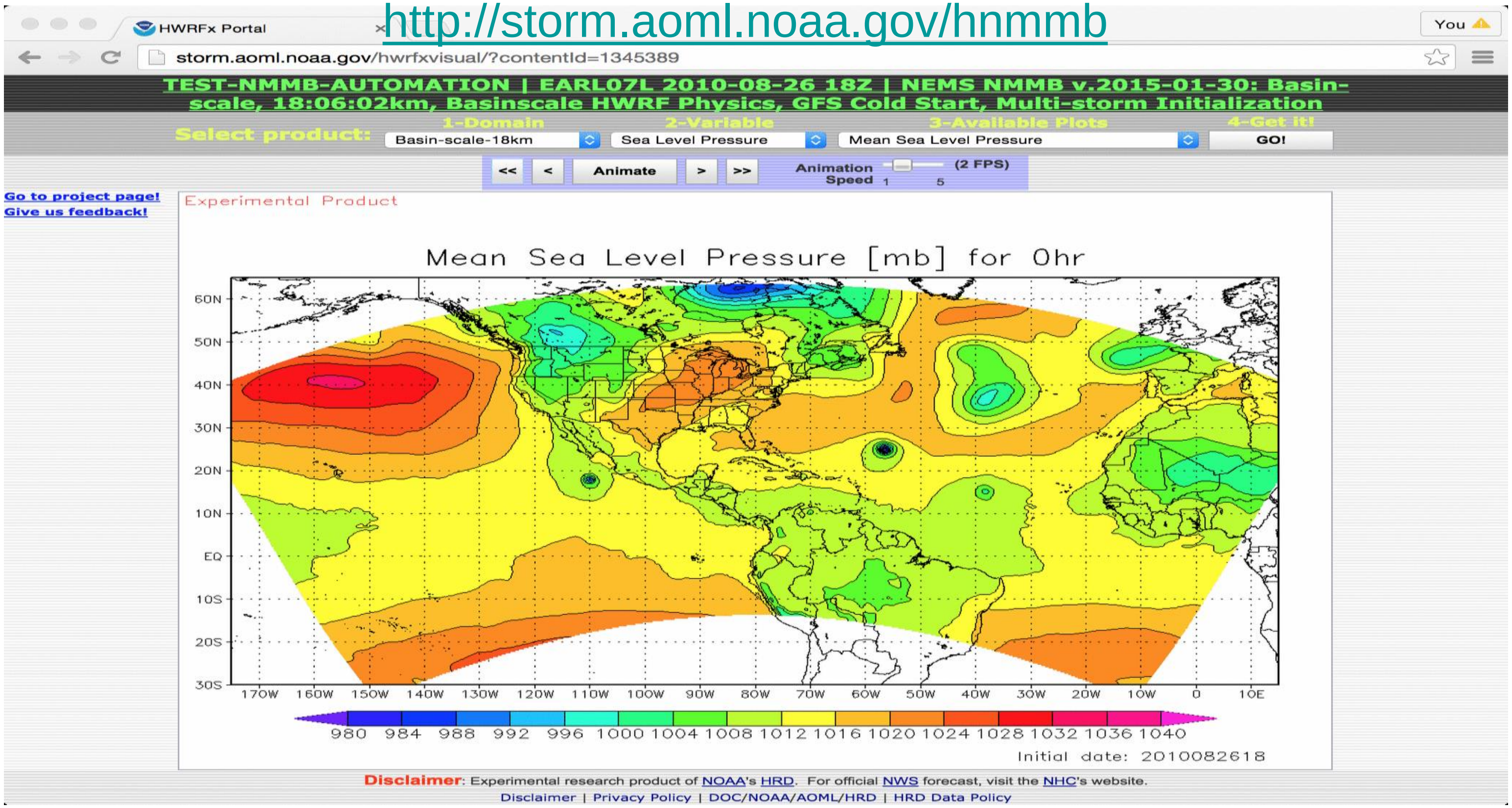
SVN Repository path: https://svnemc.ncep.noaa.gov/projects/hnmmb/trunk/sorc/util/vortex_init_b

Evaluation of the Hurricane NMMB

(EMC-HRD Collaborations supported by HIWPP and R2O/NGGPS)

- Perform quasi real-time forecasts of Basin-scale NMMB at 18:06:02km resolution for multiple-storms in 2015
  - Developed an end-to-end automation system for real-time forecasts

