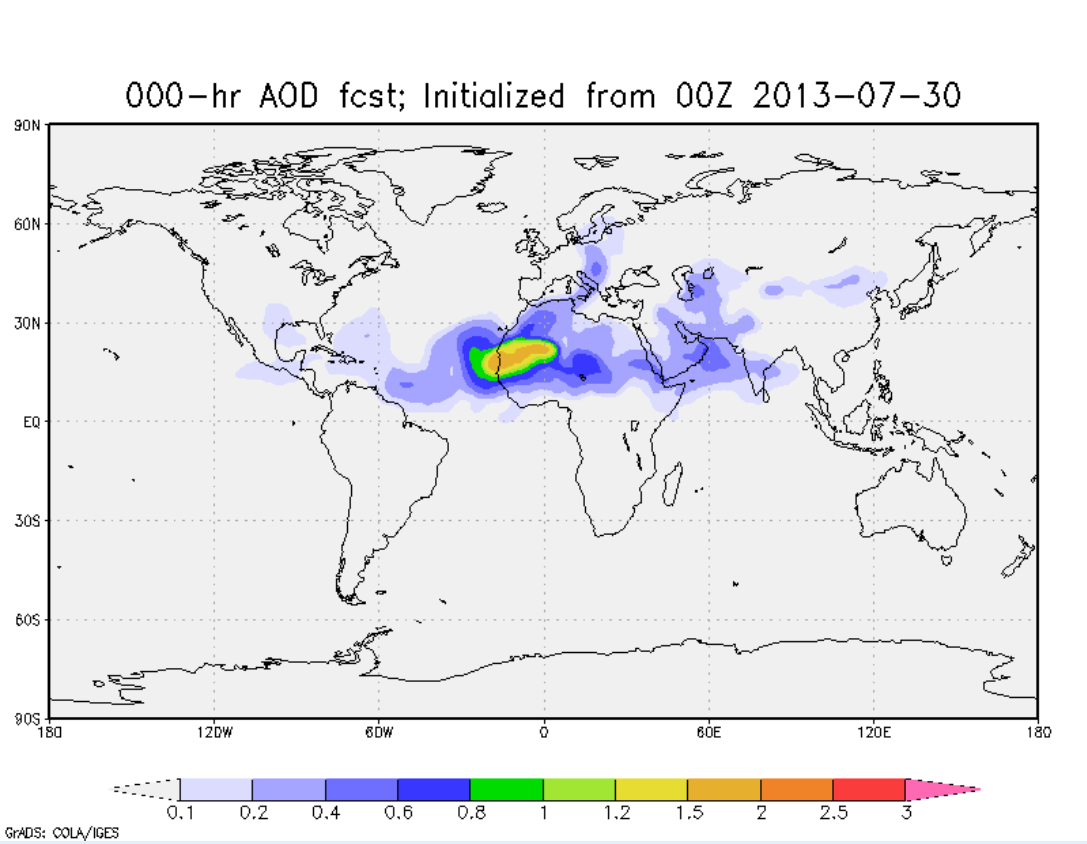
Status Update on NCEP Global Aerosol Forecasting System



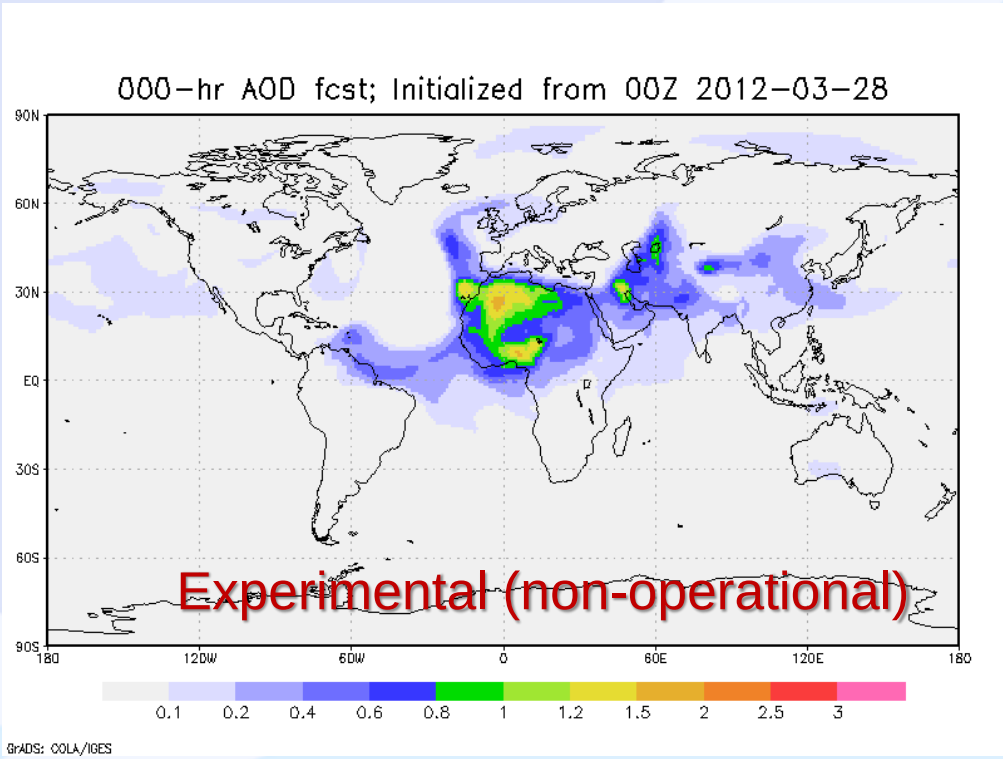
Sarah Lu (NOAA/NWS/NCEP/EMC)

Contributions from: NCEP NEMS group and AQ team, Arlindo da Silva and Pete Colarco (GSFC), Shobha Kondragunta, Pubu Ciren, and Brad Pierce (NESDIS), Xiaoyang Zhang (South Dakota State Univ.), Pius Lee and Hyun Kim (ARL), Georg Grell and Mariusz Pagowski (ESRL), Walter Sessions (Univ. of Wisc.)

Near-Real-Time NEMS GFS Aerosol Component

Current State

- Near-real-time experimental system
- The first global in-line aerosol forecast system at NCEP
- AGCM : NCEP's NEMS GFS
- Aerosol: GSFC's GOCART
- 120-hr dust-only forecast once per day (00Z), output every 3-hr
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- Operational Implementation targeted for Q4 FY12



Ongoing Activities and Future Plans

- Use near-real-time smoke emissions from satellites (collaborating with NESDIS and GSFC)
- Full package implementation (dust, sea salt, sulfate, and carbonaceous aerosols)
- Refine the prototype volcanic ash capability (collaborating with ECMWF)
- Provide aerosol information for potential downstream users (e.g., NESDIS's SST retrievals, CPC-EPA UV index forecasts; aerosol lateral boundary conditions for regional models)

Presented at ICAP - Aerosol Emission and Removal Process, May 2012 by Pete Colarco

Near-Real-Time NEMS GFS Aerosol Component

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- 120-hr dust-only forecast once per day (00Z), output every 3-hr
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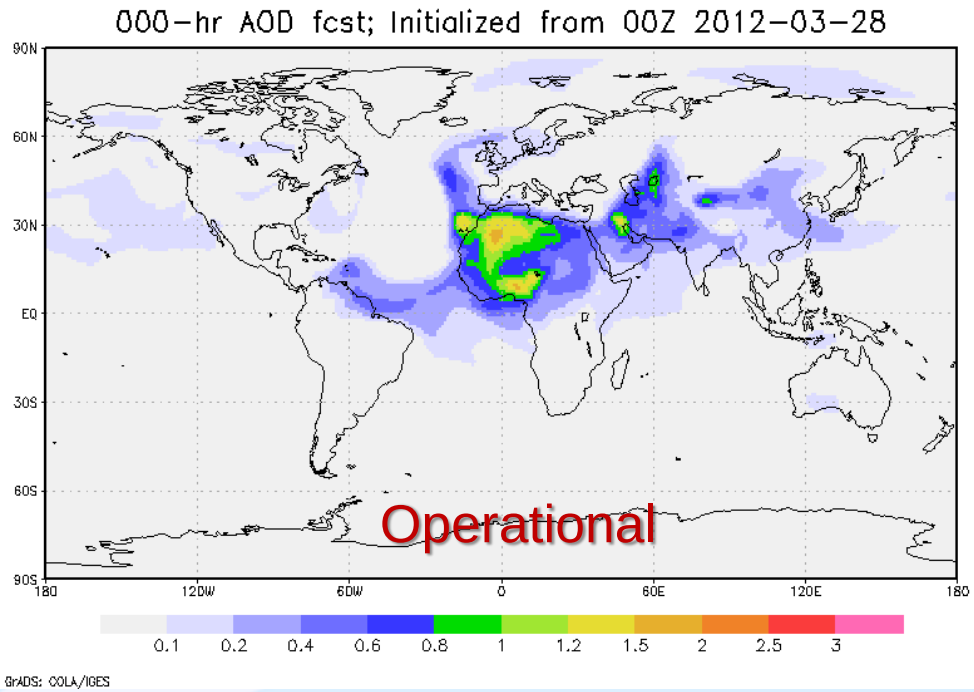
- Implemented into NCEP Production Suite in Sept 2012



Ongoing Activities and Future Plans

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- Refine the prototype volcanic ash capability (collaborating with ECMWF)
- Provide aerosol information for potential downstream users (e.g., NESDIS's SST retrievals, CPC-EPA UV index forecasts; aerosol lateral boundary conditions for regional models)

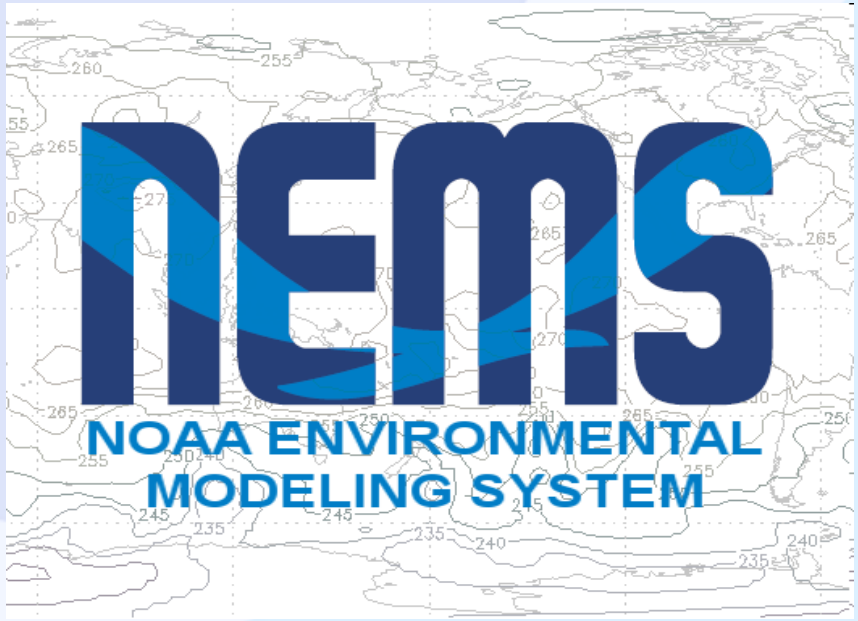
Status update at ICAP-Recent Progress in Aerosol Observability for Global Modeling

Presentation Outline

- **Current Operational Configuration**
- Future operational requirements and applications
- Ongoing NOAA wide aerosol activities
- Future Plan

Team efforts toward building global aerosol forecast capability at NCEP

Mark Iredell (NEMS project lead)
Sarah Lu (aerosol modeling)
Jun Wang (infrastructure and I/O)
Shrinivas Moorthi (physics)
Henry Juang (dynamics)
Hui-Ya Chuang (post)
Weiyu Yang (replay capability)
Nicole McKee (documentation)
Perry Shafran (verification)



