NOAA Satellite Science Week Virtual Meeting

Non-Convective Forecast Applications (Wed 9:00 - 11:05 am MDT)

Aerosol Data Assimilation and Forecasting – Volcanic Ash Prediction, Severe Storm Intensification, and Future TEMPO/GOES-R Synergies

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With Contributions from
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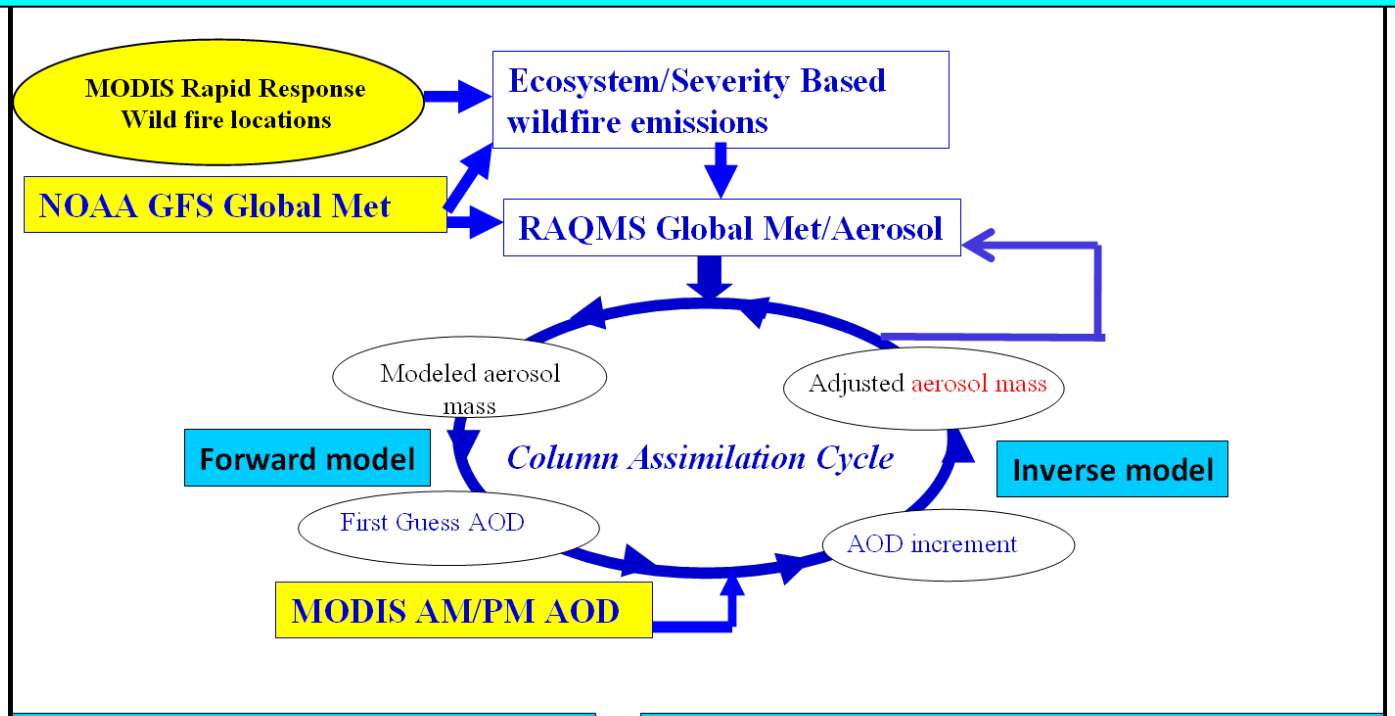
Georg Grell (NOAA/ESRL)
Martin Stuefer (University of Alaska-Fairbanks)
Mike Pavolonis (NOAA/NESDIS)
Kelly Chance (SAO)

18–22 March, 2013

Real-time Air Quality Modeling System (RAQMS)
Aerosol Optical Depth (AOD) Assimilation Procedure



Forward model:
Compute layer/species extinction based on tabulated extinction efficiency and hydroscopic growth factors

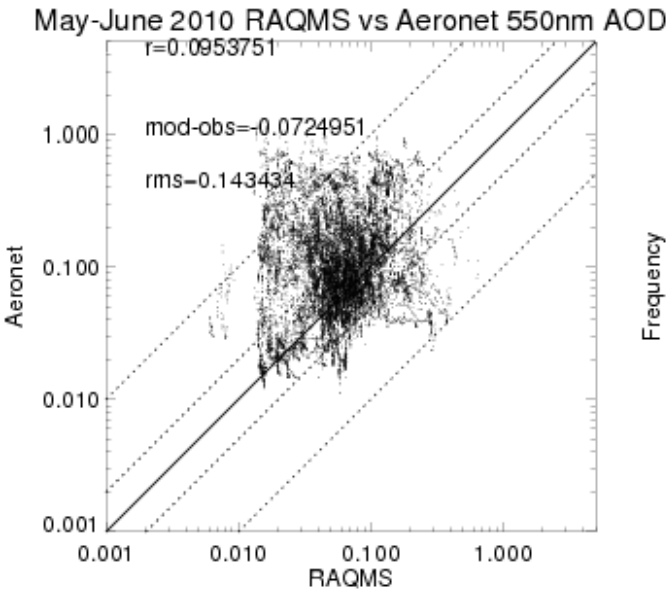
Inverse model:
Distribute total AOD increment across aerosol dry mass based on layer/species extinction accounting for extinction due to hydroscopic growth

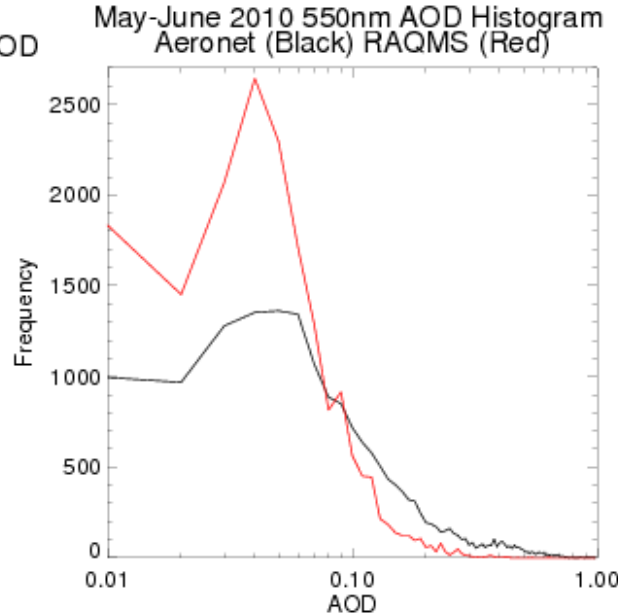
Forward model:

$$AOD = \sum_k \sum_i q_{ik} \beta_{ik} dz$$

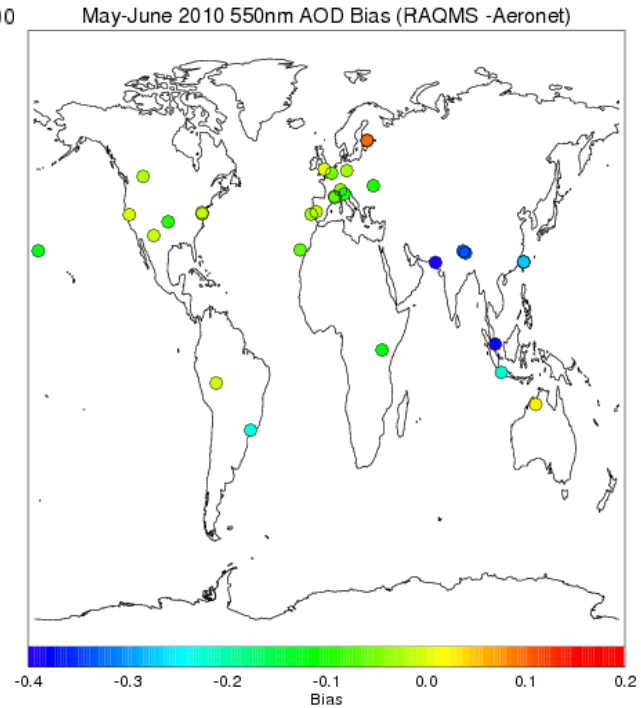
where q_{ik} is the mass mixing ratio and β_{ik} is the mass specific extinction of aerosol species i at the vertical level k. dz is the thickness of the layer. The mass specific extinction is a function of the local relative humidity.

Comparison with Level 2.0 Aeronet Measurements





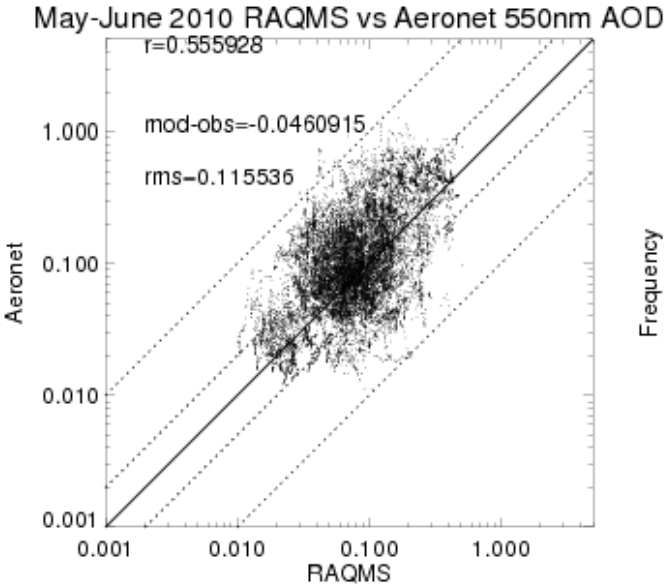
No MODIS Assimilation

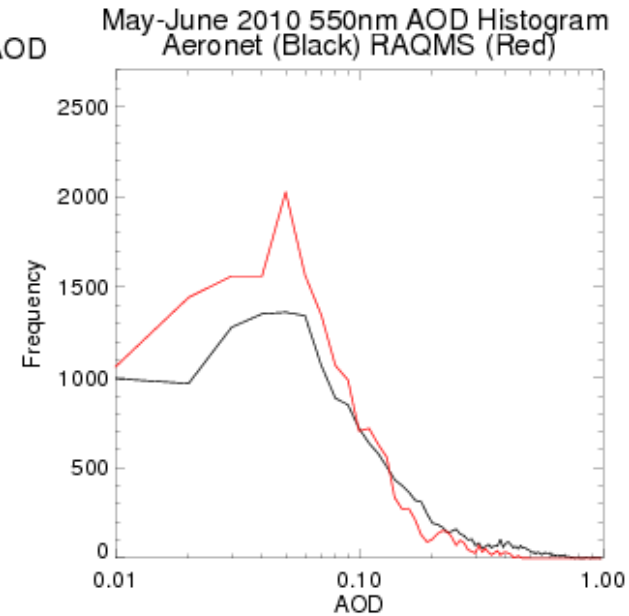


RAQMS (no assim) is not correlated with Aeronet AOD (r=.09) and underestimates clear-sky AOD by 0.07.

