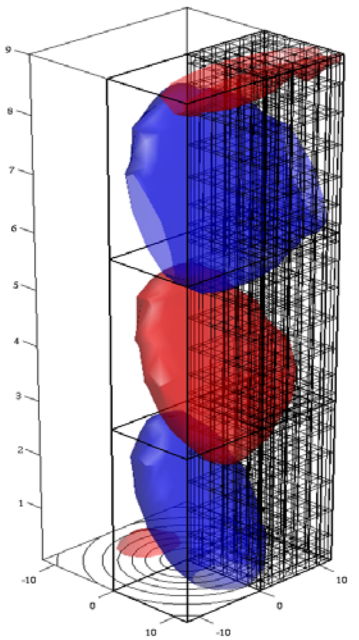
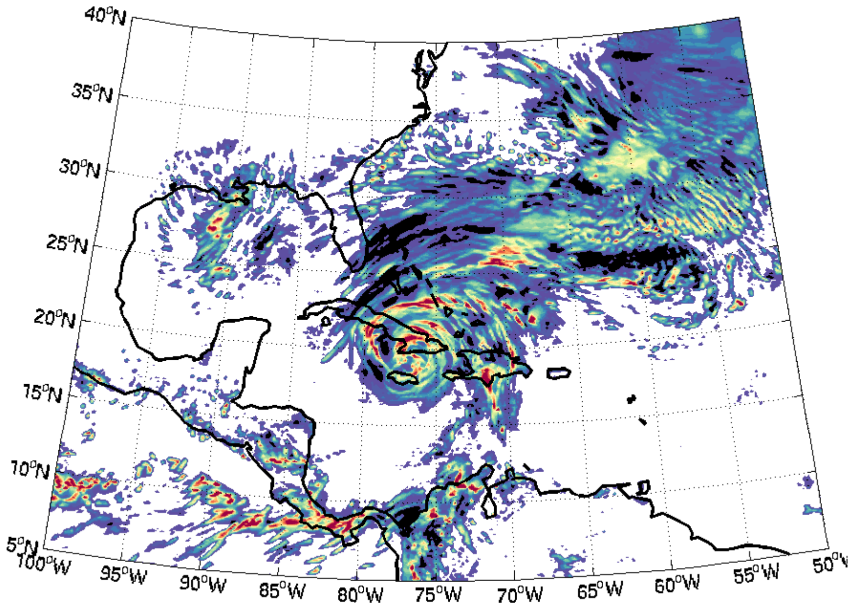
The Navy's Next-Generation NEPTUNE Modeling System





James Doyle[1], Alex Reinecke[1], Kevin Viner[1], David Flagg[1], Sasa Gabersek[1], Sarah King[1], Matus Martini[2], John Michalakes[3], David Ryglicki[1], Frank Giraldo[4]

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2 DEVINE Consulting, Monterey, CA
3 UCAR, Boulder, CO
4 Naval Postgraduate School, Monterey, CA

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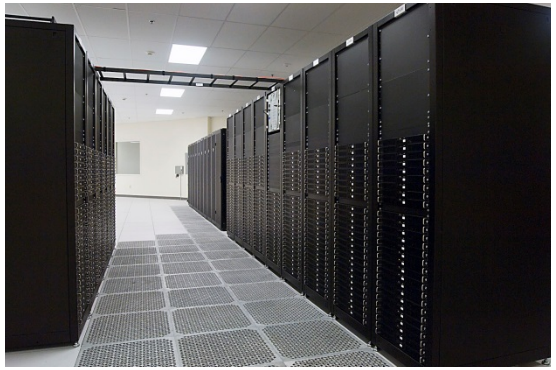
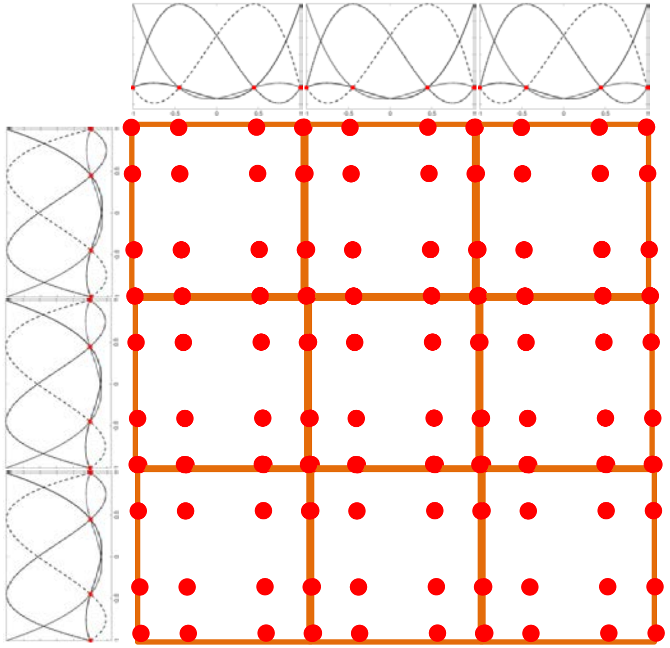
Motivation



- Future Exascale Computational Challenges
  - Systems will have ≥10^6 processors; Accelerators (e.g., GPUs)
  - Current dynamical cores will be deficient
- Current Navy NWP Systems
  - NAVGEM Global (32 km); COAMPS® Regional (1-15 km), ~100 areas
- Why Invest in a Next-Generation System?
  - Unify (global-regional) Navy Earth System Prediction Capability (ESPC)
  - Goal of <5 km global and <1 km regional NWP by ~2025
  - Need an accurate & flexible dynamical core & exploit future parallelism
- NEPTUNE [Spectral Element core NUMA] Can Meet These Needs
  - Numerical solution is represented by a local polynomial expansion
  - Flexible numerics with high-order and mesh refinement options
  - Small communication footprint implies excellent computational scaling
  - Excellent potential for dense floating point computations (accelerators)