GSFC collaborators (Arlindo da Silva, Mian Chin, Peter Colarco)
NESDIS collaborators (Shobha Kondragunta, Quanhua Liu)

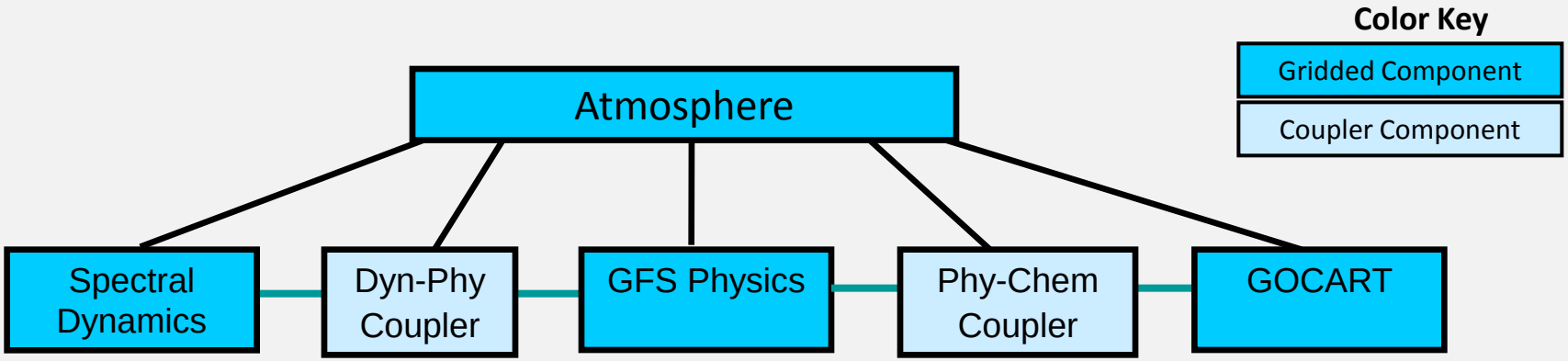
Acknowledge:
NGAC is sponsored by NASA Applied Science Program, JCSDA, and NWS. This project leverages the expertise in GSFC, NESDIS, the ICAP working group, and the WMO SDS-WAS program

An interactive atmosphere-aerosol forecast system

ESMF Earth System Modeling Framework

- **In-line chemistry advantage**
  - Consistent: no spatial-temporal interpolation, same physics parameterization
  - Efficient: lower overall CPU costs and easier data management
  - Allows for feedback to meteorology
- **NEMS GFS Aerosol Component**
  - A common modeling framework using Earth System Modeling Framework (ESMF)
  - NEMS GFS and GOCART are interactively connected using ESMF coupler components

Architecture of NEMS GFS Aerosol Component

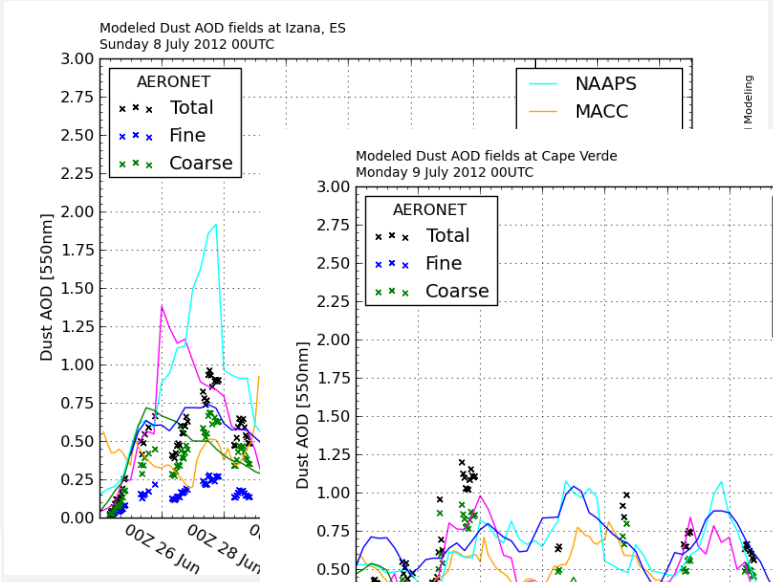


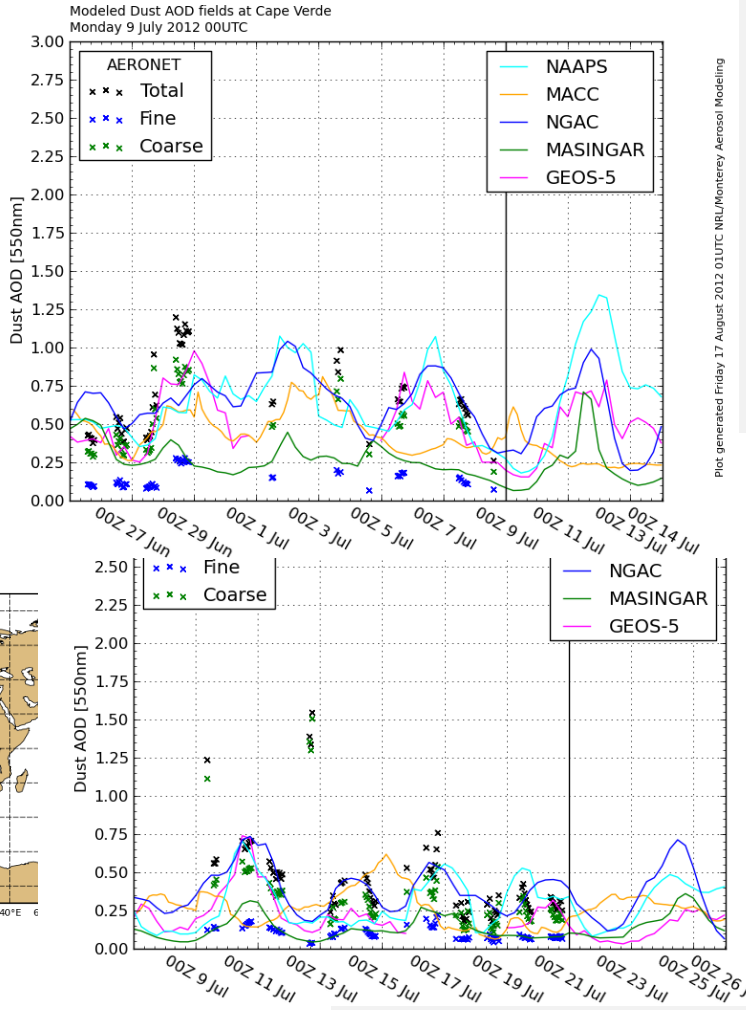
Walter Sessions (NRL, now at U Wisc) on behalf of ICAP participated in model implementation subjective evaluation in real-time 30-day parallel experiment

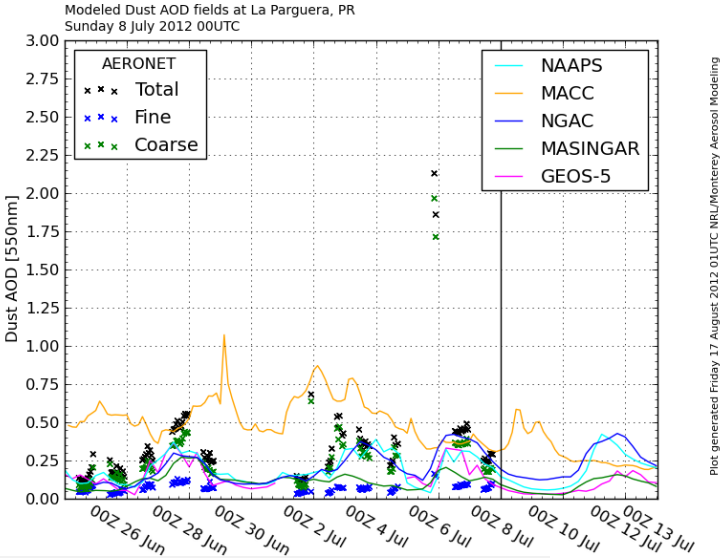
The DUST AOD product from NGAC performed well during the evaluation period.

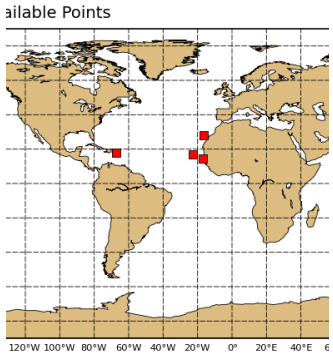
Over the Western Atlantic, it produced lower RMSE than MACC and MASINGAR models when compared to AERONET.

Off Western Africa, forecast solutions were most consistent with the Dakar site of the three aeronet locations observed. Results were mixed over Izana and Cape Verde.



