Real-time Air Quality Modeling System aerosol and ozone assimilation and forecasting experiments during the NOAA ARCPAC field mission

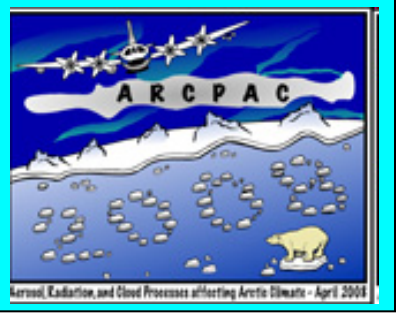
R. Bradley Pierce[1], Todd Schaack[2], Allen Lenzen[2], Jassim Al-Saadi[3], Murali Natarajan[3], Dave Winker[3], Amber Soja[4], Tom Ryerson[5], Ann Middlebrook[5], Ryan Spackman[5], Samuel Oltmans[5], Anne Thompson[6]

[1]NOAA NESDIS Cooperative Institute for Meterological Satellite Studies, Madison, WI
[2]UW-Madison Space Science and Engineering Center, Madison, WI
[3]NASA Langley Research Center, Science Directorate, Hampton, VA
[4]National Institute of Aerospace, Hampton, VA
[5]NOAA ESRL Chemical Sciences Division, Boulder, CO
[6]Penn State, University Park, PA

Theme Area 2: *Chemical Data Assimilation in AQ forecasts*
International Workshop on Air Quality Forecasting Research, December 2-3, 2009, Boulder, Colorado

During April 2008, as part of the International Polar Year (IPY), NOAA's Climate Forcing and Air Quality Programs engaged in an airborne field measurement campaign in the Alaskan Arctic.

The Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) field mission focused on direct measurements of properties and processes designed to address non-greenhouse-gas atmospheric climate forcing.



•The Real-time Air Quality Modeling System (RAQMS) chemical and aerosol forecasts, initialized with real-time satellite measurements (e.g. MLS stratospheric ozone profiles, OMI total column ozone, Terra and Aqua MODIS aerosol optical depth) were used for daily flight planning activities during ARCPAC.

•This talk presents results from post mission studies focused on evaluation of the RAQMS large-scale ozone and aerosol analyses based on comparisons with satellite, ground based, and airborne observations.

•Large-scale aerosol and ozone forecast skill is evaluated through analysis of anomaly correlations and forecast error covariances.

Model Description

1. **Online global chemical and aerosol assimilation/ forecasting system**

2. **UW-Madison hybrid $\eta\eta\eta$ coordinate model (UW-Hybrid) dynamical core**

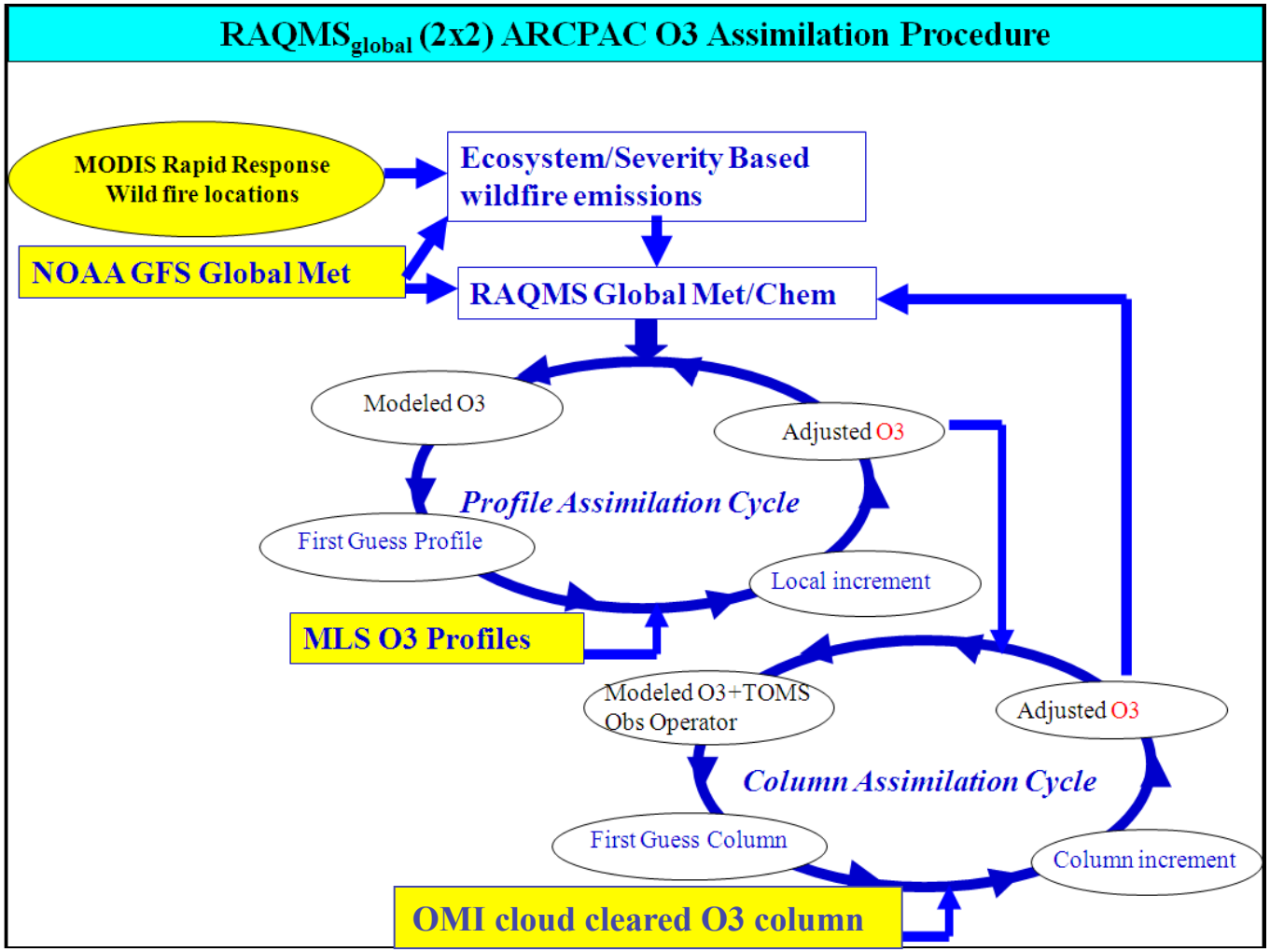
3. **Unified stratosphere/troposphere chemical prediction scheme (LaRC-Combo) developed at NASA LaRC**

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]

RAQMS ARCPAC O3 Assimilation Procedure

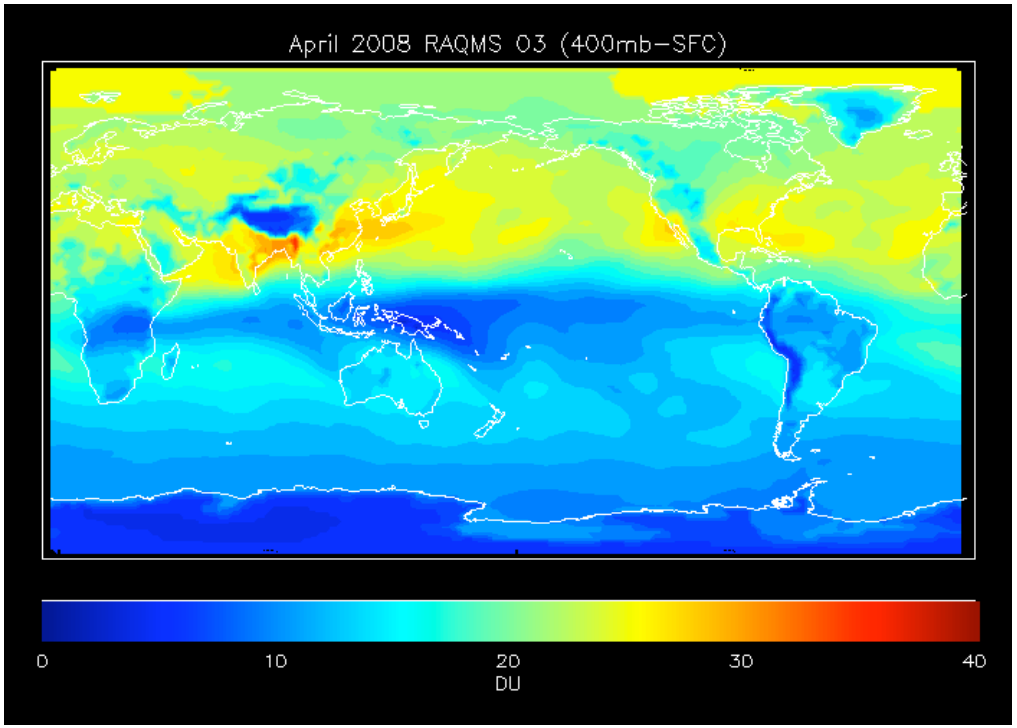


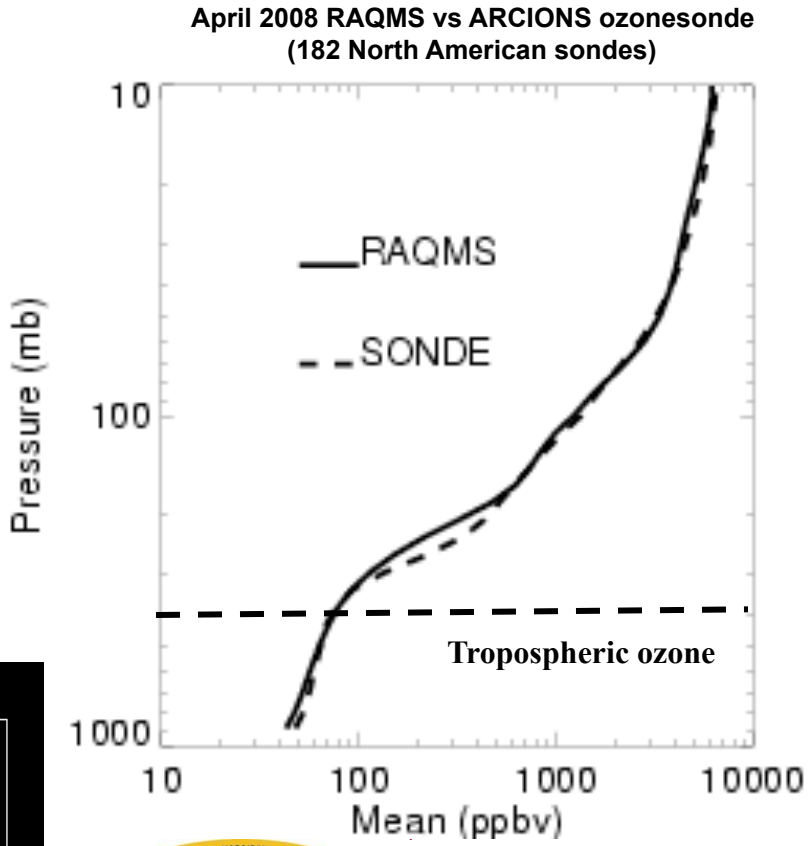
Demonstration of:

- **Real-time assimilation of Microwave Limb Sounder (MLS) stratospheric ozone profiles**
- **Real-time assimilation of Ozone Monitoring Instrument (OMI) total ozone column**
- **Real-time incorporation of Moderate Resolution Imaging Spectroradiometer (MODIS) fire detection**

