Recent Developments in NWP

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- **Global Prediction System: NAVGEM**
- **Mesocale Systems: COAMPS®**
- **Data Assimilation: NAVDAS-AR and Hybrid**
- **Aerosols: NAAPS and COAMPS®**
- **Next Generation System: NEPTUNE**

Navy Global Environmental Model (NAVGEM)

Data Assimilation

- NAVDAS-AR 4D-Var with Variational bias correction

Dynamics

- SL/SI scheme
- T359L50 (Δx=37km, top at 0.04 hPa or ~70 km)
- Time step = 360 sec

New Physics

- Simplified Arakawa-Schubert scheme
- Shallow convection
- Prognostic cloud scheme with two species
- RRTMG 4-stream radiation
- Modified cloud fraction scheme
- Modified turbulent mixing scheme

NAVGEM replaced NOGAPS in February 2013

NAVGEM 1.1 FNMOC Operational Scorecard
(Comparison between NOGAPS and NAVGEM)

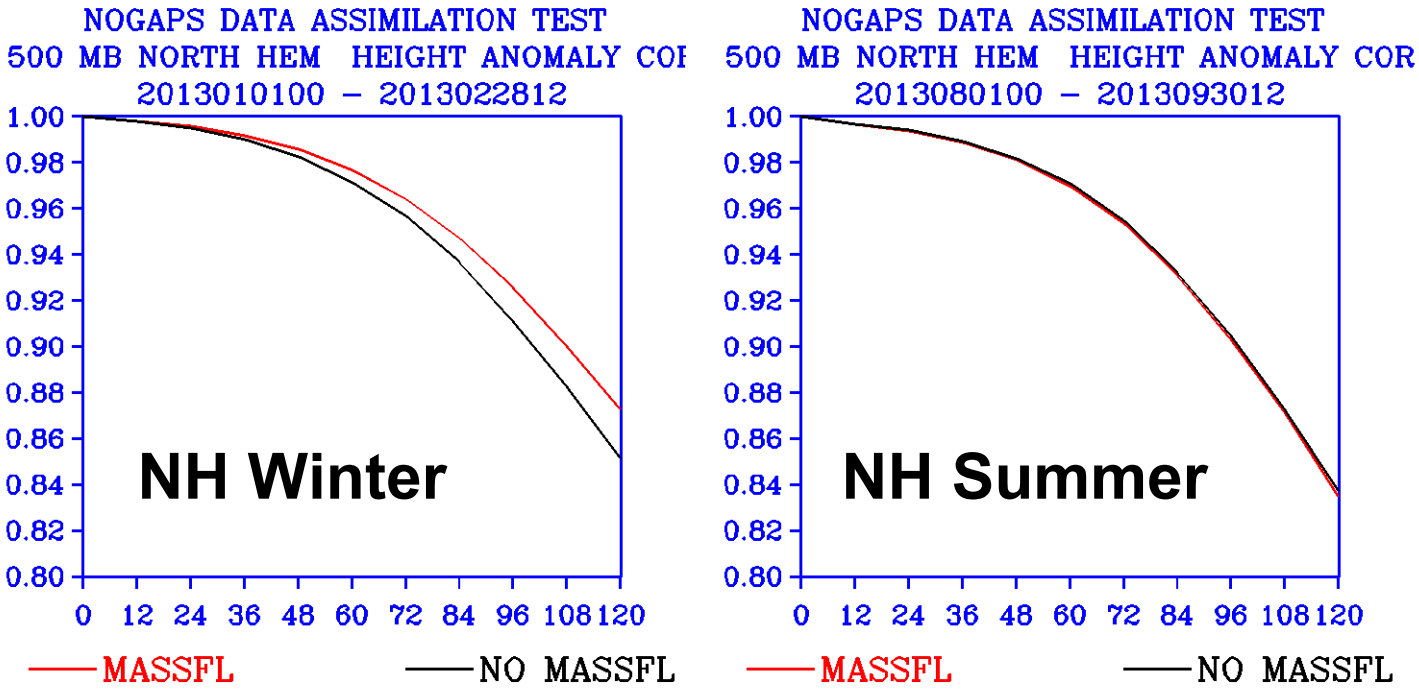
Field	Surface	Tropics	Tropical cyclone	Track error	96 hrs	+4
Field	500 mb	N Hem	Height	AC	96 hrs	+4
Field	1000 mb	N Hem	Height	AC	96 hrs	+1
Field	500 mb	S Hem	Height	AC	96 hrs	0
Field	1000 mb	S Hem	Height	AC	96 hrs	+1
Field	850 mb	Tropics	Wind	RMS	72 hrs	0
Field	250 mb	Tropics	Wind	RMS	72 hrs	0
Field	850 mb	N Hem	Wind	RMS	72 hrs	+1
Field	250 mb	N Hem	Wind	RMS	72 hrs	+1
Buoy Data	Surface	Global	Wind	Speed Error	72 hrs	0
Raob Data	850 mb	Global	Wind	RMS	72 hrs	0
Raob Data	250 mb	Global	Wind	RMS	72 hrs	0
Raob Data	850 mb	Global	Temperature	RMS	72 hrs	+1
Raob Data	250 mb	Global	Temperature	RMS	72 hrs	+1
Raob Data	500 mb	Global	Height	RMS	72 hrs	+1
Raob Data	100 mb	Global	Height	RMS	72 hrs	-1

System	Resolution
ECMWF	16kmL91
UKMO	25kmL70
NCEP	27kmL64
CMCNCEP	25kmL79
Navy	37kmL50

Total Score: +14 out of a possible +24
Highest score in past 20 years

NAVGEM 1.2 - Operational in October 2013

Eddy Diffusivity Mass Flux (EDMF) boundary layer mixing scheme (*Sušelj et al. 2013 MWR*)



EDMF improves 500-hPa AC during winter

NAVGEM 1.3 Planned Upgrades - FY14

- T425L60 (31km, 0.04mb~71km)
- P-theta dynamic core
- Revised EDMF boundary layer mixing scheme
- Reduced Gaussian Grids
- New Gravity Wave Drag Scheme
- Water Vapor Chemistry

NAVGEM currently being coupled to HYCOM (ocean) and CICE (sea ice)

COAMPS Overview

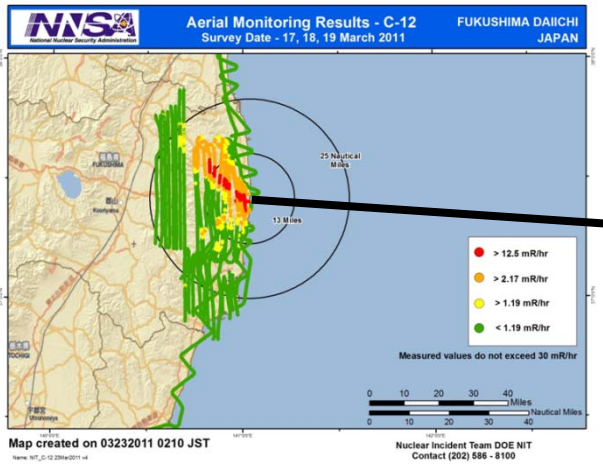
Coupled Ocean/Atmosphere Mesoscale Prediction System

