NOAA High Impact Weather Prediction Project

*Driving Towards the Next-Generation of NWP & HPC in the US*

Prepared by Tim Schneider, NOAA/ESRL/GSD
HIWPP Project Manager & the HIWPP Science Team
Today’s Goals

• Provide a broad overview of HIWPP & context for related talks:
  ✓ (Mon.) Tim Whitcomb
  ✓ (Tue.) John Michalakes; Sandy MacDonald; Mark Govett; Jim Rosinski; Tom Henderson;
  ✓ (Thu.) Craig Tierney

• To share how we are pushing the envelope on a number of fronts:
  o Global Weather Models
  o Physical Parameterizations
  o Data Assimilation
  o High-Performance Computing
  o Data & Visualization
  o Community
Hurricane/Post-Tropical Cyclone Sandy

- Was unique
  - “historically unprecedented”
- 147 direct deaths
- In the U.S.:
  - 72 direct deaths across 8 states
  - At least 75 indirect deaths
  - 24 states impacted
  - Damage estimates exceed $50B

Cuban homes inundated by floods in the wake of Hurricane Sandy.
One Lesson Learned: The public (and Congress) are paying attention...

- Overall a well forecast storm (both European and US models), but...

- “A European forecast that closely predicted Hurricane Sandy's onslaught days ahead of U.S. and other models is raising complaints in the meteorological community.”

- "The U.S. does not lead the world; we are not No. 1 in weather forecasting, I'm very sorry to say that," says AccuWeather's Mike Smith...”

Source: USA Today, October 30, 2012
A similar article appeared on October 28, 2013.
The public has not forgotten.
US National Research Council
Recommendation I.b

Numerical Weather Prediction:

“The National Weather Service (NWS) global and regional numerical weather prediction systems should be of the highest quality and accuracy, with improvements driven by user needs and scientific advances. To achieve this goal, the NWS should give priority to upgrading its data assimilation system and increasing the resolution of its deterministic and ensemble modeling systems.”
HIWPP Objectives

In an unprecedented way, the Hurricane Sandy Supplemental funding provides an opportunity to bring together the nation’s global weather modeling community and focus them on a common goal: developing a state-of-the-art, state-of-the-science, medium-range weather forecast model by the end of the decade, to improve our time-zero to two-week prediction of nature's most dangerous storms such as hurricanes, floods, and blizzards, over the whole globe.

In the next three years we seek to improve our hydrostatic-scale global modeling systems and demonstrate their skill. In parallel, we will accelerate the development and evaluation of higher-resolution, cloud-resolving (non-hydrostatic) global modeling systems that could make a quantum leap forward in our nation’s forecast skill by the end of the current decade.
HIWPP at a Glance

“Just the facts...”

- HIWPP is an OAR “Sandy Supplemental” Project
  - $12.905M
  - *Public Law 113-2, the FY2013 Disaster Assistance Supplemental*
  - Funds expire 30 September 2014
  - 36 months to execute via contracts and grants
- 12 organizations, coast-to-coast:
  - AOML; ESRL/GSD; ESRL/PSD; GFDL;
  - NCEP/CPC; NCEP/EMC;
  - CICS-P; CIMAS; CIRA; CIRES;
  - NCAR; NRL
- Project is comprised of
  - 5 Subprojects
  - 19 Tasks

How are we going to do it?

- Through partnerships...
  - HIWPP funding can help to unify and focus the NWP community
- **Build** on existing efforts
- **Enhance** and **accelerate** them
  - Drive the science to a higher technical readiness level
The structure of the HIWPP Project evolved from the following thought process:

I. Next-Gen Models
- Non-Hydrostatic
- 3-4 km Resolution
- Long-term

II. New Computing
- Run models on the new “massively parallel-fine grain” computers

III. Re-Baseline
- Hydrostatic
- 10-20 km Resolution
- Short-term help

IV. Physics & DA
- Scale-aware Physics
- State-of-the-art data assimilation
HIWPP Genesis (cont’d.)

The structure of the HIWPP Project evolved from the following thought process:

- **V. Test Program**
  - To collect, evaluate and deliver massive amounts of data

- **VI. Visualization**
  - Graphically & interact with vast amounts of information

- **VII. Never Enough Resolution**
  - Nests to capture detailed physical processes

- **VIII. Longer Time Scales**
  - Push our forecasts of high impact weather to months
**Goal:** Hydrostatic Global Models

- Improve the current generation of global NWP models
  - Near-term impact: 1-3 years
- Work with three existing models: FIM; GFS; NAVGEM
  - Run at higher resolutions (sub-20km)
  - Ensembles
- Develop and implement scale-aware physical parameterizations
- Develop and implement new 4D-En-Var hybrid assimilation techniques
- Serves as baseline for the non-hydrostatic models
- “Cut our teeth” on Massively-Parallel, Fine-Grain HPC technologies (FIM dy-cores; physics packages)

