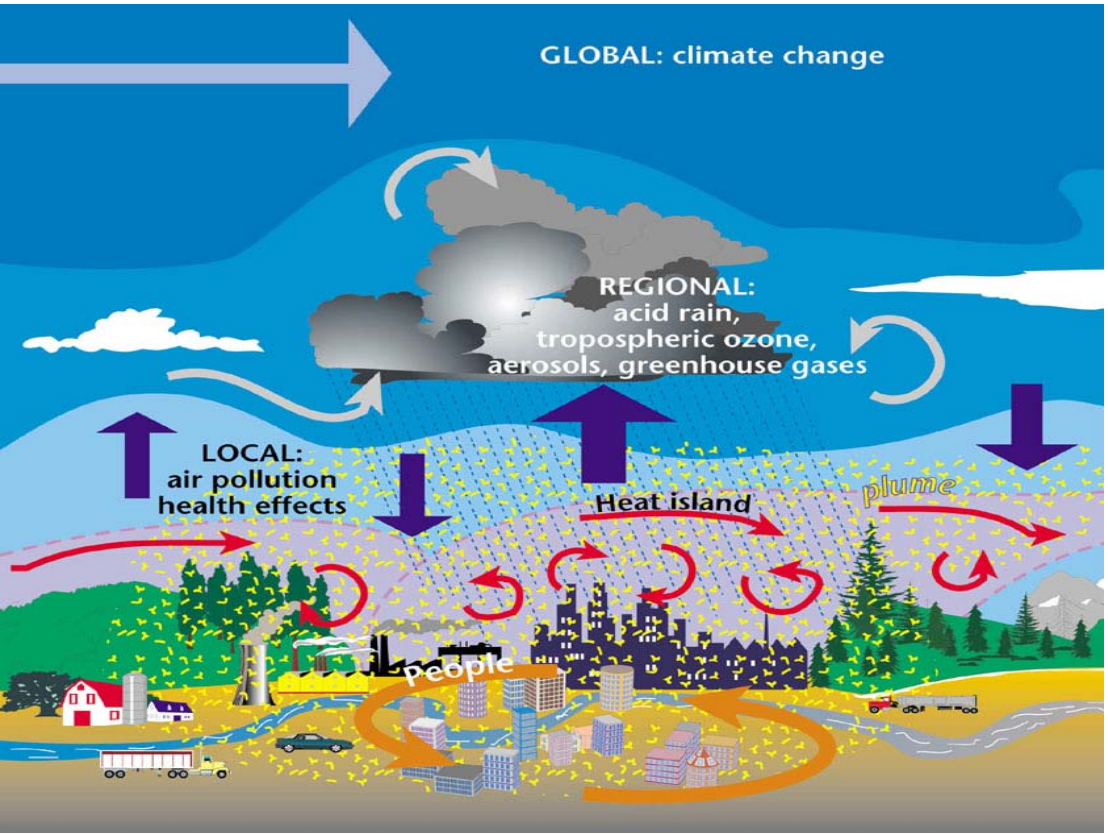
A Closer Integration of Models and Observations across Air Quality/Weather/Climate Applications -- *A Challenge and Opportunity for Improved Prediction & Analysis*

Greg Carmichael, Pablo Saide, Scott Spak, Yafang Cheng, Charlie Stanier (Univ. Iowa, USA) and Gufran Beig (IITM, India)



Today's talk -

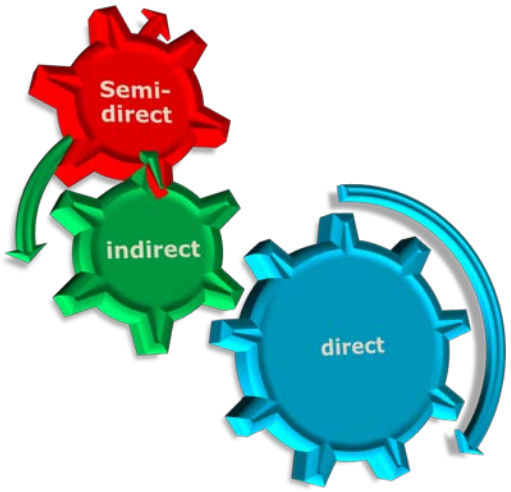
- Illustrate some multiscale air quality – weather feedbacks (aerosol focus)
- Their implications on air quality & NWP predictions and policy assessments.
- Observation/assimilation needs
- Help frame breakout discussions

Exploring Multiscale Air Quality – Weather Feedbacks

Current Applications: China, India, Chile, U.S.

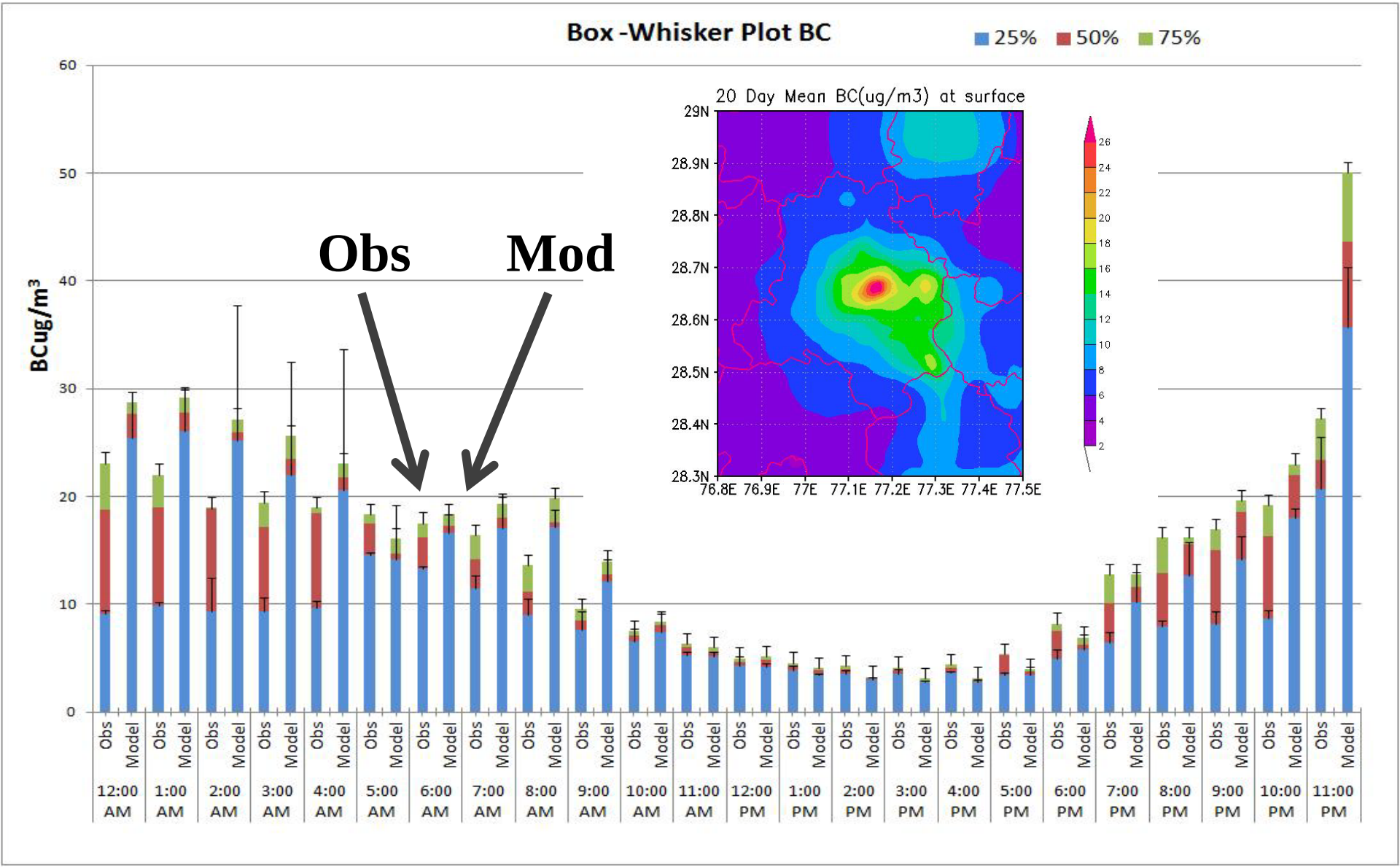
- Fast-J scheme [*Wild et al.*, 2000] within CBM-Z [*Zaveri and Peters*, 1999] to calculate **photolysis rate**

- Aerosol direct effects (direct and semi-direct: **Optical properties calculated by Mie theory** [*Fast et al.*, 2006] and then passed into the Goddard **short wave** radiative scheme.

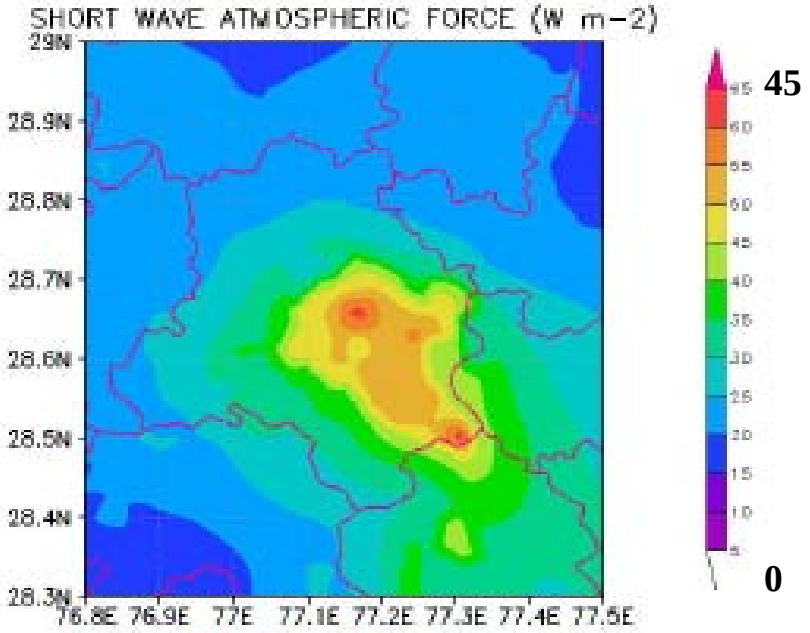


- Aerosol indirect effects (1st & 2nd)**:** **Aerosol activation** module to calculate activation of aerosols [*Ghan and Easter*, 2006, *Abdul-Razzak and Ghan*, 2002], and then passed to *Lin et al.* **Microphysics** and Goddard **short wave** radiation modules

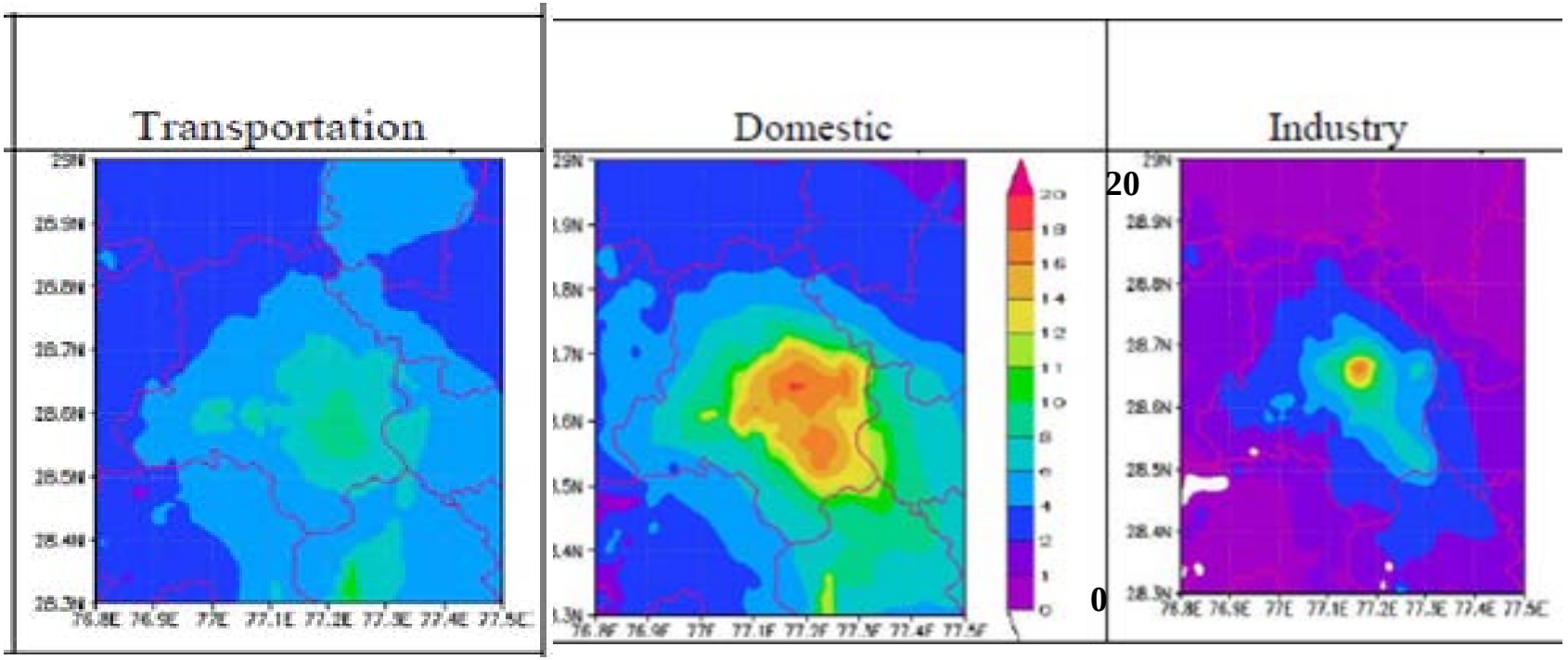
New BC (and PM2.5/10) Inventories Help Correct Previous Problems In Underestimating PM/BC Levels



