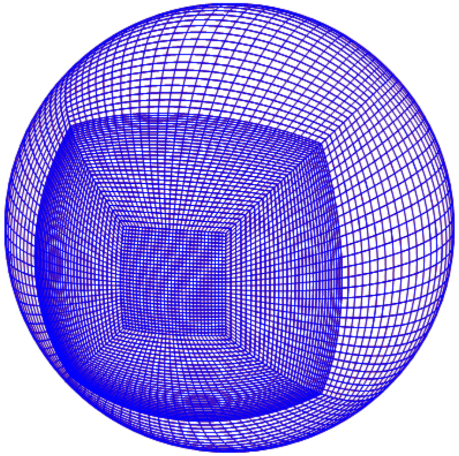
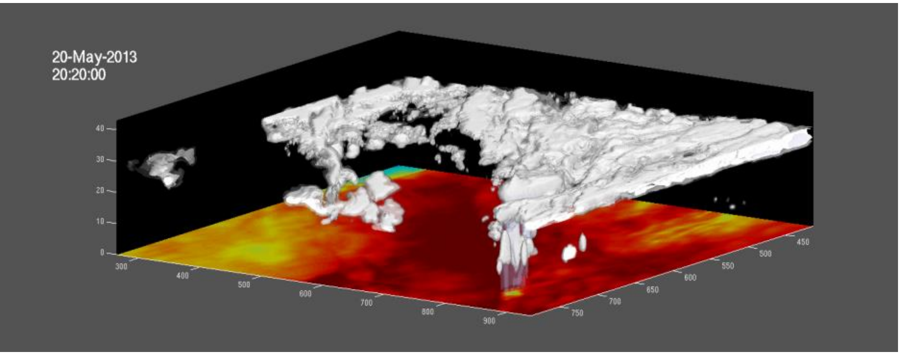
Nesting and Convective Systems

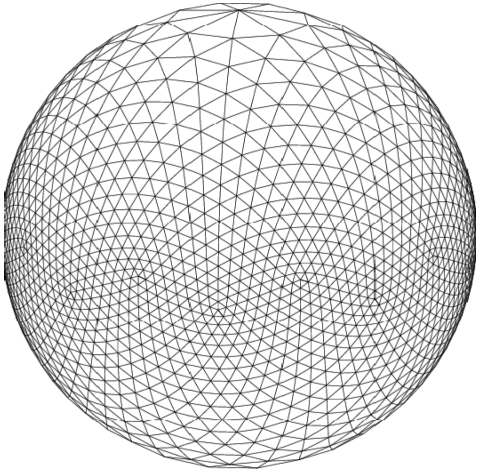
Team Plans and Activities

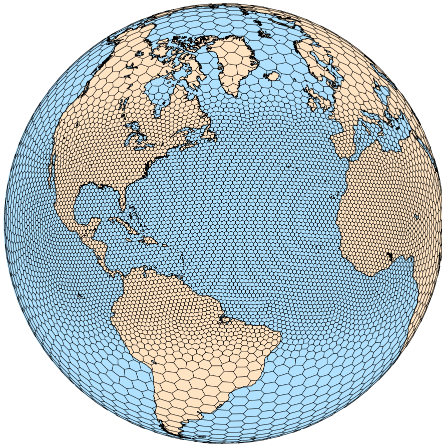


Vijay Tallapragada

NOAA/NWS/NCEP/EMC







NGGPS Annual Meeting
July 14-15, 2015

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

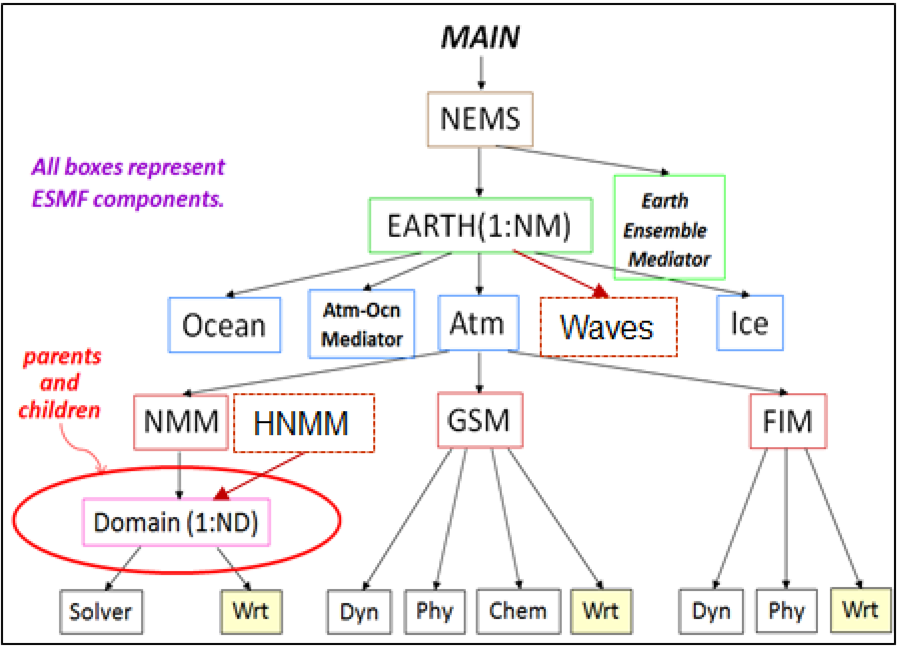
NGGPS Nesting/Convective Systems Team Objectives

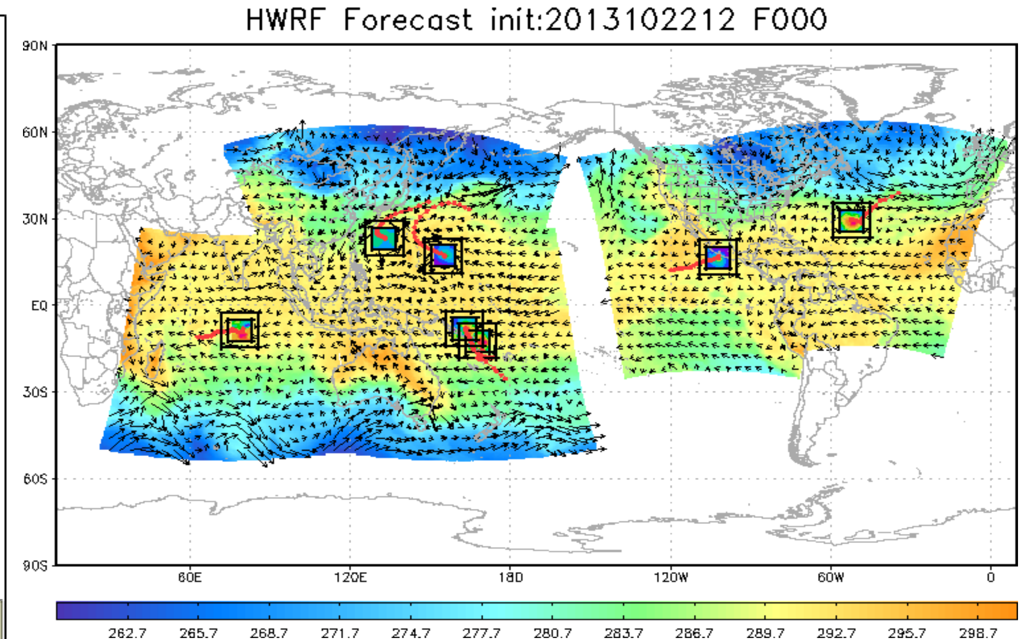
- Incorporate more sophisticated nesting or mesh refinement capabilities in the NEMS framework
- Development of generalized nesting or mesh refinement techniques
- Implement multiple static and moving nests globally, with one- and two-way interaction and coupled to other (ocean, wave, sea ice, land, 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

General Requirements for Operational Nesting or Grid Enhancement

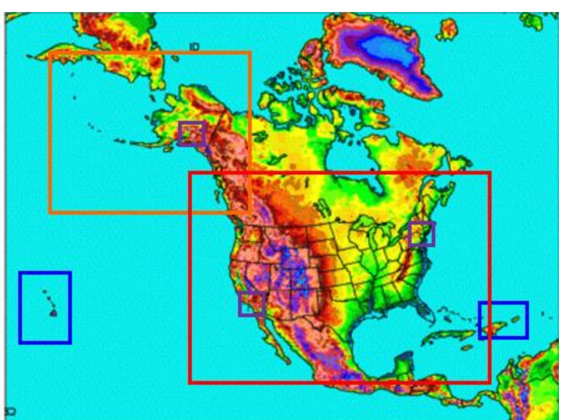
- Static/moving
- 1-way/2-way interactive (nests)
- Multiple nests run simultaneously
- Bit reproducible and restartable (static/moving/ 1-way/2-way)
- *Very fast and efficient!*
- Dynamics, physics and initialization appropriate and applicable for high-resolution nests within the global model