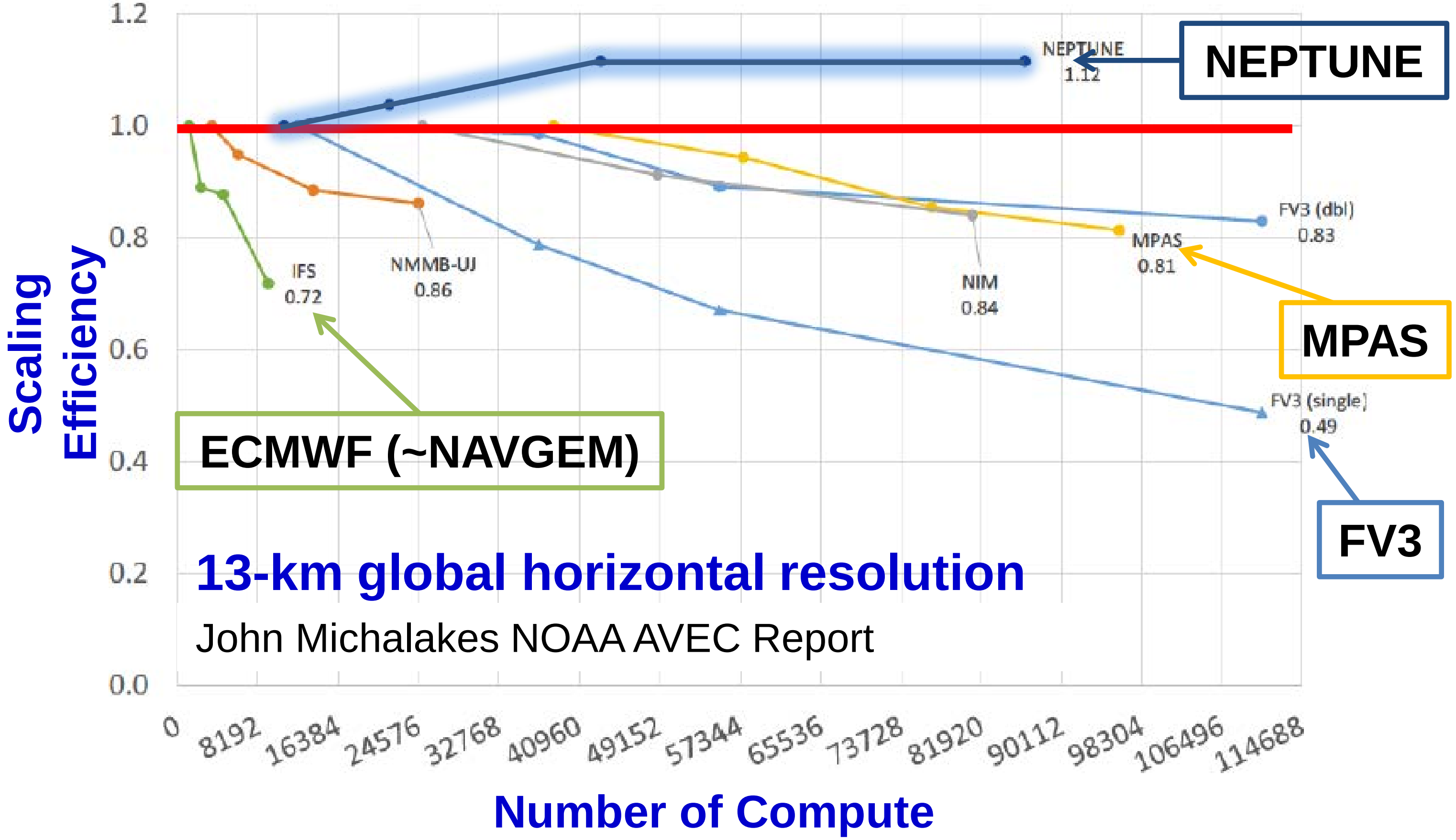


NEPTUNE**: **N**avy **E**nvironmental **P**rediction sys**T**em **U**tilizing the **N**UMA^2 cor**E

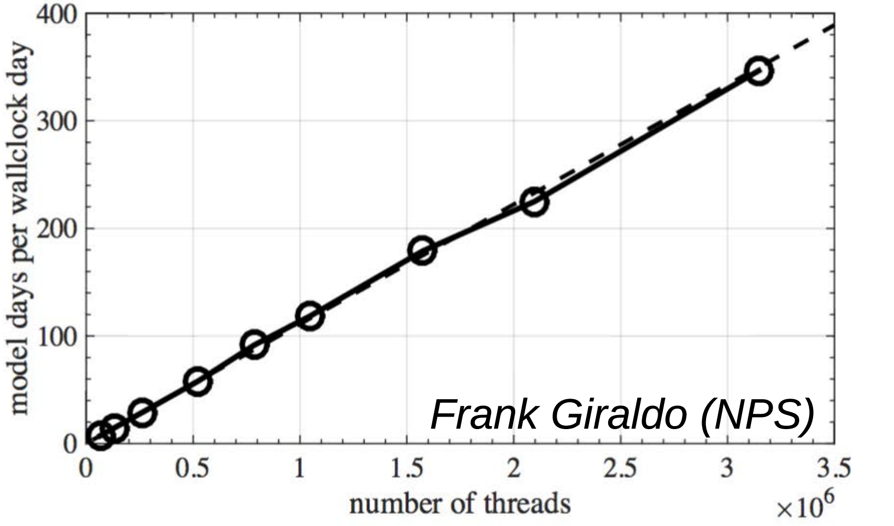
***NUMA**: **N**onhydrostatic **U**nified **M**odel of the **A**tmosphere (F. Giraldo NPS)*

