Assimilation of Aerosol Observations

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With contributions from:

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Pablo Saide and Greg Carmichael (U-Iowa/CGRER)
Sarah Lu (NWS/EMC)

WMO 5th DAOS Working Group University of Wisconsin Madison, 19-20 Sep 12

Outline

- ❑Motivation
  - •Anthropogenic changes in atmospheric composition
  - •Aerosol Global Observing System

- ❑Operational (and Pre-Operational) Aerosol assimilation
  - •MACC-II (EU)
  - •NAAPS (Navy)
  - •GEOS-5 (NASA)
  - •NEMS (NCEP)
  - •WRF-CHEM (ESRL)

- ❑ RAQMS Global Aerosol Forecast Skill Assessment
  - •CalNex (http://www.esrl.noaa.gov/csd/projects/calnex/)
  - •ARCPAC (http://www.esrl.noaa.gov/csd/arcpac/)

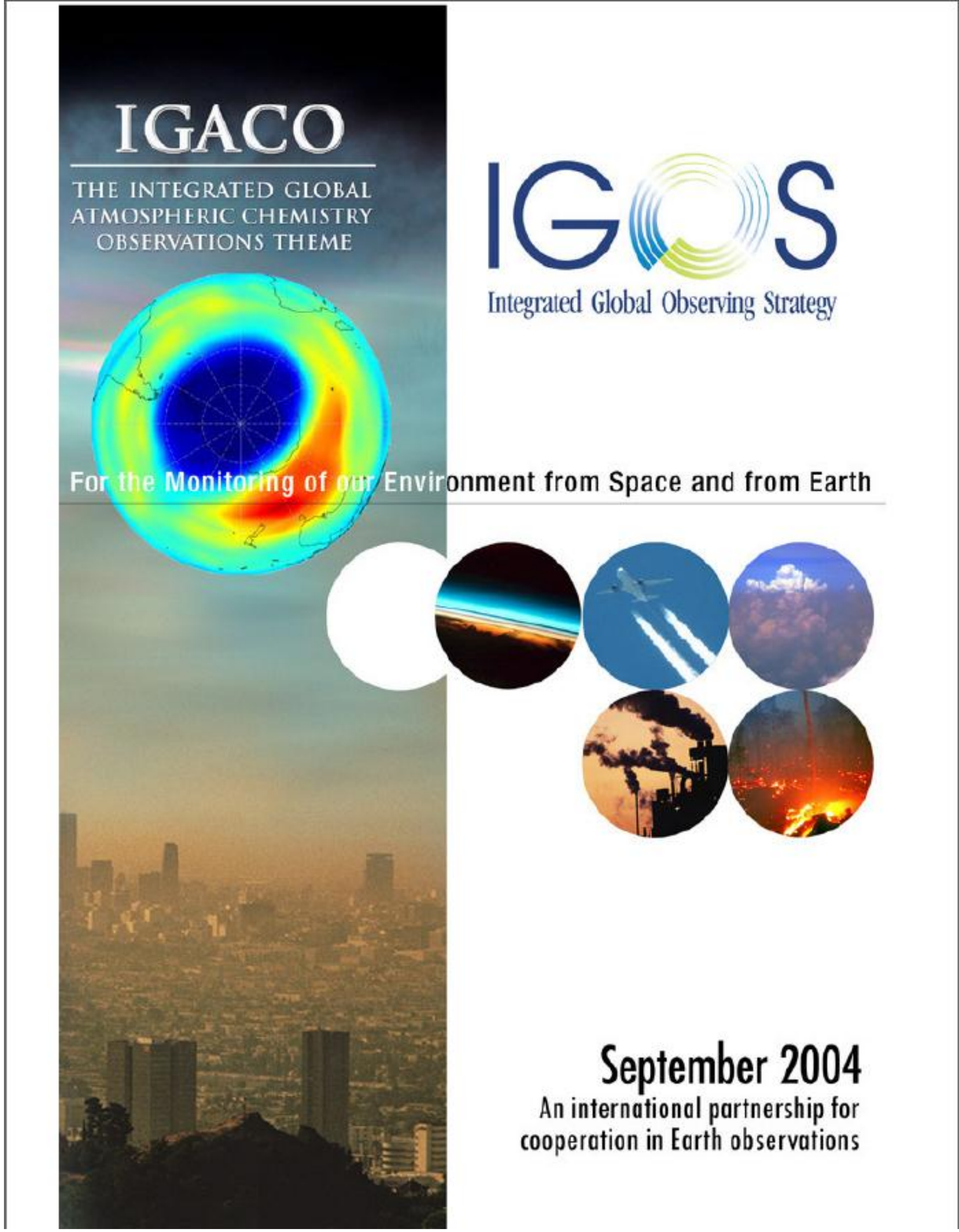
- ❑Current research directions
  - •Links between aerosols and severe weather (preliminary results)

Motivation

Changes in atmospheric composition since the industrial revolution

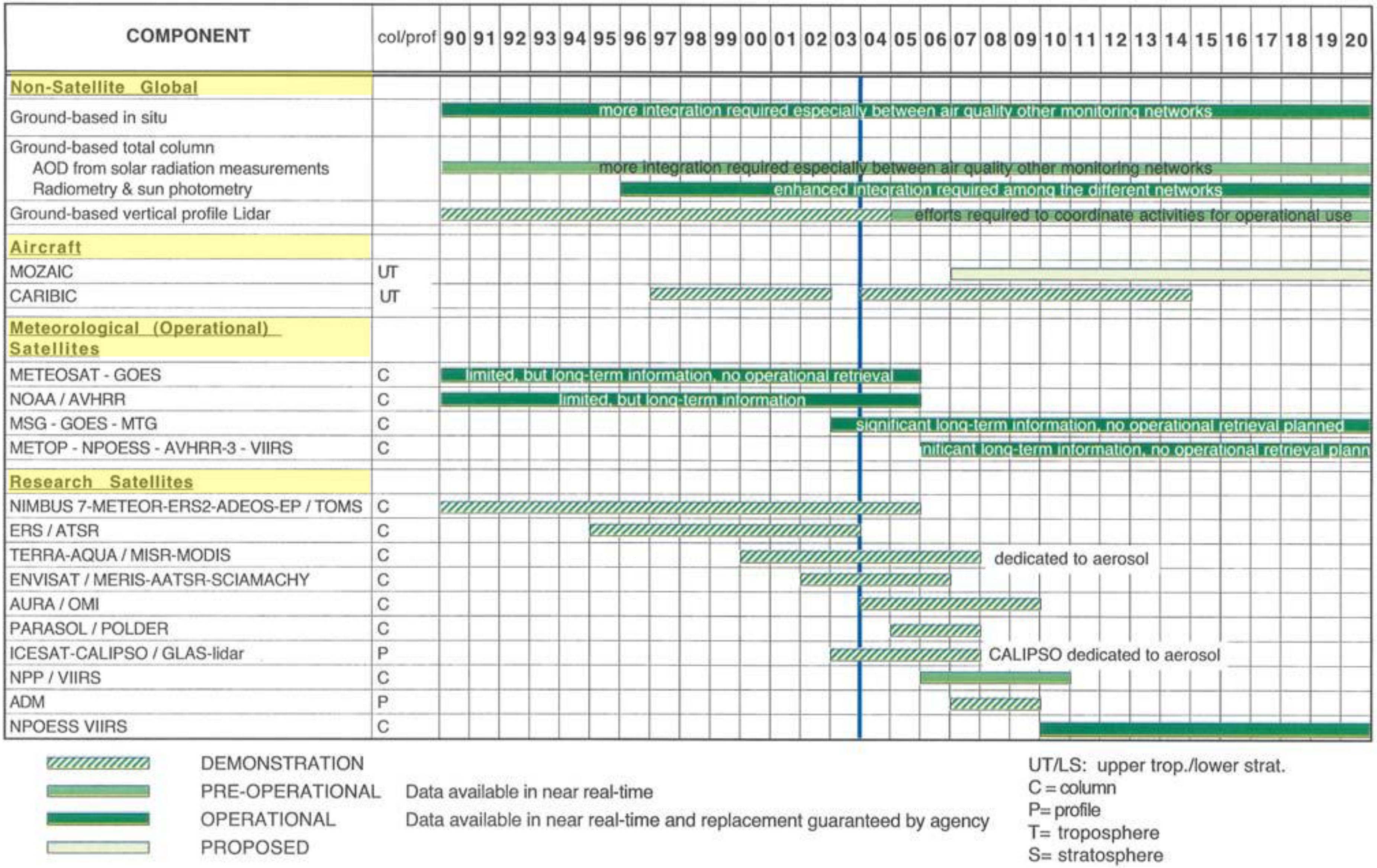
- Decreases in stratospheric ozone and increases in surface ultraviolet radiation
- Occurrence of urban smog and increased ozone background in the northern troposphere
- Increases in greenhouse gases and aerosols and associated climate change
- Acid rain and eutrophication of surface waters
- Enhanced aerosol and photo-oxidant levels due to biomass burning
- Increases in fine particles, reduction in visibility and human health effects
- Long-range transport of air pollution

"Many of these changes in atmospheric composition have socio-economic consequences through adverse effects on human and ecosystem health, on water supply and quality, and on crop growth."



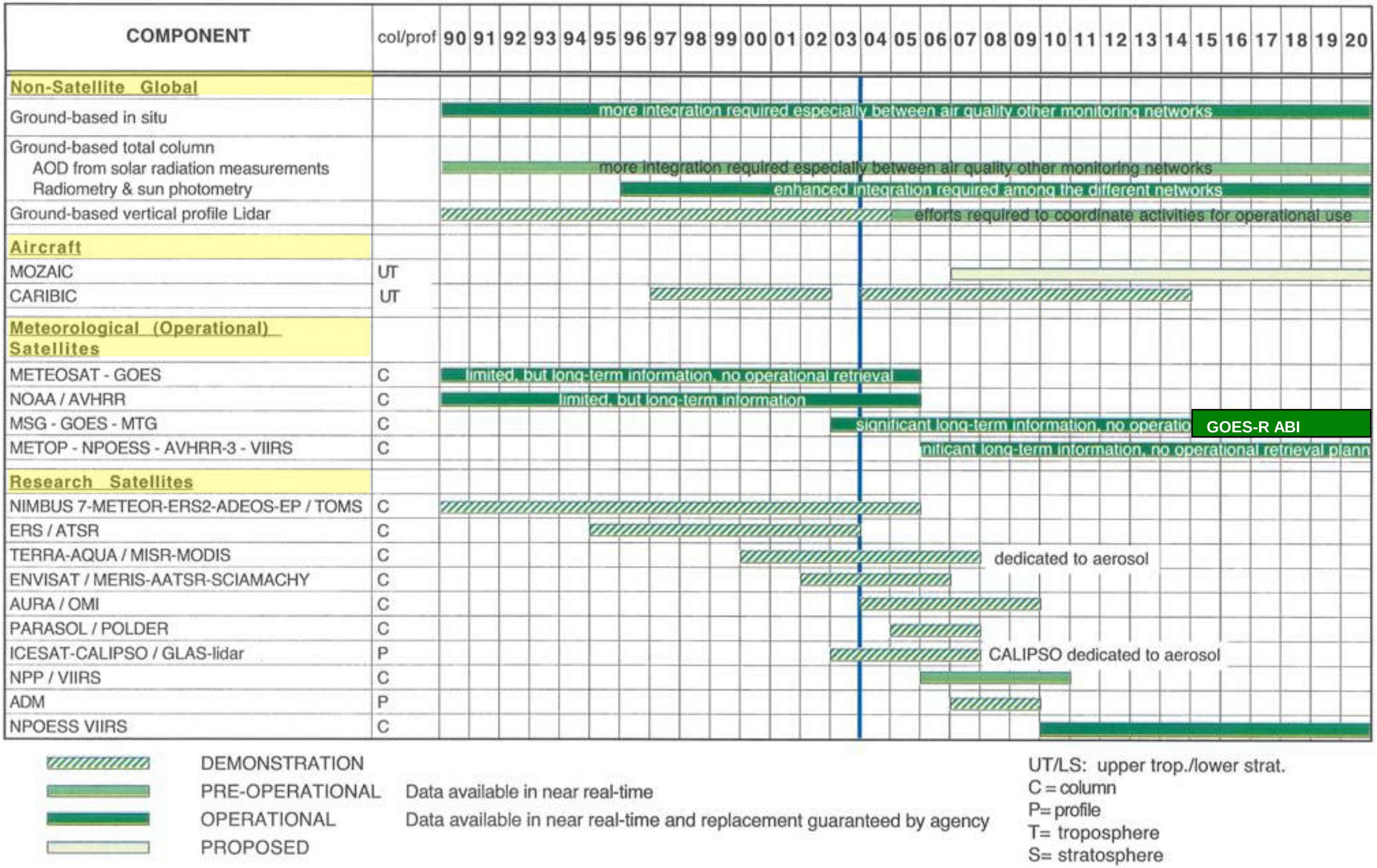
From IGOS Atmospheric Chemistry Theme Report 2004

Satellite, ground-based and aircraft measurements for tropospheric aerosol optical properties



(From IGOS Atmospheric Chemistry Theme Report 2004)

Satellite, ground-based and aircraft measurements for tropospheric aerosol optical properties (Updated)



http://www.goes-r.gov/products/ATBDs/baseline/AAA_AODASP_v2.0_no_color.pdf

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Development of GMES atmospheric services

ESA-funded PROMOTE (2004-2009) and EU FP6 GEMS (2005-2009) projects provided initial development of GMES atmospheric services

EU FP7 project MACC (2009-2011) continued activities initiated in GEMS and incorporated core elements of PROMOTE

EU FP7 project MACC-II offering essentially operational core services began on 1 Nov 2011

Development of constituent and aerosol assimilation/ forecasting within ECMWF Integrated Forecast System (IFS) Framework

The ECMWF aerosol model

12 additional aerosol-related prognostic variables:
* 3 bins of sea-salt (0.03 – 0.5 – 0.9 – 20 μm)
* 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
* Black carbon (hydrophilic and –phobic)
* Organic carbon (hydrophilic and –phobic)
* SO_2 -> SO_4

Sources, horizontal and vertical advection by dynamics, vertical advection by vertical diffusion and convection, dry deposition, sedimentation, wet deposition by large-scale and convective precipitation, hygroscopicity (SS, OM, BC, SU)

* Forward modelling: Morcrette et al.,2009, JGR
* Analysis including assimilation of MODIS tau550: Benedetti et al., 2009, JGR