•Data Assimilation:	**3D-Var: NAVDAS (Atmosphere), NCODA (Ocean) EnKF and 4D-Var (underway), Adjoint obs. impact**
•Atmosphere:	**Nonhydrostatic, NRL fluxes, PBL, NRL microphysics, LSM, dust/aerosols, Fu-Liou radiation, TC physics**
•Ocean:	**Navy Coastal Ocean Model (NCOM), Wave (SWAN,WWIII)**
•Ensemble:	**Ensemble Kalman Filter, Coupled Ensemble Transform**
•Tropical Cyclone:	**COAMPS-TC, TC analysis, TC physics, moving nests**
•Operations: FNMOC & NAVO	**Globally relocatable, 60+ areas (2-4x daily), Δx~1.6-27km, coupling, COAMPS-OS turn-key system, COAMPS-TC**

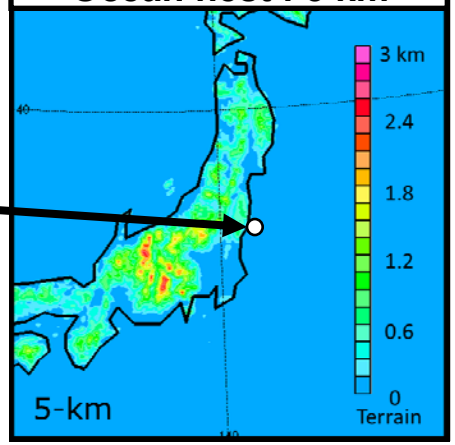
COAMPS Fukashima Ensemble Results

Coupled Ocean/Atmosphere Mesoscale Prediction System

11 Mar 2011 Fukushima Release

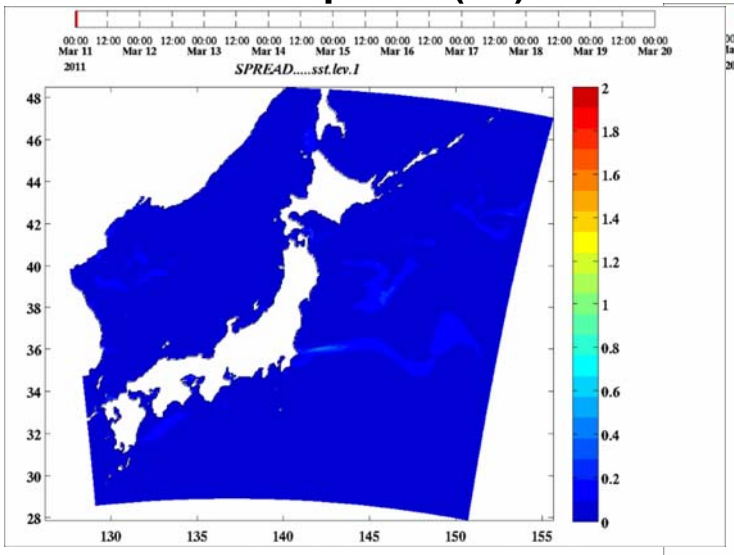


Atmos nests: 45,15,5 km
Ocean nest : 5 km

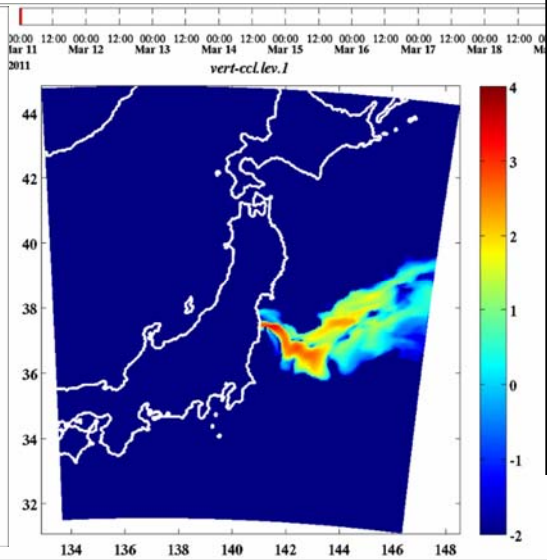


- **12-h forecasts from 11-20 Mar 2011:**
  - 29 coupled ET members
  - 2-way air-ocean coupled forecasts
  - Separate ET on atmosphere and ocean
  - 12-h data assimilation cycle
- **Passive tracers** are continuously released within COAMPS at Fukushima on nest 3, responding to dynamic and thermodynamic model forcing at every time step.
- **Atmospheric model perturbations:**
  - Boundary layer mixing
  - Surface fluxes
  - Cumulus trigger functions
  - Cloud microphysics

Sea Surface Temperature Ensemble Spread (°C)



Sfc. Tracer Mass Load (log) Continuous 10-m Release



- Coupled ET ensemble:
  - ➢ Fluctuating winds impact atmospheric transport.
  - ➢ SST variance is maximum near Fukishima (Kurosio).
- Coupled Ensemble capability highlights the uncertainty in the atmosphere and ocean transport predictions for Fukishima.