Scalability

NOAA NGGPS Intercomparison



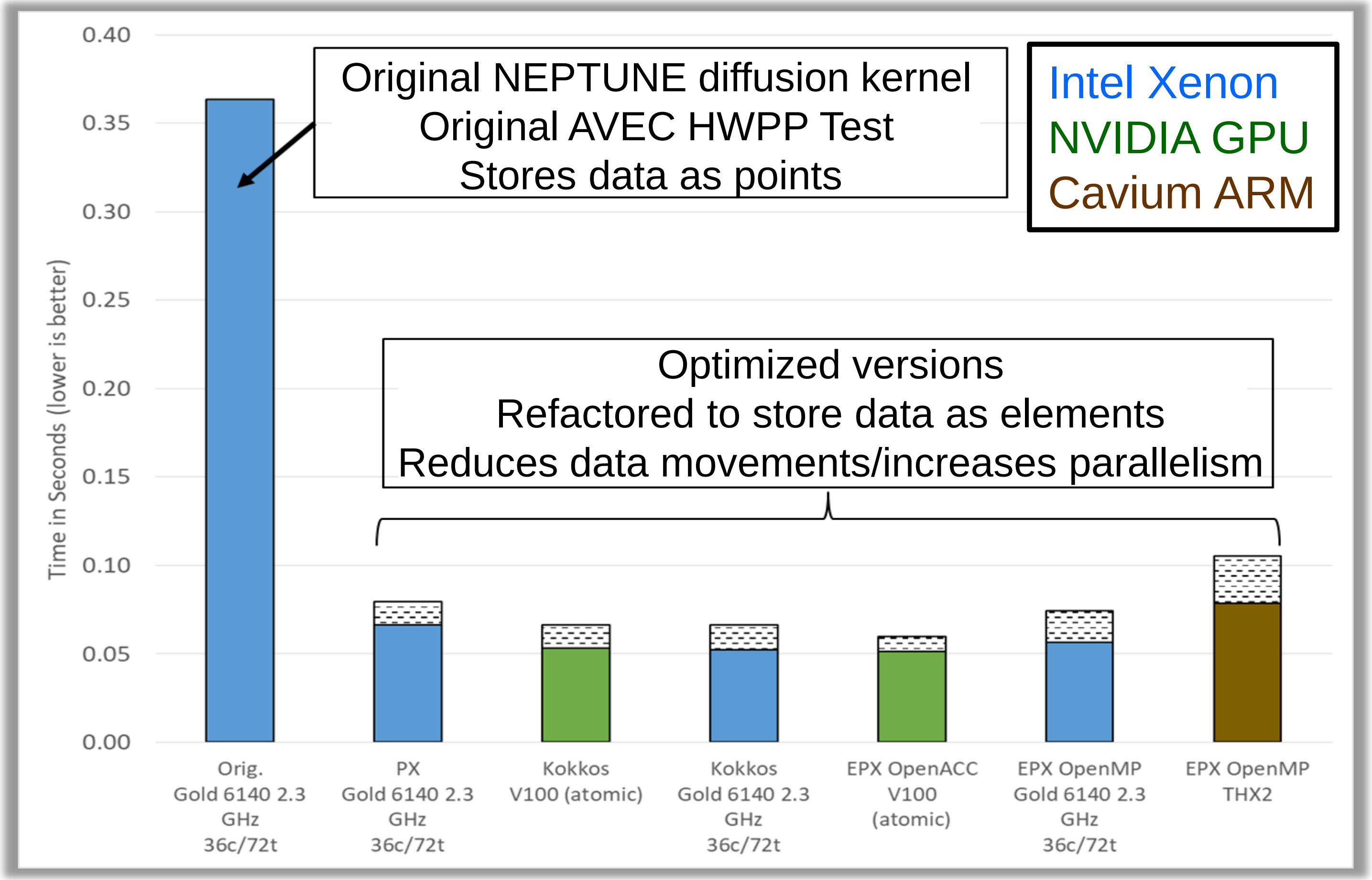
Scaling to 3 Million MPI Ranks



NUMA Strong Scaling on Mira (Argonne) IBM Blue Genie/Q for 3-km resolution using 3 million MPI ranks

- NEPTUNE has higher scaling efficiency compared to other dynamical cores
- NEPTUNE projects better onto next generation Exascale computing
- NUMA dynamics scales very well on standard CPUs and GPUs

Optimization



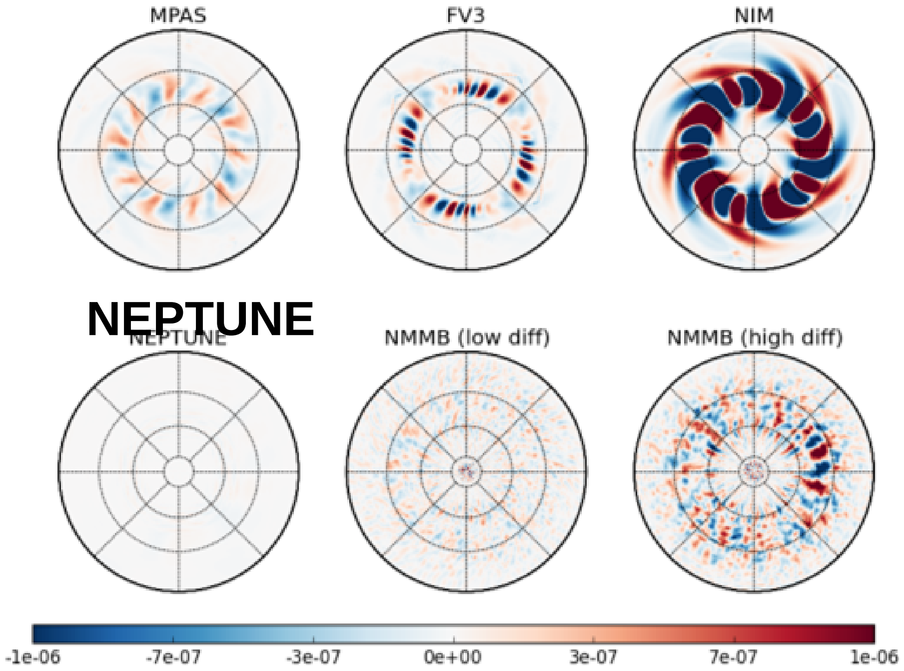
- NEPTUNE kernels tested with various optimization methods on: i) Intel Xenon, ii) NVIDIA GPU, iii) Cavium ARM
- Results are very promising (4-5X speedups!).

John Michalakes (1.2): *NEPTUNE Development for Next Generation HPC*

NOAA Dynamical Core Idealized Intercomparison Tests

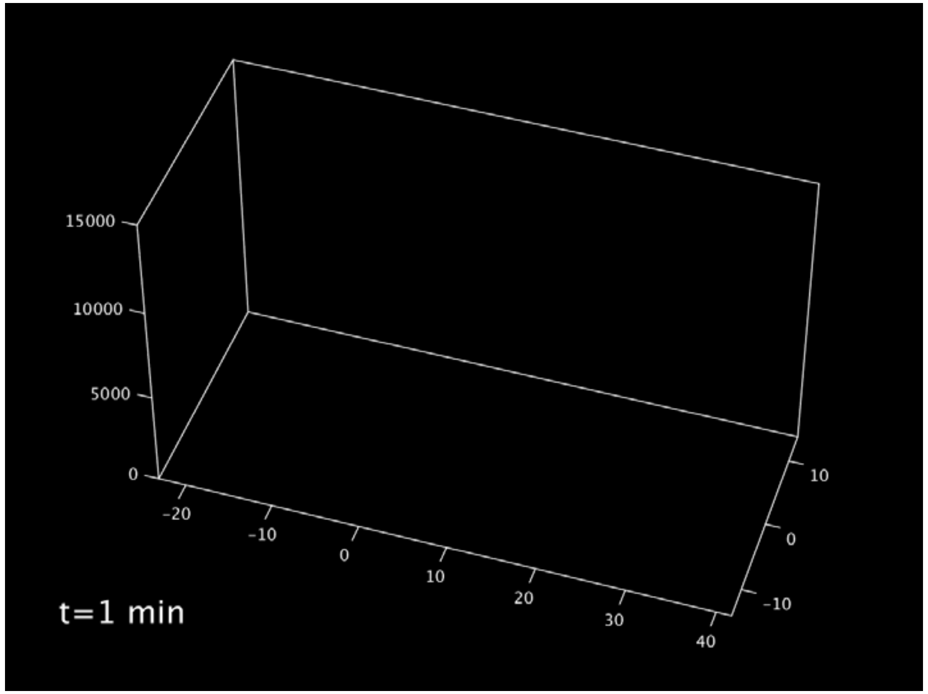
NOAA HIWPP Intercomparison of Next-Gen. Dynamical Cores

