Improving Air Quality *(and Weather)* Predictions using Advanced Data Assimilation Techniques Applied to Coupled Models

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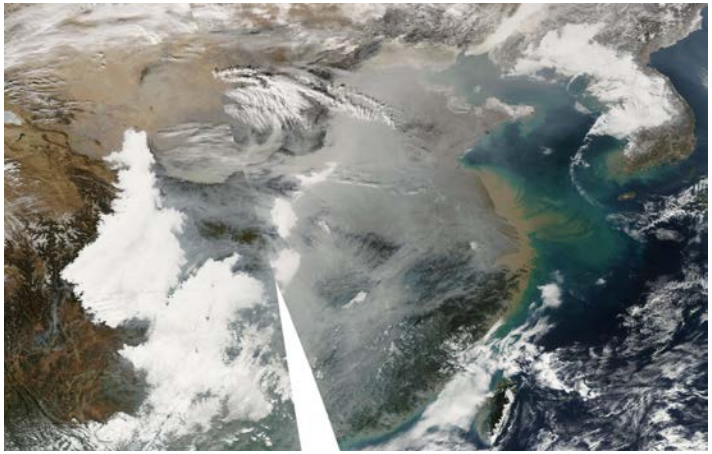
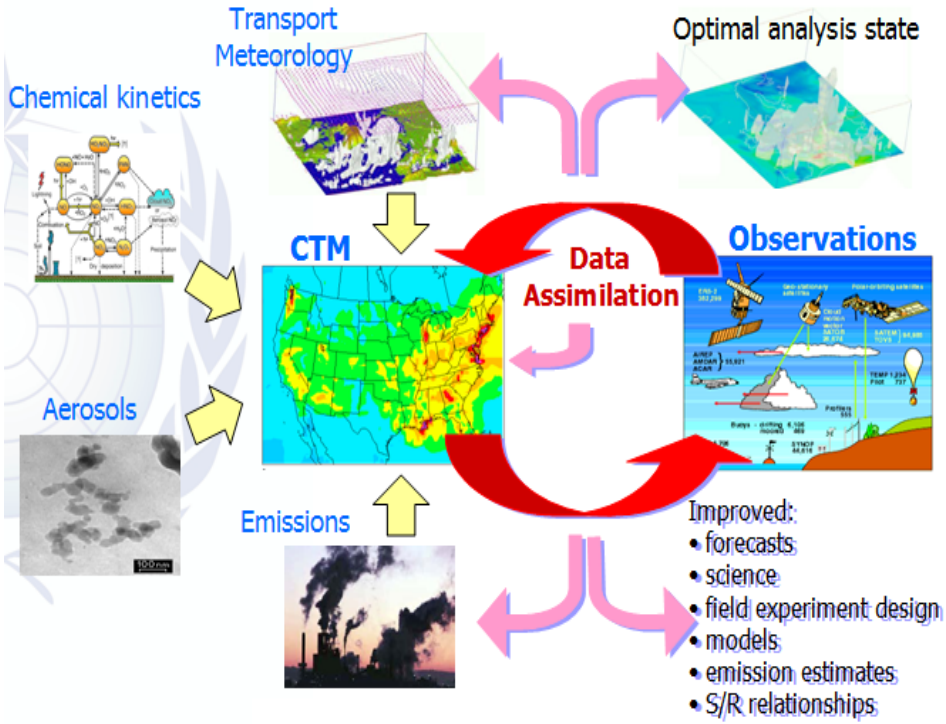
Challenges to Coupled AQ/Met Modeling:

Forcings are real … how best to include?