Current Operational Nests for Regional Models: NAM and HWRF





2015 HWRF Global Tropical Cyclone Forecasts: 7-storm capability



NAM: Parent runs at 12 km to 84 hr
Four static nests run to 60 hr

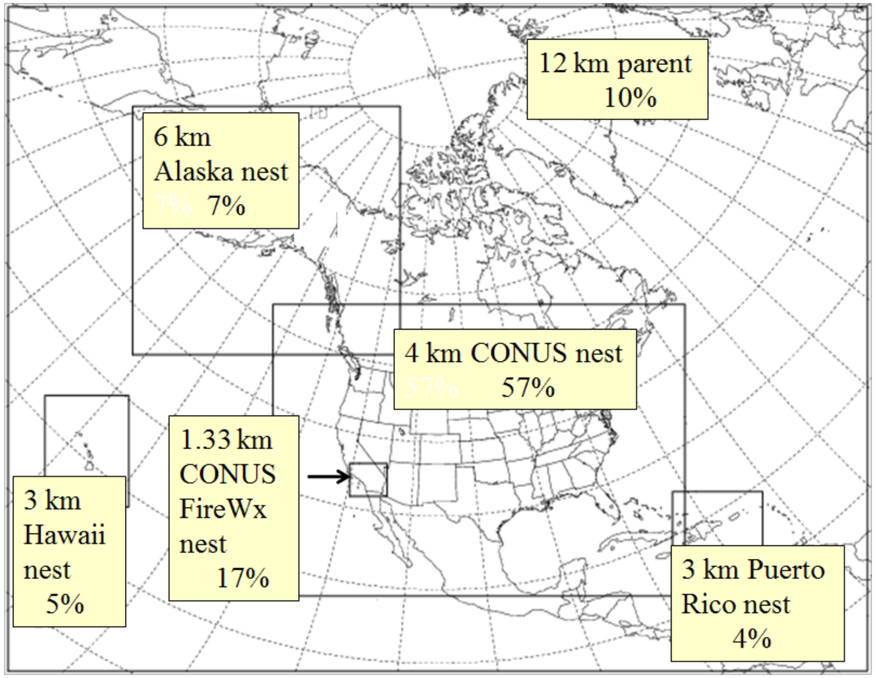
- **4 km CONUS nest (3-to-1)**
- **6 km Alaska nest (2-to-1)**
- **3 km HI & PR nests (4-to-1)**

Single relocatable 1.33km or 1.5km FireWeather grandchild run to 36hr (3-to-1 or 4-to-1)

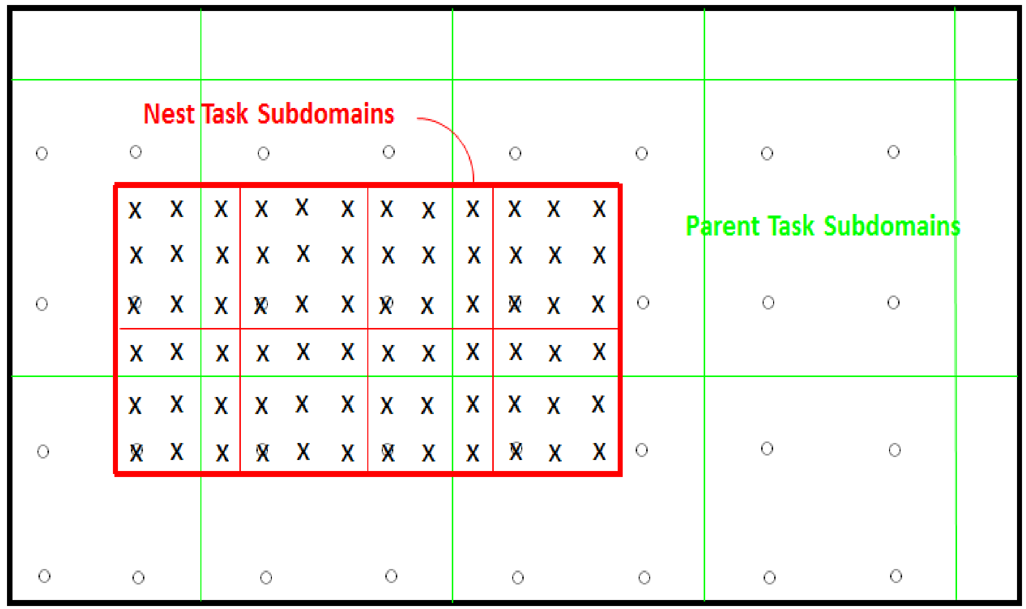
HWRF: Parent runs at 18 km with storm following 2-way interactive nests at 6 km and 2 km resolution out to 126 hr

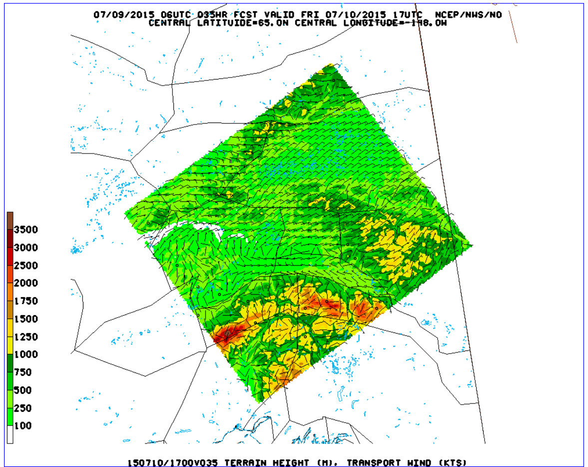
- **Coupled to Ocean (and Waves)**
- **ENSVAR inner core aircraft DA**
- **Seven storms all over the world**
- **Transition to NMMB/NEMS in progress**

Relative Compute Resources used by NAM Nests Running Concurrently



Portion of Parent Domain





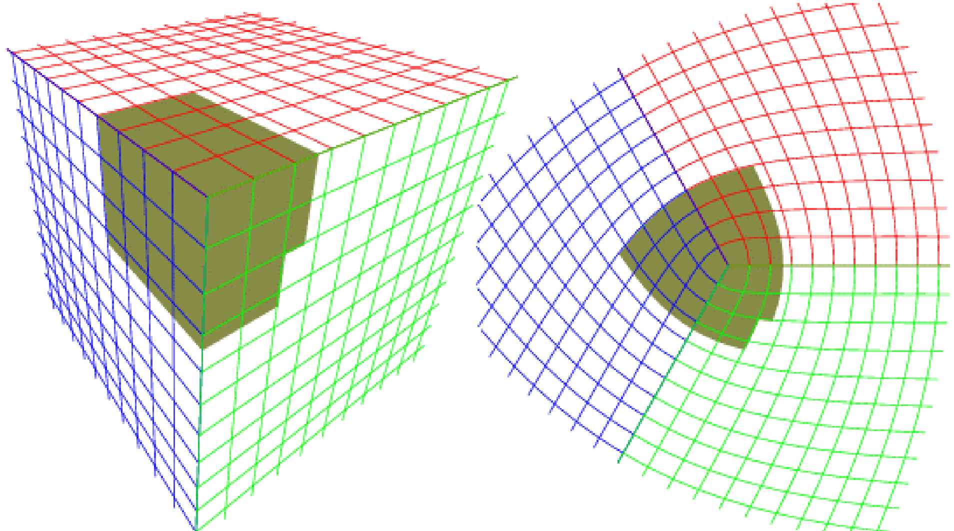
1.5 km child of the Alaska nest (grand child of NAM domain)

Relocatable NMM-B Fire Weather Nest

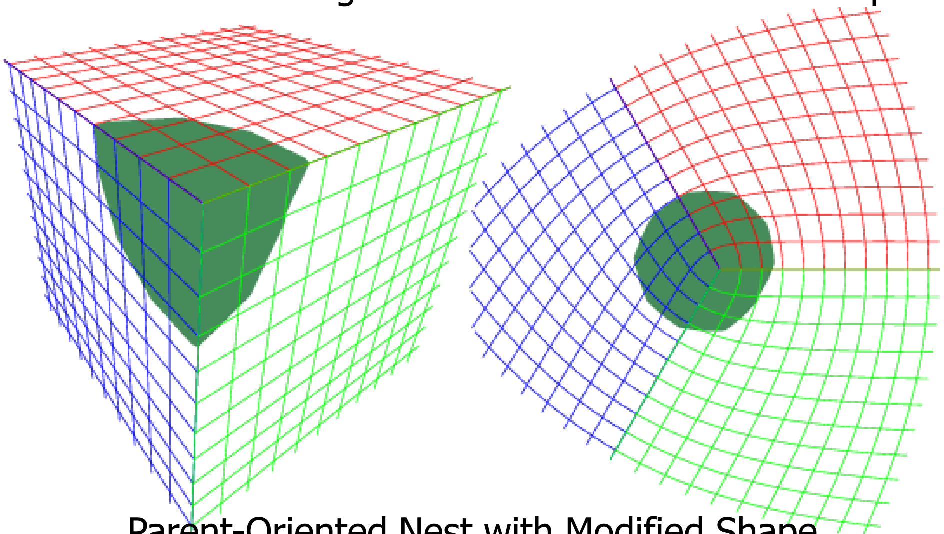
Parent-associated nest vs. freestanding nest on a global lat/lon (NMMB) or NMMUJ