Baroclinic Wave Grid Imprinting
Southern Hemisphere (Day 9, 120 km)



J. Whitaker, NOAA

Splitting Supercell (Δx=500 m)
Hydrometeors (shaded)



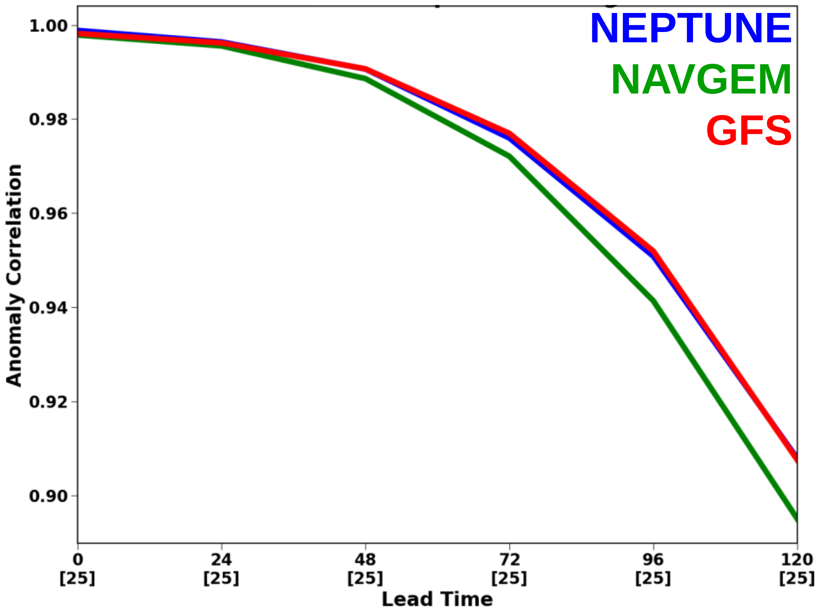
- NOAA HIWPP dynamical core tests (baroclinic wave, super cell, mtn waves)
- NEPTUNE compares favorably to other leading cores for all idealized tests
- NEPTUNE has smallest grid imprinting of any core (4th order numerics)

Global NWP Forecast Experiments

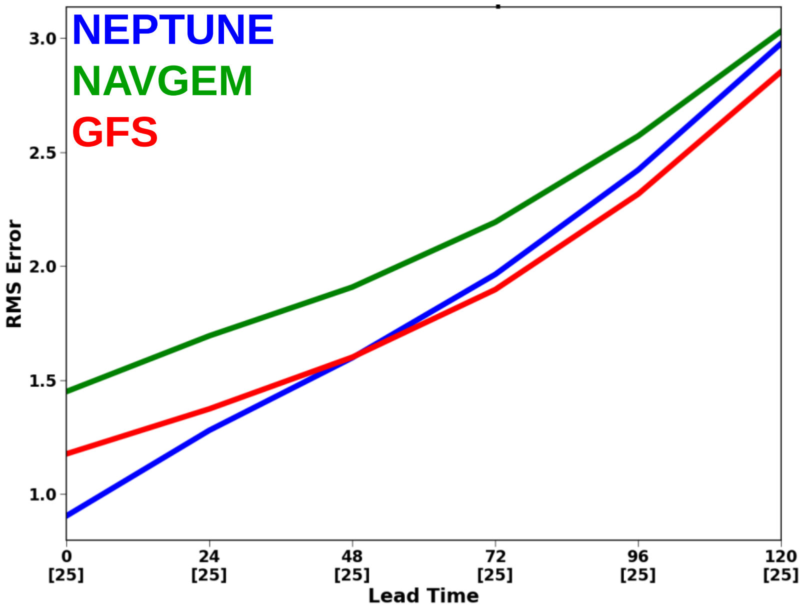
March 2018 Forecast Statistics

- Initialize NEPTUNE with GFS
  - 00 UTC 1-31 March 2018
  - 120-h forecasts
- GFS physics using Interoperable Physics Driver (IPDv4) (no tuning)
- NEPTUNE: 13-km grid spacing
- GFS: 13-km grid spacing
- NAVGEM: 32-km grid spacing (soon to be 19 km)
- ECMWF analysis for statistics

500-hPa NH GHT Anomaly Correlation



850-hPa NH Temperature RMS

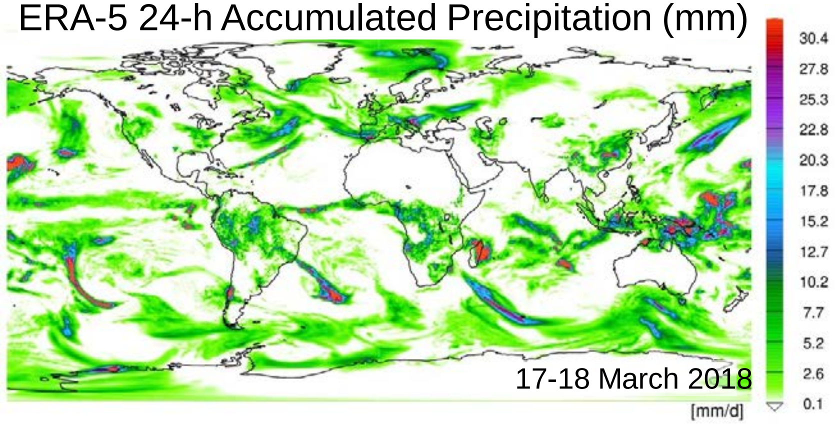


- NEPTUNE at 13-km resolution has comparable verification statistics as GFS
- NEPTUNE at 32-km resolution has slightly better verification statistics than NAVGEM
- NEPTUNE (with GFS physics) is sensitive to the horizontal resolution (see Alex Reinecke, 4.2 at 3:15 pm)