4D-var assimilation system for aerosols

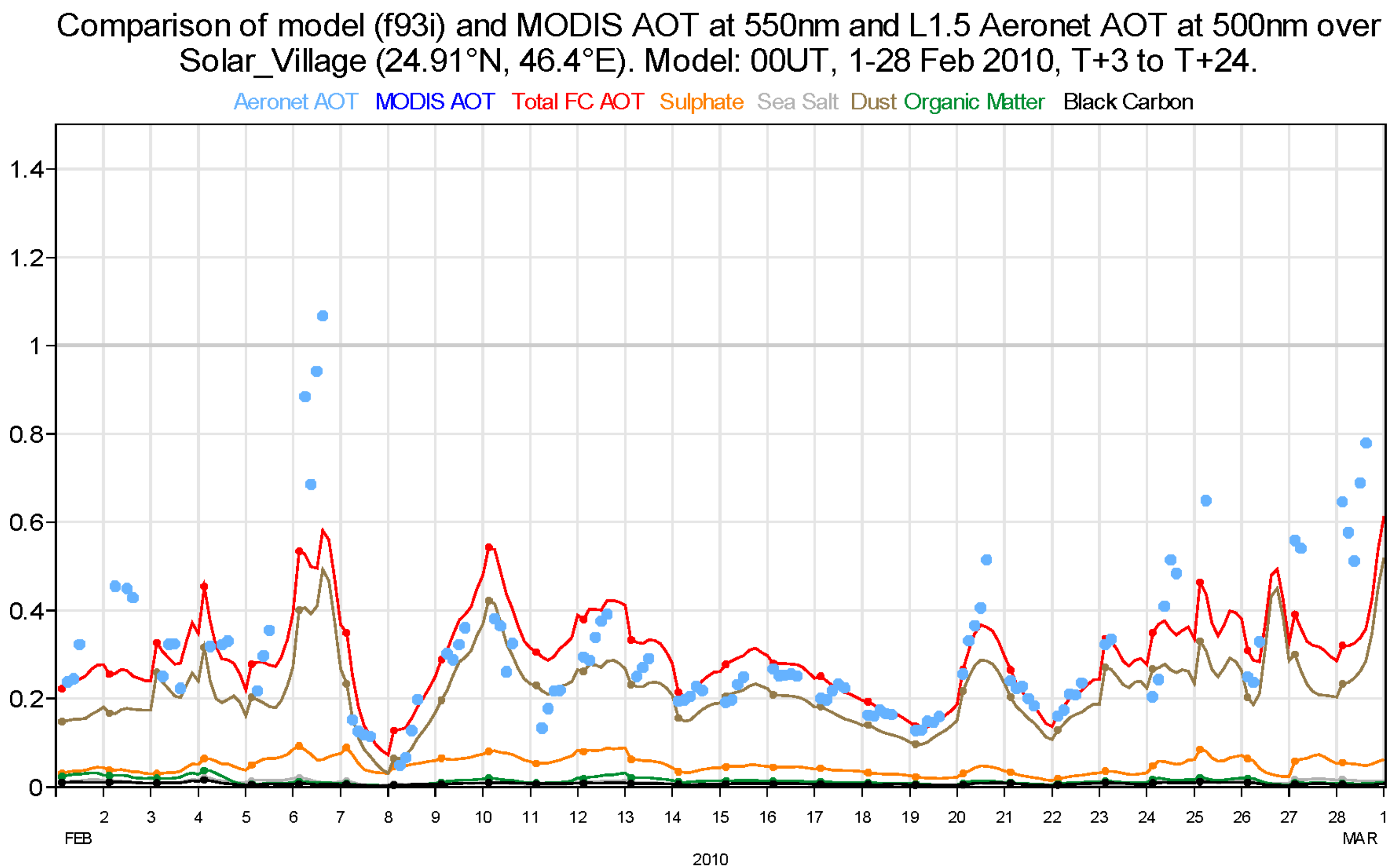
- The control variable is formulated in terms of the total aerosol mixing ratio

- Background error statistics have been computed using the NMC method

- Assimilated observations: MODIS Aerosol Optical Depths (AODs) at 550 nm over land and ocean. Observation errors are prescribed as a percentage of the observed optical depth value (now changed to fixed values as a result of investigation into observations bias using the variational approach).

- Validation datasets: optical depths from the AErosol Robotic NETwork (AERONET) and lidar backscattering from CALIPSO

AERONET site comparisons (February 2010)



•**Dust-dominated site (Solar Village) show good agreement between the analysis and AERONET despite the lack of MODIS data over this type of sites**

Angela Benedetti, ECMWF: International Cooperative for Aerosol Prediction (ICAP)/AEROCAST: 3rd Workshop: Ensemble Forecasts and Assimilation (http://bobcat.aero.und.edu/jzhang/ICAP/)

Operational AOD assimilation
Naval Research Laboratory (NRL)

Aerosol physics uses a version of the NRL operational Atmospheric Variational Data Assimilation System (NAVDAS) called NAVDAS-Aerosol Optical Depth (NAVDAS-AOD)

- 2D variational approach
- constant aerosol mass adjustment for all species
- no adjustment for hydroscopic growth

Used to improve the NRL Aerosol Analysis and Prediction System (NAAPS)'s aerosol forecasting capability

Meteorological analysis and forecast fields from the Navy Operational Global Analysis and Prediction System (NOGAPS)

NAVDAS-AOD assimilates over-water MODIS AOD from the NOAA NESDIS Near Real Time Processing Effort (NRTPE) (latency of 3 h or less in most cases)

Strict QA procedure is necessary to remove outliers associated with cloud artifacts [Zhang and Reid, 2006]

Zhang, J., J. S. Reid, D. L. Westphal, N. L. Baker, and E. J. Hyer (2008), A system for operational aerosol optical depth data assimilation over global oceans, J. Geophys. Res., 113, D10208, doi:10.1029/2007JD009065

Aeronet Sun photometer validation

D10208 ZHANG ET AL.: AEROSOL DATA ASSIMILATION D10208

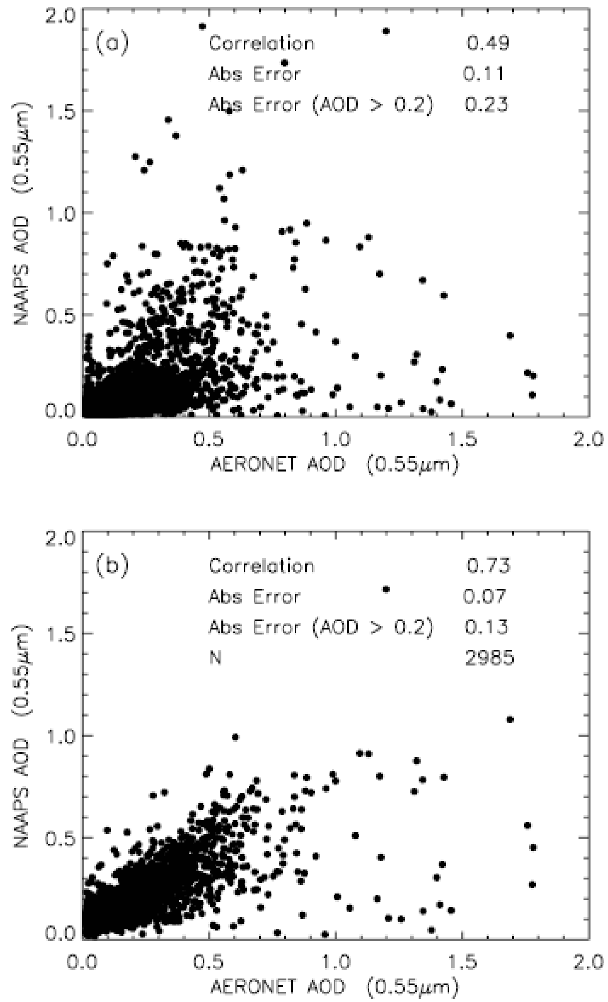
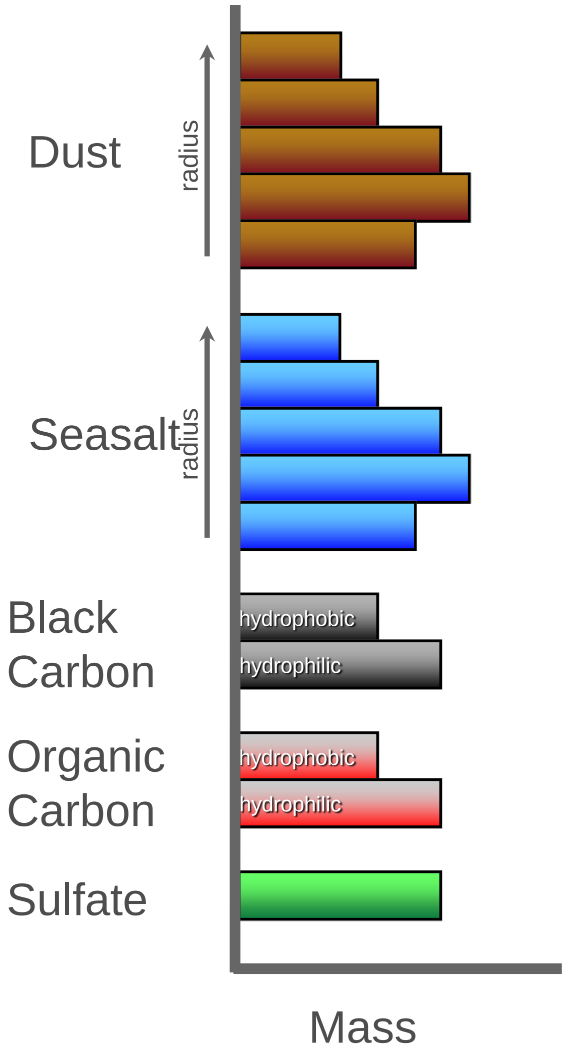


Figure 3. (a) AERONET versus NAAPS τ for 5-month (January–May 2006) NAAPS nonassimilation run; (b) AERONET versus NAAPS τ for 5-month (January–May 2006) NAAPS run with the aerosol data assimilation process.

January-May 2006
No Assimilation

Aeronet comparisons limited to the coastal and island AERONET sites

January-May 2006
MODIS Assimilation



- **Goddard Chemistry, Aerosol, Radiation, and Transport Model [Chin et al. 2002]**
- **Sources and sinks for 5 <u>non-interactive</u> species**

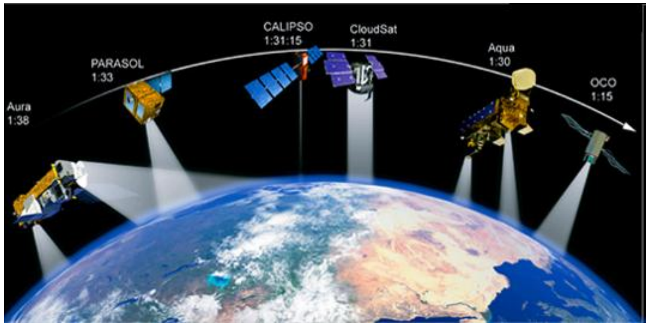
dust	wind and topographic source, 5 mass bins
sea salt	wind driven source, 5 mass bins
black carbon	anthropogenic and wildfire source, mass hydrophic and hydrophilic
organic carbon	anthropogenic, biogenic, and wildfire source, mass hydrophic and hydrophilic
sulfate	anthropogenic and wildfire source of SO2, oxidation to SO4 mass

- **Convective and large scale wet removal**
- **Dry deposition (and sedimentation for dust and sea salt)**
- **Optics based primarily on OPAC**

Slides provided by Arlindo da Silva Global Modeling and Assimilation Office, NASA/GSFC

GEOS-5 Aerosol Data Assimilation

Focus on NASA EOS instruments, MODIS for now

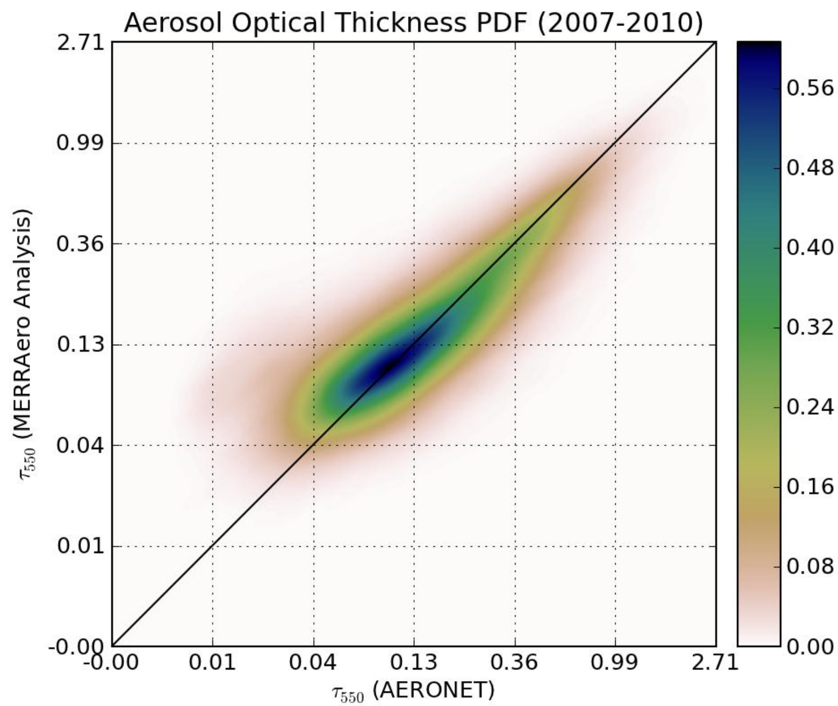


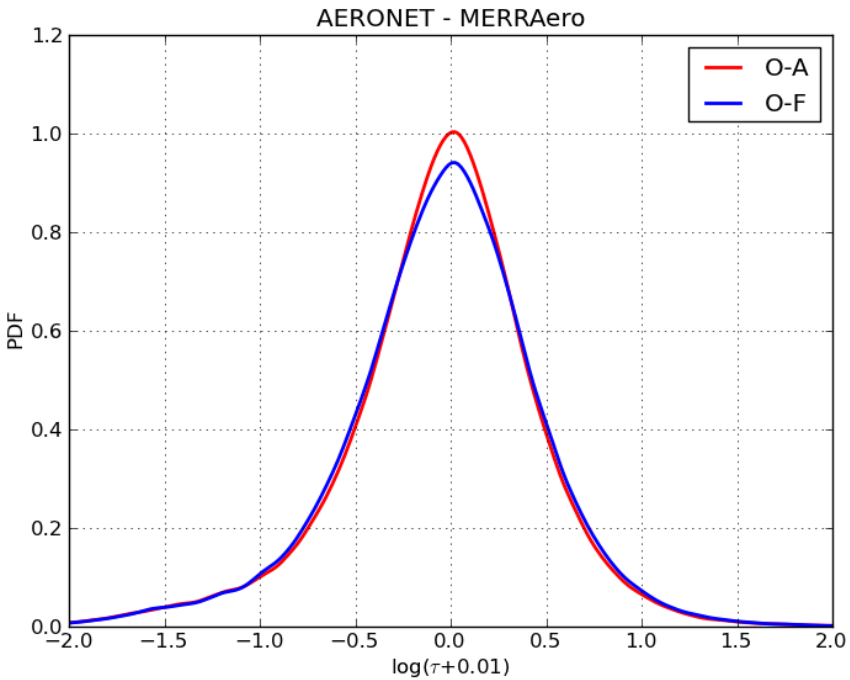
Global, high resolution 2D AOD analysis

3D increments by means of Local Displacement Ensembles (LDE)

- Simultaneous estimates of background bias (*Dee and da Silva 1998*)
- Adaptive Statistical Quality Control (*Dee et al. 1999*):
  - State dependent (adapts to the error of the day)
  - Background and Buddy checks based on log-transformed AOD *innovation*
- Error covariance models (*Dee and da Silva 1999*):
  - Innovation based
  - Maximum likelihood

AERONET Validation of Aerosol Assimilation





$$h = \log(t + 0.01)$$

Based on 2007-10 data, aerosol assimilated fields.