Risk-mitigation for Operational assimilation of OMPS on NPOESS

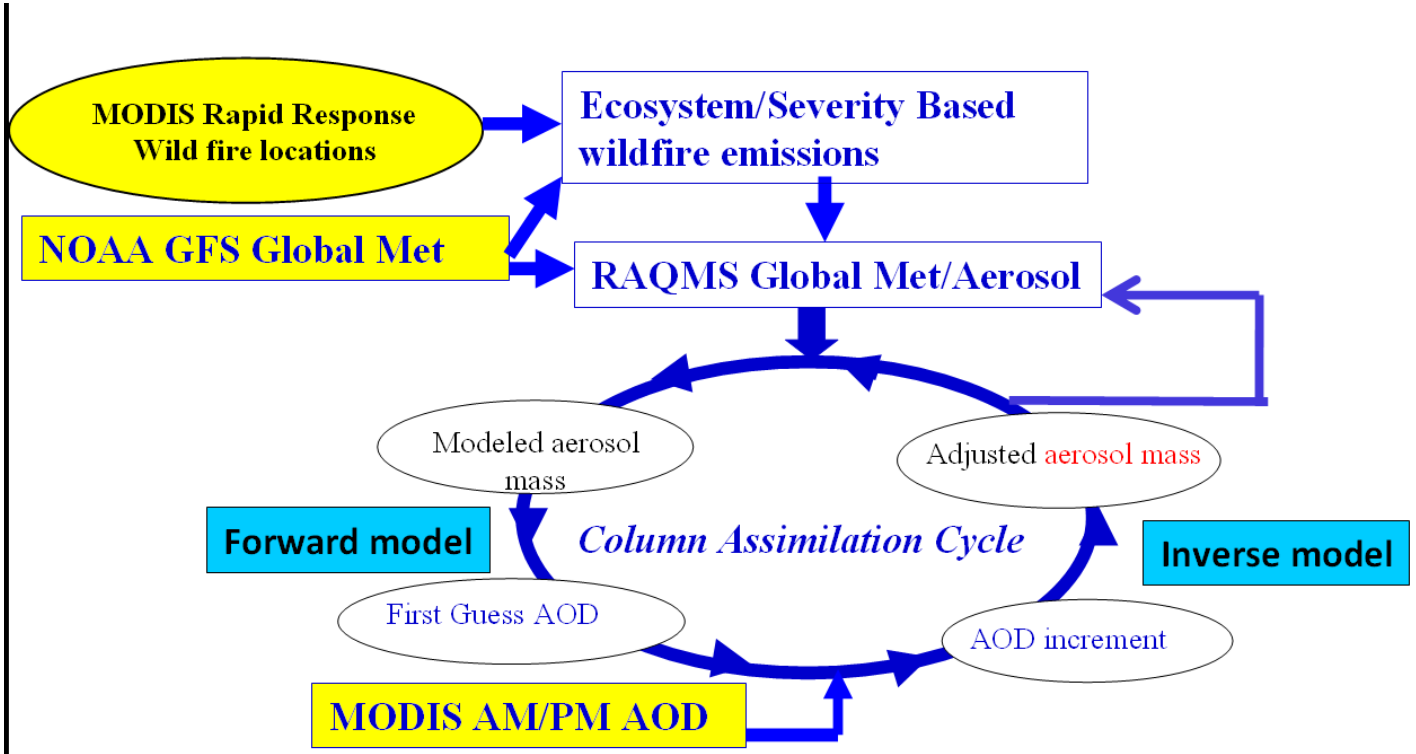
RAQMS Ozonesonde Validation April 2008





1-Alert, NU, CAN
2-Eureka, NU, CAN
3-Summit, GL
4-Resolute, NU, CAN
5-Barrow, AK, US
6-Whitehorse, YT, CAN
7-Yellowknife NWT, CAN
8-Churchill, MB, CAN
9-Stonyplain, AL, CAN
10-Kelowna, BC, CAN
11-Bratts Lake, SK, CAN
12-Trinidad Head, CA, US
13-Boulder, CO, US
14-Goose Bay, ND, CAN
15-Sable Island, NS, CAN
16-Yarmouth, NS, CAN
17-Egbert, ON, CAN
18-Narragansett, RI, US
19-Huntsville, AL, US

RAQMS ARCPAC AOD Assimilation Procedure



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

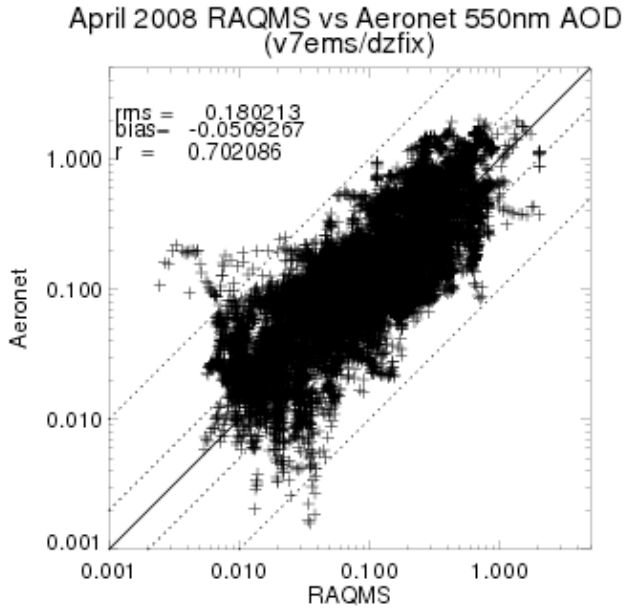
Inverse model:
Distribute total AOD increment across aerosol dry mass based on layer/species extinction accounting for extinction due to hydroscopic growth

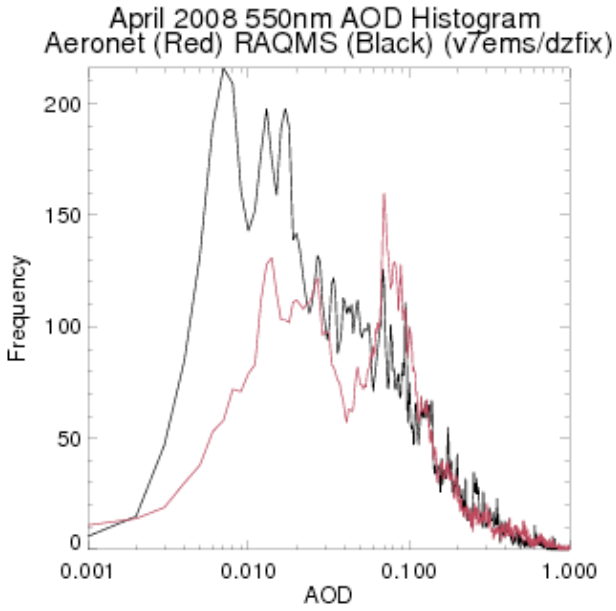
Demonstration of:

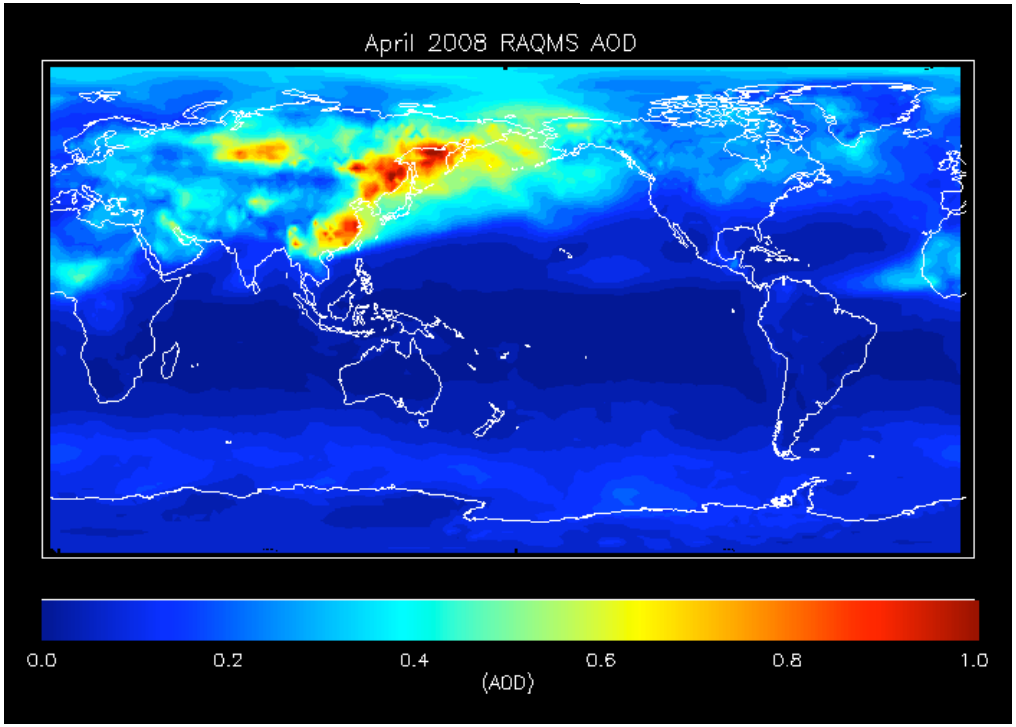
- Real-time assimilation of MODIS Aerosol Optical Depth (AOD)
- Real-time incorporation of MODIS based biomass burning emissions

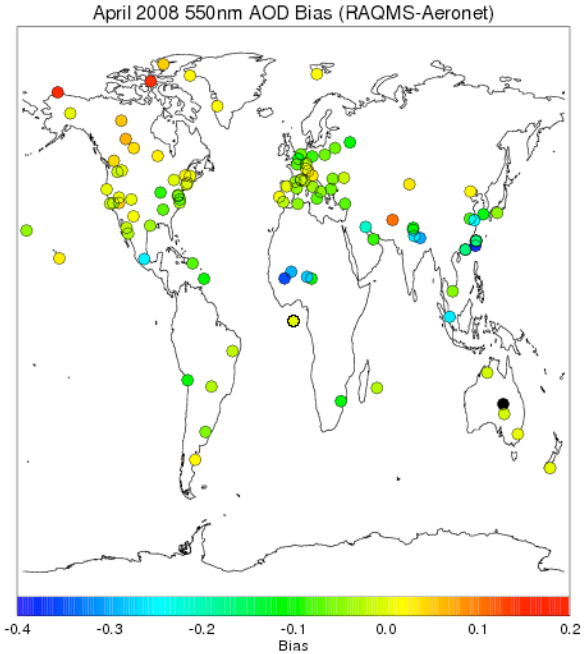
Risk-mitigation for Operational assimilation of VIIRS on NPOESS

RAQMS Aeronet Validation April 2008

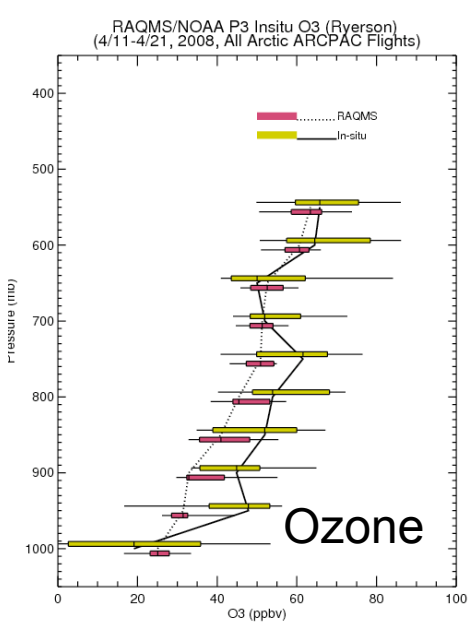


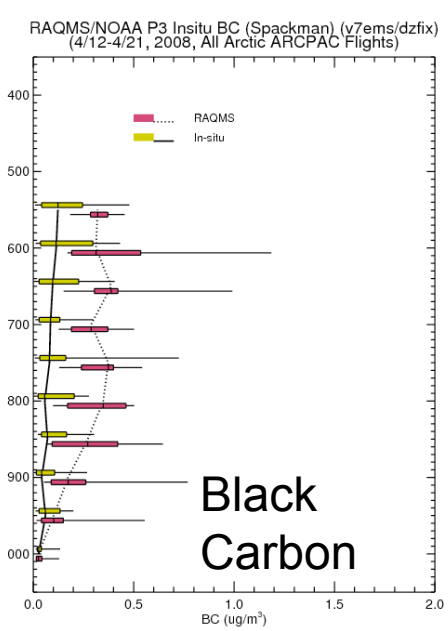


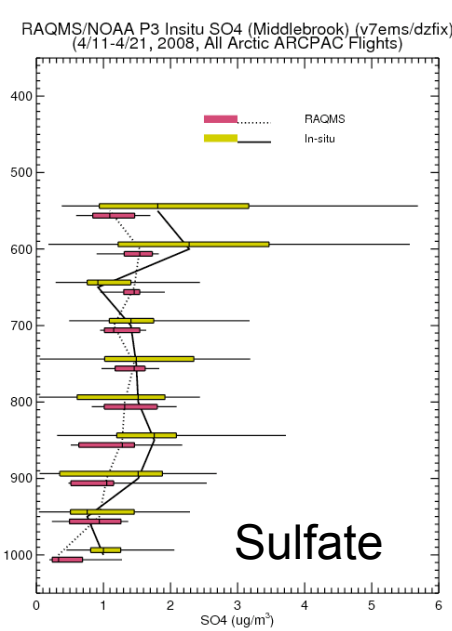


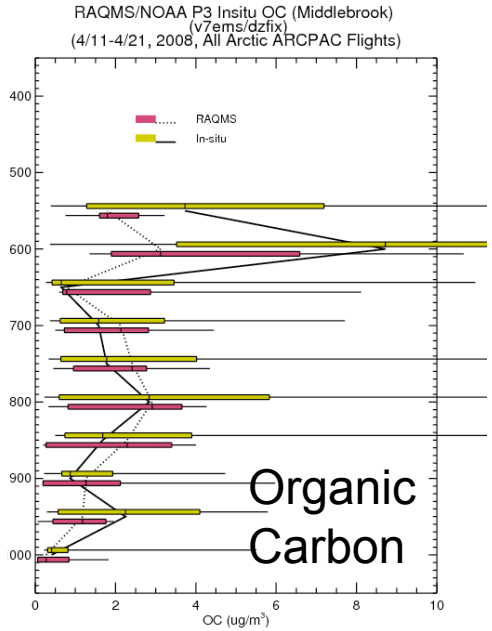


RAQMS O3/aerosol ARCPAC P3 Validation









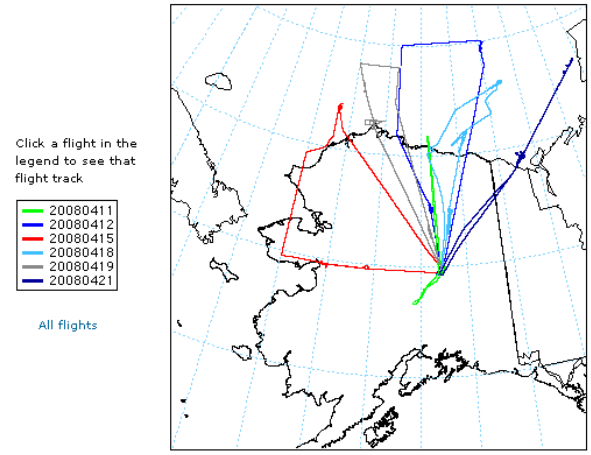
•MLS and OMI O3 assimilation leads to underestimates in lower tropospheric ozone compared to P3