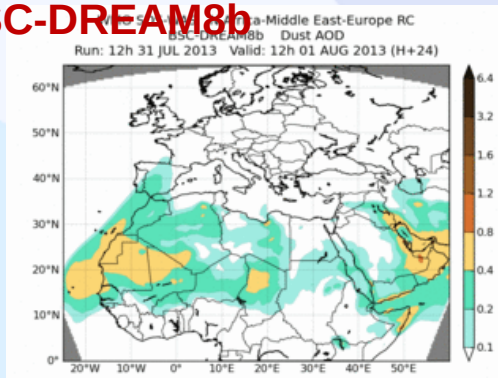




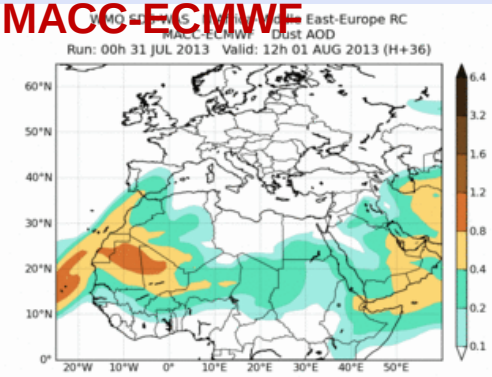


WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS): Model Intercomparison

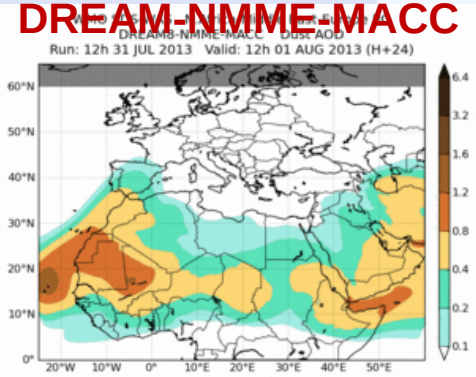
BSC-DREAM8b



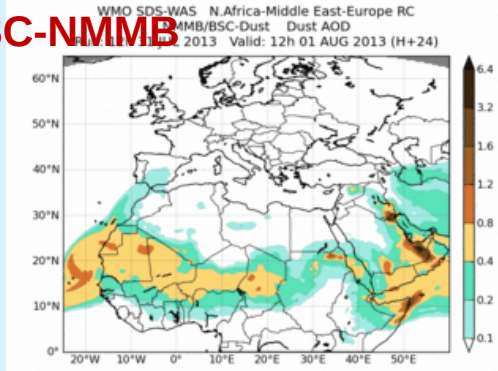
MACC-ECMWF



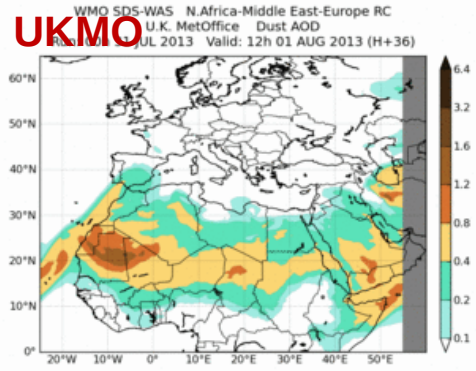
DREAM-NMME-MACC



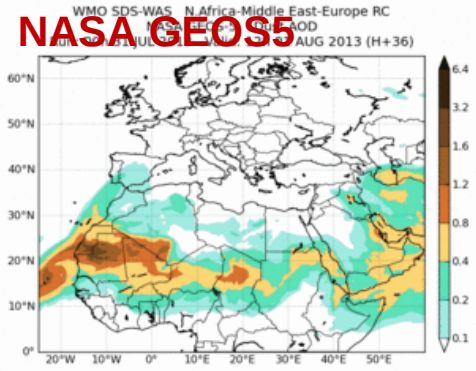
BSC-NMMB



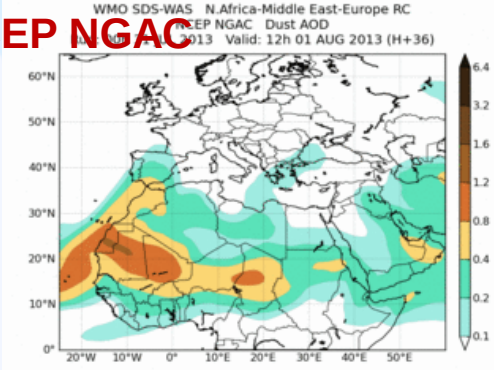
UKMO



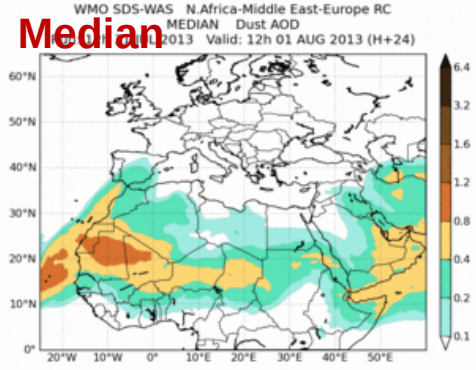
NASA GEOS5



NCEP NGAC



Median



- SDS-WAS Africa node, conducts daily inter comparison for dust AOD and dust surface concentration
- NCEP participated in the SDS-WAS model inter comparison since Oct 2012

Results of 1-year operational NGAC forecasts from 09/2012-09/2013

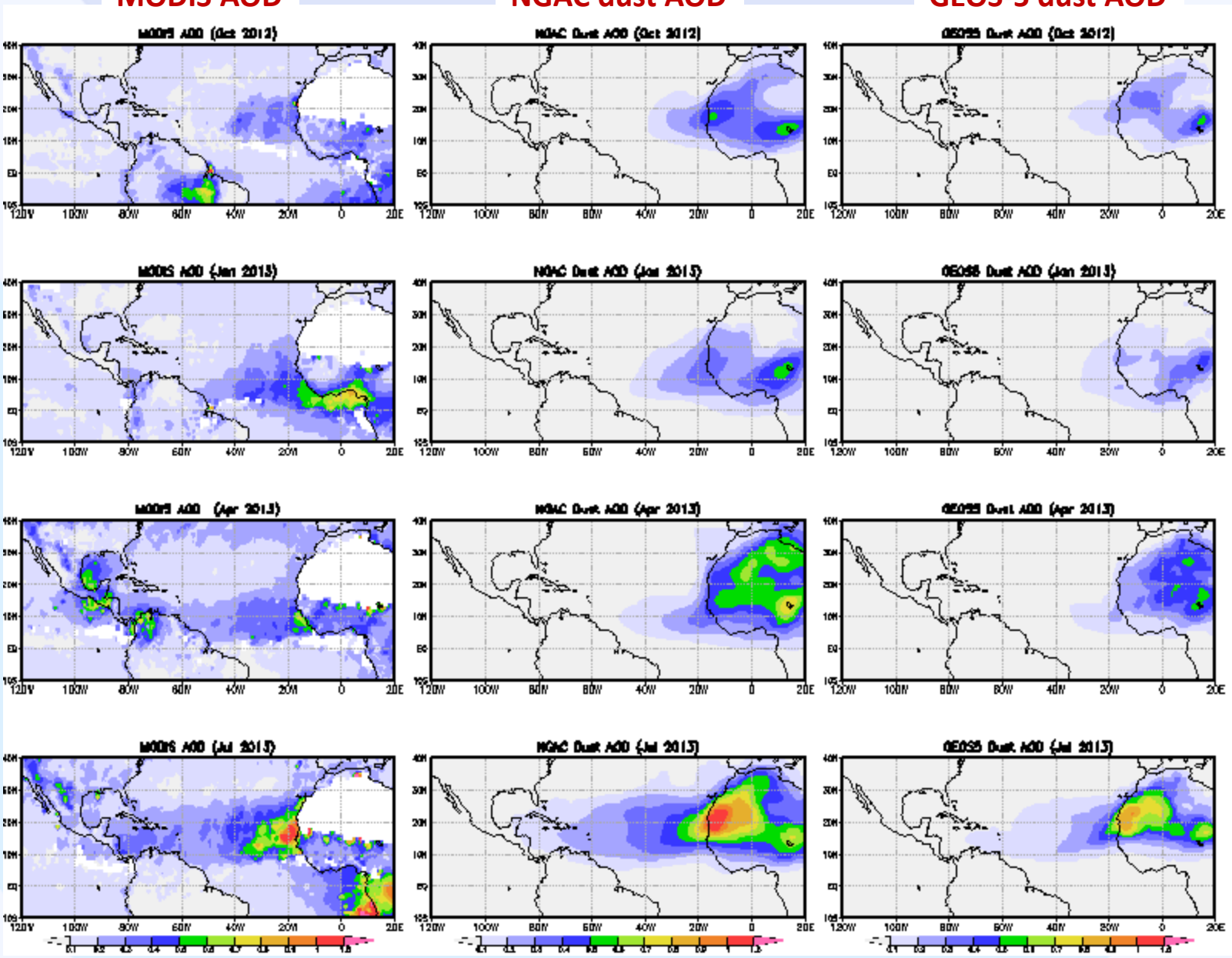
MODIS AOD | NGAC dust AOD | GEOS-5 dust AOD

Oct 2012

Jan 2013

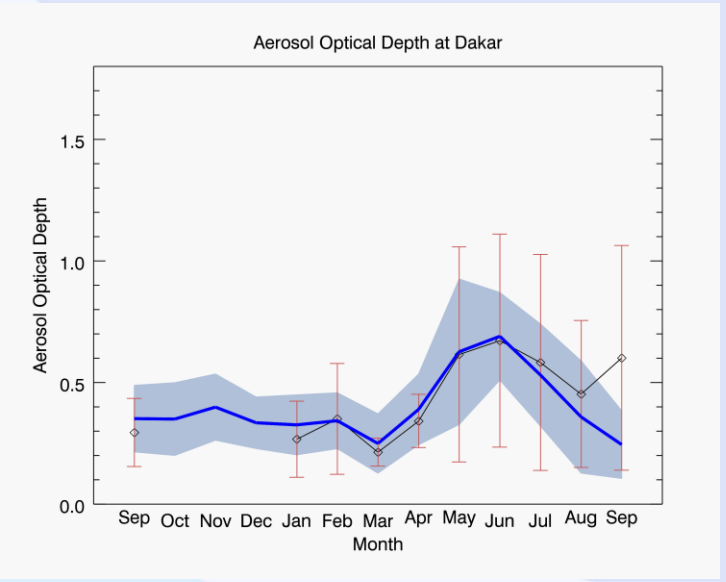
Apr 2013

Jul 2013

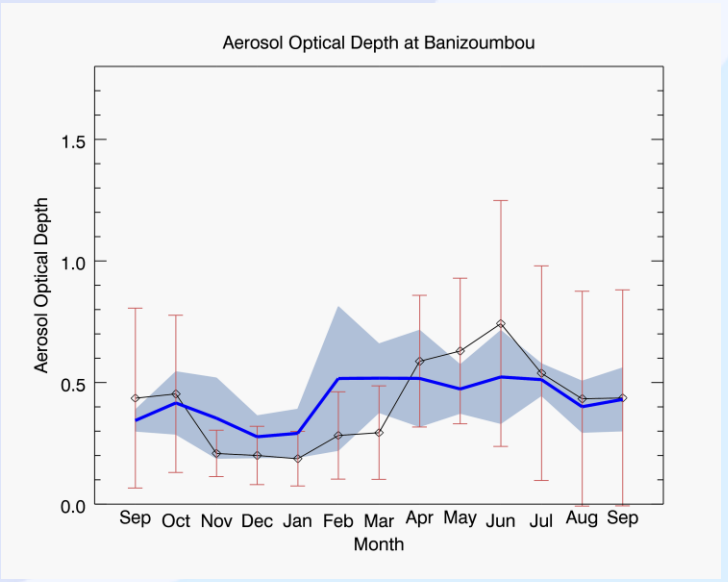


Results of 1-year operational NGAC forecasts from 09/2012-09/2013

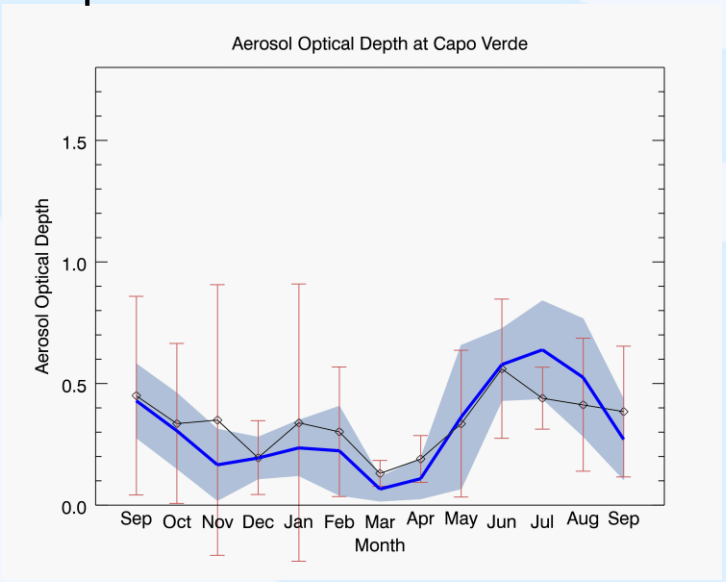
Dakar



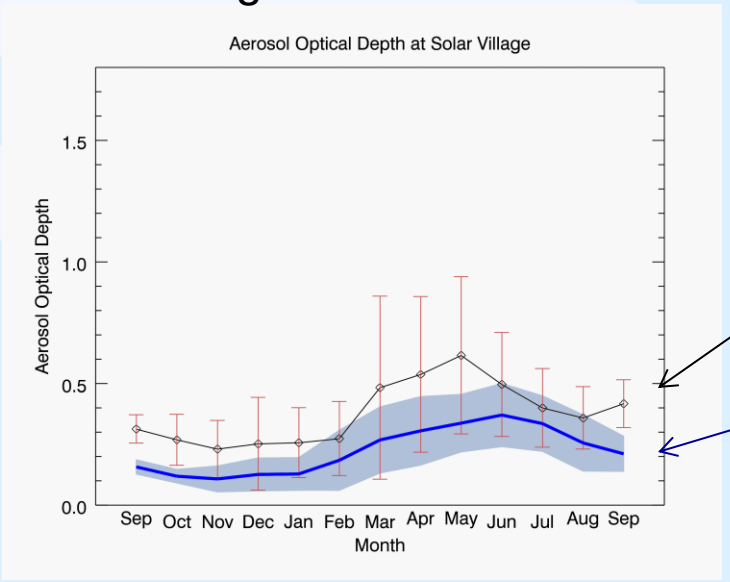
Banizoumbou



Capo Verde



Solar Village



AERONET

NGAC

Presentation Outline

- Current Operational Configuration
- **Future operational requirements and applications**
- Ongoing NOAA wide aerosol activities
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NGAC Product Suite and Applications