Images courtesy of: S. Benjamin
# Quick Dive: HIWPP Hydrostatic Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Agency</th>
<th>Resolution (at 40° Lat.)</th>
<th>Initial Output Freq. &amp; Resolution</th>
<th>Vertical Levels</th>
<th>NEMS ready</th>
<th>Initial Condit.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FIM</strong></td>
<td>ESRL/GSD</td>
<td>15km to 16day (10 km in future)</td>
<td>1 hr</td>
<td>1/8°</td>
<td>64</td>
<td>Y</td>
<td>Icosahedral grid; isentropic sigma vertical coordinates; finite volume core GFS 2012 (w/updates) physics;</td>
</tr>
<tr>
<td><strong>GFS</strong></td>
<td>NCEP</td>
<td>13km to 10 days 27km to 16 days</td>
<td>1 hr (0-12 hrs) 3 hrs (12+ hrs)</td>
<td>1/4°</td>
<td>64</td>
<td>Y</td>
<td>Spectral core (spherical harmonic basis functions w/ transformation to a Gaussian grid); vertical sigma pressure hybrid coordinate; GFS 2014 physics;</td>
</tr>
<tr>
<td><strong>NAVGEM</strong></td>
<td>Navy</td>
<td>25km</td>
<td>3 hrs</td>
<td>1/4°</td>
<td>64</td>
<td>N</td>
<td>semi-Lagrangian, semi-implicit core; vertical sigma pressure hybrid coordinate; NAVGEM physics package</td>
</tr>
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Goal: Non-Hydrostatic Global Models

• Next generation of medium-range (0-16 days), global NWP models
  – By the end of the current decade (2020)
  – 3km resolution; drive towards convection and cloud resolving
• Thoroughly evaluate and test five existing dynamical cores (HiRAM/FV3; MPAS; NIM; NMMB; NUMA/NEPTUNE)
• Migrate one or more models onto newer and faster MPFG-HPC systems
• Develop and implement scale-aware physical parameterizations
• Develop and implement new 4D-En-Var hybrid assimilation techniques

Images courtesy of Bill Skamarock, NCAR
# Quick Dive: HIWPP Non-Hydrostatic Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Organization</th>
<th>Characteristics</th>
</tr>
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<tbody>
<tr>
<td>HiRAM</td>
<td>GFDL</td>
<td>Finite-volume dynamical core on a cubed-sphere grid. Developed as a global climate model, with capability to simulate statistics of tropical storms; parameterized convection helps the resolved scale convection, parameterization of shallow convection by Bretherton et. al. (2004)</td>
</tr>
<tr>
<td>MPAS</td>
<td>NCAR</td>
<td>Comprised of geophysical fluid-flow solvers that use spherical centroidal Voronoi tessellations (nominally hexagons) to tile the globe and C-grid staggering of the prognostic variables; supports non-uniform horizontal meshes and/or nests; terrain following height coordinate or hybrid coordinate relaxed at constant height. Advanced WRF physics package</td>
</tr>
<tr>
<td>NEPTUNE</td>
<td>Navy</td>
<td>Based on NUMA (Non-hydrostatic Unified Model for the Atmosphere), a spectral element/discontinuous Galerkin dynamical core; uses cubed-sphere grid; adaptive mesh refinement under development</td>
</tr>
<tr>
<td>NIM</td>
<td>ESRL/GSD</td>
<td>Multi-scale model based on 3D finite-volume solver. Vertical coordinate system is physical heights. GFS and WRF physics options. Evolving from the FIM, NIM was designed for and is currently being tested on massively parallel fine grain computers (GPU)</td>
</tr>
<tr>
<td>NMMB</td>
<td>NCEP</td>
<td>Based on NEMS framework; global versions uses lat-long grid. Horizontal differencing preserves properties of differential operators and conserves energy and enstrophy; 1-way and 2-way nesting supported; WRF NMM’s physics</td>
</tr>
</tbody>
</table>
Goals: Moving Hurricane Nests and Seamless Long-range Weather Forecasts

Moving Hurricane Nest:

- Integrate HWRF into NMMB
  - fully two-way interactive moving nested, multi scale, non-hydrostatic modeling system using NMMB/NEMS framework
- Options to test HWRF nests in NMMB/NEMS framework with initial and boundary conditions from other models
- Proof of concept of global tropical cyclone model with multiple moveable nests placed around all tropical systems in the world and an open process

NMME Expansion:

- Evaluate & establish the predictive capability of hurricanes & other high-impact weather events out to several months
- Leveraging activity to build a seamless suite of medium- to long-range weather forecasts

Image courtesy of: S. “Gopal” Gopalakrishnan
Goal: Test Program

• Statistical Post-Processing
  – Statistical post-processing of high-resolution HIWPP deterministic models and of coarser-resolution ensembles

• NOAA Earth Information System (NEIS)
  – a new tool to quickly access and visualize massive amounts of gridded data

• Verification
  – “Honest broker” evaluations, consistent and uniform assessments across all of the models
  – Integrate multiple systems

• Real time IT Operations
  – Getting data where it needs to be; when it needs to be there
A Case Study with NEIS

Tropical Cyclone Megi; a triple-wrapped low in the Gulf of Alaska; lowest-low in MN
About the Image

The case study featured in this image was a FIM simulation of Typhoon Megi that hit the southeast coast of China. The FIM forecast was initialized for October 21st, 2010 and ran for a 7 day period with hourly output (current operational models provide output at a 6 hour resolution).

