Next Generation Global Prediction System (NGGPS)

Climate Test Bed Meeting

9 November 2015

Fred Toepfer, NGGPS Project Manager
NGGPS Over-Arching Objectives

• Re-establish US as the world leader in global weather prediction
  – Extend forecast skill beyond 8 to 10 days
  – Improve hurricane track and intensity forecast
• Extend weather forecast to 30 days
  – Implement a weather-scale, fully-coupled NWP System - atmosphere, ocean, waves, sea ice, land surface, aerosols and atmospheric composition
  – Support development of products for weeks 3 and 4
• Support unification of the NWS numerical weather prediction suite
• Multi-year community effort
• Position NWS to take advantage of advanced high performance computing architectures
Over-Arching NGGSPS Strategy

• Implement multi-year NWS-led community effort to build and implement
  – Future global weather prediction system supporting multiple forecast applications at NCEP
  – Community codes

• Accelerate forecast performance improvement through accelerated research to operations
  – Community codes supporting both R&D and operations
  – Implement a Global Modeling Test Bed

• Overall system designed (re-architected) to take advantage of evolving HPC architectures (CPU/GPU Hybrid or Massively Integrated Cores (MIC))
  – Highly scalable
  – Adapt to continued evolution of HPC
  – Support modeling suite migration to fine grain computing
NGGPS
Description

- Fully coupled (ocean, waves, sea ice, land surface, atmosphere, aerosols and atmospheric composition) system
- Built using NEMS/Earth System Modeling Framework
- Each component model will be community code
NGGPS
Planned Operational Applications

NGGPS
Unified Global Coupled Model

GFS
Short term weather

GEFS
Week 2 through 4-6

CFS
Seasonal & annual

Whole Atmosphere Model

Application = Ensemble + Reanalysis + Reforecast

Adapted from Hendrik Tolman
Major Activities

- Implementation plan – Team participation across NOAA line offices/laboratories, Navy, NASA, and UCAR
- Broaden community participation
- Conduct atmospheric model dynamic core evaluation
- Initiate NGGPS Test Bed activities / Global Modeling Test Bed
- Accelerate NEMS - Develop prototype coupled system
- Software engineering
- Upgrade EMC infrastructure to support community participation
Atmospheric Dynamic Core Development Schedule

- Test Computational Efficiency
  - Report Results (6/30/2015)
- Test Meteorological Performance
  - Select NGGPS Dynamic Core (4/1/2016)
- Dynamic Core Testing (18 months)
  - Development and Pre-implementation Testing
  - Parallel Testing
- Operationally Implement Dynamic Core (4/1/2019)
NGGPS Project Manager Recommendation

Proceed to Phase 2 testing on schedule with two dynamic cores:
  – FV3 and MPAS

• Dynamic Core Test Group (DTG) reviewed testing conduct and results and concurred with recommendation
• Director, NCEP was briefed on Phase 1 results and concurred with recommendation
• Director, NWS was briefed and strongly endorsed recommendation
• AA, OAR was briefed and concurred
## Phase 2 Testing Criteria

<table>
<thead>
<tr>
<th>Phase 2 Eval #</th>
<th>Evaluation Criteria</th>
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<tbody>
<tr>
<td>1</td>
<td>Plan for relaxing shallow atmosphere approximation (deep atmosphere dynamics)</td>
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<tr>
<td>2</td>
<td>Accurate conservation of mass, tracers, entropy, and energy.</td>
</tr>
<tr>
<td>3</td>
<td>Robust model solutions under a wide range of realistic atmospheric initial conditions using a common (GFS) physics package</td>
</tr>
<tr>
<td>4</td>
<td>Computational performance with GFS physics</td>
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<tr>
<td>5</td>
<td>Demonstration of variable resolution and/or nesting capabilities, including physically realistic simulations of convection in the high-resolution region</td>
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<tr>
<td>6</td>
<td>Stable, conservative long integrations with realistic climate statistics</td>
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<tr>
<td>7</td>
<td>Code adaptable to NEMS/ESMF</td>
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<tr>
<td>8</td>
<td>Detailed dycore documentation, including documentation of vertical grid, numerical filters, time-integration scheme and variable resolution and/or nesting capabilities</td>
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<tr>
<td>9</td>
<td>Evaluation of performance in cycle data assimilation</td>
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<tr>
<td>10</td>
<td>Implementation Plan (including costs)</td>
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</table>
Common Physics Package/Driver