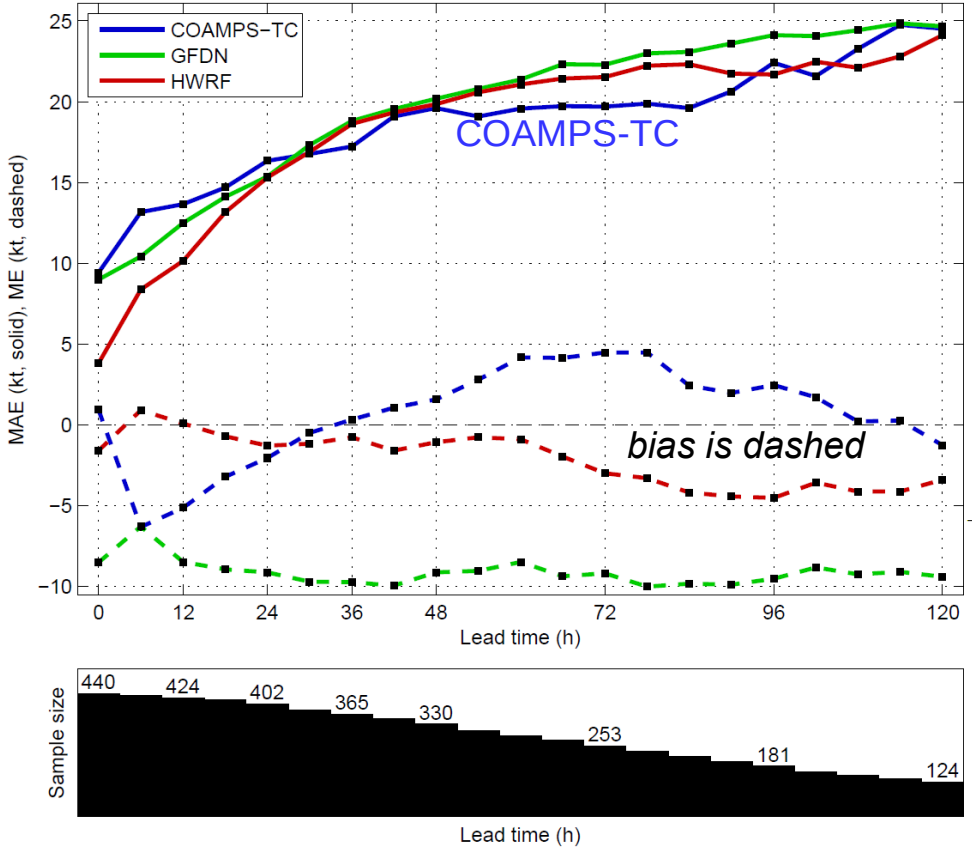
T. Holt

COAMPS-TC System

Tropical Cyclone Intensity, Structure, Track Prediction

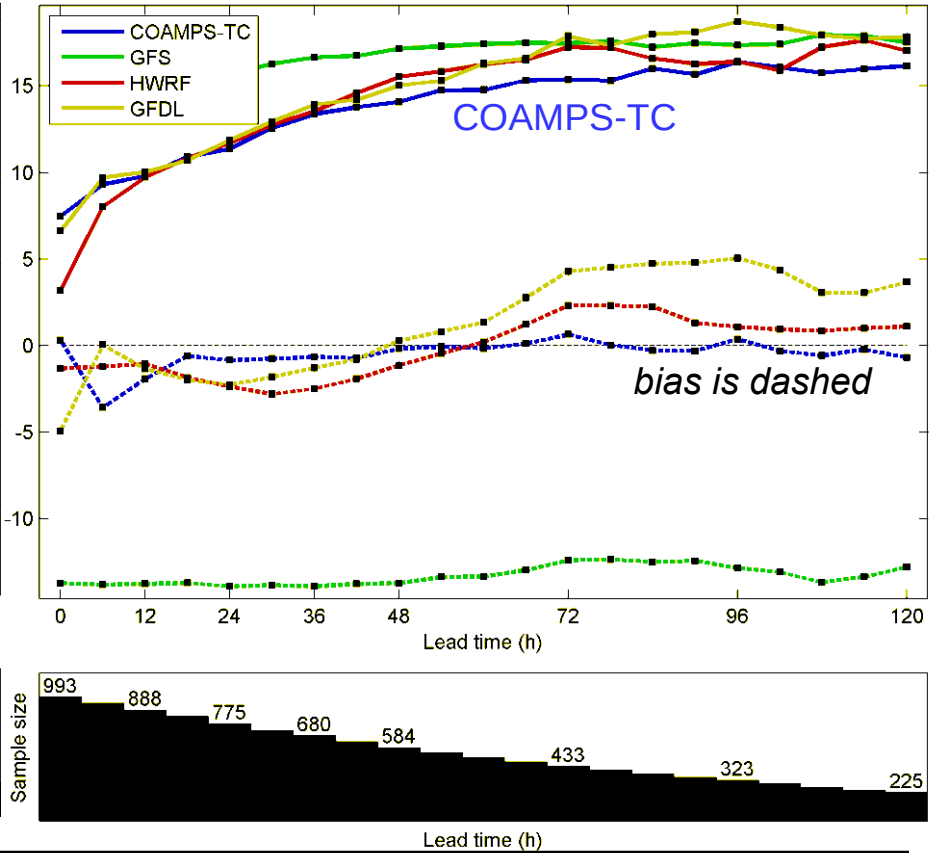
W. Pacific Intensity Error (kt)

2012



W. Atlantic Intensity Error (kt)

2010-2012



- COAMPS-TC real-time forecasts in W. Pacific (2012) and W. Atlantic (2010-2012) were among the most accurate dynamical intensity models.
- COAMPS-TC was transitioned to Navy operations at FNMOC in June 2013.

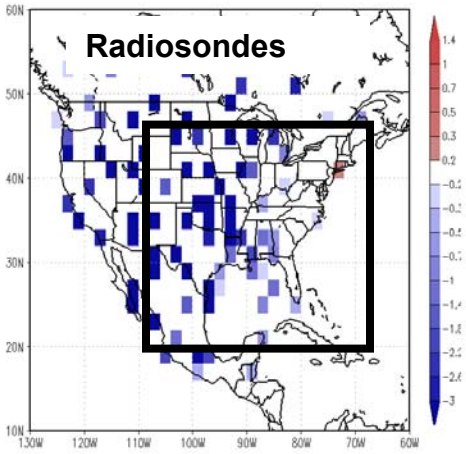
COAMPS Adjoint

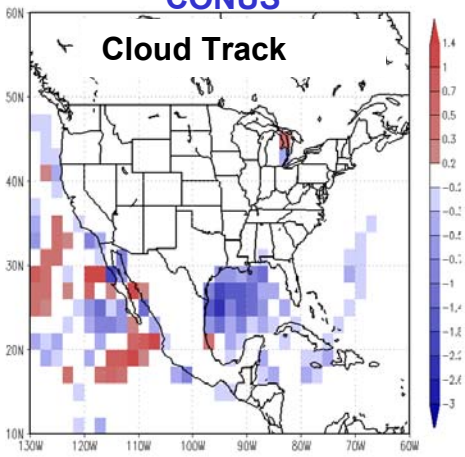
Mesoscale Observation Impact System

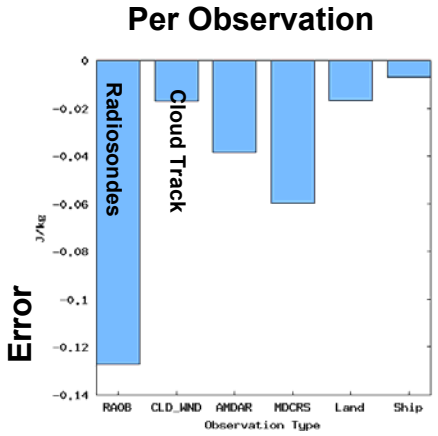
Linked adjoints of analysis (3D-Var) and nonhydrostatic model