NGAC provides 1x1 degree products in GRIB2 format once per day.
Product files and their contents include:

UV index forecasts — AOD assimilation — AVHRR SST — AIRS retrievals

- **ngac.t00z.aod_$CH, CH=340nm, 440nm, 550nm, 660nm, 860nm, 1p63um, 11p1um**
  - Aerosol Optical Depth (AOD) at specified wavelength from 0 to 120 hour

- **ngac.t00z.a2df$FH, FH=00, 03, 06, ….120**
  - AOD at 0.55 micron
  - Dust emission, sedimentation, dry deposition, and wet deposition fluxes
  - Dust fine mode and coarse mode surface mass concentration ← **Air quality**
  - Dust fine mode and coarse mode column mass density ← **Budget**

Budget, ocean productivity

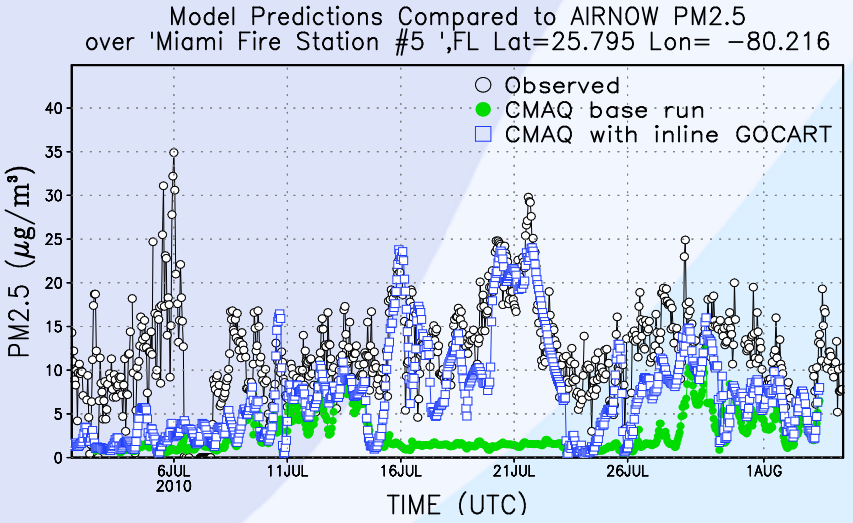
- **ngac.t00z.a3df$FH, FH=00, 03, 06, ….120** ← **Atmospheric correction**
  - Pressure, temperature, relative humidity at model levels
  - Mixing ratios for 5 dust bins (0.1-1, 1-1.8, 1.8-3, 3-6, 6-10 micron) at model levels

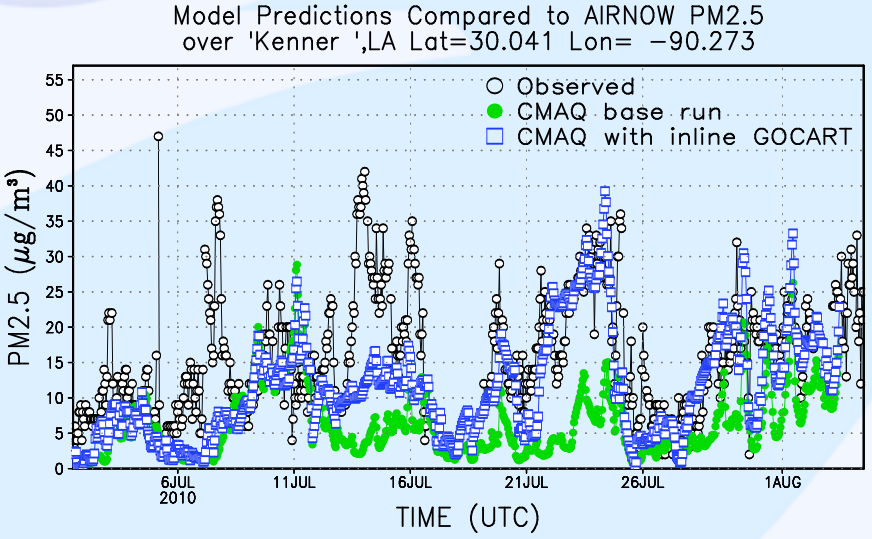
Potential applications for NGAC products are highlighted in red.

Dynamic LBCs for regional models

- Baseline NAM-CMAQ with static LBCs versus experimental NAM-CMAQ with dynamic LBCs from NGAC, verified against AIRNOW observations
- The inclusion of LBCs from NGAC prediction is found to improve PM forecasts (e.g., reduced mean biases, improved correlations)

	CMAQ Baseline	**CMAQ Experimental**
Whole domain July 1 – Aug 3	MB= -2.82 R=0.42	MB= -0.88 R=0.44
South of 38°N, East of -105°W July 1 – Aug 3	MB= -4.54 R=0.37	MB= -1.76 R=0.41
Whole domain July 18– July 30	MB= -2.79 R=0.31	MB= -0.33 R=0.37
South of 38°N, East of -105°W July 18– July 30	**MB= -4.79 R=0.27**	**MB= -0.46 R=0.41**





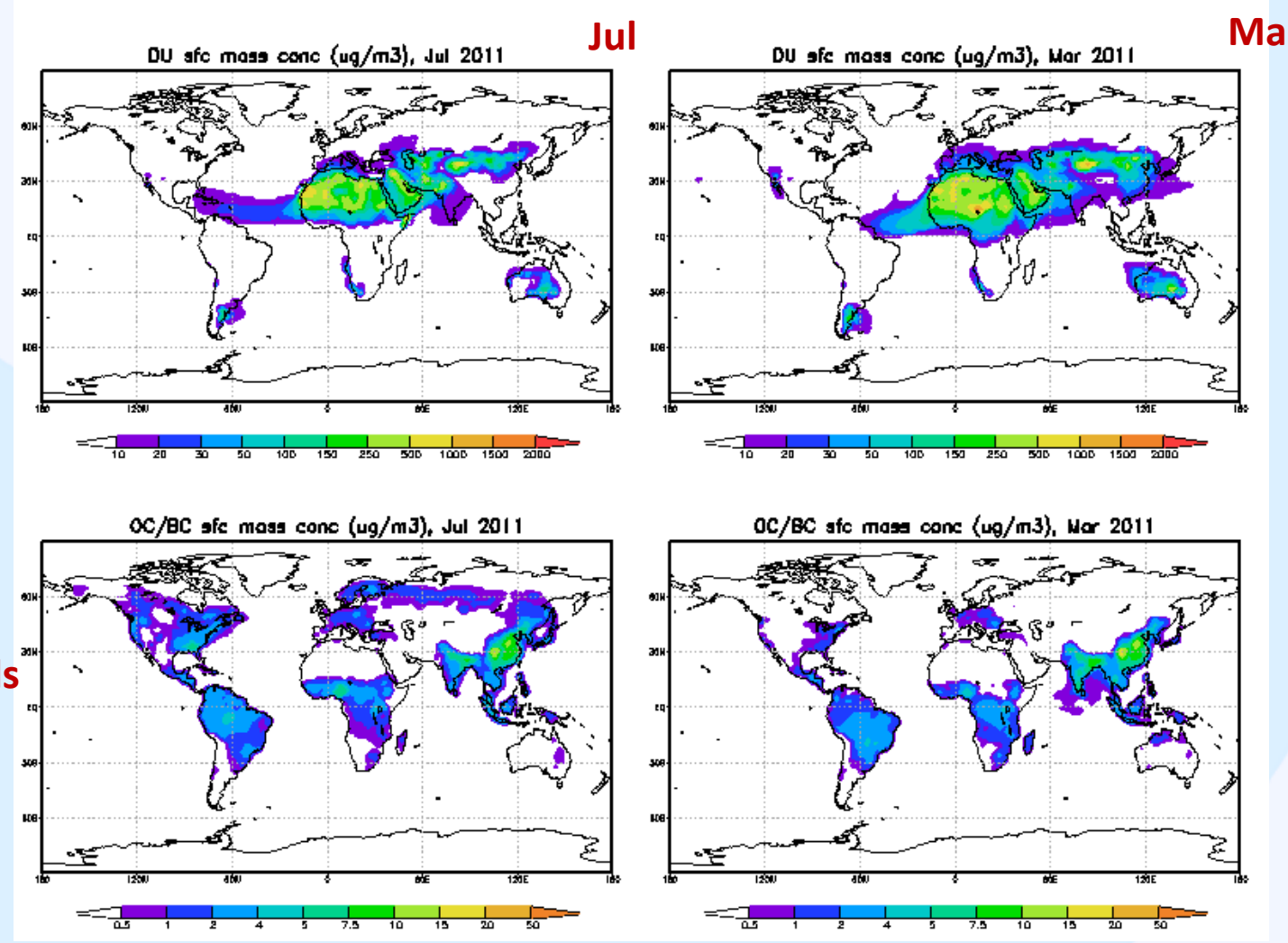
Youhua Tang (EMC, now at NESDIS)

NGAC aerosol forecasts

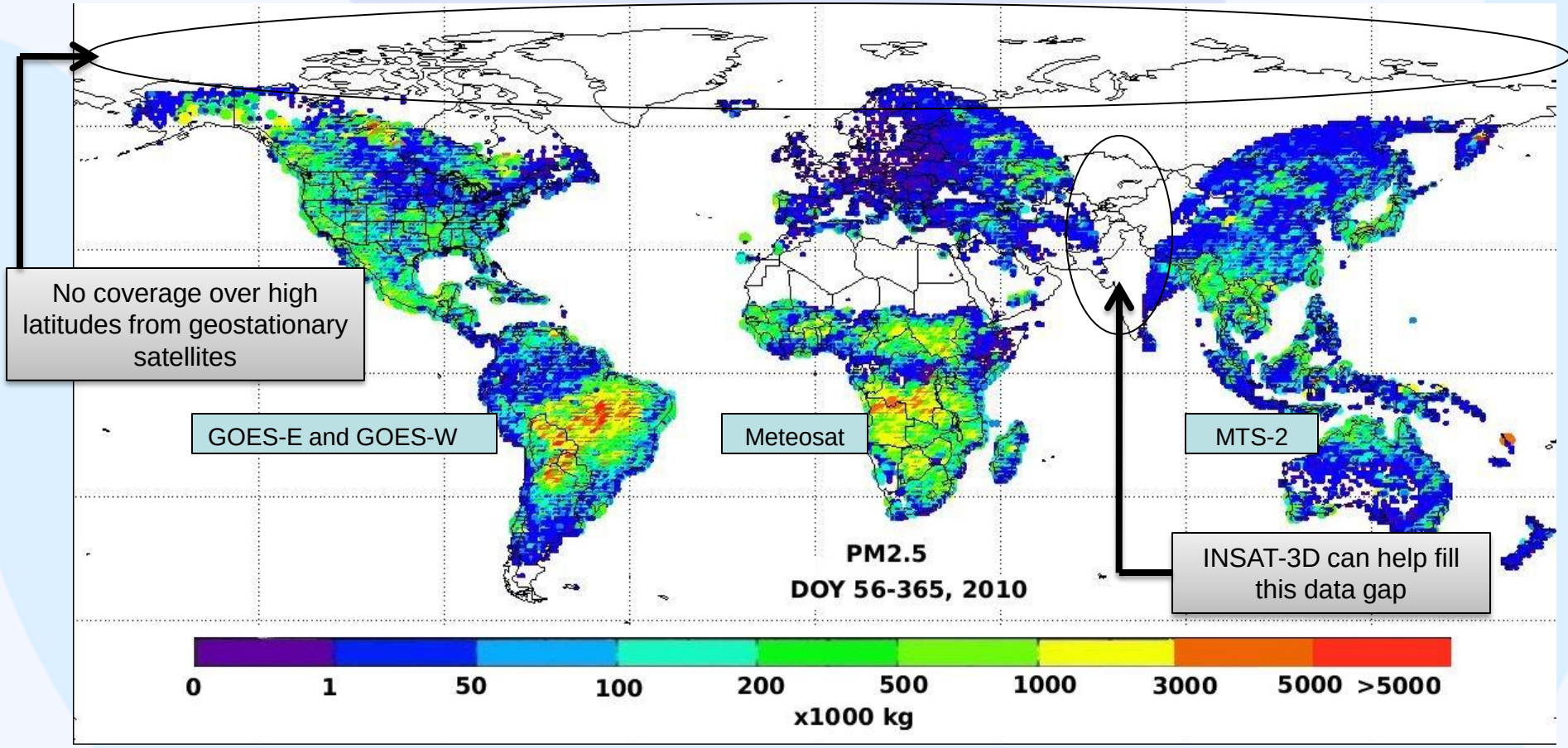
- NGAC has the capability to simulate dust, sulfate, sea salt, and carbonaceous aerosols.
- An example is given here where NGAC experiments for 2011 are conducted