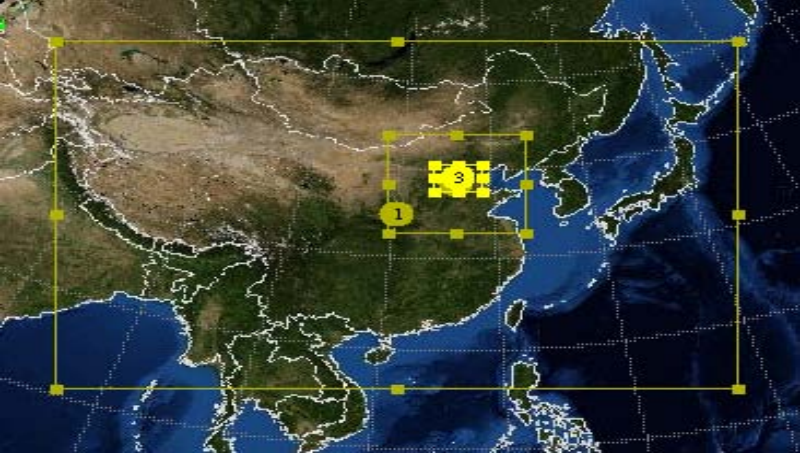
Anthropogenic Radiative Forcing Analysis By Sector in Delhi Shows Warming Due to Transport, Domestic and Industry - Implications for Policy

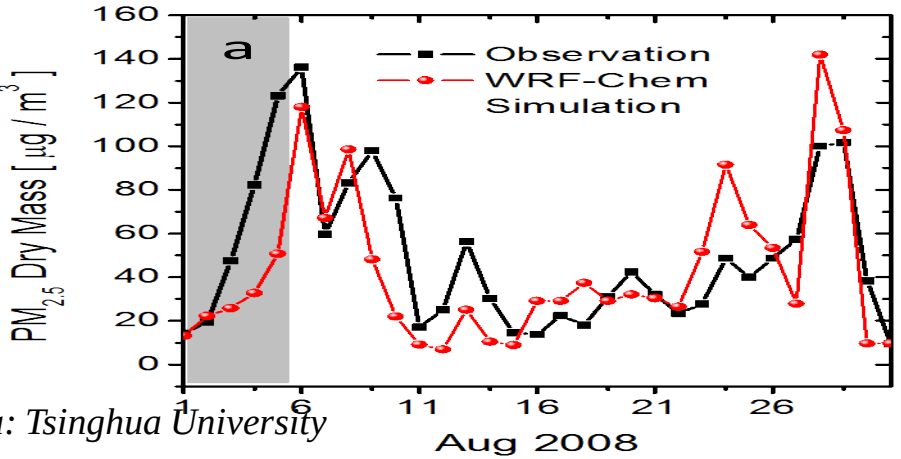


Anthro Rad Atmos Forcing (W/m²)

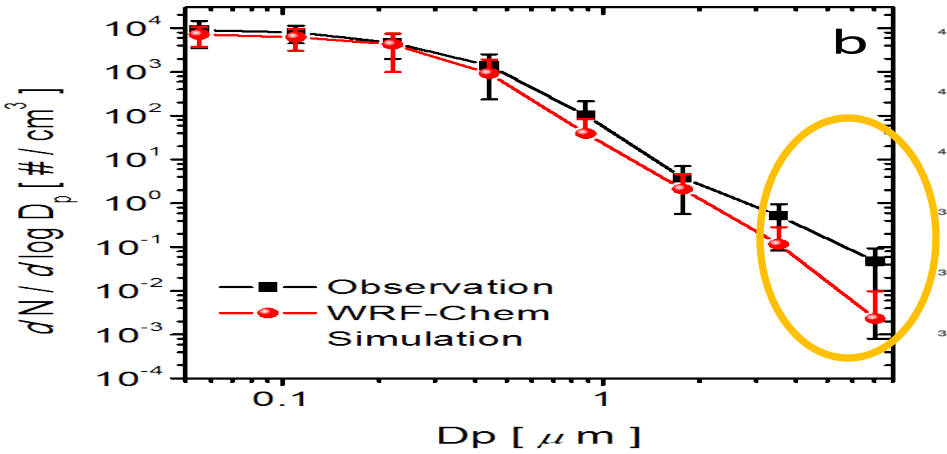


Exploring Multiscale Urban Air Quality – Weather Feedbacks with WRF-Chem China

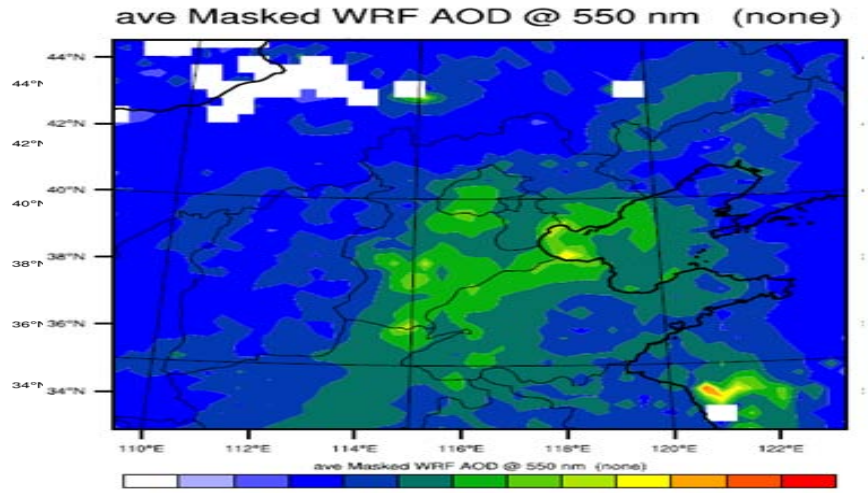


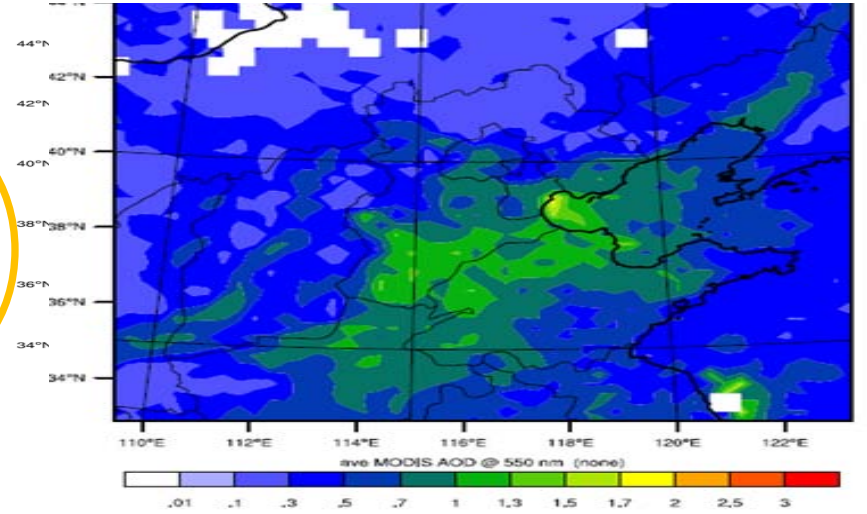


Data: Tsinghua University



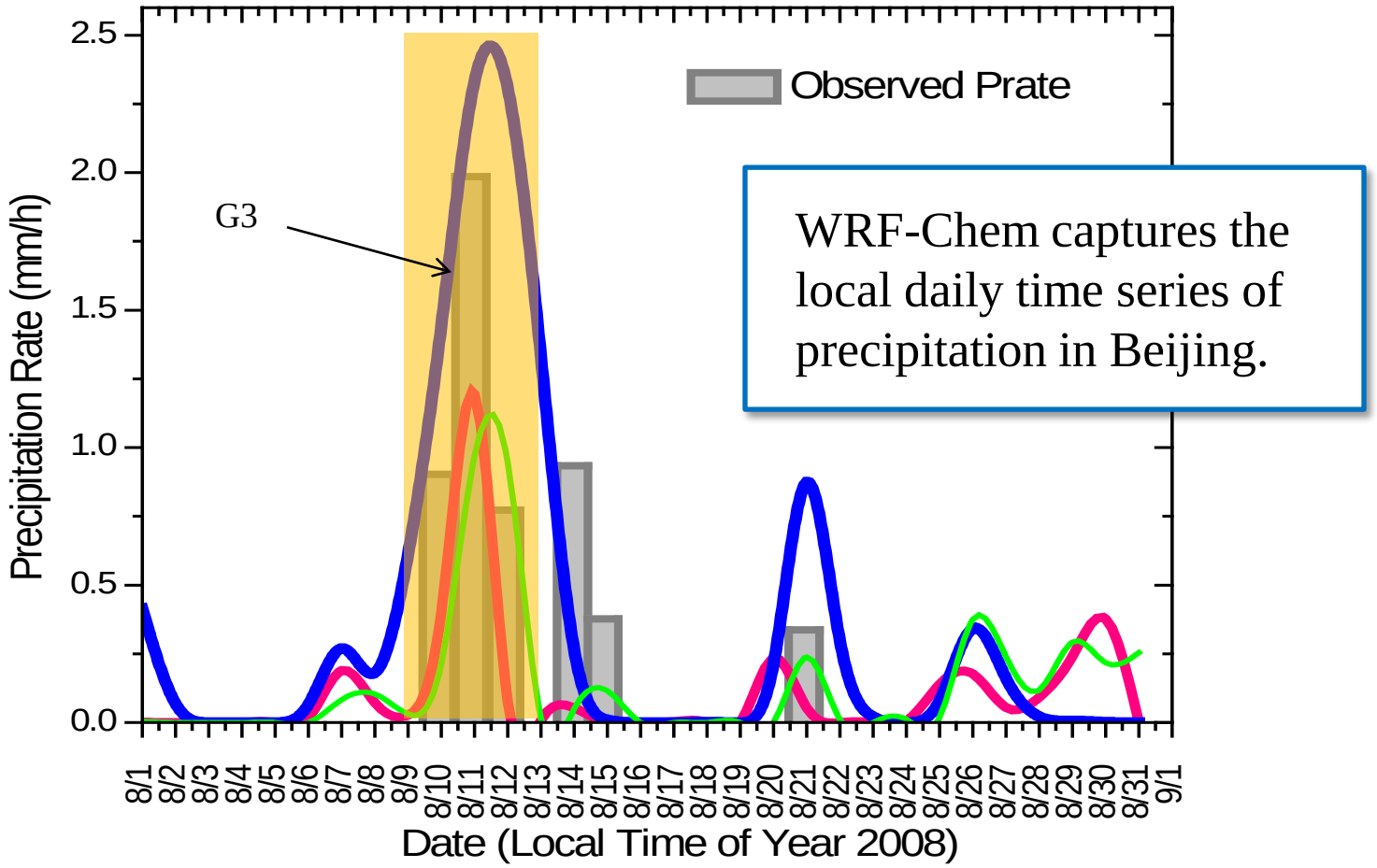
Data: Peking University





Simulating Continental Precipitation Events

Observations: Beijing Monitoring Center (*Wang et al.*, 2010)

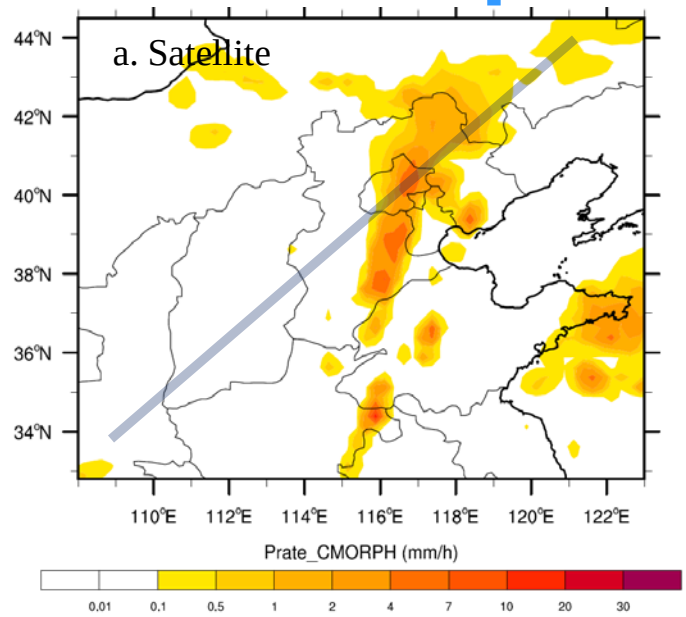


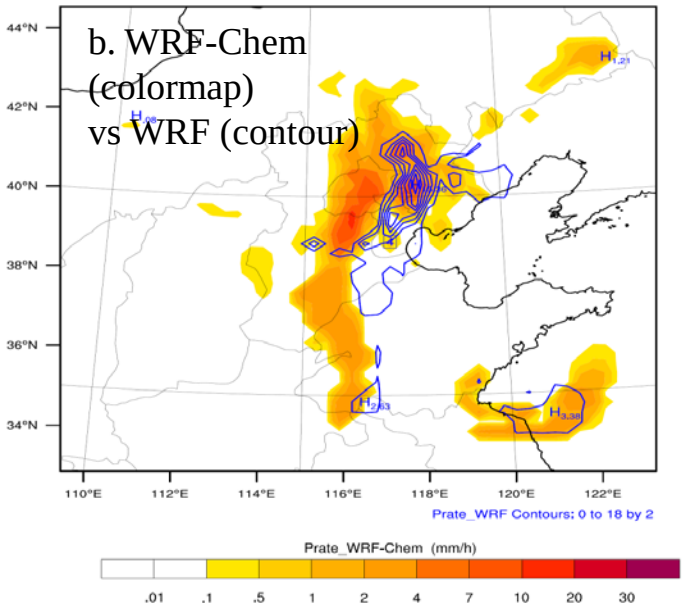
WRF-Chem captures the local daily time series of precipitation in Beijing.