http://storm.aoml.noaa.gov/hnmmb

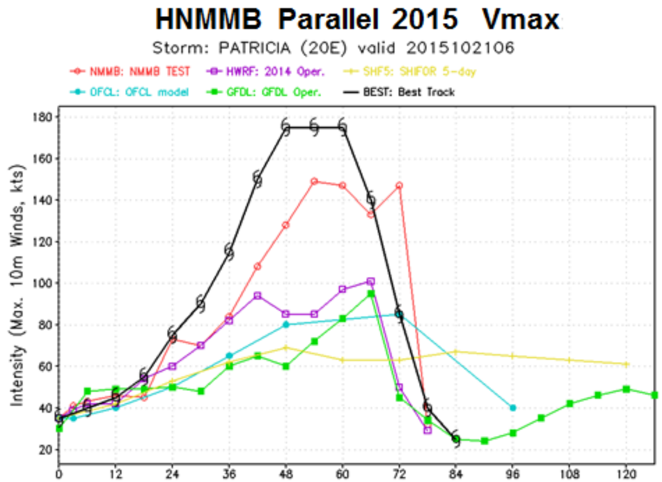


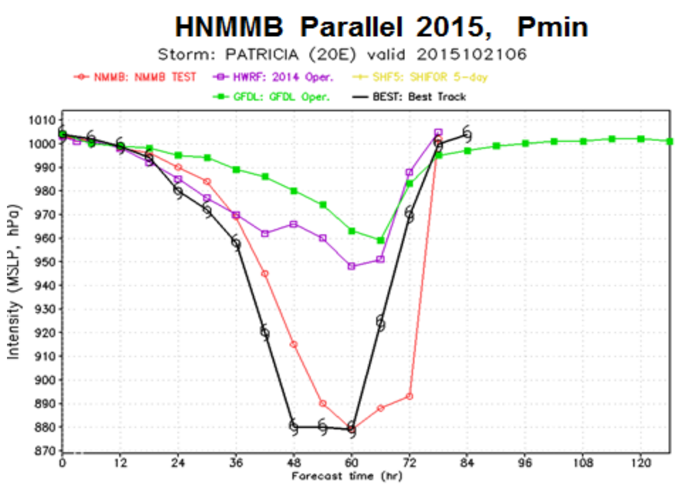
Slide courtesy: Thiago Quirino, HRD/AOML

Progress of HNMMB at EMC

1. The latest HWRF (2015) physics package has been added to HNMMB, and tested.
2. HWRF moving nest algorithm has been implemented in HNMMB, and tested
3. HNMMB Restart capability has been implemented.
4. HNNMB can be complied/run using PC-linux-based gfortran.
5. (1) , (2), (3), and (4) have been added to NMMB trunk
6. Post and tracker scripts are working with NMMB, and tested.
7. Rocoto workflow is being built. Main part of it (NPS, relocation, NMMB, post, tracker) is working now. Lin is still working on pulling data, and archiving..
8. Start to change NMMB scripts from ksh to python. Keqin is leading this effort.

Performance of HNMMB for Hurricane Patricia (2015)