Overview of the NOAA Environmental Modeling System (NEMS) GFS Aerosol Component

- **Configuration:**
  - Forecast model: Global Forecast System (GFS) based on NOAA Environmental Modeling System (NEMS), NEMS-GFS
  - Aerosol model: NASA Goddard Chemistry Aerosol Radiation and Transport Model, GOCART
  - A common modeling framework using Earth System Modeling Framework (ESMF)
  - In-line modeling approach:
    - Consistent: no spatial-temporal interpolation, same physics parameterization
    - Efficient: lower overall CPU costs and easier data management
    - Allows for feedback to meteorology (aerosol-radiation feedback has been developed in GFS physics)
- **Phased Implementation:**
  - Dust-only guidance established in Q4FY12
  - Full-package aerosol forecast after real-time global smoke emissions are available and tested (NCEP-NESDIS-GSFC collaborative activities funded by JCSDA)

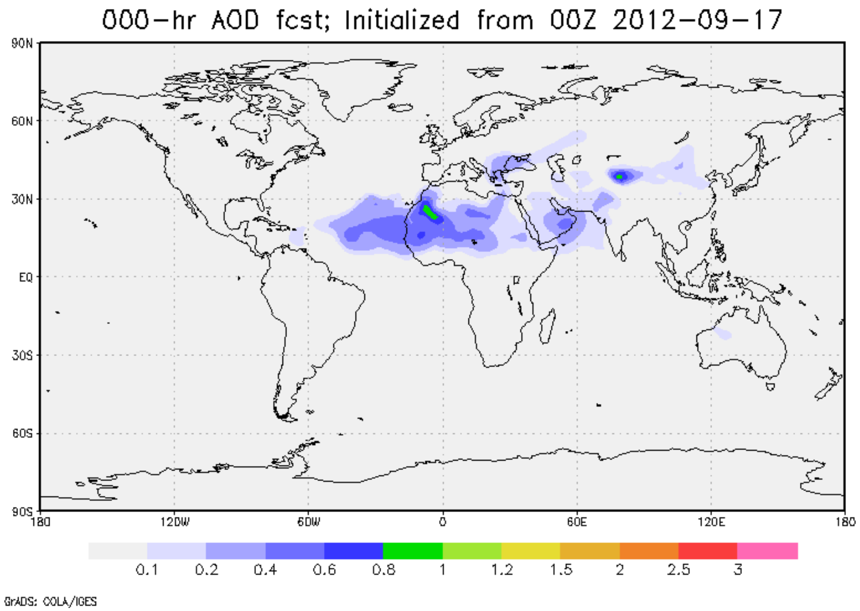
GOCART module from GSFC's GEOS5 has been implemented into NEMS GFS (with funding support from NASA Applied Sciences Program, JCSDA, and NWS). NEMS-GFS now has the capability to simulate dust, sulfate, sea salt and carbonaceous aerosols

Slides provided by Sarah Lu, NOAA/NCEP

Near-Real-Time NEMS GFS Aerosol Component

Current Status:

- 5-day dust forecast once per day (at 00Z), output every 3 hour
- Resolution: T126 L64
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- GRIB2 products in 1x1 degree: 3-d distribution of dust aerosols (5 bins from 0.1 – 10 µm) and 2-d aerosol diagnosis fields (e.g., aerosol optical depth, surface mass concentration)
- NCEP operational implementation on Sept 2012



Future Operational Benefits Associated with the NEMS GFS Aerosol Component

- Enables future operational global short-range (e.g., 5-day) aerosol prediction
- Allows aerosol impacts on medium range weather forecasts (GFS/GSI) to be considered
- Provides global aerosol information required for various applications (e.g., satellite radiance data assimilation, satellite retrievals, SST analysis, UV-index forecasts)
- Provides a first step toward an operational aerosol data assimilation capability at NCEP
- Allows NCEP to explore aerosol-chemistry-climate interaction in the operational Climate Forecast System (CFS)--- Note that GFS is a candidate for the AGCM component of the next version of the CFS.
- Provides lateral aerosol boundary conditions for regional aerosol forecast system

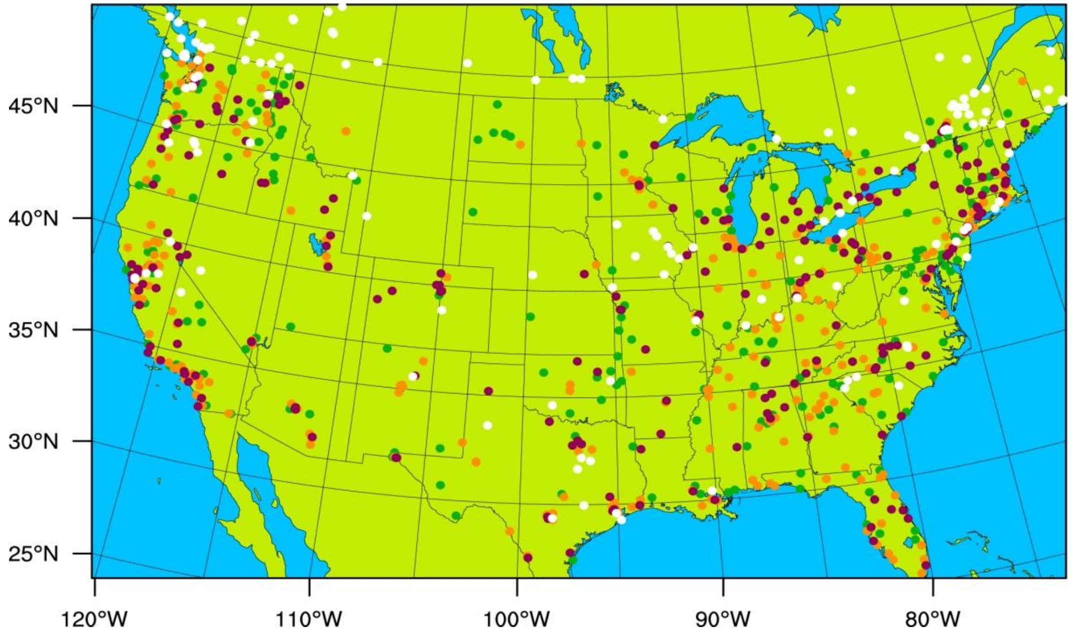
http://www.emc.ncep.noaa.gov/gmb/sarah/NGAC/html/realtime.ngac.html

Assimilation of United States Environmental Protection Agency (EPA) AIRNow surface PM2.5 (fine particle) measurements

WRF-CHEM Experiments

Name	Description
NoDA	No aerosol assimilation
GSI	3D-VAR assimilation of $PM_{2.5}$, $PM_{2.5}$ as a state variable
EnKF_TOT	EnKF assimilation of $PM_{2.5,}$ $PM_{2.5}$ as a state variable
EnKF_SPEC	EnKF assimilation of $PM_{2..5}$, aerosol species as state variables

AIRNow network dark brown – urban, light brown – suburban, green – rural, white – unknown.

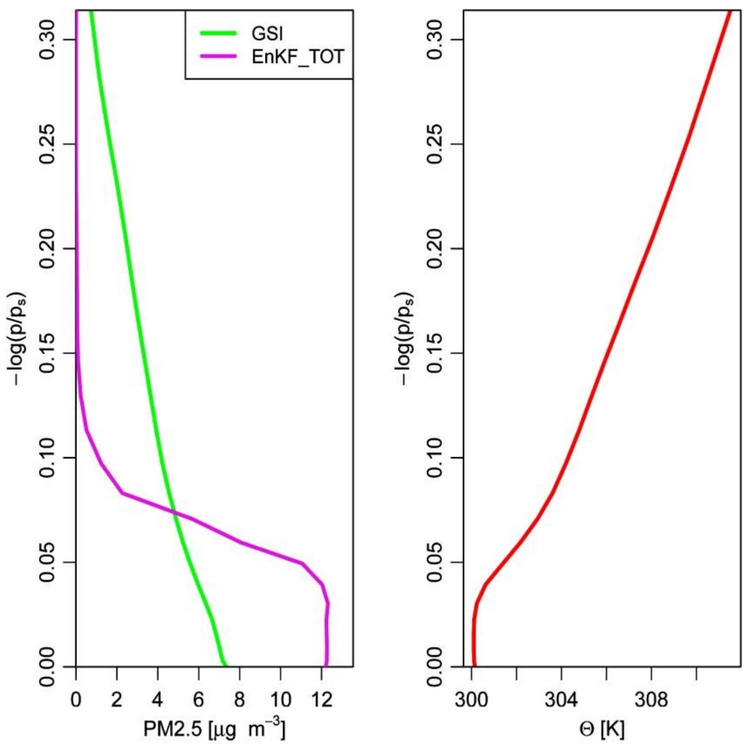


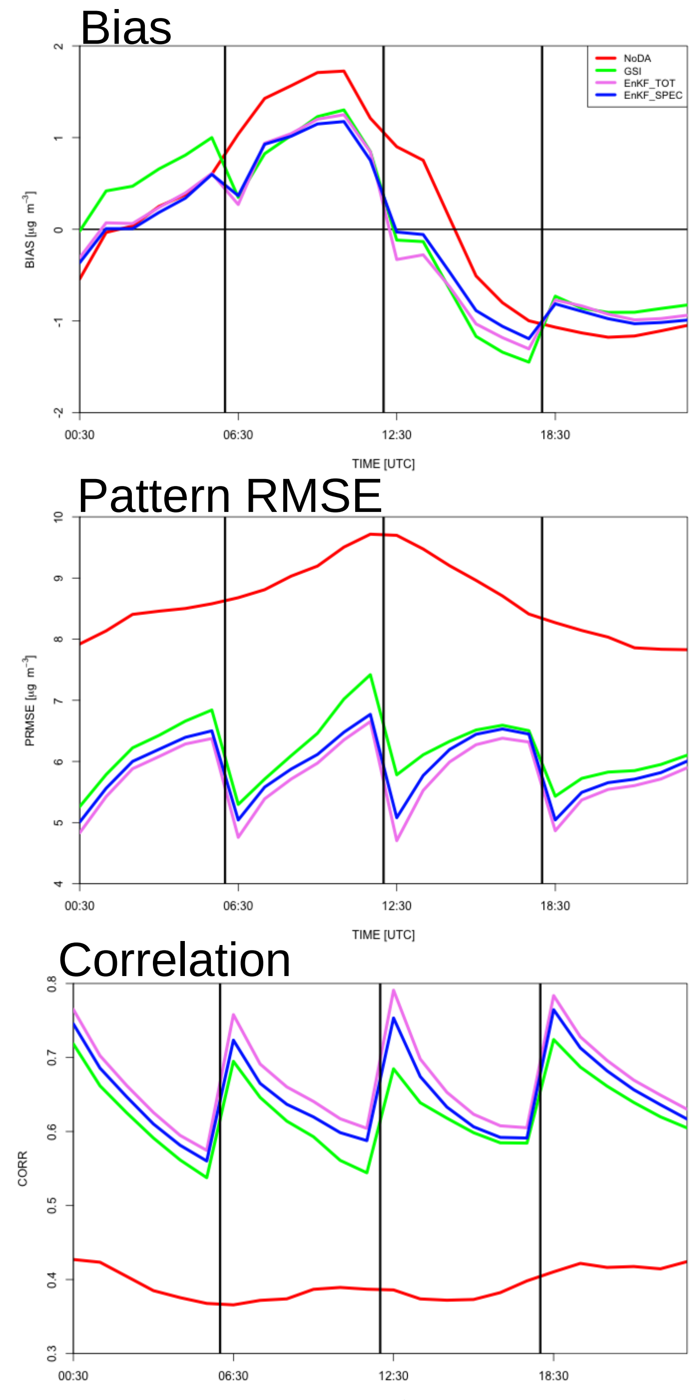
Pagowski & Grell, "Experiments with the assimilation of fine aerosols using an ensemble Kalman filter and GSI", JGR, 2012, (pending minor revisions)

Slides provided by Mariusz Pagowski, NOAA/ESRL

Rapid growth of Pattern RMSE and reductions in correlation after assimilation points to the limitations of applying a simple aerosol parameterization such as GOCART for predicting air quality over the Continental US. (Verification for 0-6hr forecasts)

Vertical profile of $PM_{2.5}$ increment and potential temperature





Evaluation statistics calculated during June-July 15, 2010 demonstrate the advantage of EnKF over 3D-VAR

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❑Current research directions
- Links between aerosols and severe weather (preliminary results)

Model Description

1. Online global chemical and aerosol assimilation/ forecasting system

2. UW-Madison hybrid θ–η 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 (OI) assimilation system developed by James Stobie (NASA/GFSC)

RAQMS has been used to support airborne field missions [Pierce et al, 2003, 2007, 2008], develop capabilities for assimilating satellite trace gas and aerosol retrievals [Pierce et al., 2007, 2008, Fishman et al., 2008, Sunita et al., 2008] and assess the impact of global chemical analyses on regional air quality predictions [Song et al., 2008, Tang et al., 2008]

Forward model:

$$AOD = \sum_k \sum_i q_{ik} \beta_{ik} dz, \quad q_{ik} \beta_{ik} = \mathbf{ext}_{ik}$$

where q_{ik} is the mass mixing ratio and β_{ik} is the mass specific extinction of aerosol species i at the vertical level k. dz is the thickness of the layer. The mass specific extinction is a function of the local relative humidity.

Inverse model:

1) Obtain new extinction for each species

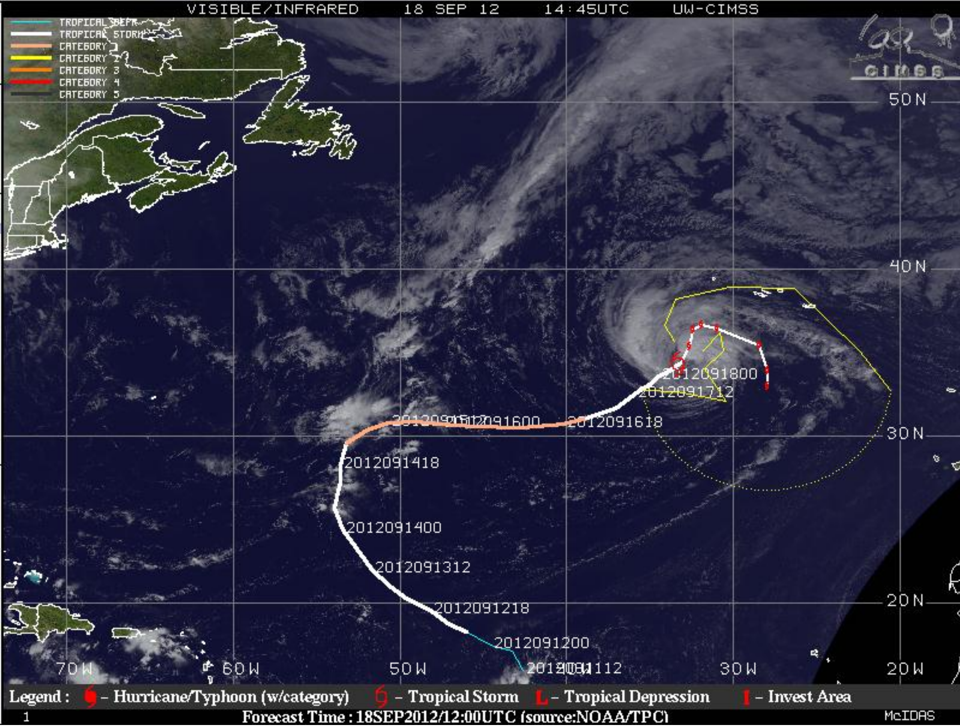
$\mathbf{ext\_new}_{ik}\mathbf{=ext\_guess}_{ik}\mathbf{+aodinc}_{i}\mathbf{*ext\_guess}_{ik}\mathbf{/aod\_guess}_{i}$

2) Obtain new dry mass for each species based on mass extinction coefficient

$\mathbf{totalmass\_new=ext\_new}_{ik}\mathbf{/mass\_ext}_{ik}$

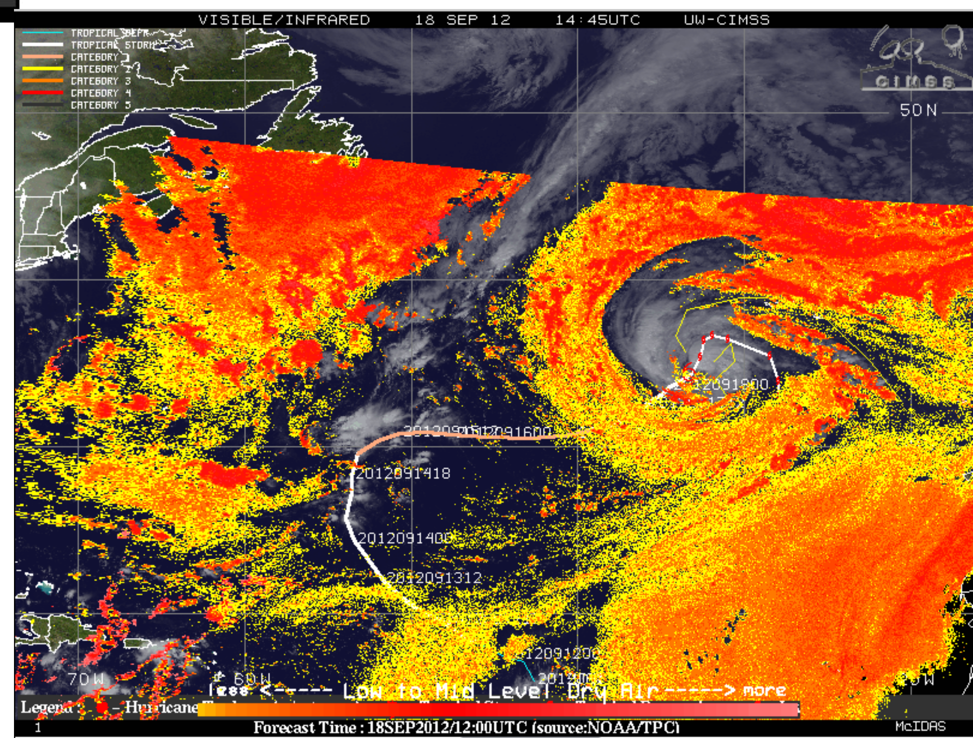
Effects of hydroscopic growth on aerosol extinction are linear with respect to mass