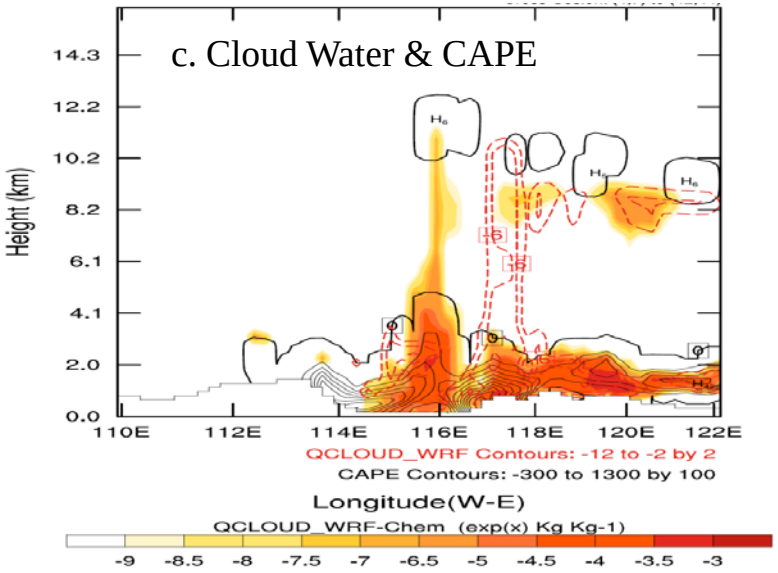
Grell 3 cumulus scheme

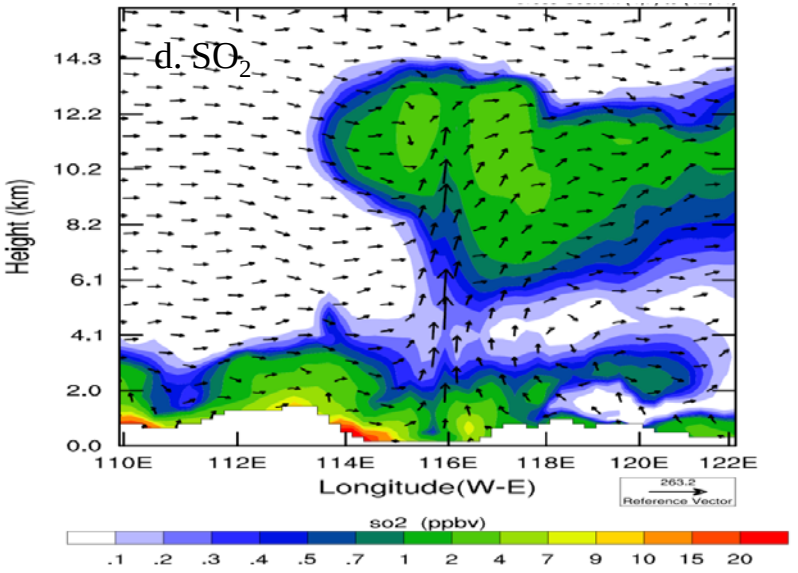
Sensitivity runs with **KF** and **GD** cumulus schemes

Aerosol Feedbacks Lead To Better Precip Predictions



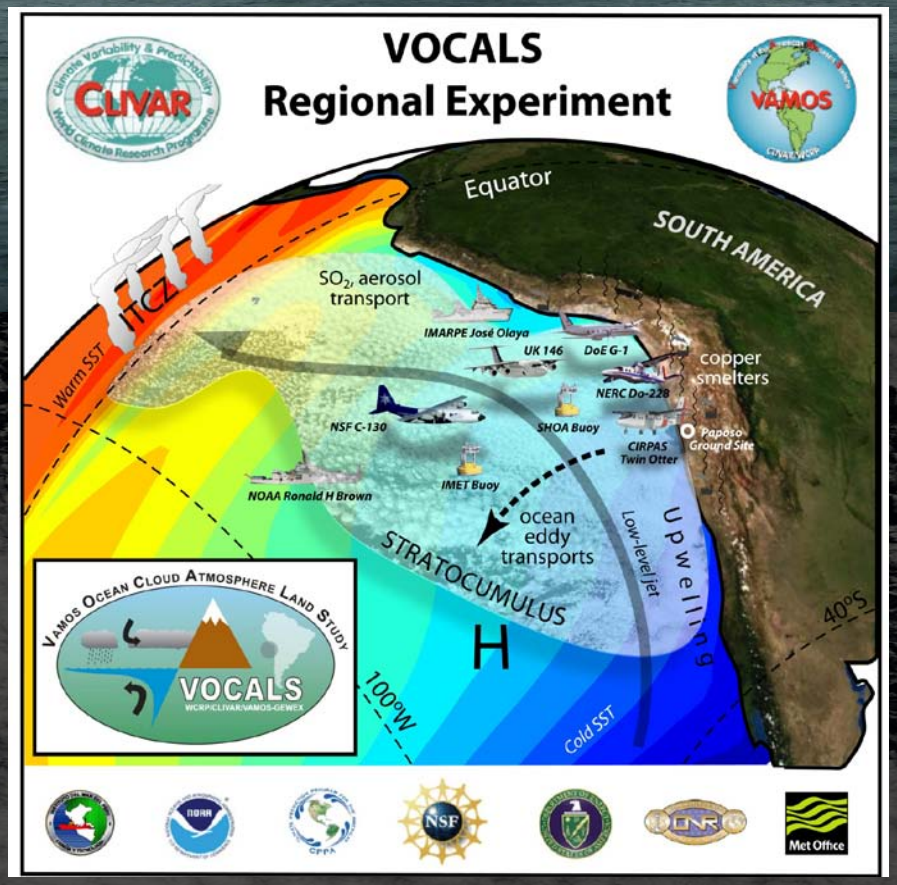






The Southeast Pacific
A Climate and Aerosol Modeling Challenge

The world's most widespread, persistent subtropical low cloud regime.

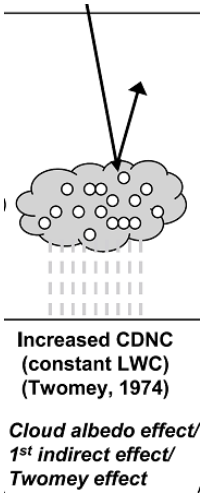


- WRF-Chem v3.3 CBMZ-MOSAIC/MYNN/Lin
- Fine vertical resolution: 75 levels, ~60m Δz < 3km
- Long spin-up: ~3-4 days

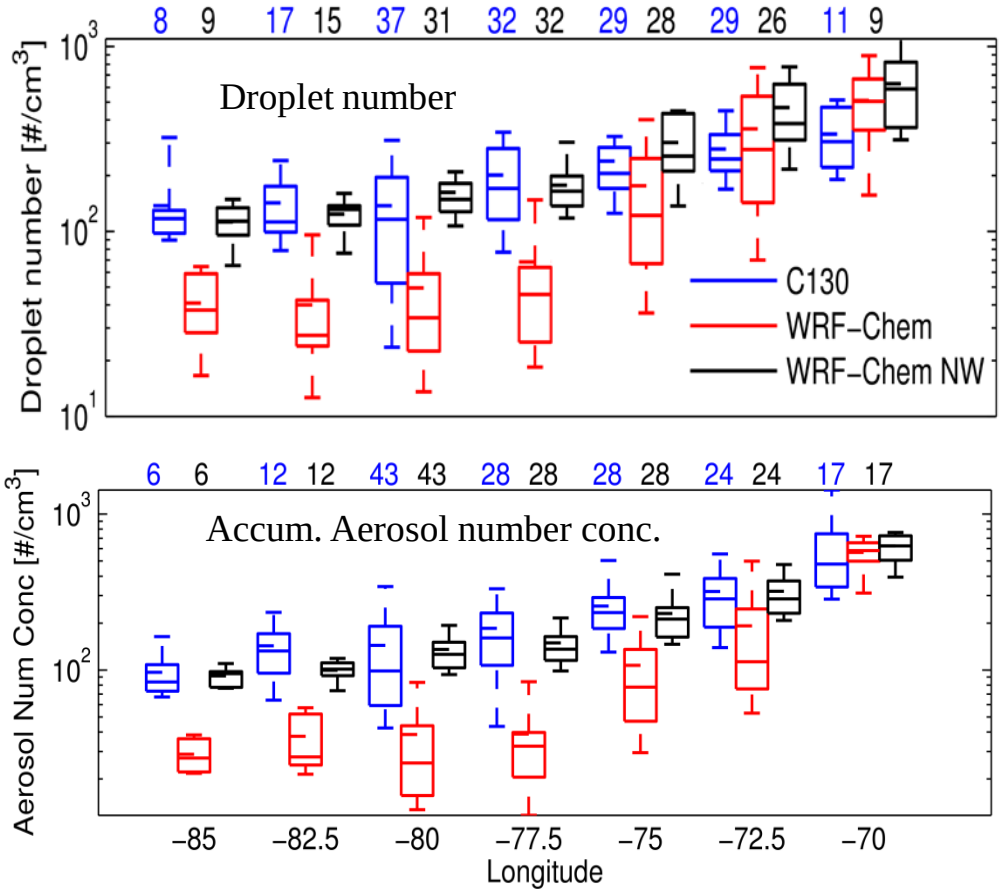
Reference: *Wood et al.* (2011)

Cloud Microphysics Comparison

- Observed aerosol #: Passive Cavity Aerosol Spectrometer Probe (PCASP)
- Observed droplet #: Cloud Droplet Probe (CDP)
- No wet dep model better for aerosol and for clouds (Indirect effects working OK)



WRF-Chem Base
WRF-Chem No Wet deposition
observations



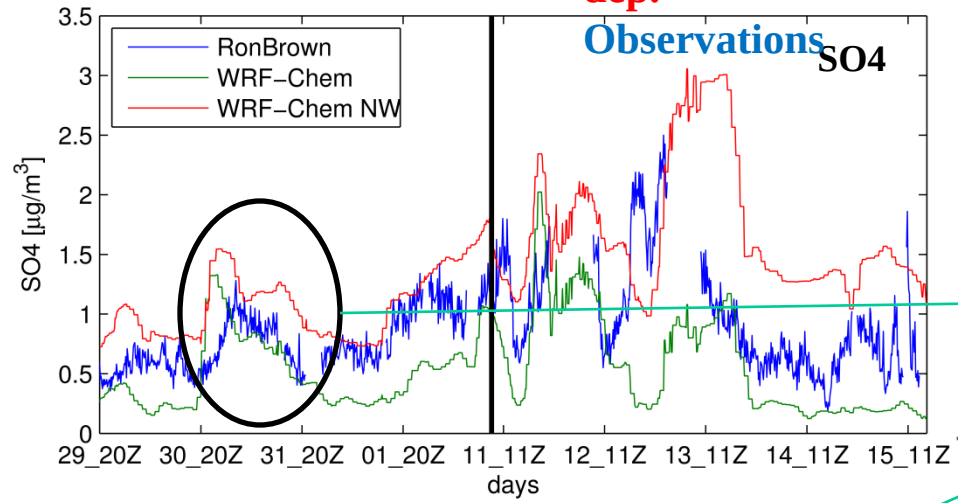
Saide et al., ACPD, 2011

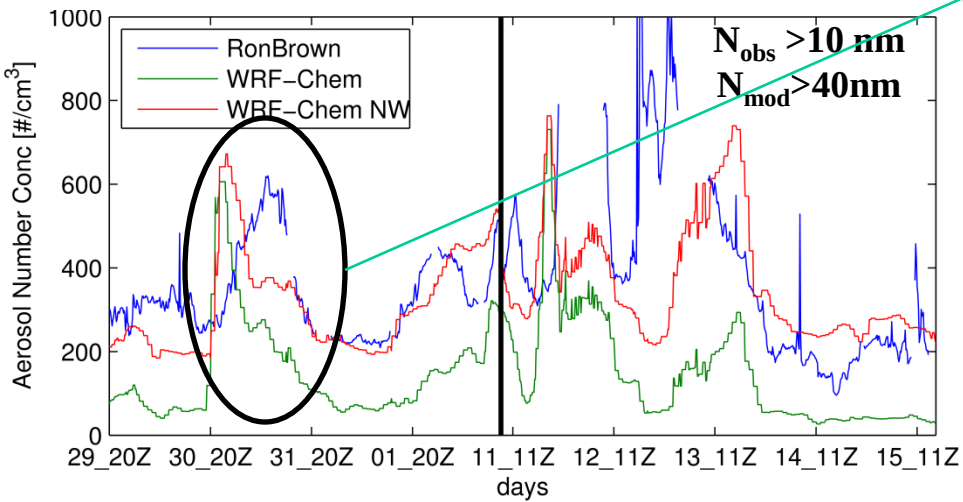
Linkage to Anthropogenic pollution

Continental sulfate pollution often seen at 75W, with clear influence on accumulation mode aerosol