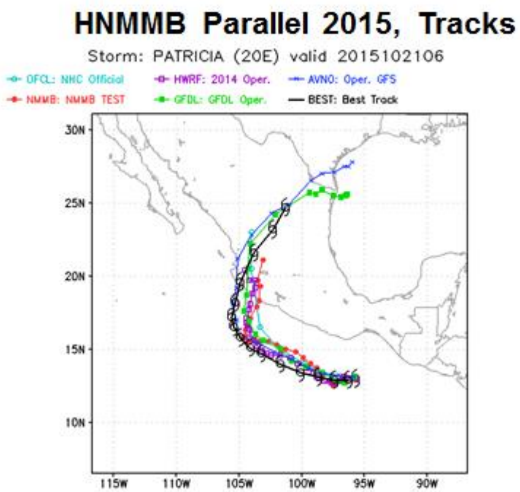




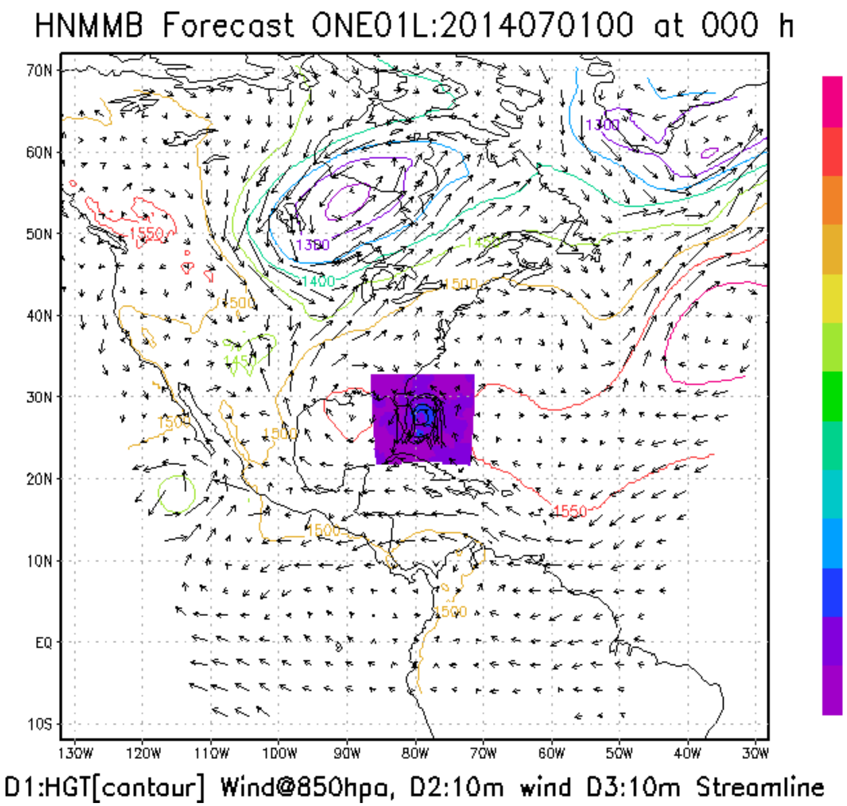
Red: HNMMB, no ocean, no DA

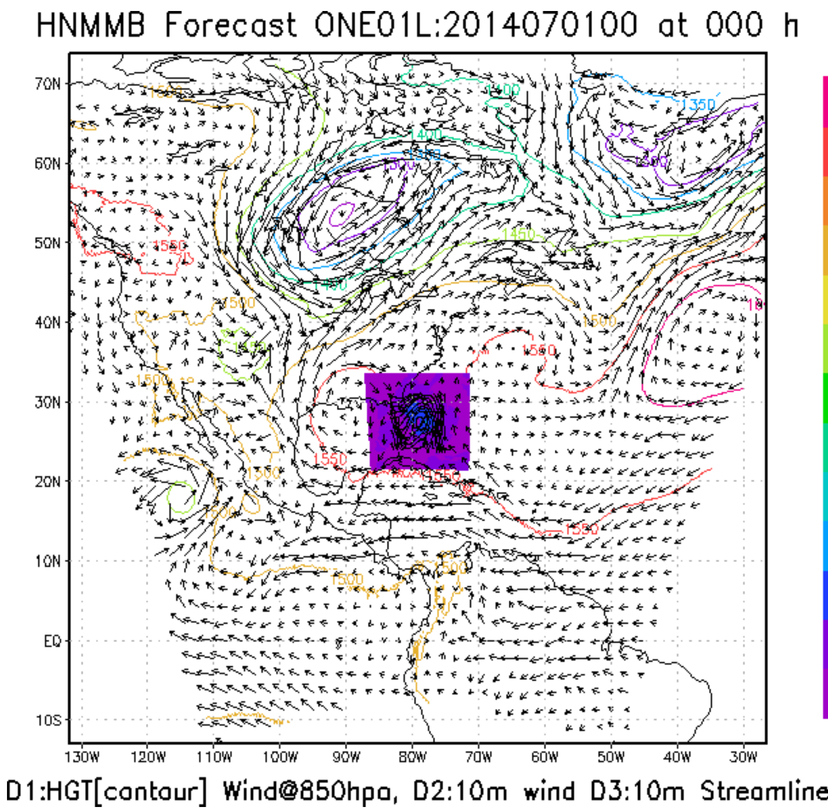
Purple: HWRF, no ocean, no DA

Amazing intensity/Pmin forecast from HNMMB.



HNNMB Nest motion algorithm





Old algorithm: difficult to follow storms when vortex is not well organized or near islands.

New algorithm: follow the storm

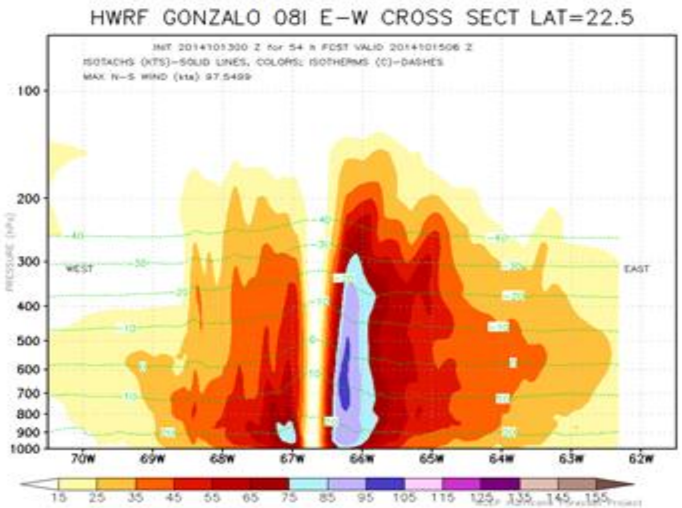
Physics options in HNMMB

Options	2014	2015
microphys	Fer	Fer_hires
shortwave	GFDL	RRTM
longwave	GFDL	RRTM
turbulence	GFSHUR	GFSHUR (updated)
convection	SASHUR	SASHUR (scale-aware)
Sfc_layer	GFDL	GFDL
Land_surface	GFDL	noah

