Recent Developments in Navy NWP

Carolyn Reynolds, Nancy Baker, James Doyle, Douglas Westphal, Liang Xu, and Melinda Peng

Naval Research Laboratory, Marine Meteorology Division, Monterey, CA, USA

- Global Prediction System: NAVGEM
- Earth System Prediction Capability (ESPC)
- Mesocale Systems: COAMPS®
- Aerosols: NAAPS and COAMPS®
- Next Generation System: NEPTUNE

NRL transitions NWP upgrades to our operational partner, Fleet Numerical Meteorology and Oceanography center (FNMOC)

Navy Global Environmental Model
NAVGEM 1.3 currently being transitioned to FNMOC

Data Assimilation

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

NAVGEM 1.3 Upgrades

- Increased resolution from T359L50 to T425L60
- New stratospheric physics for water vapor photo chemistry, sub-grid-scale non-orographic gravity wave drag, and stratospheric humidity quality control
- New dynamics formulation utilizing perturbation virtual potential temperature to improve numerical stability and reduce semi-implicit decentering
- Convective cloud fraction predicted based on Xu-Randall
- Improved initialization of ground wetness and temperature

Future Upgrades

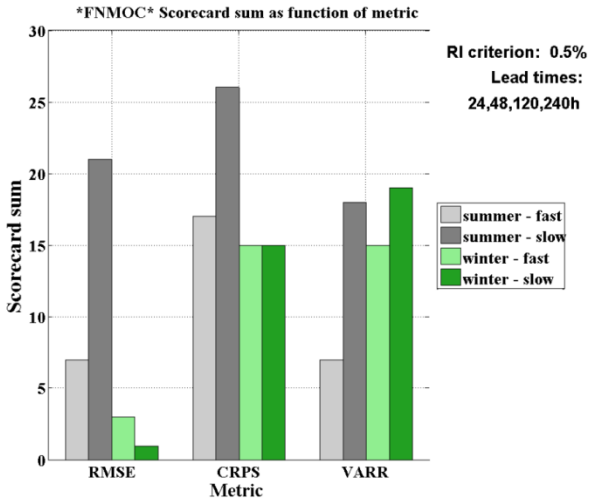
- Short Term: dynamic sea ice (CICE) model via ESMF coupling, T681L80: (~19 km) and 0.01 hPa model top
- Longer Term: 10 km resolution, interactive aerosols, coupled atmosphere-ocean-ice-wave extended-range prediction system

Navy Global Environmental Model
NAVGEM 1.3 currently being transitioned to FNMOC

- **Current system: NAVGEM T239L50**
  - **80-mem, 4 times per day, to 6h, 20-mem, 2 times per day, to 16 days**
  - **Banded local ET initial perturbations, no model uncertainty**
  - **Used to force surface wave ensemble**

- **Spring 2015 upgrade**
  - **Stochastic Kinetic Energy Backscatter with a moisture convergence mask (SKEB-MC)**

- ***Overall positive impact, especially for 10-m wind speed***
- ***Slow (6-h) vs. fast (40-min) temporal variability has bigger impact in summer***



- **FY15-FY16: SST initial perturbations, diurnal cycle, persistent anomaly capability, T359L60**

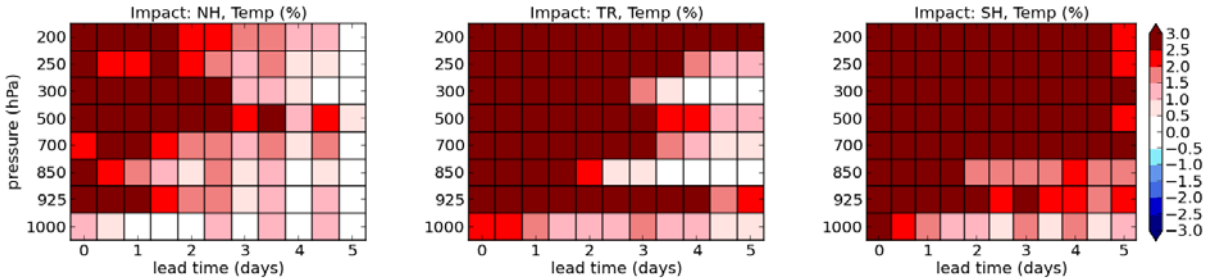
NAVGEM 1.3 Hybrid 4DVar 90-day Benchmark Testing

Comparison: NAVDAS-AR (4DVar, α=0.0) and Hybrid 4DVar (α=0.5)

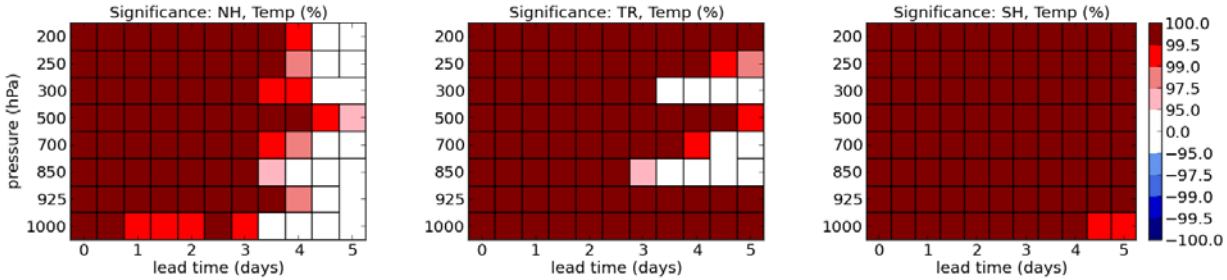
$$\mathbf{P}^{\mathbf{f}} = \alpha \mathbf{P}^{\mathbf{f}}_{ENS} + (1-\alpha)\mathbf{P}^{\mathbf{f}}_{CONV}$$

NAVGEM 1.3 vs. Hybrid 4DVar α =0.5
Temperature verified with ECMWF analysis

Forecast Impact



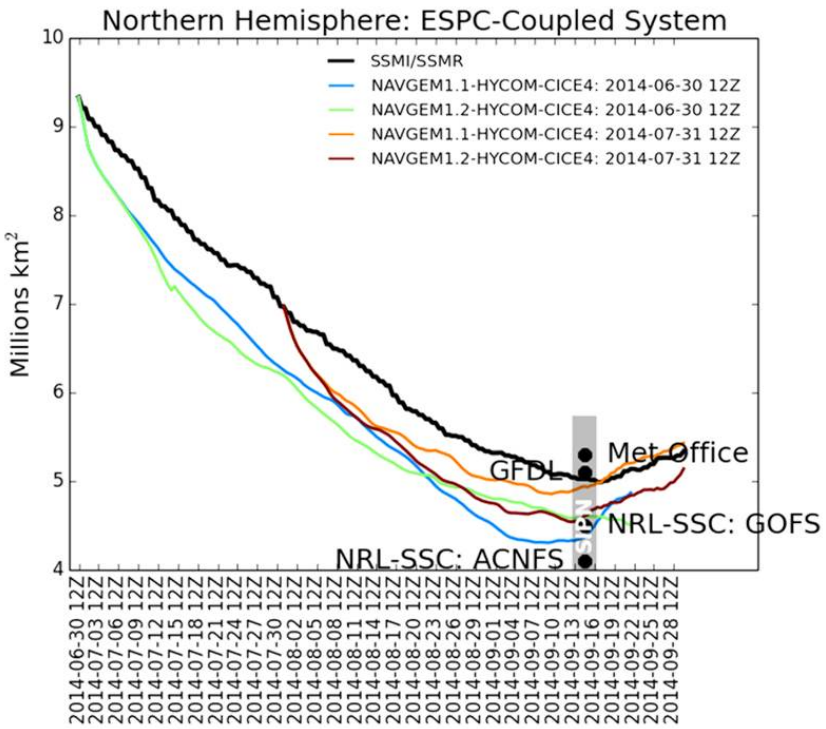
Statistical Significance



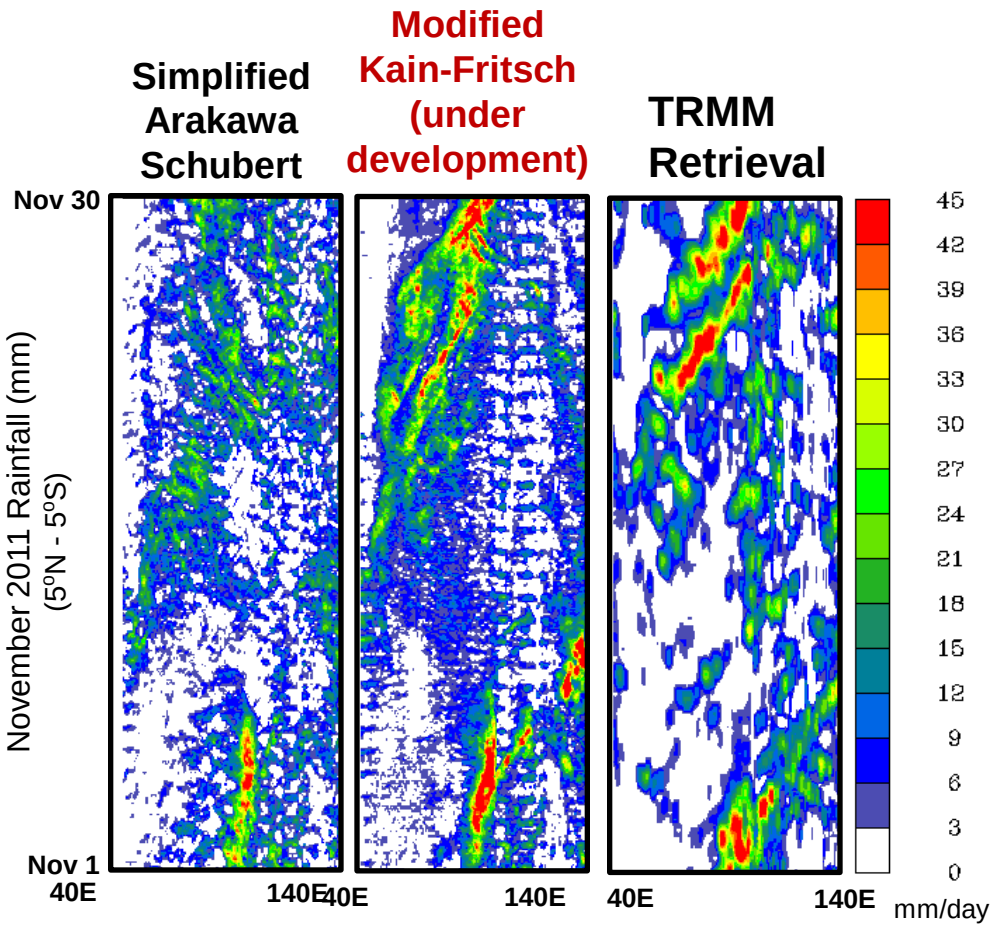
Red Shading ➔ Hybrid DA is better; Blue Shading ➔ NAVDAS-AR is better