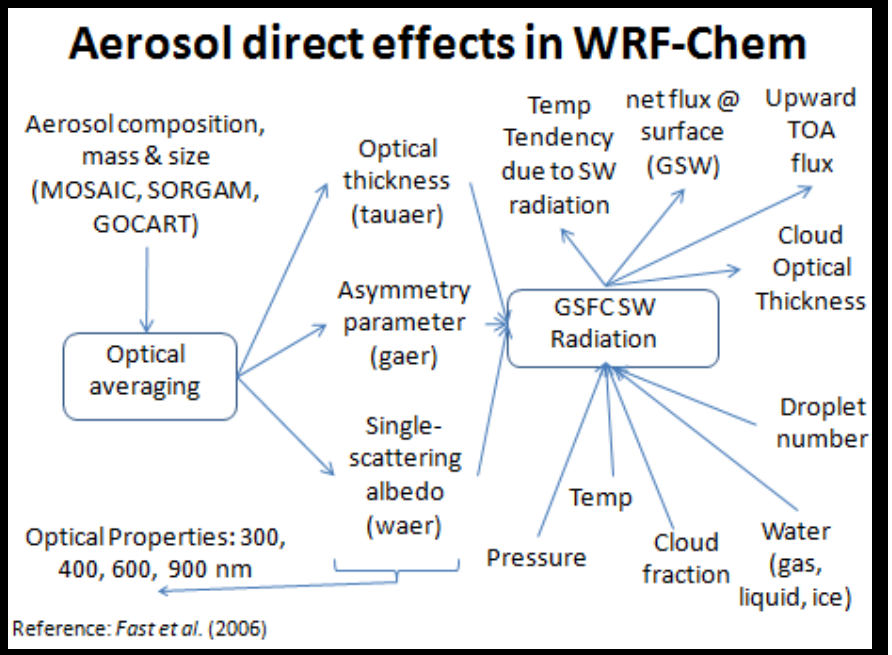


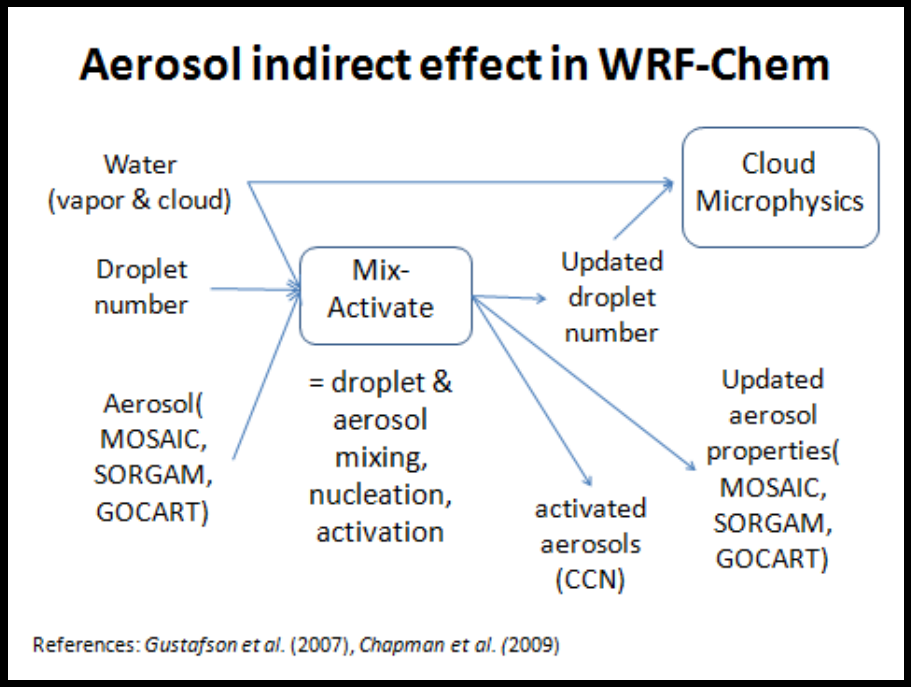
Models Constrained With Observations Play Increasing Important Roles In Research and Applications

Little experience with coupled models!

Building Assimilation System for WRF-Chem

WRF-Chem Direct & Indirect Forcing





We are developing the adjoint of the full WRF-Chem Model

Ref: Saide et al., 2013, Saide et al., PNAS 2012, GRL 2014, 2015a,b; Guerette and Henze GMD, 2015