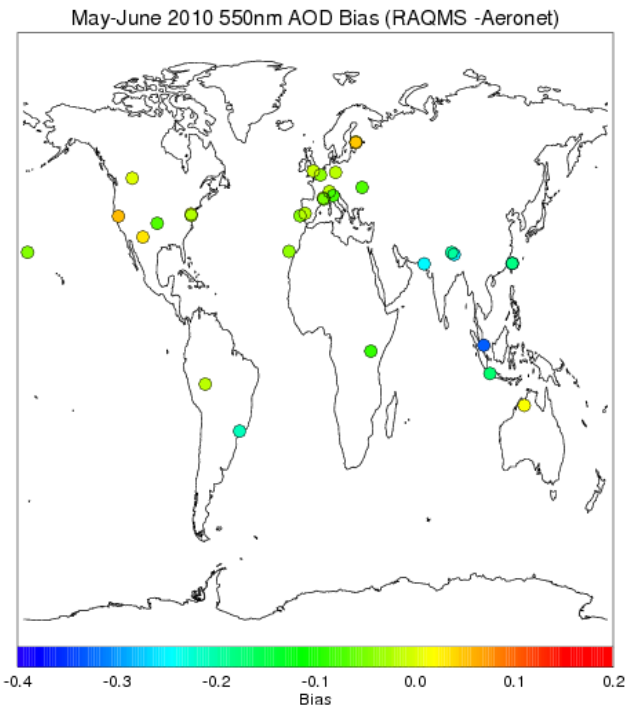
RAQMS (no assim) significantly overestimates the frequency of low AOD (<0.1) and significantly underestimates the frequency of high AOD (>0.1).

Comparison with Level 2.0 Aeronet Measurements





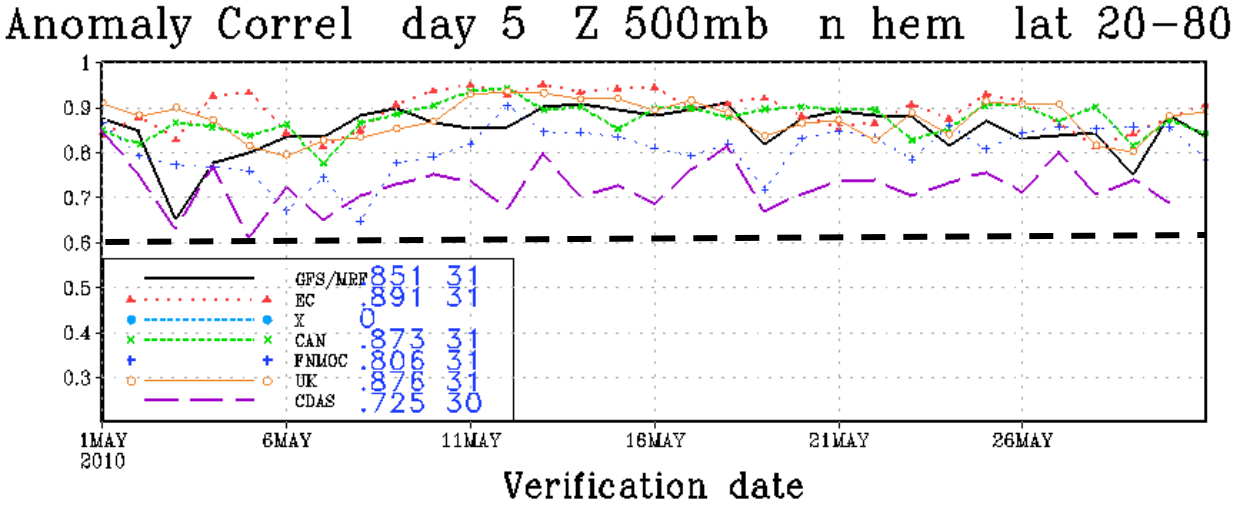
MODIS Assimilation



MODIS assimilation significantly improves correlation with Aeronet AOD (r=.56) and reduces the overestimates the frequency of low AOD (<0.1) and underestimates the frequency of high AOD (>0.1).

Assessment of Global 850mb Aerosol Extinction Forecast Skill – May-June 2010

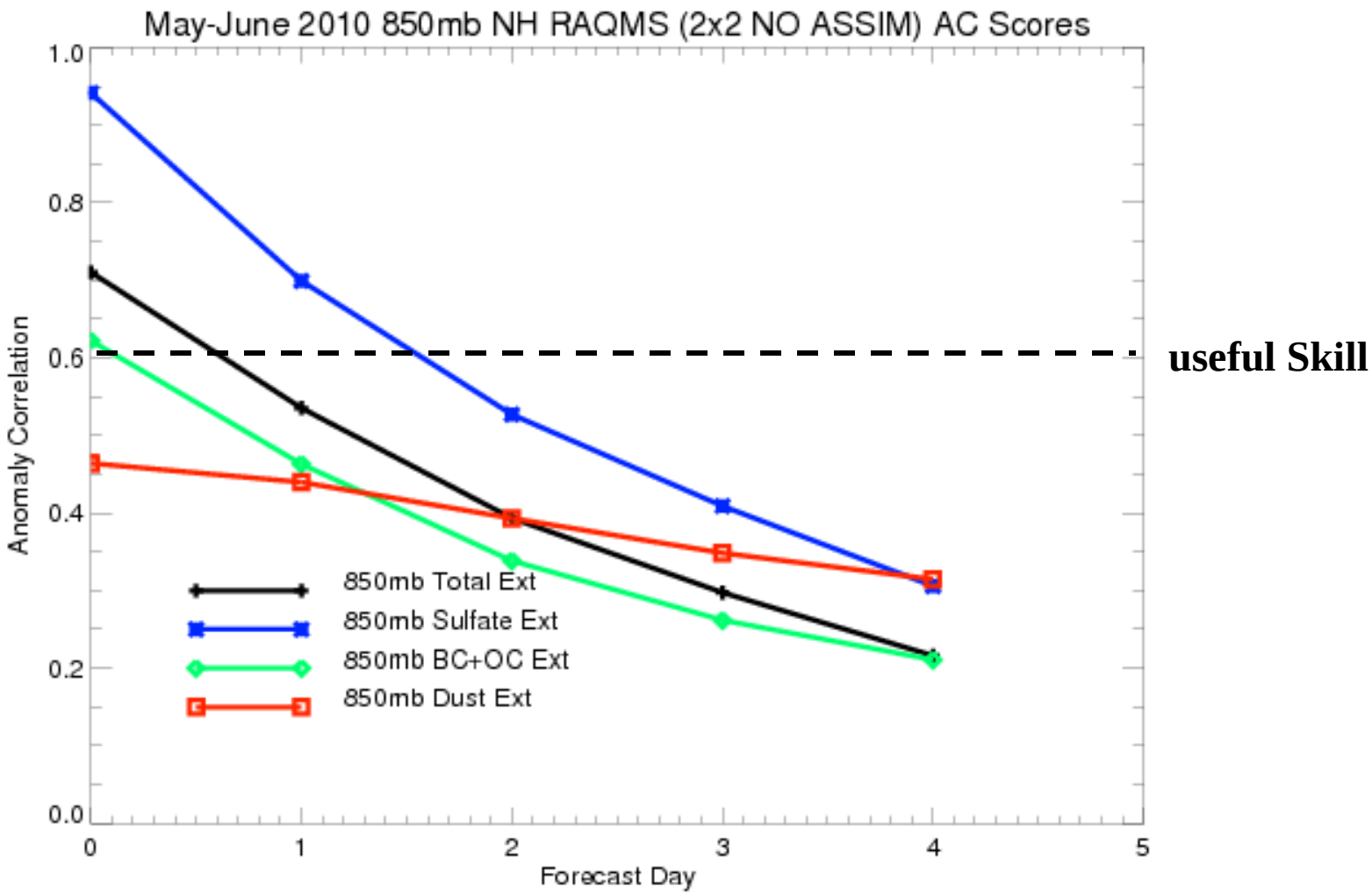
- Anomaly Correlations (AC)
  - Correlation between forecast and analysis
  - May-June mean removed
  - Spectrally truncated to wavenumber 20
  - Averaged from 20N-80N