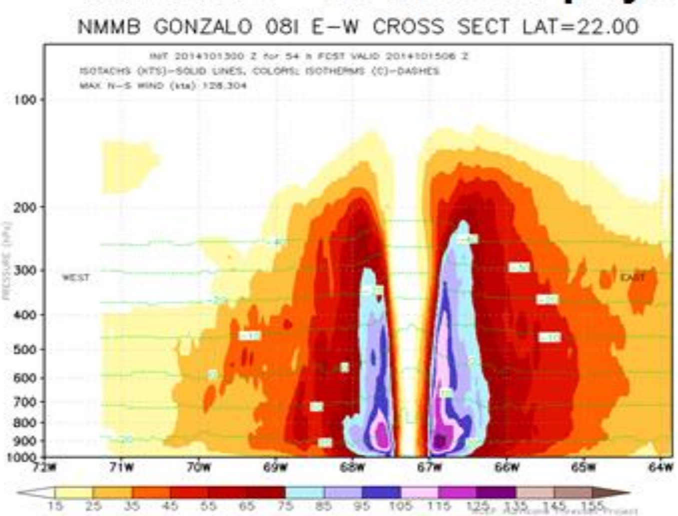
Red: a new option or updated

Impact of Physics on Hurricane Structure

2014 Operational HWRF

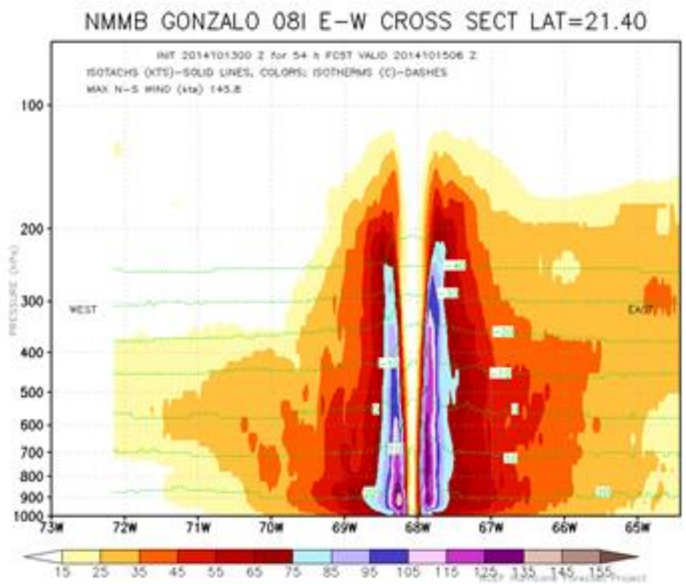


HNMMB + 2014 hwrf phys



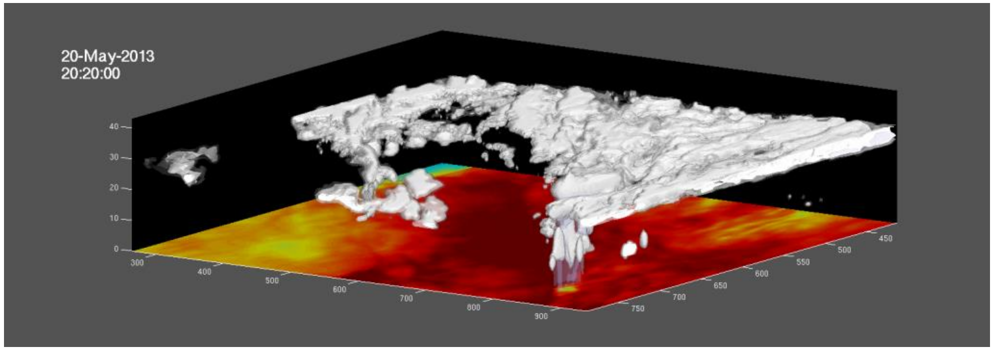
Vertical X-Z cross section of wind:
With 2015 hwrf phys, size and intensity forecasts improved.

HNMMB + 2015 hwrf phys



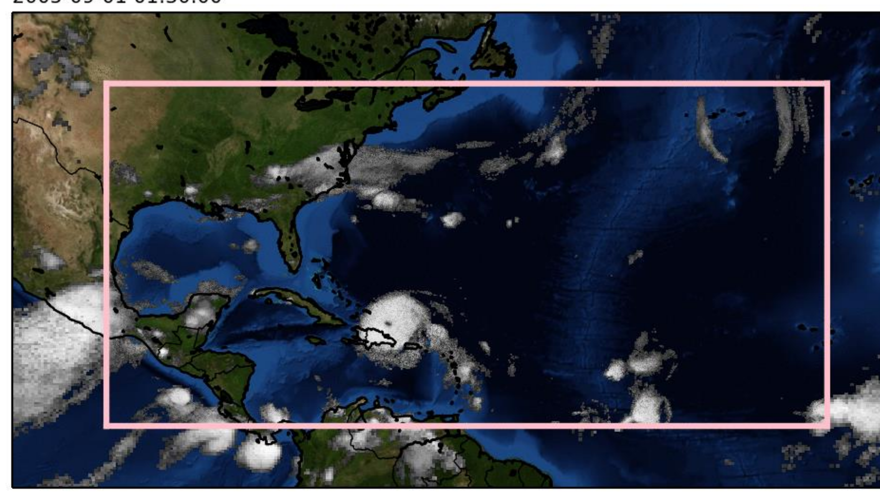
Two-Way Nesting Capabilities in GFDL FV3

(Recent developments using HiRAM and FV3)

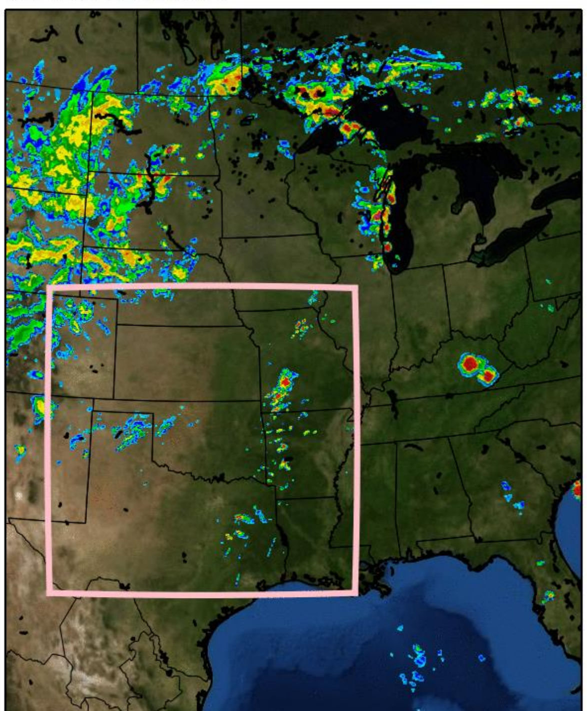


Examples of high-resolution nested grid simulations using HiRAM and FV3

2005-09-01 01:30:00



2013-05-20 12:30:00



three-day HiRAM forecasts of severe convection during the Moore, OK tornado outbreak of May 2013, in a simulation nesting down to 1.3 km over the southern plains (using HIWPP 3km global runs)

Year-long nonhydrostatic HiRAM simulation using 2005 SSTs, using an 8-km nest over the tropical Atlantic

Slide courtesy: Lucas Harris, GFDL

Two-Way Nesting Capabilities in GFDL FV3
(Recent developments using HiRAM and FV3)

- Two-way nests in FV3 designed for simultaneous, consistent, coupled regional and global solutions