Dust aerosols

Carbonaceous aerosols



Annual Global Biomass Burning Aerosol Emissions from Satellite-derived Fire Radiative Power (FRP)

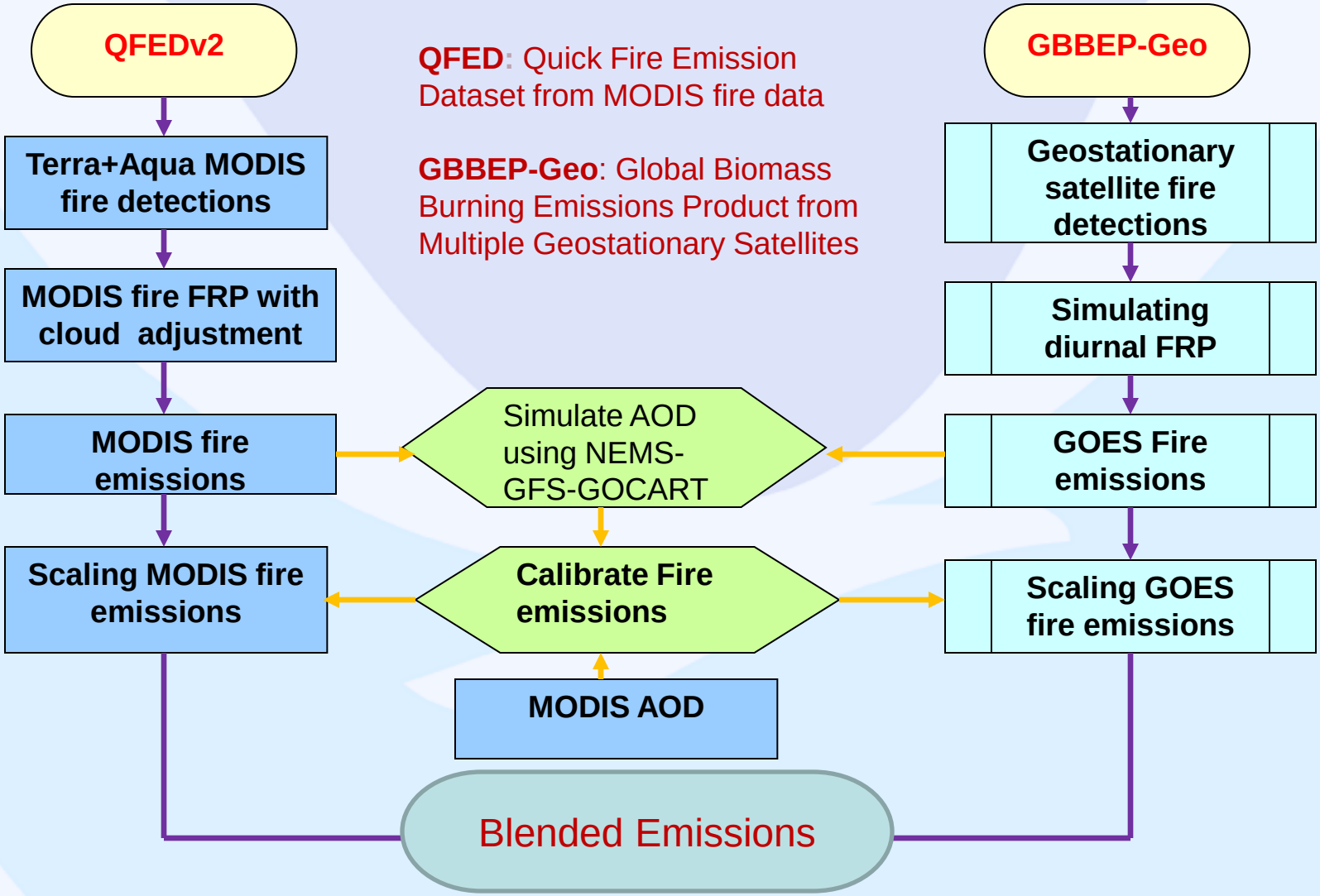


Zhang, X. Y, S. Kondragunta, J. Ram, C. Schmidt, H-C. Huang, ***Near-real time global biomass burning emissions product from geostationary satellite constellation*****, JGR, 2012**

Key:
PM2.5: Particulate mass for particles smaller than 2.5 um in size
DOY: Day of the Year
Kg: Kilograms

Shobha Kondragunta (NESDIS/STAR)

Flowchart for blended Polar and Geo biomass burning emissions



- Scaling factors are region and biome dependent but static.
- Blended emissions will be generated daily at NESDIS/OSPO for NGAC.
- Scaling factors need to be re-generated only if there is a new satellite replacing an old satellite.

Shobha Kondragunta (NESDIS/STAR)

Planned Implementation

- FY14: No implementation due to the Moratorium (no upgrades while transition to next NCEP Central Computing System)
  - Sync NCEP and GSFC code repositories
  - Establish the parallel system using NESDIS near-real-time biomass burning emissions and upgraded GOCART
- FY15: Extend the dust-only system to include sulfate, sea salt, and carbonaceous aerosols
- FY16: Link low-resolution NGAC with high-resolution GDAS Hybrid EnKF and GFS

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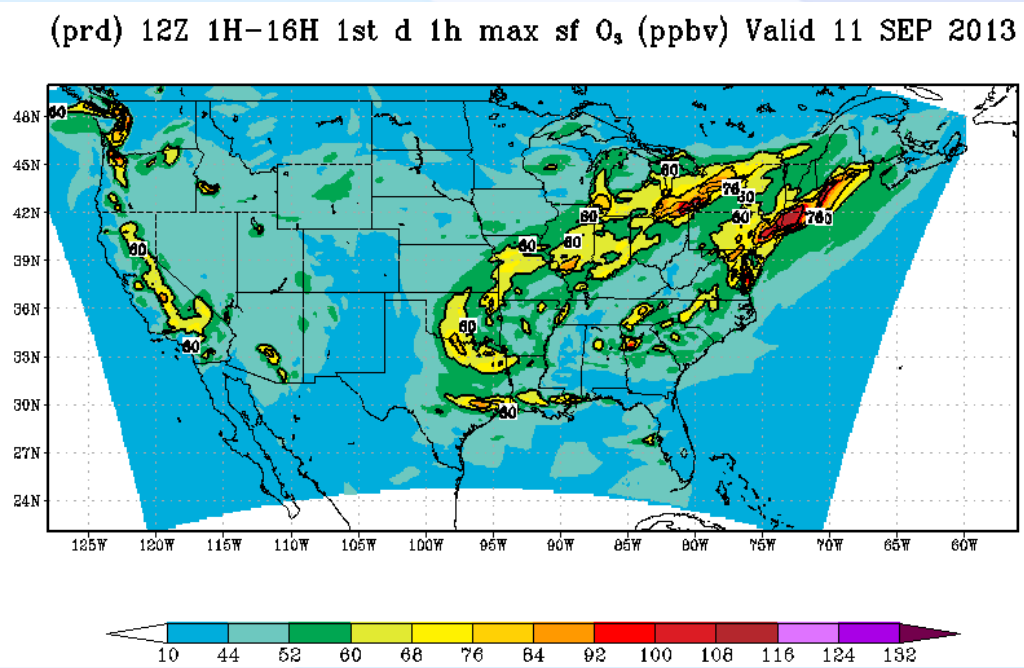
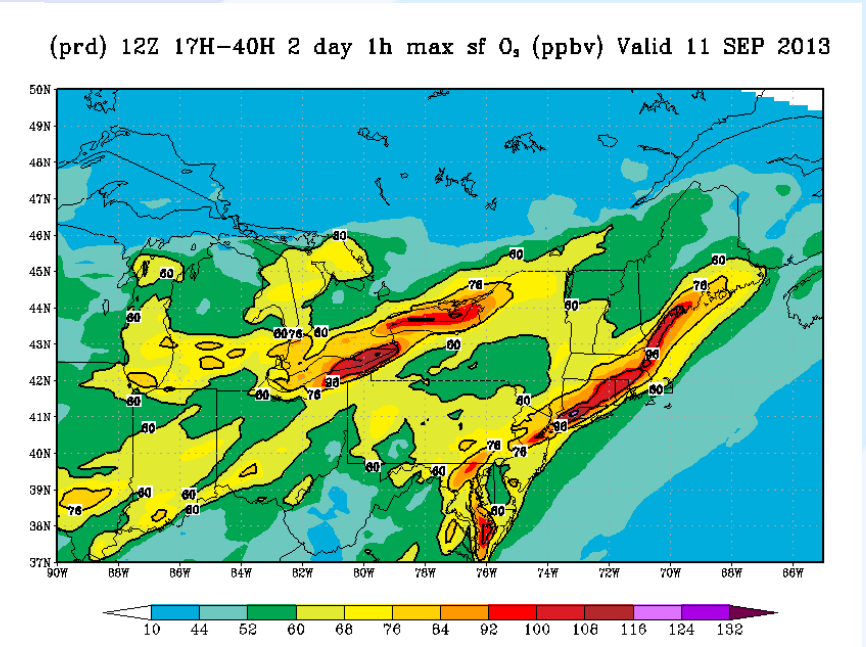
CMAQ Operational Ozone Forecasts

Ozone Updates:

- *Continued to use 2012 emission updates:*
  - *Mobile6 used for mobile emissions, but with emissions scaled by growth/reduction rate from 2005 to 2012*
  - *Non-road area sources use Cross State Rule Inventory*
  - *Canadian emissions use 2006 inventory*
- *FY14: CMAQ V4.6 ozone transferred to NCEP Production run*
  - *PM product experimental*
- *Suspended : Testing of V4.7.1, inclusion of smoke, PM data assimilation at EMC*





http://www.emc.ncep.noaa.gov/mmb/aq/prod/web/html/max_p6.html

HYSPLIT Dispersion

Dust updates:

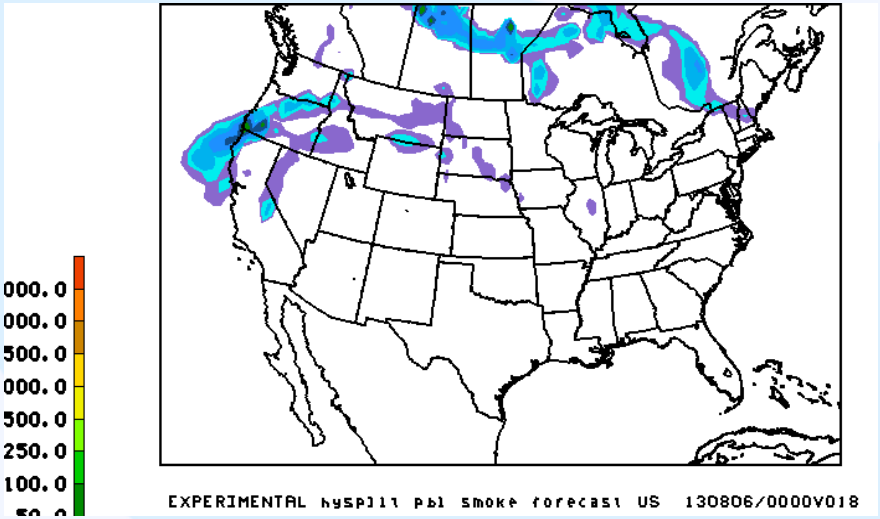
- ***Dust predictions implemented operationally in March 2012***
- *Dust emissions are modulated by real-time soil moisture*