When animated in NEIS, this case shows the global influence of weather on local events, underscoring the importance of global prediction for local events. In the full animation, off the north east corner of the typhoon, subtropical moisture is carried by an upper level jet to higher latitudes, feeding a very strong storm in the Gulf of Alaska, where the cloud bands can be seen to become triply-wrapped as the storm intensifies. Later in the animation a low pressure system develops over Colorado, which eventually reaches low pressure of 954.96 MB over Minnesota (a record low pressure for the region).

The visualization uses cloud properties from the high-resolution FIM model (15 km grid spacing; hourly output) and an empirical relationship to simulate imagery of clouds as they might be seen from a satellite (though in this case the Earth is uniformly illuminated). The imagery is overlaid on a blue marble completing the image.
HIWPP’s Legacy: The Next Generation Global Prediction System (NGGPS)

- Resources to mature R&D
- Jump start the process (hitting the accelerator)

HIWPP

NGGPS
(ref: John Michalakes’ talk)

- Builds upon HIWPP
- Resources for extended “R2O” and “O2R”
Summary: We are Pushing the Limits

• Driving current generation models to their physical limits
  – Hydrostatic models to 10 km
• Reaching for the next generation of models by the end of this decade...
  – Non-Hydrostatic models at 3-4 km
  – Never done before operationally
• State-of-the-art data assimilation
• Scale-aware physical parameterizations
• New statistical post processing techniques
• Leading the migration into new computing paradigms
• Building a new verification approach
• Data & Visualization
  – Timeliness and efficiency distributing massive amounts of data
  – Innovative ways to interact with, analyze, and inter-compare these large quantities of data
• Enabling real-time research and building partnerships
Questions?

http://hiwpp.noaa.gov/
Contact: Timothy.Schneider@noaa.gov

Thank You!
BACKUP SLIDES
# Structure: HIWPP Partnerships

<table>
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<tr>
<th>Organization</th>
<th>Role/ Expertise</th>
<th>Notes</th>
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<tbody>
<tr>
<td>NOAA OAR/Laboratories</td>
<td>Applied R&amp;D expertise (model development, high resolution nesting, physics, statistical post-processing, new data assimilation); verification; HIWPP data &amp; visualization infrastructure; R2O</td>
<td>AOML, ESRL/GSD, ESRL/PSD, GFDL</td>
</tr>
<tr>
<td>NOAA NWS/NCEP</td>
<td>Operational numerical weather prediction and model development (GFS, NMMB, NAEFS, physics, data assimilation); verification, R2O</td>
<td>EMC; CPC</td>
</tr>
<tr>
<td>NOAA Cooperative Institutes</td>
<td>Academic and applied R&amp;D in partnership with NOAA labs and centers</td>
<td>CICS-P, CIMAS, CIRA, CIRES</td>
</tr>
<tr>
<td>NSF/UCAR</td>
<td>R&amp;D model development of non-hydrostatic model (MPAS); NMME data system</td>
<td>NCAR</td>
</tr>
<tr>
<td>Navy</td>
<td>R&amp;D and operational modeling with NAVGEM (hydrostatic) &amp; NUMA/NEPTUNE (non-hydrostatic)</td>
<td>NRL</td>
</tr>
<tr>
<td>Weather Enterprise</td>
<td>Interface with public perceptions and commercial needs, and academia; evaluation and feedback</td>
<td>HIWPP Trusted Partners, AMS community (FIG)</td>
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HIWPP Six-Point Strategy

- Drive the current generation (hydrostatic) of global NWP models to max performance & resolution (10km-20km), to medium-range and beyond
- In parallel, accelerate the development of the next generation (non-hydrostatic) of high-resolution (3km) medium-range global and nested NWP models
- Utilize the latest hybrid assimilation techniques (4D-En-Var) and scale-aware physical parameterizations
- Migrate models to newer and faster HPC technologies (MPFG/GPU)
- Provide new tools to quickly access and visualize massive amounts of gridded data
- Engage with “trusted users” for feedback and an open process
HIWPP Work Flow Concept

- Models
  - Hydrostatic
  - Non-Hydrostatic
  - HWRF
  - NMME

- Data Collection
  - Collect
  - Monitor
  - QC

- Ensembling
  - Statistical Post-Processing

- Post-Processing
  - HIWPP Verification

- Consolidated Data
  - Monitor & QC
  - Fast Access

- Dissemination
  - View
  - Analysis
  - Extraction
  - Data pull

Feedback

Trusted Users