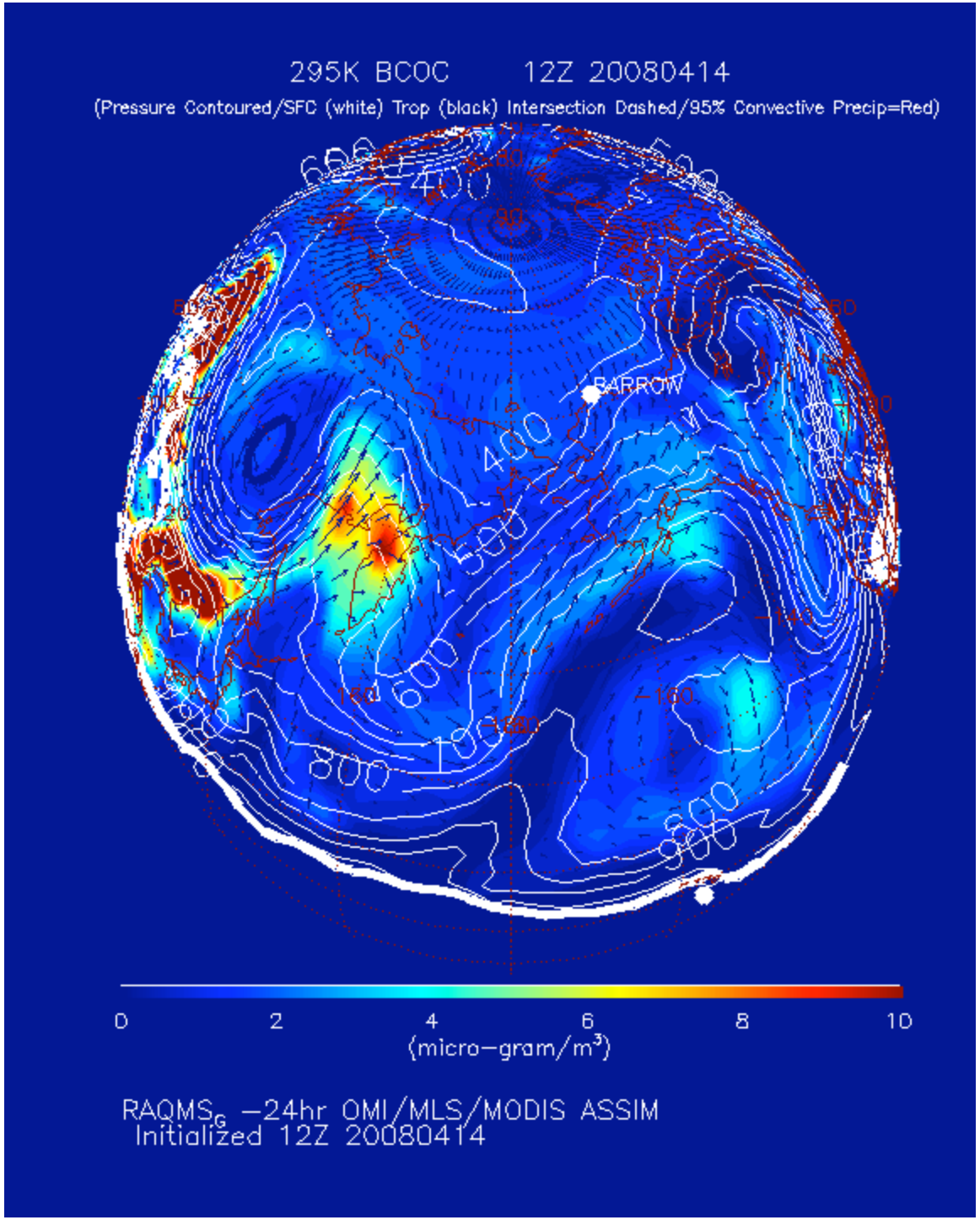
•MODIS aerosol optical depth (AOD) assimilation results in good agreement with P3 insitu SO4 and Organic Carbon (OC) measurements but overestimates Black Carbon (BC) mass.

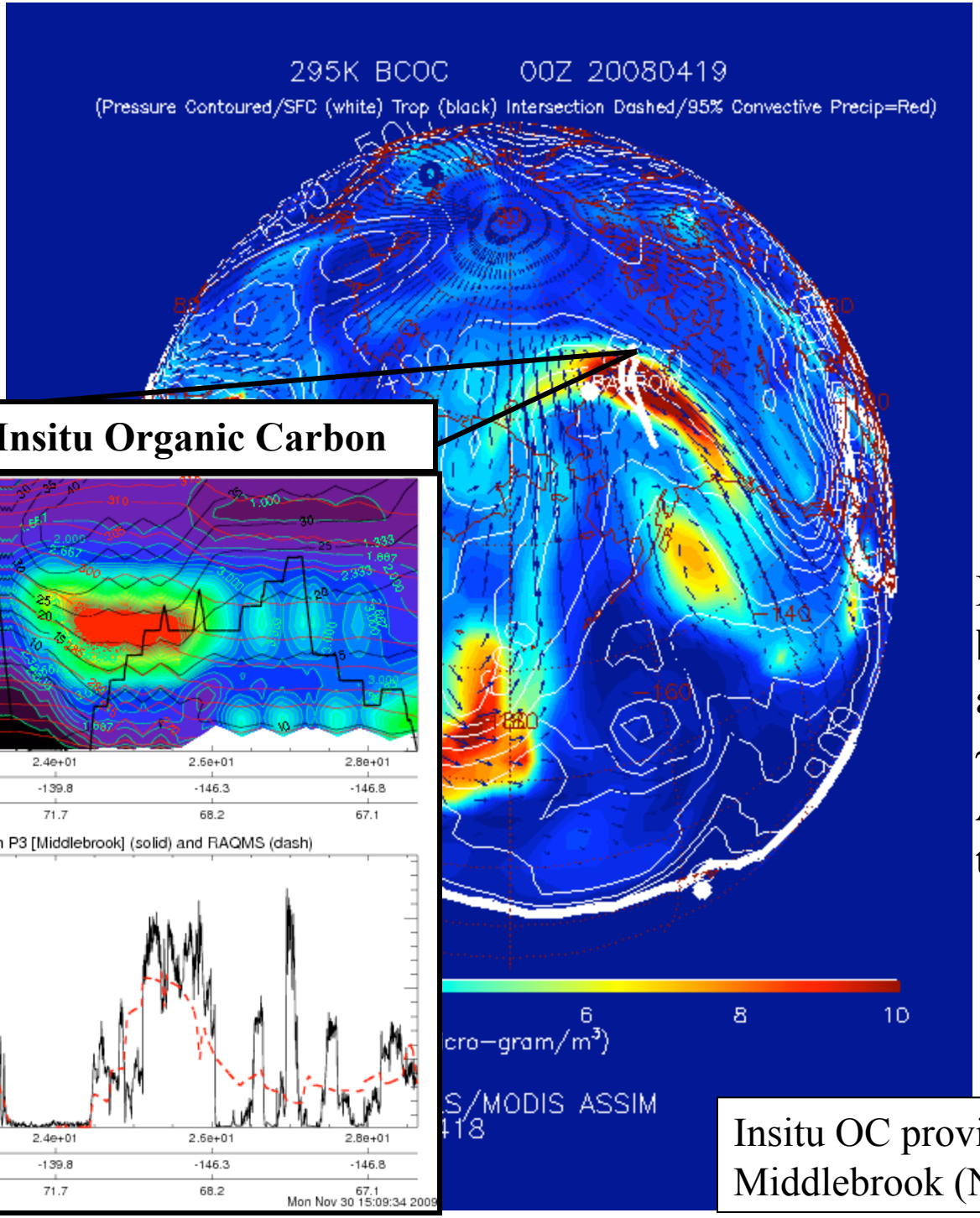
NOAA P3 insitu data provided by Tom Ryerson, Ryan Spackman and Ann Middlebrook (NOAA/ESRL)

WP-3D Flight Track Map

Flight tracks in Alaska.




295K BCOC 12Z 20080414
(Pressure Contoured/SFC (white) Trop (black) Intersection Dashed/95% Convective Precip=Red)
BARROW
0
2
4
6
8
10
(micro-gram/m3)
RAQMSG –24hr OMI/MLS/MODIS ASSIM
Initialized 12Z 20080414

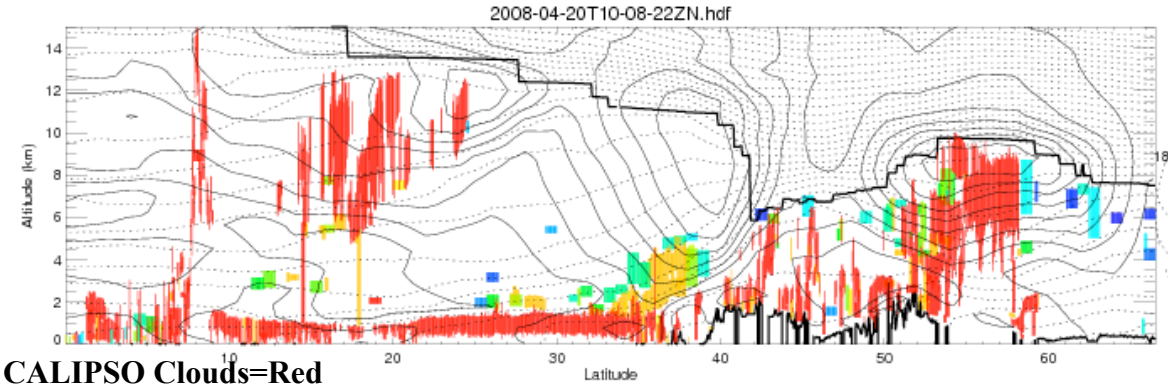


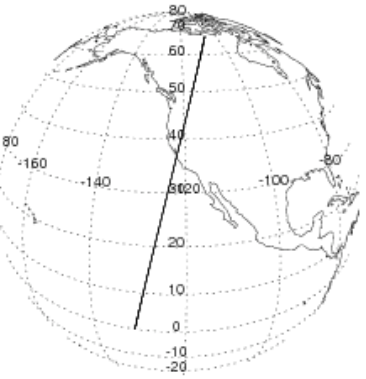
RAQMS vs P3 Insitu Organic Carbon

Biomass burning aerosols at ~5km (295K) in Arctic upper troposphere

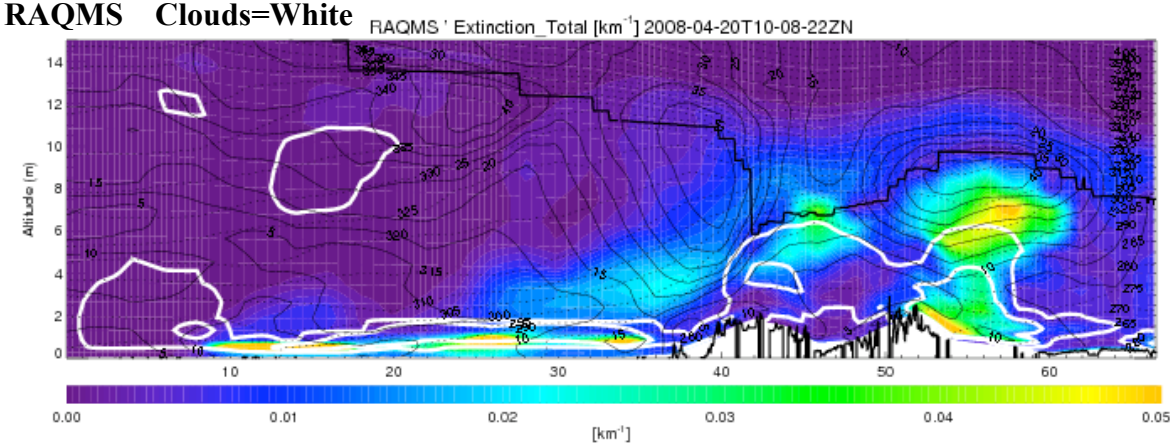
Insitu OC provided by Ann Middlebrook (NOAA/ESRL)