***Smoke updates*: CONUS, Alaska, Hawaii in July 2013**

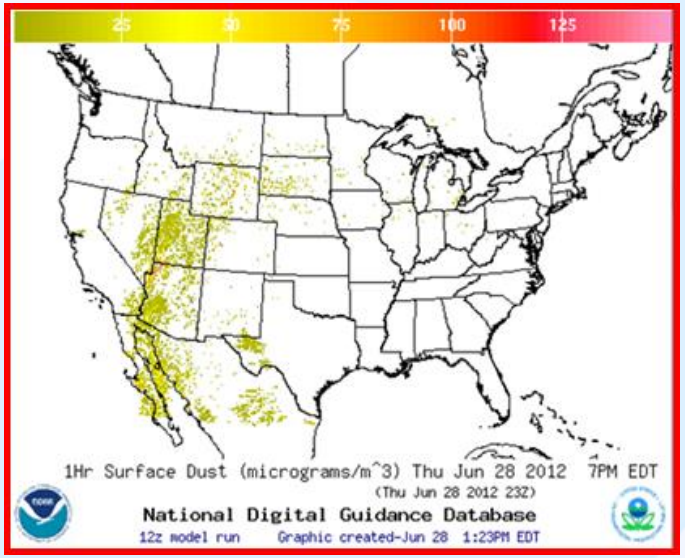
- *updates to plume rise and deposition parameters*

***Emergency Response*, On-Demand**: *Upgraded July 2013*

- *Volcanic ash, WMO Center for emergency response for radiological release*
- *Comprehensive Test Ban Treaty Rad. Source Location support*



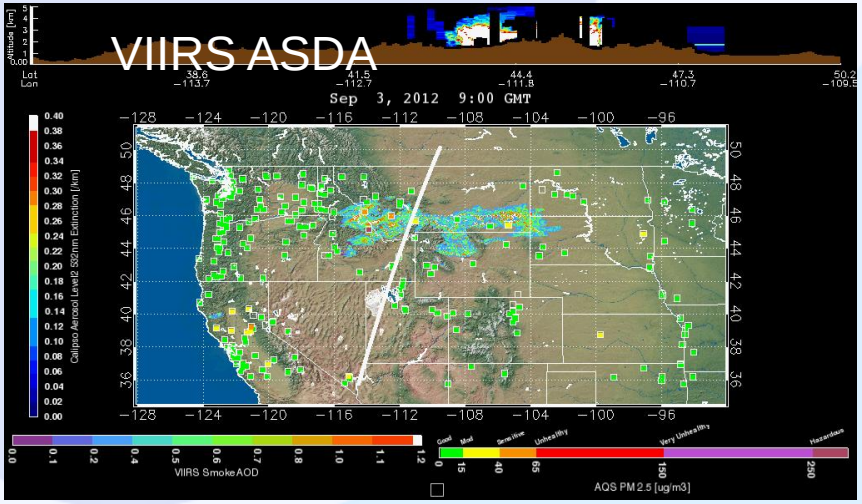
Column Smoke

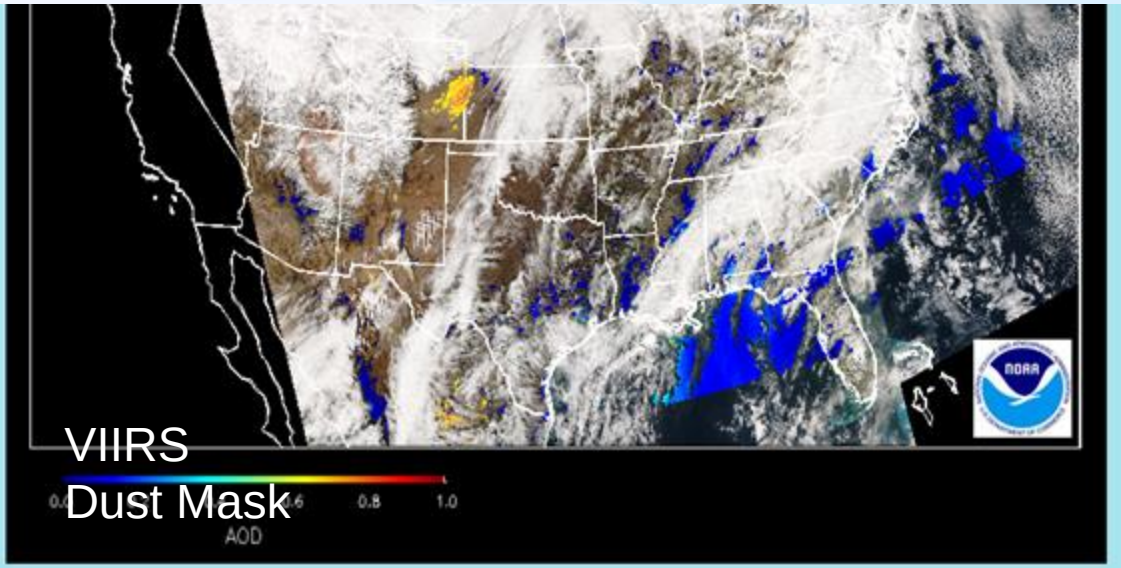


Surface Dust

Using Satellite Data to Improve Operational Air Quality Forecasting Capabilities

- Routine use of NESDIS smoke and dust product by NWS to verify operational forecasts:
  - ASDA work started in 2005. GOES-E product became operational in 2008 and GOES-W in 2009.
  - Aqua MODIS dust mask work started in 2008. Product became operational in 2012.
- NESDIS continuing to refine the dust mask algorithm and applying it to SNPP VIIRS



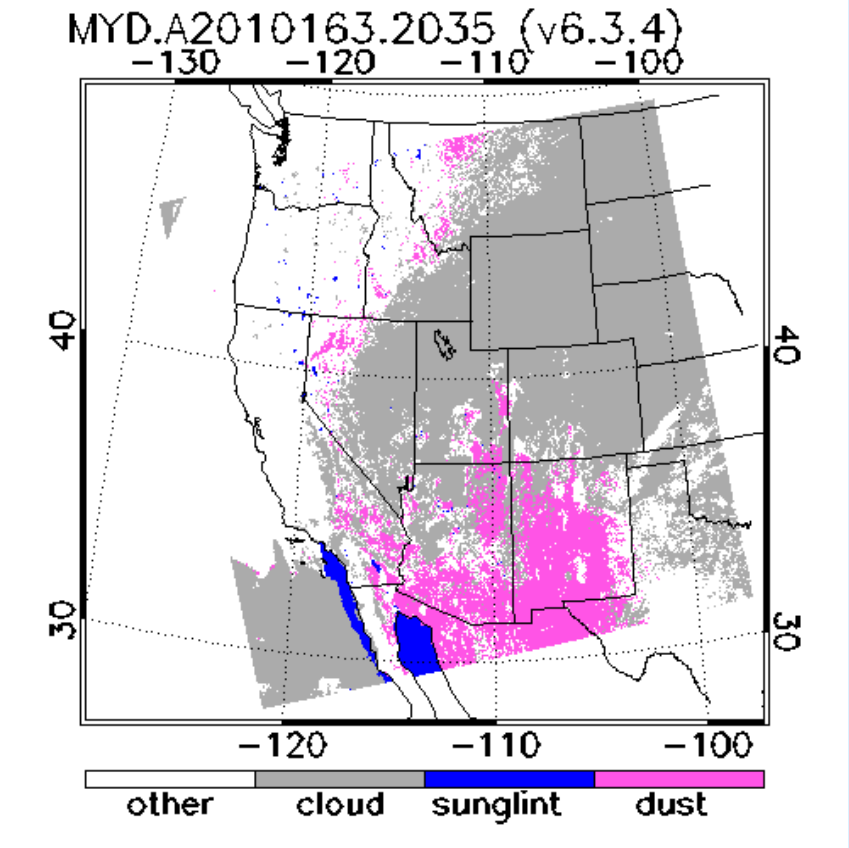


Shobha Kondragunta (NESDIS/STAR)

Using Satellite Data to Improve Operational Air Quality Forecasting Capabilities

- Column average dust concentration (μg/m^3)
  - Uses Aqua MODIS deep blue AOD and an independently derived dust flag
  - Dust mass concentration (m_c) is obtained using AOD (τ), mass extinction efficiency (*k*), and aerosol height (*h*)
- Product specifications
  - ***Name:*** *MODIS Dust Mask*
  - ***Satellites:*** *Aqua*
  - ***Accuracy:*** *70%*
  - ***Spatial resolution:*** *0.1°*
  - ***Temporal resolution:*** *daily*
  - ***Latency:*** *one day*
  - ***Data format:*** *netCDF4 and GRIB1*
  - ***Data availability:*** *2013 - present*

Aqua MODIS Dust Mask Product



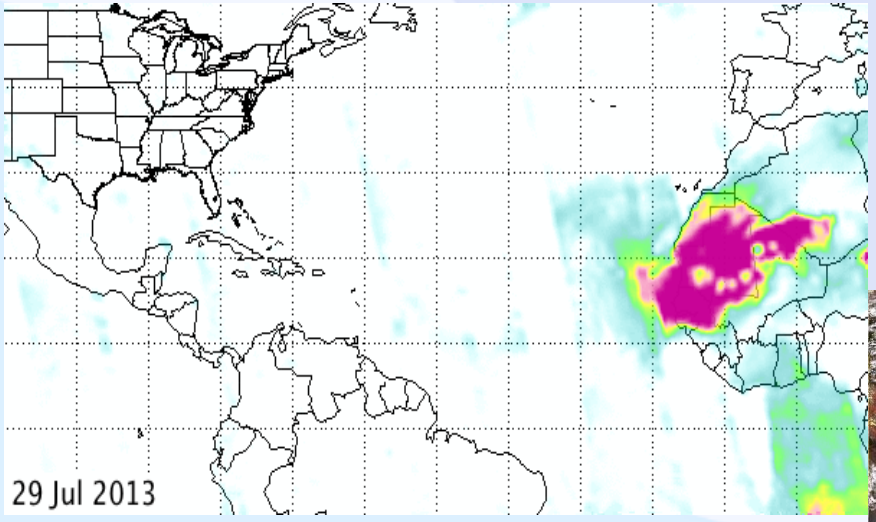
$$DBDI = -100[log_{10}(R_{412nm} / R_{440nm}) - log_{10}(R'_{412nm} / R'_{440nm})]$$

$$NDAI = -10[log_{10}(R_{412nm} / R_{213nm})]$$

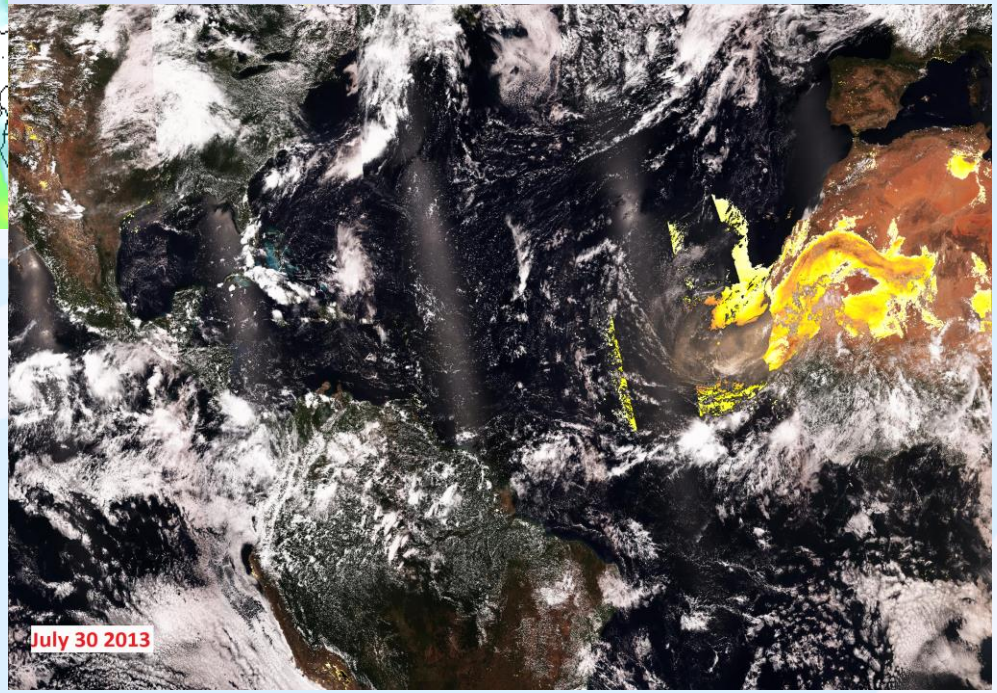
Shobha Kondragunta (NESDIS/STAR)