Earth System Prediction Capability (ESPC)
NAVGEM-HYCOM-CICE Coupled System

NAVGEM-HYCOM-CICE seasonal prediction of Arctic sea ice minimum in line with other center predictions



Improvements to physics resulting in much better simulation of DYNAMO MJOs



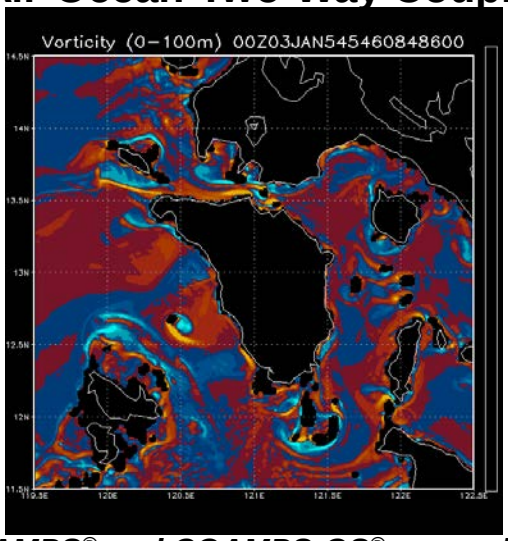
NRL Monterey and NRL Stennis

COAMPS Overview

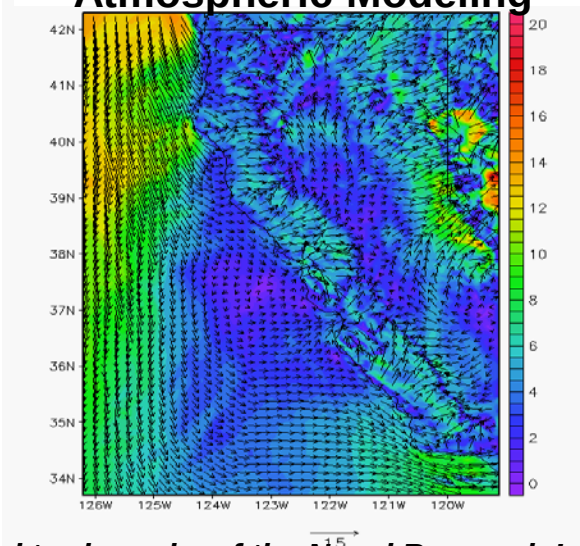
Coupled Ocean/Atmosphere Mesoscale Prediction System

- **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
- **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
- **Field Projects:** DeepWave, HS3, TCI, CalWater, Trident Warrior
- **Operations:** FNMOC & NAVO — Globally relocatable, 70+ areas (2-4x daily), Δx~1.6-27km, coupling, COAMPS-OS turn-key system, COAMPS-TC