Freestanding => on a projection different from the parent's

Actively being developed for NMM in NEMS framework. Courtesy: Tom Black and Jim Purser



Parent-Oriented Moving Nest on a Corner of a Cubed Sphere



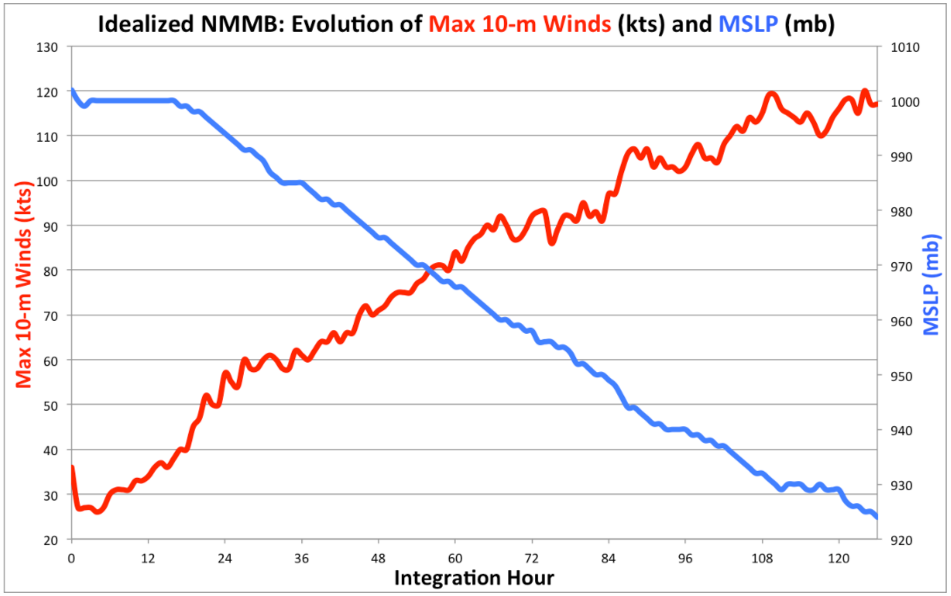
Parent-Oriented Nest with Modified Shape

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

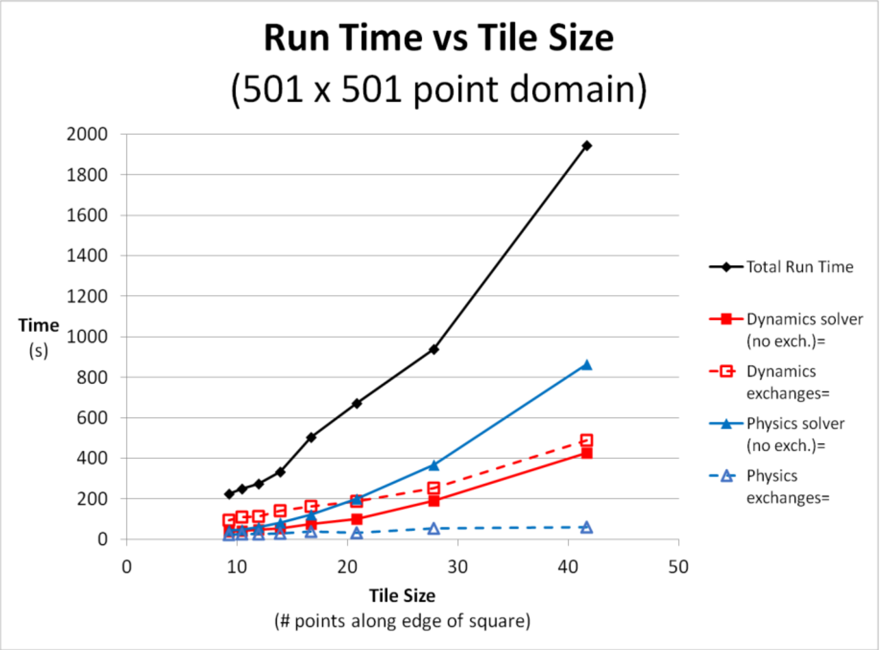
1) Resolution: 18:06:02km, 61 levels, 2mb model top.
2) Initial TC intensity: 20 m/s at 1002 mb.
3) Physics package: HWRF with high-frequency calls

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



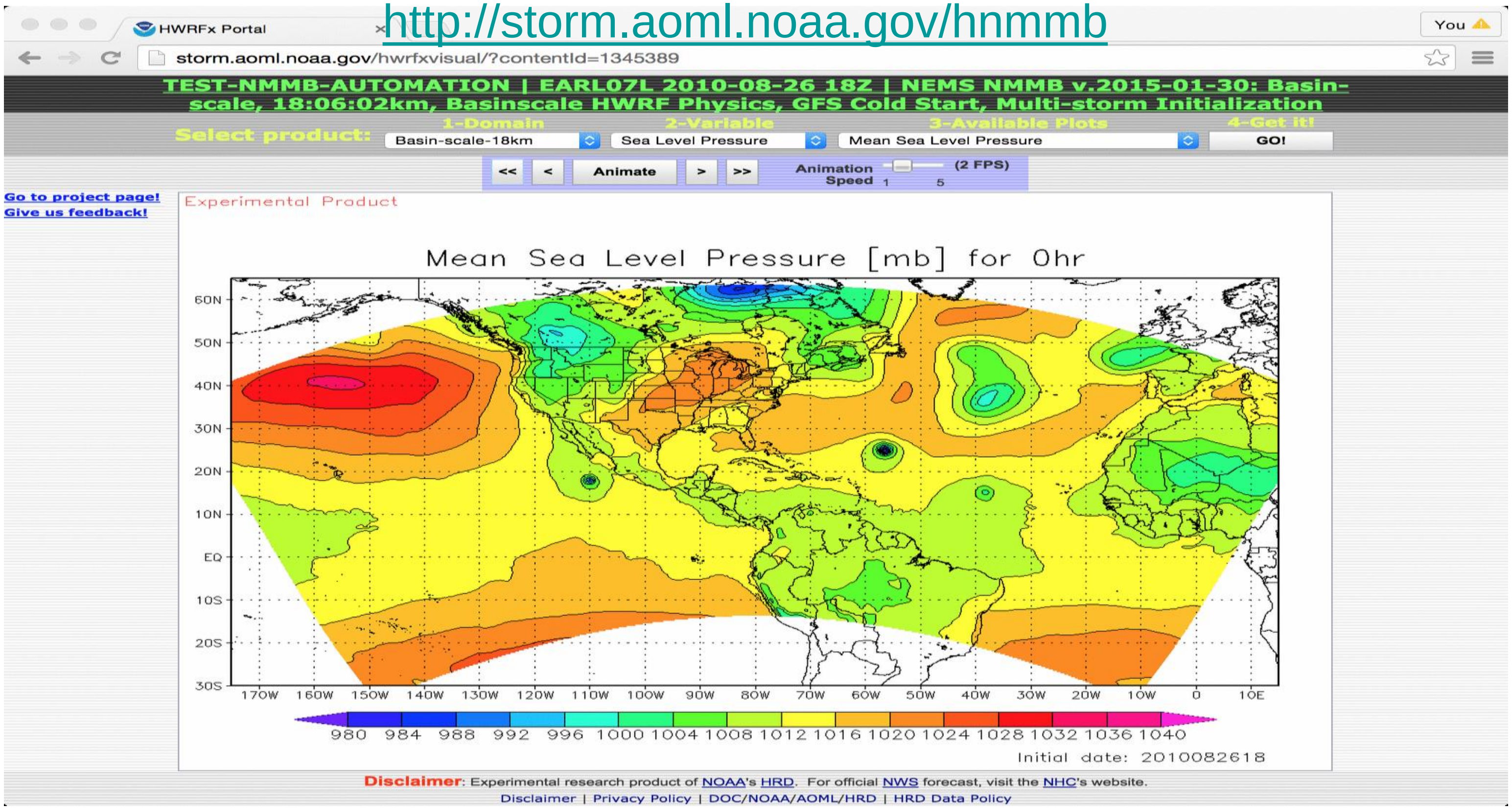
Slide courtesy: Thiago Quirino, HRD/AOML