Saharan Dust Transport as Observed by Satellites

OMPS Aerosol Index

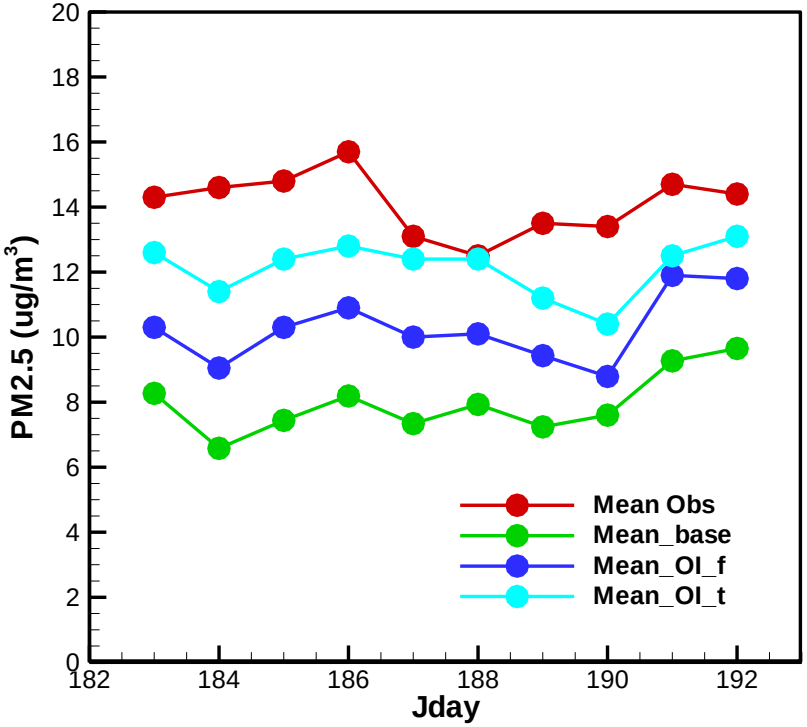


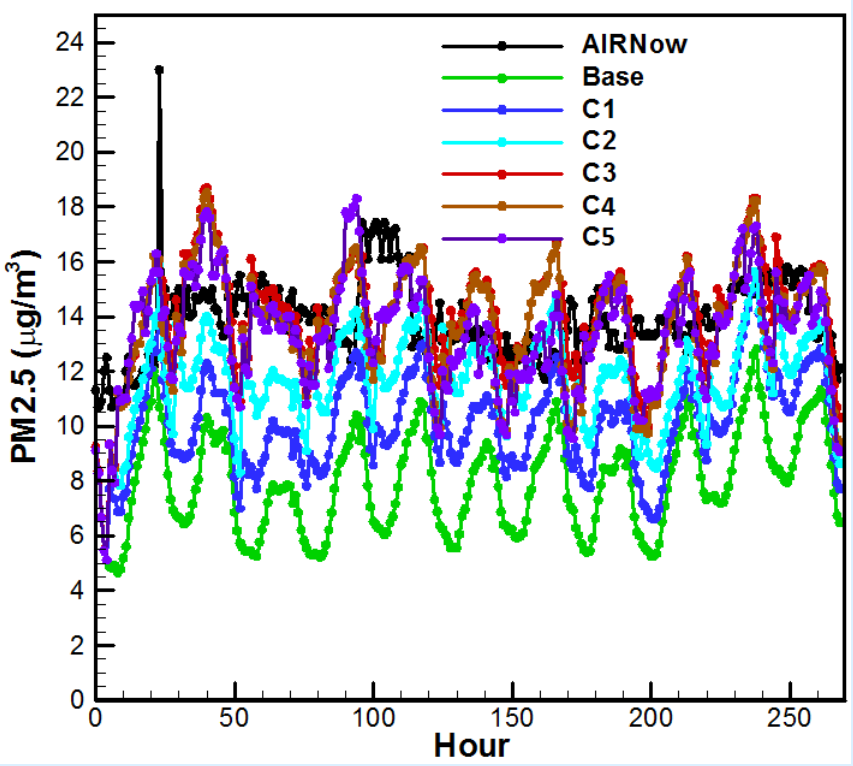
VIIRS Dust Aerosol Index: MODIS dust mask algorithm applied to VIIRS globally



Pubu Ciren and Shobha Kondragunta (NESDIS/STAR)

- A developmental version of NAQFC run that assimilates surface PM2.5 observations and MODIS AOD using GSI shows positive effect in improving aerosol forecasts, but impact is limited





Mean Obs: CONUS and daily averaged AIRNow observations
Mean_base: Base case without assimilation
Mean_OI_f: After assimilation of fine mode AOD
Mean_OI_t: After assimilation of total AOD

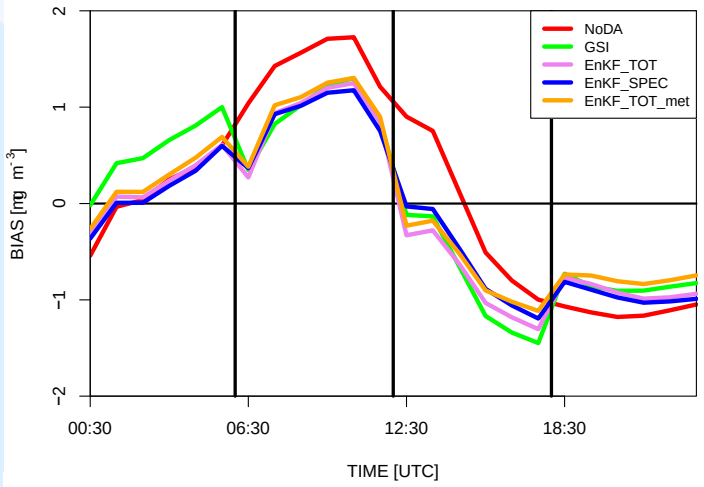
C1: Terra fine-mode AOD at 17Z
C2: Terra total AOD
C3: Terra total AOD & Aqua total AOD
C4: Terra total AOD & Aqua total AOD & **AIRNow PM2.5 at 12Z**
C5: Terra total AOD & Aqua total AOD & **AIRNow PM2.5 every 6 hours**

Pius Lee (ARL) and Brad Pierce (NESDIS/STAR)

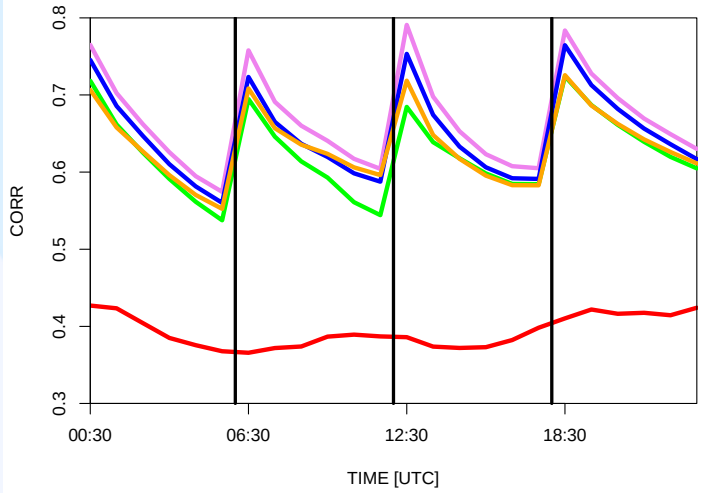
Assimilation of PM2.5 using WRF-Chem with EnKF and GSI

Evaluation period: June 1 - July 15, 2010

BIAS



CORR



ARW WRF-Chem

grid length 60 km, 40 vertical levels;

GOCART aerosol for computational reasons;

assimilation of AIRNow PM2.5 in 6-hr cycle;

GSI: 3D-VAR i.e. climatological error statistics

EnKF: 50 ensembles. i.e. flow-dependent error

Conclusions

- Assimilation has large positive effect on PM2.5 forecasts;
- Because of errors is emissions and chemical parameterizations the impact is limited to about 24 hours;
- EnKF has advantage over 3D-VAR since correction to forecasts is situation dependent;
- Work in progress to increase ensemble spread and parameterize model error.

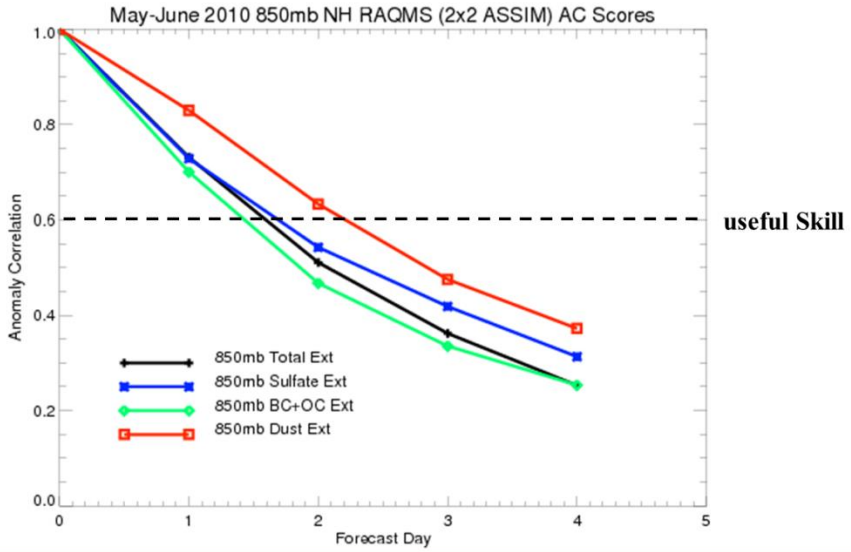
1) **Online global chemical and aerosol assimilation/forecasting system**
2) **UW-Madison sigma-theta hybrid coordinate model (UW-Hybrid) dynamical core**
3) **Unified stratosphere/troposphere chemical prediction scheme (LaRC-Combo) developed at NASA LaRC**
4) **Aerosol prediction scheme (GOCART) developed by Mian Chin (NASA GSFC).**
5) **Statistical Digital Filter assimilation system developed by James Stobie (NASA/GFSC)**

RAQMS has been used to support airborne field missions, develop capabilities for assimilating satellite trace gas and aerosol retrievals and assess the impact of global chemical analyses on regional air quality predictions