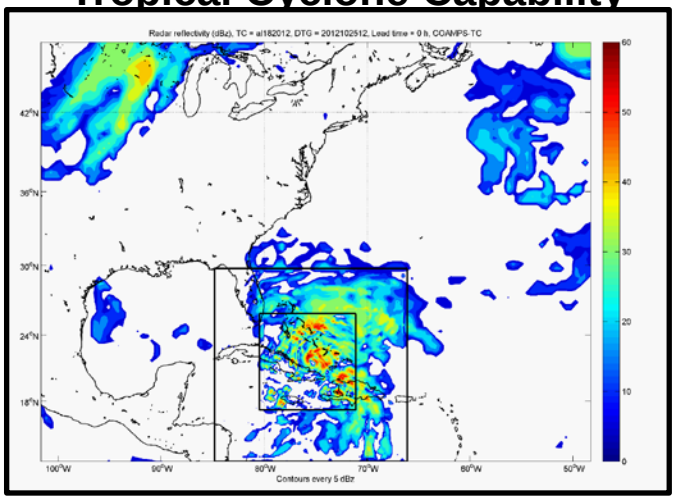
Air-Ocean Two-Way Coupling



Atmospheric Modeling



Tropical Cyclone Capability



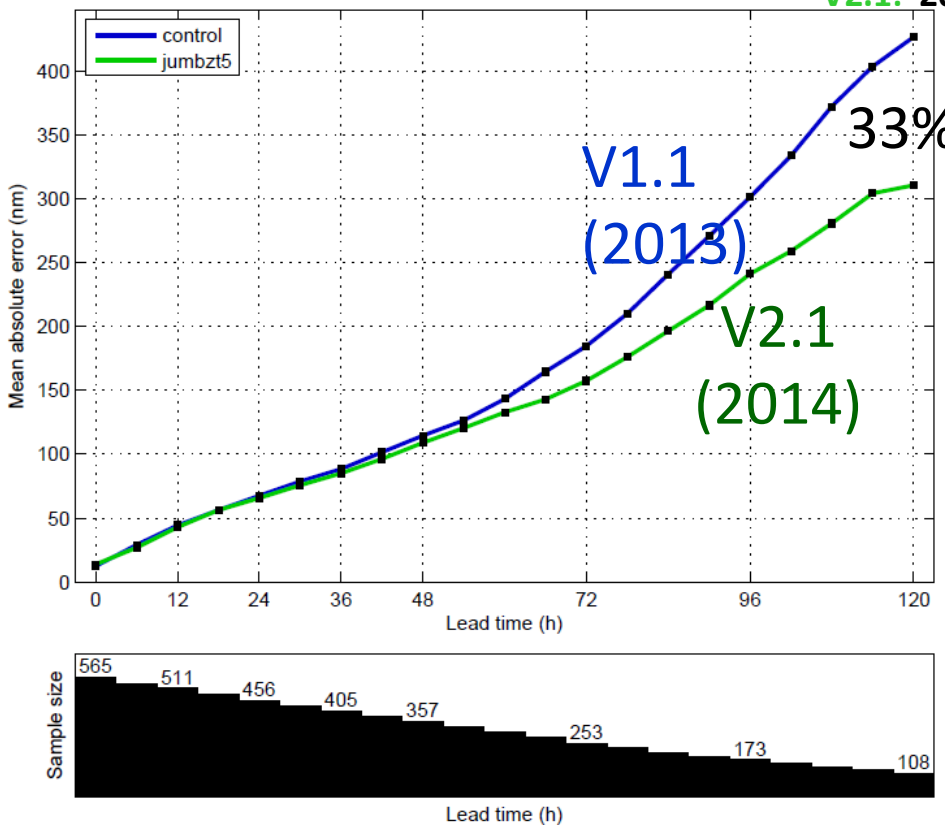
COAMPS-TC Improvements

Position Forecast Error

Track error, NHC criteria

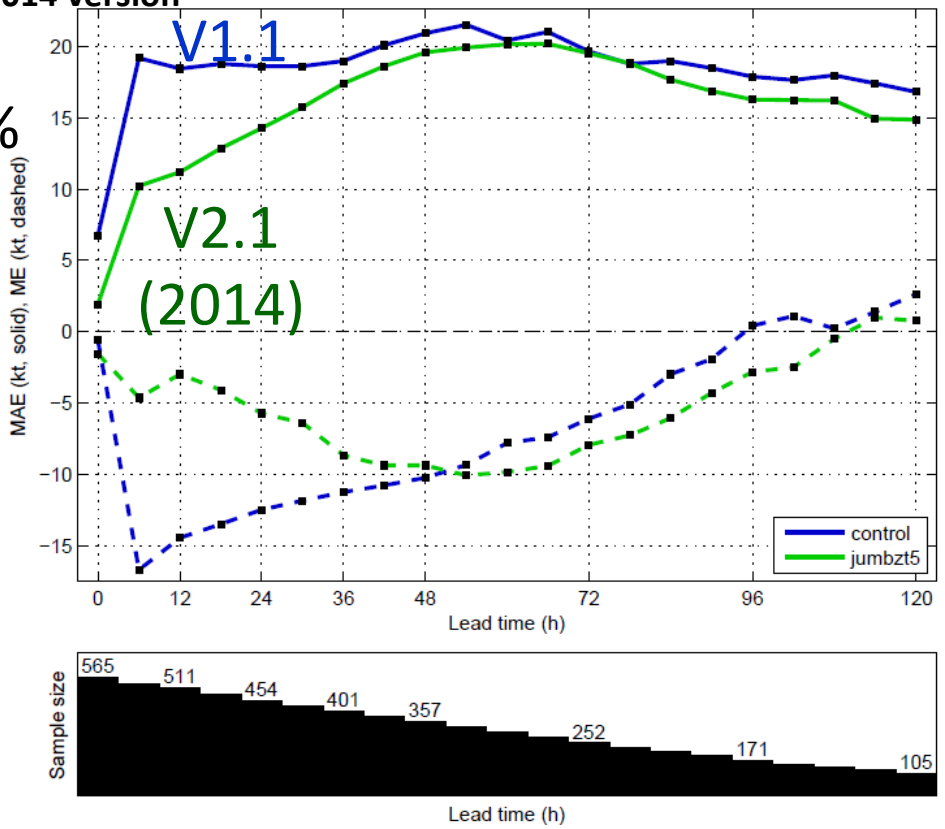
V1.1: 2013 version

V2.1: 2014 version



Intensity Forecast Error

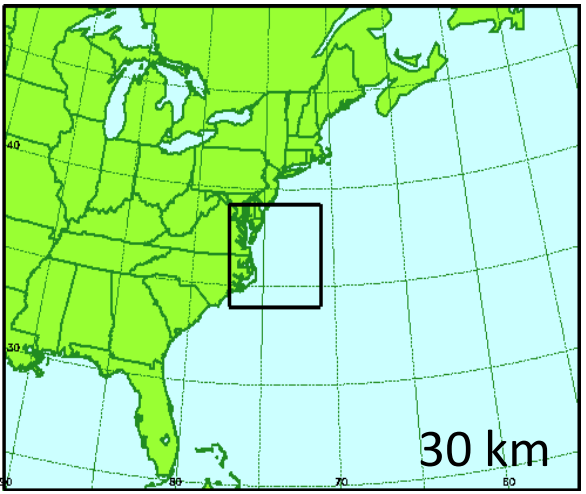
Intensity error, NHC criteria

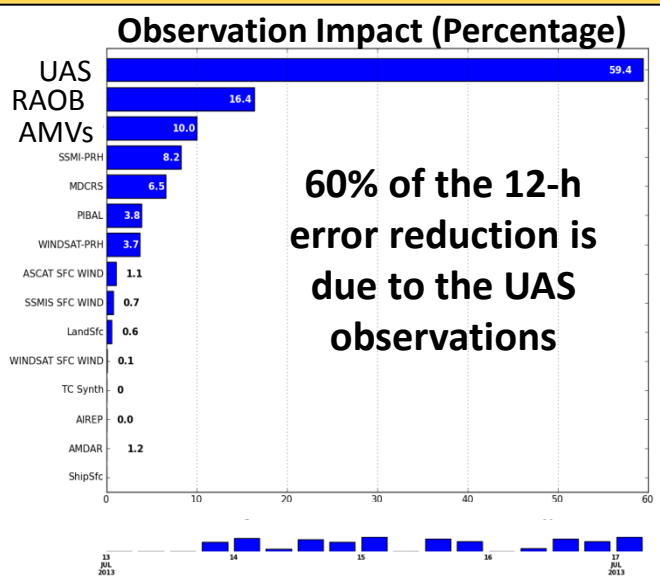


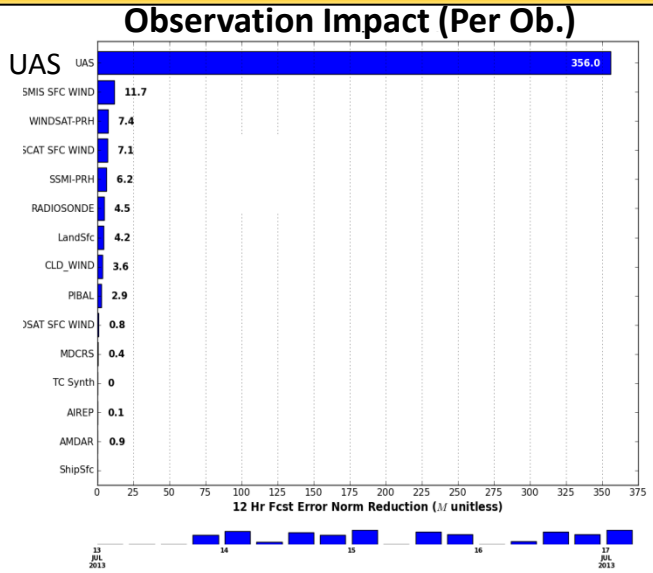
- Synoptic scale initialization, blend zone, new terrain improve TC position forecasts
- Vortex initialization change improves intensity prediction, particularly at short lead times, mitigates “spin-down”
- COAMPS-TC 10-member EPS contributes to the HFIP Multi-model Ensemble

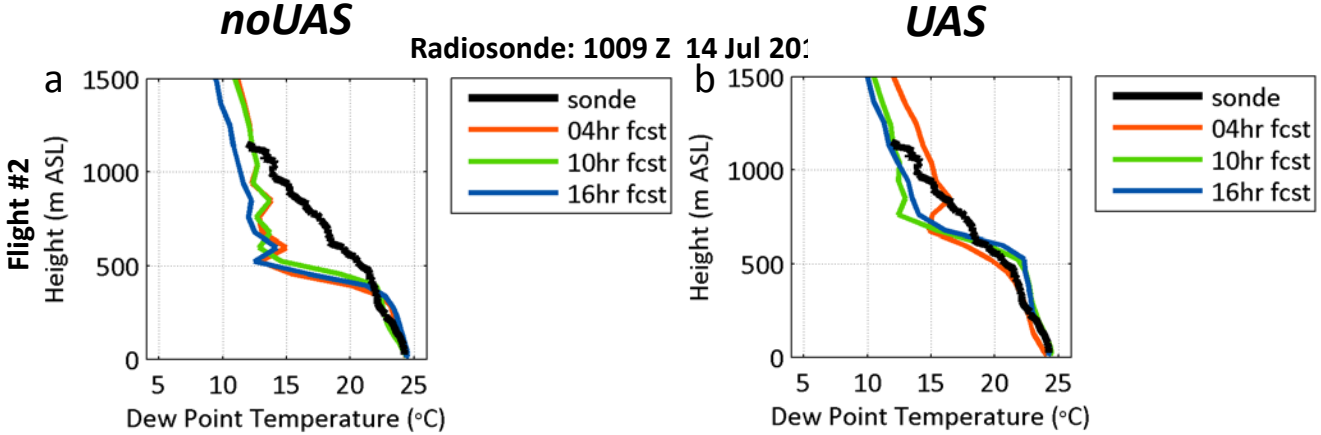
COAMPS

Impact of Unmanned Aerial Systems (ScanEagle)









- Observation impact computed using adjoints of COAMPS and NAVDAS

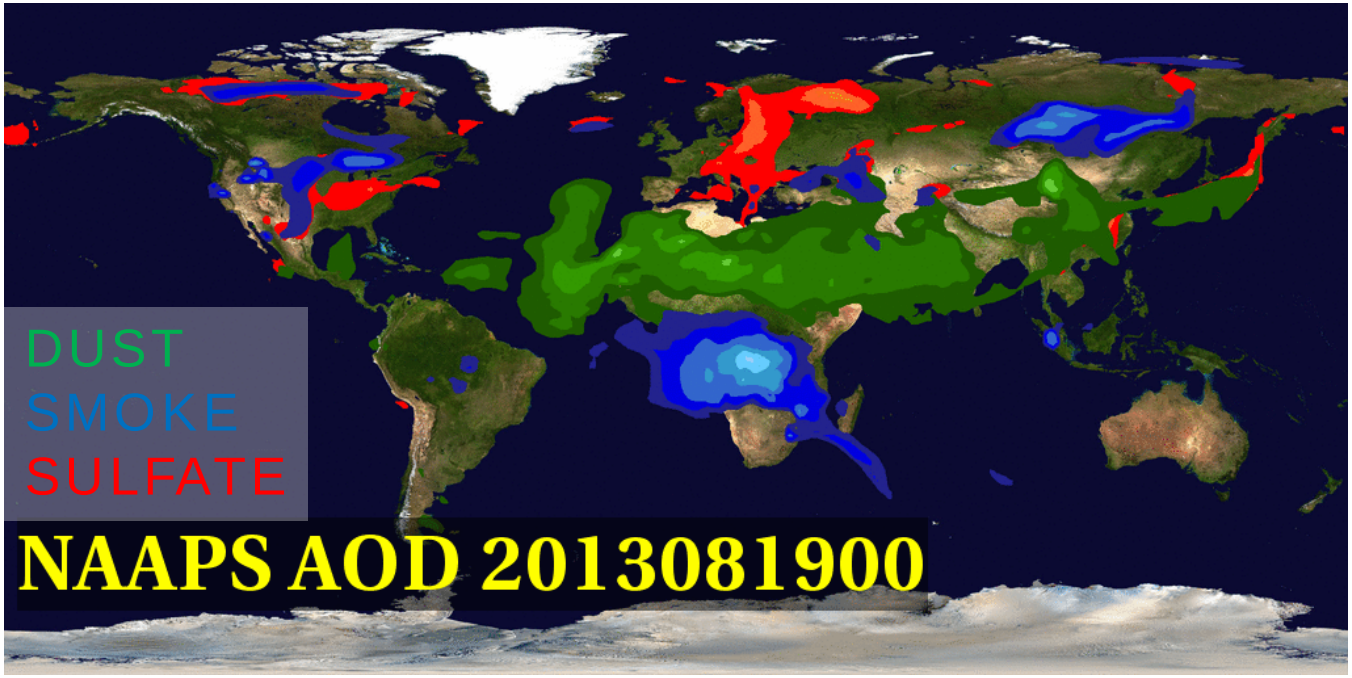
Navy Aerosol Analysis and Prediction System (NAAPS)

Components and Satellite Input

NAAPS: Global aerosol transport and evolution model

- Uses NAVGEM meteorology from T359L50 resampled to 1/3 ° spatial resolution
- Tracks Dust, smoke, sea salt, sulfate, SO2 (organics coming soon)
- Each species has its own complete microphysics and optical properties: wet and dry deposition, extinction coefficients

The International Cooperative for Aerosol Prediction (ICAP, extra slide) multi-model ensemble