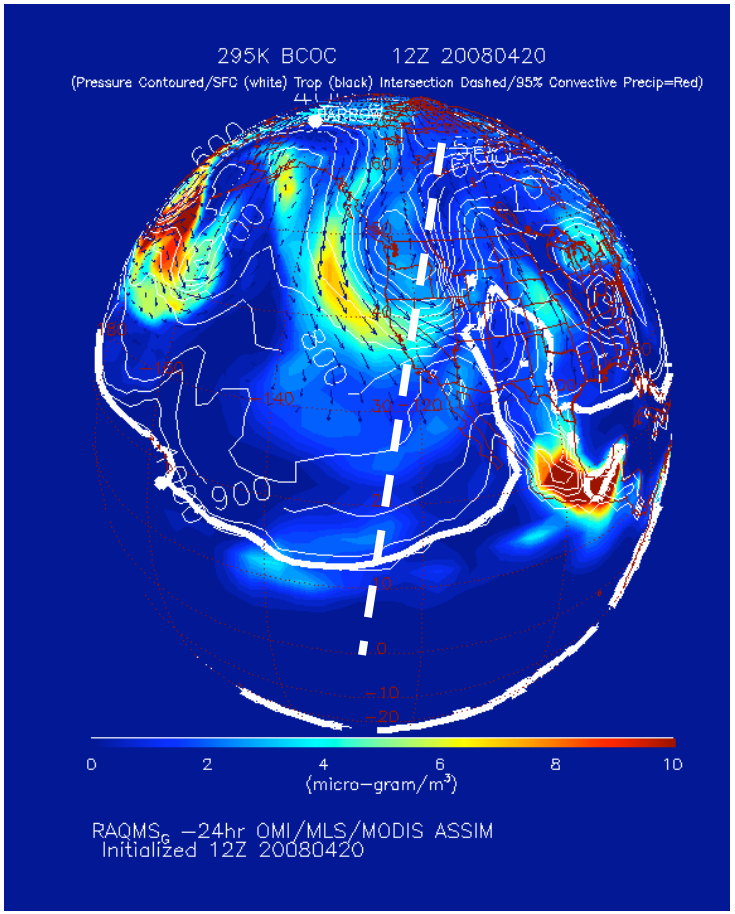
CALIPSO vs RAQMS Extinction: April 20, 2008





CALIPSO Clouds=Red
RAQMS Clouds=White

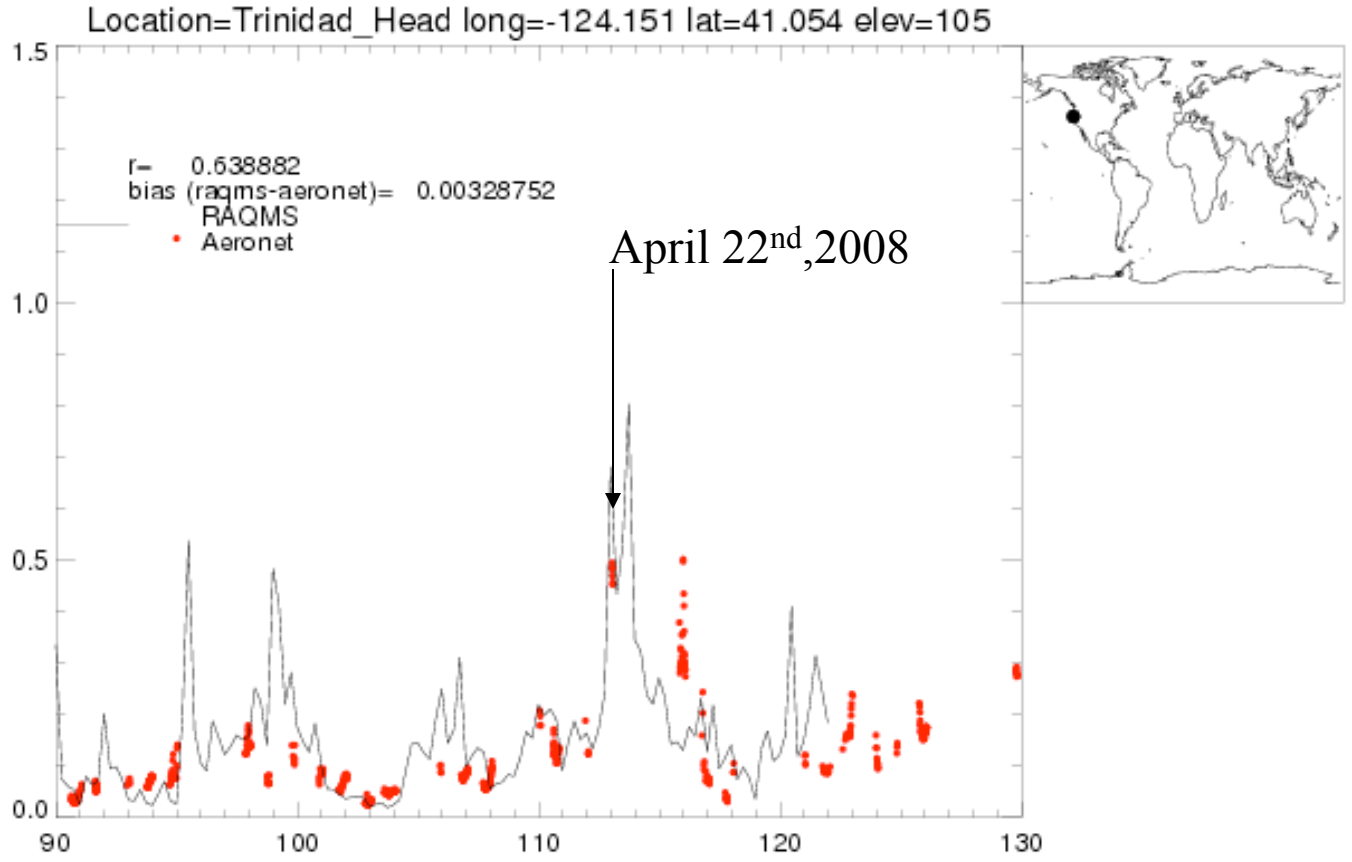




Biomass burning aerosols at ~2-4km (295K) in Mid-latitude lower troposphere

RAQMS analysis underestimates total extinction associated with biomass burning plume relative to CALIPSO

Trinidad Aeronet vs RAQMS AOD: April 2008



Biomass burning aerosols observed at Trinidad Head on April 22, 2008

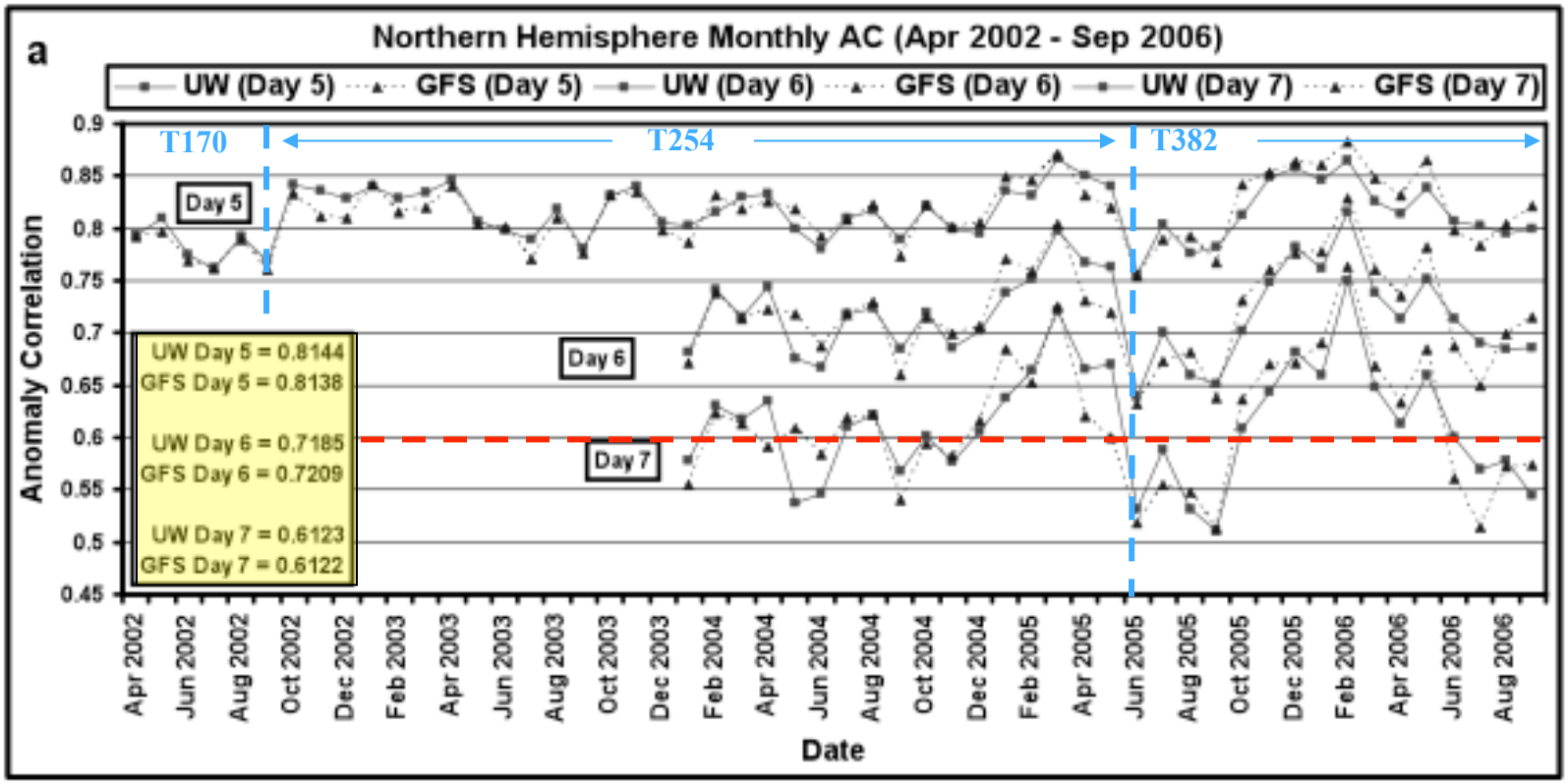
RAQMS analysis overestimates AOD associated with biomass burning plume relative to Aeronet

Assessment of Global Forecast Skill

- Anomaly Correlations (AC)
  - April Monthly mean removed
  - Spectrally truncated to wavenumber 20
- Distribution of RMS errors

$$S_{time}(\text{Analysis-Forecast})^2$$

UW-Hybrid (0.7x0.7) Global Forecast Skill (500mb heights)



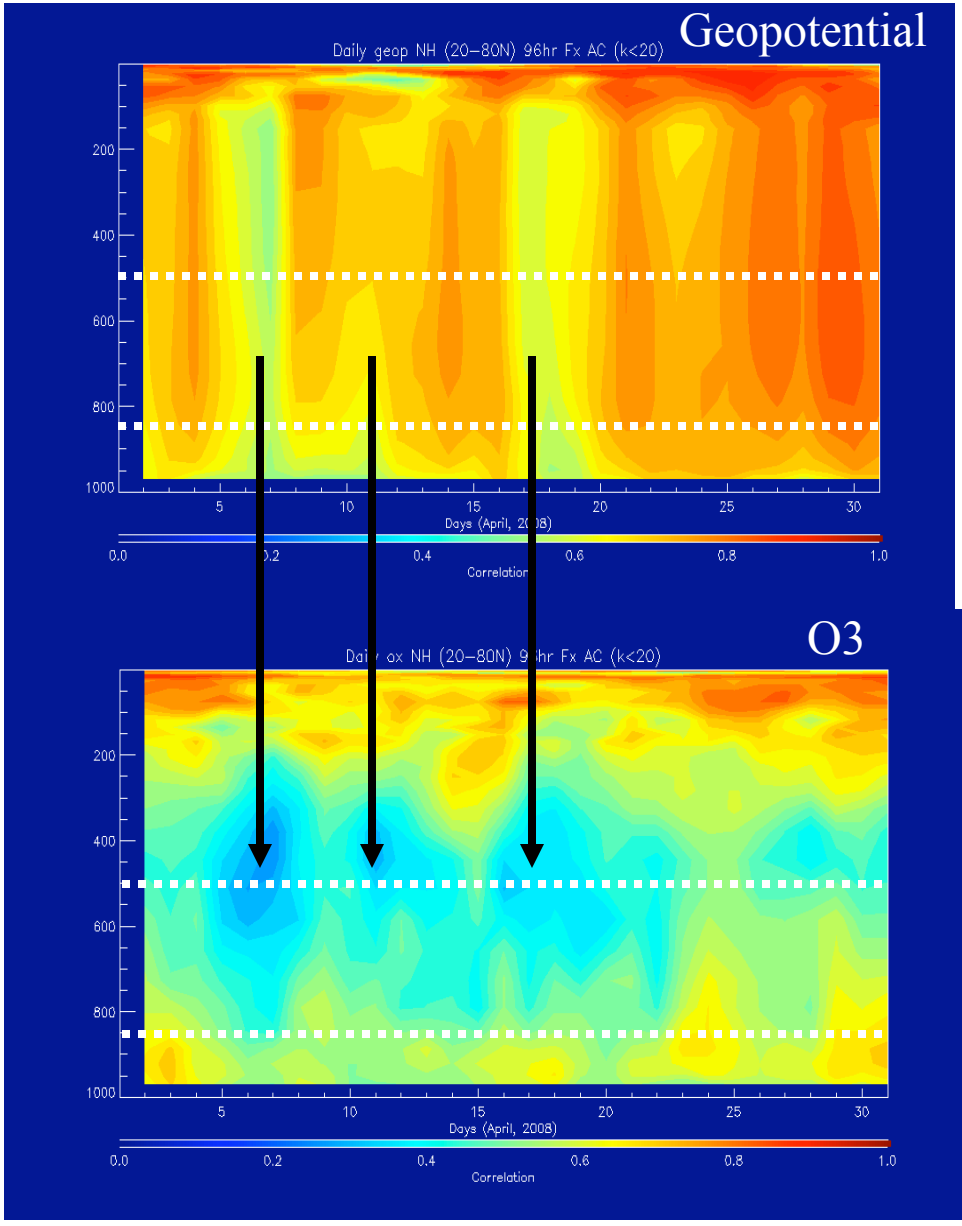
useful Skill

NH (20-80N) Anomaly Correlation (AC) between analysis and forecast 500mb heights (Identical physics, planetary wave numbers 1-20)