COAMPS Impacts 12/24-31 2010

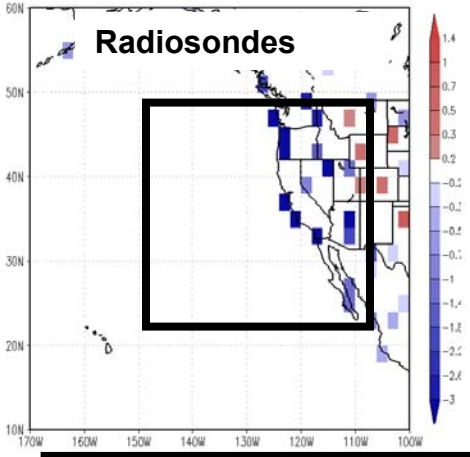
CONUS

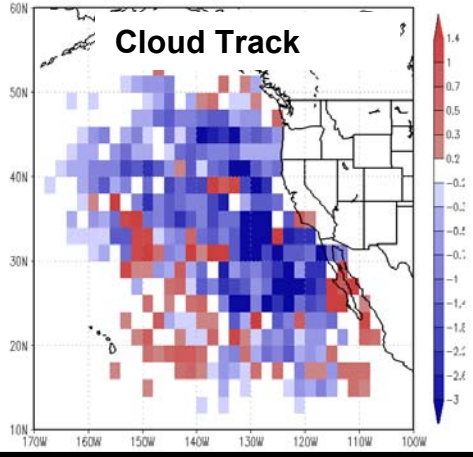


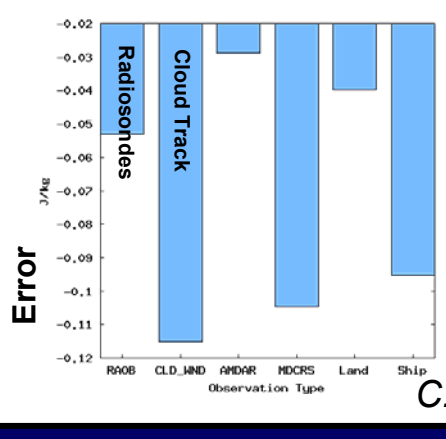




EPAC





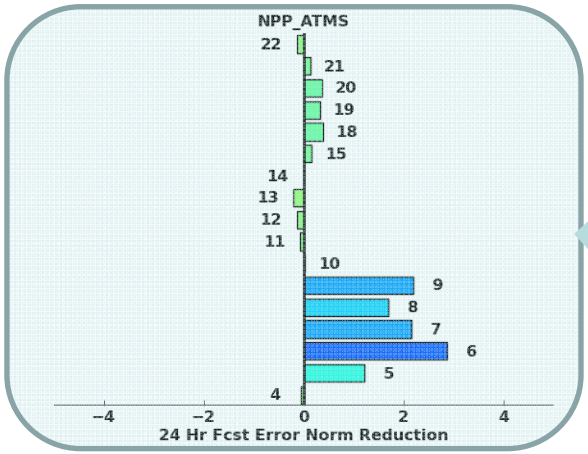


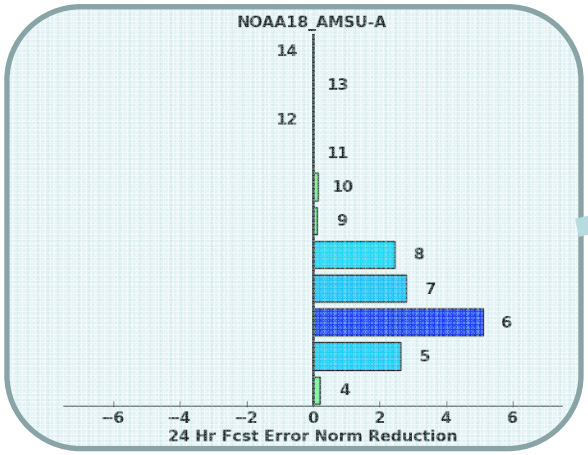
C. Amerault, J. Doyle

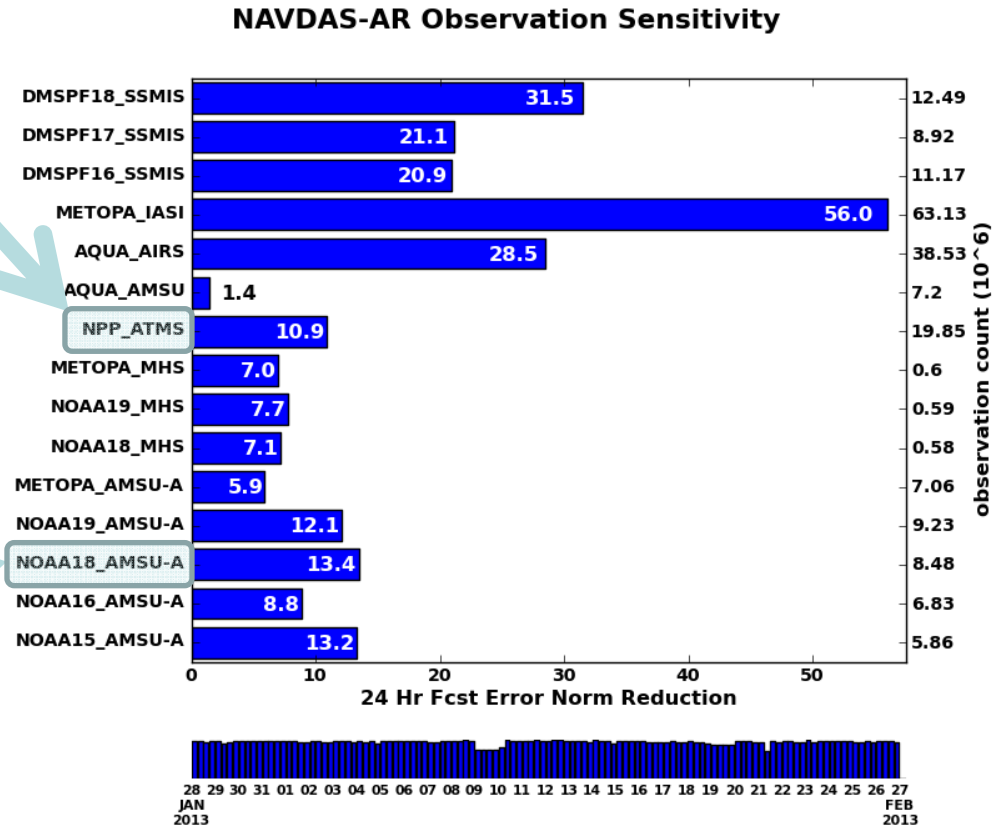
Observation impact depends on region of interest.

DA: NAVDAS-AR Observation Impact

NPP ATMS Assimilation: Sensor impact on forecast error







ATMS performs similar to an AMSU-A, but ATMS has moisture channels (as does SSMIS)