useful Skill

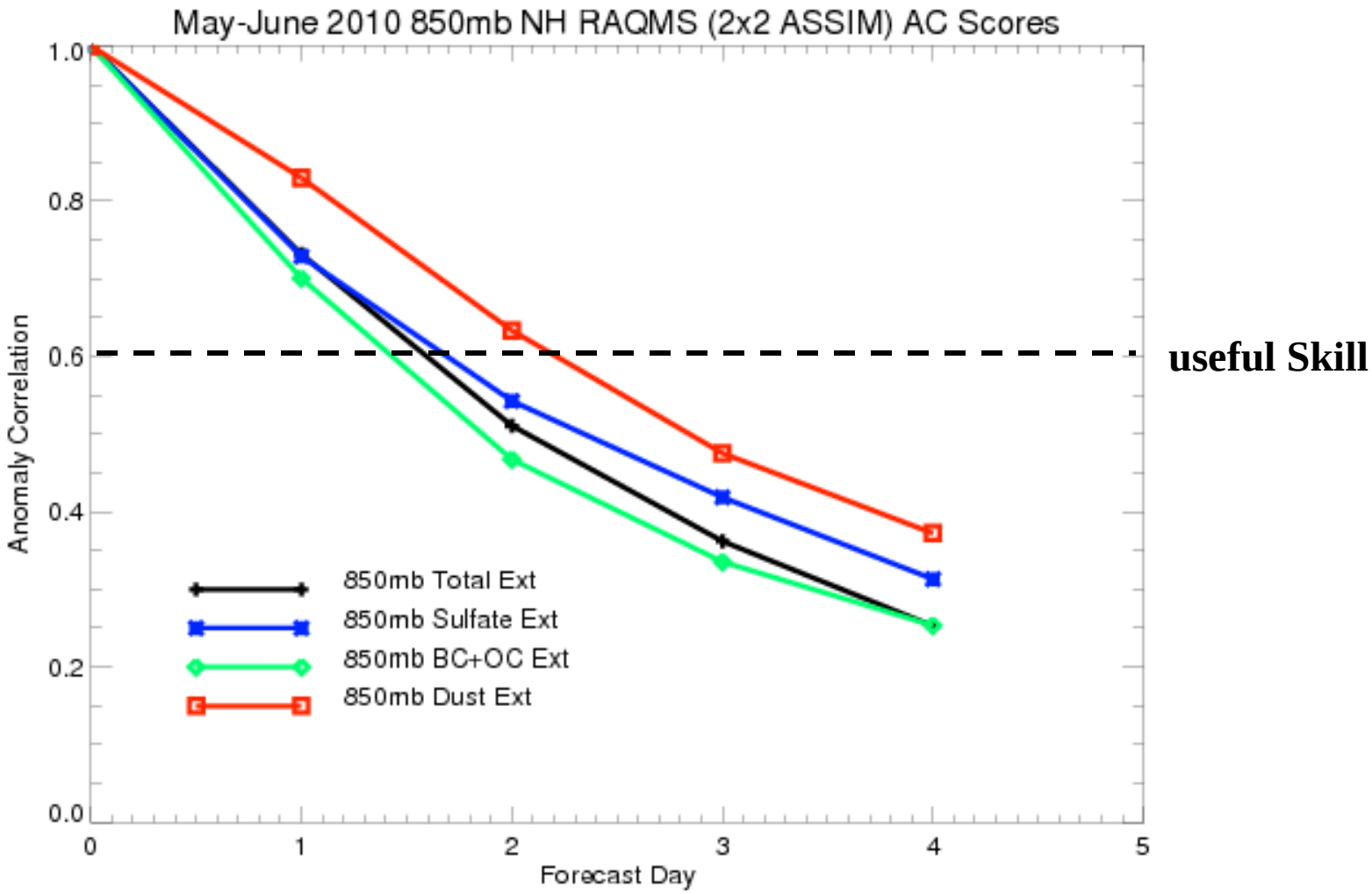
http://www.emc.ncep.noaa.gov/gmb/STATS/html/monarch.html

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)

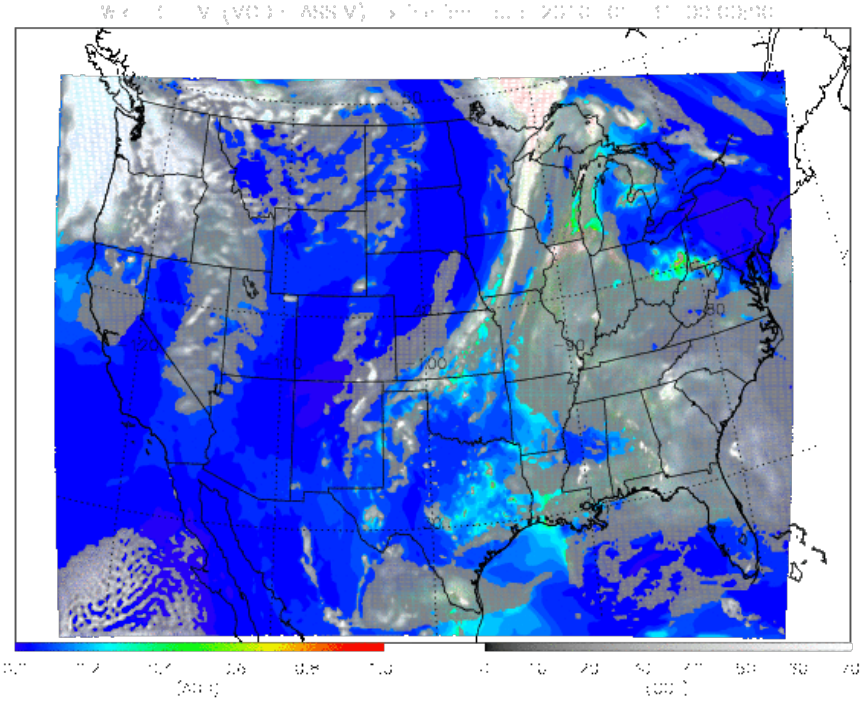


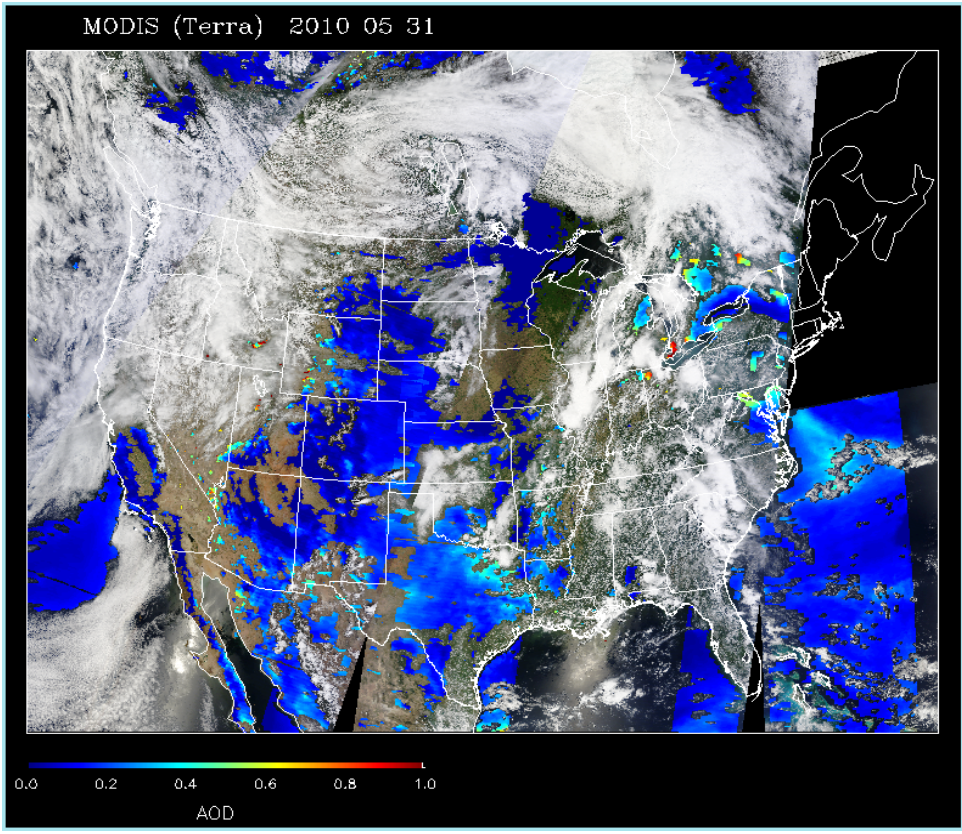
•MODIS AOD assimilation results in small changes in 850mb SO4 extinction forecasts
•MODIS AOD assimilation results in significant improvements in black and organic carbon (BC+OC) and dust forecast skill (dust prediction useful at 2 days)

Nested RAQMS/WRF-CHEM
May-June 2010 aerosol analysis

GOCART aerosol module, MODIS AOD assimilation, Two nests: 36km and 12km

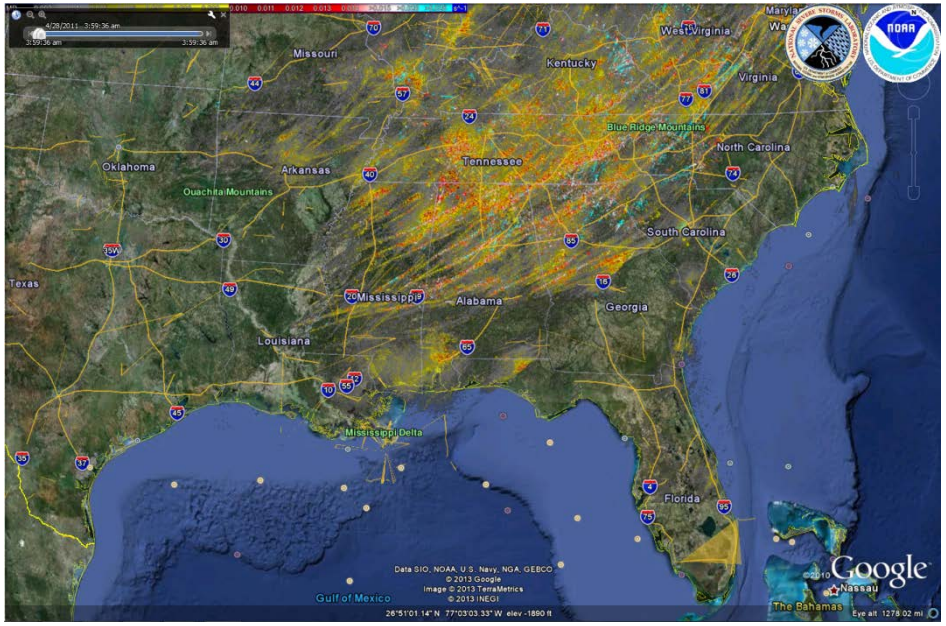
12km WRF-CHEM
00Z-24Z May 31st, 2010





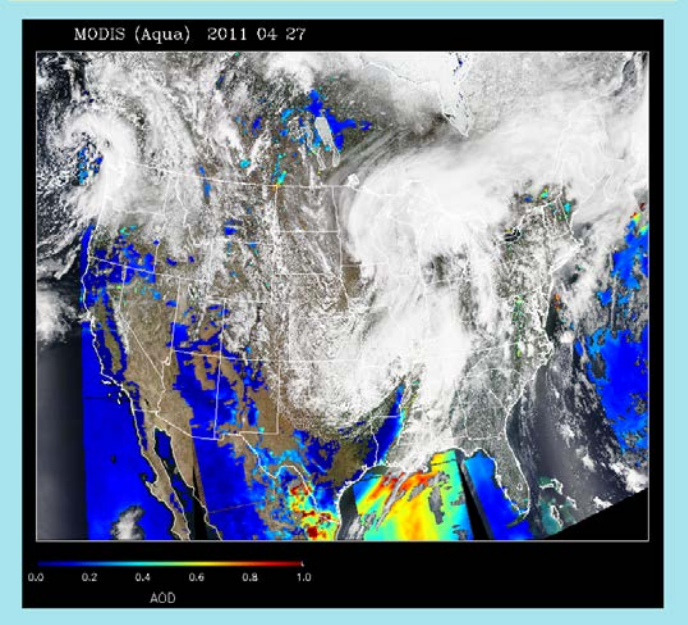
Severe Storm Intensification due to smoke