Evaluation of the Hurricane NMMB

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

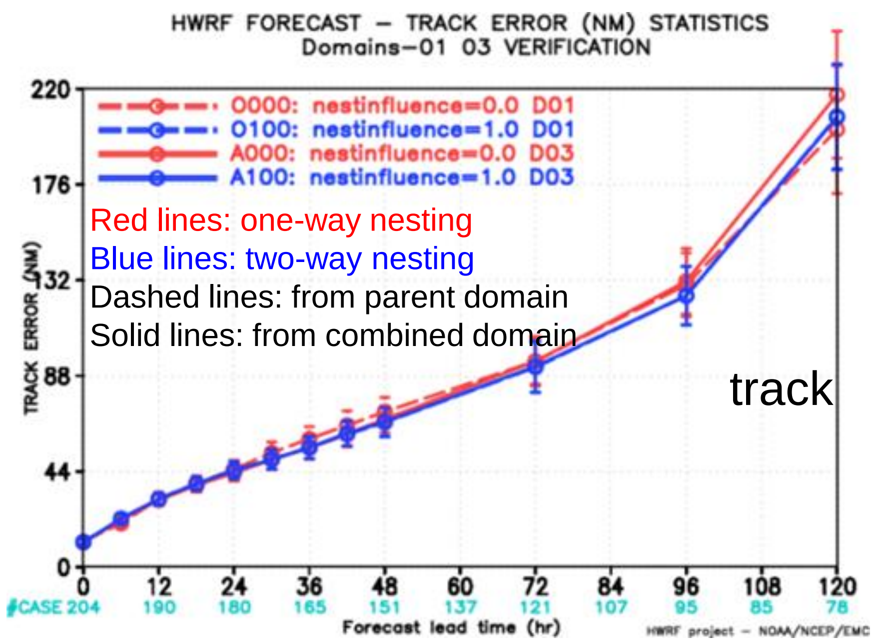
- Perform quasi real-time forecasts of Basin-scale NMMB at 18:06:02km resolution for multiple-storms in 2015
  - Developed an end-to-end automation system for real-time forecasts

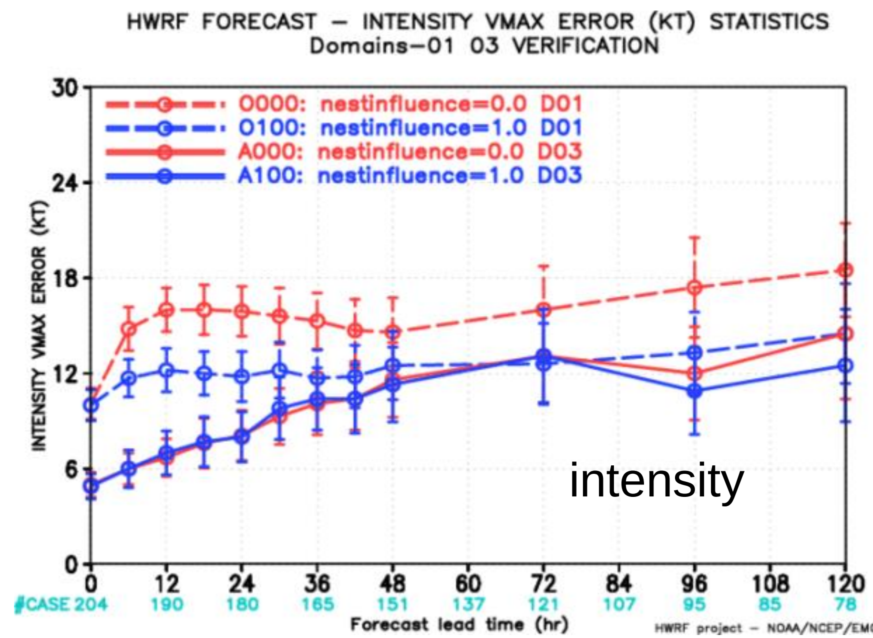
http://storm.aoml.noaa.gov/hnmmb



Slide courtesy: Thiago Quirino, HRD/AOML

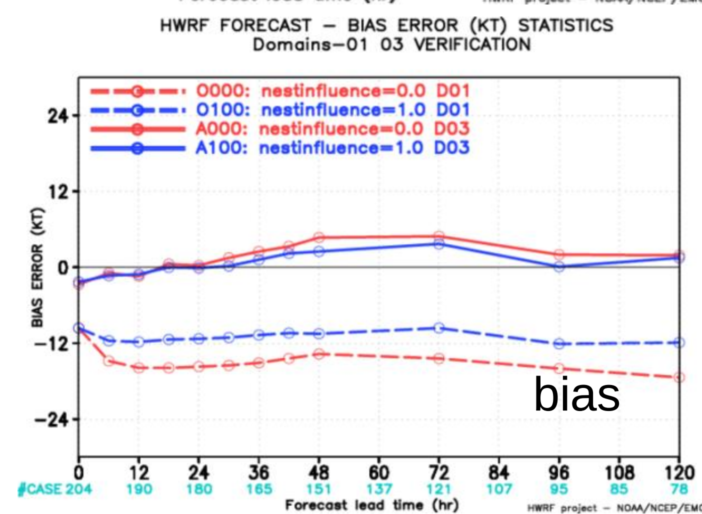
Impact of Two-Way Nesting on Hurricane Track and Intensity Forecasts from Operational HWRF





For track forecasts, two-way nesting reduces errors by 5% compared to one-way nesting

For intensity forecasts, two-way nesting provided significantly better performance compared to one-way nesting runs. Significant reduction of negative bias is apparent. Skill improvements are of the order of 30% in the outer domain and about 10% in the high-resolution domain.



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

- The nested-grid boundary conditions are simple linear interpolation in space of all variables from the parent grid, and a linear extrapolation in time, permitting all of the grids to be integrated simultaneously while allowing the boundary conditions to evolve.

- Boundary conditions for nonhydrostatic simulations are computed using the same semi-implicit solver as the interior nonhydrostatic solution. The nest-to-parent interaction is done only for the winds and temperature.

- The parent grid's winds and temperature are completely replaced, using a vorticity-conserving averaging for the horizontal winds and a spatial average for temperature and vertical velocity.

Slide courtesy: Lucas Harris, GFDL

Two-Way Nesting Capabilities in GFDL FV3

(Recent developments using HiRAM and FV3)

- Grid nesting improves small-scale features in idealized baroclinic cyclones and orographic flows without disrupting the general circulation (Harris and Lin, 2013).

- Multi-decade comprehensive climate simulations using grid nesting improved orographic precipitation, hurricane intensity, and monsoon development (Harris and Lin, 2014).

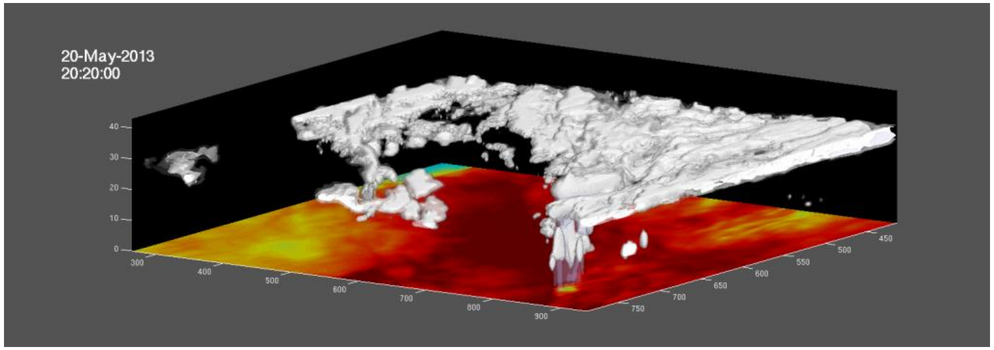
- Grid nesting efficiently improved the simulation of nocturnal Great Plains convection, intense Atlantic hurricanes, and severe thunderstorm outbreaks. (Harris and Lin, 2014).

- Each grid is integrated simultaneously on its own set of processors, opening the possibility, in computing environments with many processors, of running a nested grid in a global simulation with only a minor time penalty.