- Should be similar to SSMIS or AMSU-A+MHS sum

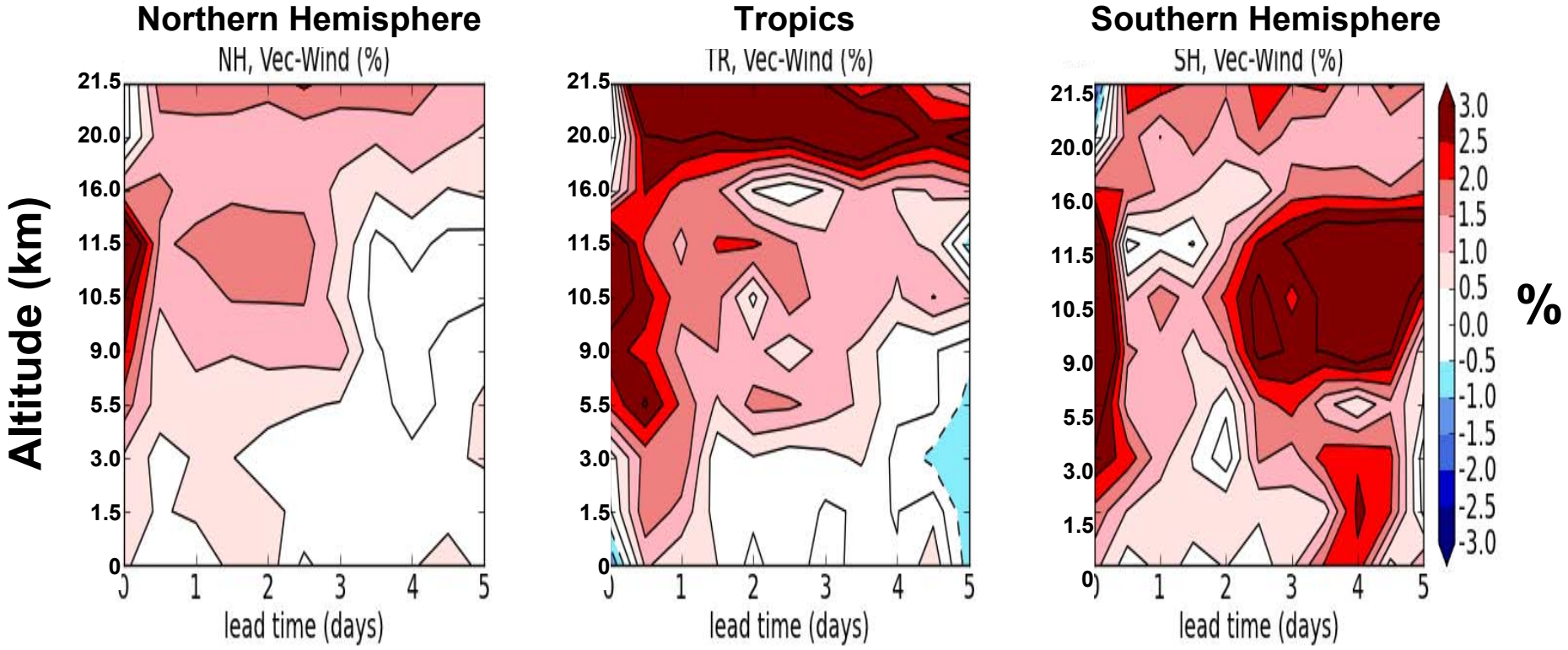
Inherent noise in sensor introduces correlated error which reduces impact

- NOAA supported cal/val efforts; active collaboration with JPSS/JCSDA colleagues

DA: 4D-Var Hybrid Data Assimilation

$$P_b^0 = \alpha\, P_b^0\,(\text{computed}) + (1 - \alpha)\, P_b^0\,(\text{ensemble})$$

Improvement (red) or degradation (blue) in wind analyses and forecasts for hybrid 4D-Var relative to current 4D-Var assimilation as validated against raobs



D. D. Kuhl, T. E. Rosmond, C. H. Bishop, J. McLay and N. L. Baker, "Comparison of hybrid ensemble/4D-Var and 4D-Var within the NAVDAS-AR data assimilation framework," Monthly Weather Review, 141 (2013) 2740-2758.

Navy Aerosol Modeling
Spanning Global to Mesoscale

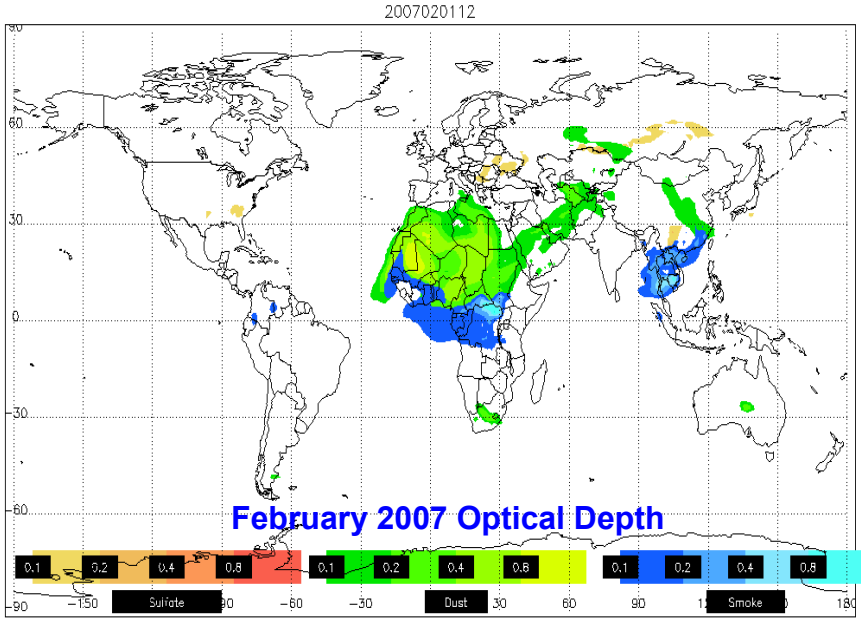
http://www.nrlmry.navy.mil/aerosol/

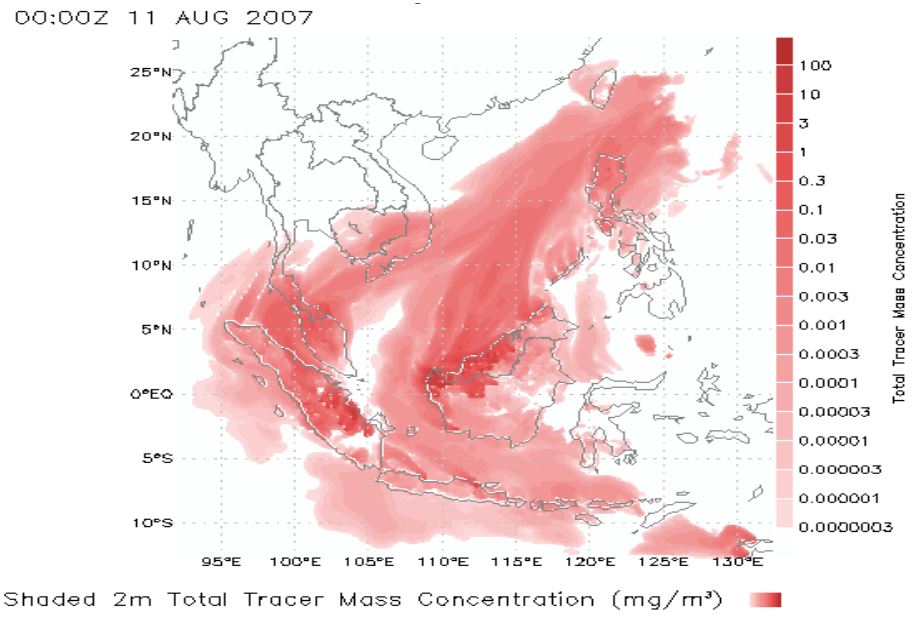
Global Modeling: Navy Aerosol Analysis and Predication System (NAAPS)

- Navy's operational global aerosol model; now at 1/3 degree resolution using NAVGEM meteorology.
- 6-day forecasts of dust, smoke, pollution, and sea salt run 4x/day
- First to operationally assimilate MODIS aerosol & geostationary fire data streams.

Mesoscale Modeling: Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS®)

- Dust, smoke and other aerosol types integrated within COAMPS.
- Mesoscale capability for aerosol/cloud/radiation interactions.
- High-res. dust source database yields detailed dust plumes.