FLAMBE: Smoke source model for NAAPS

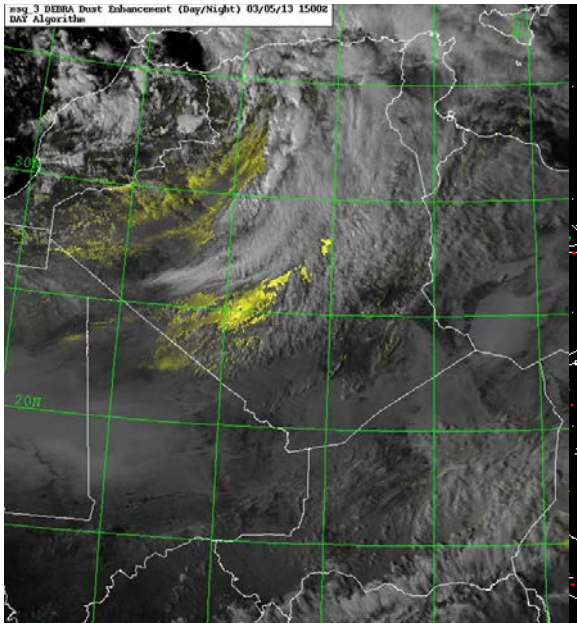
- MODIS and geostationary fire data used to estimate smoke aerosol release
- MODIS + GOES observations included 3-6 hours after overpass
- Global geostationary in development

NAVDAS-AOD: Aerosol assimilation for NAAPS

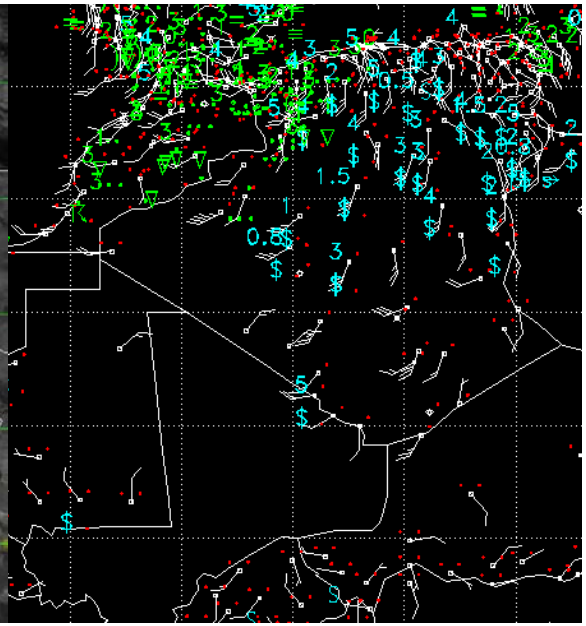
- Satellite aerosol optical depth variational assimilation in observation space (2D column integrated extinction)
- Uses MODIS AOD over land and ocean; VIIRS AOD over ocean will be assimilated soon

COAMPS Aerosol Modeling
Aerosol Microphysics for NWP

Satellite Image of Event



Surface Observations



Output From Verification Package

```
-----------------------------------------------
  Visibility threshold (km)     3.500000
-----------------------------------------------
total both dust obs             221    10.01359
total both clear obs           1490    67.51246
total false postive             143    6.479384
total false negative            353    15.99456
total obs                      2207
-----------------------------------------------

Total dust observations:          574
 Dust Storm Prediction Rate:     38.50174
Dust Storm False Alarm Rate:     8.756889
    Dust Storm Threat Score:     30.82287
    Dust Storm Gilbert Skill Score:   0.2029956
      Total Prediction Rate:     77.52605
```

- **Dust, smoke and other aerosol types integrated within COAMPS.**
- **Developed real-time verification of visibility and AOD.**
- **Update to NRL Dust Source Database improved dust storm prediction rate**
- **Goal is to improve Navy operational capability with a new generation of cloud and aerosol products**

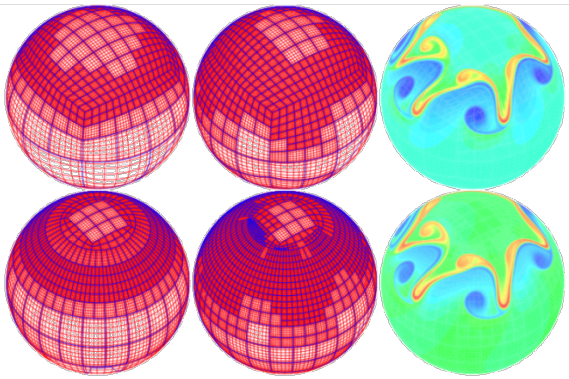
D. Westphal, S. Lowder, J. Schmidt, M. Liu, A. Walker

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



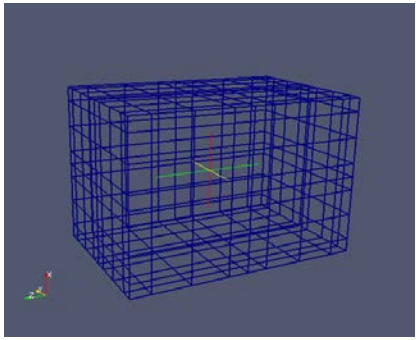
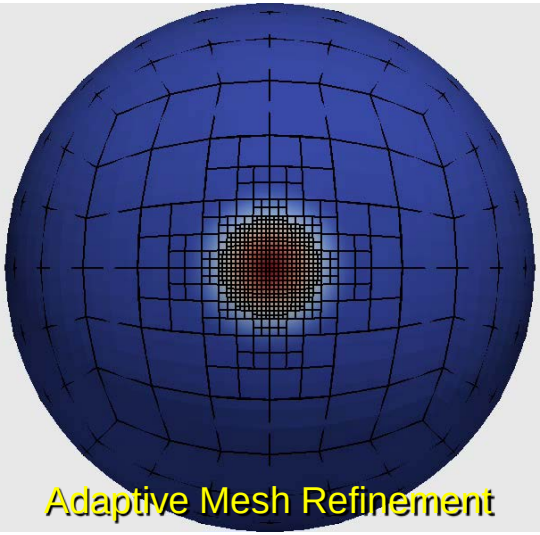


Figure 15. Dynamic adaptive grid refinement on the cubed-sphere (top row) and RLL (bottom row). From left to right: initial grid, refined grid at day 6, vorticity field at day 6. Refinement was triggered by a vorticity value of $|\lambda| < 3e-5s^{-1}$.

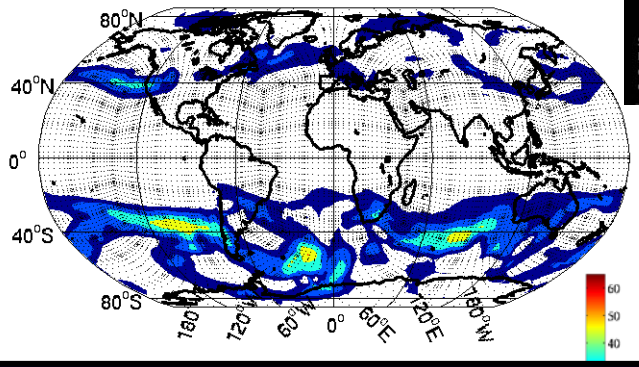


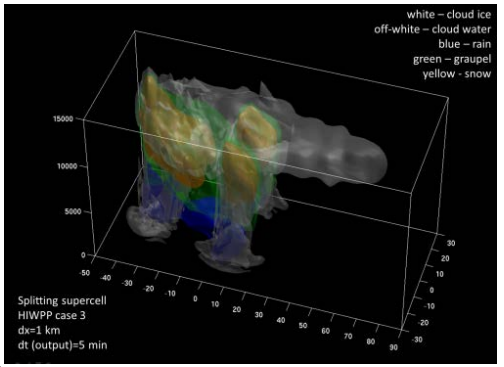
Adaptive Mesh Refinement

Real-Data Simulation

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

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





Example of a 6-class microphysics scheme in NEPTUNE for an idealized splitting supercell case.

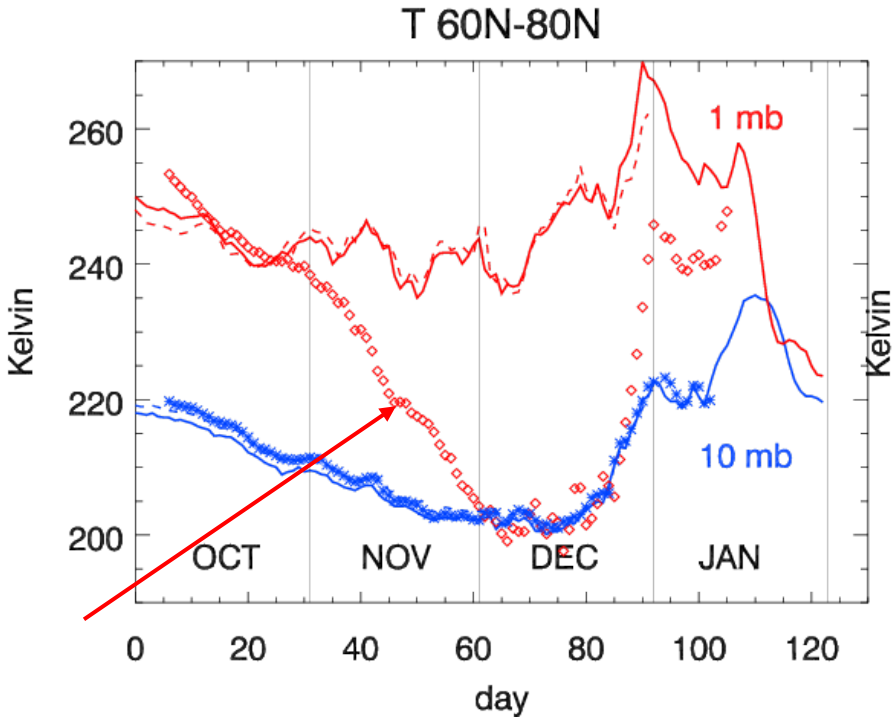
NEPTUNE is being developed as a possible next-generation unified global-regional prediction system using the NUMA spectral element core.