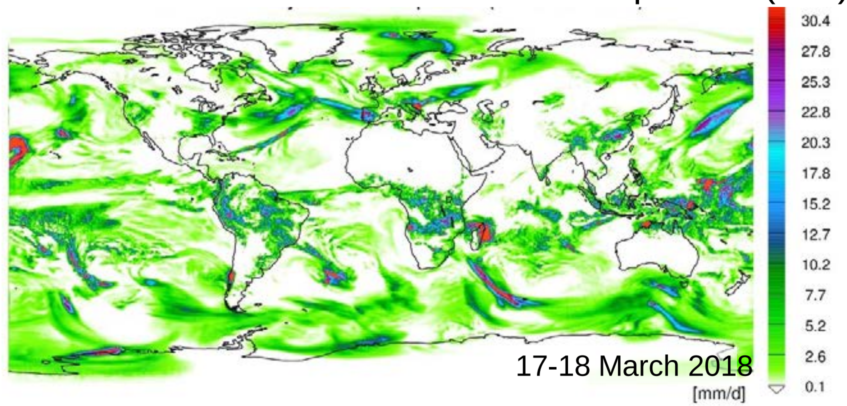
Global NWP Forecast Experiments

Precipitation Forecasts

ERA-5 24-h Accumulated Precipitation (mm)

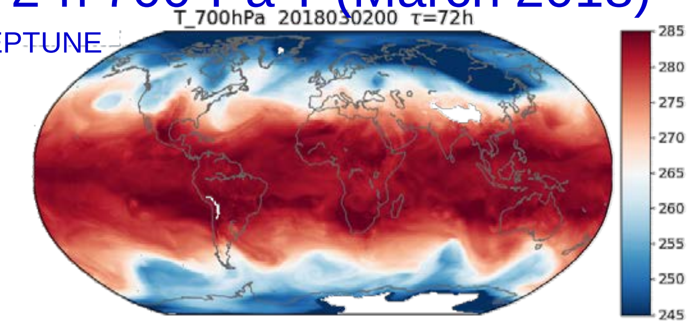


NEPTUNE 48-72-h Accumulated Precipitation (mm)

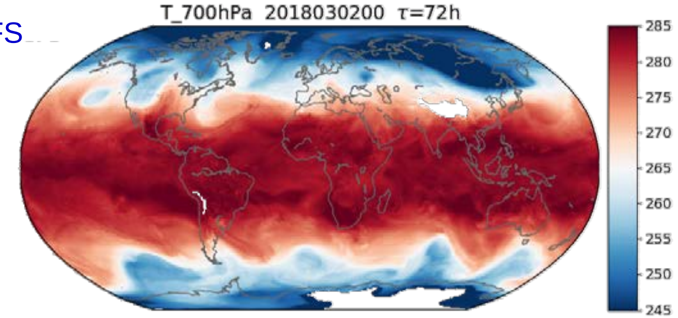


72-h 700-Pa T (March 2018)

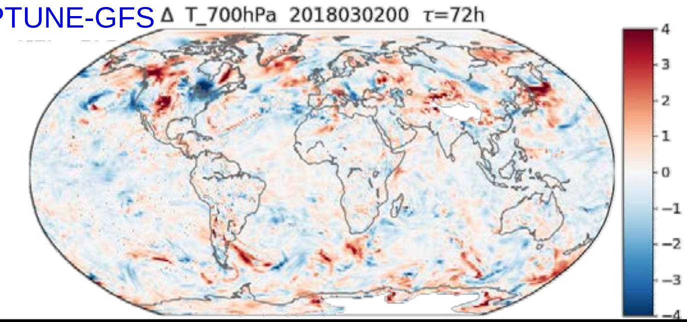
NEPTUNE



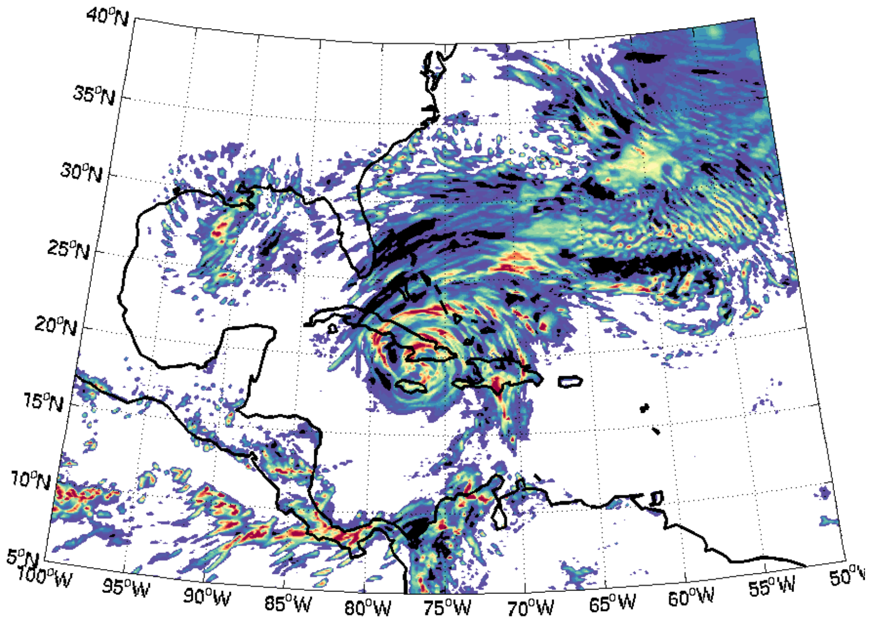
GFS



NEPTUNE-GFS



Superstorm Sandy (2012) (Δx~5 km)