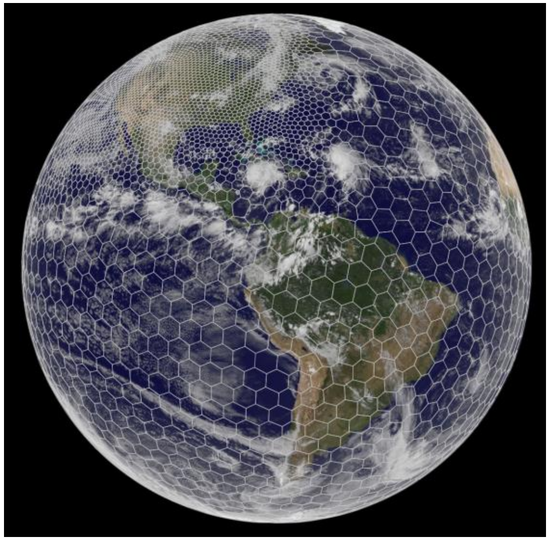
<u>Progress since last July:</u>

- Improvements to nested grid algorithm to improve stability and accuracy of boundary conditions, especially in regions of steep terrain.
- Simple renormalization-based update to ensure conservation of tracer mass, which can now be conservatively updated to the coarse grid
- Maintenance of bitwise-reproducibility of solutions when changing processor counts or restarting
- Started experimental sub-seasonal to seasonal (S2S) predictions in HiRAM using a 8-km nested grid over the tropical Atlantic, based on existing Chen and Lin seasonal prediction system

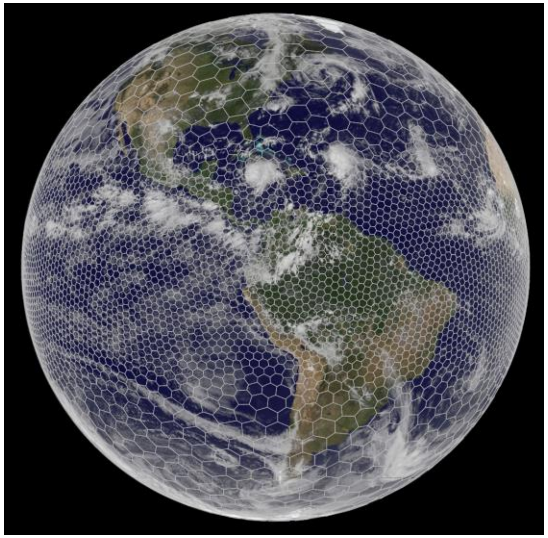
Slide courtesy: Lucas Harris, GFDL

MPAS: Mesh Generation: Lloyd's Method

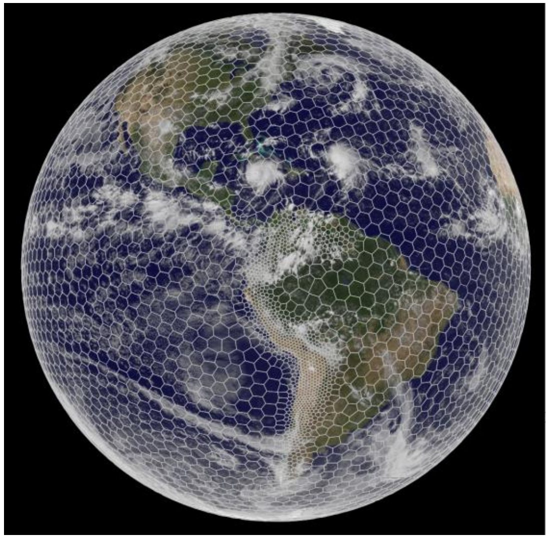
(iterative, using a user supplied density function)



North American refinement



Equatorial refinement

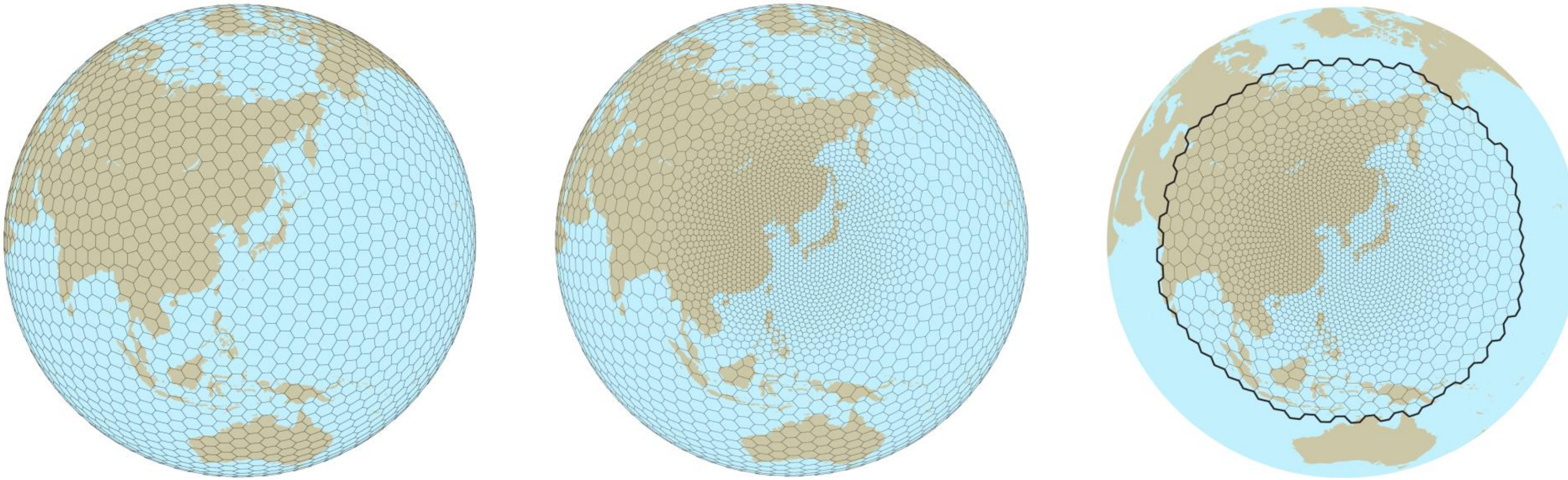


Andes refinement

MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

MPAS: Global Mesh and Integration Options



Global Uniform Mesh | Global Variable Resolution Mesh | Regional Mesh - driven by

(1) previous global MPAS run
    (no spatial interpolation needed!)
(2) other global model run
(3) analyses

Voronoi meshes allows us to cleanly incorporate both downscaling and upscaling effects (avoiding the problems in traditional grid nesting) & to assess the accuracy of the traditional downscaling approaches used in regional climate and NWP applications.

MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

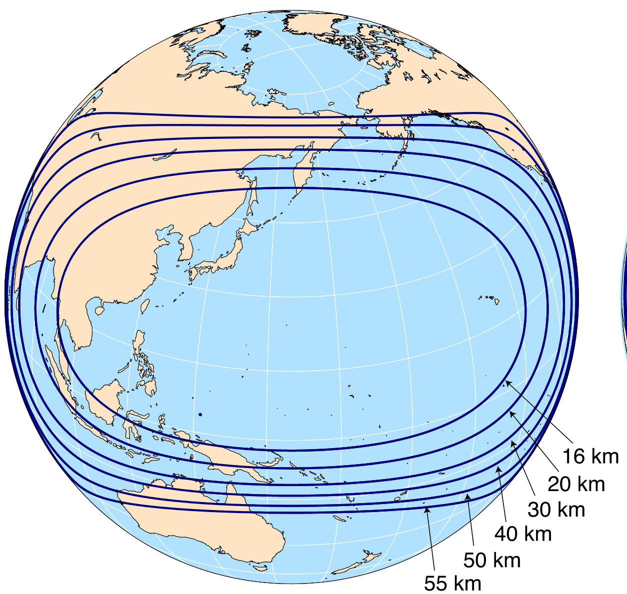
Forecast Experiments with Variable-Resolution Meshes