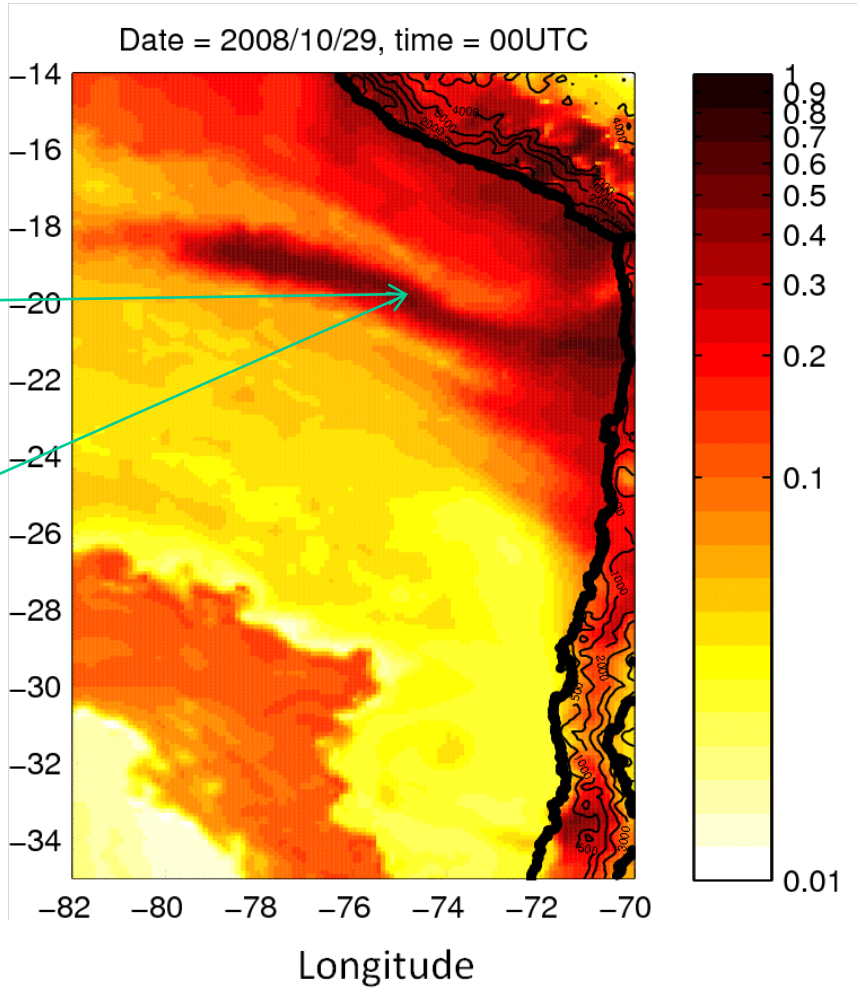
TWO 4 DAY PERIODS OF RON BROWN AT 75W

WRF-Chem Base
WRF-Chem No Wet dep.
Observations





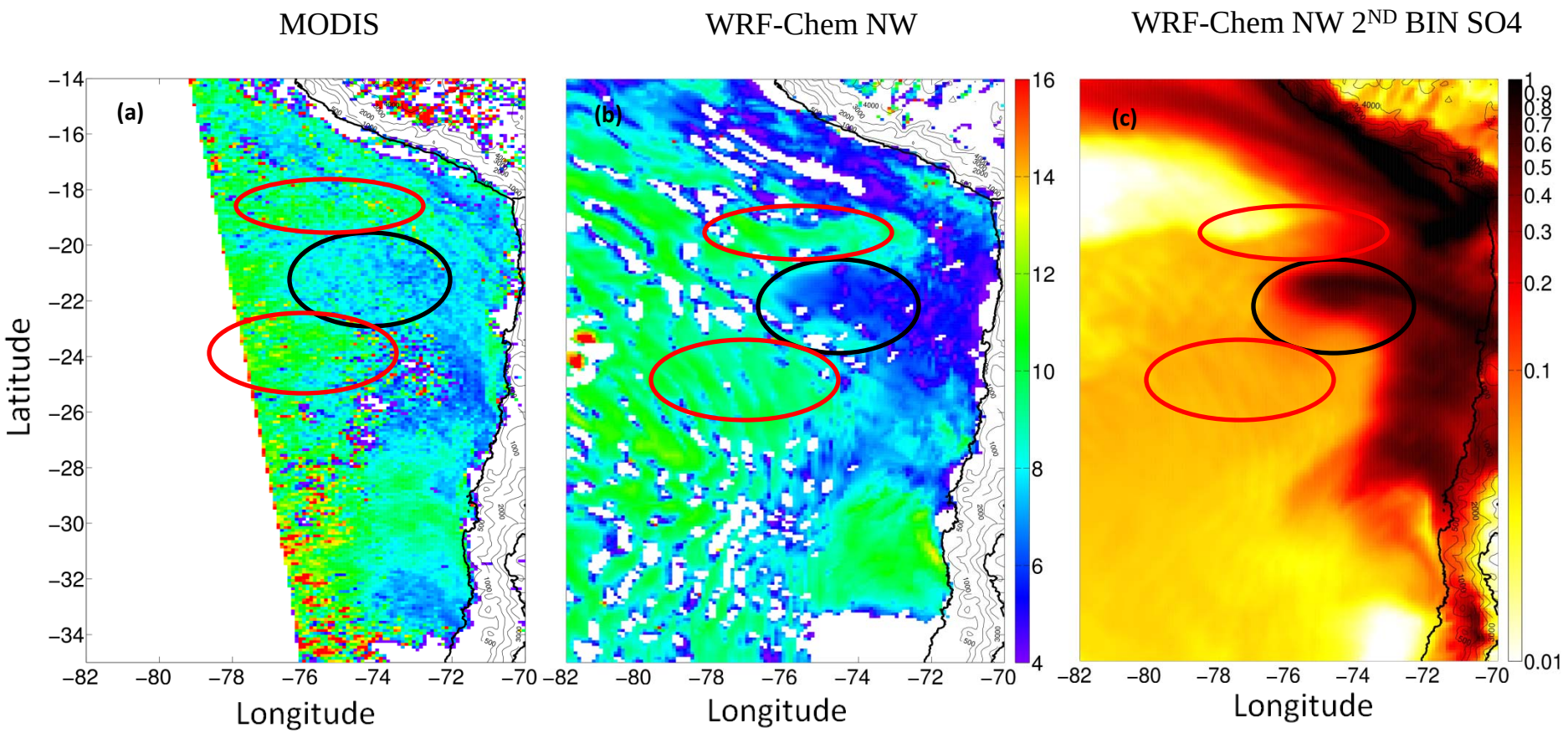
SO4 2ND BIN PLUME TRACKING



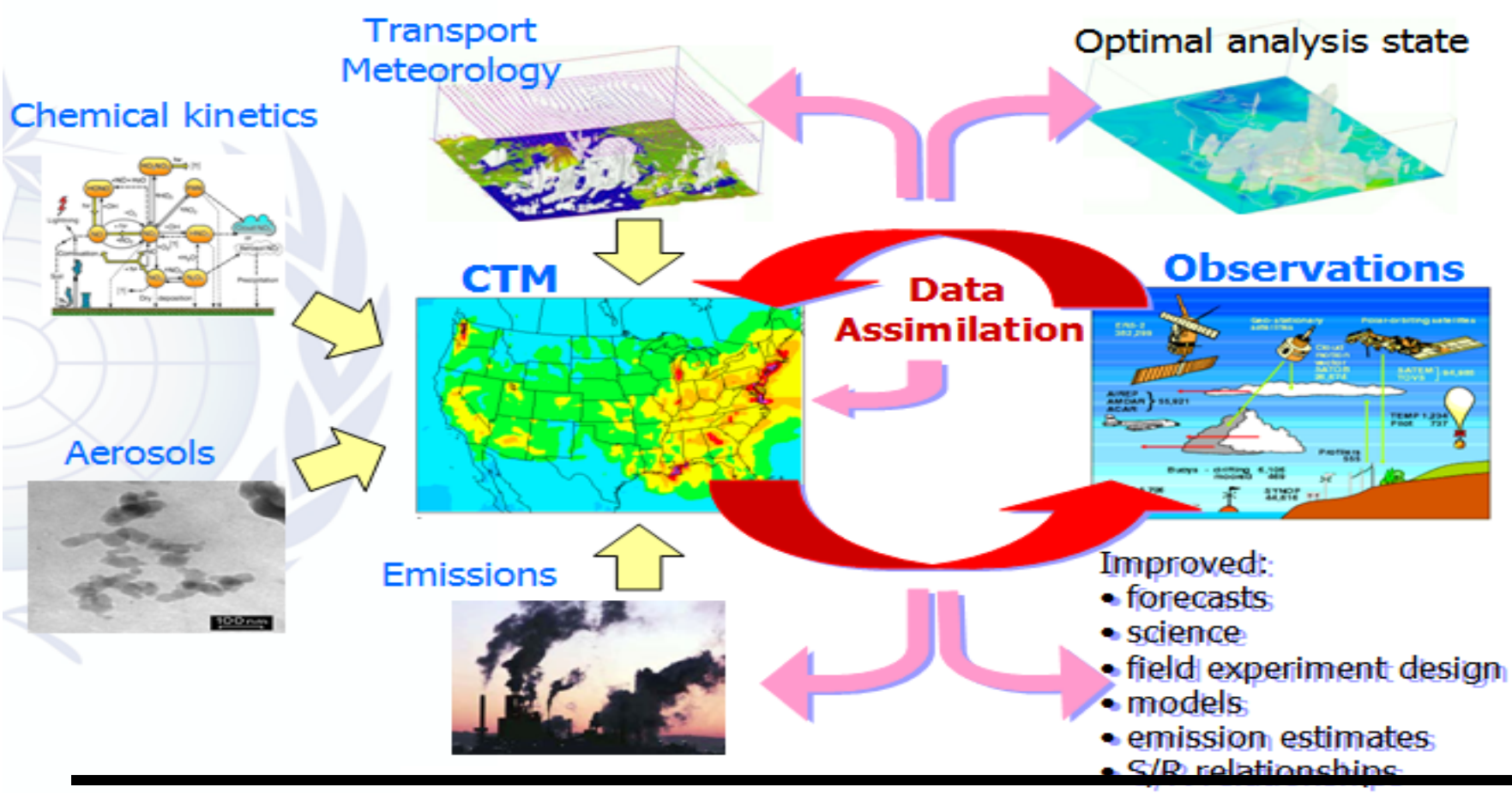
Cooling by smelters and power plants (coastal, brighter clouds) and Santiago / central Chile (offshore, longer cloud lifetime)

\+ aerosol number concentration

− cloud effective radius

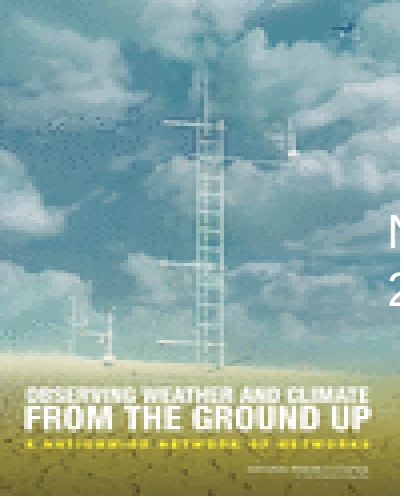


Challenge: Achieving A Closer Integration Of Observations And Models



+ Need to Integrated Air Quality & Met. Model assimilation systems

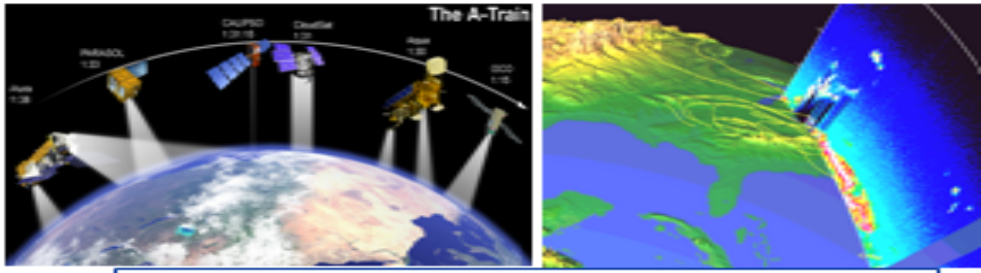
+ New requirements for NRT data, observing systems, and assimilation systems for chemical applications!!