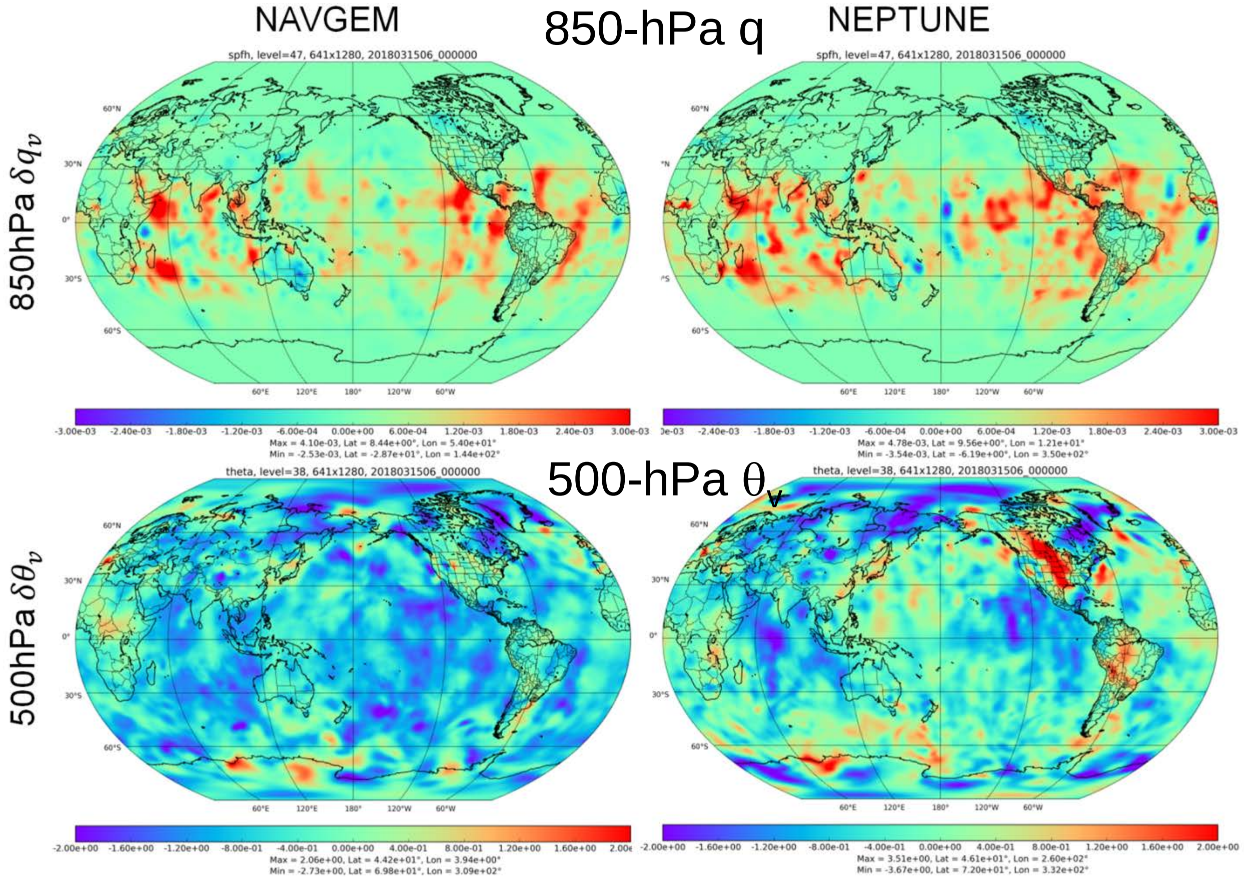
- NEPTUNE/NUMA has numerous grid options (cubed sphere, icosahedral…)
- Next steps: Incorporate the Common Community Physics Package (CCPP) software

Global NWP Forecast Experiments

- Cycle in NAVGEM / NAVDAS-AR data assimilation (no ensemble DA) and NEPTUNE
- Comparison of DA increments from single cycle

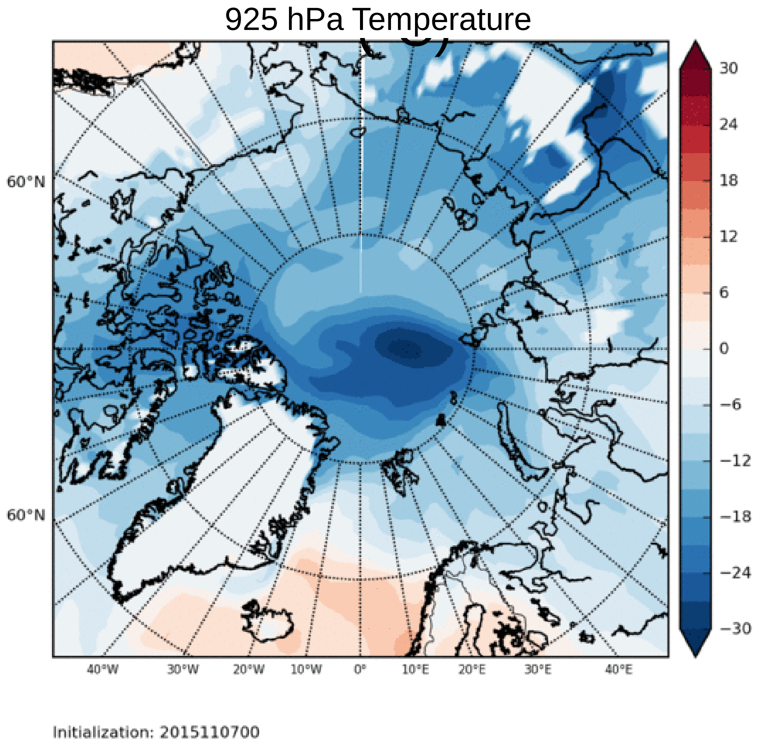
- NEPTUNE tends to have larger increments, but in broadly similar patterns to NAVGEM
- Linking NEPTUNE with NAVDAS-AR (4DVar) for cycling tests with physics