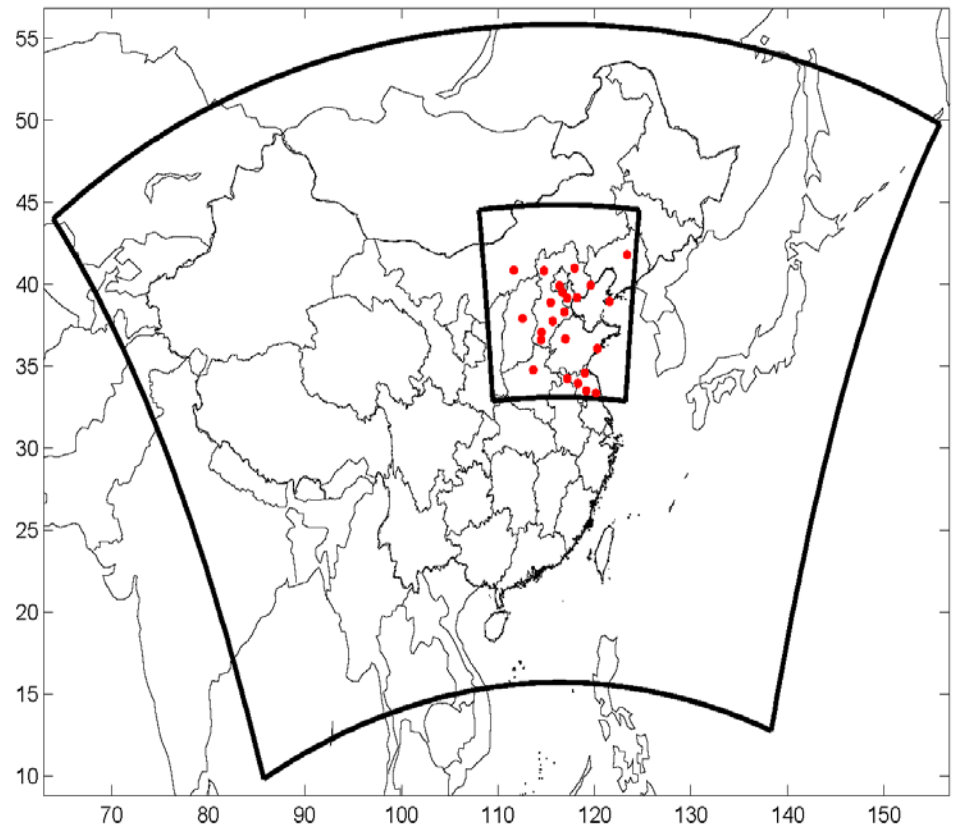
Need for ***More*** Aerosol and Atmospheric Composition Data for Use in Assimilation

New observations streams are in the pipe-line …

are our modeling systems ready ?

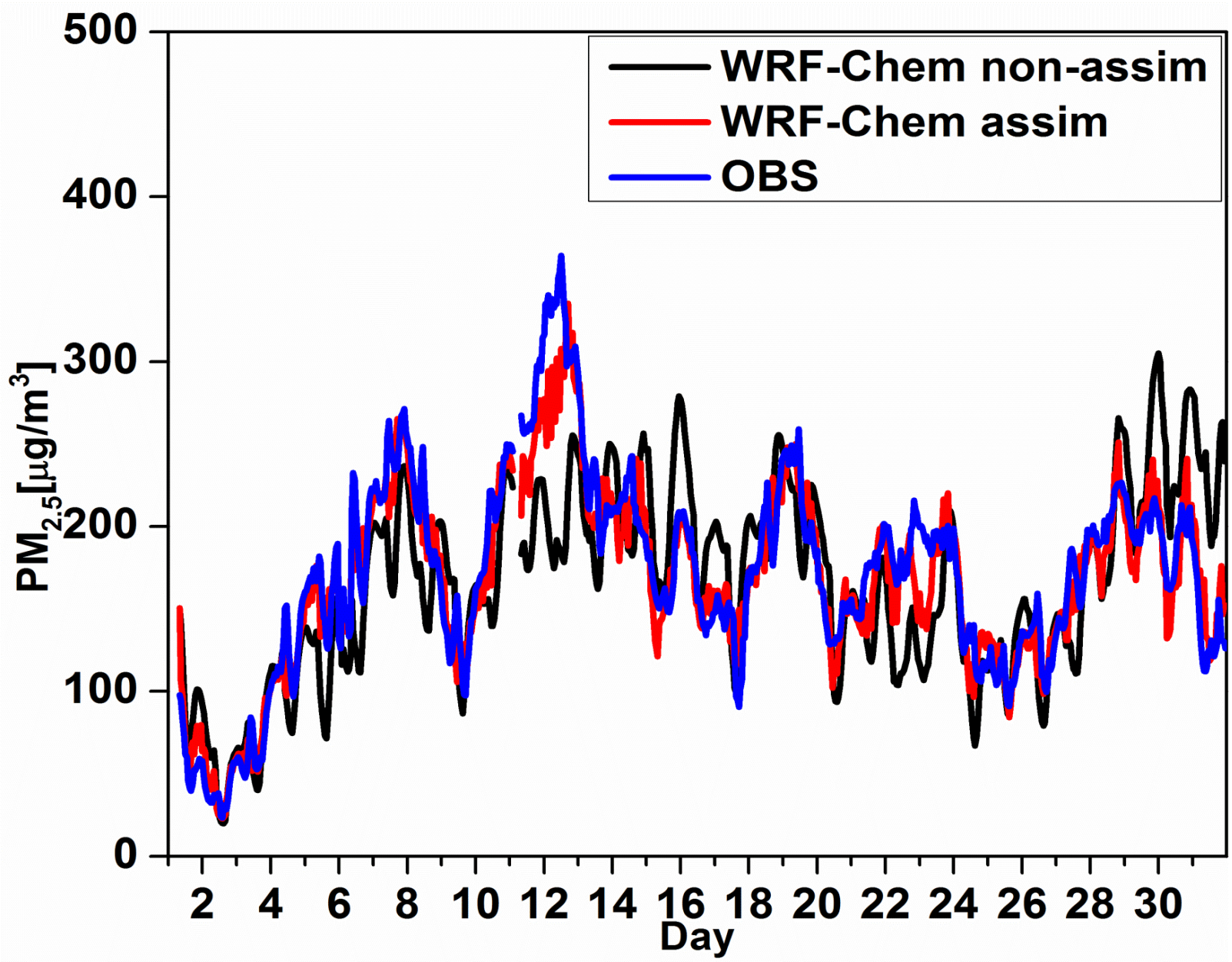
Wintertime Haze (Jan 2013)