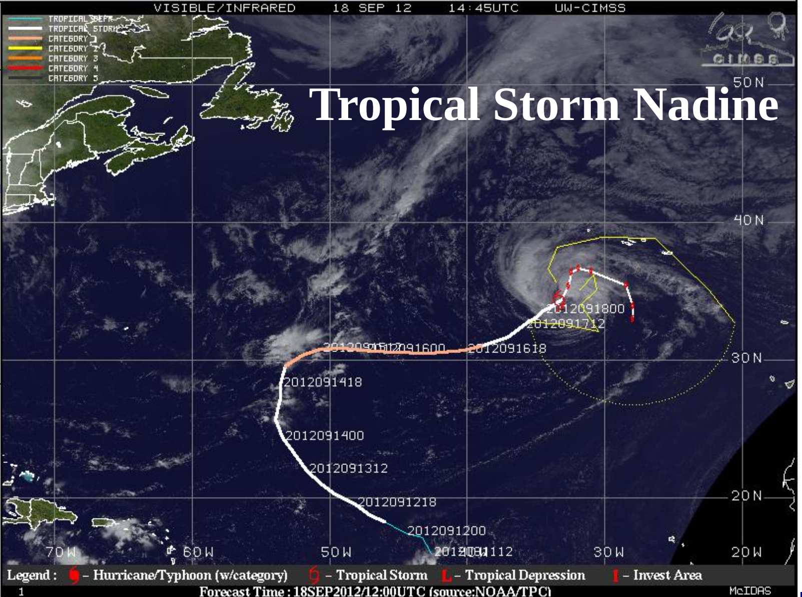
Saharan Dust Forecast Illustration

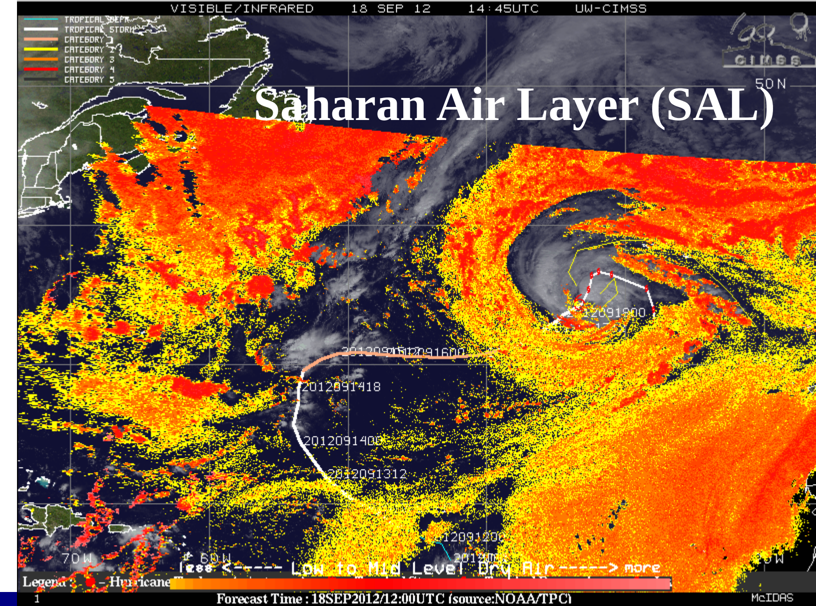


Tropical Storm Nadine
12Z Sep 18th, 2012
Track shown from 12Z 09/11

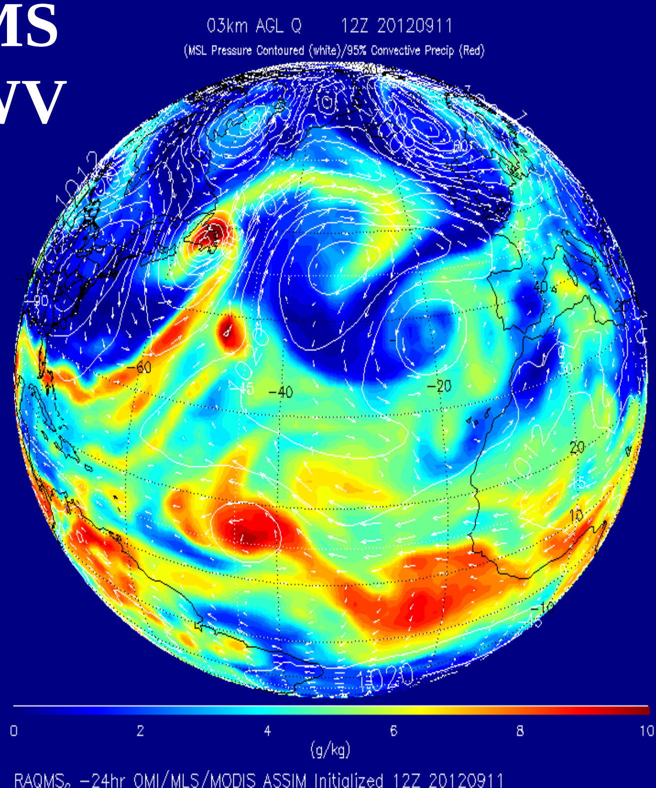
Saharan Air Layer (SAL)



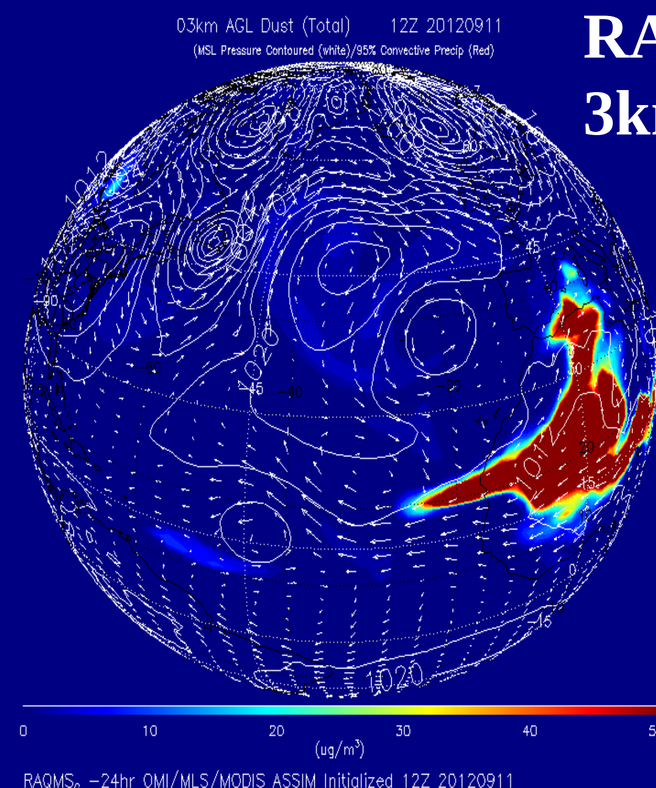


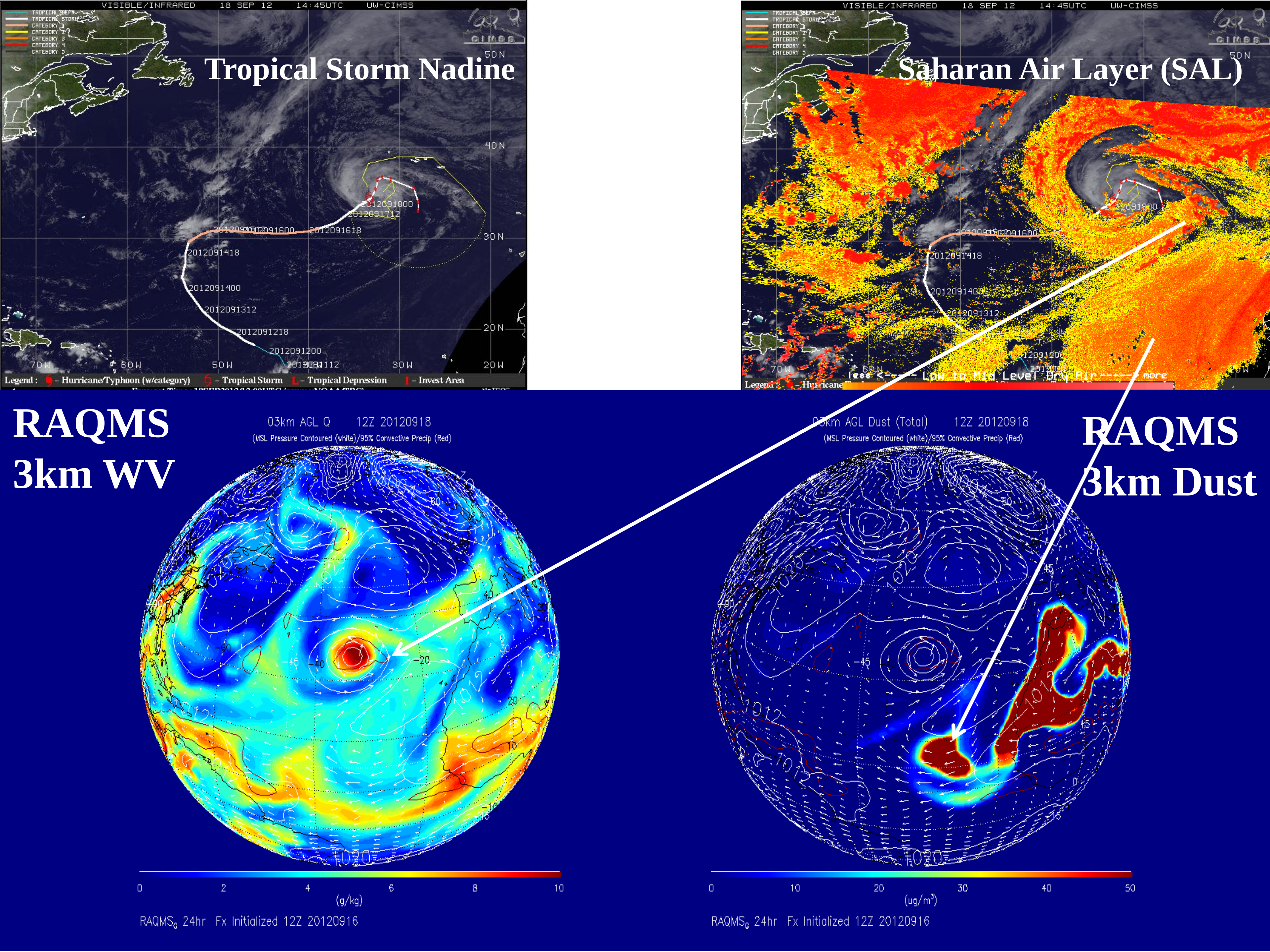


RAQMS
3km WV



RAQMS
3km Dust




VISIBLE/INFRARED 18 SEP 12 14:45UTC UW-CIMSS
Tropical Storm Nadine
Saharan Air Layer (SAL)
Legend : - Hurricane/Typhoon (w/category) - Tropical Storm - Tropical Depression - Invest Area
Low to Mid Level Dry Air
RAQMS
3km WV
RAQMS
3km Dust
03km AGL Q 12Z 20120918
(MSL Pressure Contoured (white)/95% Convective Precip (Red)
03km AGL Dust (Total) 12Z 20120918
(MSL Pressure Contoured (white)/95% Convective Precip (Red)
0 2 4 6 8 10
(g/kg)
0 10 20 30 40 50
(ug/m³)
RAQMS₀ 24hr Fx Initialized 12Z 20120916
RAQMS₀ 24hr Fx Initialized 12Z 20120916

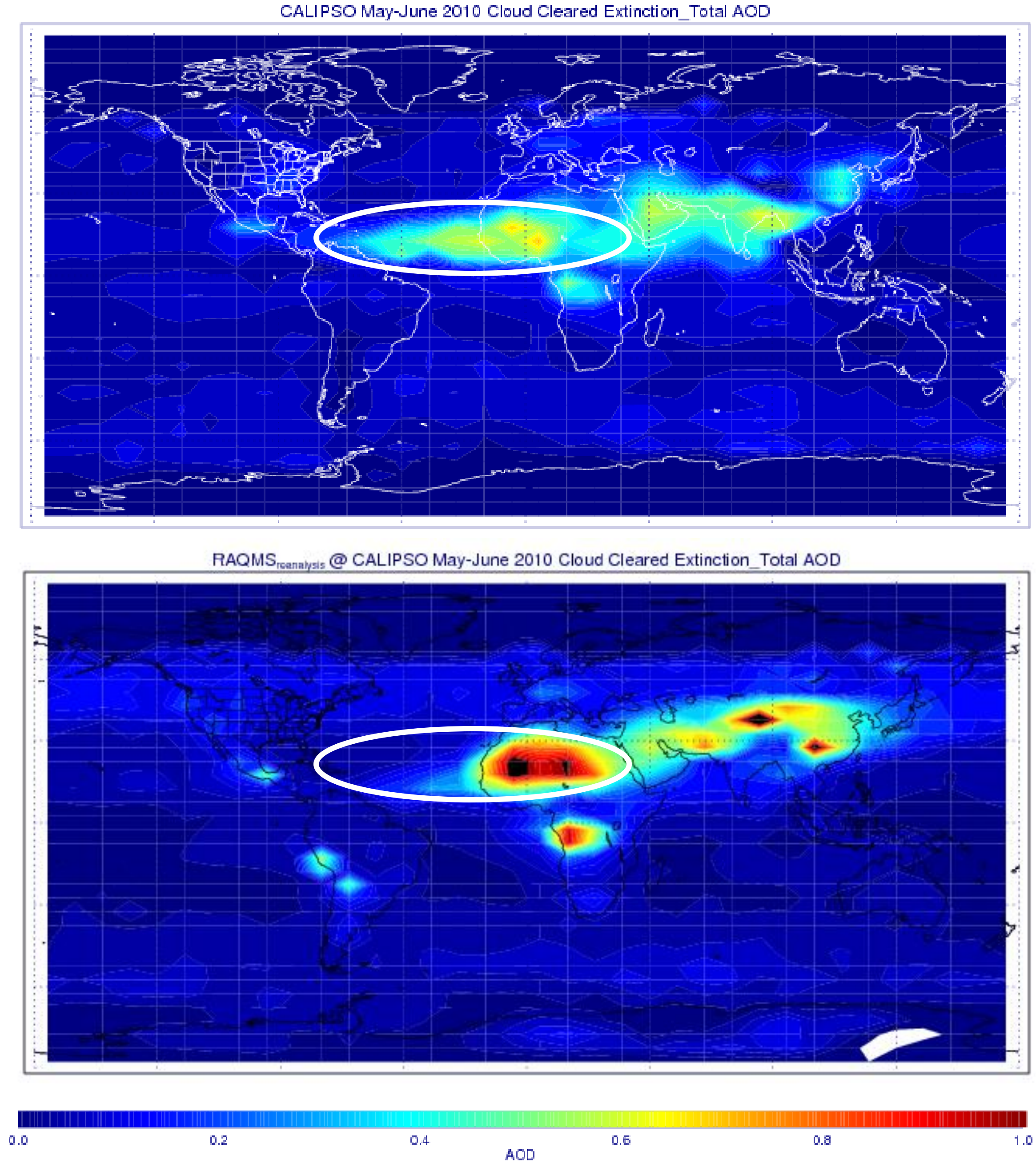
CALIPSO and Co-located RAQMS AOD May-June 2010