• Snapshot of GFS physics will be used in dynamic core Phase II testing
  – GFS physics and prototype driver interface delivered
  – NUOPC Physics Interoperability leading design effort for driver interface

• EMC/NUOPC Physics Interoperability group have been coordinating requirements
  – GFS Physics Driver Software Requirements Specification (V1.0 rev. 3 of 13 Feb 2015) prepared

• EMC/NGGPS Physics Team to work specifications for common community physics package
  – Scale-aware physics parameterizations
  – Suitable for variable-resolution grids
Global Modeling Test Bed

- Extension of current DTC (NCAR and GSD partnership)
- Pre-implementation testing of new functionality
- Fosters community involvement in ongoing development of operational modeling systems
  - Community code management
  - Test platform management
  - Provides necessary infrastructure for community to interact with code system
  - Supports code system to external developers
  - Independent test and evaluation of proposed upgrades to operational system from external community
GMTB Tasks

• Task 1: Development and Testing of a Common Community Physics Package
  – Code management and community support
  – Testing and evaluation of innovations in physical parameterizations

• Task 2: Code Management and User Support for Interoperable Physics Driver

• Task 3: Integration, Testing, and Improvement of a Sea Ice Model for NGGPS (establish baseline for weather version of CICE code)

• Task 4: Program Management Support
NGGPS Summary Activities

• Phase 2 dynamic core testing in progress with final decision anticipated spring 2016
  – Public release of NWS endorsement on Phase 1 downselect decision being coordinated
  – Further dynamic core development and parallel testing required after dycore selection
• NGGPS Implementation Plan team planning/actions continue
  – Efforts in collaboration with EMC FY16 spend plan prioritization
  – Establishing Science Steering Group to review priorities and strategic direction
• Planning for next grants cycle
• Implementation of physics plan is in progress – includes community code development (focus will be on scale aware physics)
• Focus on accelerated development of model components
  – As community code
Questions?

NGGPS Website:
http://www.nws.noaa.gov/ost/nggps
Back-up
NGGPS Implementation

Test & Eval Dynamic Cores

Pre-Implementation & Development / Testing

Phase 1 Tests completed

Select Core

Common Physics Driver

Implementation Ready

Parallel Testing

NOAA Environmental Modeling System

Development and Testing of Fully Coupled System

Ongoing GFS Development

Completed in January

Implement semi-Lagrangian version

Increased vertical levels (schedule not yet established)

Upgrade GFS with New Dynamic Core

* NOTE: Dashed milestones are pre-implementation

Prototype Coupled System Ready for Testing

* Prototype

Fully Coupled System Ready for Implementation
NGGPS Implementation Plan

- Team plan briefings conducted for NGGPS and EMC management to support FY16 spend plan development
- EMC support task (SCITECH contract) awarded 16 July (funds approx 20 positions)
- EMC providing lead recommendations for Science Working Groups and Test and Evaluation Group to support Physics Team planning
  - Convection and Boundary Layer
  - Cloud Microphysics
  - Gravity Wave and Large-scale Orographic (& non-Orographic) Drag
  - Radiation
  - Earth System Surface Fluxes and State
- Physics and Post-Processing Teams planning workshops early 2016
- Team plans to be posted as individual links on website – allows for tailored/responsive updates
Planning and Development Teams

- Atmospheric Prediction – Dynamics (including Nesting)
- Atmospheric Prediction – Physics
- Aerosols and Atmospheric Composition
- Atmospheric Data Assimilation
- Ocean Prediction (includes waves, sea ice, and data assimilation)
- Land Prediction
- Post-Processing
- Ensemble Design
- Overarching System (architecture and integration including NEMS/ESMF)
- Software Architecture and Engineering
- Infrastructure
- Verification and Validation
- Testbeds

Team participation across NOAA line offices/laboratories, Navy, NASA, UCAR and coordination with the High Impact Weather Prediction Project and the National Earth System Prediction Capability program.
## FY15 Spend Plan & Execution Status