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

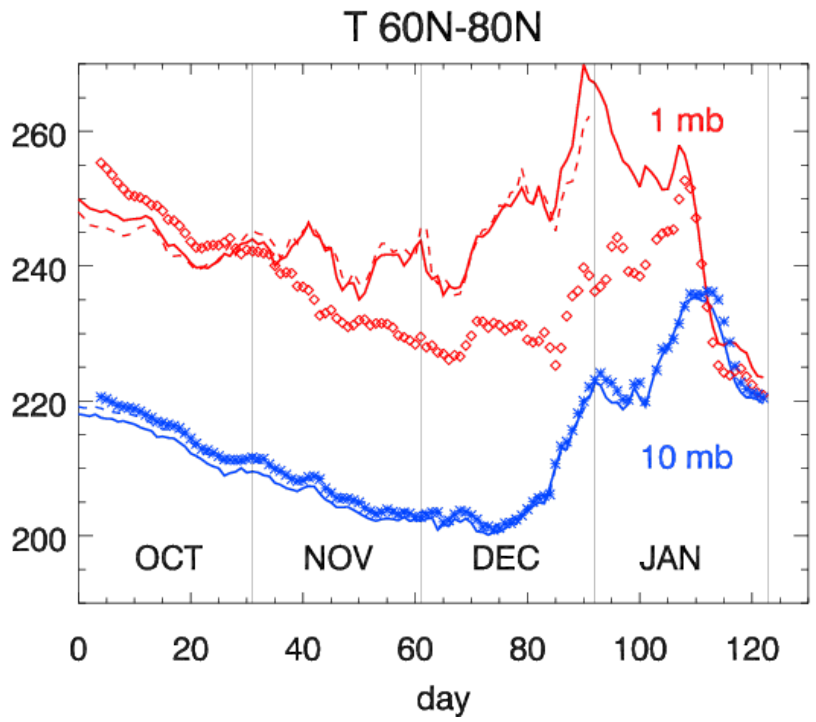
Questions?

NAVGEM 1.3
Non-Orographic Gravity Wave Drag (NGWD)

No Parameterized NGWD



With Parameterized NGWD



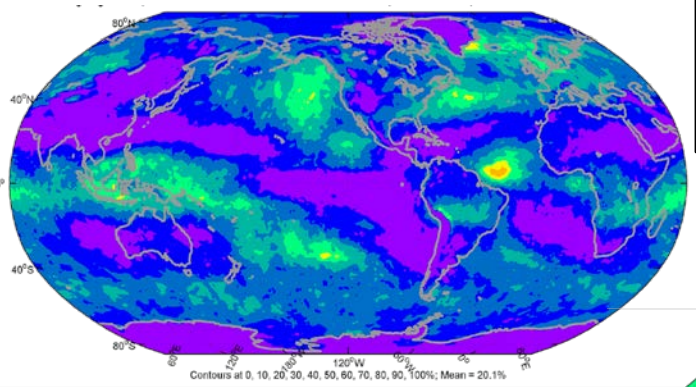
1 hPa
◊ NAVGEM T359L60
NASA MLS
NOGAPS-ALPHA

10 hPa
* NAVGEM T359L60
NASA MLS
NOGAPS-ALPHA

NGWD Reduces 1 hPa Cold Bias

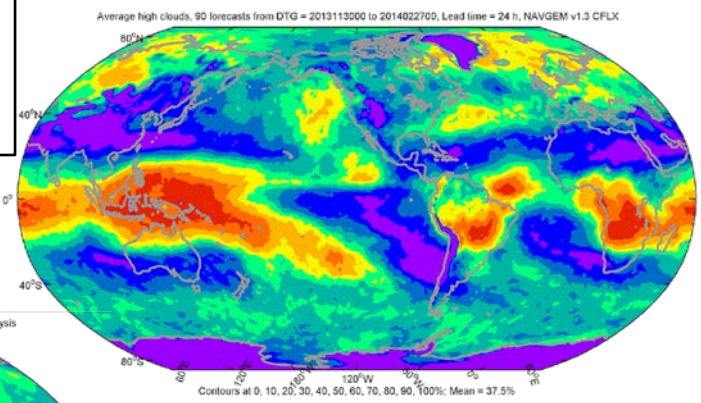
Improved Cloud Fractions
Xu-Randall

High cloud cover: DJF 2013/2014



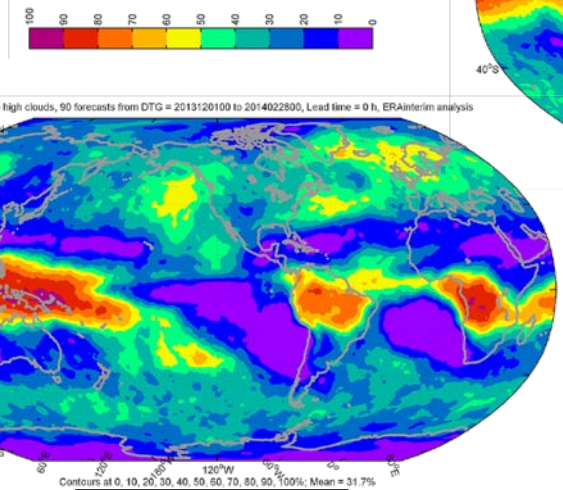
NAVGEM v1.2.1

Mean = 20.1%



NAVGEM v1.3

Mean = 37.5 %



ERA-interim analysis

Mean = 31.7 %

- **The high cloud cover shows perhaps the most notable improvement, particularly in tropical convective regions.**
- **Significant improvement in the surface solar radiation budget.**

NAVGEM Operational Real-time Data Counts
10.8 Million Total OBs per Day Assimilated

DTG:2014121700

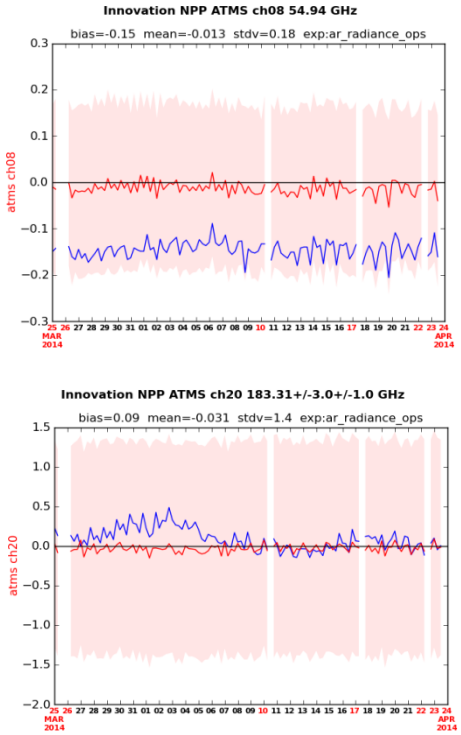
Ob Type	Sensor	OB Count/Day	% Total	OB Impact %
Satellite	All	9.82×10^6	90.88	59.3
HyperSpec IR	IASI(2), AIRS	4.80×10^6	44.44	16.5
MW Sounder	AMSUA(7), ATMS SSMIS(3), MHS(4) GPS-RO (10)	3.19×10^6	29.56	22.8
Feature Tracked Winds	GOES(3), Polar(3), MeteoSat(2), GMS, LeoGeo,	1.70×10^6	15.77	23.5
OSWV	ASCAT(2), WindSat	6.40×10^4	0.59	2.2
MW Imager OSWS, TPW	SSMIS, WindSat(TPW)	7.20×10^4	0.67	4.0

Monitoring Satellites in NWP

- Monitoring of operational data streams at FNMOC
  - http://www.nrlmry.navy.mil/metoc/ar_monitor/