MPAS-Atmosphere 2013-2014-2015

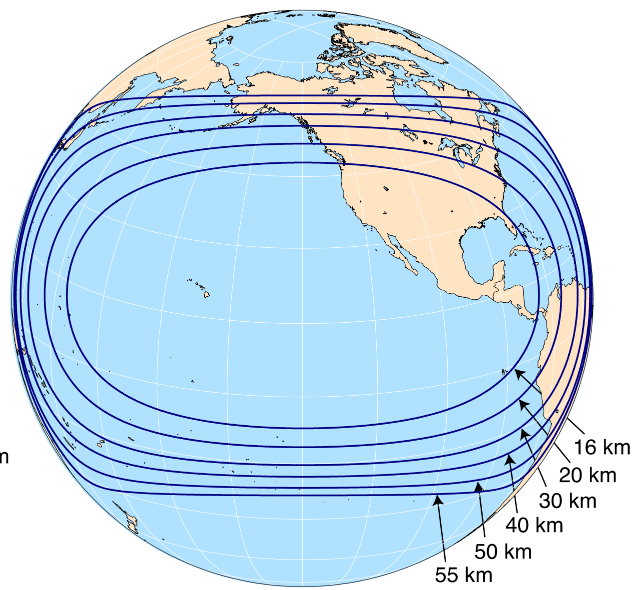
Tropical Cyclone Forecast Experiments

daily 10-day forecasts during the NH tropical cyclone season

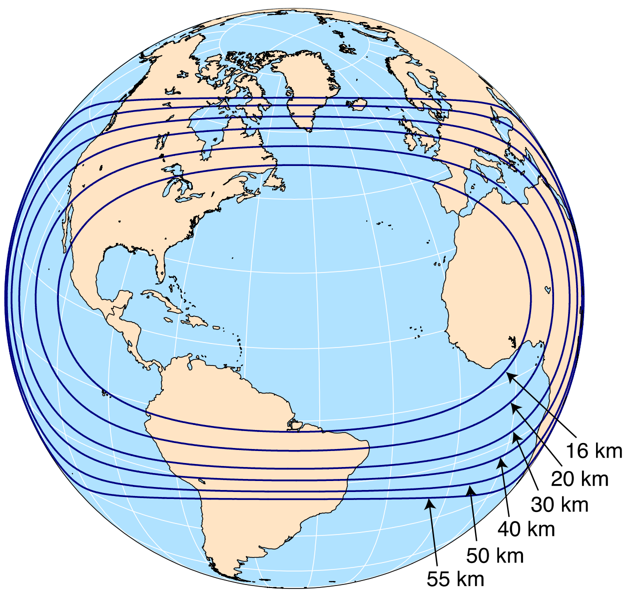
Western Pacific basin mesh



Eastern Pacific basin mesh



Atlantic basin mesh

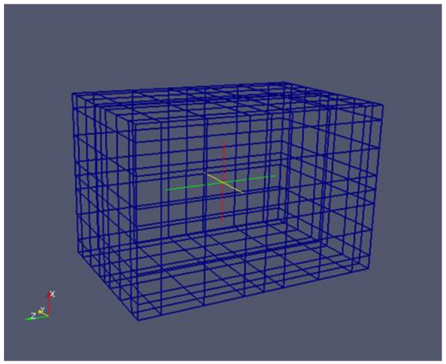


MPAS
Model for Prediction Across Scales

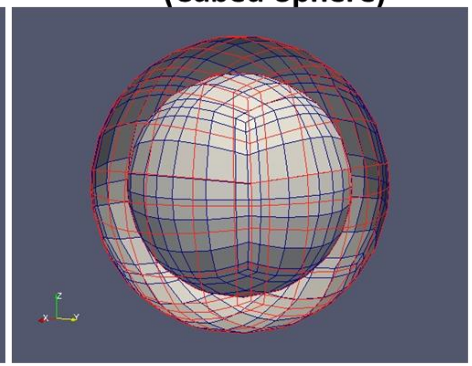
Slide courtesy: Bill Skamarock, NCAR

Mesh Examples for NEPTUNE/NUMA

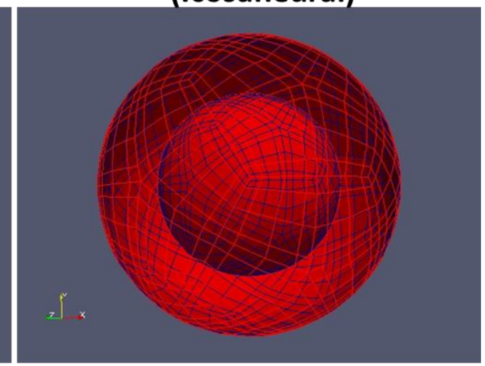
Limited-Area Mode

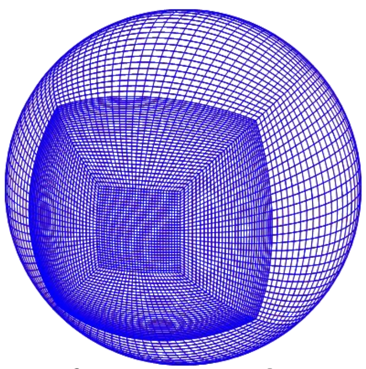


Global Modeling Mode (Cubed-Sphere)

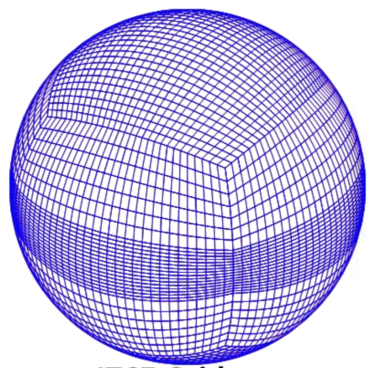


Global Modeling Mode (Icosahedral)

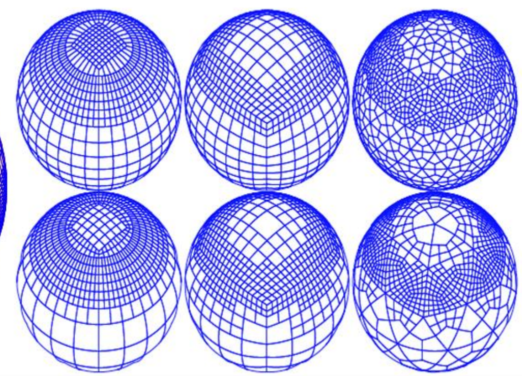




Telescoping Grid



ITCZ Grid



F. Giraldo (NPS)

NEPTUNE-NUMA has a very flexible core that allows for static mesh refinement, cubed-sphere, icosahedral meshes, limited area meshes.

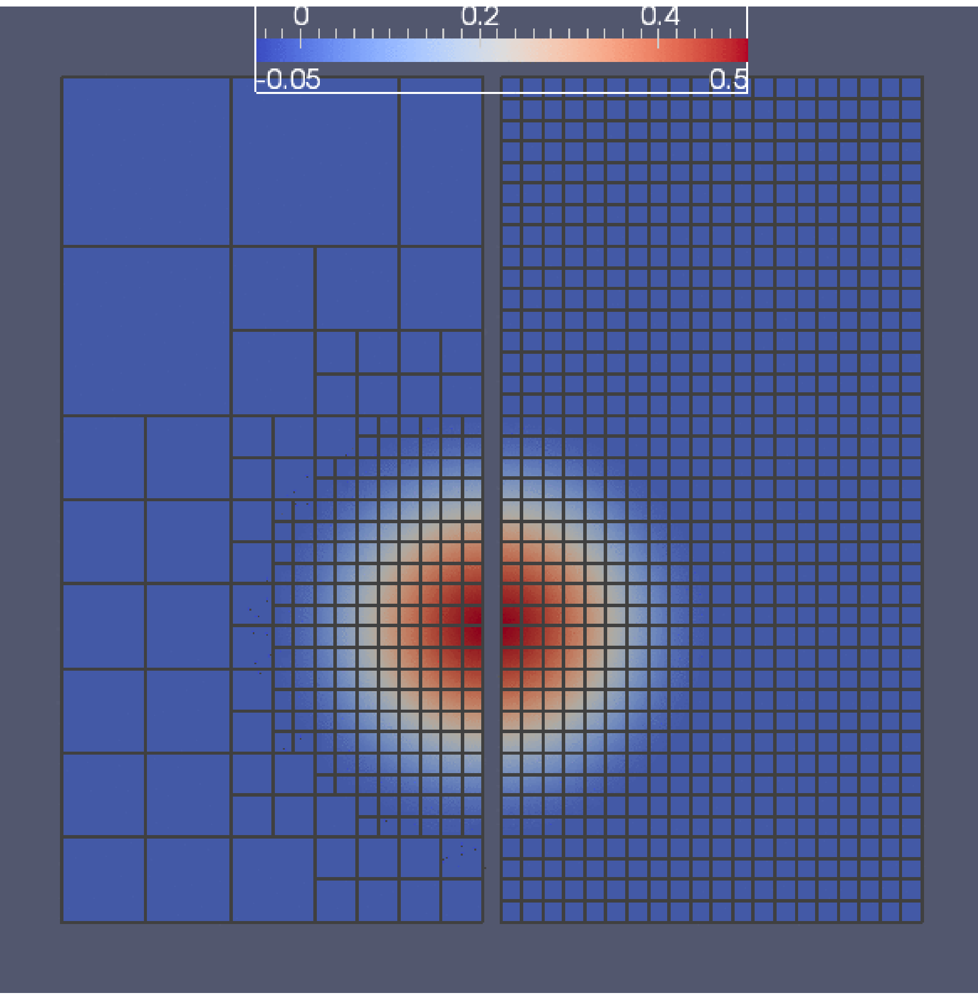
NEPTUNE: *Navy Environmental Prediction sysTem Utilizing the NUMA^2 corE*