### NWS R2O Funnel to Success

<table>
<thead>
<tr>
<th>NWS R2O Funnel</th>
<th>NGGPS Activities</th>
<th>FY15 Funds</th>
<th>Execution Status</th>
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</thead>
<tbody>
<tr>
<td>General R&amp;D</td>
<td>Partner R&amp;D</td>
<td>$0K</td>
<td>-</td>
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<tr>
<td>Mission Oriented R&amp;D</td>
<td>Competitive NGGPS AO under expanded CSTAR FFO</td>
<td>$2,400K</td>
<td>2nd year awards – in progress GMD</td>
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<tr>
<td>Directed R&amp;D and Transition efforts including Testbeds</td>
<td>Competitive FFO NGGPS/Testbeds</td>
<td>$1,500K</td>
<td>2nd year awards – in progress GMD</td>
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<tr>
<td></td>
<td>Testbed Infrastructure</td>
<td>$300K</td>
<td>Obligated</td>
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<tr>
<td></td>
<td>Internal funding for Fed Labs /Centers (GMTB)</td>
<td>$3,900K</td>
<td>Funded OAR, EMC, and Navy</td>
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<td></td>
<td>Global DTC Support (NCAR)</td>
<td>$1200K</td>
<td>NSF IAA cleared by OGC</td>
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<td>Operational System Development and Implementation</td>
<td>Science, Engineering, &amp; Infrastructure @EMC</td>
<td>$750K</td>
<td>Partial funding-Option period</td>
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<td>Reforecast/Reanalysis</td>
<td>$1,200K</td>
<td>Obligated</td>
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<td></td>
<td>ESMF</td>
<td>$600K</td>
<td>Obligated</td>
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<td>Project Mgmt</td>
<td>Project office</td>
<td>$1,350K</td>
<td>Committed</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$13,200K</strong></td>
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Global Modeling Test Bed (GMTB) Concept

- Implement concept of **Community Development**
- System Code based on Operational Code (O to R)
- Community System Code supports both Operations and Research
- Proposal for first year activities in development
  - Common community physics package
  - Ice modeling package

**SC** – System Code
**CC** – Community Code
NGGPS Phase 1 Testing
Project Summary Assessment

<table>
<thead>
<tr>
<th></th>
<th>Idealized Tests</th>
<th>3-km, 3-day forecasts</th>
<th>Performance</th>
<th>Scalability</th>
<th>Nesting or Mesh Refinement</th>
<th>Software Maturity</th>
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</thead>
<tbody>
<tr>
<td>FV3</td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
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<td>MPAS</td>
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<td>NIM</td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Red" /></td>
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<tr>
<td>NMM-UJ</td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Yellow" /></td>
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<tr>
<td>NEPTUNE</td>
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<td><img src="#" alt="Yellow" /></td>
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- ![Green](#): Meets or exceeds readiness for needed capability
- ![Yellow](#): Some capability but effort required for readiness
- ![Red](#): Capability in planning only or otherwise insufficiently ready
## Dycore Readiness Project Risk Assessment

<table>
<thead>
<tr>
<th></th>
<th>Overall Risk</th>
<th>Comment</th>
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<tbody>
<tr>
<td>FV3</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>MPAS</td>
<td>Mostly Low</td>
<td>Computational Performance</td>
</tr>
<tr>
<td>NIM</td>
<td>Moderate</td>
<td>Maturity – Nesting, high resolution</td>
</tr>
<tr>
<td>NMM-UJ</td>
<td>Moderate</td>
<td>Maturity – Idealized Testing</td>
</tr>
<tr>
<td>NEPTUNE</td>
<td>High</td>
<td>Maturity</td>
</tr>
</tbody>
</table>

Neither readiness for potential future computing architectures (fine-grain computing) nor future computing relative scarcity/abundance judged to be overarching requirements at this time.
• 1-km resolution within central US for predictions of tornado outbreak events; ~10 km resolution over Europe and Asia
• The two-way interactive (red) nest (1-km) runs parallel-in-time with, and finishes at the same time as the variable-resolution global model
• The combined regional-global model (1-km to 10-km in the northern hemisphere) can finish a 10-day forecast in less than 2 hours with HPC available today
Global meshes and local refinement

MPAS is a collection of geophysical fluid-flow solvers based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.

MPAS-Atmosphere (NCAR) is a fully-compressible nonhydrostatic 3D solver. Much of its numerics is based on the Advanced Research WRF model, with modifications to accommodate the unstructured Voronoi mesh.