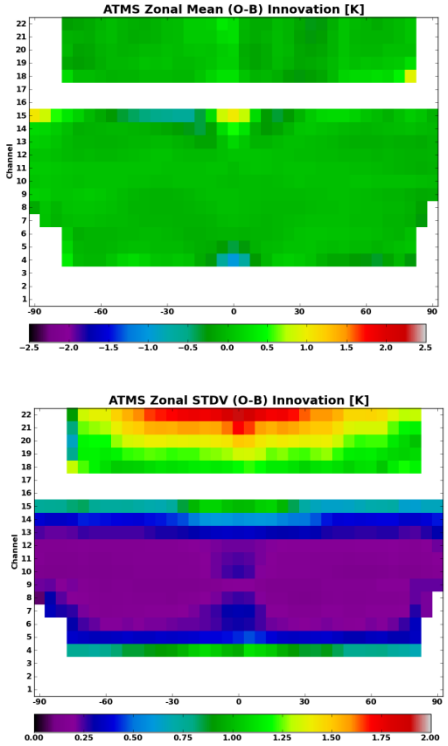
Radgrams

Global mean and stdv of innovation



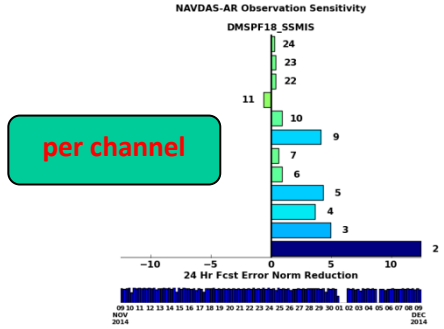
Zonal Innovation

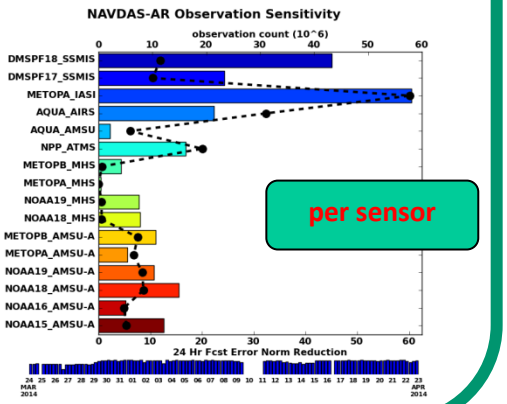
Latitudinal dependence of mean and stdv



Observation Impact

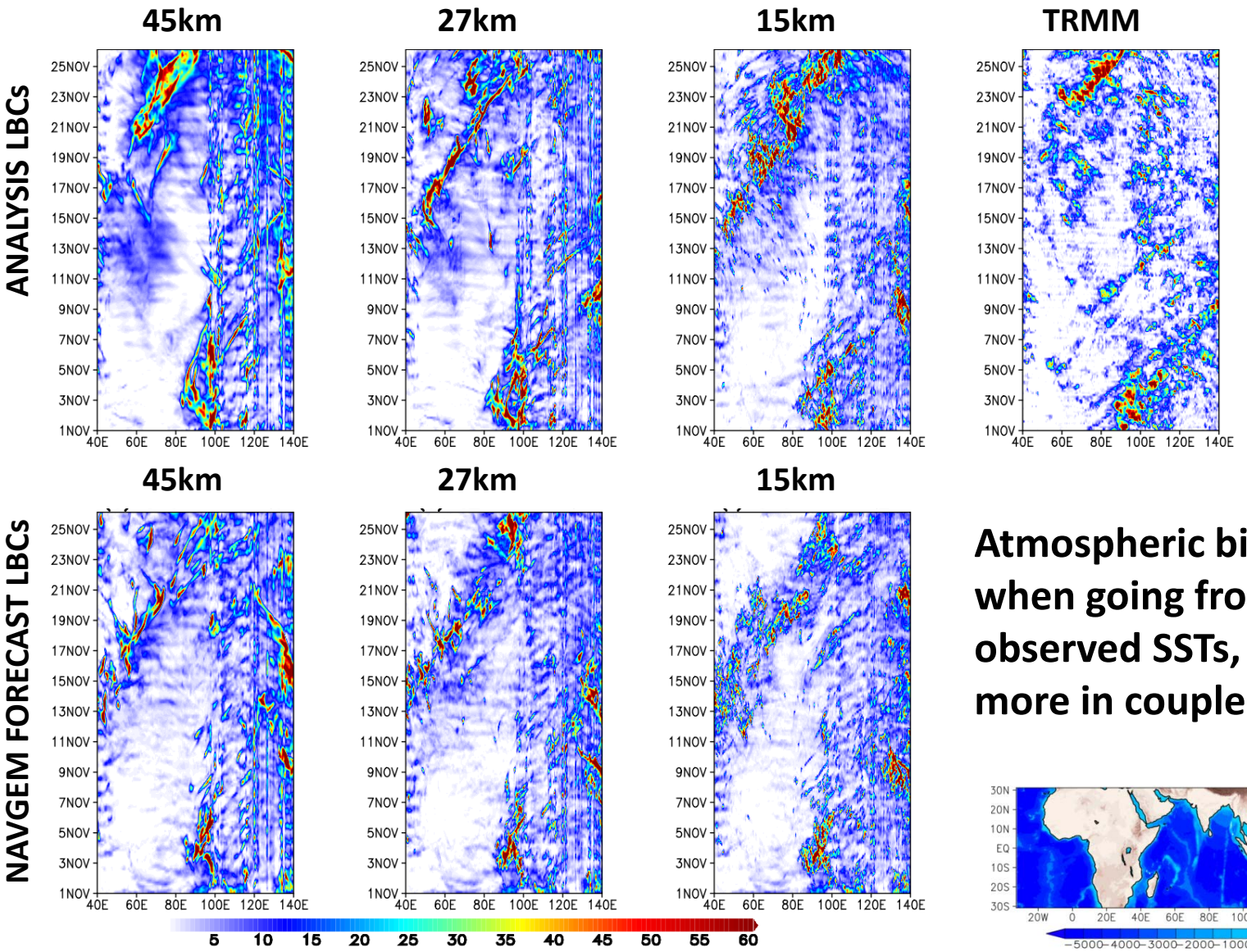
Reduction of NWP error due to observation





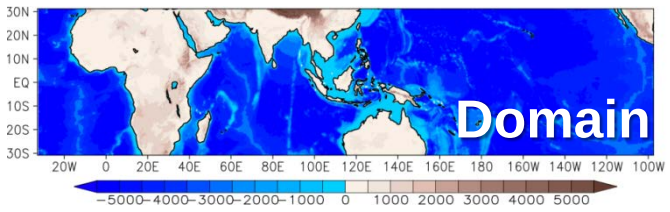
COAMPS

Air-Sea Coupled Forecasts During DYNAMO Period



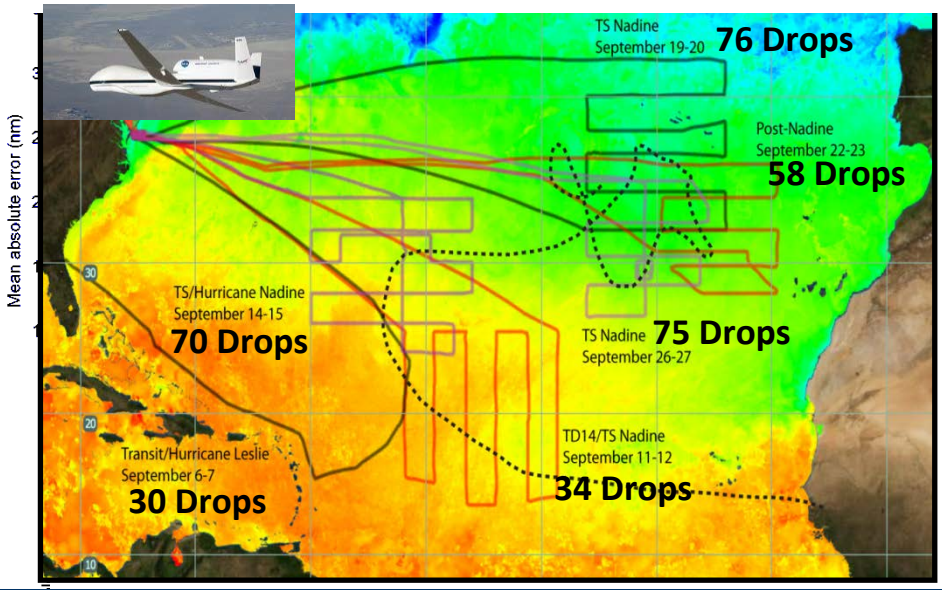
With higher resolution, MJO less likely to get stuck over MC

Atmospheric biases reduced when going from fixed to observed SSTs, reduced even more in coupled system.

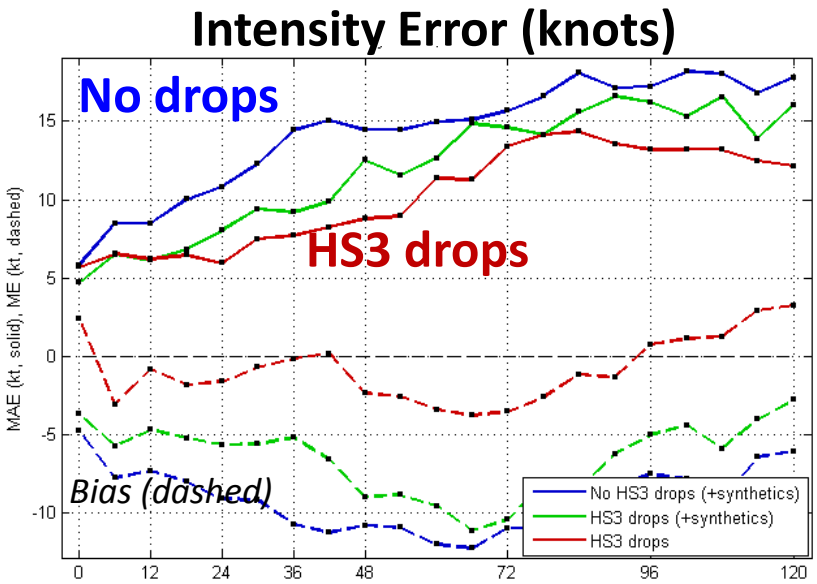


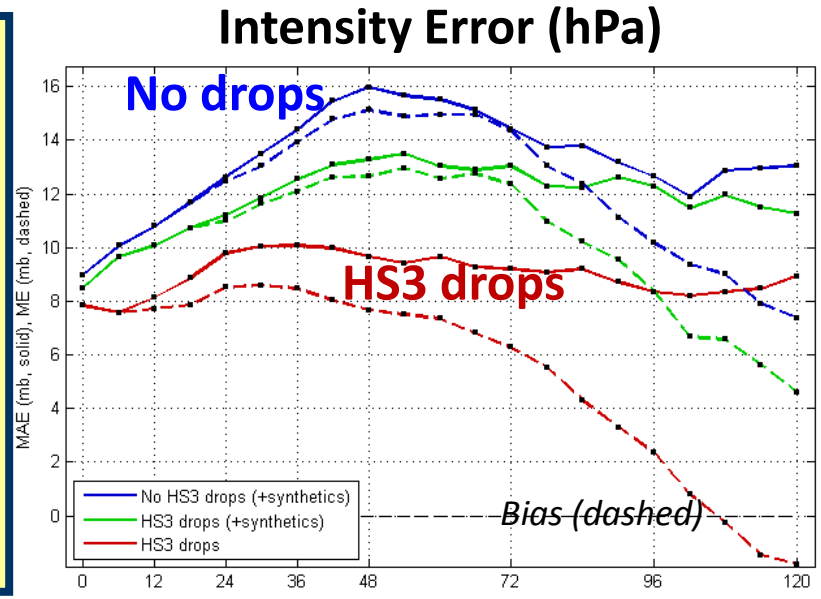
Impact of HS3 Dropsondes for Nadine

HS3 Global Hawk Flight Tracks: Nadine



- **Sensitive regions in Nadine were often well observed by HS3 dropsondes**
- **Dropsonde impact experiments performed for 19-28 Sep. (3 flights)**
  - HS3 drops
  - HS3 drops with synthetics
  - No drops with synthetics
- **COAMPS-TC intensity and track skill are markedly improved using HS3 drops.**
  -Future: impact vs. altitude; EnKF,4D-Var