Slide courtesy: Lucas Harris, GFDL

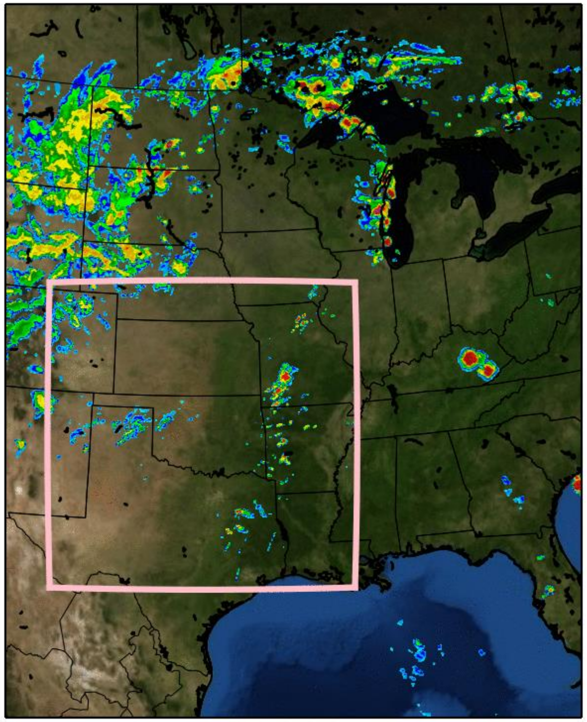
Two-Way Nesting Capabilities in GFDL FV3

(Recent developments using HiRAM and FV3)



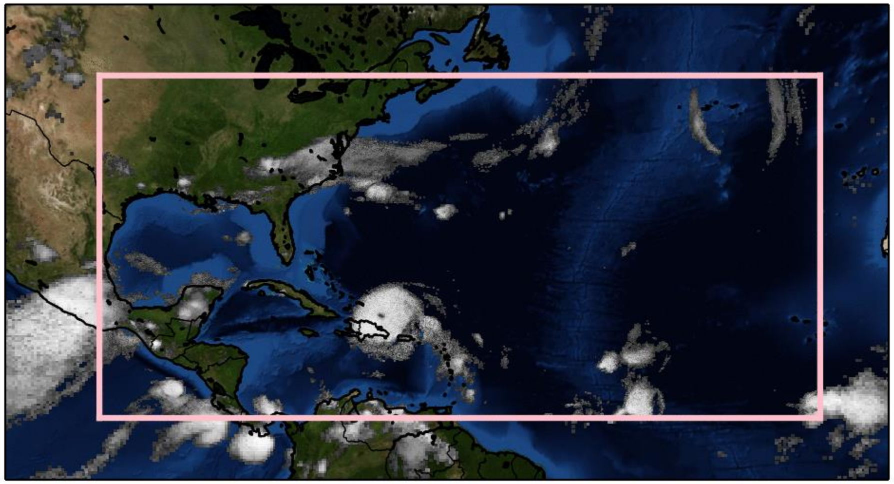
Examples of high-resolution nested grid simulations using HiRAM and FV3

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)

2005-09-01 01:30:00



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

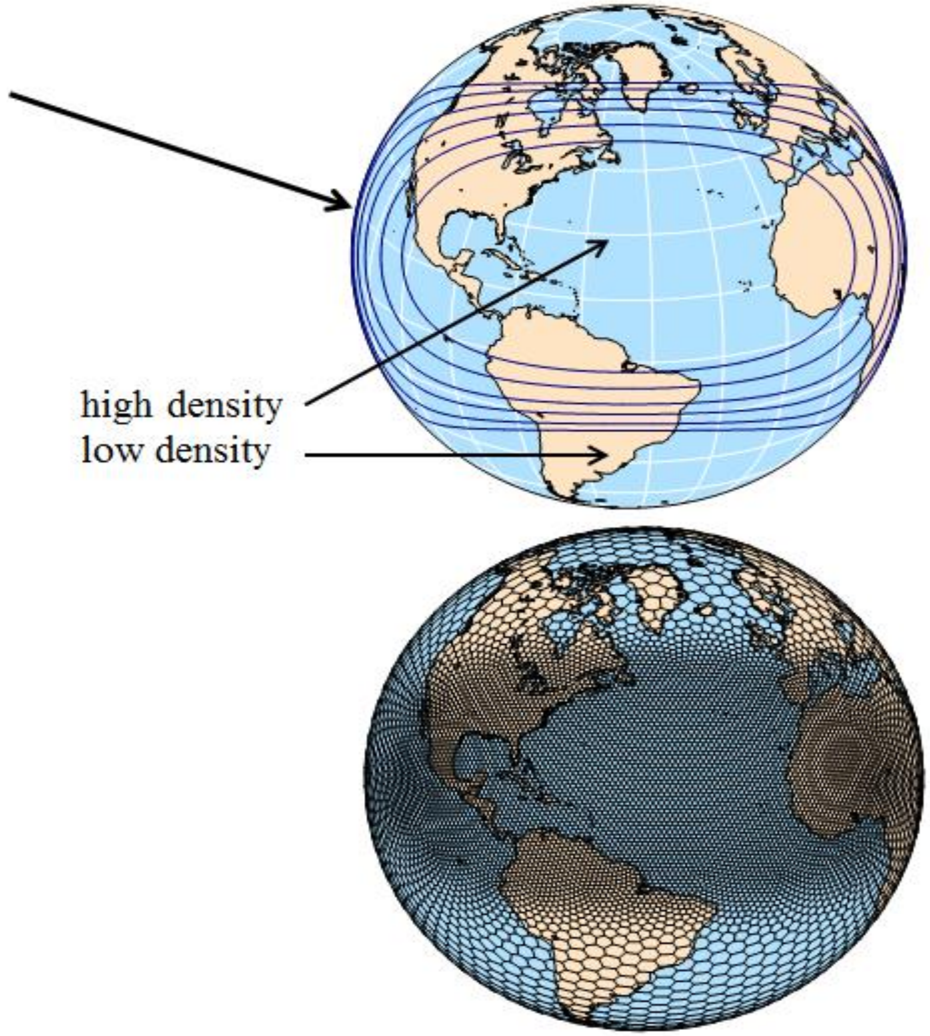
Slide courtesy: Lucas Harris, GFDL

Mesh Refinement Capabilities in NCAR MPAS: Mesh Generation

(1) User-specified density function

(2) Lloyd's method

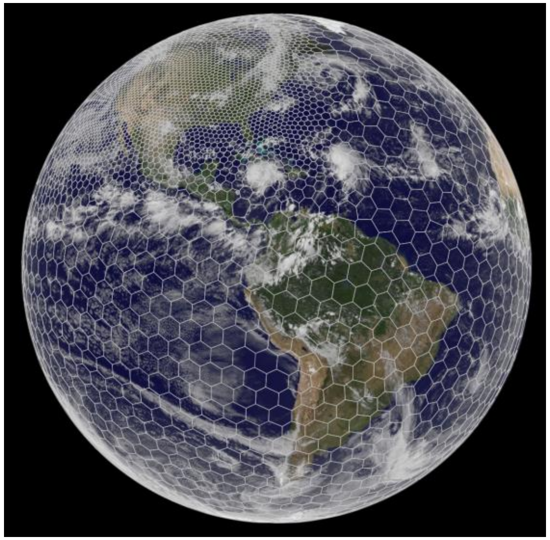
1. Begin with any set of initial points (the generating point set)
2. Construct a Voronoi diagram for the set
3. Locate the mass centroid of each Voronoi cell
4. Move each generating point to the mass centroid of its Voronoi cell
5. Repeat 2-4 to convergence



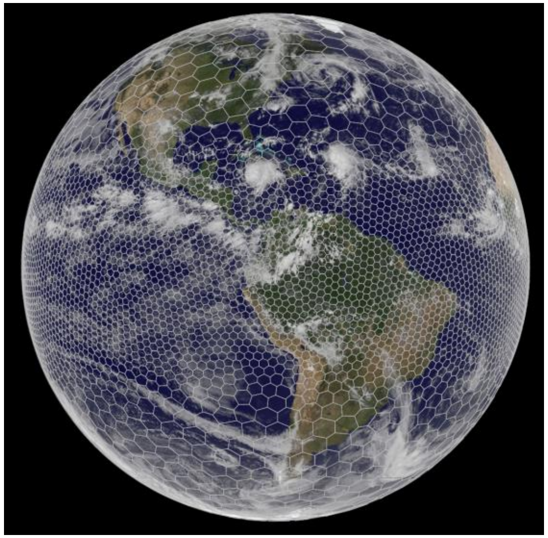
MPAS
Model for Prediction Across Scales

MPAS: Mesh Generation: Lloyd's Method

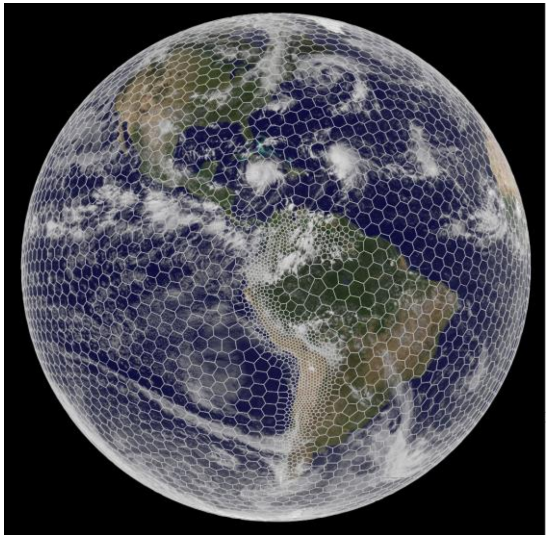
(iterative, using a user supplied density function)