Ozone Assimilation Studies: August 2006 NOAA Texas Air Quality Study (TEXAQS II)
Ozone/Aerosol Assimilation Studies: April 2008 NOAA Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC)
Ozone/Aerosol Assimilation Studies: May-June NOAA California Nexus (CalNex)

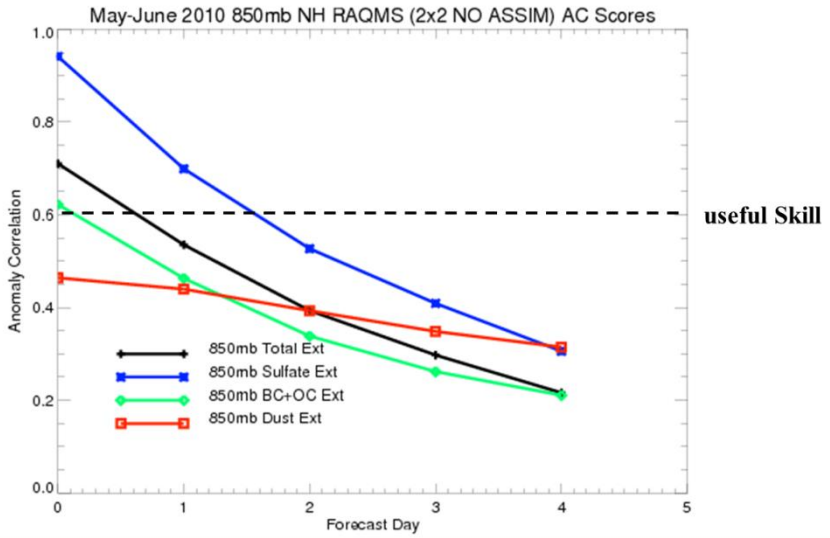
Assessment of Global 850mb Aerosol Extinction Forecast Skill
May-June 2010 NH Anomaly Correlations (AC)

Northern Hemisphere 850mb May-June 2010 Anomaly Correlations (AC)
(With MODIS Assimilation)



- MODIS AOD assimilation results in small changes in 850mb SO4 extinction forecasts
- MODIS AOD assimilation results in significant improvements in black and organic carbon (BC+OC) and dust forecast skill (dust prediction useful at 2 days)

Northern Hemisphere 850mb May-June 2010 Anomaly Correlations (AC)
(No Assimilation)



- Only 850mb SO4 extinction forecasts useful skill past 1 day
- Black and organic carbon (BC+OC) and dust extinctions are both poorly initialized and forecasted

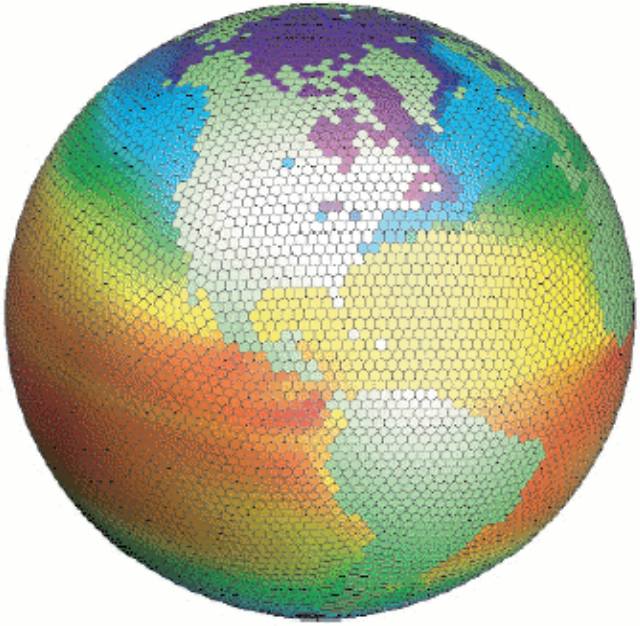
FIM: Flow-following- finite-volume Icosahedral Model (ESRL)

FIM-Chem

- Resolution: G7 (dx~60km), 64 vertical levels, ptop=.0.1mb
- Chemistry: only GOCART, optical routines, deposition, emissions, plumerise for wildfires, sub-grid transport from WRF, 4 size bins for volcanic ash. Much improved dust scheme
- Fire data from WFABBA for the America's, Brazilian info for South America added, TERRA and AQUA MODIS for the rest of the world
- Anthropogenic emissions from EDGAR/RETRO, not very good
- Statistics from summer of 2010 (August through October), 10 year data set is being evaluated now (Jan 2001 – Dec 2010)

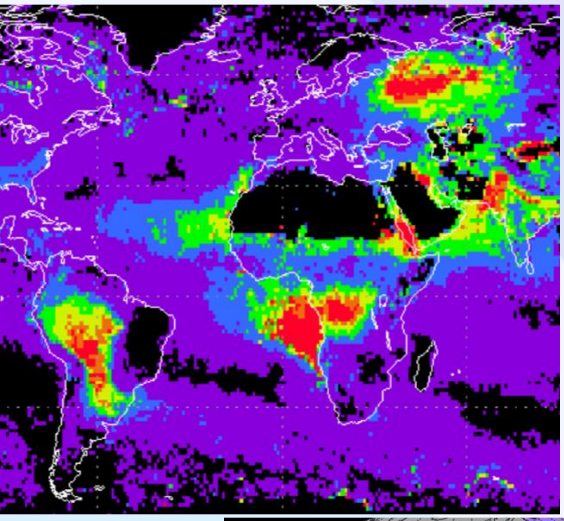
No chemical data assimilation for first evaluation

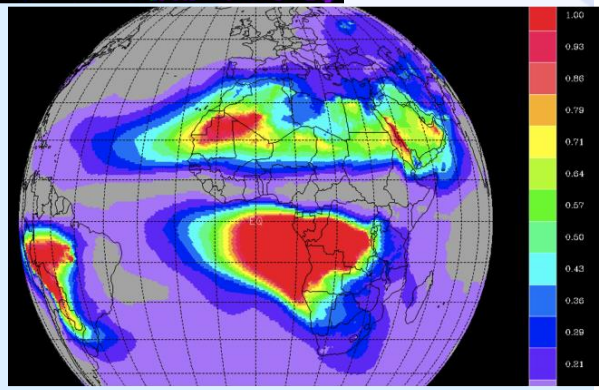
Icosahedral grid

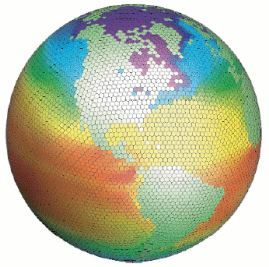


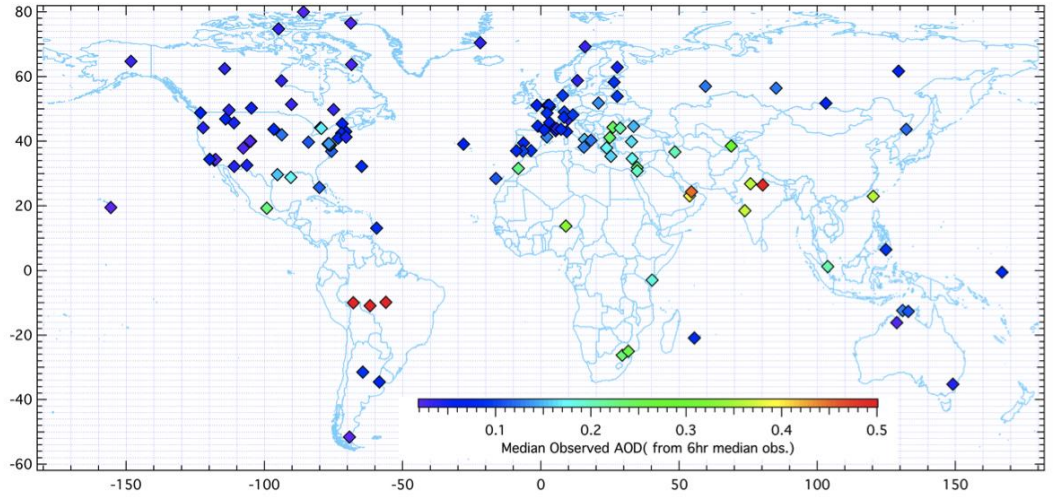
Nearly equal size of grid volumes, including near poles

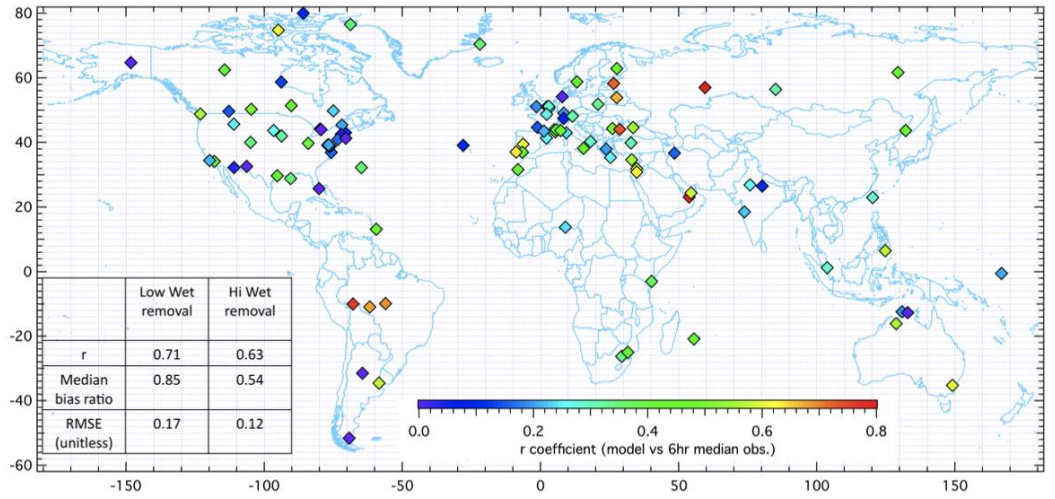
Evaluation of FIM-Chem: Comparison with AERONET data, August through October 2010, 24 hr forecasts, 11835 points











	Low Wet removal	Hi Wet removal
r	0.71	0.63
Median bias ratio	0.85	0.54
RMSE (unitless)	0.17	0.12

- Good performance in or near wildfires and dust sources
- Not good in or near major anthropogenic emission sources (Europe and US)
- Should improve with chemical data assimilation and new emissions data sets

Presentation Outline

- Current Operational Configuration
- Future operational requirements and applications
- Ongoing NOAA wide aerosol activities
- **Future Plan**

Future Operational Benefits Associated with NEMS GFS Aerosol Component

- Provides a first step toward an operational aerosol data assimilation capability at NOAA
- Allows aerosol impacts on medium range weather forecasts (GFS/GSI) to be considered
- Allows NOAA to explore aerosol-chemistry-climate interaction in the Climate Forecast System (CFS) as NEMS GFS is the atmospheric model of CFS
- Provides global aerosol information required for various applications (e.g., satellite radiance data assimilation, satellite retrievals, SST analysis, UV-index forecasts, solar electricity production)
- Provides lateral aerosol boundary conditions for regional aerosol forecast system

Priority System Enhancements

- **Long-term goal**
  - Enable global atmospheric constituents forecasting capability to provide low-resolution aerosols and space weather forecasts routinely and high-resolution air quality and volcanic ash forecasts on-demand.
  - Provide quality atmospheric constituents forecast products to serve a wide-range stakeholders, such as health professionals, aviation authorities, policy makers, and climate scientists
- **Challenges and Lessons Learned**
  - The development has been affected by uncertainties in NWS priority and resources
  - The project builds up extensive collaboration with NOAA labs/centers and external community
  - NCEP will continue leveraging the expertise in GSFC, NESDIS, OAR, the ICAP working group, the WMO SDS-WAS program

Thank You