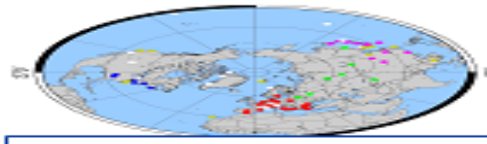
Challenge: Observations Needed

MOST NEEDED:

- **Height of the planetary boundary layer**
- **Soil moisture and temperature profiles**
- **High resolution vertical profiles of humidity**
- **Measurements of air quality and atmospheric composition above the surface layer**

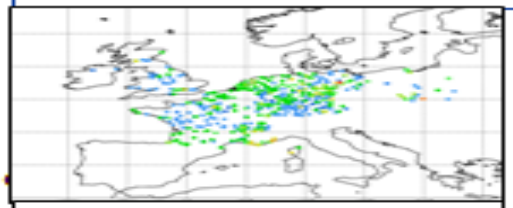


Three dimensional observing systems
&
Geostationary Satellite Obs



GALION
Surface-based
LIDAR

GAW/AERONET/
SKYNET
Surface-based
AOD



PM

19

Idea – Constraining aerosols by assimilating cloud satellite retrievals

- Improving aerosol loadings improves cloud macro and micro physical properties.
- Data assimilation technique (4dVar) could be used to improve aerosol loadings given cloud satellite retrievals ***(add info to AOD assimilation)***
- Optimize for aerosol number conc. and update mass conc. accordingly (same phase, same bin)
- Sensitivities are computed using the WRF-Chem adjoint ***(we have several pieces)***
- 5D correlations: x,y,z,bins(1:8),phase(dry/wet)

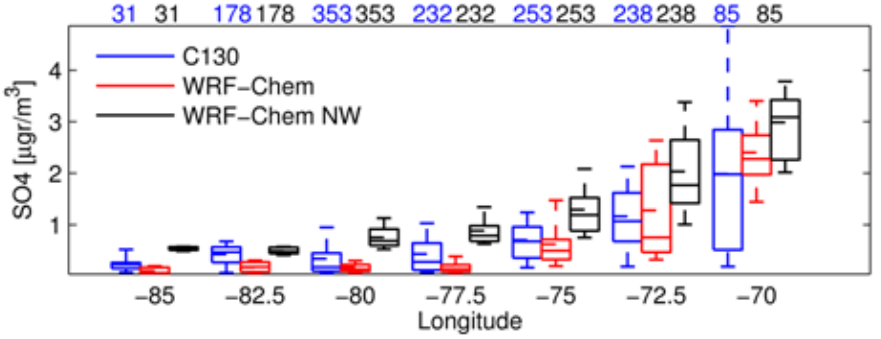
$$N_d = K \tau^{1/2} r_e^{-5/2}$$

τ: Cloud opetical Depth (COD)
r_e: Effective radius
N_d: Cloud Number of droplets
τ and r_e can be obtained from MODIS or GOES

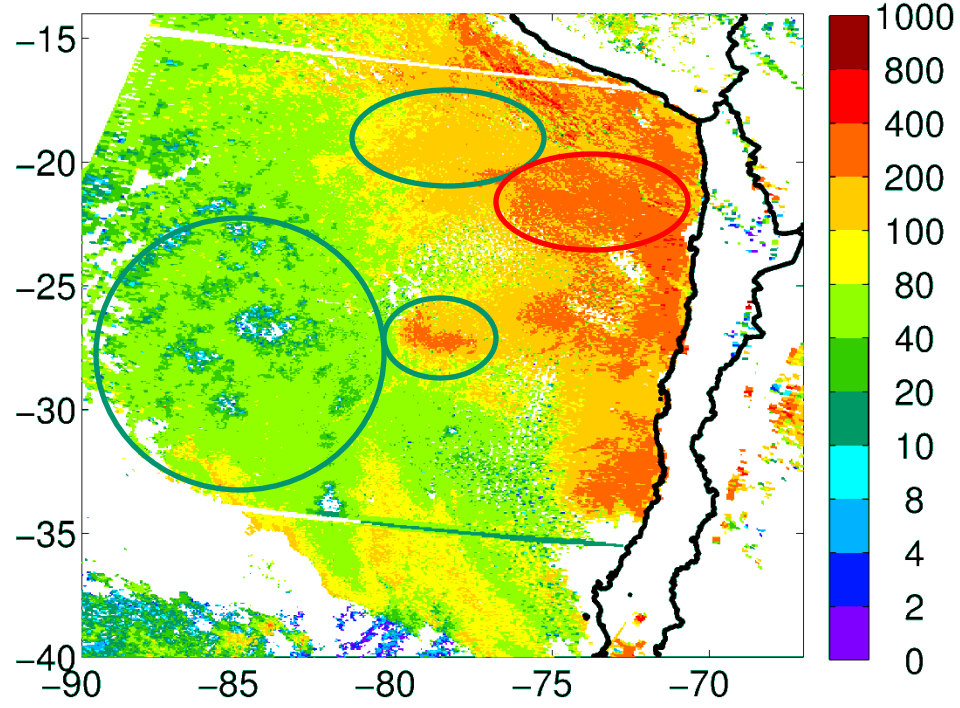
*Pablo Saide (1), **G. Carmichael** (1), S. Spak (1), P. Minnis (2), K. Ayers (2) CGRER, The University of Iowa, NASA LARC*

Test case

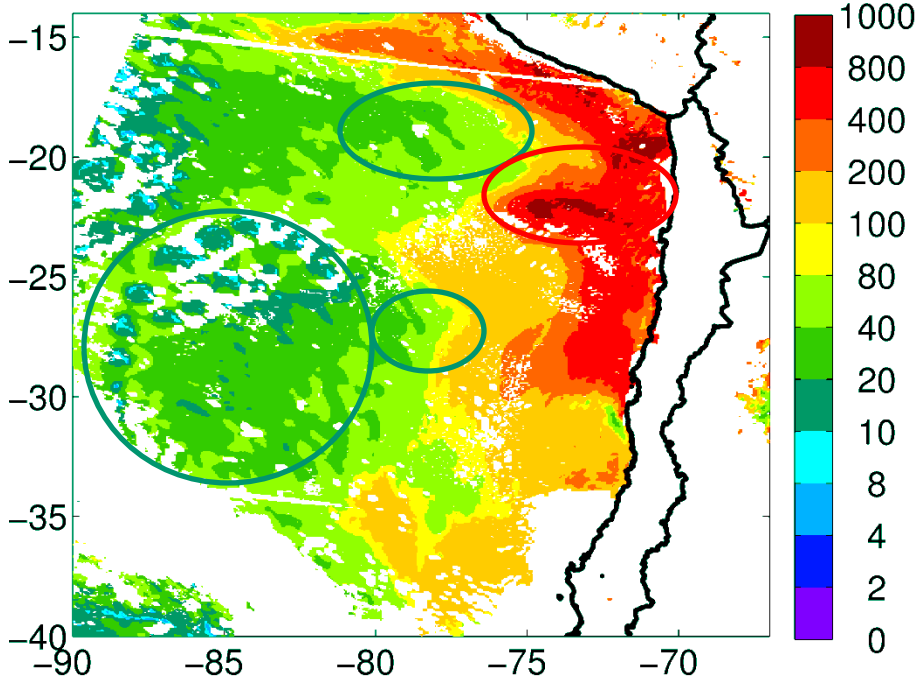
- Extensive cloud cover to perform assimilation
- Remote zone with lower Nd, close shore higher Nd



MODIS Terra N_d



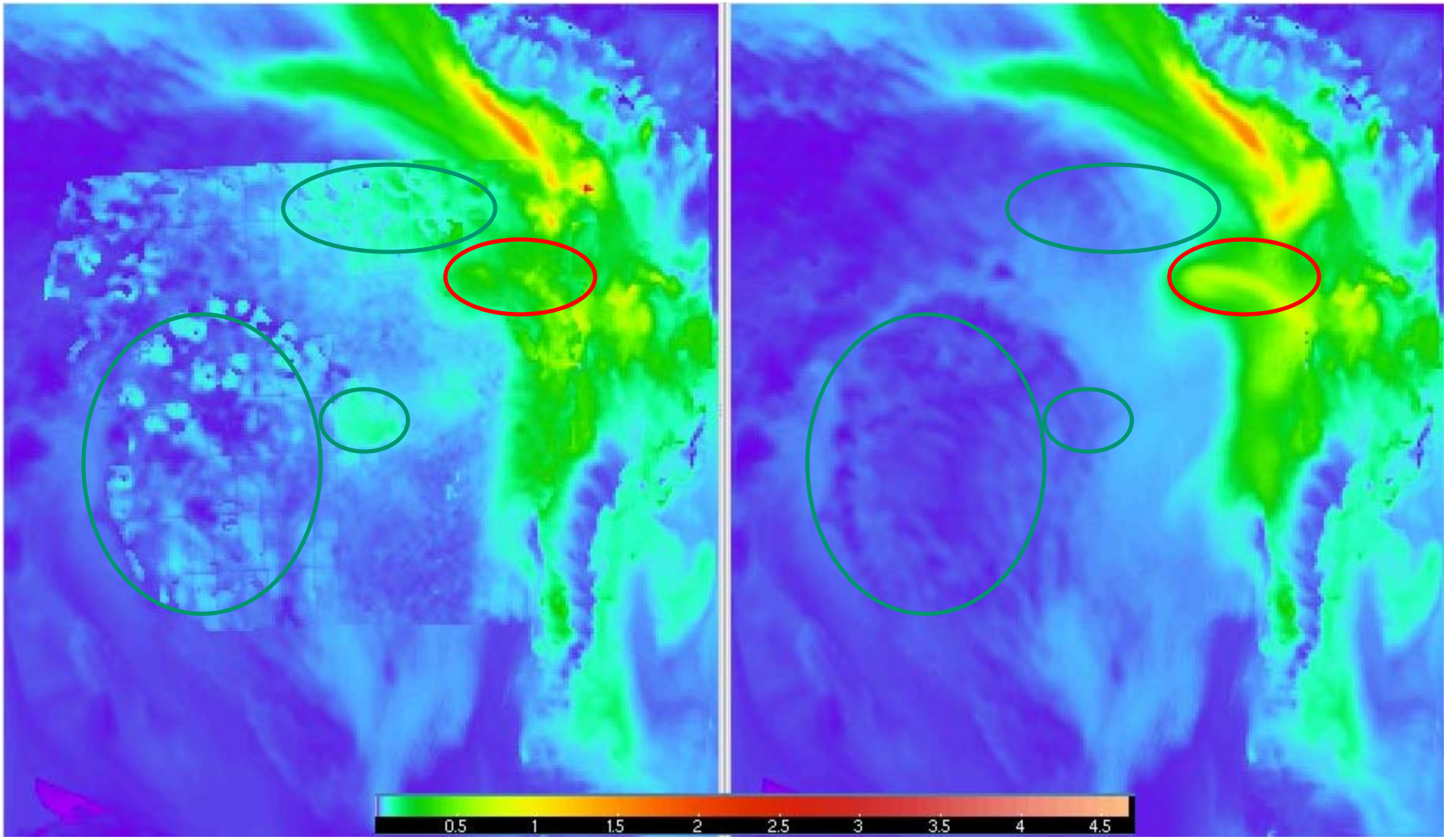
Base WRF-Chem N_d



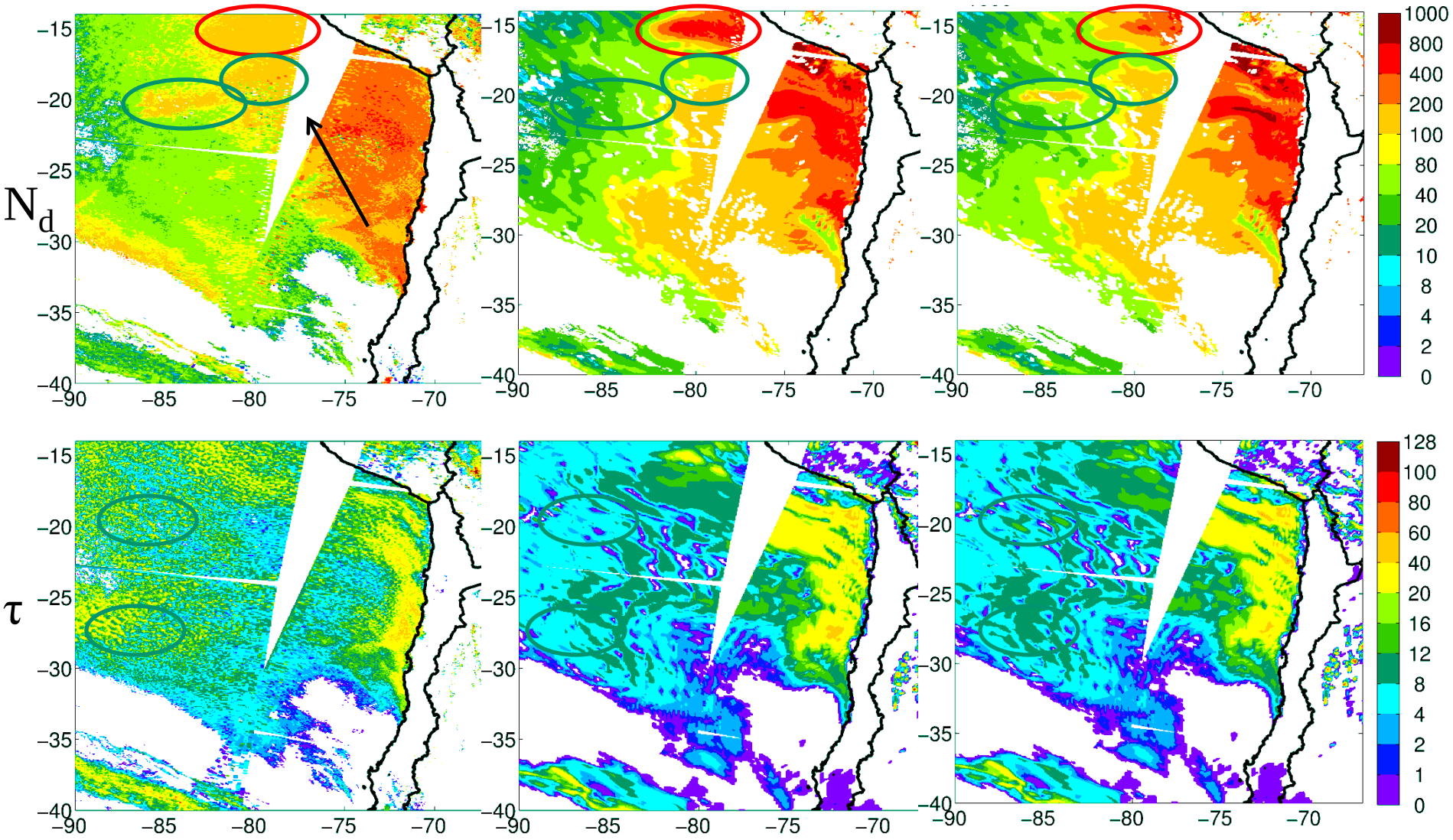
Impact of Assimilation: Sulfate mass 2nd bin (78-156 nm), 1st level