Tornado rotation tracks on April 27-28, 2011
(NSSL On Demand Severe Weather Verification System[1])

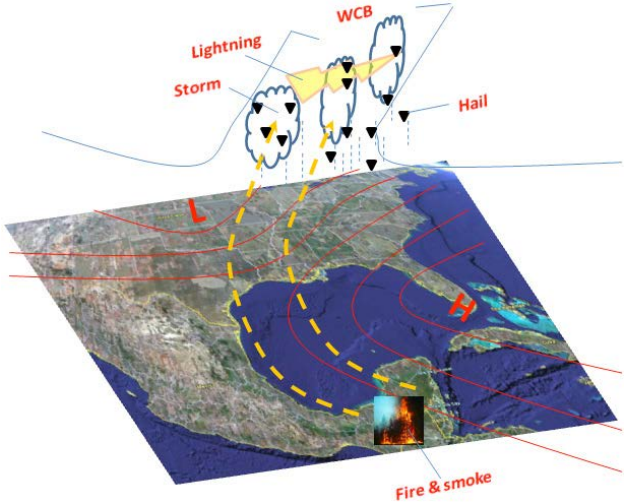


[1]**Part of NSSL's Warning Decision Support System – Integrated Information (WDSS-II) Multi-Radar/Multi Sensor platform.**

MODIS AOD/COT April 27, 2011[2]



[2]**http://www.star.nesdis.noaa.gov/smcd/spb/aq/**



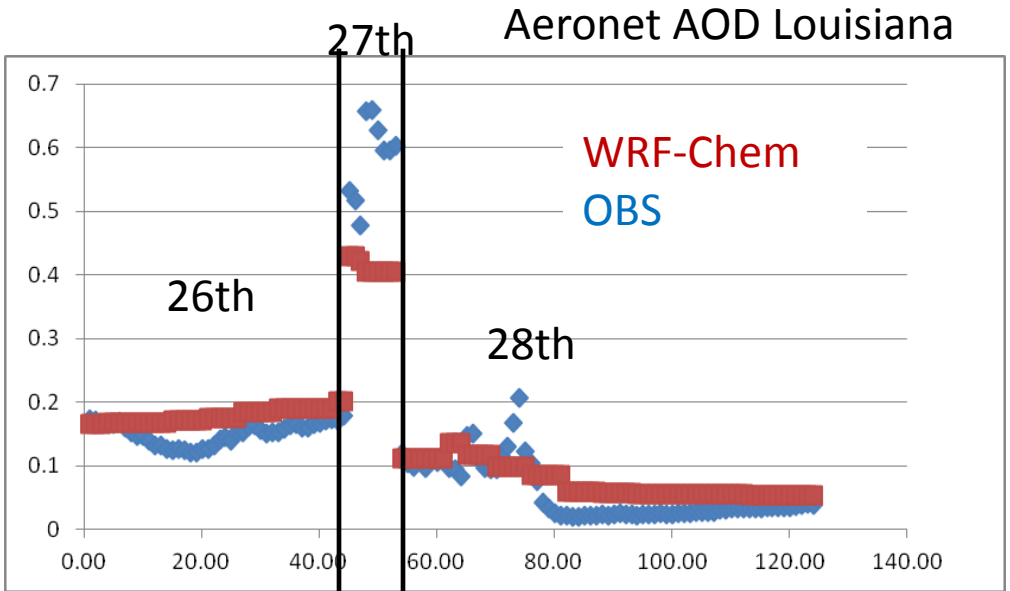
The indirect aerosol mechanisms pertinent to smoke particles include[3]:

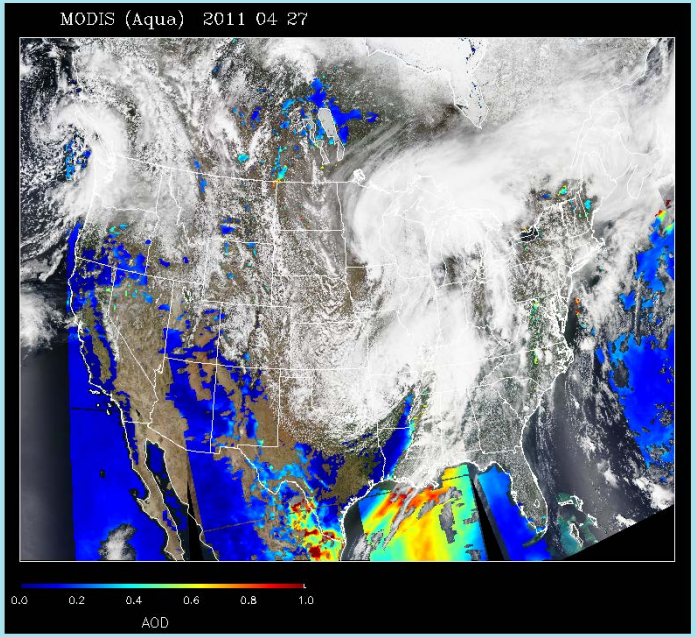
(1) the first indirect effect, where the size of water cloud droplets decreases
(2) the semi-direct (choking) effect, where absorption of solar radiation by smoke particles increases atmospheric stability
(3) the second indirect effect, where the smaller cloud droplets result in longer cloud lifetimes
(4) the invigoration effect, where warm rain process is delayed through first and second indirect effects,

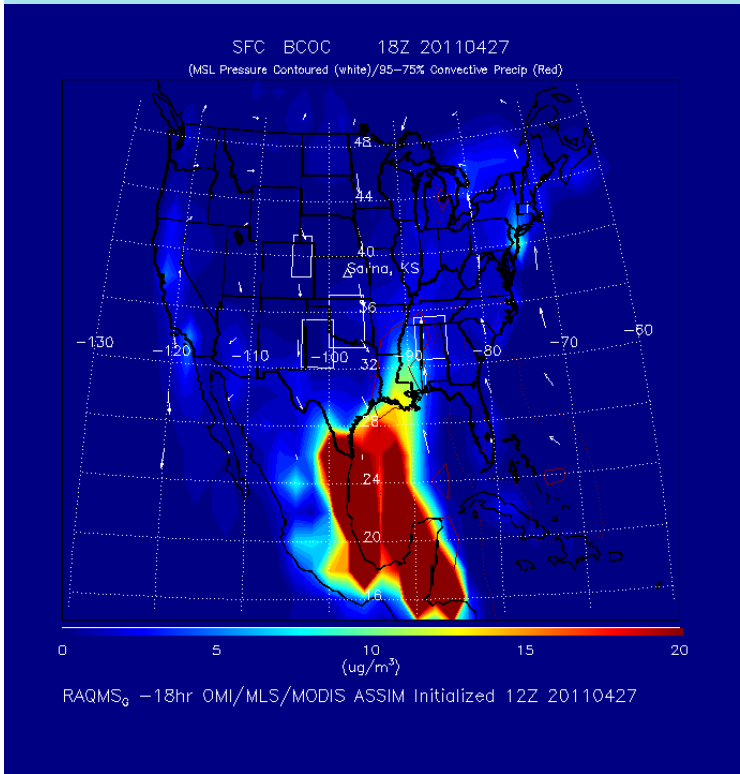
[3]**From Wang et al, Environ. Res. Lett. 4 (2009)**