- WRF-Chem v3.4.1
- CBMZ-MOSAIC 8 bin aerosols
- QFED2 biomass burning emissions, MICS-Asia, sea-salt, dust, biogenics, etc.
- Aerosol-cloud-radiation interactions
  - Abdul-Razzak & Ghan activation, Morrison MP
  - RRTMG radiation, Mie theory + Shell-Core approach
  - MACC-Boundary conditions
- AOD and PM data assimilation in **GSI** for sectional aerosol model (Saide et al., ACP 2013)



Impacts of assimilating surface $PM_{2.5}$

Mean over all surface observation

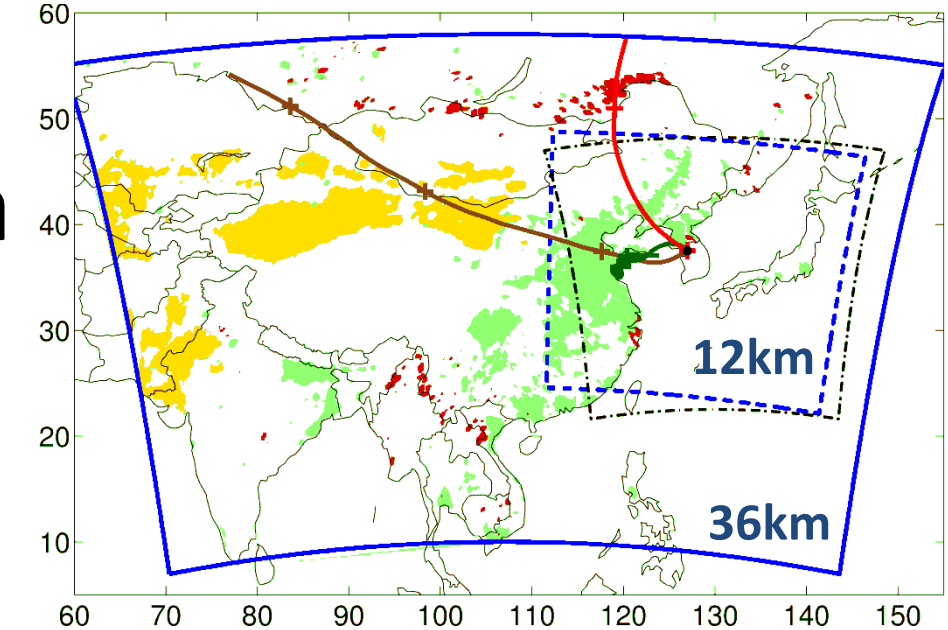


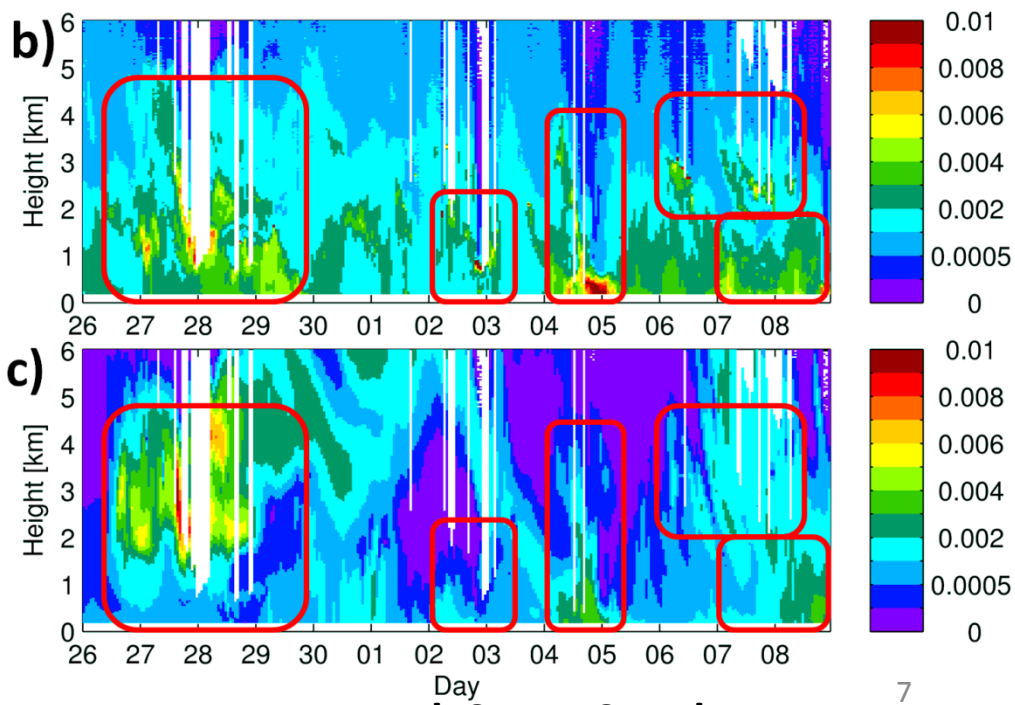
- **R noDA 0.67**