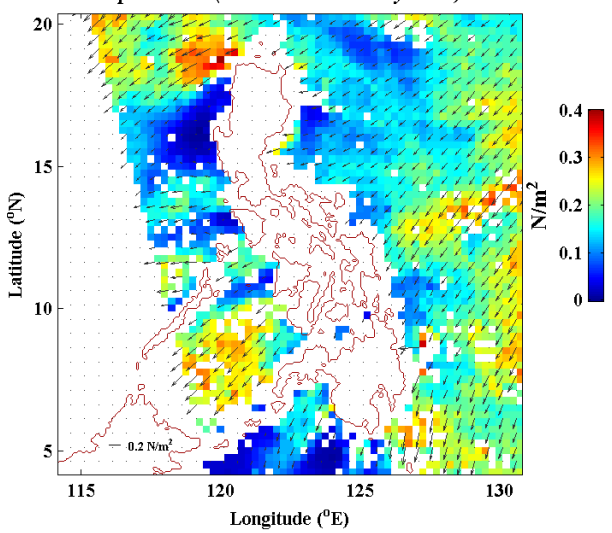




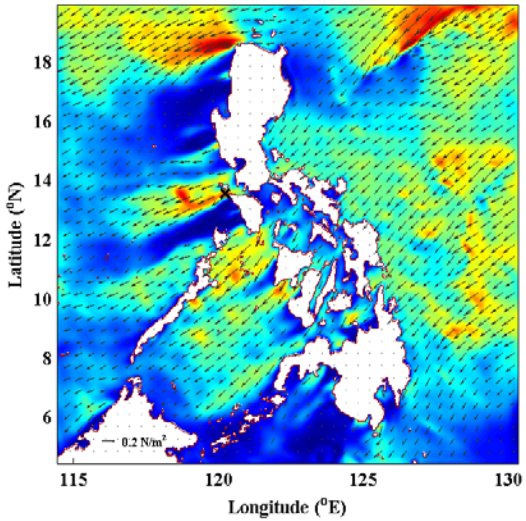
COAMPS Air-Ocean Coupling

ONR Philippine Straits Experiment

QuikSCAT Stress

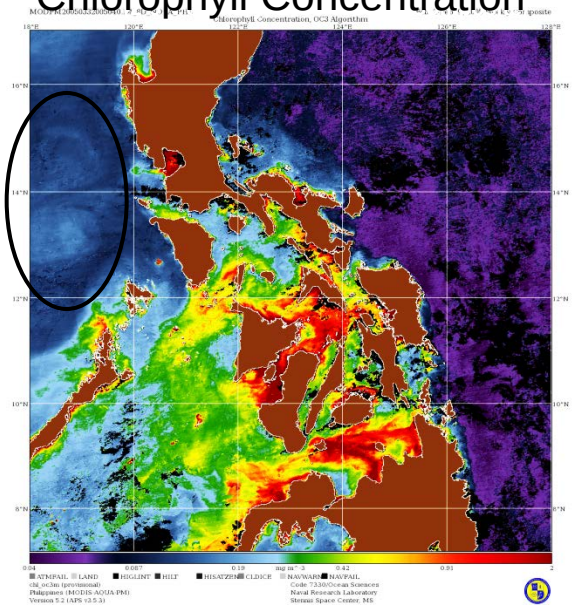


COAMPS Stress



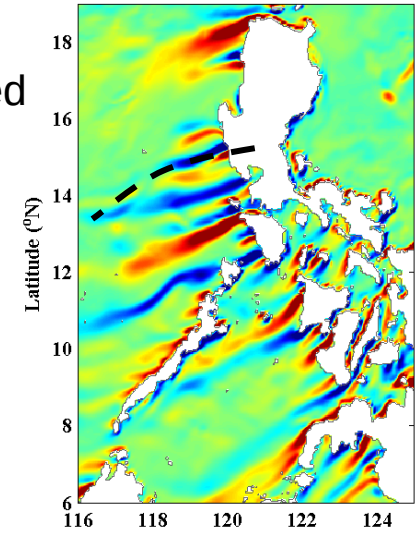
Easterly monsoon surge produces oceanic dipole eddy pair propagating west/northwest

Chlorophyll Concentration

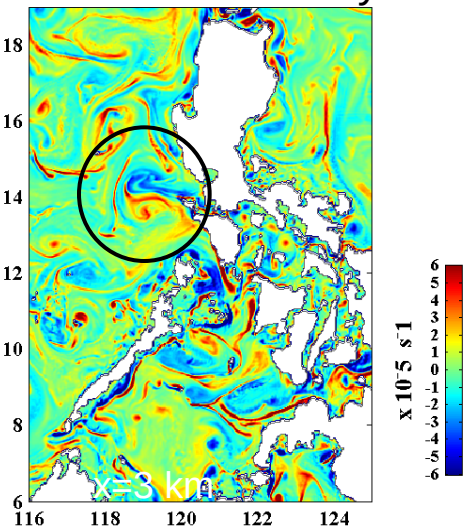


COAMPS
2-Way Coupled

Wind Stress Curl



Ocean Sfc. Vorticity

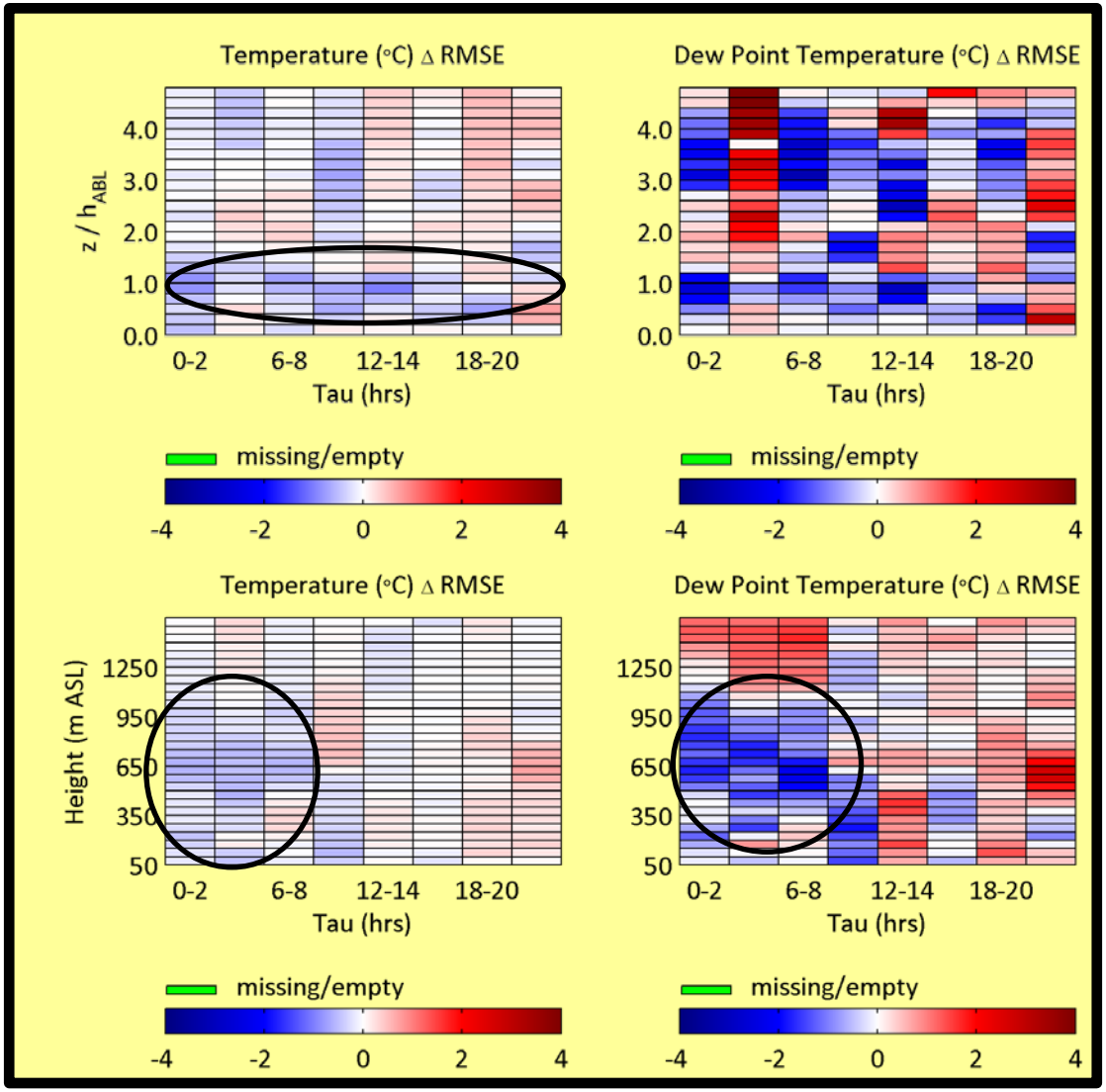


Pullen et al.
(GRL)

COAMPS

Impact of Unmanned Aerial Systems (ScanEagle)