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**



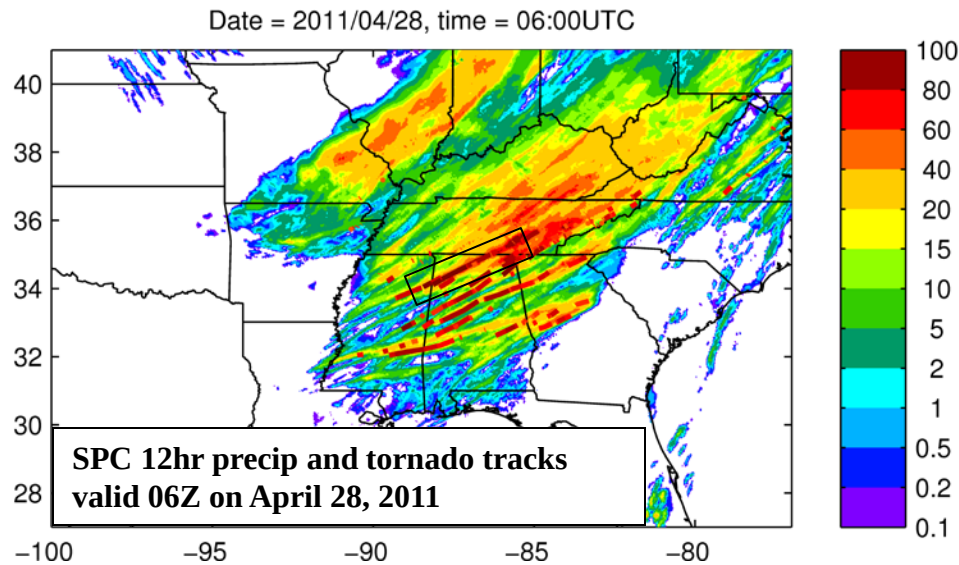


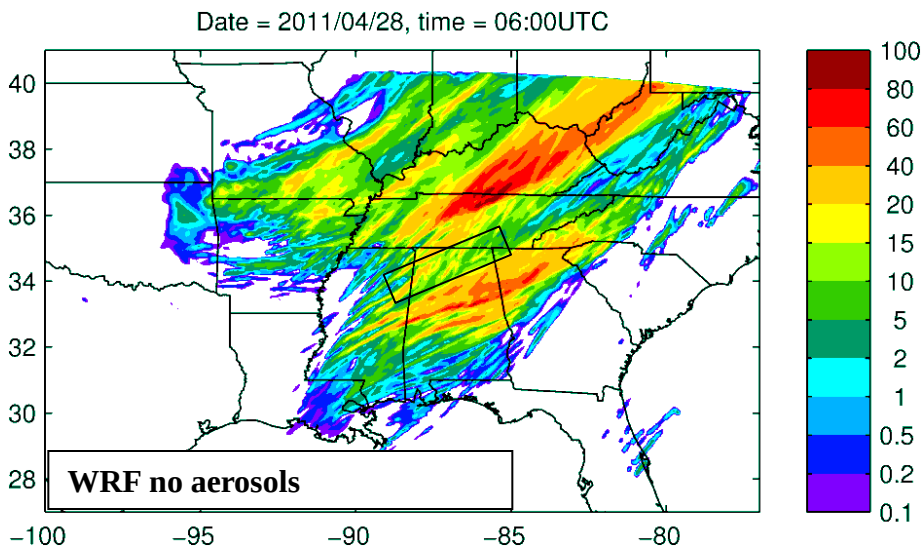


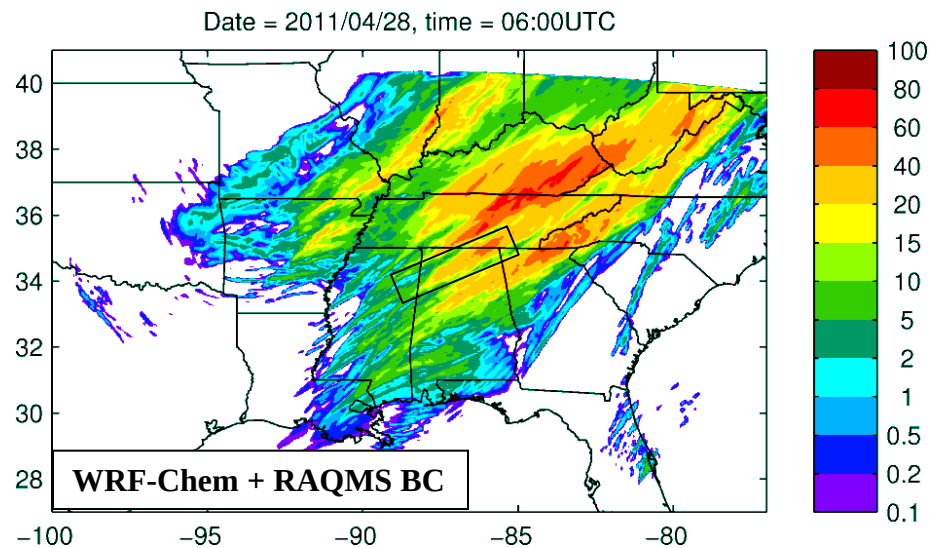
Case Study: Severe weather April 27th, 2011 (Huntsville tornado)

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

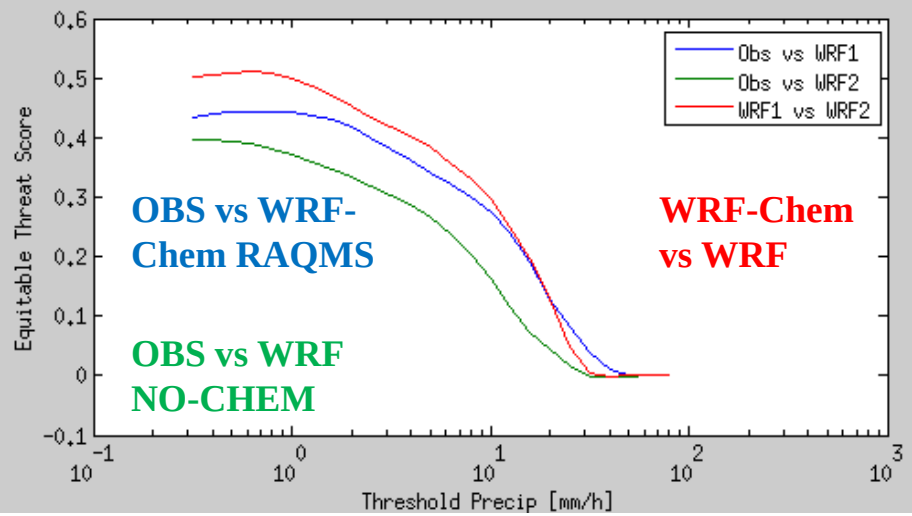




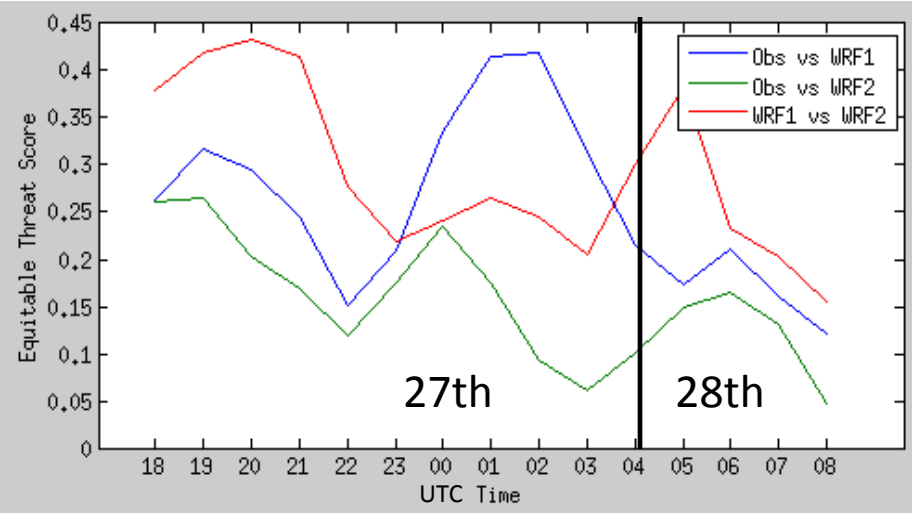


Precip. Obs vs WRF & WRF-Chem

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



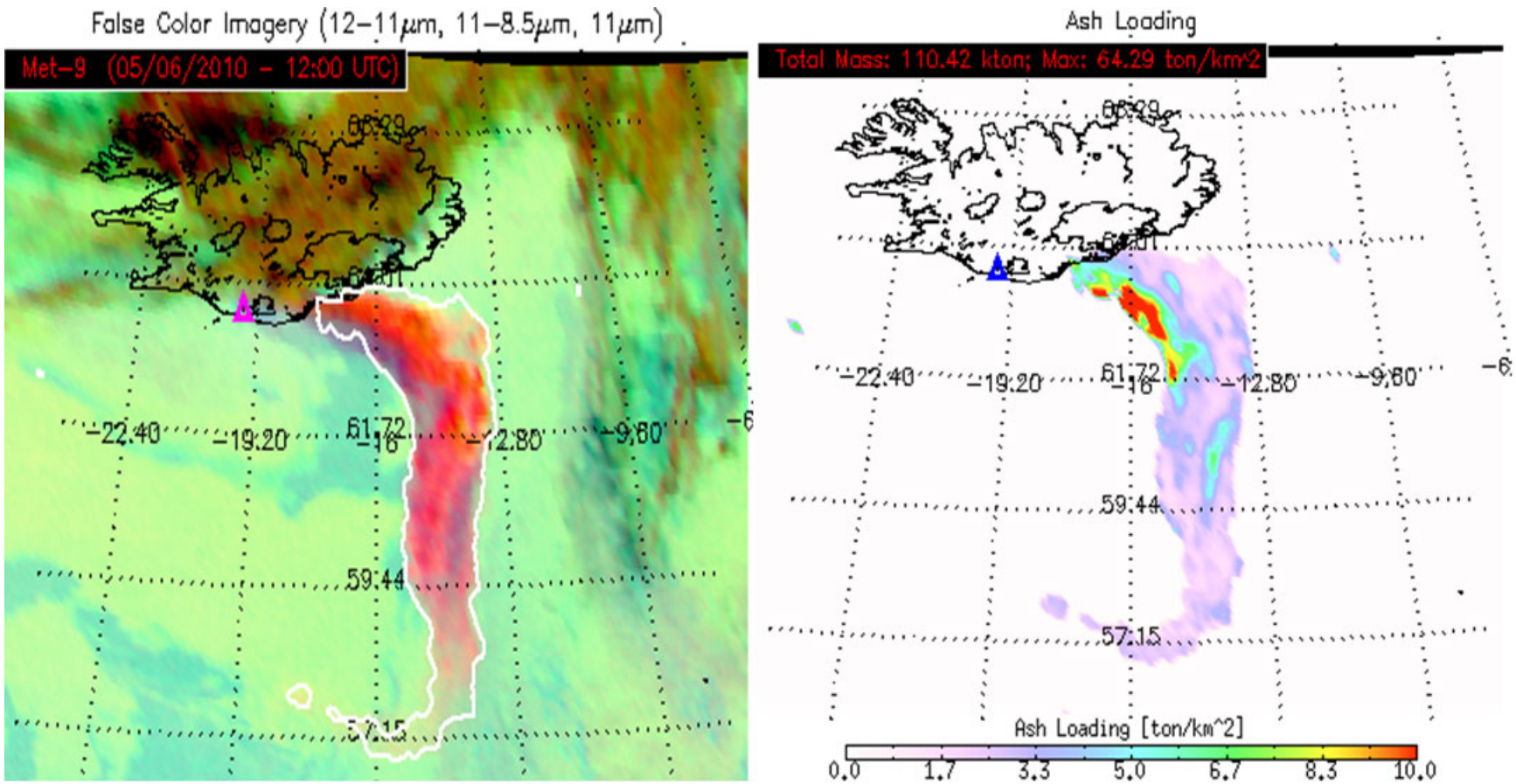
Skill for 3h accum. precip. over 10mm



- 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

Volcanic Ash Prediction

2010 Eyjafjallajokull volcanic eruption



Ash Detection product (left) and Ash Loading (right) using the GOES-R Volcanic Ash Algorithm applied to Meteosat-9/SEVIRI data[1] (From Mike Pavolonis, NESDIS/STAR, and Justin Sieglaff, CIMSS)