UW ¥¥¥ model: 0.7 degree (~T170), 37 layers (L37)

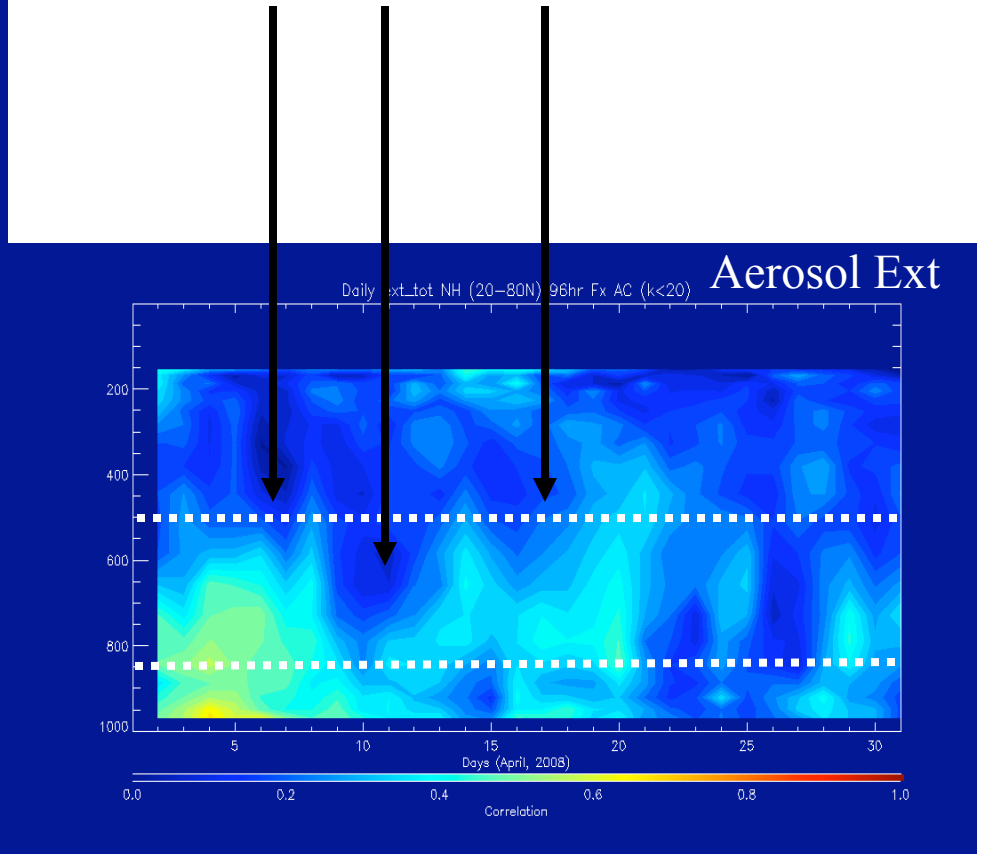
From Zapotocny et al., 2007, "Daily Numerical Weather Prediction with the Global University of Wisconsin Hybrid ¥¥¥ Model", unpublished manuscript

2008 RAQMS (2x2) Global Forecast Skill (96hr NH Geopotential, O3 & Aerosol Extinction)

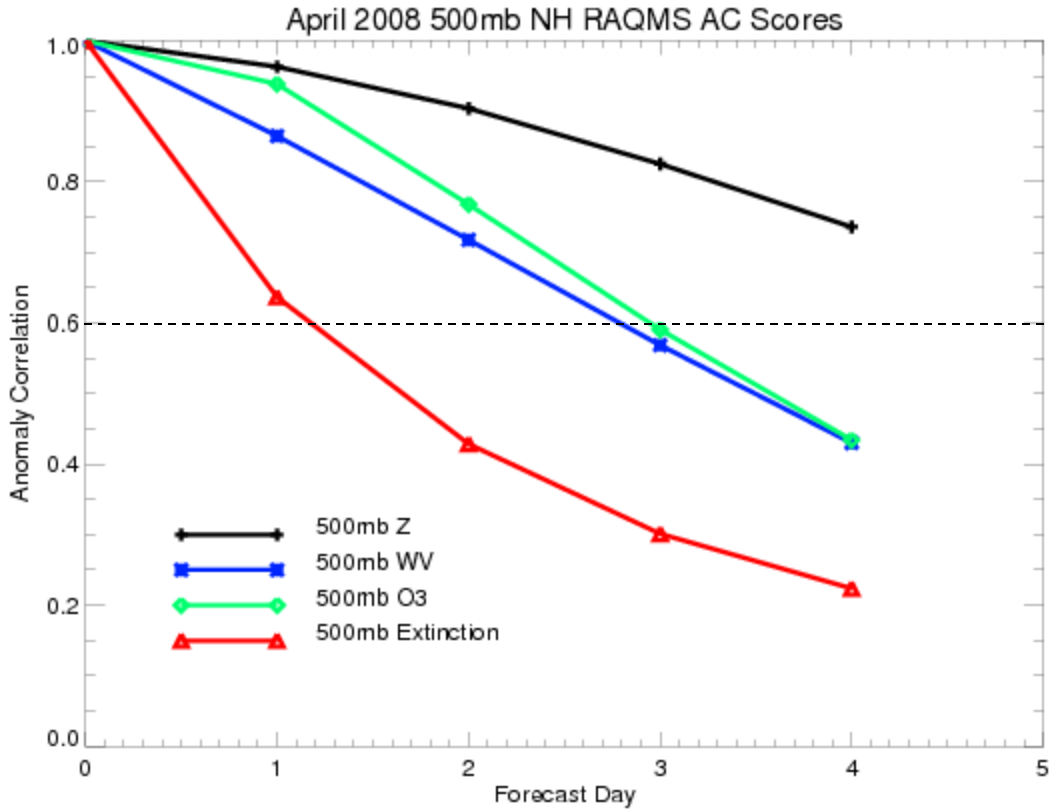


Mid-troposphere O3 and aerosol AC closely linked to Dynamical AC

Not true in lower troposphere



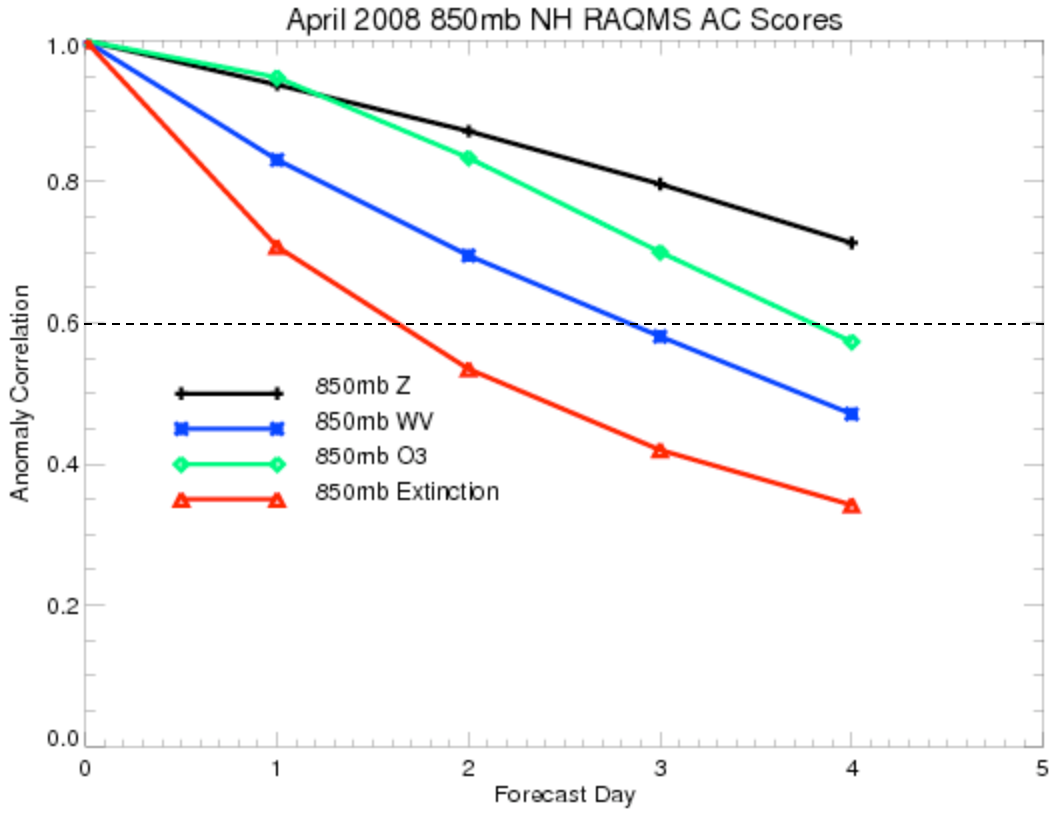
RAQMS (2.0x2.0) Global O3/Aerosol Forecast Skill
(500mb with MODIS and OMI assimilation)



Skill Threshold

- **500mb ozone forecasts have useful skill to 3 days (slightly better than water vapor)**
- **500mb extinction forecasts have useful skill for 1 day**

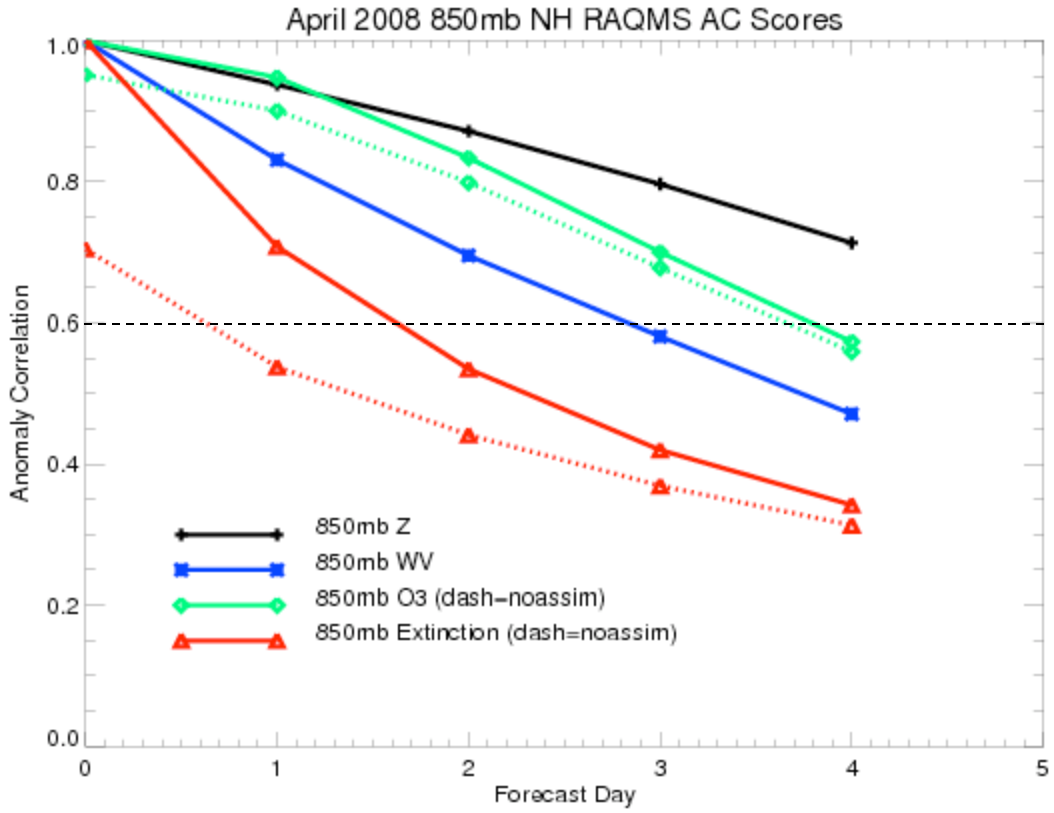
RAQMS (2.0x2.0) Global O3/Aerosol Forecast Skill
(850mb with MODIS and OMI assimilation)