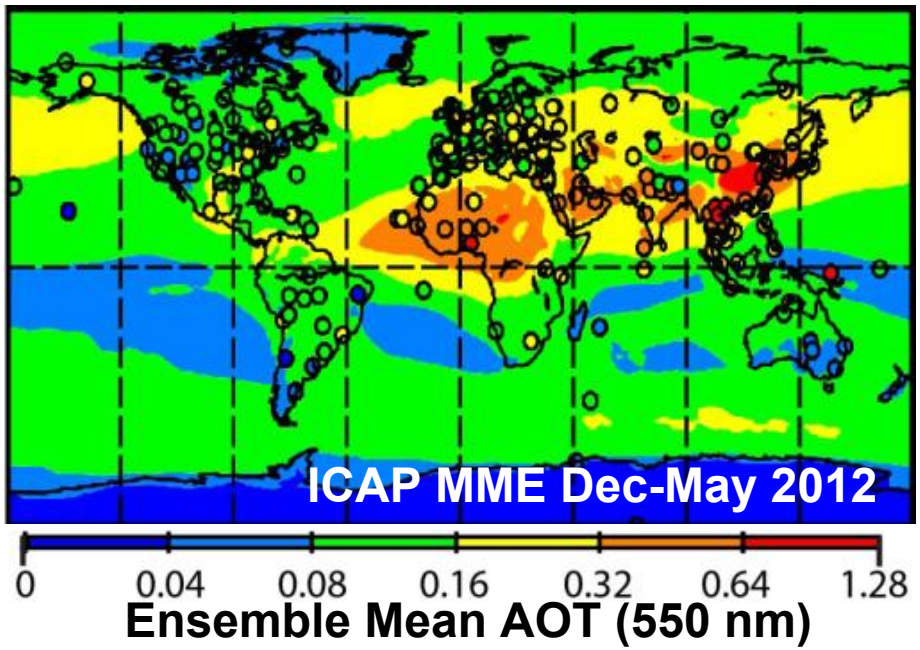


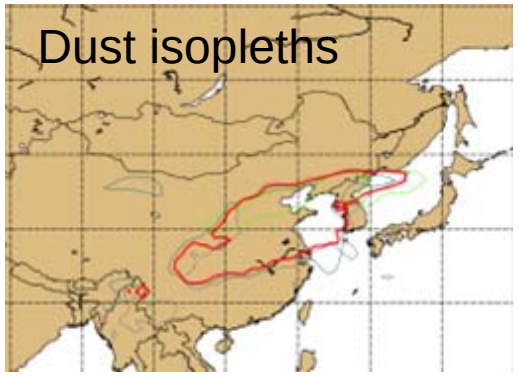


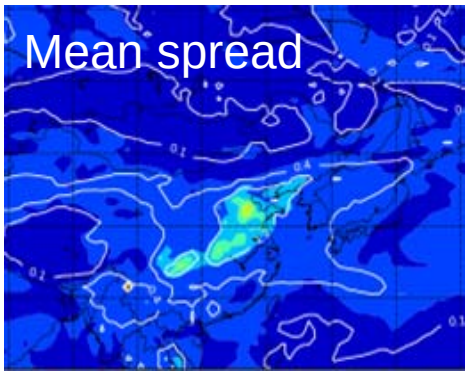
NRL Developed ICAP Global Multi-model Aerosol Forecast Ensemble:

BSC, ECMWF, FNMOC/NRL, JMA, NASA, NOAA, UKMO

- The International Cooperative for Aerosol Prediction (ICAP): aerosol forecast developers share best practices and make recommendations for DA aerosol observation needs.
- Ensemble open to any quasi-operational global aerosol model. Currently working on AOT and surface concentrations for multi species and dust only, but looking towards 3D.
- Specific error metrics are kept by centers, ensemble products distributed anonymously.
- The ICAP MME has the best RMSE scores and a more consistent bias distribution over the globe.





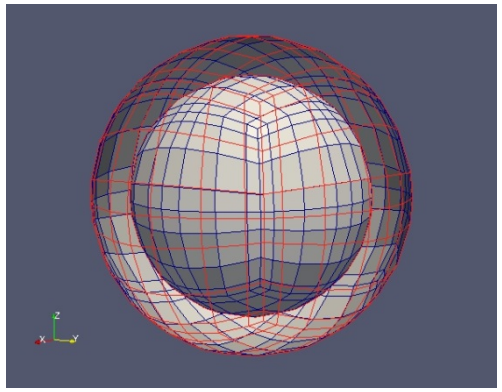


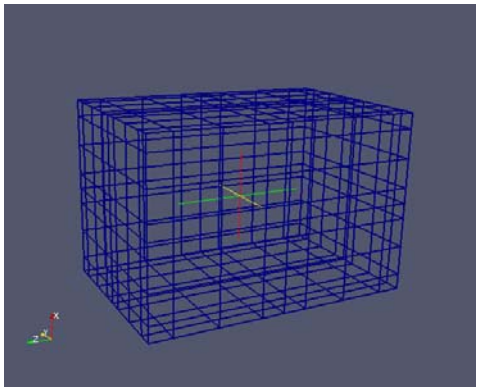
Next Generation Global-Regional System

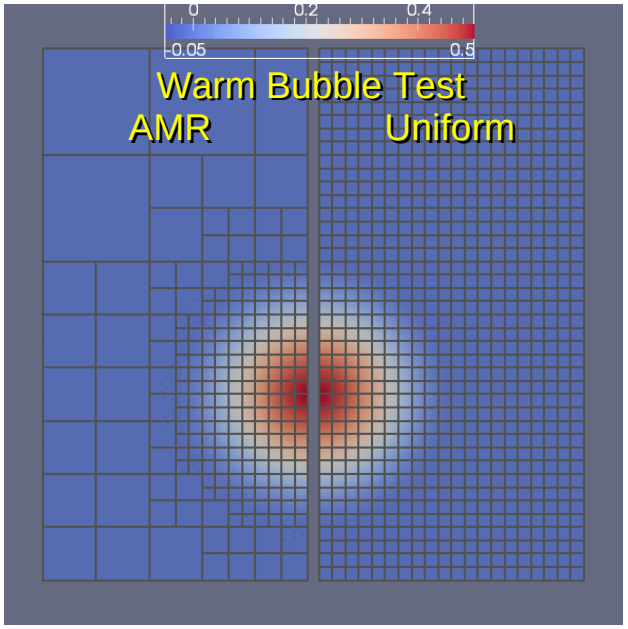
Navy Environ. Pred. SysTem Utilizing the NUMA CorE (NEPTUNE)

3-D Spectral Element Model

- High order accuracy core (NUMA)
- Extremely scalable
- Mesoscale, global options (w/ MPI)
- Adaptive mesh refinement (AMR)
- Incorporation of physics underway



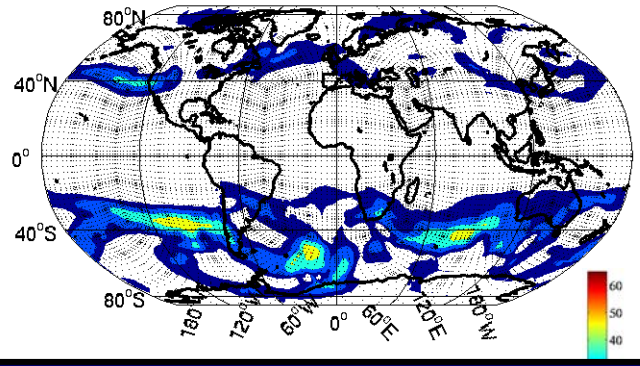




Real-Data Simulation

(Dx=100 km, 24 h fcst from 00Z 25 June 2013)

500-hPa Wind Speed (m s^{-1})



NEPTUNE is being developed as a possible next-generation unified global-regional prediction system using the NUMA spectral element core.