NUMA: *Nonhydrostatic Unified Model of the Atmosphere (F. Giraldo NPS)*

Slide courtesy: Jim Doyle, NRL

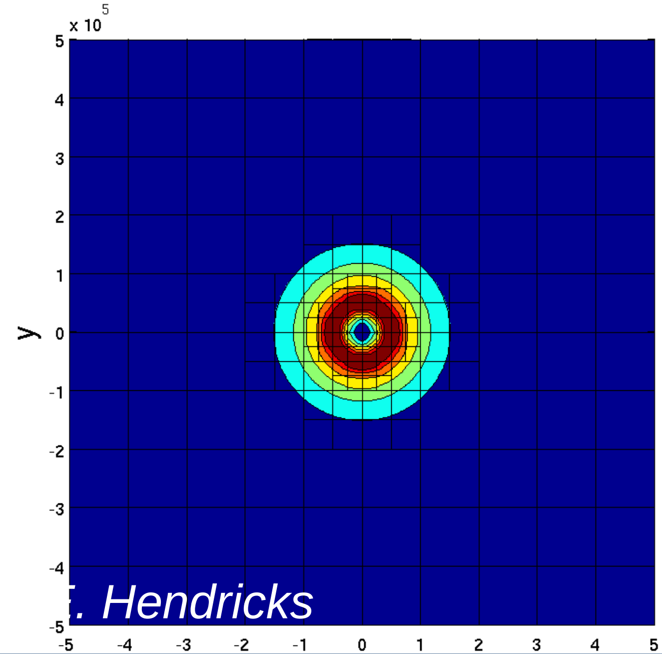
NEPTUNE-NUMA Adaptive Mesh Refinement

2-D Rising Bubble



Kopera and Giraldo JCP (2013)

2-D Vortex



- **Non-conforming adaptive mesh refinement (AMR) capability in NEPTUNE will increase efficiency**
- **Possible applications: tropical cyclones, dispersion, urban, coastal, severe storms…**

Slide courtesy: Jim Doyle, NRL

Variable Resolution Capabilities for NGGPS: Phase 2 Testing

- Purpose is to demonstrate a baseline capability to provide enhanced resolution over certain regions of interest, especially for hurricanes and convective systems

- Approximately a 4:1 variation in horizontal resolution (3 km in the vicinity of convective systems including hurricanes, up to 13 km in the far field) Individual groups can configure as they choose, using fixed or moving high-resolution region, 1-way or 2-way nests

- Groups will be required to run the test with GFS physics, but may submit supplementary tests with their own physics (since ‘scale-aware’ physics may be desirable in this case)

NGGPS Nesting Team Milestones and Deliverables (2015-2016)

- ***NCEP/AOML:***
  - *Transition HIWPP funded upgrades, including ports of the HWRF nest movement algorithm and idealized tropical cyclone framework into NEMS repository*
  - *Determine the efficiency and scalability of NMMB/NEMS with two-way interactive nests*
  - *Develop, test, and evaluate generalized grid-independent interpolation techniques for free-standing nests in the NMMB/NEMS framework*
  - *Test and evaluate the basin-scale HWRF multi-storm initialization in NMMB/NEMS framework and assess potential for demonstrating the initialization real-time in FY16 and implementing it in FY17*
  - *Implement scale-aware physics in NMMB for multi-storm multiple nest applications*
  - *Develop preliminary capabilities for atmosphere-land-ocean-wave coupled system for hurricane applications*
  - *Proof of concept of global to local scale modeling system for hurricane predictions*
- ***GFDL:***
  - *Subseasonal hurricane prediction in a prototype variable-resolution global NGGPS model*
- ***PSU:***
  - *Advancing Storm-Scale Forecasts over Nested Domains for High-Impact Weather*

Green: Completed; **Red: Ongoing**

NGGPS Nesting Team: Updates from PSU

Advancing Storm-Scale Forecasts over Nested Domains for High Impact Weather

- Selected two best cases: 28 April 2014 (153 tornado reports from Mississippi to Kentucky) and 6 May 2015 (65 tornado reports from Texas to Nebraska) based on reasonable performance of NAM 4-km nests (location and timing of CI and subsequent evolution of storms)
- Rerun fire weather nests at 1.33 km resolution (support from SPC forecasters and Geoff DiMego/Eric Rogers, EMC)
- Transferred datasets (>2TB) to PSU from EMC
- Developed diagnostic tools to evaluate the case studies

NGGPS Nesting Team Long-Term Objectives

- Continue to increase resolution of nests that can operate at cloud-resolving scales
- Couple nesting capability with more components as added to NEMS
- Demonstrate global models operating at cloud resolving scales with high-resolution nests for more accurate forecasts of significant weather events
- Develop advanced post-processing techniques, products, verification and diagnostic tools.
- Close interactions with other NGGPS atmospheric dynamics, physics, data assimilation, overarching system, software architecture and engineering teams

Questions?