MPAS mesh configurations

Global Uniform Mesh

Global Variable Resolution Mesh

Regional Mesh - driven by
(1) previous global MPAS run
(2) other global model run
(3) analyses
FV3: thunder-storm resolving resolution Today!

1) Grid **stretching**
   - Moderate stretching (2.5 x) maintains excellent global circulation – for **regional climate simulations**
   - Aggressive stretching (20 x) – for **short term severe weather predictions** (tornadoes and hurricanes)

2) 2-way **nesting** (Harris and Lin 2014)

3) Combination of the “**stretching**” and “**nesting**” (most efficient approach)

Grid-stretching and a two-way nest running parallel in time; capable of meeting NCEP’s operational requirement

~ 3 km without the nest (red)
~ 1 km with a 2-way nest
Global meshes and local refinement

MPAS meshes are *unstructured*. They are generated using Lloyd’s method (an iterative technique) and a user-specified density function. They are *not* remappings of an icosahedral mesh.
AVEC Phase 1 Evaluations: Performance

- Performance:
  - Number of processor cores needed to meet operational speed requirement with 13-km workload
  - Rankings (fastest to slowest): NMM-UJ, FV3, NIM, MPAS, NEPTUNE

(Lower is better)
AVEC Phase 1 Evaluations: Performance

- **Performance:**
  - Number of processor cores needed to meet operational speed requirement with 13-km workload
  - Rankings (fastest to slowest): NMM-UJ, FV3, NIM, MPAS, NEPTUNE (Lower is better)
AVEC Phase 1 Evaluations: Scalability

- Scalability: ability to efficiently use large numbers of processor cores
  - All codes showed good scaling
  - Rankings (most to least scalable): NEPTUNE, MPAS, NIM, FV3, NMM-UJ

(Higher is better)
Evaluations: Scalability

• Scalability: ability to efficiently use large numbers of processor cores

 Rankings (most to least scalable): NEPTUNE, MPAS, NIM, FV3, NMM-UJ (Higher is better)
NGGPS Development Strategy

• Establish Planning and Implementation Teams
  – Community participation through external grants to universities, support to test beds, and broad laboratory participation
  – Establish software engineering and infrastructure support at EMC

• Select a future atmospheric dynamic core from existing research and operational models

• Define Community Code Baseline (where doesn’t already exist) for NGGPS components, including NEMS

• Begin conversion of GFS Physics package into the Common Community Physics Package

• Establish Global Modeling Test Bed

• Extend NEMS infrastructure to include sea ice, ocean, wave, land surface, and aerosol and atmospheric composition model components

• Demonstration of a fully coupled system
Project Activities and Status

• Develop Implementation Plan
  – Plan drafted
  – Revising team plans
    • Team component leads established/approved
    • Incorporated proposal work into team plans

• Broaden community participation
  – Federal Funding Opportunity: $3.9M awarded to University PI’s
  – Internal Announcement: $2.4M awarded to federal labs
  – Use of community codes/components

• Conduct Atmospheric Model Dynamic Core Evaluation
  – Phase 1 testing completed and results assessed
  – Final report and public release being prepared
  – Phase 2 testing begins in FY15Q3
  – GFS Physics driver delivered for dycore testing
Project Activities and Status cont.

• Initiate NGGPS Test Bed activities/ Propose Global Modeling Test Bed
  – Test bed activities defined and funded through FFO
  – Global Modeling Test Bed Proposal approved
    • Includes code management support for common physics package and interoperable physics driver
• Accelerate NEMS - Develop Prototype Coupled System
  – Components (including MOM5, HYCOM, WW3, CICE, NOAH and GFS) to be coupled in a test-ready system by FY16Q2
• Upgrade EMC infrastructure to support community participation
  – Software and Scientific Development at EMC (SciTech Task) being awarded
    • Technical support for NEMS development
    • Software engineering, technical support for infrastructure upgrades
    • R&D for upgrade of global modeling components
Overall Deliverables

• Annual upgrades to operational data assimilation
• Upgrades to NEMS infrastructure
• Upgrades to component models (ocean, atmosphere, ice, land surface, wave, aerosols) for a coupled system
  – As coordinated effort delivering community code
• Coupled global system using re-engineered system component models
• Improved utilization of HPC resources and cost effective implementation of science
• Agile HPC environment with quicker operational transition of research and development efforts