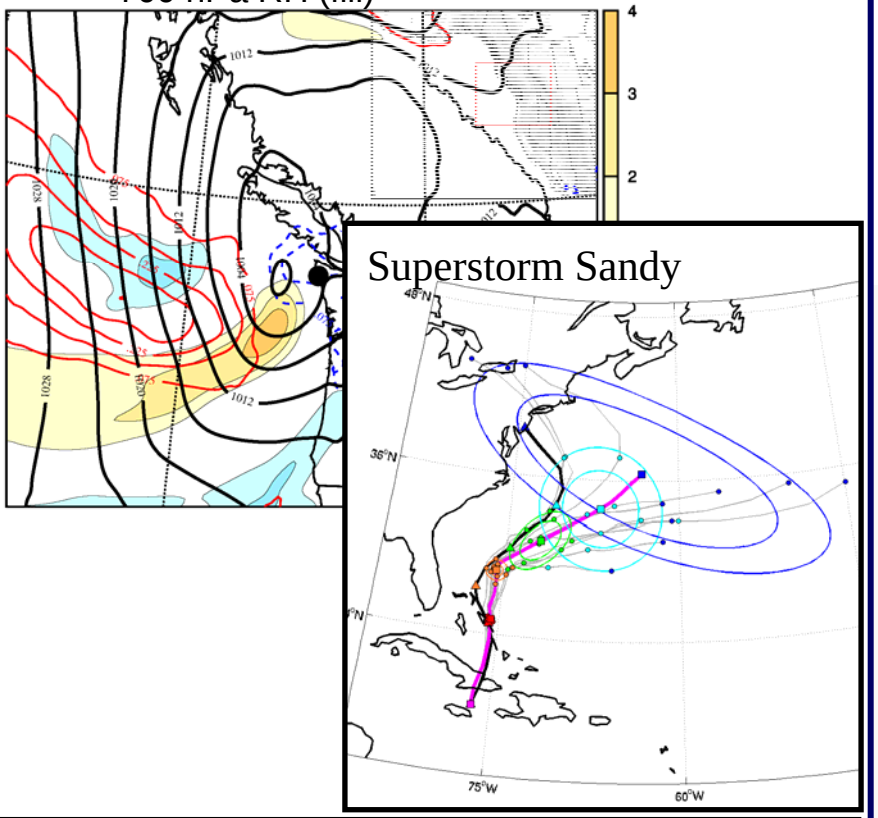
F. Giraldo (NPS), S. Gabersek, A. Reinecke, K. Viner, E. Hendricks, J. Doyle (NRL)

Questions?

Ensemble and Adjoint Capabilities

EnSRF Data Assimilation, Adjoint/Ensemble Sensitivity

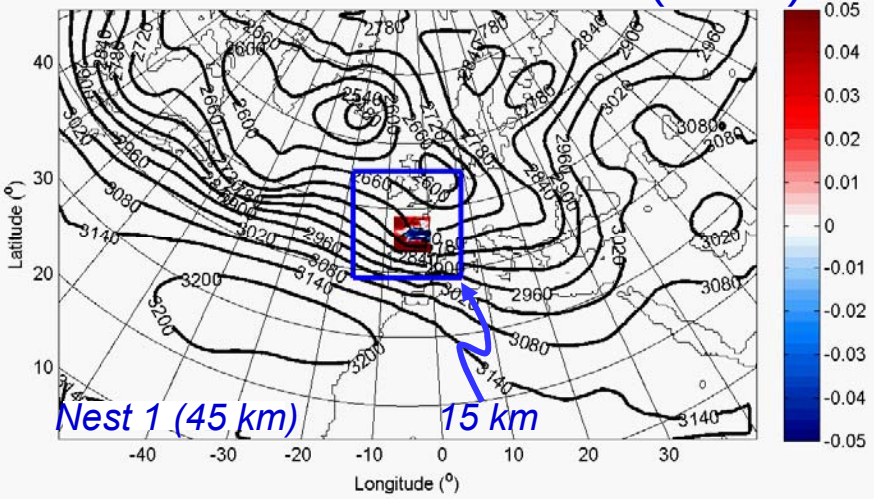
Covariance between SLP and
700 hPa Temp (contours)
700 hPa RH (fill)



- EnSRF (Ensemble Square Root) w/ DART.
- Predictability and data impact studies.

- COAMPS Nested adjoint modeling system.
- Multi-scale sensitivity used for mesoscale targeting during ONR T-PARC/TCS08, ITOP, and NASA-ONR HS3.

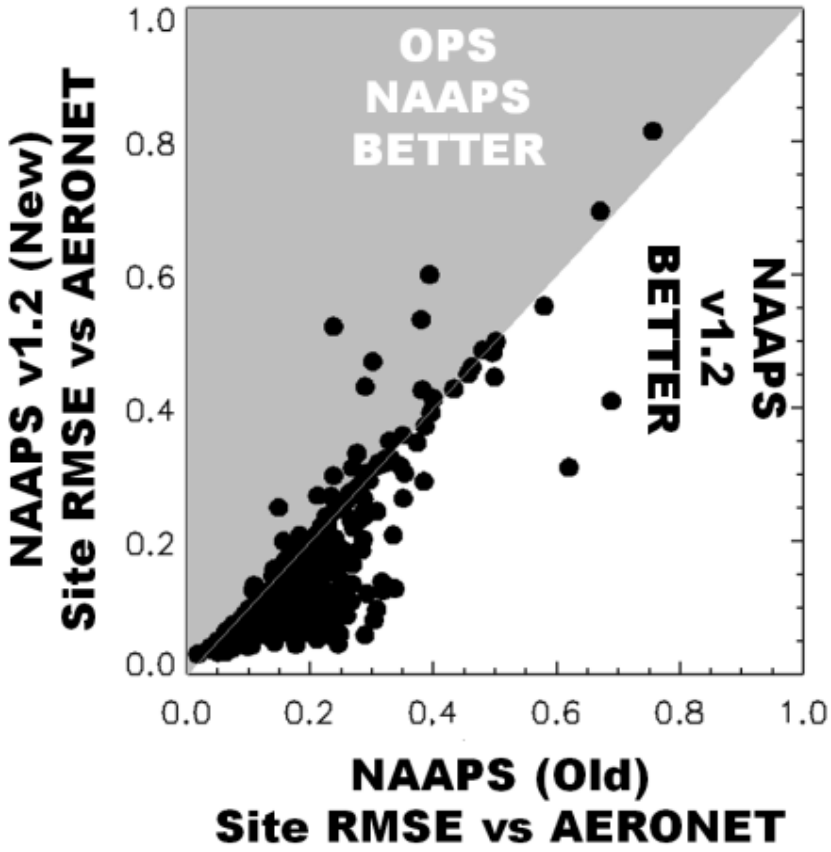
36-h Nested Adjoint
Severe European Cyclone Klaus
12Z 22 Jan 2009