V3-01 aerosol profile retrievals
5° Lat, 10° Lon, 1km bins
CAD< -20, COT=0.0
QC=0,1 (unadjusted retrievals)

Clear sky CALIPSO scenes are dominated by Saharan Dust and South Asian emissions during May-June 2010

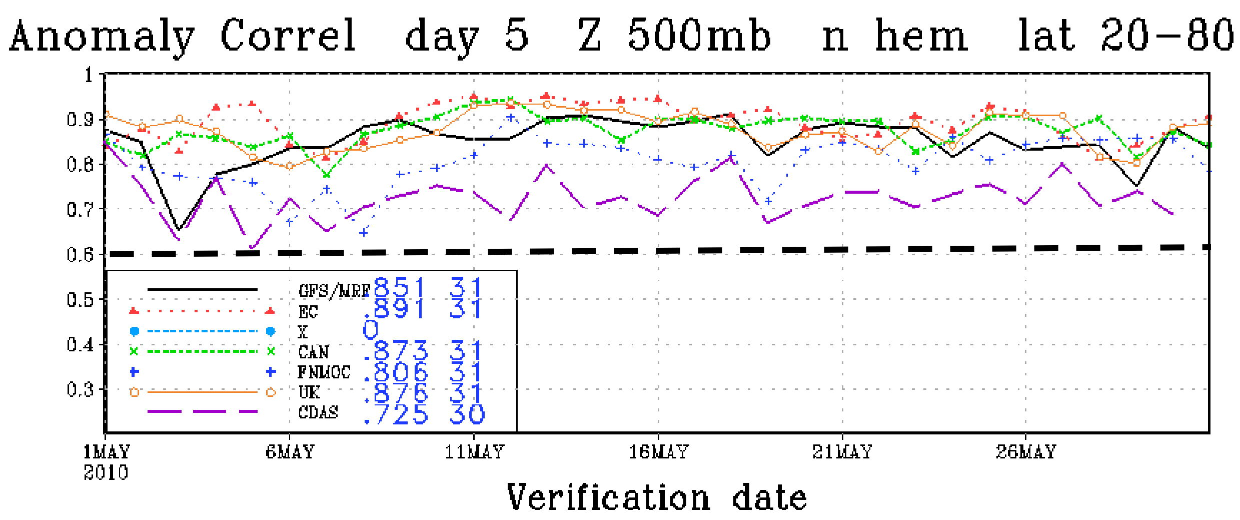
RAQMS overestimates Saharan Dust and SE Asian and S African biomass burning AOD over source regions relative to CALIPSO during May-June 2010

RAQMS underestimates Saharan Dust transport over Equatorial Atlantic during May-June 2010



Assessment of RAQMS (2x2) Global 850mb Aerosol Extinction Forecast Skill

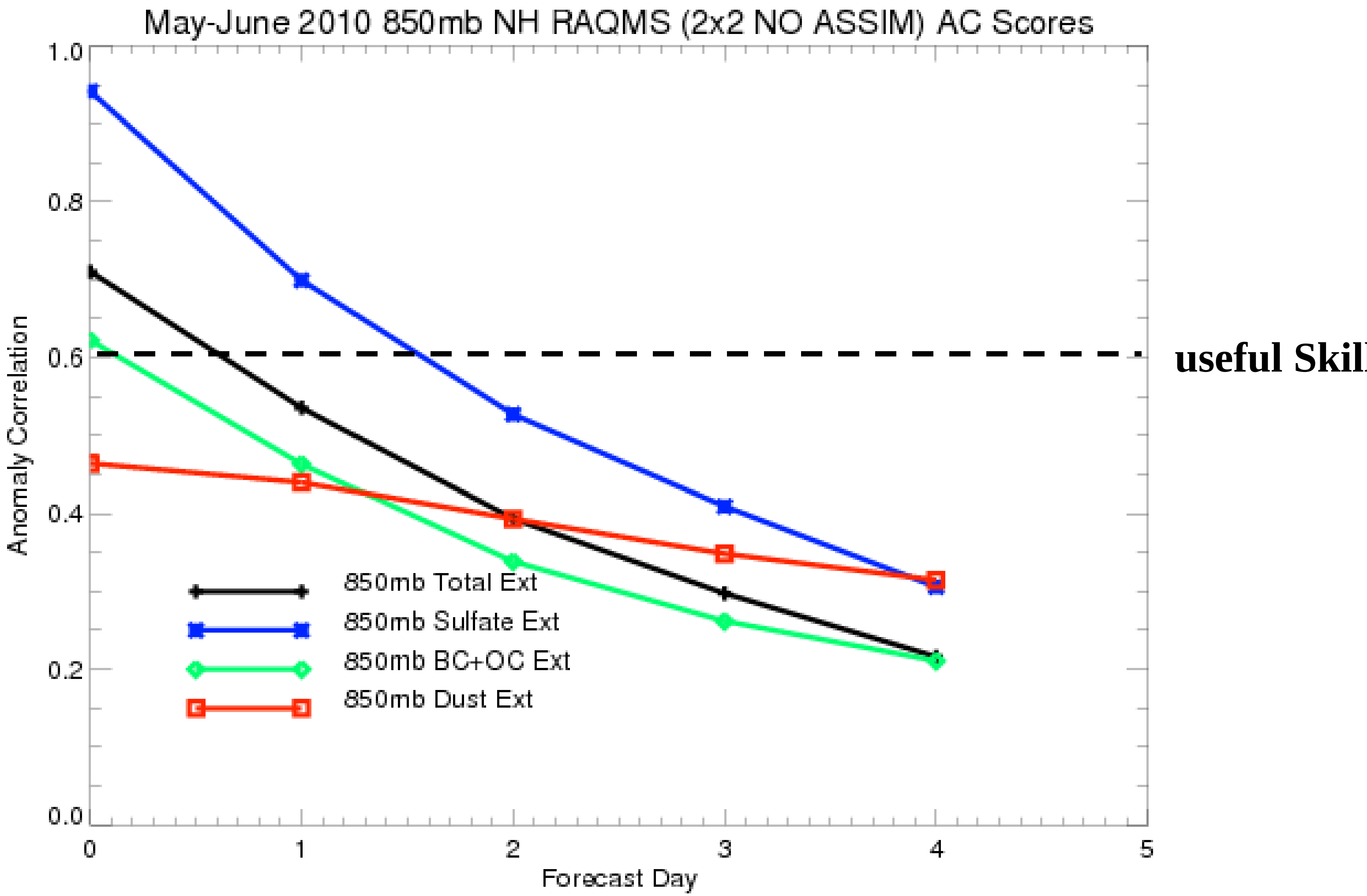
- Anomaly Correlations (AC)
  - Correlation between forecast and analysis
  - May-June mean removed
  - Spectrally truncated to wavenumber 20
  - Averaged from 20N-80N



useful Skill

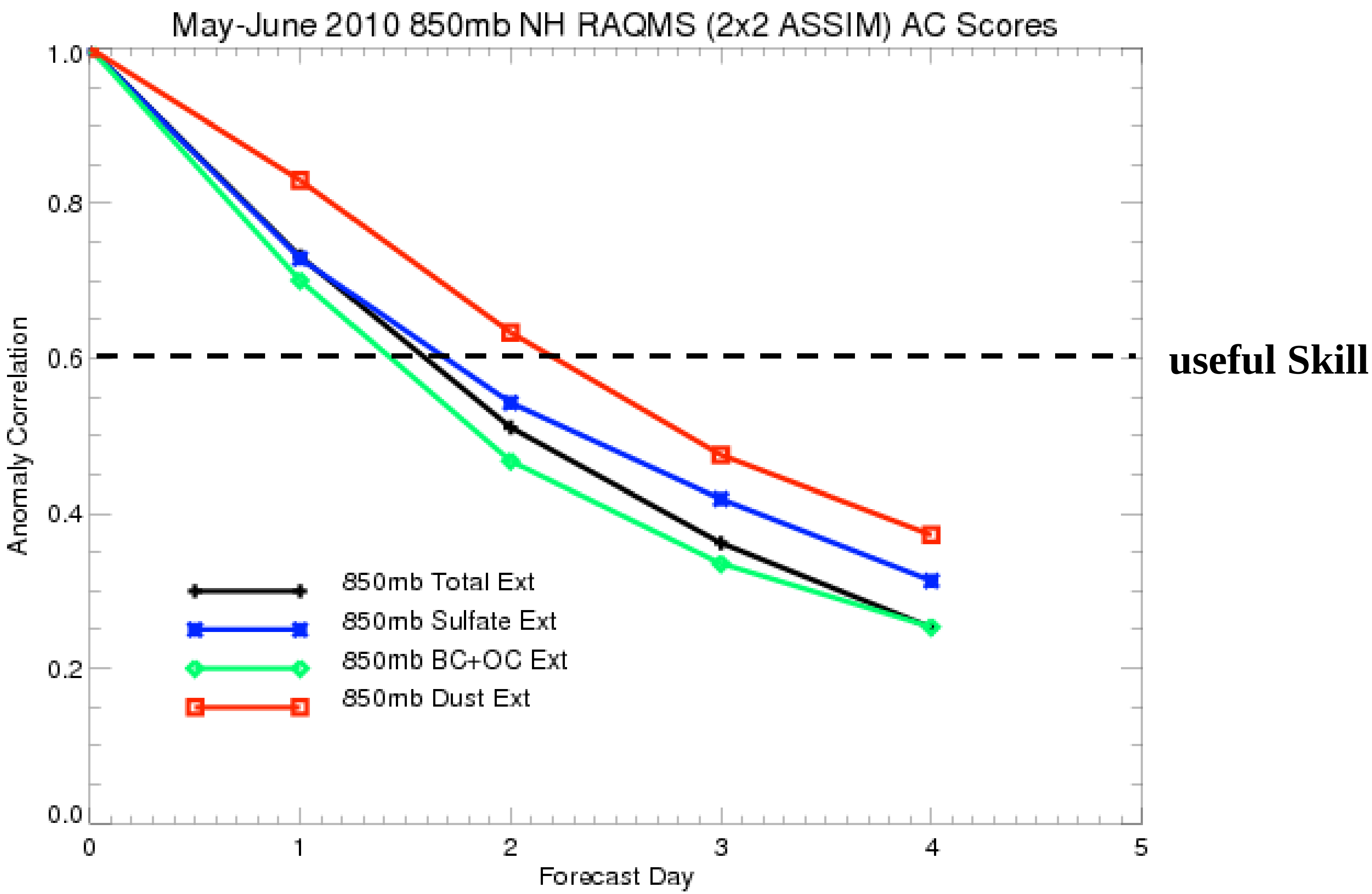
http://www.emc.ncep.noaa.gov/gmb/STATS/html/monarch.html

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



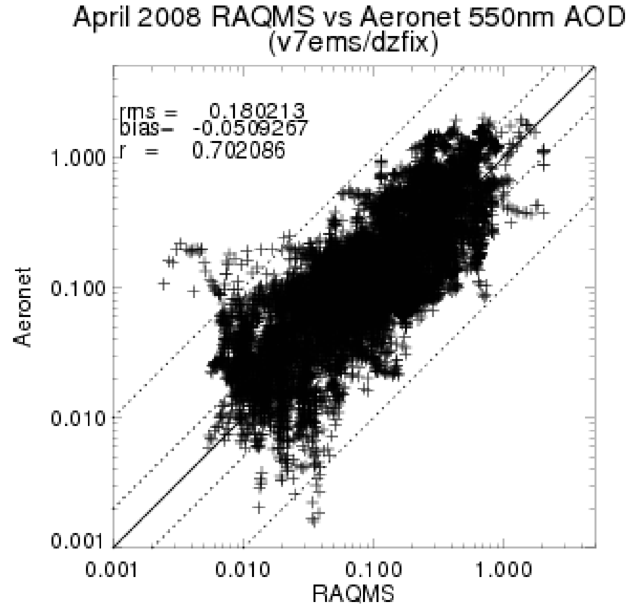
- Only 850mb SO4 extinction forecasts useful skill past 1 day
- Black and organic carbon (BC+OC) and dust extinctions are both poorly initialized and forecasted

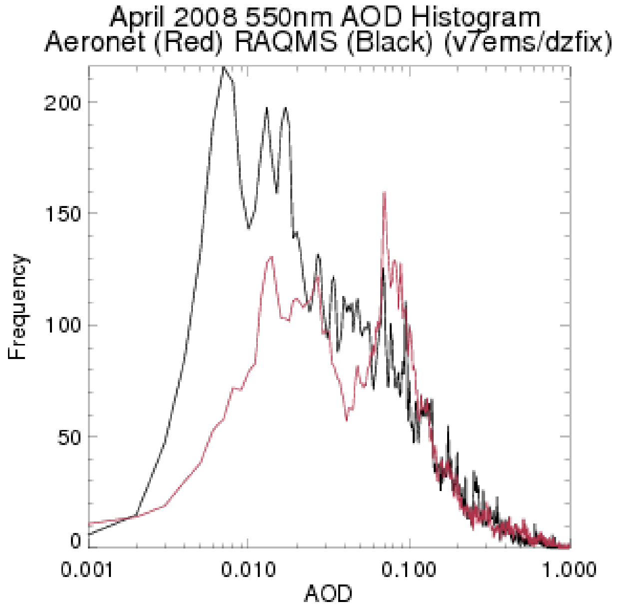
Northern Hemisphere 850mb May-June 2010 Anomaly Correlations (AC)
(With MODIS Assimilation)

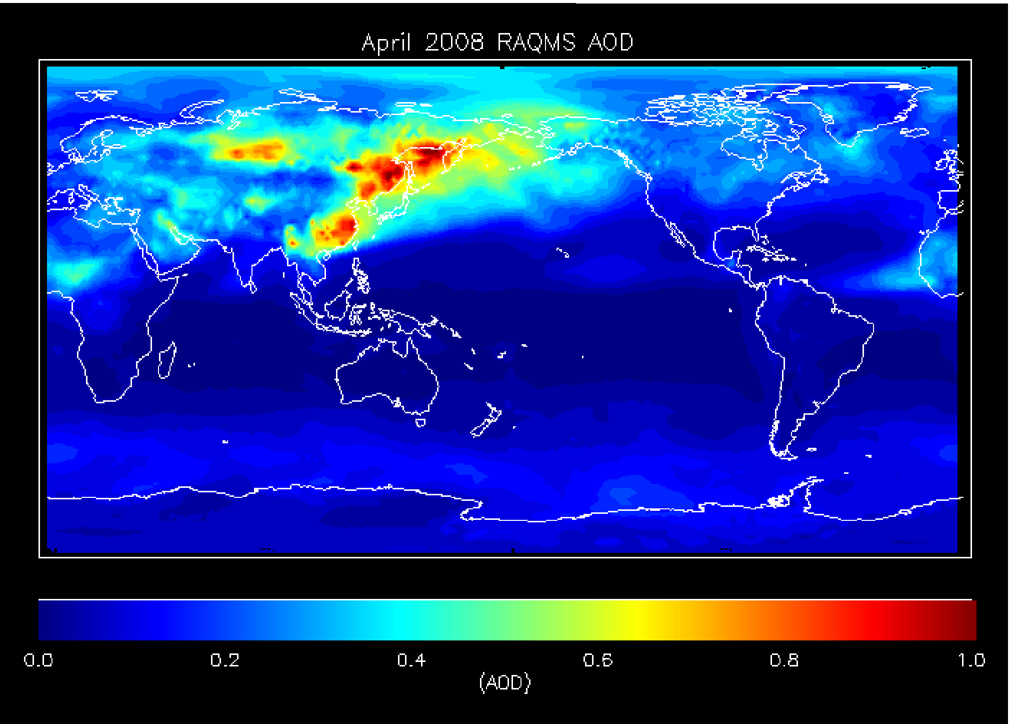


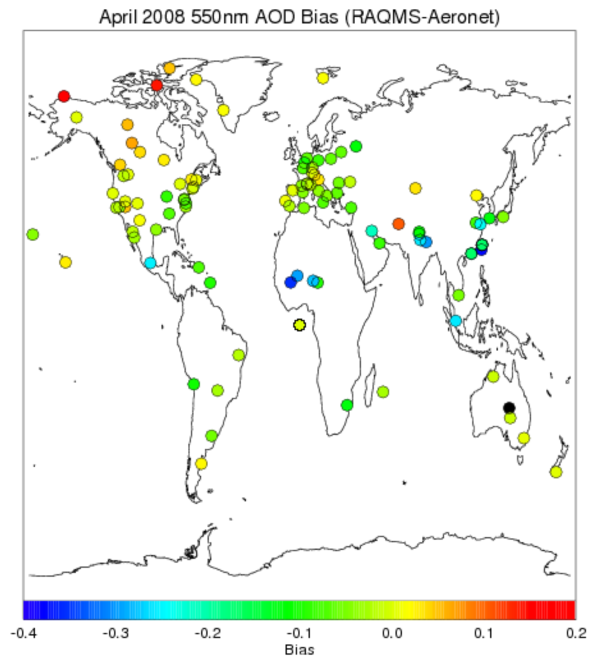
•MODIS AOD assimilation results in small changes in 850mb SO4 extinction forecasts
•MODIS AOD assimilation results in significant improvements in black and organic carbon (BC+OC) and dust forecast skill (dust prediction useful at 2 days)