[1]**http://www.goes-r.gov/products/baseline-volcanic-ash.html**

WRF-CHEM Volcanic Ash Module

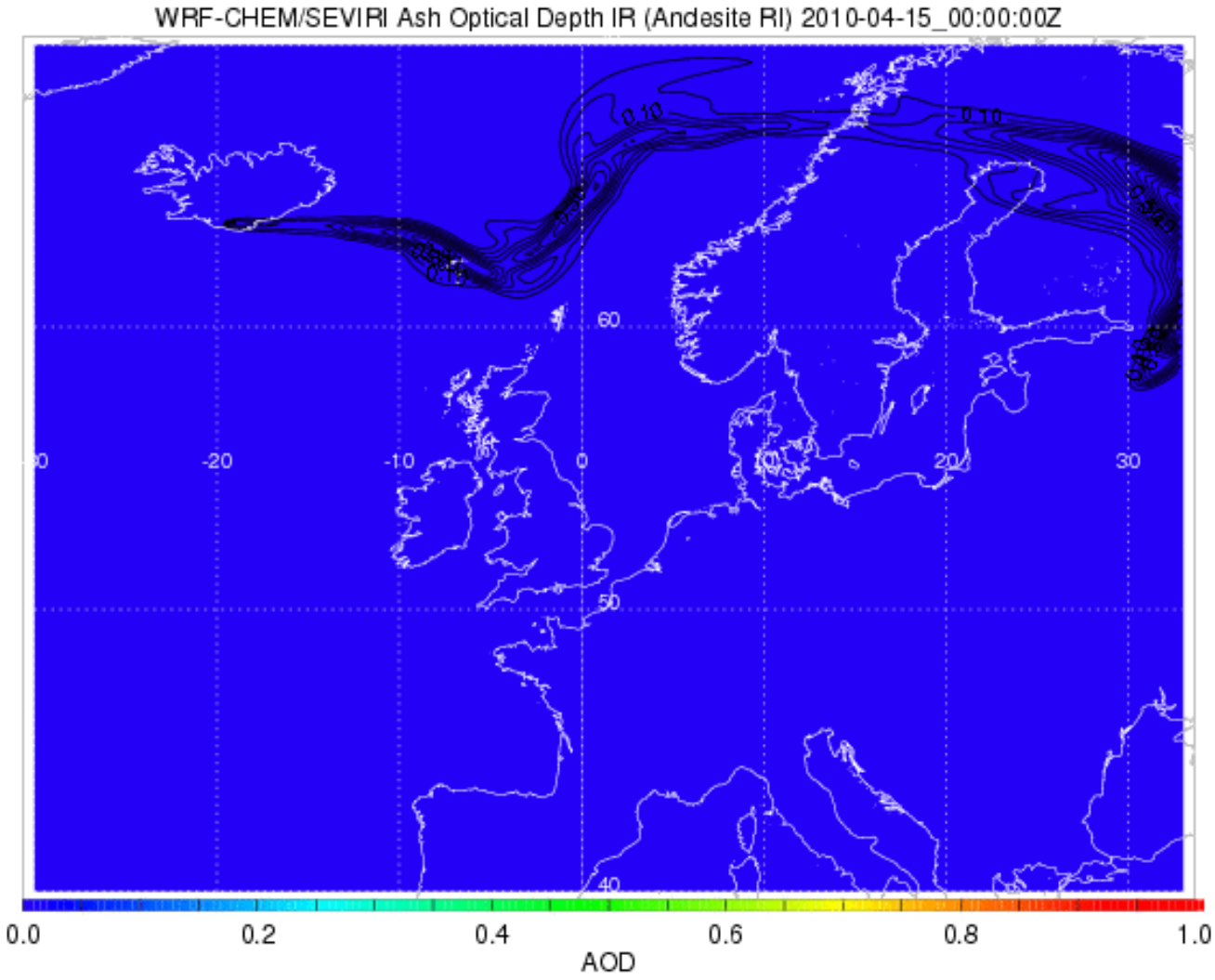
- **A 4-bin WRF-CHEM volcanic ash module developed by George Grell at Earth System Research Laboratory (ESRL) and Martin Stuefer at the University of Alaska, Fairbanks (UAF) is used in forecasting volcanic ash.**

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

- **SEVIRI volcanic ash retrievals are assimilated into WRF-CHEM using the Gridpoint Statistical Interpolation (GSI)**

- **SEVIRI 11 micron volcanic ash extinction is assimilated**

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

Modified NMC method for Background Errors

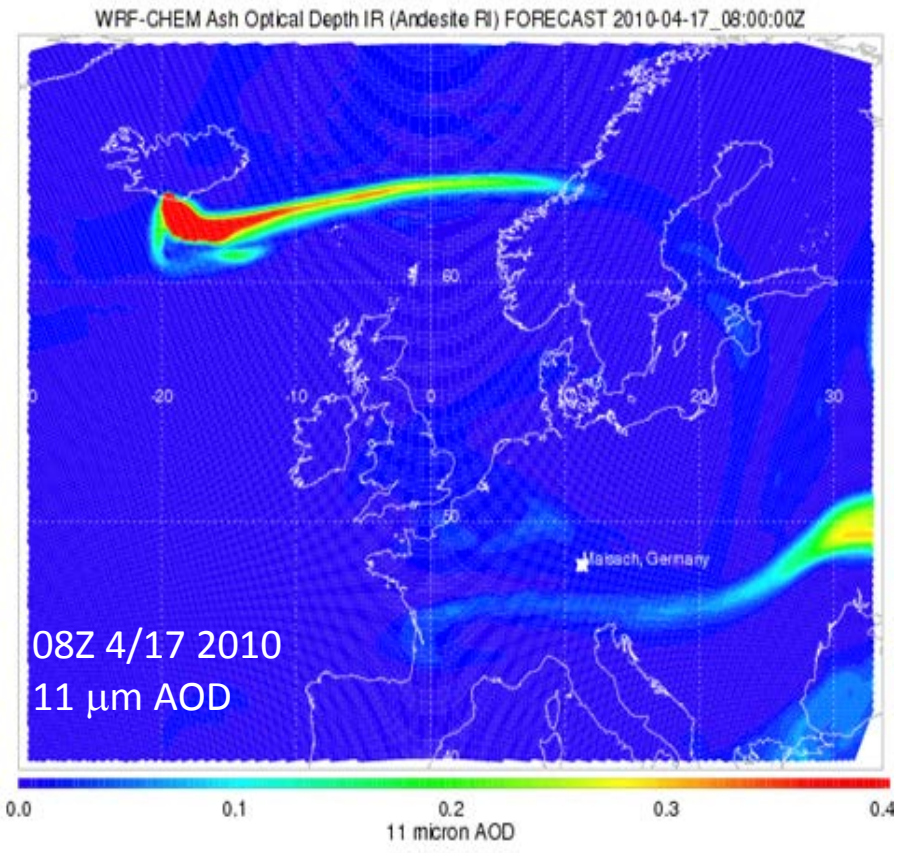
2 forecasts:

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

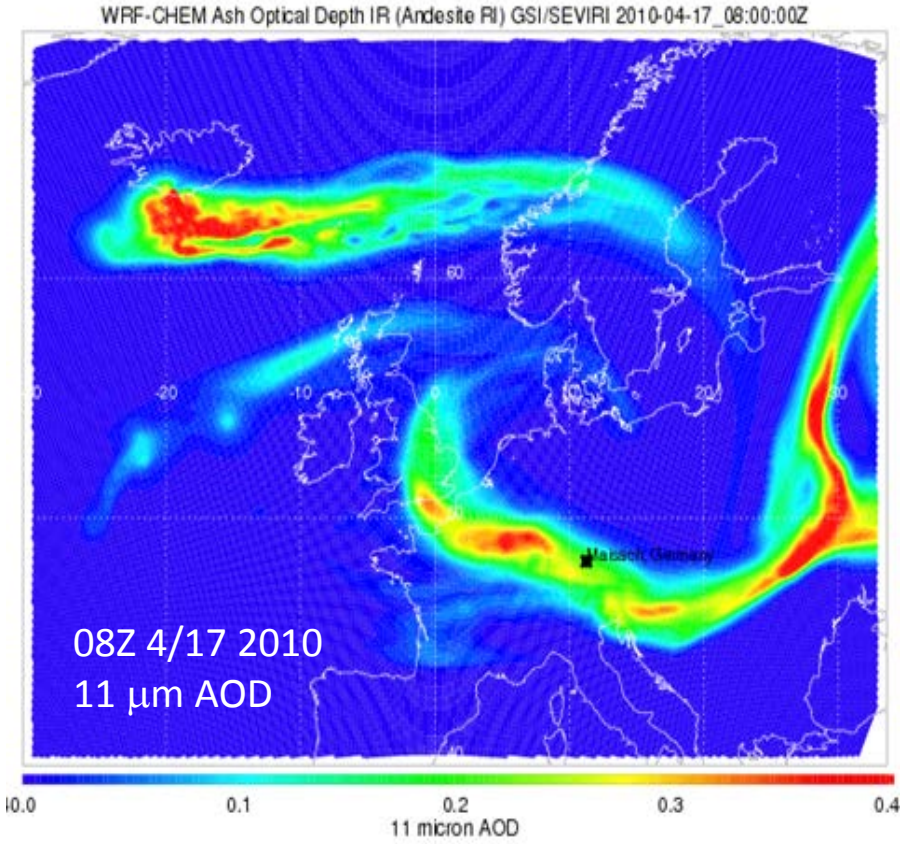
Used differences between 00z April 14 to 00z April 19, 2010 hourly forecast (valid at same time) to build the statistics

Results

WRF-CHEM Baseline



GSI/SEVIRI assimilation



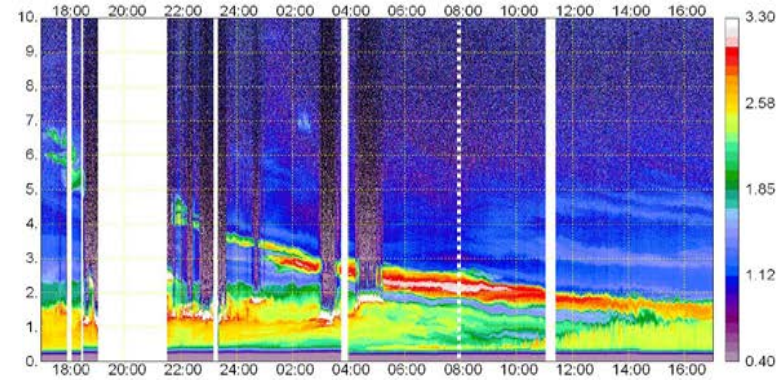
Significant increase in 11 micron AOD for older plume with GSI/SEVIRI assimilation

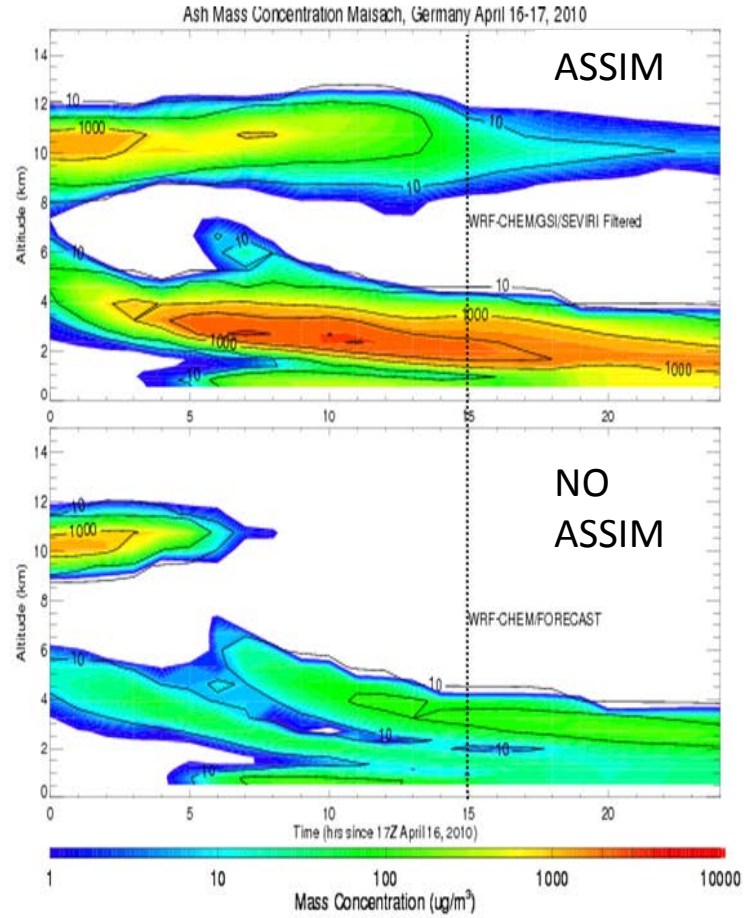
Verification

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.