A. Reinecke, C. Amerault, J. Doyle

Components of NAAPS
Recent Operational Upgrades

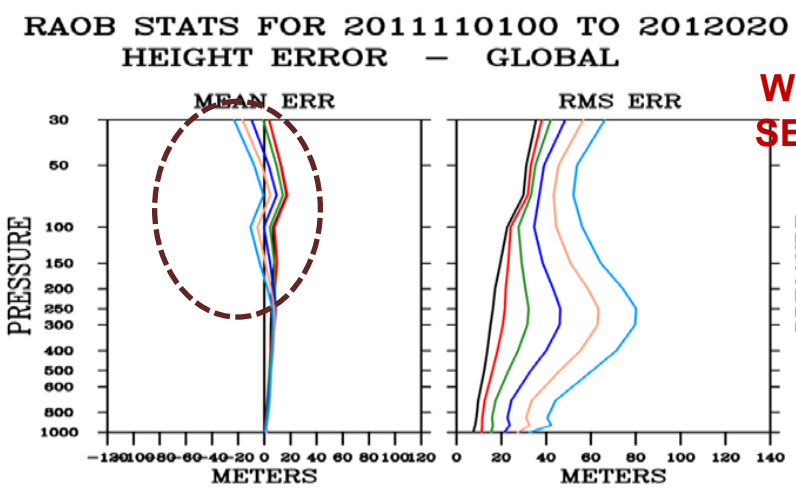
- **NAAPS: Global aerosol transport and evolution model**
  - Upgraded from 1° to 1/3 ° resolution to run using NAVGEM. Errors down by 20%
  - Dust, smoke, sea salt, sulfate, POA, SOA
  - Semi-Lagrangian transport scheme modified so each species can have its own complete microphysics
- **NAVDAS-AOD: AOD assimilation for NAAPS**
  - 2d Var scheme upgraded to use NAVGEM
  - MODIS AOD pre-processor upgraded to assimilate higher resolution obs
- **FLAMBE: Smoke source model for NAAPS**
  - Latency improved from 12-36 hours after overpass to 3-6 hours
  - Separate processing for each sensor



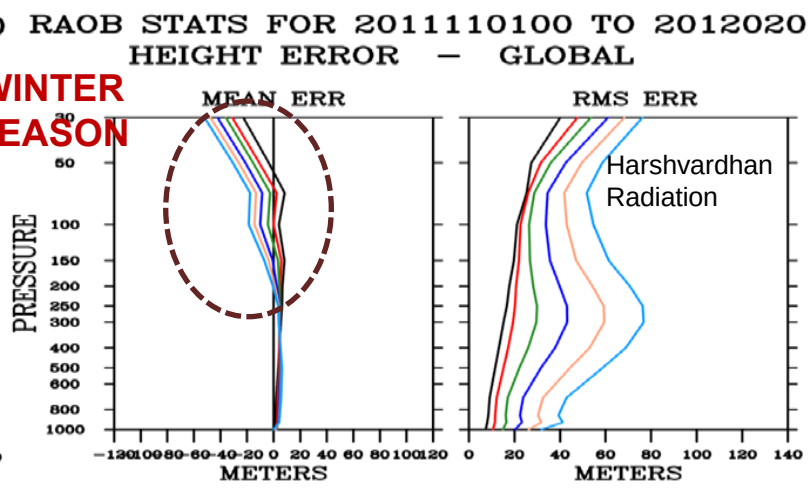
Model evaluation vs. AERONET in situ AOD data. The new NAAPS V1.2 is clearly more accurate with a lower RMSE in 280 of 341 (82%) of the sites with 100+ AERONET AOD observations, and 141 of 154 (92%) of sites where mean NAAPS AOD differed by 0.1 or more between the two systems.

Height Errors and Bias

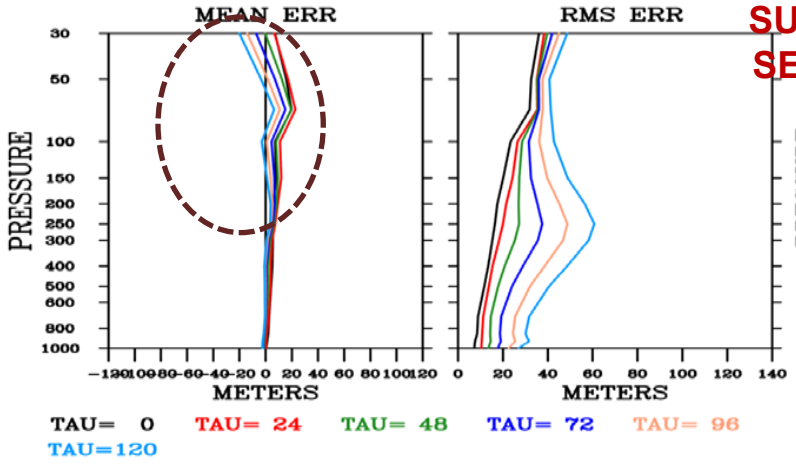
RRTMG and One-total Cloud



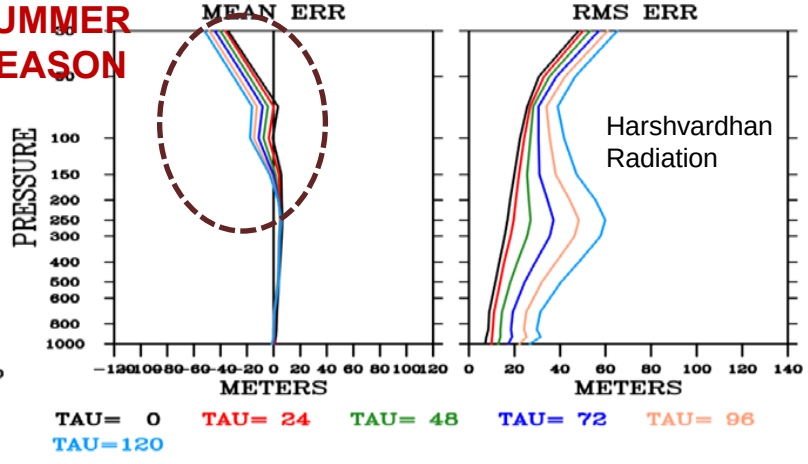
NOGAPS



WINTER SEASON



SUMMER SEASON



RRTMG, new cloud scheme and SL/SI reduce

NAVGEM 1.3 Planned Upgrades:
SL Advection of θ_v'

- Semi-implicit advection schemes are used to relax stability constraints on time step size associated with fast waves- true for Eulerian and SL cores
- For SL cores, a conservative thermodynamic prognostic variable is inherently unstable
  - Stability maintained through various damping methods and limiters, reducing accuracy
- Stability can be maintained in a system which is split into a basic state θ_0 and perturbation θ_v'
  - The semi-implicit scheme must be redesigned to use θ_v' as the prognostic variable; θ_0 is a diagnostic function of pressure which is advected in an Eulerian fashion
- In this manner the semi-implicit scheme can sufficiently modify the fastest waves for increased stability
  - Additional damping techniques and limiters can be removed