Data Assimilation Increments

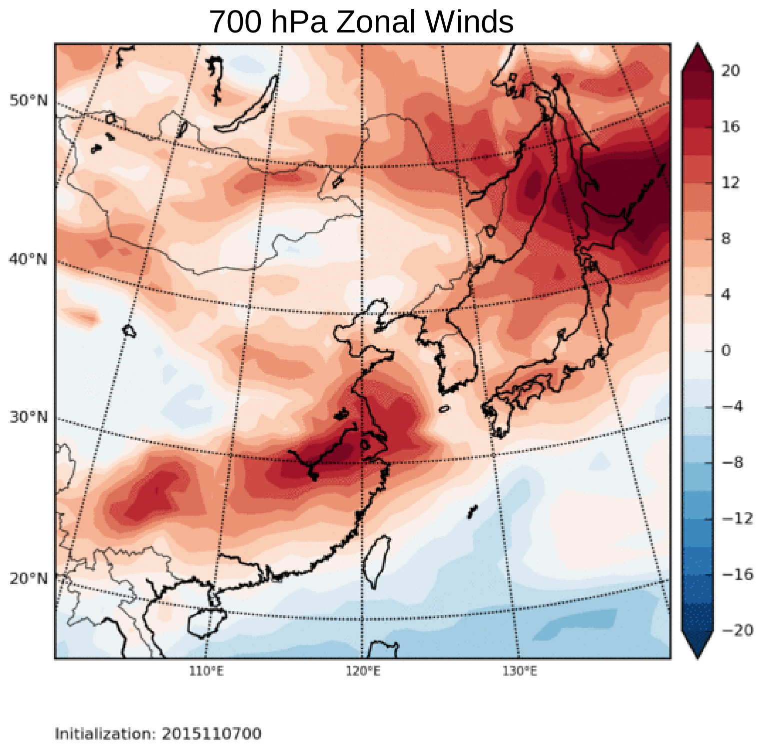


Limited Area Applications

Arctic Grid: 925-hPa Temperature



East Asia Grid: 700-hPa Zonal Winds



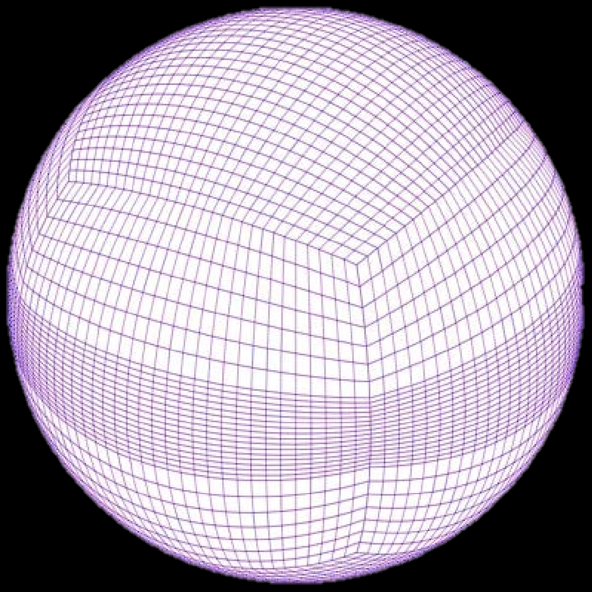
- NEPTUNE unified the global and limited area capabilities
- Designed to meet Navy's limited-area unclass & class domain requirements
- Used to efficiently test high-resolution physics without needing to run a high-resolution version of the global configuration

NEPTUNE / NUMA Mesh Refinement

- Mesh refinement: Increase elements where high resolution is needed
  - Application of adaptive mesh refinement to global and regional NWP
  - High resolution and computationally feasible
- Resolve relevant features/follow battle groups for Navy applications