RAQMS Aeronet Validation April 2008

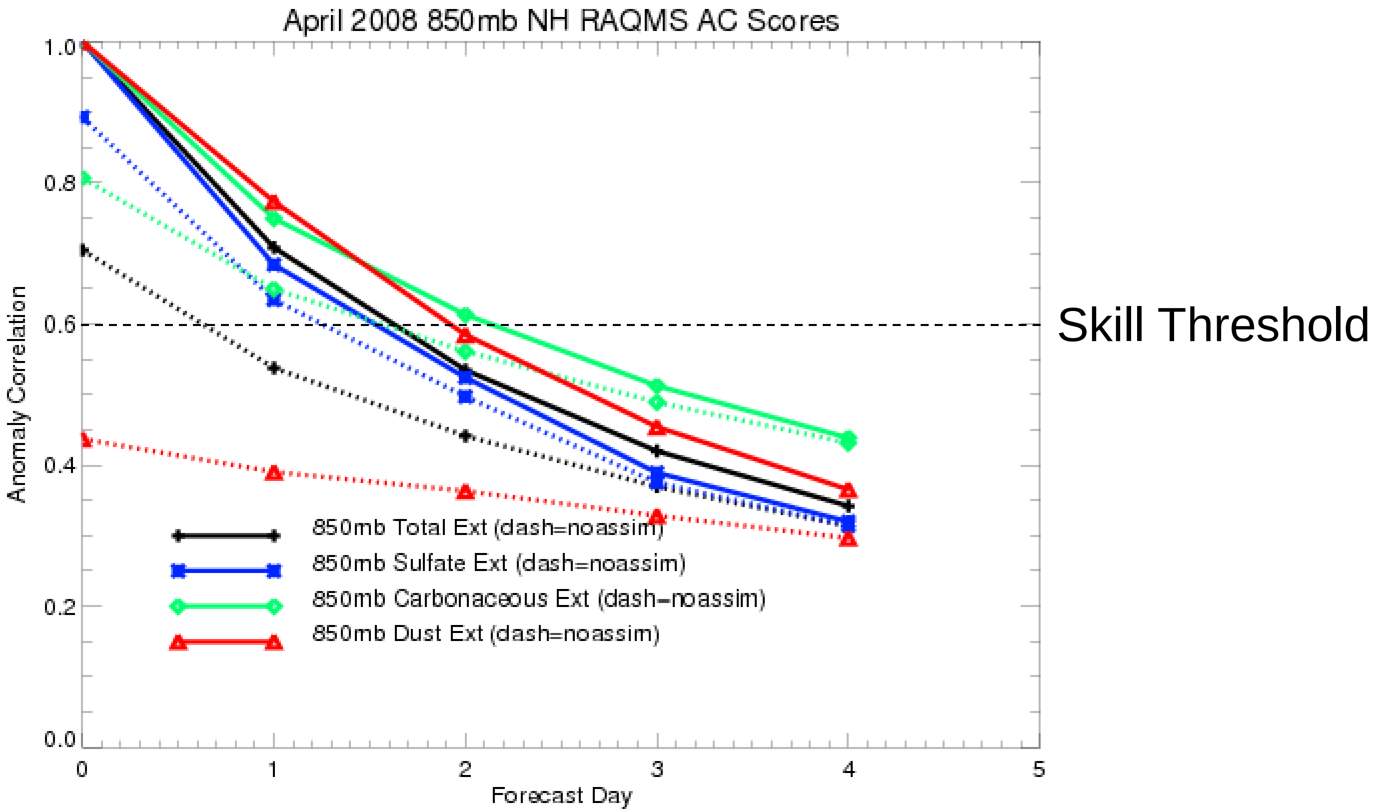






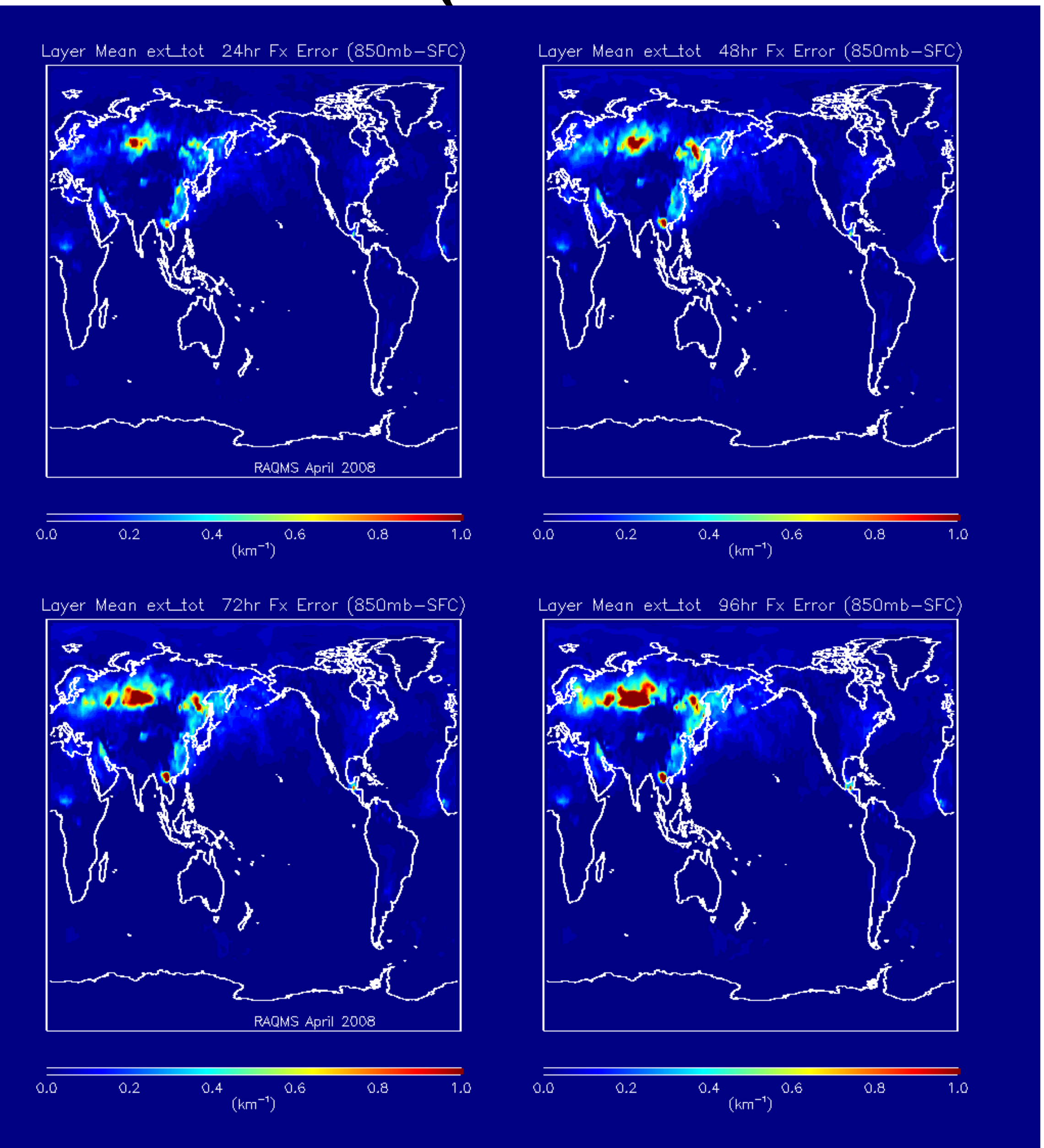


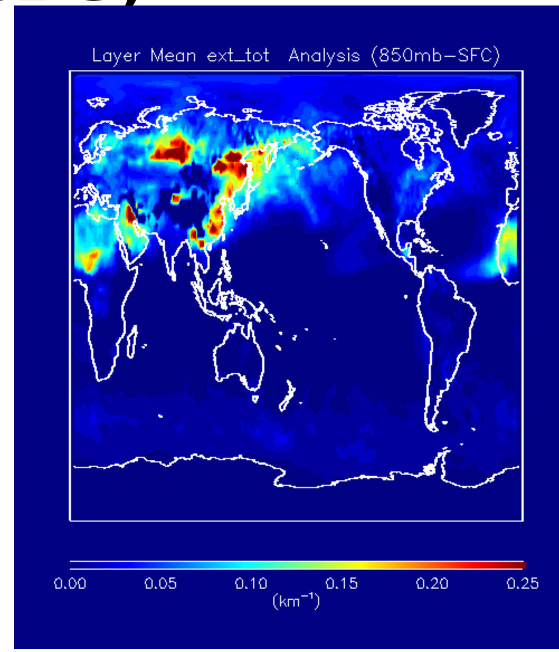
RAQMS (2.0x2.0) Global Aerosol Forecast Skill
(850mb with and without MODIS assimilation)



•**Carbonaceous and Dust extinctions are most significantly impacted by AOD assimilation**

RAQMS April 2008 Aerosol RMS Errors
(Total Extinction 850mb-SFC)





Large errors in Aerosol Extinction forecasts over Southern Siberia (Kazakhstand, Baykal) and S.E. Asia (Thailand)

Note: Fx error color scale is 4x mean extinction color scale!

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❑ Global Aerosol Forecast Skill Assessment

- CalNex (http://www.esrl.noaa.gov/csd/projects/calnex/)
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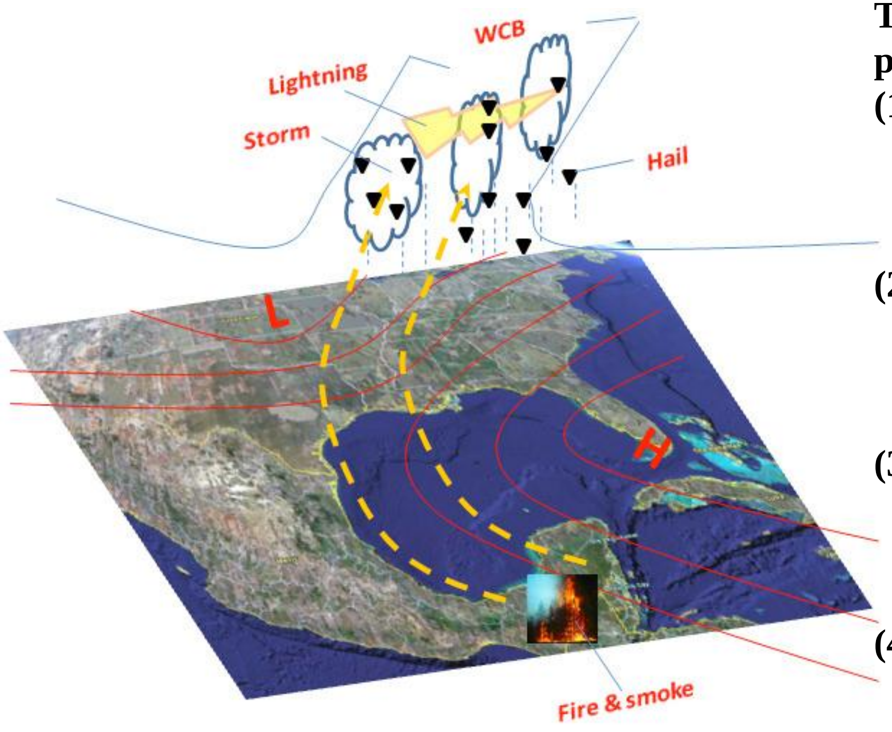
❑Current research directions

- Links between aerosols and severe weather (preliminary results)

A conceptual model for the link between Central American biomass burning aerosols and severe weather over the south central United States



The indirect aerosol mechanisms pertinent to smoke particles include:

(1) the first indirect effect, where the size of water cloud droplets decreases as smoke particles enhance the number of cloud condensation nuclei available for activation (Twomey 1974);

(2) the semi-direct (choking) effect, where absorption of solar radiation by smoke particles increases atmospheric stability and consequently suppresses the low-level cloud formation (Koren *et al* 2004);

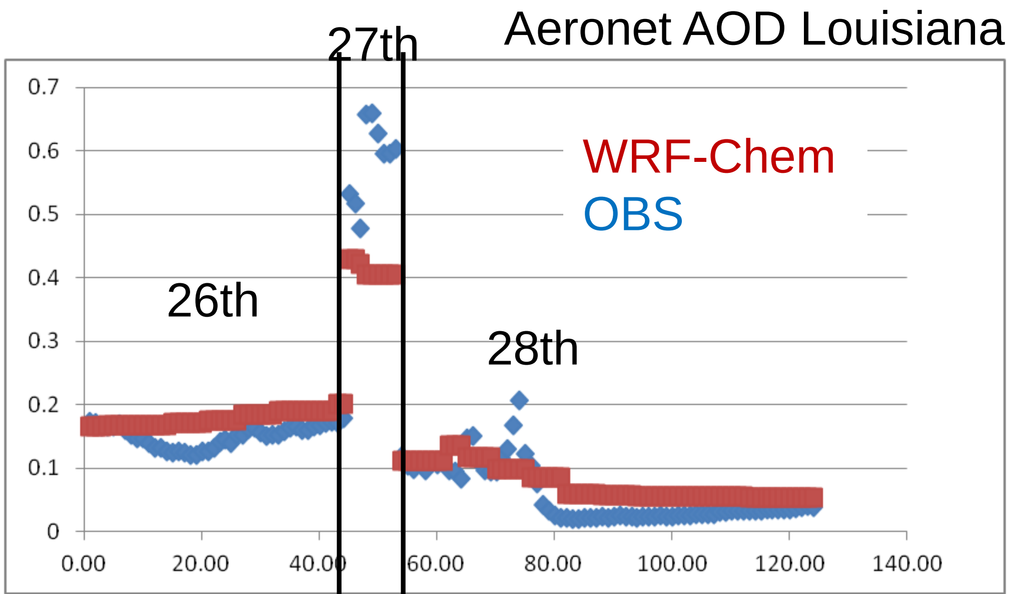
(3) the second indirect effect, where the smaller cloud droplets arising from the first indirect effect of smoke particles result in longer cloud lifetimes and larger cloud fractions (Albrecht 1989, Kaufman *et al* 2005);

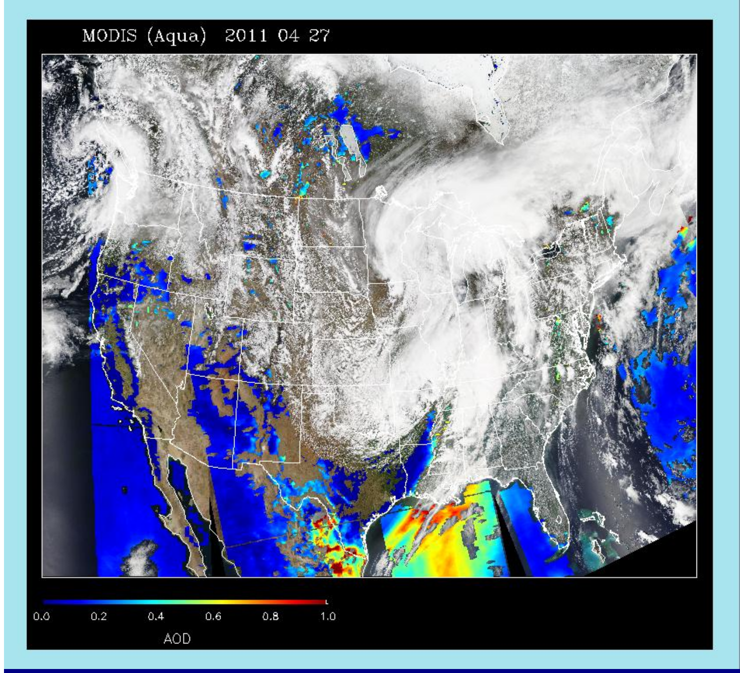
(4) the invigoration effect, where for strong convection storms the warm rain process is delayed by the smoke through its first and second indirect effects, which in turn allows for more cloud water to be transported vertically, a greater release of latent heat, and a subsequent invigoration of the updrafts, thus supporting the development of intense thunderstorms and large hail (Rosenfeld 1999, Andreae *et al* 2004, Lin *et al* 2006).