Skill Threshold

- **850mb ozone forecasts have useful skill past 3 days (significantly better than water vapor)**
- **850mb extinction forecasts have useful skill for ~1.5 days**

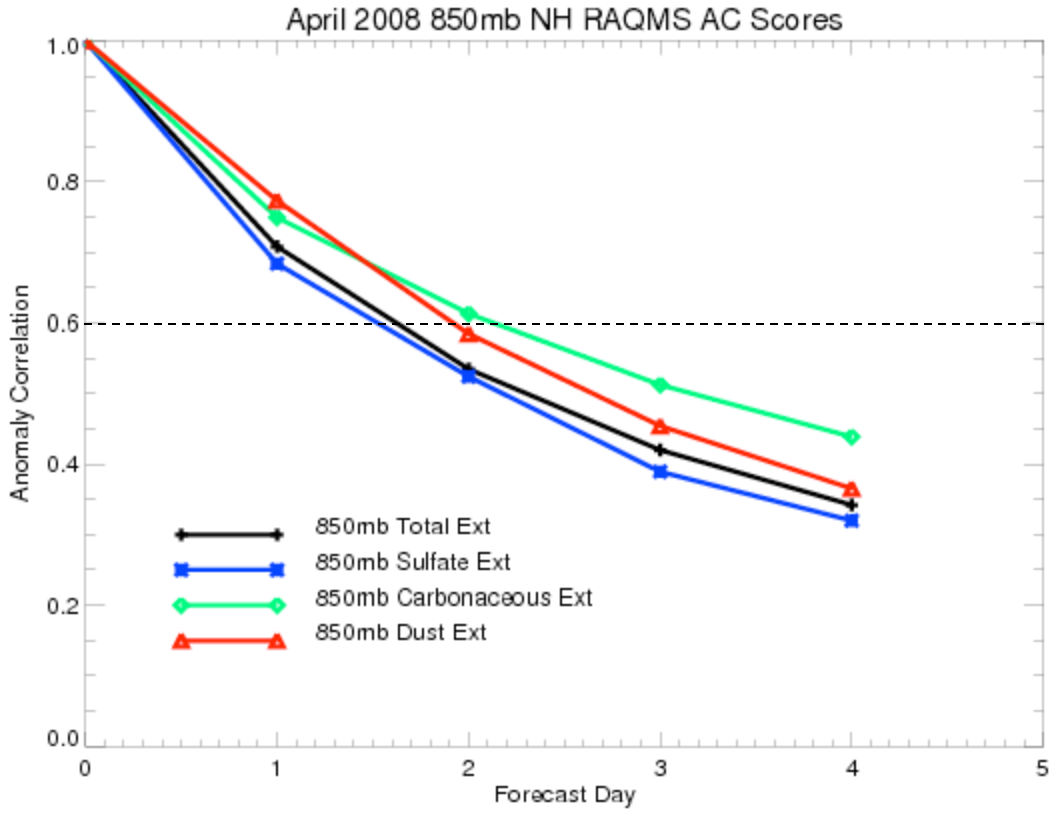
RAQMS (2.0x2.0) Global O3/Aerosol Forecast Skill
(850mb with and without MODIS and OMI assimilation)



Skill Threshold

- **Assimilation of OMI O3 column has a positive impact on 850mb Ozone**
- **Assimilation of MODIS AOD has a large positive impact on 850mb extinction**

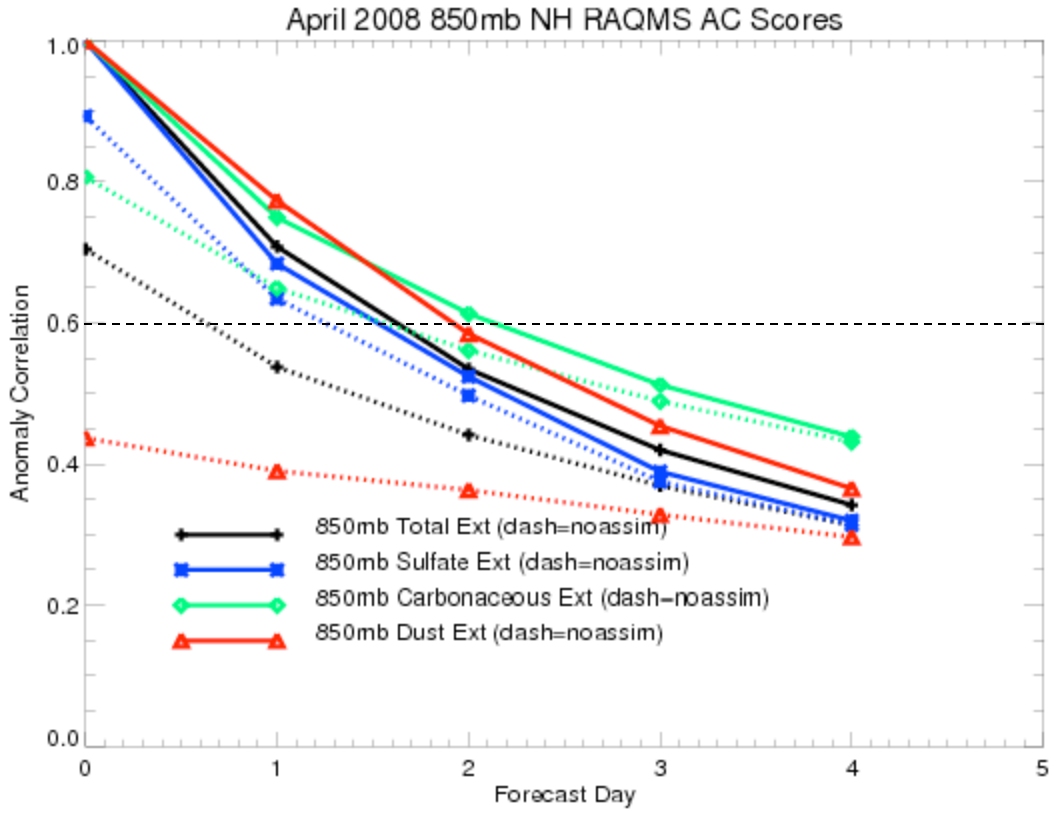
RAQMS (2.0x2.0) Global Aerosol Forecast Skill
(850mb with MODIS and OMI assimilation)



Skill Threshold

•**Reduced Sulfate aerosol forecast skill determines Total aerosol forecast skill**

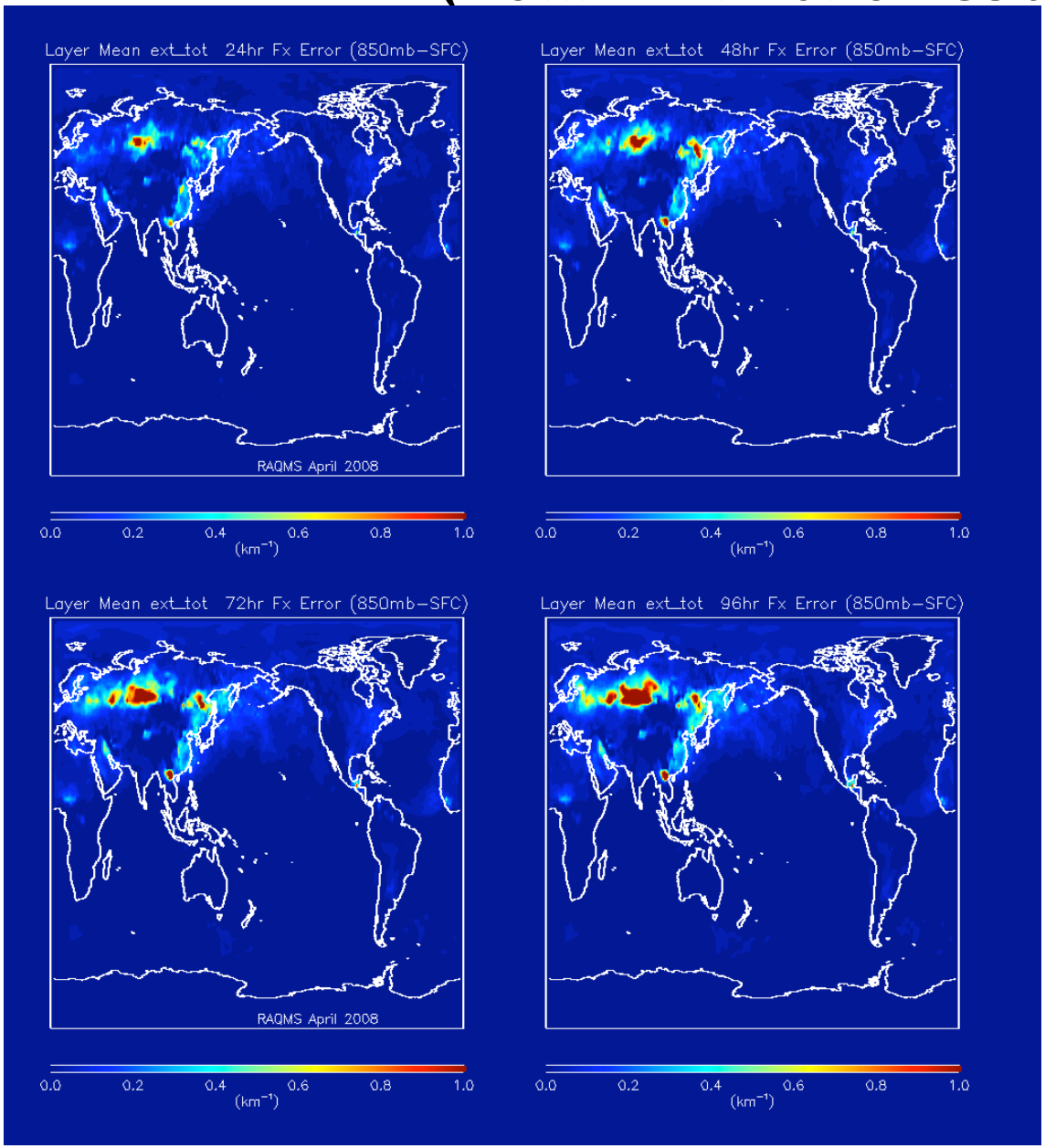
RAQMS (2.0x2.0) Global O3/Aerosol Forecast Skill
(850mb with and without MODIS and OMI assimilation)