North American refinement



Equatorial refinement

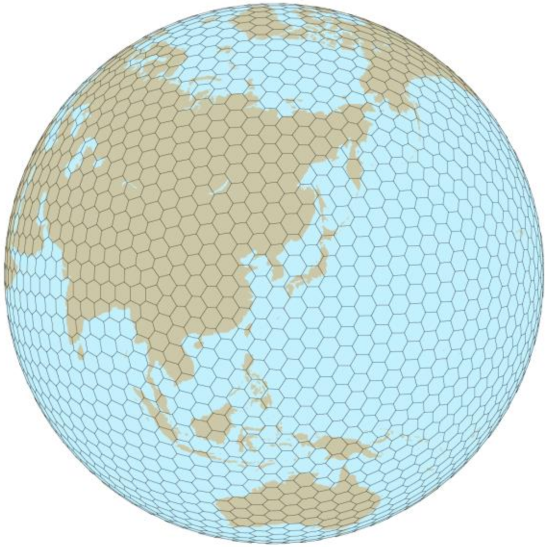


Andes refinement

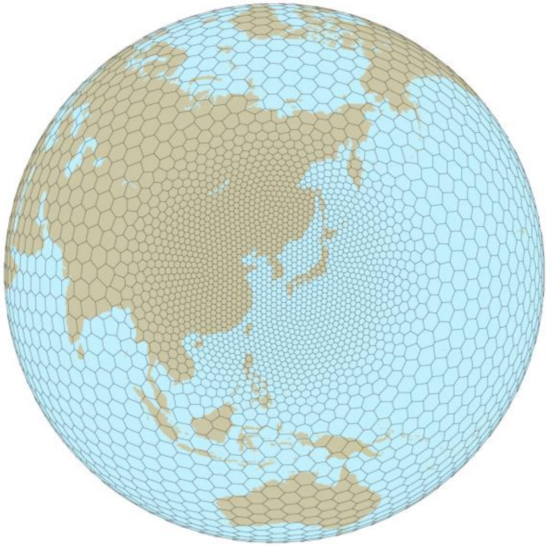
MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

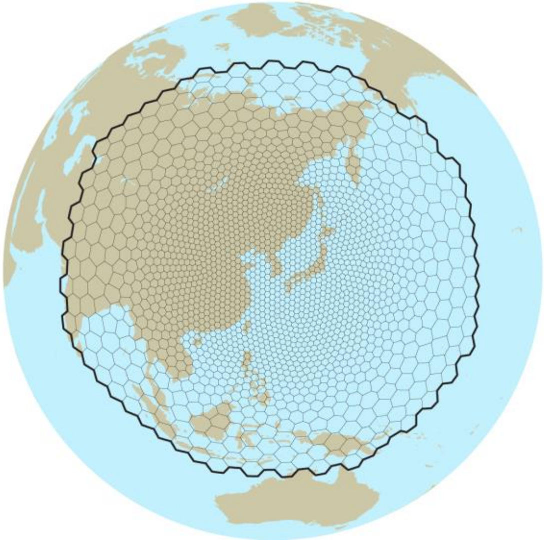
MPAS: Global Mesh and Integration Options



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

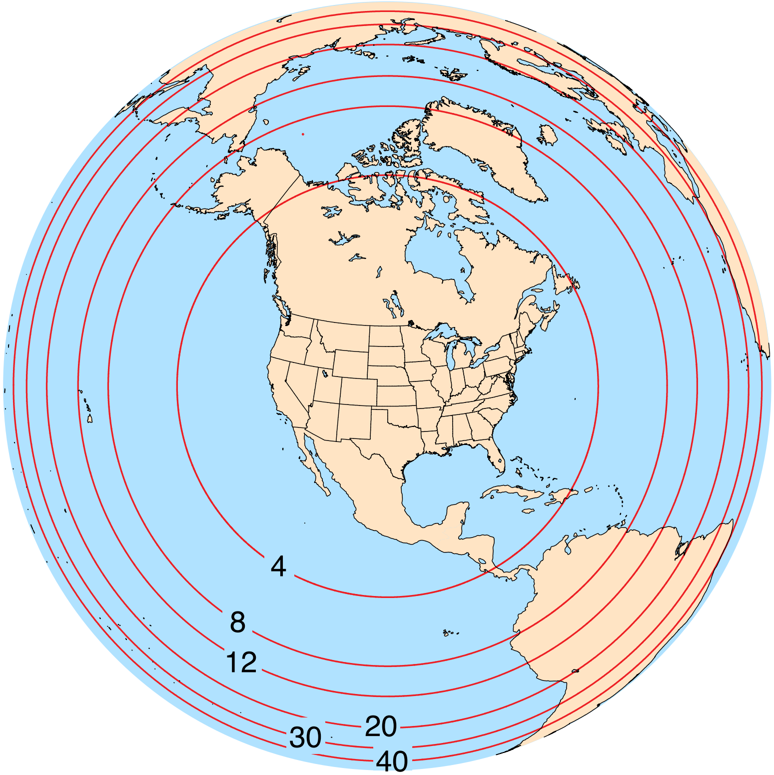
Voronoi meshes allows us to cleanly incorporate both downscaling and upscaling effects (avoiding the problems in traditional grid nesting) & to assess the accuracy of the traditional downscaling approaches used in regional climate and NWP applications.

MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

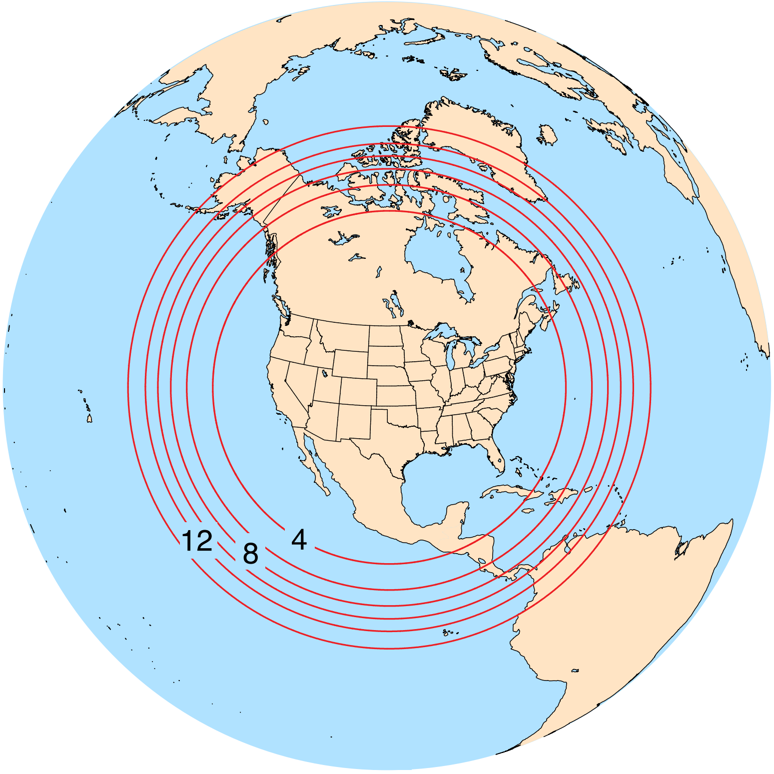
MPAS Forecast Experiments with Variable-Resolution Meshes

HWT Spring Experiment
5-day forecasts, 50 – 3 km mesh 1-31 May 2015



3-50 km mesh, Δx contours 4, 8, 12, 20, 30, 40
approximately 6.85 million cells
68% have < 4 km spacing

PECAN field campaign
3-day forecasts, 15 – 3 km mesh
7 June – 15 July 2015



3-15 km mesh, Δx contours
approximately 6.5 million cells
50% have < 4 km spacing

MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

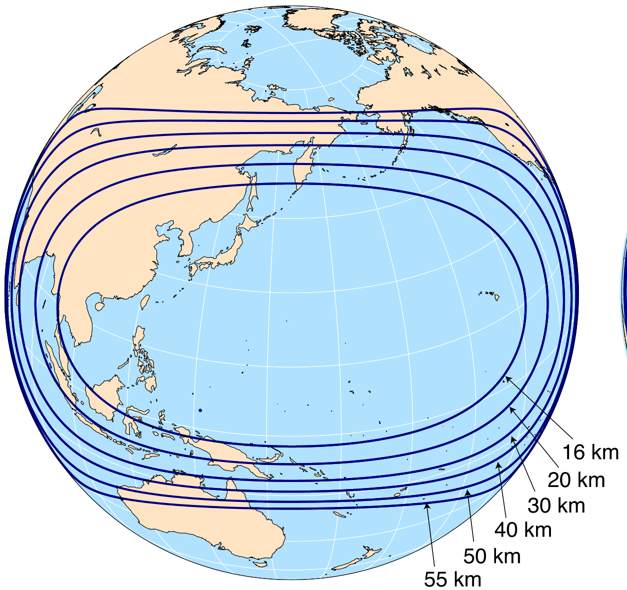
Forecast Experiments with Variable-Resolution Meshes