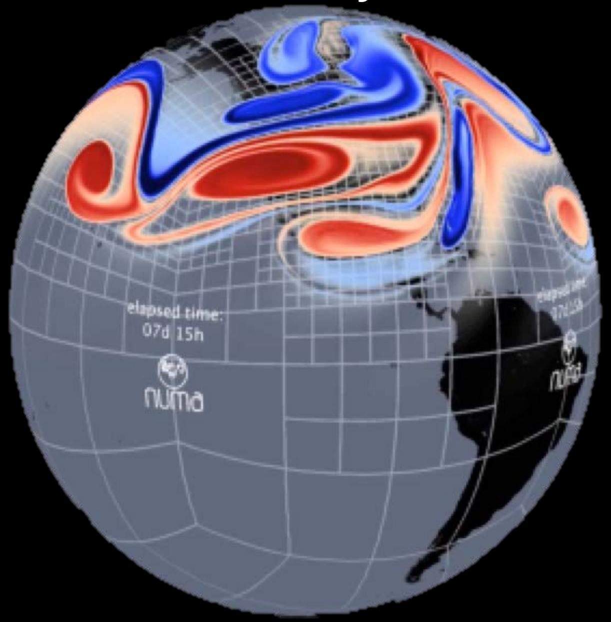
Static Mesh Refinement

Equatorial Belt

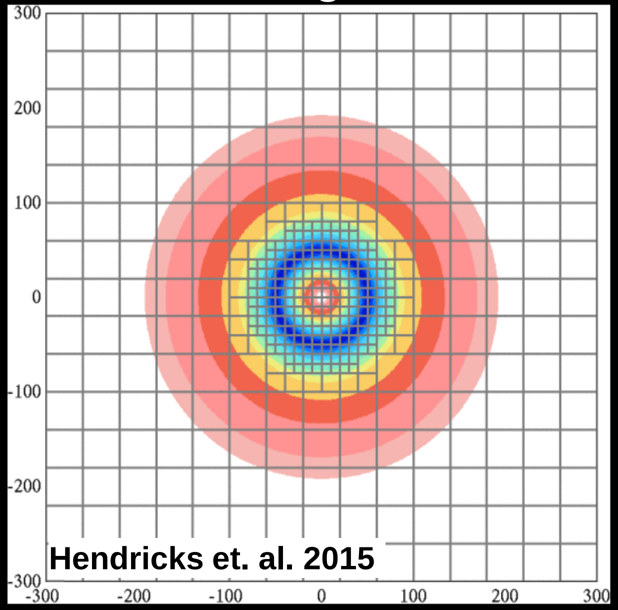


Adaptive Mesh Refinement

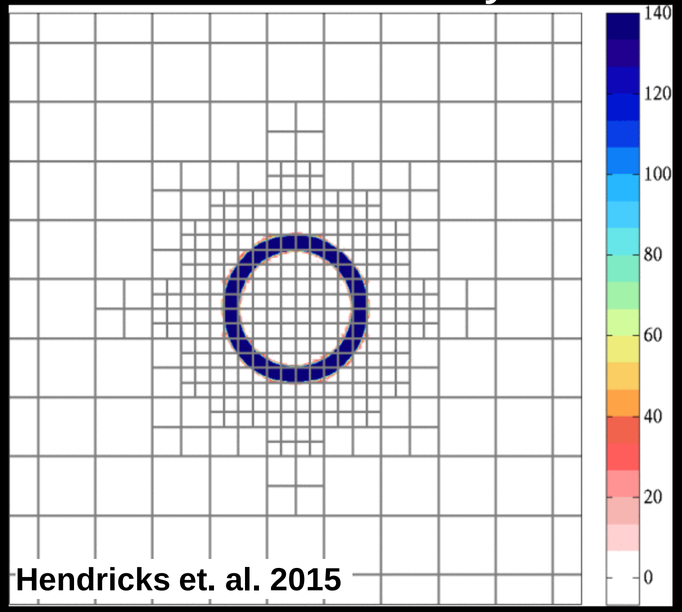
Vorticity



Translating Vortex



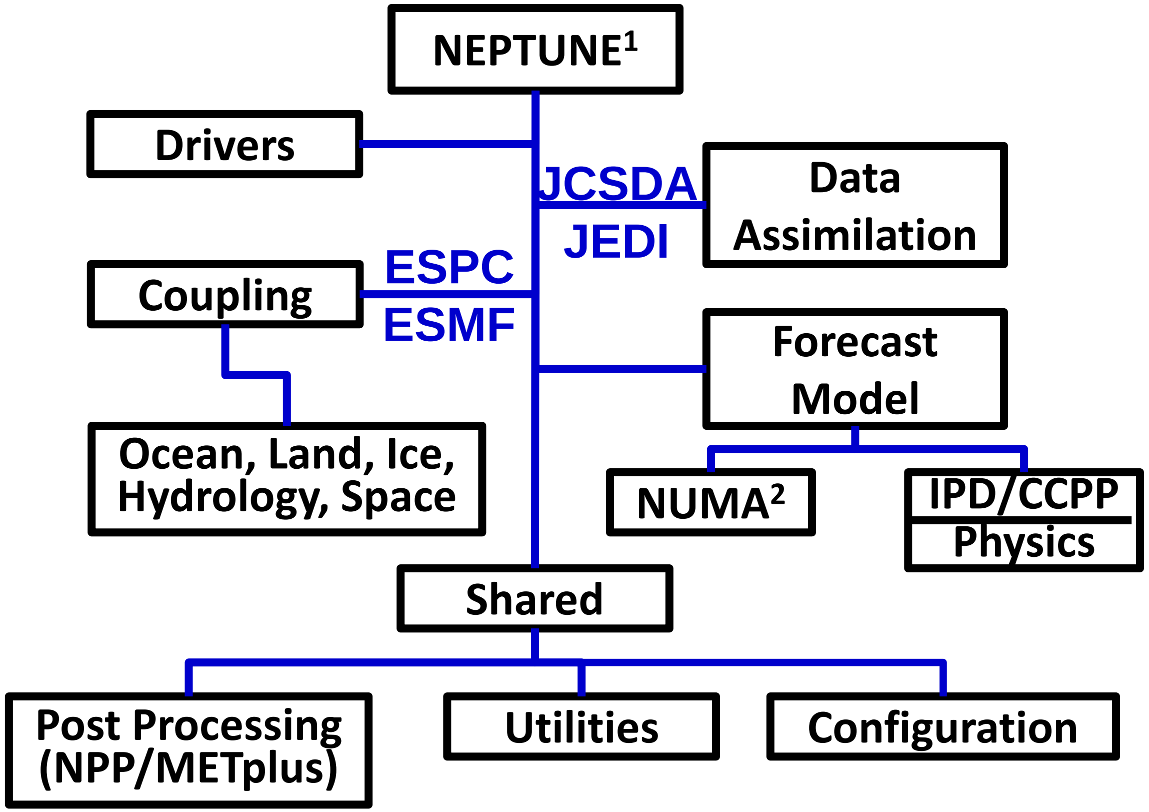
Vortex Instability



Frank Giraldo and NUMA Team (NPS)

NEPTUNE Overview and Strategy

Navy will partner with community (ESPC, JCSDA, NASA, NOAA, NCAR…) on key aspects of NEPTUNE: framework, dynamics, physics, data assimilation, coupling, post processing, diagnostics, verification…



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

[2]***NUMA:*** *Nonhydrostatic Unified Model of the Atmosphere (Giraldo et. al. 2013)*

NEPTUNE Summary and Future Plans

Summary

- NEPTUNE is designed to meet future computational & scientific needs for the Navy ESPC
  - Ideal for next-generation computers: highly scalable; amendable to accelerators
  - Accurate higher-order numerics; flexible grids (mesh refinement); deep atmosphere equations
  - Global & regional coupled air-ocean-land-ice capabilities in a single unified system
- Real data NWP and idealized evaluations continue to show promising results
- Optimization and refactoring of NEPTUNE code show significant speedups (4-5X) are possible

Future Plans

- Focus NEPTUNE development on unique Navy mission needs & requirements (PBL, coupled…)
- Partner with the community on major challenges ahead
  - Physics, gray zone, dynamics, multi-scale DA (JEDI), exascale computing, coupling (ESMF)
- Next Steps: Real data NWP tests, PBL & coupling, JEDI DA, cycling DA tests, high-altitude option
- Targeted for operations ~2025

NRL has exciting opportunities in next-generation modeling and computational science.
Please contact James Doyle (james.doyle@nrlmry.navy.mil)

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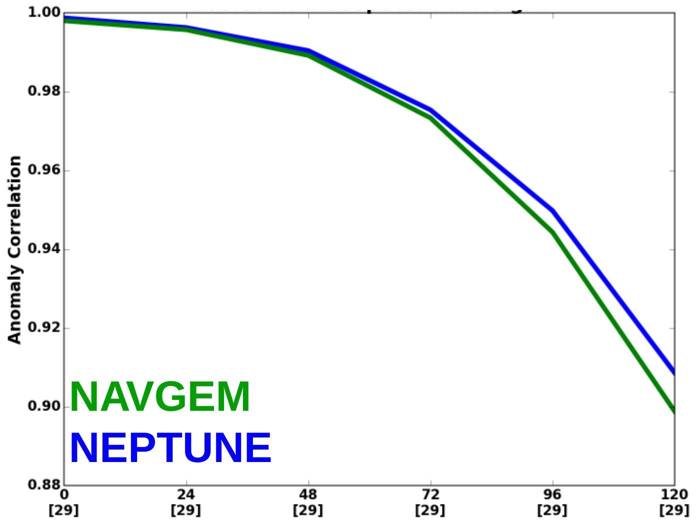

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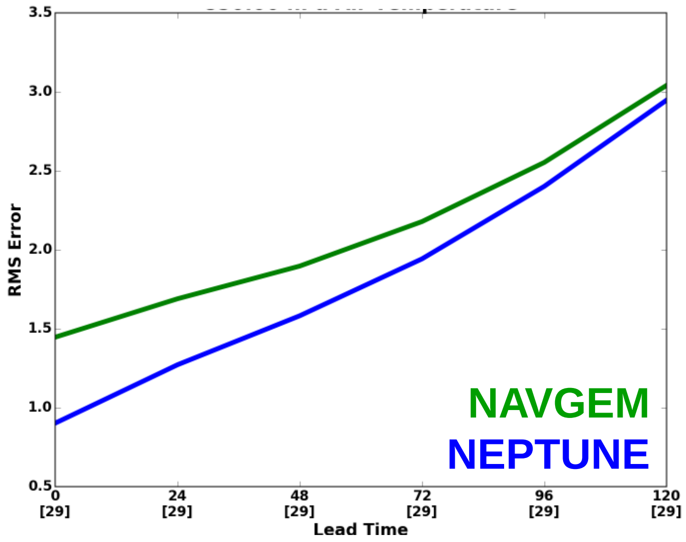

- NEPTUNE (with GFS cold starts) has improved verification statistics relative to NAVGEM
  - NEPTUNE has better NH 500-hPa ACs and 850-hPa temperature RMSEs
  - NEPTUNE has better winds at 850-hPa, 500-hPa, and 200-hPa
  - NEPTUNE has a larger tropical temperature bias in mid-troposphere