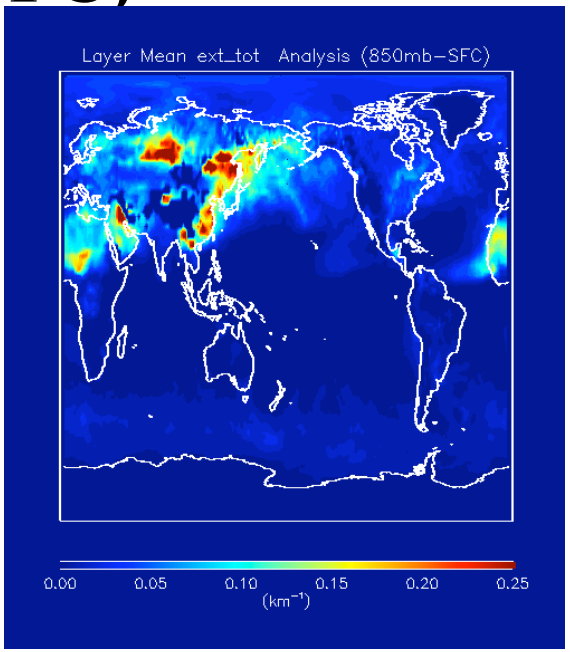


Skill Threshold

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

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

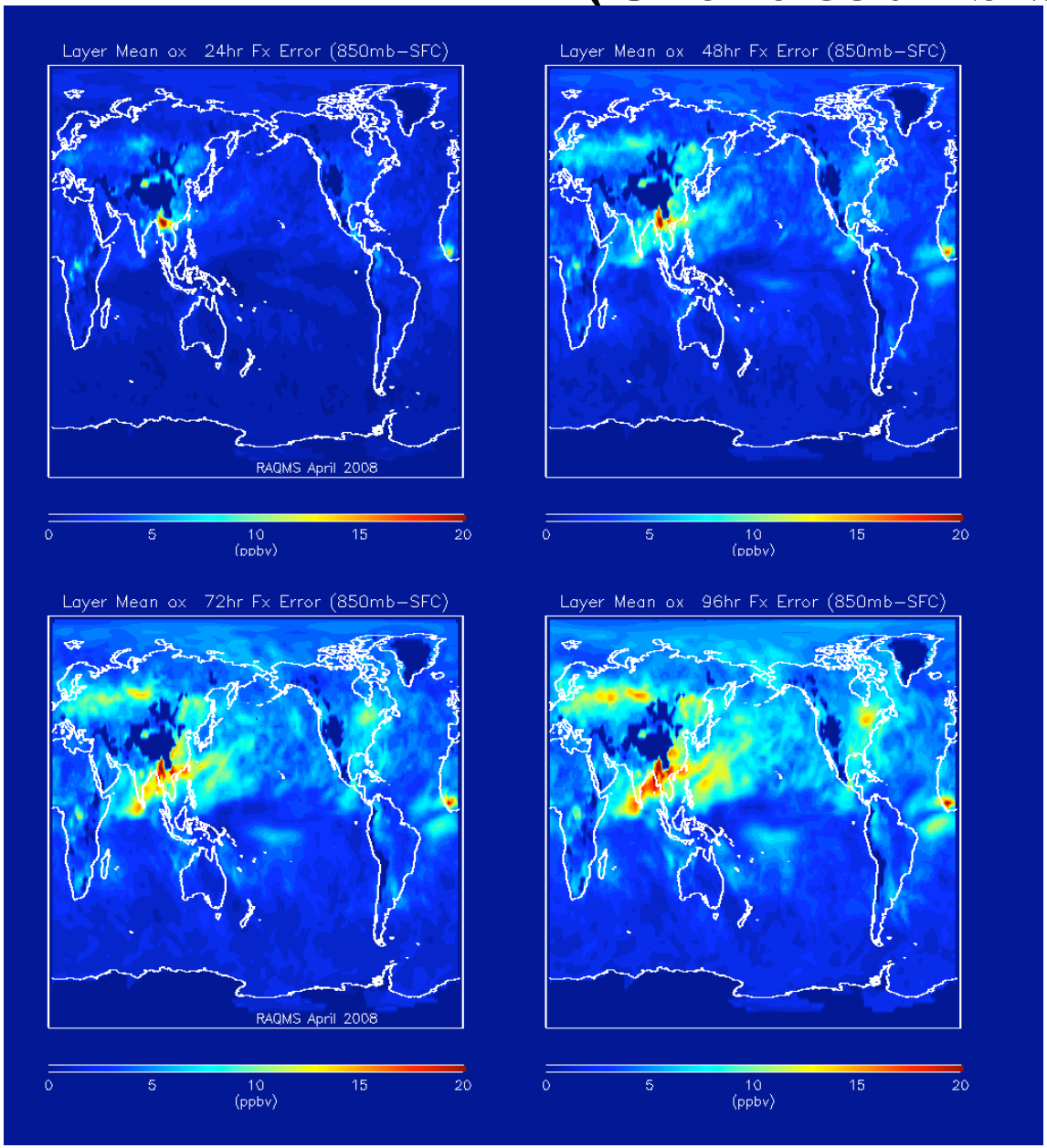


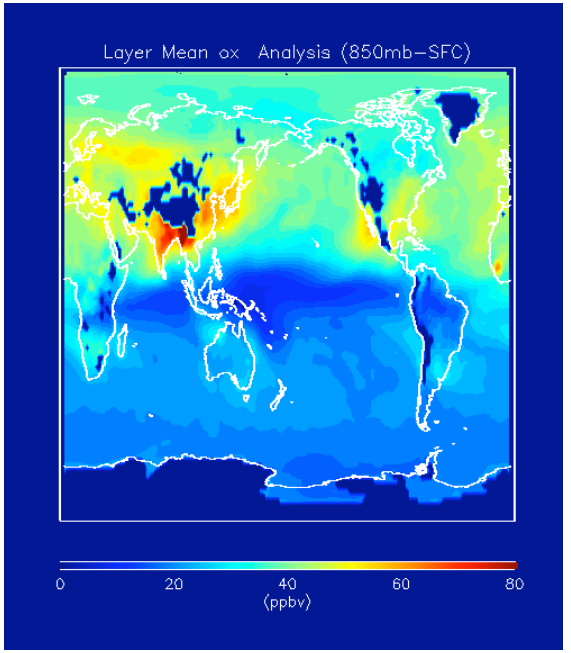


Large errors in Aerosol Extinction forecasts over Southern Siberia (Kazakhstand, Baykal) and S.E. Asia (Thailand)

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

RAQMS April 2008 O3 RMS Errors
(Ozone 850mb-SFC)

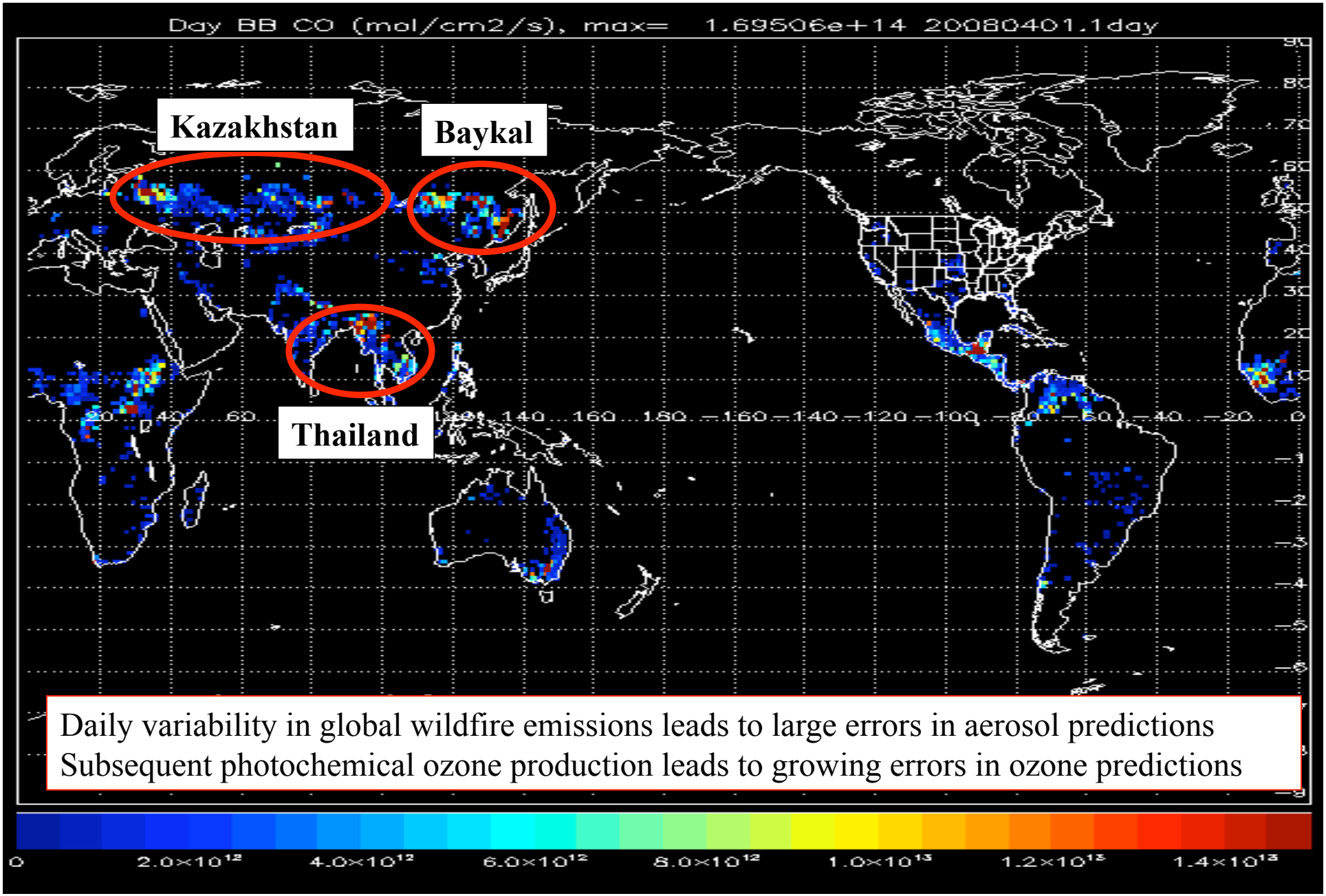




Largest error growth in ozone forecasts occur over Southern Siberia (Kazakhstan, Baykal) and S.E. Asia (Thailand)

Note: Fx error color scale is 1/4 mean extinction color scale!

April 2008 Biomass Burning CO Emissions



Daily variability in global wildfire emissions leads to large errors in aerosol predictions
Subsequent photochemical ozone production leads to growing errors in ozone predictions

Conclusions

Ozone

•Assimilation of MLS (stratospheric) and OMI (total column) ozone results in good (<10% except in lower stratosphere) agreement with ARCIONS ozonesonde

•Global ozone forecasts have useful skill to 3 days (500mb) and past (850mb)

Aerosol

•Assimilation of MODIS aerosol optical depth results in good (r=0.7, bias=-0.05) agreement with Aeronet

•Global extinction forecasts have useful skill for 1 day (500mb) and 1.5days (850mb)

- •Reduced Sulfate aerosol forecast skill determines total aerosol forecast skill
- •Carbonaceous and Dust extinctions are most significantly impacted by AOD assimilation

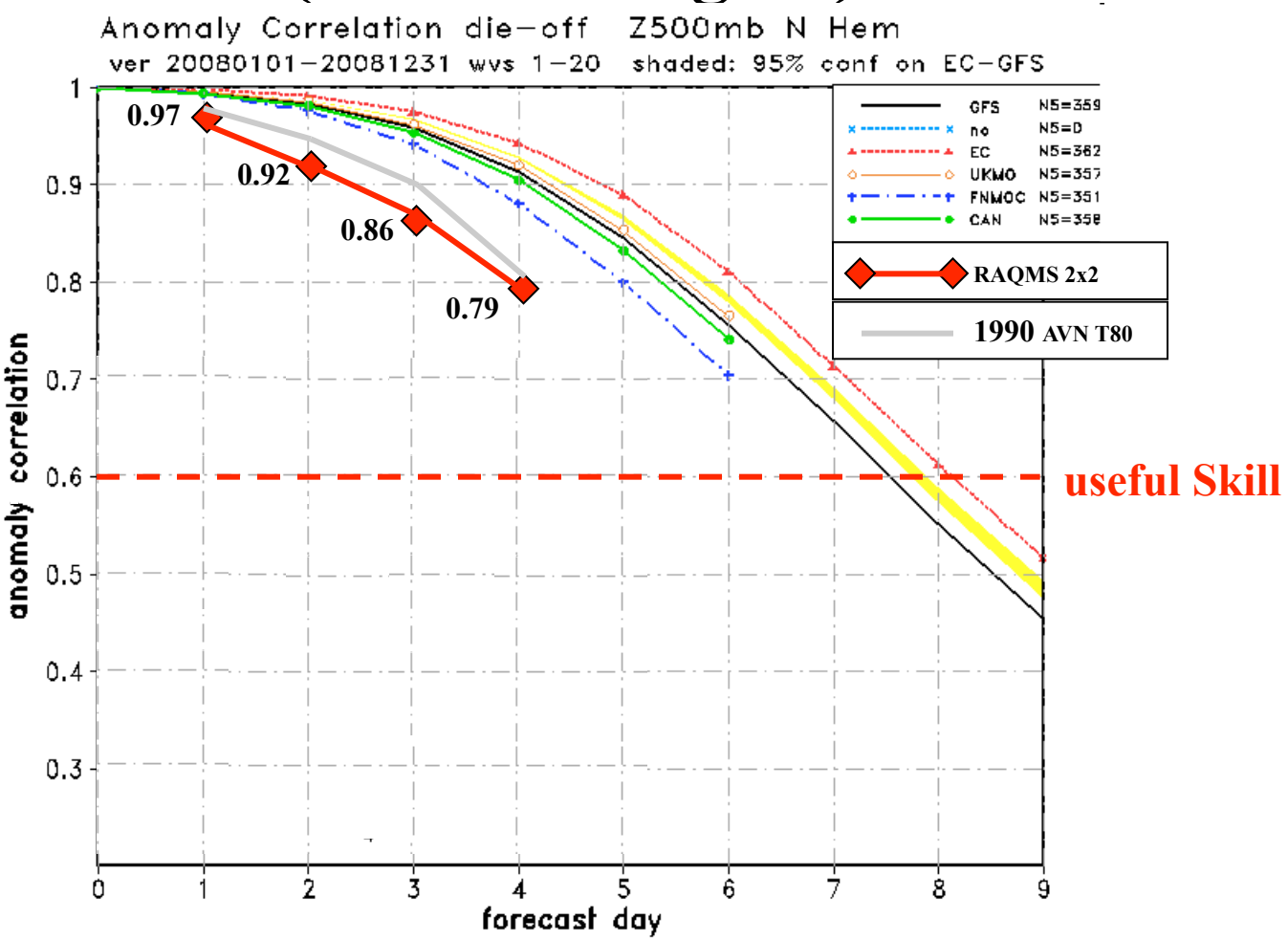
Wildfire Impacts

•Trans-Pacific transport of ozone and aerosol precursors from Kazakhstan, Baykal, and Thailand wildfires impacted Alaska and the continental US in April 2008