MPAS-Atmosphere 2013-2014-2015

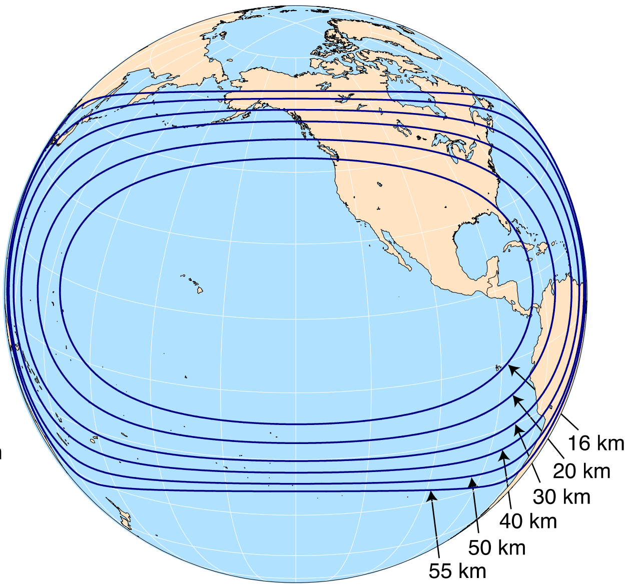
Tropical Cyclone Forecast Experiments

daily 10-day forecasts during the NH tropical cyclone season

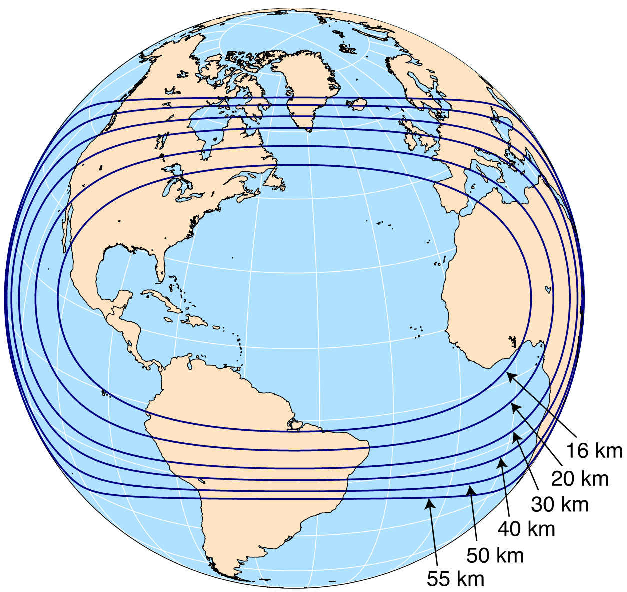
Western Pacific basin mesh



Eastern Pacific basin mesh



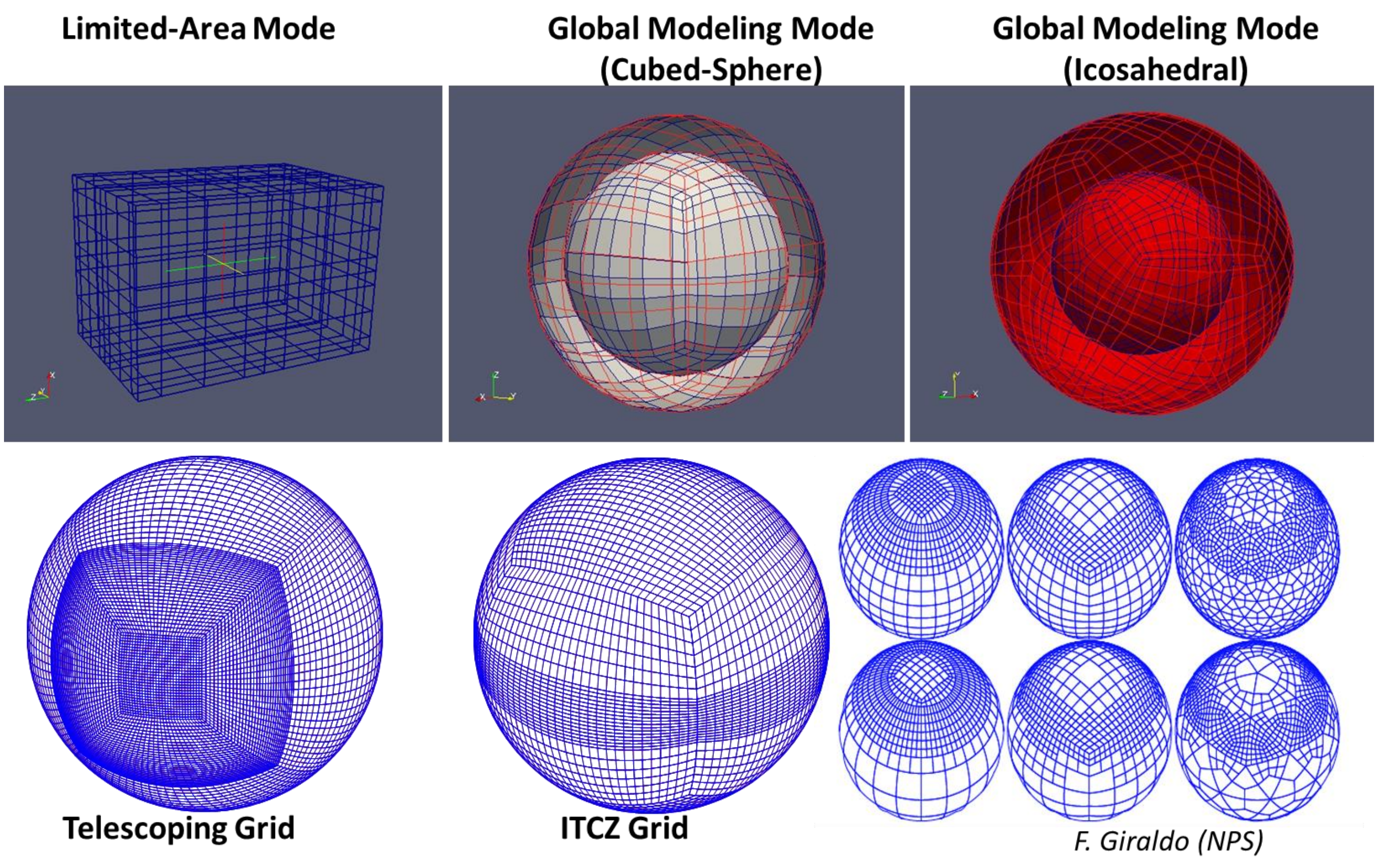
Atlantic basin mesh



MPAS
Model for Prediction Across Scales

Slide courtesy: Bill Skamarock, NCAR

Mesh Examples for NEPTUNE/NUMA



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

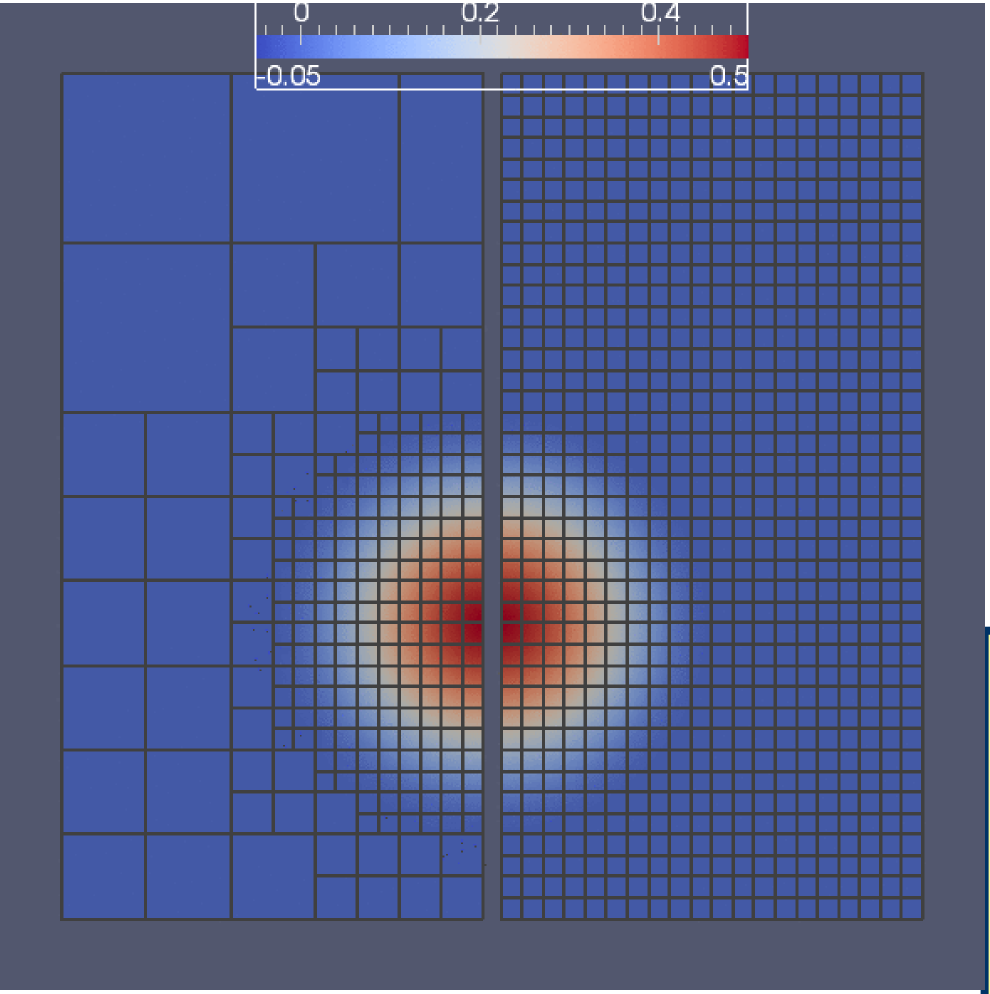
NEPTUNE: *Navy Environmental Prediction sysTem Utilizing the NUMA[2] corE*

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

Slide courtesy: Jim Doyle, NRL

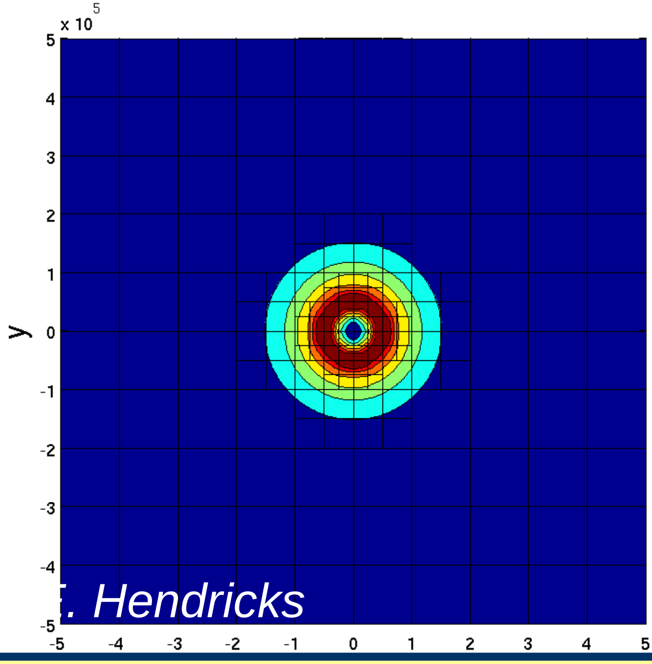
NEPTUNE-NUMA Adaptive Mesh Refinement

2-D Rising Bubble



Kopera and Giraldo JCP (2013)

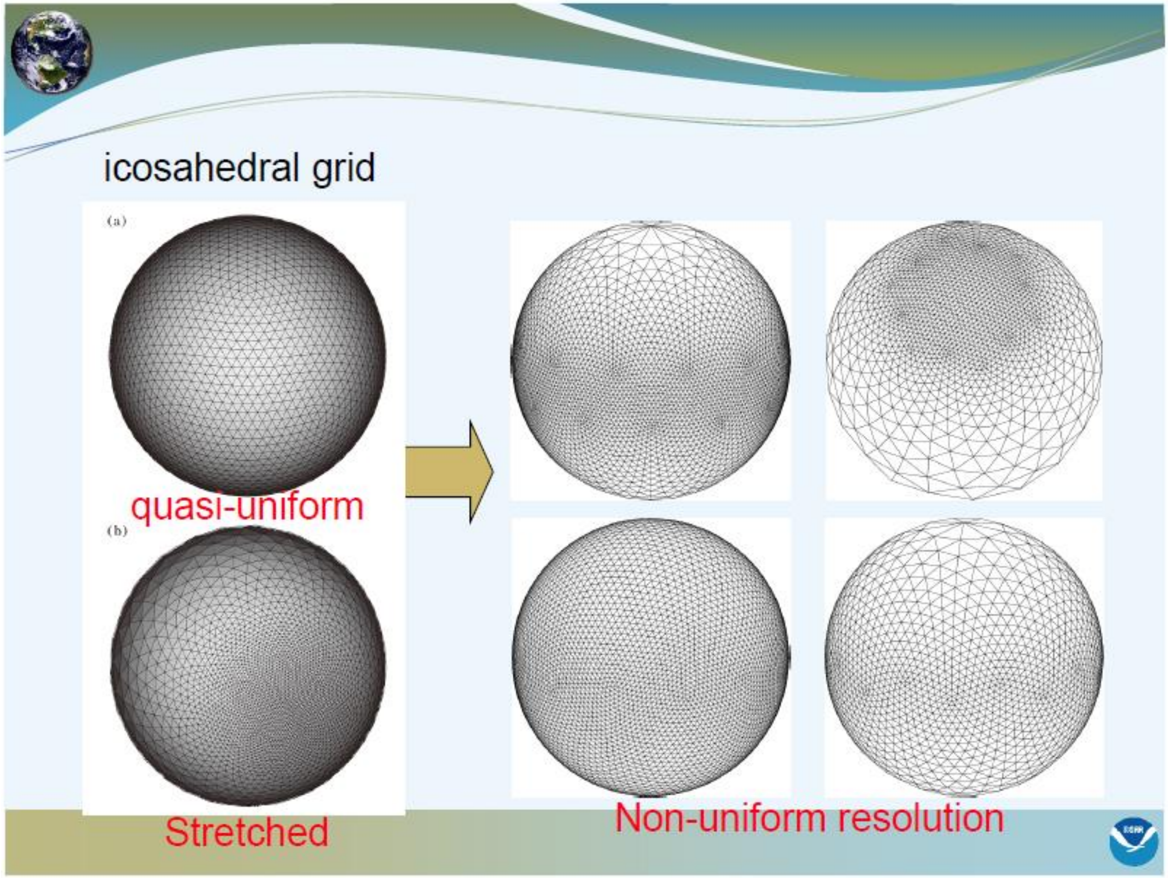
2-D Vortex



- **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

Mesh Refinement Options in NIM



NIM uses a generalized grid structure with an arbitrary number of sides from 4-7 (super-icosahedral) which will accommodate the stretched icos grid that the MPAS grid-generator can produce.

NIM can run with the stretched grid for nesting

NIM can also set up a formal regional nesting capability, similar to that envisioned for MPAS

Slide courtesy: Stan Benjamin, ESRL

Variable Resolution (Nesting or Mesh Refinement, 1-way or 2-way) 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)
- **HWRF physics for hurricanes and HRRR physics for convective systems are needed for evaluating high-resolution simulations for global model with high-resolution nests.**
- **Should be NEMS compliant for future expansion to Unified Global Modeling System**

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***

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

Unified Global Model

Whole Atmosphere Model

NGGPS
Unified Global Coupled Model
(with two-way interactive nests)

"GFS"	"GEFS"	"CFS"
Actionable weather	Week 1 through 4-6	Seasonal & annual

Application
=
Ensemble
+
Reanalysis
+
Reforecast

1 y	2 y	4 y	**Update cycle**
3 y	20-25 y	1979 - present	**Reanalysis**
6h	6-24h	???	**cycling**
WCOSS	WCOSS	WCOSS ?	**where**

NGGPS Nesting/Conevctive 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

- Now that we know of the choice of NGGPS global dycores (FV3 or MPAS)
  - 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 in FV3 and moveable mesh refinement techniques in MPAS
  - Future systems should have genesis tracker in the global domain so we know when to spawn a new nest for a new storm. Nests' resources have to be able to be "held in reserve" for when a nest is activated (or re-activated) for a new storm

Questions?