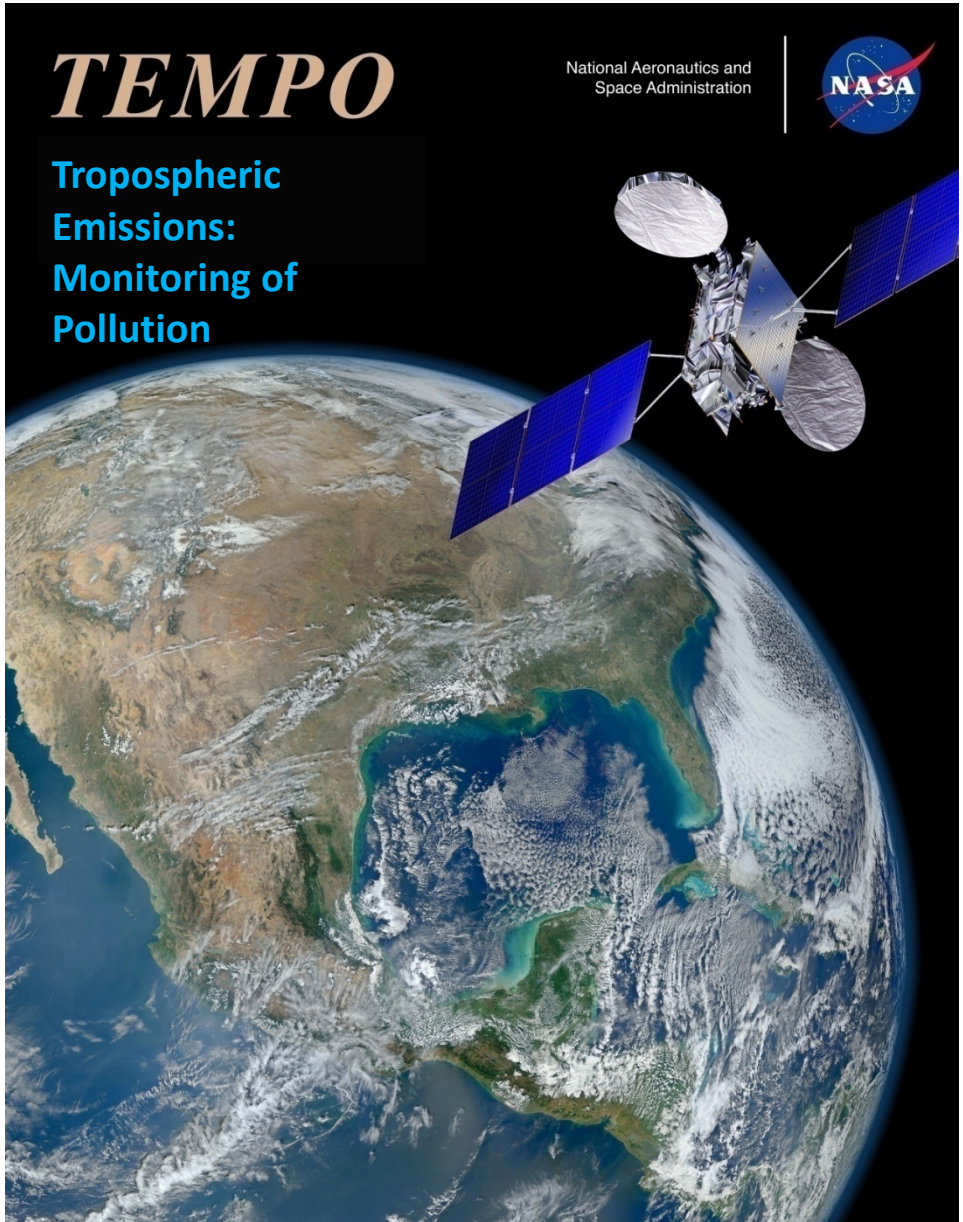
Both experiments show an additional plume at 10km which is not observed.

Maisach 1064 nm aerosol backscatter





TEMPO/GOES-R Synergies



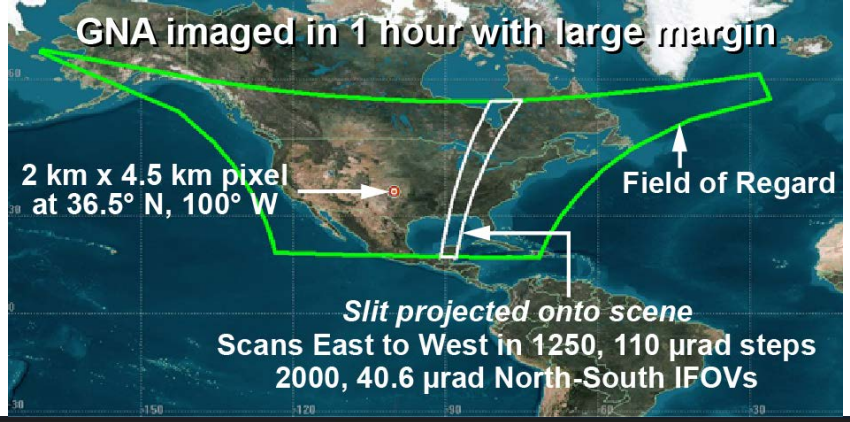
Tropospheric Emissions: Monitoring of Pollution

PI: Kelly Chance (Smithsonian Astrophysical Observatory)

- TEMPO is NASA's first Earth Venture Instrument award under the agency's Earth System Science Pathfinder program.
- TEMPO spectroscopic measurements in the ultraviolet and visible provide a tropospheric measurement suite that includes the key elements of tropospheric air pollution chemistry
- TEMPO will be launched on a commercial satellite as a hosted payload with a target launch in 2019
- TEMPO will be a component of a global GEO constellation for pollution monitoring along with Europe (Sentinel-4) and Asia (Geostationary Environment Monitoring Spectrometer)

Each 2 km × 4.5 km pixel is a 2K element spectrum from 290-690 nm!

GEO platform selected by NASA for viewing greater North America



KEY INSTRUMENT CHARACTERISTICS

Requirements		Comment
Field of Regard	GNA	Mexico City to Canada tar sands & Atlantic to Pacific
Imaging Time	1 hr	1250 scan positions with 2.8 sec integration
Footprint N/S	2.0 km	Native pixel achieved by 44 cm telescope effective focal length
Footprint E/W	4.5 km	
Spectral Range	290-690 nm	1,024 spectral channels matched to 2k focal plane
Spectral Resolution	0.6 nm	Achieved by spectrometer design
Spectral Sampling	0.2 nm	

Heritage-based grating spectrometer efficiently achieves the requirements derived directly from the Science Traceability Matrix.

Species	λ Band nm	SNR Reqs	SNR Predict	EOL Margin
SO_2	305-345	1297	1820	40%
H_2CO	327-354	487	2094	330%
NO_2	423-451	1233	1910	55%
$C_2H_2O_2$	433-457	1350	2331	73%
O_3 (UV)	303-345	1122	1635	46%
O_3 (Vis)	546-648	958	1254	31%
AOD	354, 388	1000	1596	60%

Substantial margins for predicted signal-to-noise ratios are the foundation for a low-risk program.

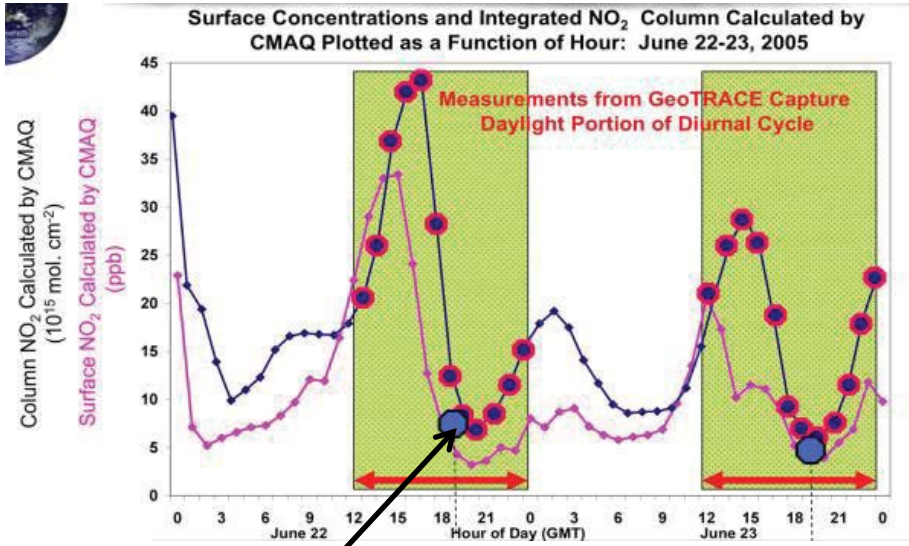
INSTRUMENT COMPLEMENT

TEMPO moves high heritage LEO hardware to GEO following a low-risk build philosophy. The high design maturity of the TEMPO spectrometer is leveraged from LEO-proven heritage from GOME, SCIAMACHY, OMI, and OMPS, as well as from GEO studies and risk reduction activiites. This, coupled with substantial performance margins, results in a low-risk, compact configuration ideally matched to deliver a high value science product.