Assimilated WRF-Chem

Base WRF-Chem



Impact of Assimilation: Predicted Fields after 1 day of run



Closing Thoughts/Challenges

Need to continue to improve forward AQ and weather models (especially those aspect related to chemical weather e.g., pbl, clouds)

Need to continue to improve process understanding and key model inputs (e.g., emissions)

Need to evolve the observation infrastructure to help improve forward model and to support assimilation

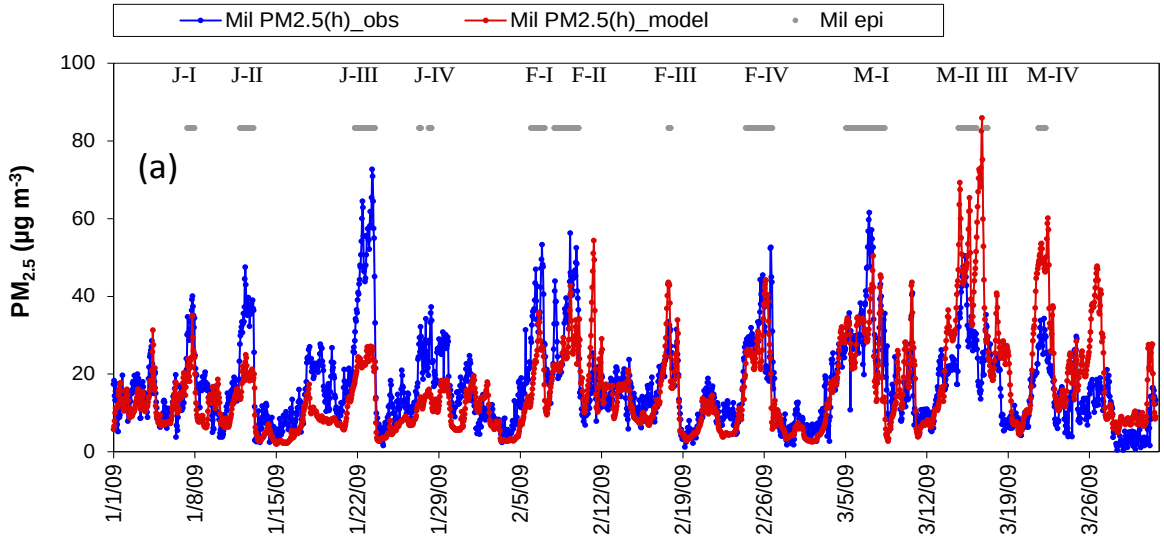
Improve data assimilation techniques for AQ prediction improvements - and use also to define/design observational needs

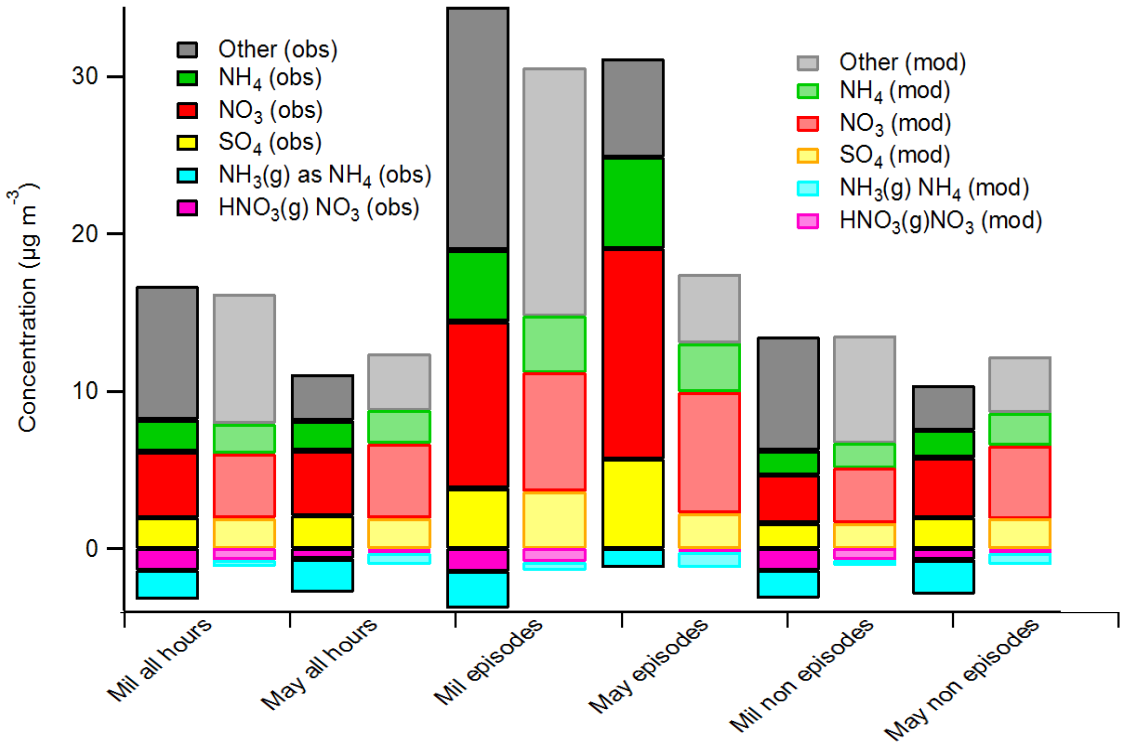
Important to demonstrate the real benefits of better models and observing systems

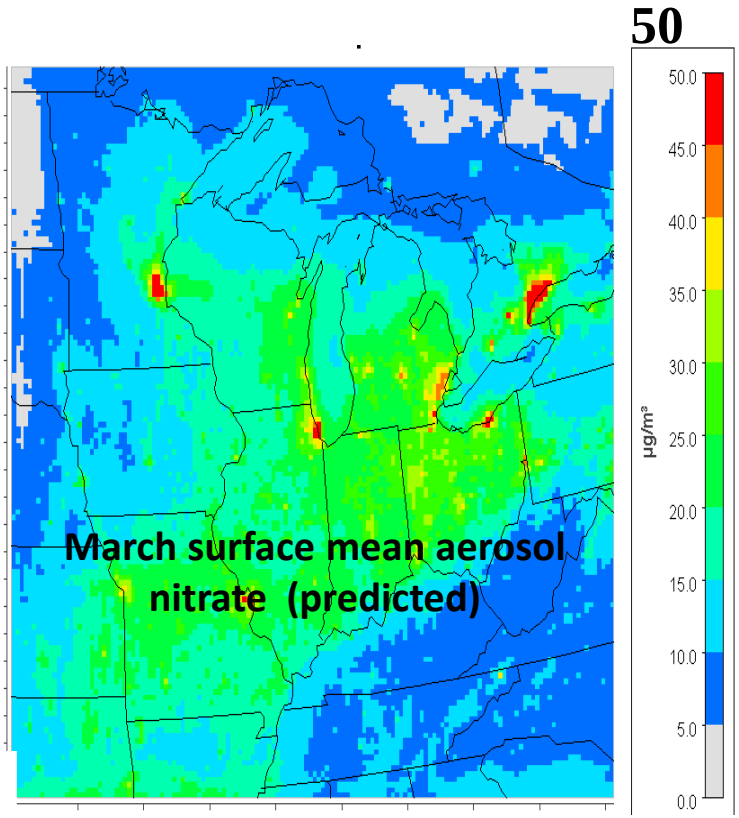
Winter Time Nitrate Aerosol Prediction

Important implications for compliance

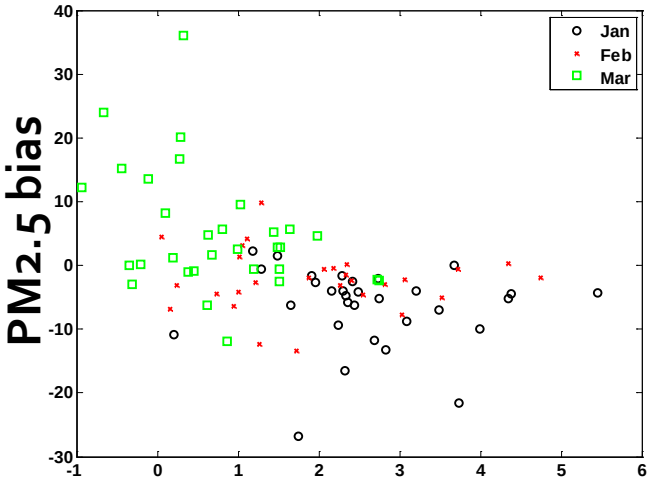
Models underestimate nitrate

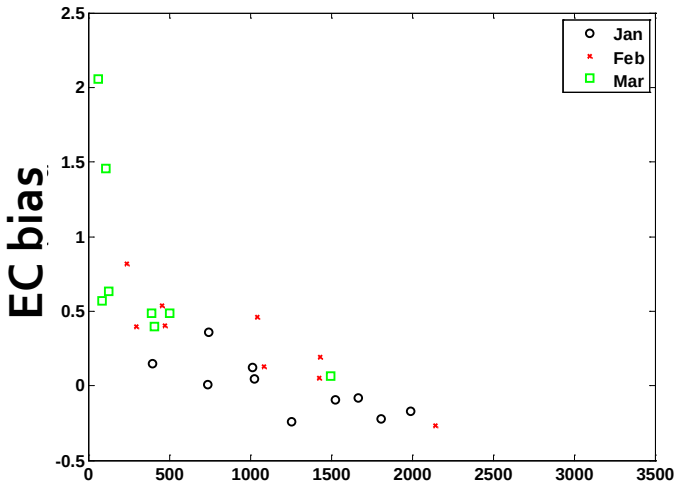






PBL dynamics are crucial to model skill





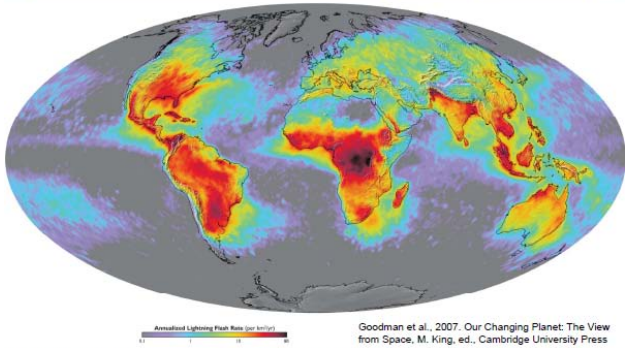
Shallow model mixed layer and neg. bias in wind speed drive overprediction in primary and secondary PM2.5 concentrations during wintertime fine particle events. RH bias (snow melt), enhanced photolysis and nighttime chemistry are also important factors.