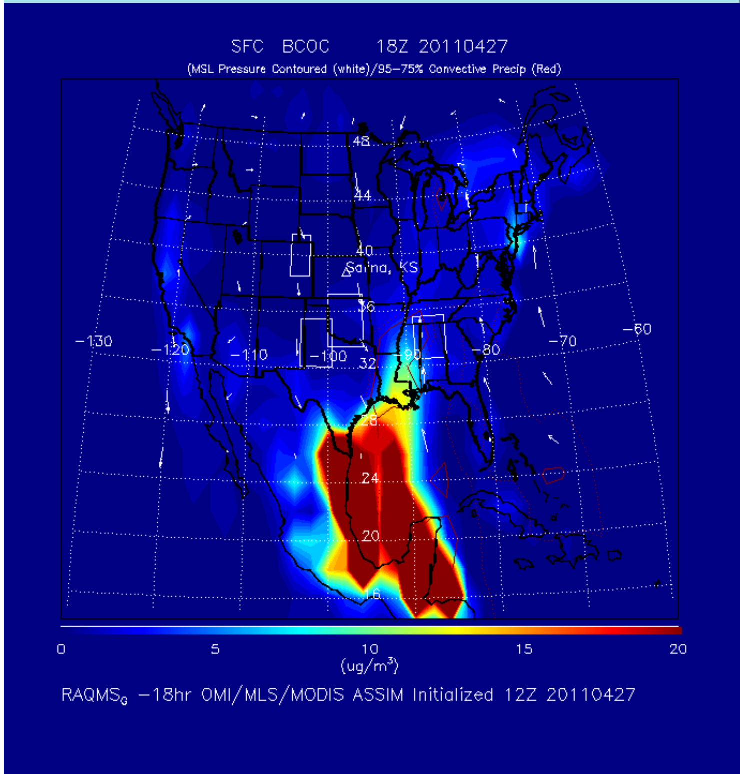
Wang et al, Environ. Res. Lett. **4** (2009) http://dx.doi.org/10.1088/1748-9326/4/1/015003

Case Study: Severe weather April 27th, 2011 (Huntsville tornado)

- MODIS aerosol optical depth (AOD) shows significant aerosol loading over Gulf within warm sector of storm
- RAQMS surface Black and Organic Carbon (BCOC) analysis shows highly elevated aerosols
- RAQMS used to initialize and provide lateral boundary conditions for 4km WRF-CHEM with explicit (MOSAIC) aerosol/cloud interaction



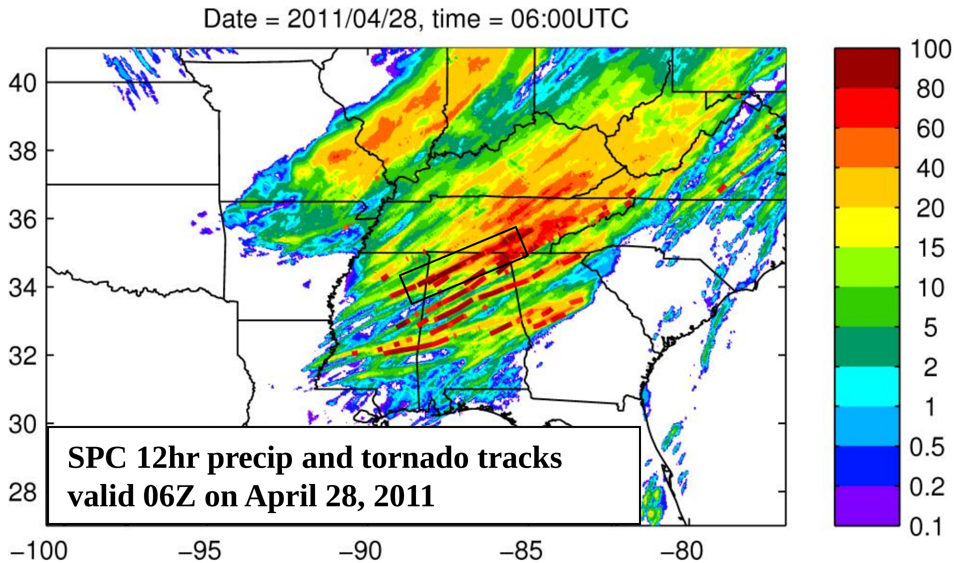


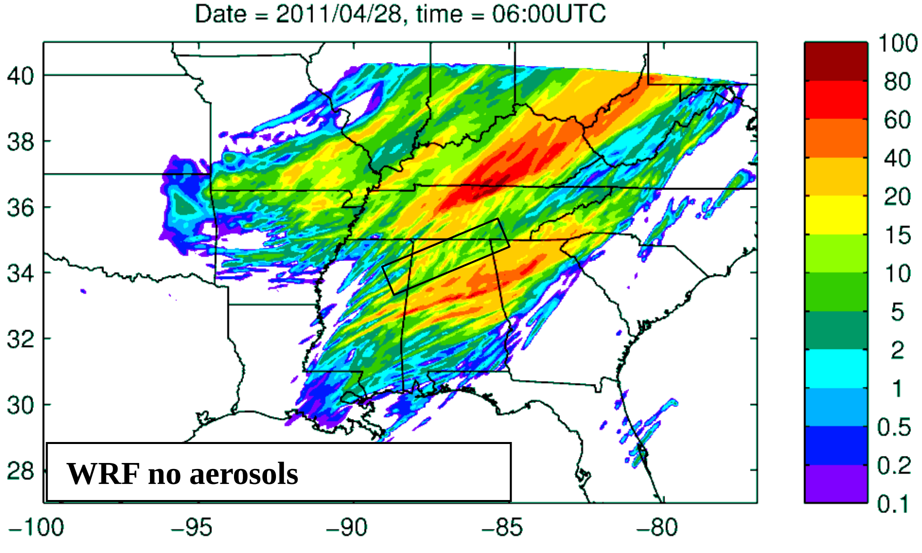


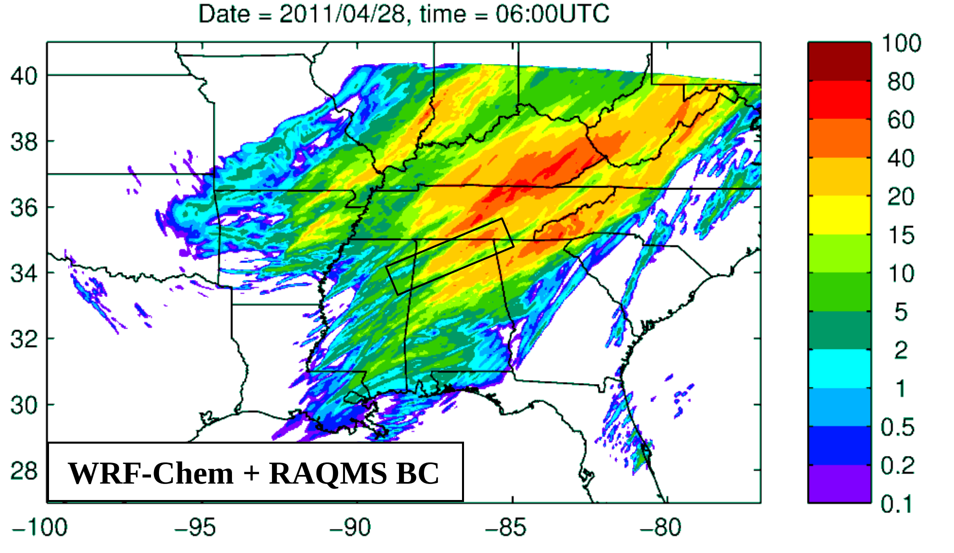
Case Study: Severe weather April 27th, 2011 (Huntsville tornado)

WRF-CHEM simulations conducted by Pablo Saide in collaboration with Greg Carmichael and Scott Spak (U-Iowa)

Inclusion of aerosol cloud interactions significantly impacts the predicted precipitation distribution and improves forecast over Huntsville, AL

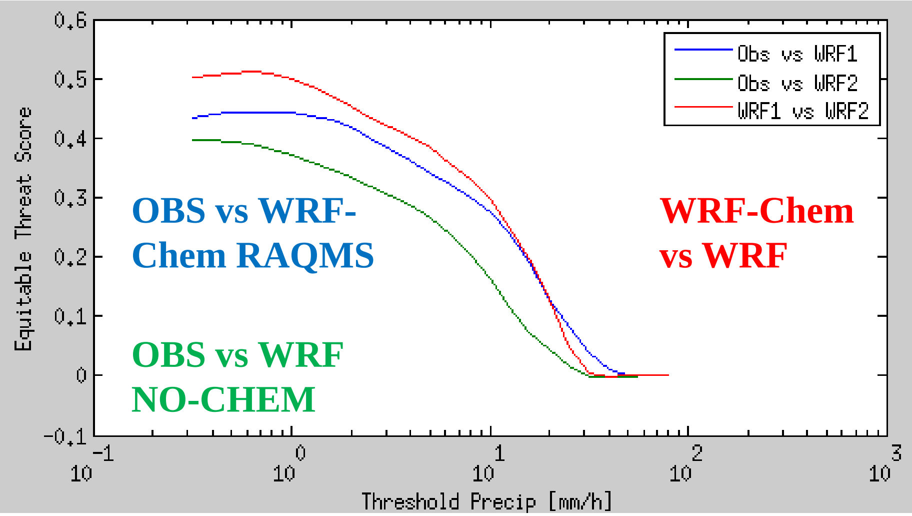




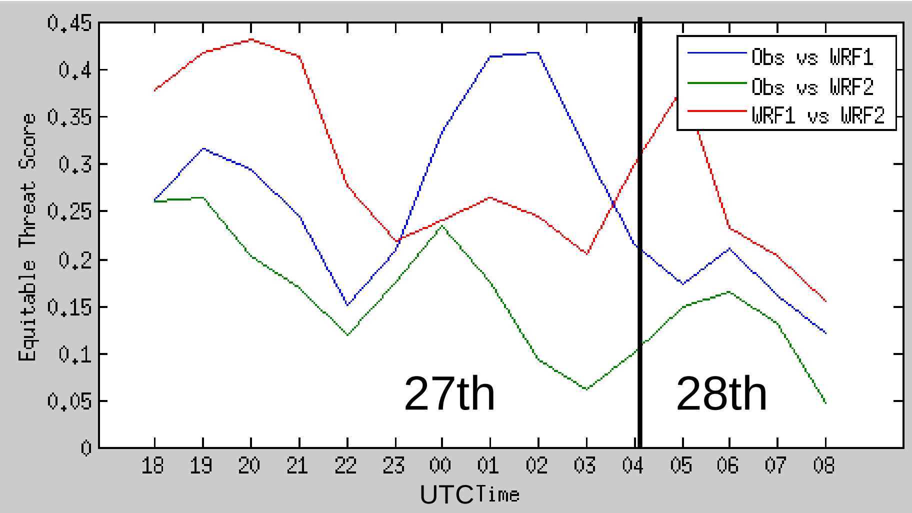


Precip. Obs vs WRF & WRF-Chem

Skill for 3h accum precip. vs different precip. thresholds



Skill for 3h accum. precip. over 10mm



- Simulations with and without aerosol effects yield very different precipitation fields
- Skill to represent observation is reduced for the larger precip. values
- There is improved skill when considering aerosol effects

International Cooperative for Aerosol Prediction (ICAP/AEROCAST)

- ICAP is an international forum for aerosol forecast centers, remote sensing data providers, and lead systems developers to share best practices and discuss pressing issues facing the operational aerosol community.

- Infrastructure and data protocols need to be developed between operational centers in order to fully support this emerging field.

- Participants include ECMWF, ESA, EUMETSAT, FNMOC, GMAO, JAXA, JMA, NCEP, NESDIS, NRL and NASA GMAO, LANCE,and LarC as well as several universities.

Aerosol Emission and Removal Processes: May 14 – 17, 2012, ESA/ESRIN, Frascati, Italy
Inquiries: Angela.Benedetti@ecmwf.int

Ensemble Forecasts and Data Assimilation: 11 - 13 May, 2011 Boulder, CO Inquiries: peter.r.colarco@nasa.gov

Model Verification: 30 September-1 October, 2010 Oxford England (Joint with 9th AEROCOM Workshop)
Inquiries: angela.benedetti@ecmwf.int

Aerosol Observability: 27-29 April, 2010 Monterey CA
Inquiries: jeffrey.reid@nrlmry.navy.mil

http://bobcat.aero.und.edu/jzhang/ICAP/

International Workshop on Air Quality Forecasting Research (IWAQFR)

- The goal of the International Workshop on Air Quality Forecasting Research (IWAQFR) is to provide a venue for the discussion of science issues and advancements related to air quality forecasting.

- Workshop objectives include improving operational air quality forecasts, promoting collaborations among air quality forecasting researchers and practitioners, and nurturing an international air quality forecasting community.

1st: 2-3 December 2009, NOAA David Skaggs Research Center, Boulder, Colorado
Sponsored by NOAA and Environment Canada (http://www.esrl.noaa.gov/csd/events/iwaqfr/)

2nd: 17-19 November 2010, Quebec City, Canada
Sponsored by Environment Canada's Meteorological Service

3rd: November 29 - December 1, 2011, Potomac, MD
Sponsored by NOAA, Environment Canada and WMO (http://www.arl.noaa.gov/IWAQFR_home.php)

4th: 12-14 December 2012, Geneva, Switzerland
Sponsored by WMO Global Atmosphere Watch (GAW): Urban research (http://www.wmo.int/pages/prog/arep/gaw/IWAQFR_4.html)

Thank you!

brad.pierce@noaa.gov

Extra Material

Development of Data Assimilation Capabilities for SEVIRI Volcanic Ash retrievals

With
Georg Grell (NOAA/ESRL)
Martin Stuefer (UAF)
Mike Pavolonis (NOAA/NESDIS)

As part of the NOAA Volcanic Ash Working Group (VAWG) Science Team we are testing assimilation of SEVIRI volcanic ash optical depth retrievals using WRF-CHEM/GSI.