•Largest global scale ozone and aerosol forecast errors are associated with prediction of wildfire emissions

Extra Slides

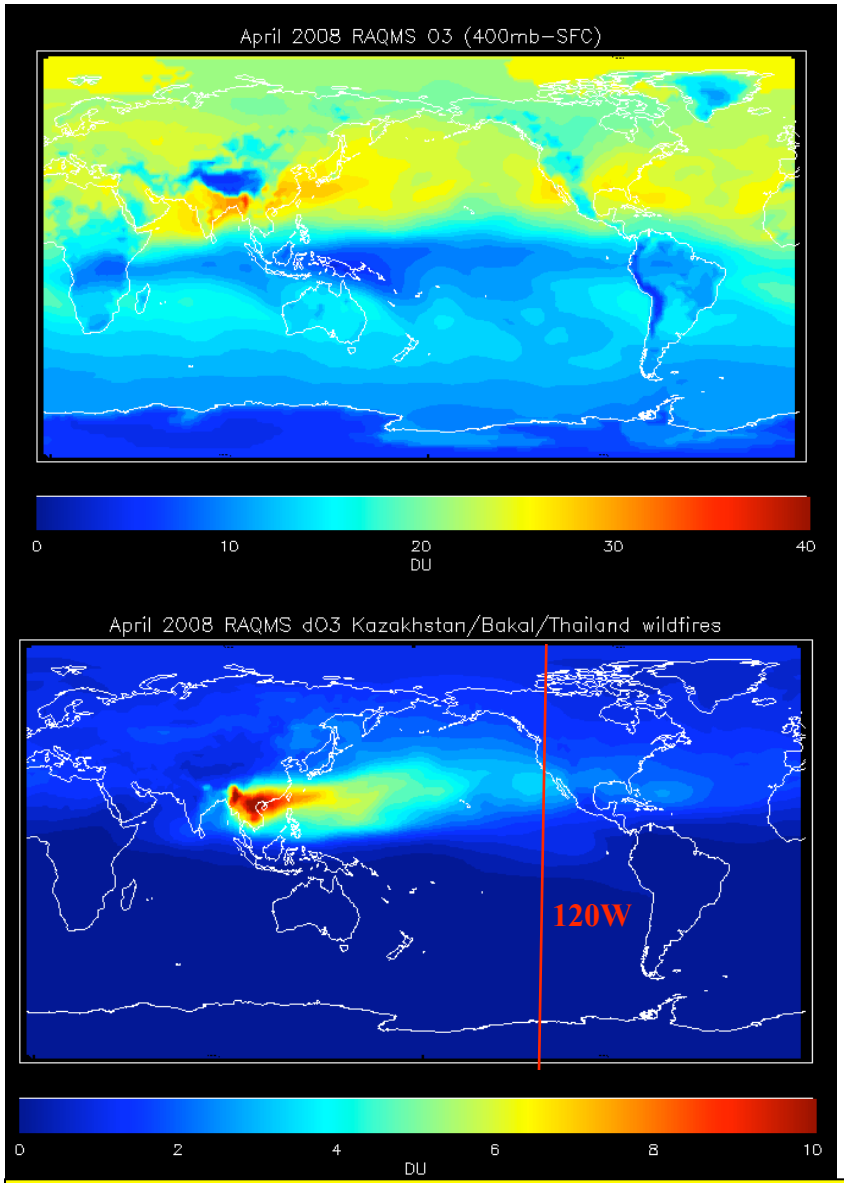
2008 RAQMS (2x2) Global Forecast Skill (500mb Heights)

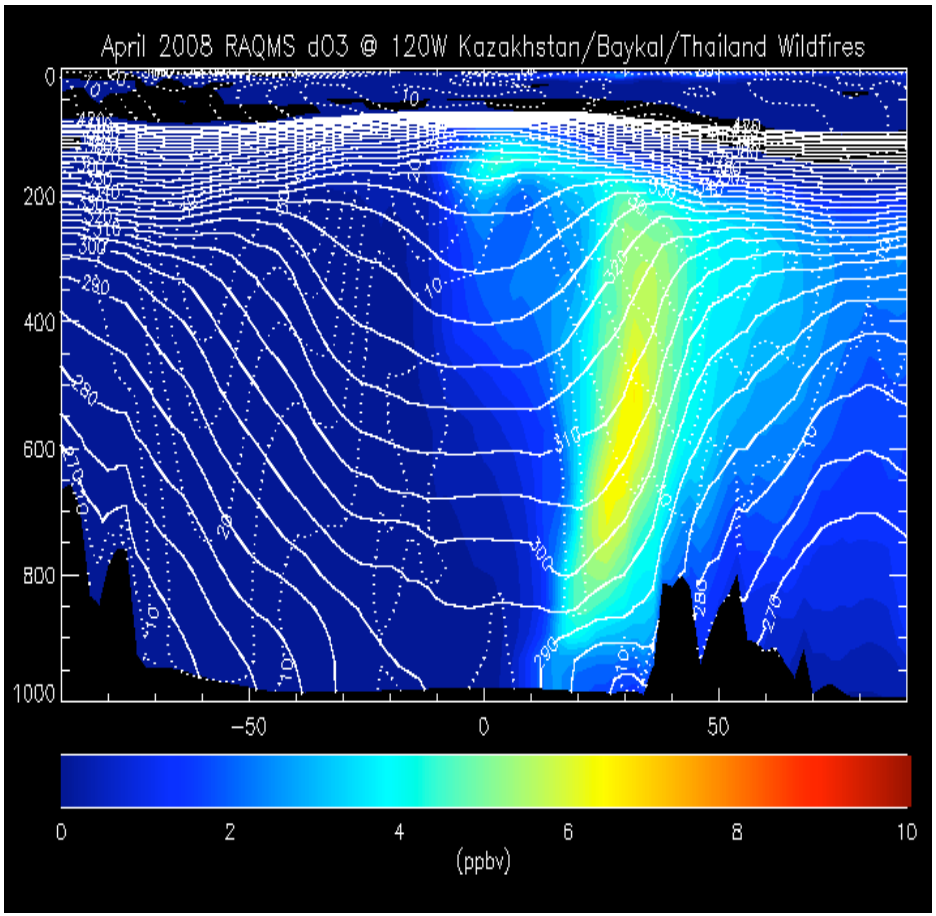


NH (20-80N) Anomaly Correlation (AC) between analysis and forecast 500mb heights (Different physics, RAQMS 2x2 vs GFS T382)

The RAQMS 2x2 NH Z500mb AC score is comparable to the 1990 AVN (T80~1.5 degrees)
UW-Hybrid (0.7x0.7) NH Z500mb AC score is comparable to 2005 GFS (T256 ~0.5degrees)

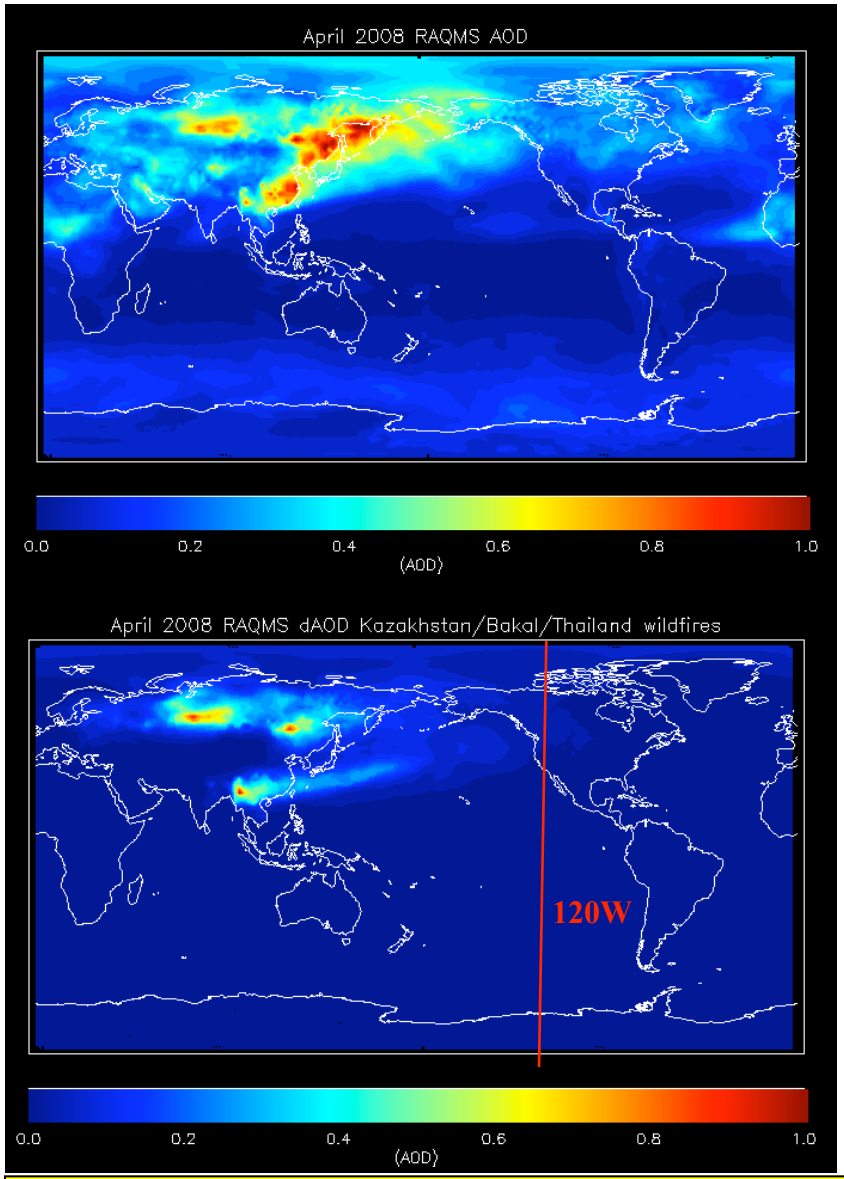
Impacts of Kazakhstan/Baykal/Thailand wildfires

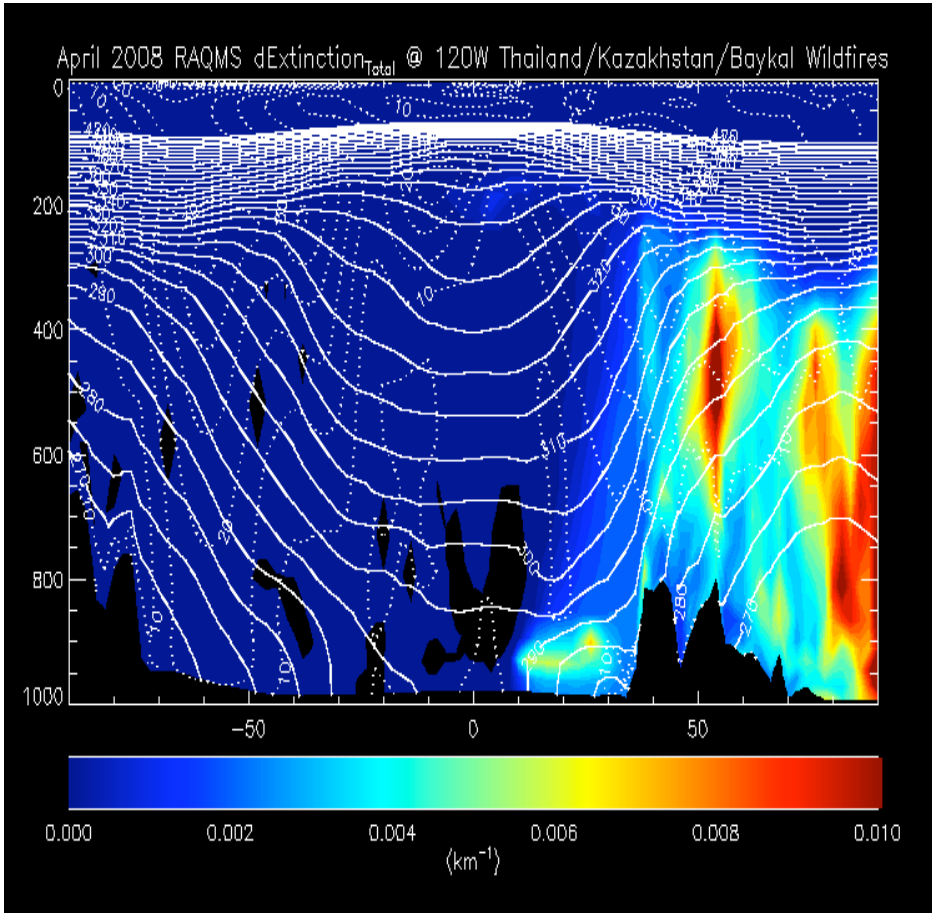




Impact of Thailand wildfires on tropospheric ozone production extends into North America with potential US Air Quality impacts

Impacts of Kazakhstan/Baykal/Thailand wildfires





Impact of Kazakhstan/Baykal/Thailand wildfires on tropospheric aerosols extends into North America with potential US Air Quality impacts