Challenge: Need to Estimate ALL Emissions at Appropriate Scales to Predict Chemical Weather (*and they are constantly changing in space and time*)

Anthropogenic: NEI99
Biomass Burning: MODIS hotspot
Dust: f(u*)
Volcanic: SO_2 estimated
Biogenic: none at present

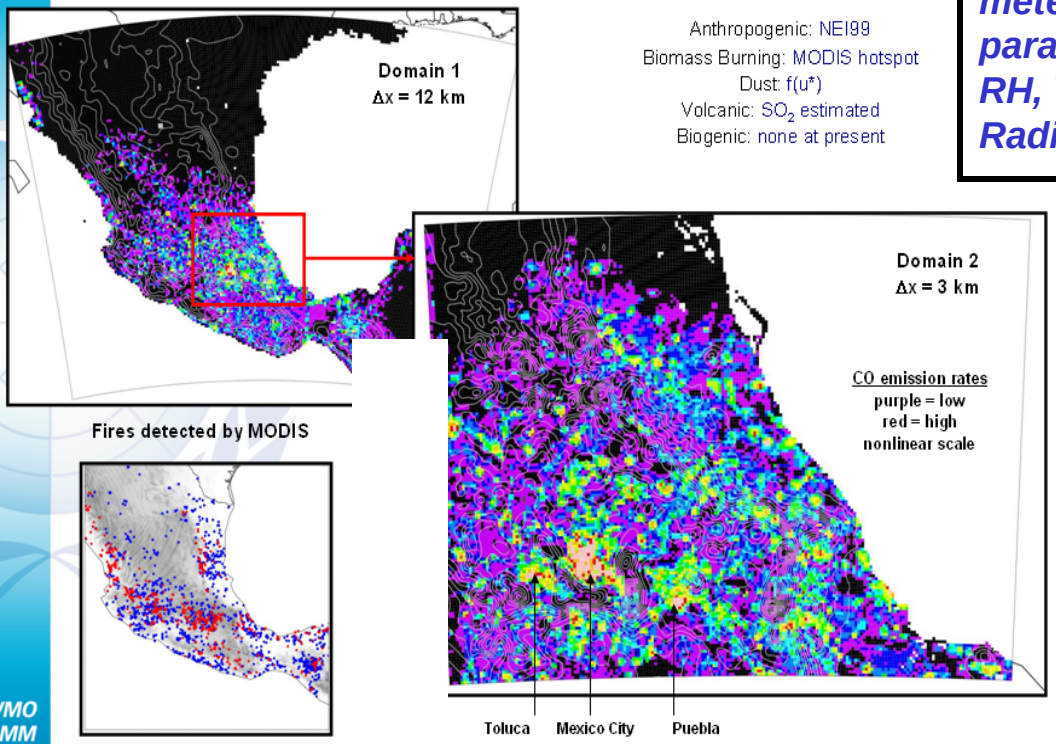
Links to meteorological parameters (T, RH, WS, Radiation, etc.)

Global Distribution of Lightning Activity



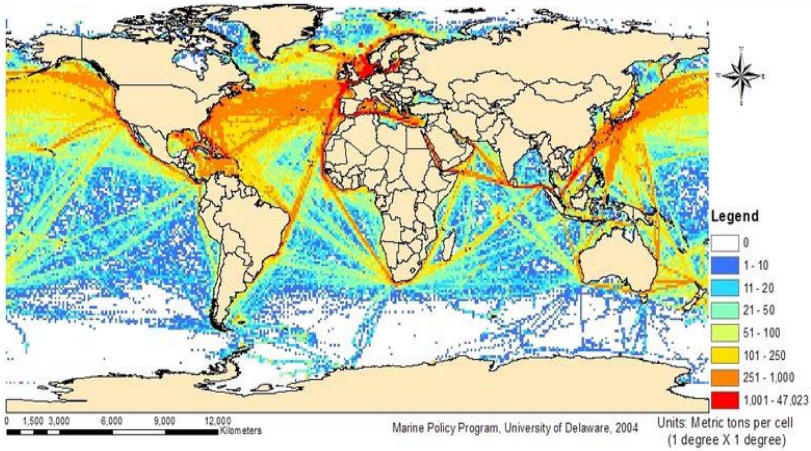
Goodman et al., 2007. Our Changing Planet: The View from Space, M. King, ed., Cambridge University Press

Mean annual global lightning flash rate (flashes km^{-2} yr^{-1}) derived from a combined 8 years from April 1995 to February 2003. (Data from the NASA OTD instrument on the OrbView-1 satellite and the LIS instrument on the TRMM satellite.)

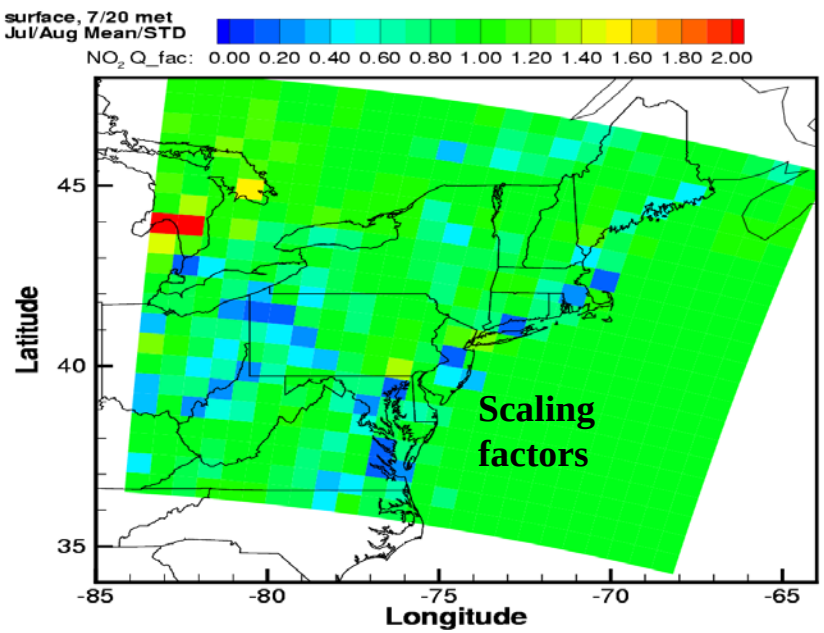


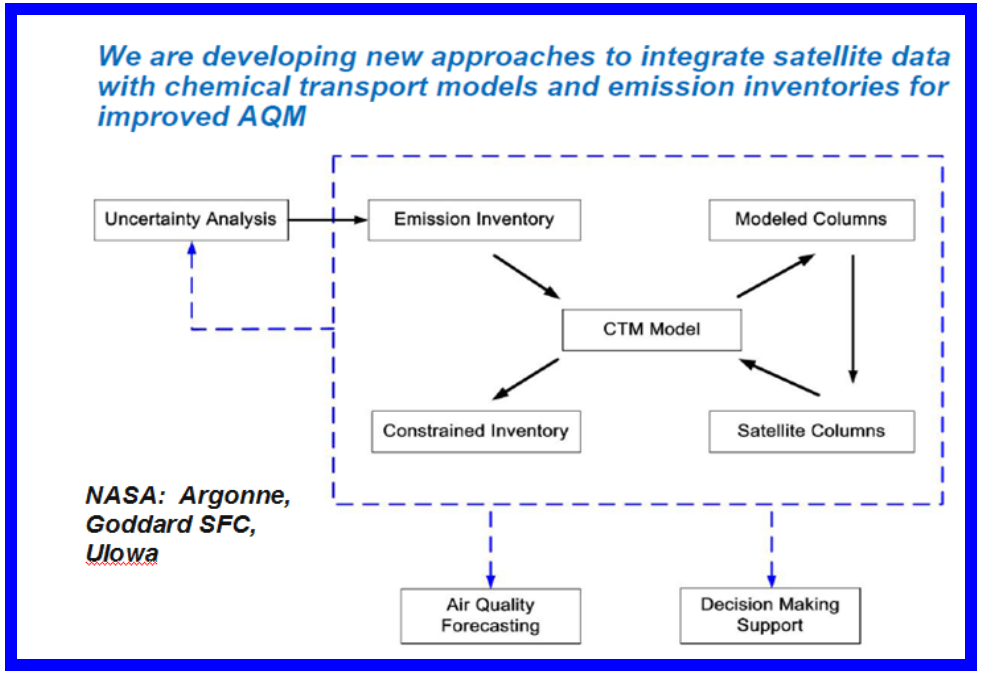
Fires detected by MODIS

SOx Emissions



Rapid Updates of Emissions Are Needed





4D-Var setup:

Time window:

July , 2004

Control:

Initial ozone, and NOx emissions

Observations:

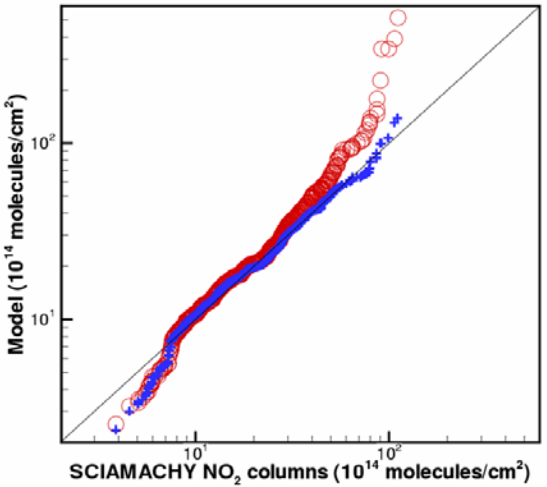
Ozone from different platforms, and SCIAMACHY tropospheric NO_2 columns

Emission changes over domain
(ratio of new emission over NEI01)

Case	Surface (level 1)	Elevated (2 & above)	Total (all levels)
1 E only	0.934	0.849	0.920
2 E & IC	0.928	0.881	0.908
"OI"	1.318	1.030	1.246

Chai et al., AE 2009

Quantile-quantile plot

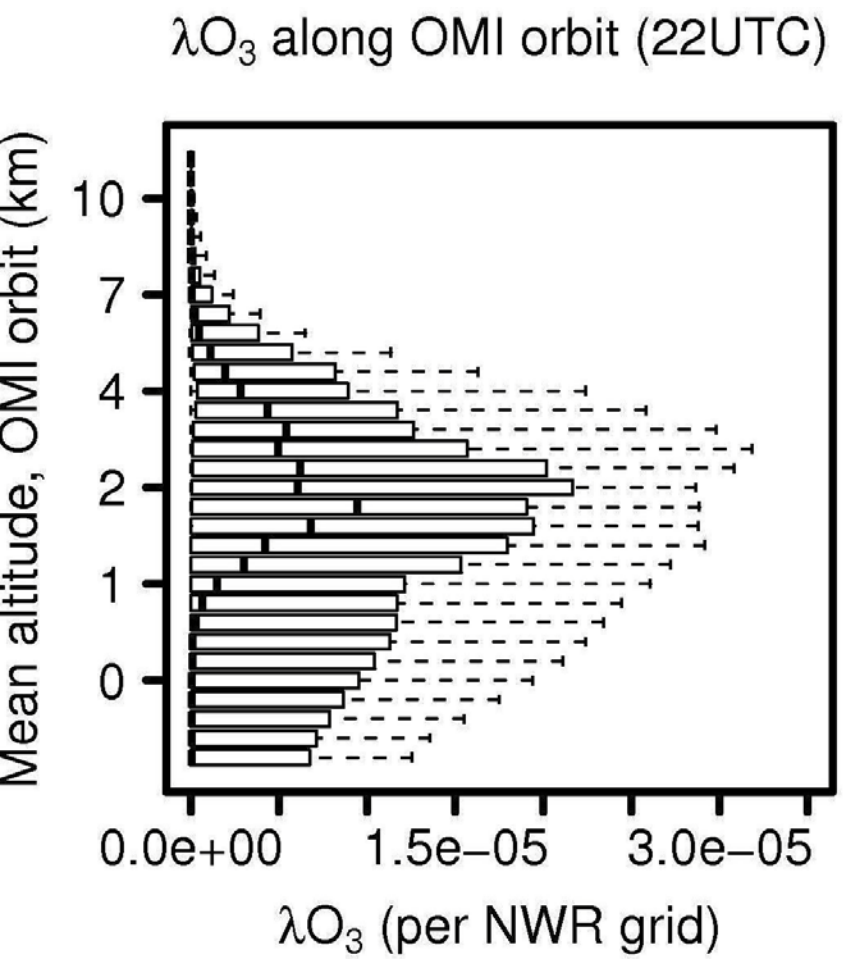


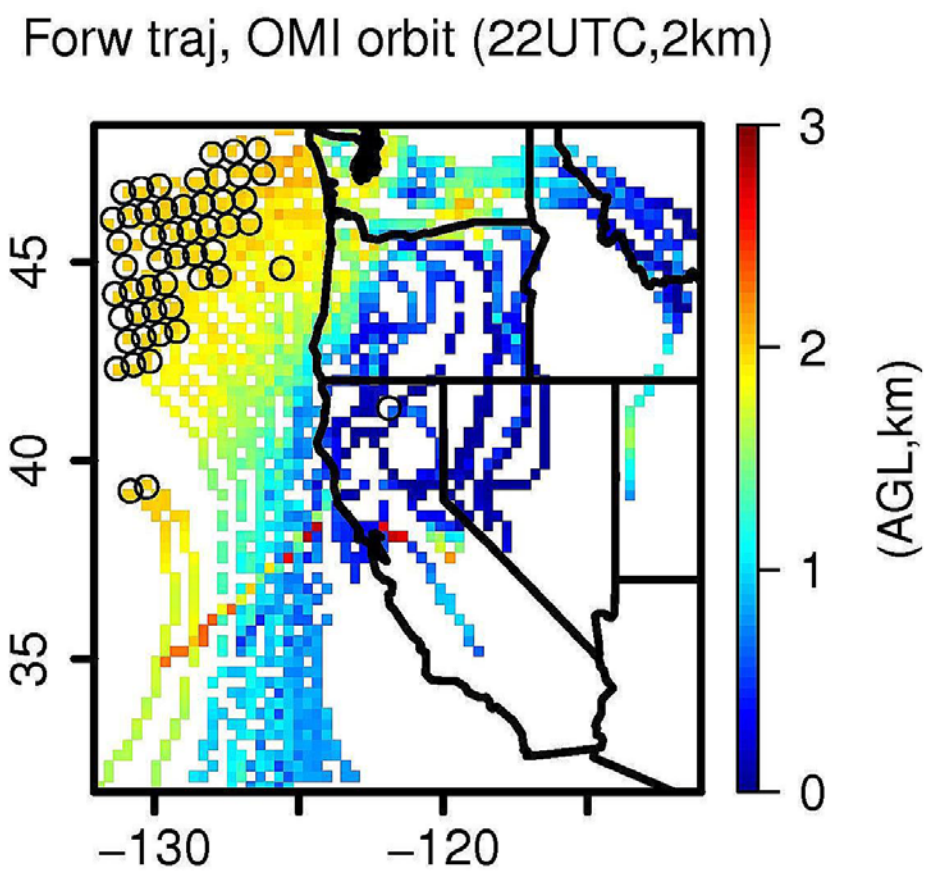
Blue:

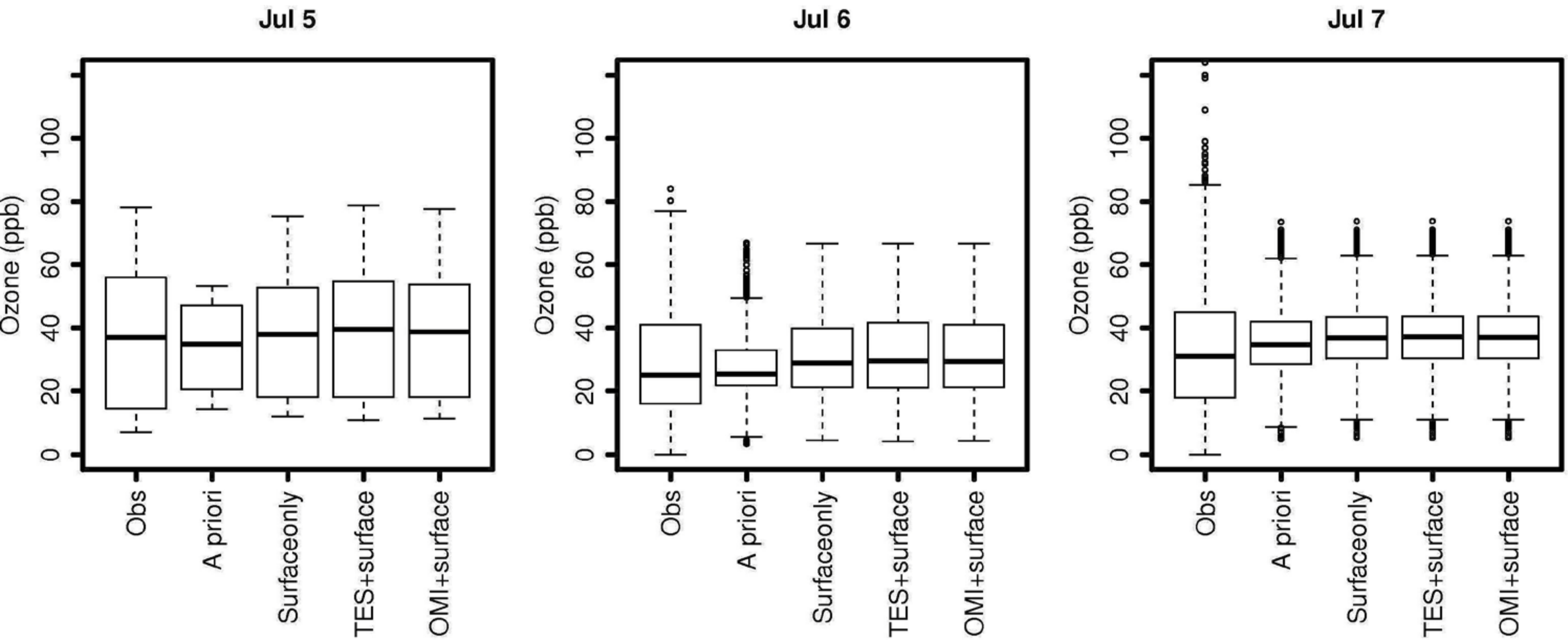
After NOx Emission adjustmentent

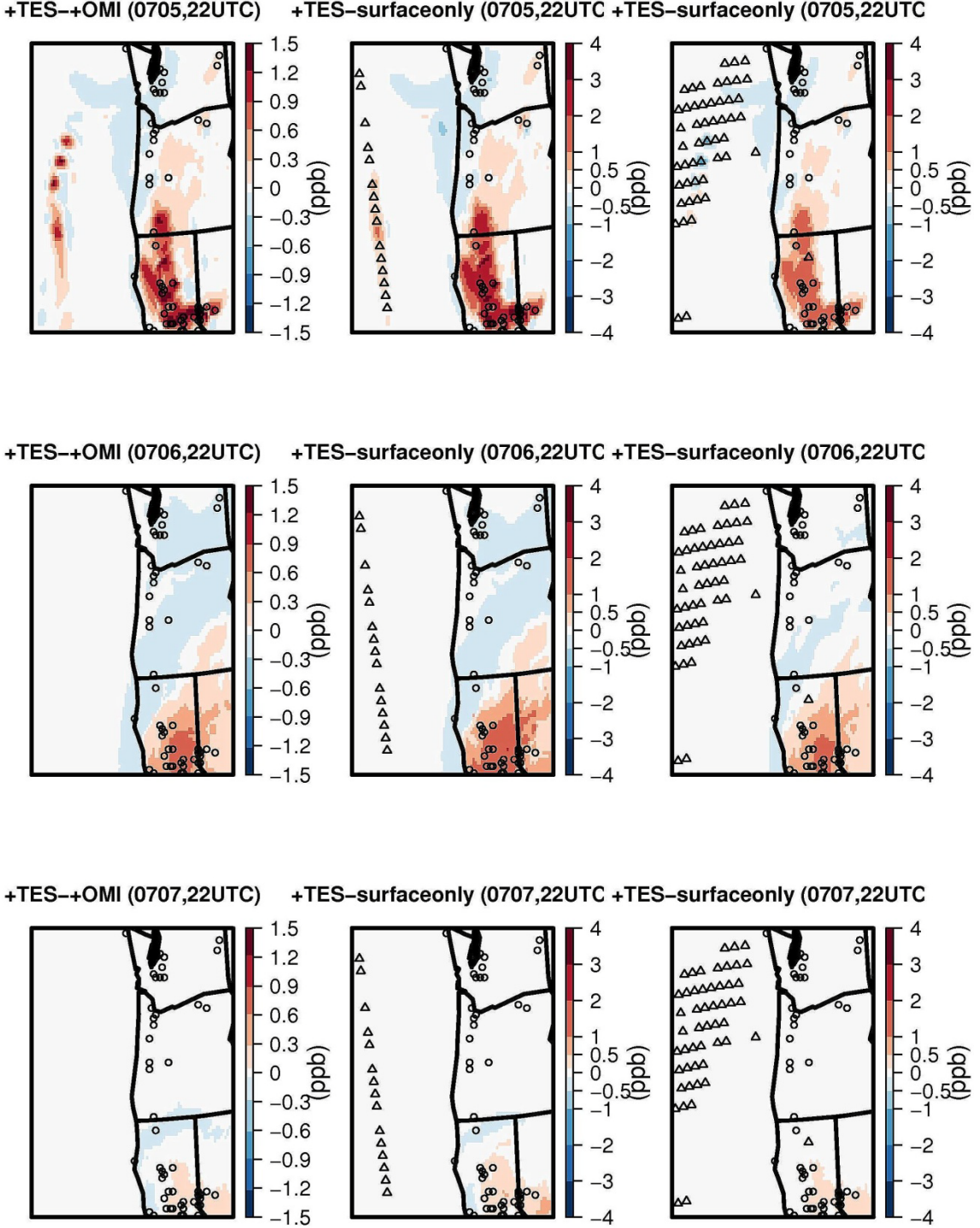
Red:

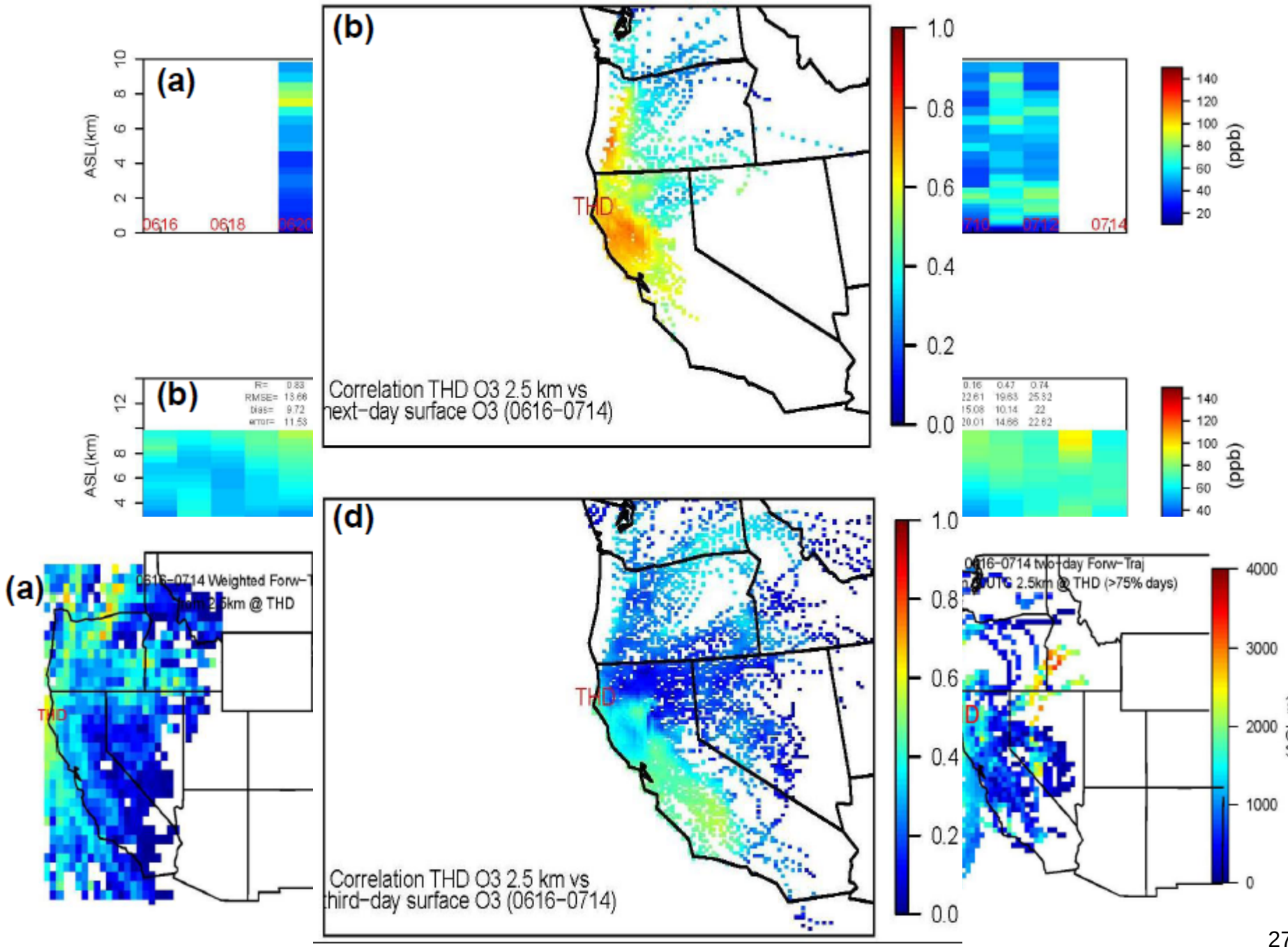
Before NOx Emission adjustmenter


λO3 along OMI orbit (22UTC)
Mean altitude, OMI orbit (km)
10
7
4
2
1
0
0.0e+00
1.5e−05
3.0e−05
λO3 (per NWR grid)


Forw traj, OMI orbit (22UTC,2km)
45
40
35
−130
−120
3
2
1
0
(AGL,km)


Jul 5
Jul 6
Jul 7
Ozone (ppb)
0
20
40
60
80
100
Obs
A priori
Surfaceonly
TES+surface
OMI+surface


+TES−+OMI (0705,22UTC)
+TES−surfaceonly (0705,22UTC
+TES−surfaceonly (0705,22UTC
+TES−+OMI (0706,22UTC)
+TES−surfaceonly (0706,22UTC
+TES−surfaceonly (0706,22UTC
+TES−+OMI (0707,22UTC)
+TES−surfaceonly (0707,22UTC
+TES−surfaceonly (0707,22UTC
(ppb)


(a)
ASL(km)
0616
0618
0620
(b)
THD
Correlation THD O3 2.5 km vs
next-day surface O3 (0616-0714)
1.0
0.8
0.6
0.4
0.2
0.0
0710
0712
0714
140
120
100
80
60
40
20
(ppb)
(b)
R= 0.83
RMSE= 13.66
bias= 9.72
error= 11.53
ASL(km)
12
8
6
4
0.16 0.47 0.74
22.61 19.63 25.32
15.08 10.14 22
20.01 14.66 22.62
140
120
100
80
60
40
(ppb)
(a)
0616-0714 Weighted Forw-T
from 2.5km @ THD
THD
(d)
THD
Correlation THD O3 2.5 km vs
third-day surface O3 (0616-0714)
1.0
0.8
0.6
0.4
0.2
0.0
0616-0714 two-day Forw-Traj
from 2.5km @ THD (>75% days)
4000
3000
2000
1000
0
(AGL,m)

Other Physical Parameters Also Play Important Roles - Impact of Land Use Changes