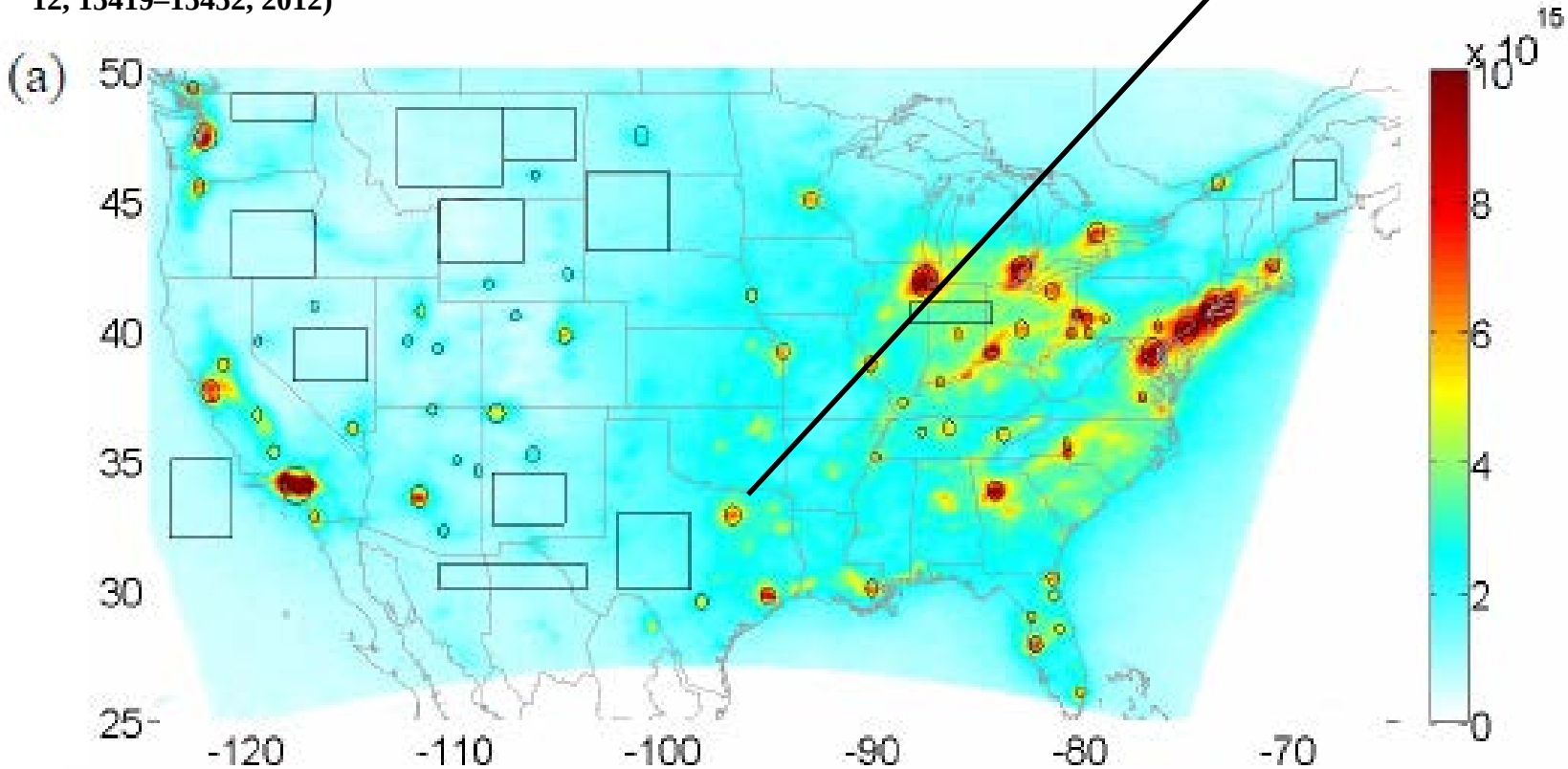
Requirements	TEMPO		
	Current Best Estimate	Contingency	Maximum Expected Value
Mass (kg)	92	17%	107.9
Average Power (W)	81.6	22%	99.4
Downlink Rate (Mbps)	8.95		
Volume (l x w x h)	1.02m x 1.07m x 0.96m		

The low resource requirements for TEMPO can be accommodated by any of the commercial GEO buses over GNA, ensuring flexibility to selection of a host platform.

TEMPO measurements will capture the diurnal cycle of NO_2 that is missed by current LEO observations – ***Will complement GOES-R fire detection and GOES-R GLM for improved emission inventories***



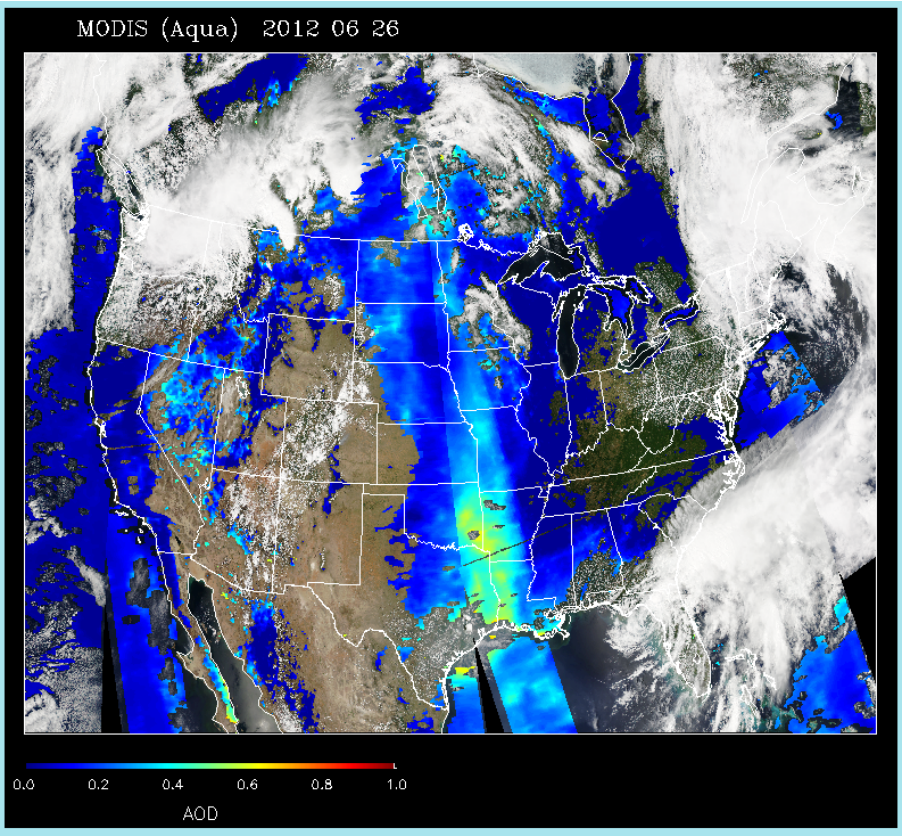
Average summertime (April–September) OMI BEHR NO2 column densities for 2005, (From Russell et al., Atmos. Chem. Phys. Discuss., 12, 15419–15452, 2012)



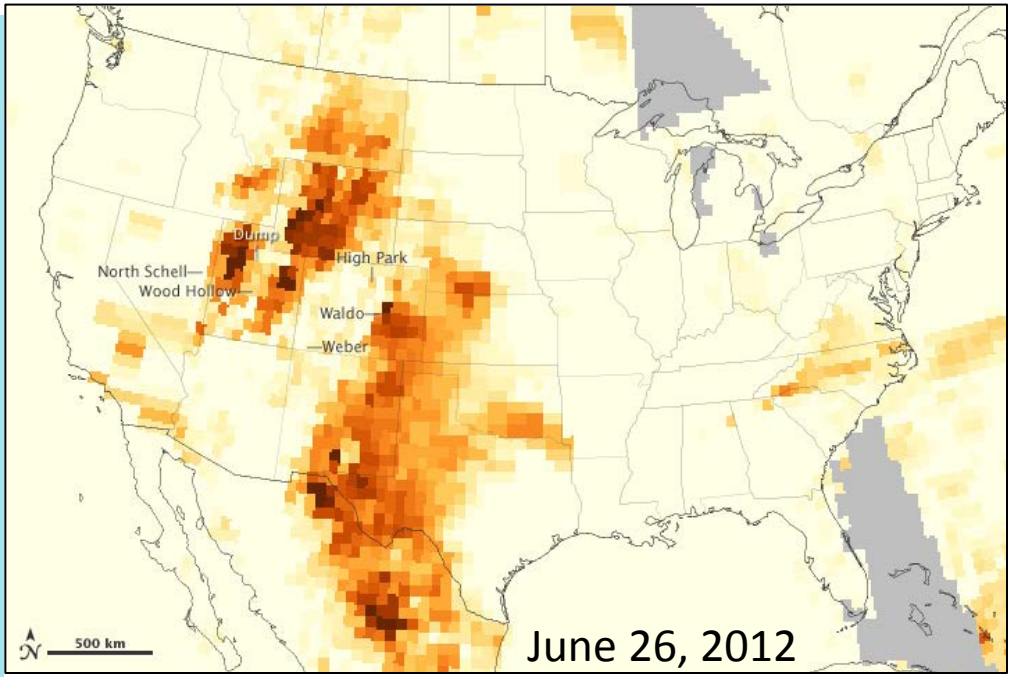
TEMPO UV-Vis observations significantly improve sensitivity to O3 near the surface over the use of UV only – *Will complement GOES-R Total Column Ozone retrieval*

TEMPO measurements will retrieve Absorbing Aerosol Optical Depth (AAOD) to detect elevated layers of absorbing aerosols. – *Will complement GOES-R ABI AOD retrieval and allow determination of altitude of smoke, dust and ash plumes*

MODIS AOD retrieval from Aqua



OMPS AAOD retrieval from Suomi-NPP



Credit: NASA image by Jesse Allen, using OMPS data provided courtesy of Colin Seftor (SSAI)
Source: http://earthobservatory.nasa.gov/IOTD/view.php?id=78389

Summary

- Assimilation of MODIS AOD retrievals from polar orbit improves global forecast skill
  - ***Assimilation of GOES-R ABI AOD and TEMPO AAOD retrievals will improve regional forecast skill***
- Aerosol/cloud interactions during significant smoke events have been shown to improve the prediction of precipitation during the April 2011 Tornado outbreak
  - ***Neglected microphysical process in current model guidance for severe storm prediction***
- Assimilation of SEVIRI 11 micron AOD improves volcanic ash forecast skill over Europe
  - ***Assimilation of GOES-R ABI volcanic ash and TEMPO AAOD retrievals will improve volcanic ash and SO2 forecast skill over North America***