WRF-CHEM Volcanic Ash Module

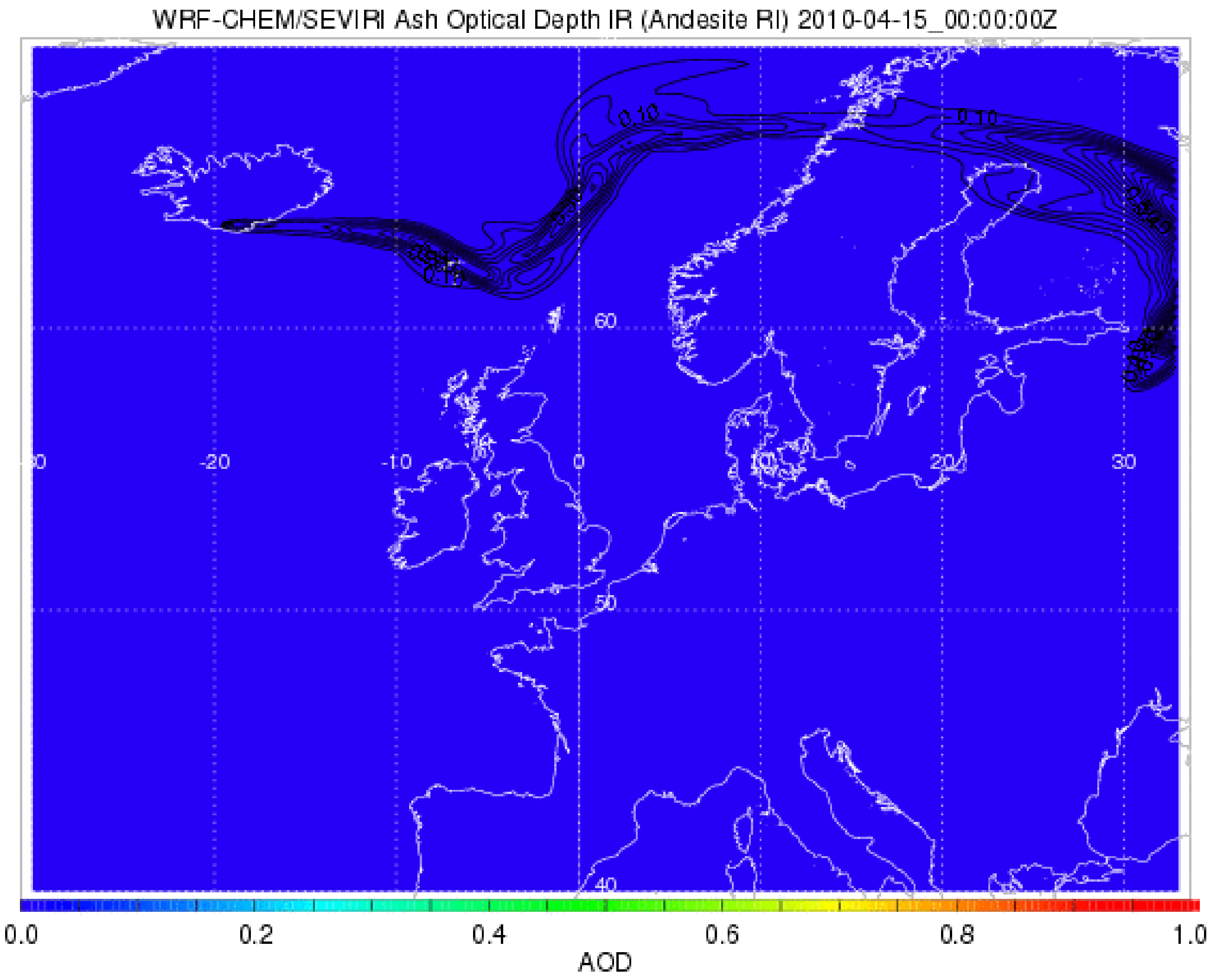
- **A 4-bin WRF-CHEM volcanic ash module developed by George Grell at Earth System Research Laboratory (ESRL) and Martin Stuefer at the University of Alaska, Fairbanks (UAF) is used in forecasting volcanic ash.**

Volcanic Ash Forecast Uncertainties

- **The mass estimates are estimated from the height of the erupted ash. For the Eyjafjatjalla case, eruption heights are constrained with radar data (~150 km from the volcano).**

- **There is high uncertainty with the erupted mass: A 500 meter offset in the height changes the total mass estimate by almost 60% for injection heights <5km.**

- **There is also high uncertainty in the assumed size distribution of the ash particles, which determines the plume lifetime.**



WRF-CHEM Volcanic Ash Forecast (contours) and SEVIRI 11 micron AOD (colored) during the 2010 Eyjafjoll eruption in southern Iceland.

GSI Volcanic Ash Assimilation

- **The OMI Total column ozone template is used for assimilation of SEVIRI volcanic ash retrievals within the Gridpoint Statistical Interpolation (GSI)**

- **SEVIRI 11 micron volcanic ash extinction is assimilated with modifications made for extinction instead of ozone**

- **11 micron AOD is computed within WRF-CHEM (updated with Andesite optical properties)**

Modified NMC method for Background Errors

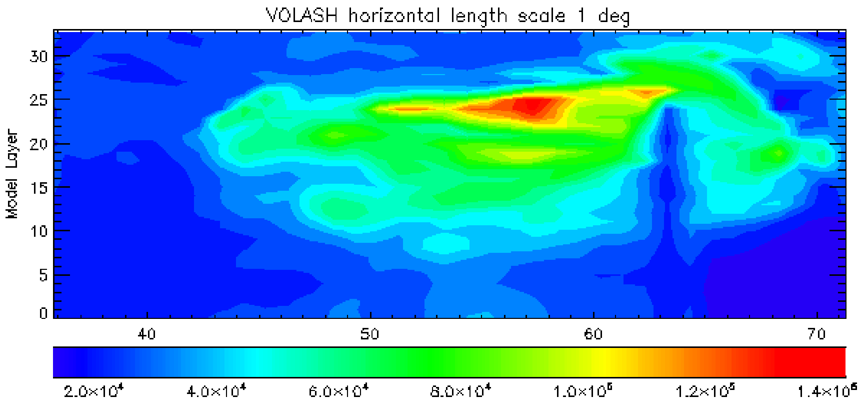
2 forecasts:

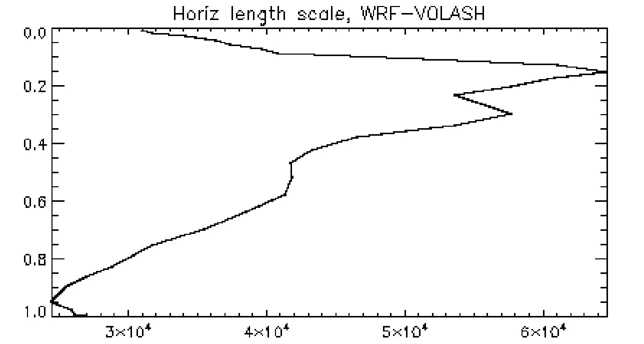
1) **emission heights 1.2 times larger than control experiment**
2) **emission heights 0.8 times higher than control**

Used differences between 00z April 14 to 00z April 19, 2010 hourly forecast (valid at same time) to build the statistics

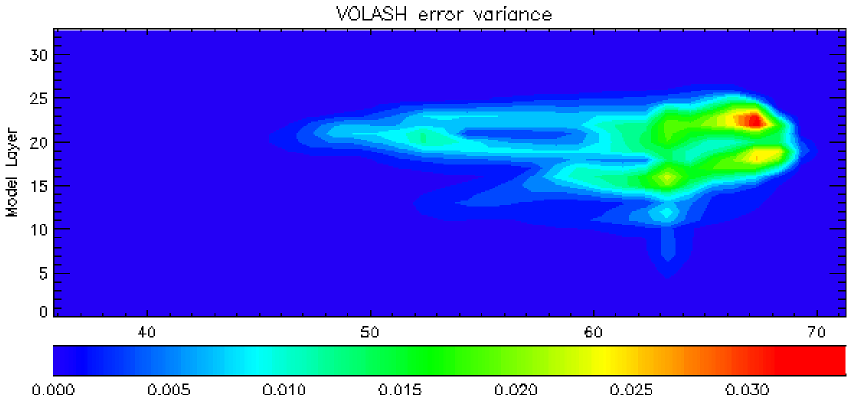
Cross section 35 – 72 N

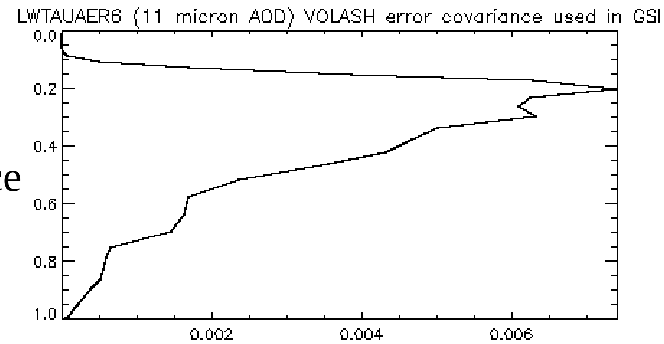
1-d



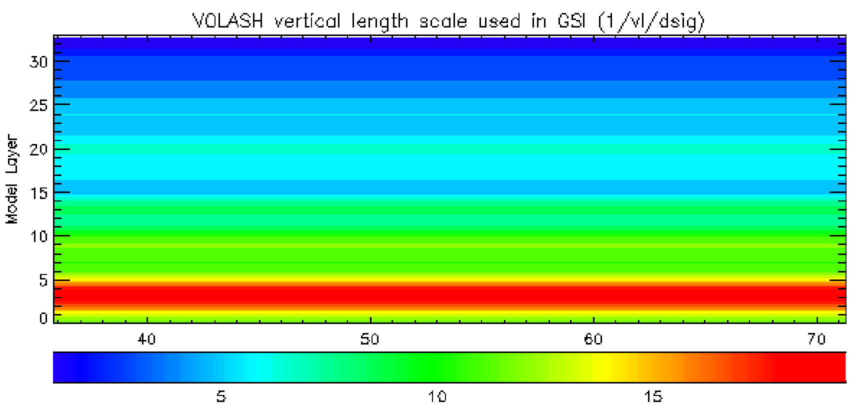


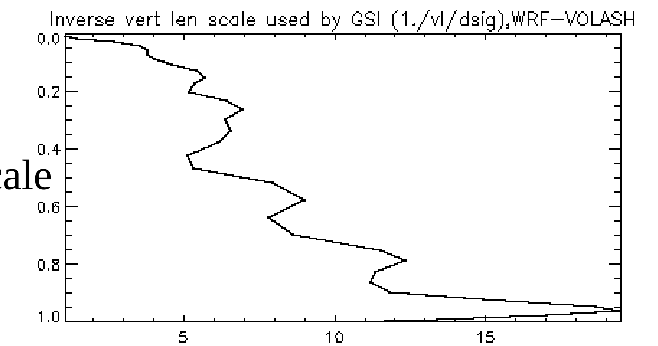
Horizontal
Length scale





Error covariance

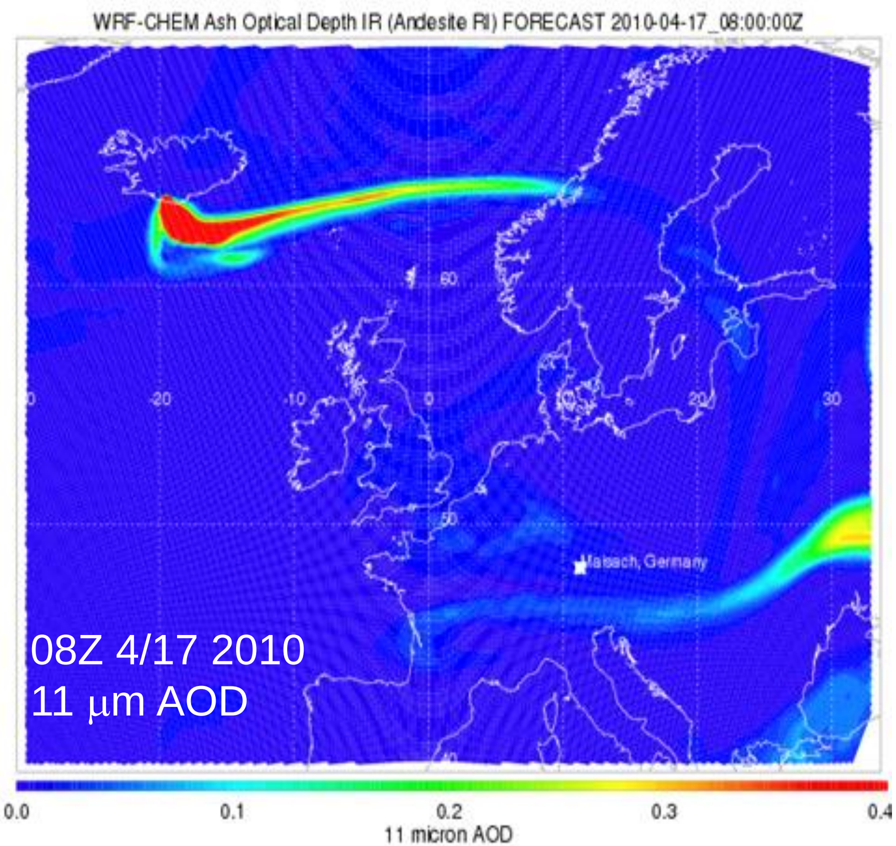




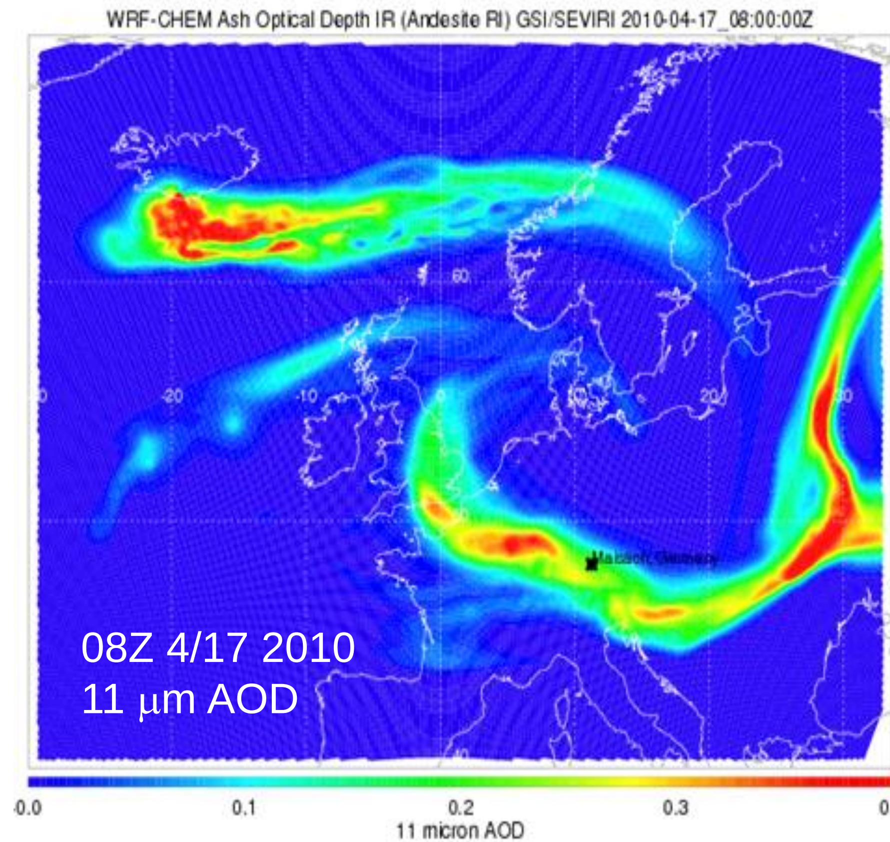
Vertical length scale
In GSI
(1/vl/dsig)

Results

WRF-CHEM Baseline



GSI/SEVIRI assimilation



Significant increase in 11 micron AOD for older plume with GSI/SEVIRI assimilation

Verification

Comparisons with RAMAN lidar measurements at Maisach, Germany show that maximum volcanic ash mass concentrations near the vicinity of the observed plume reached 3,226 mgm^{-3} in the GSI/SEVIRI assimilation experiment and only 155 mgm^{-3} in the baseline experiment. Gasteiger et al. [2011] estimated maximum volcanic ash mass concentrations of 1,100 mgm^{-3} (650 to 1,800 mgm^{-3}) at an altitude of 2.2km at 08Z on April 17, 2010.

Both experiments show an additional plume at 10km which is not observed.

Maisach 1064 nm aerosol backscatter