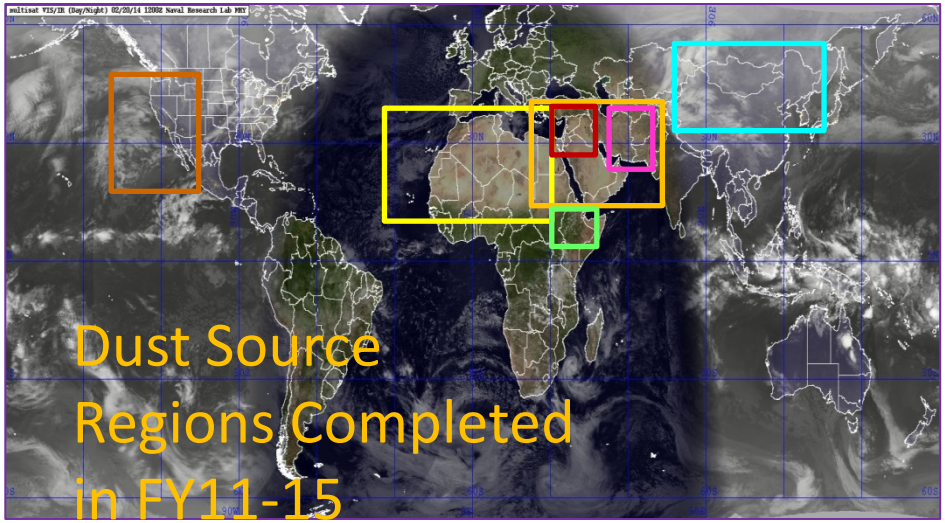
UAS-NoUAS Assimilation Experiments

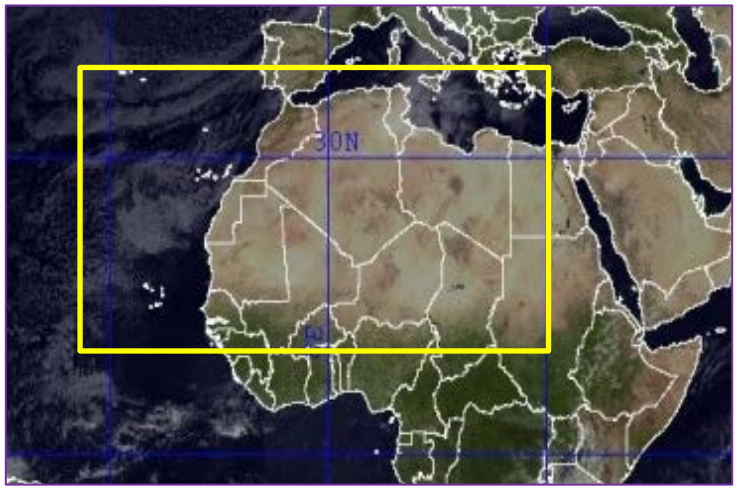


Significant error reduction in temperature and moisture in MABL.

COAMPS Aerosol Modeling
Aerosol Microphysics for NWP

Upgrades to the NRL Dust Source Database (DSD)





- Variable-resolution DSD
- One month Sahara summer case study (May 30-June 25, 2014) completed **1QFY15**
- Higher dust storms prediction rate for the NRL DSD (45.64%) versus the OPS TOMS DSD (38.5%)
- Nearly equal skill with respect to visibility

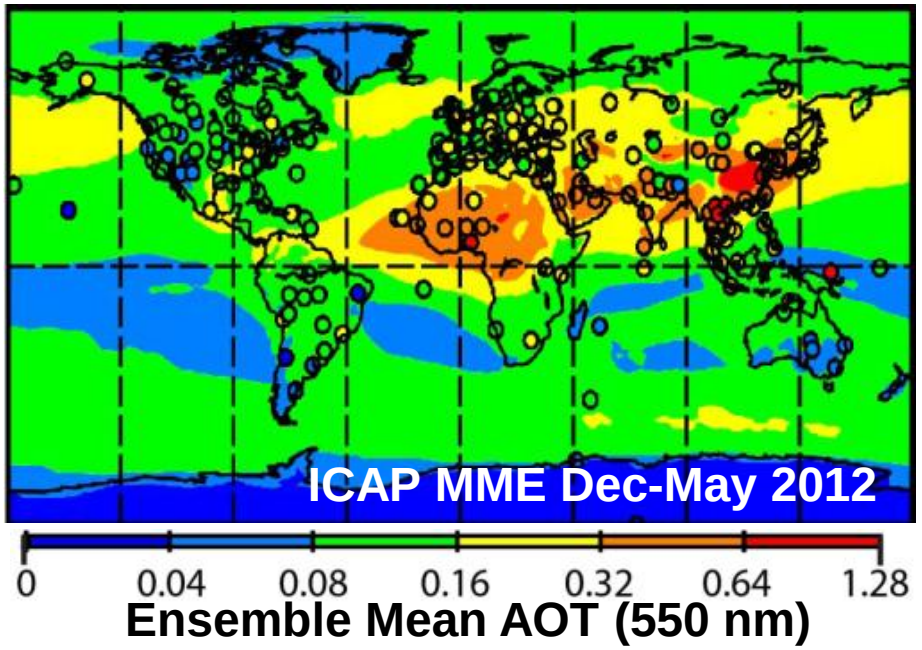
COAMPS Sahara Case Study May 30-June 25, 2014

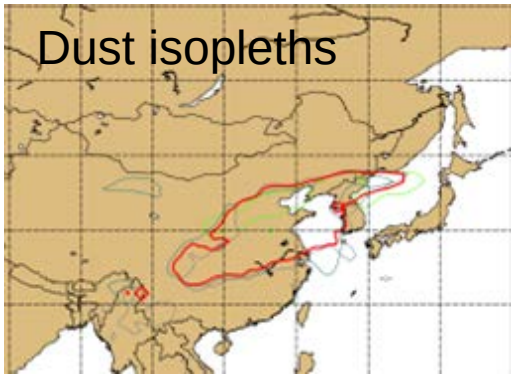
Dust databases:	**DSD (1 km)**	**TOMS (1 deg)**
Total WMO station obs:	2207	2207
Total dust storm obs:	574	574
Dust Storm Prediction Rate:	**45.64**	**38.50**
Dust Storm False Alarm Rate:	13.10	8.76
Dust Storm Threat Score:	33.25	30.82
Dust Storm Gilbert Skill Score:	0.21	0.20
Visibility Prediction Rate:	**76.17**	**77.53**

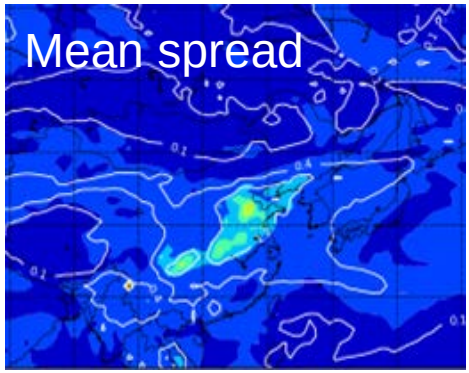
NRL Developed ICAP Global Multi-model Aerosol Forecast Ensemble:

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

- The International Cooperative for Aerosol Prediction (ICAP) is a grass roots organization of aerosol forecast developers to share best practices and speak with a common voice on aerosol observation needs for DA.
- Ensemble open to any consistent quasi-operational global aerosol model. Currently working on AOT and surface concentrations for multi species and dust only versions, but looking towards 3 full dimensions.
- Specific error metrics are kept by centers, ensemble products distributed via GODAE server.
- As expected from a multi model ensemble, the ICAP MME has the best RMSE scores and a more consistent bias distribution over the globe.





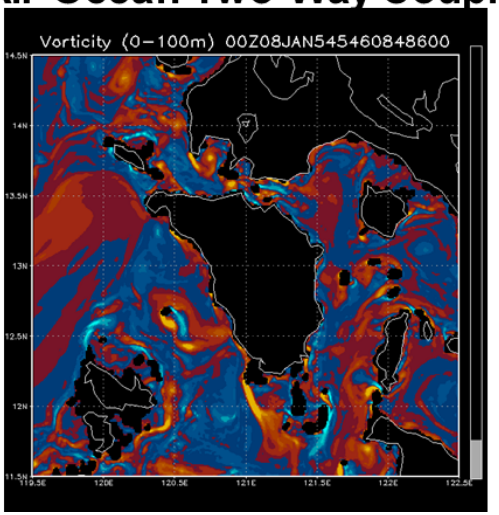


Global DA:
NRL Global Hybrid 4D-Var

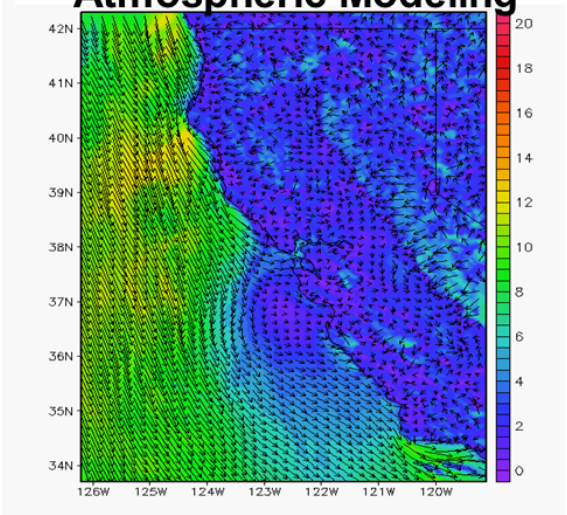
- **The NRL hybrid 4D-Var is an observation-space based global 4D-Var data assimilation system implicitly using a partial flow-dependent initial background error covariance.**
- **Ensemble technique and traditional error covariance model are used to generate the flow-dependent and the static initial background error covariance, respectively.**
- **The matrix-vector multiplications of the flow-dependent and static initial background error covariance with the adjoint sensitivity at initial time are combined.**
- **Preliminary results suggested that hybrid 4D-Var resulted better NOVGEM forecasts then original 4D-Var. Additional validation tests are underway.**
- **The hybrid 4D-Var requires about 50% computational resource than the original 4D-Var.**
- **We are in the process to transition the global hybrid 4D-Var system to operations.**

Global DA:
NRL Global Hybrid 4D-Var

Air-Ocean Two-Way Coupling



Atmospheric Modeling



Tropical Cyclone Capability