- **R DA 0.95**

Modeling pollution episodes over Korea

- April 26 – May 9 2012, 3 types of events:
  - **Dust**
  - **Anthropogenic**
  - **Biomass burning**

- WRF-Chem v3.5 CBMZ ***(coupled/feedbacks),*** 8bin MOSAIC, **anthropogenic (MICS)** , biomass burning (QFED2), dust (GOCART), **MACC boundary conditions**





LIDAR Back Scat., Seoul Nat. U.

Application: Impacts of Geostationary AOD Assimilation

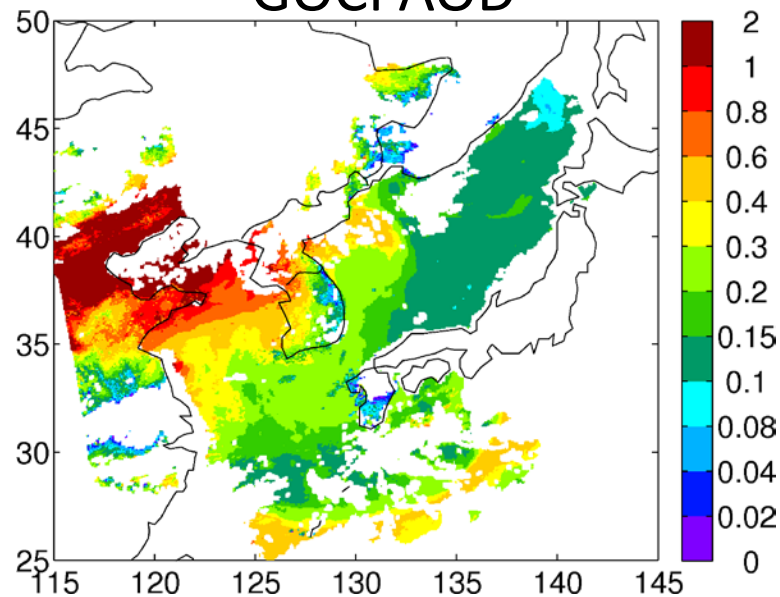
(Are we "ready " to see an impact?)

- **Objectives:** Assess performance of assimilating Geostationary GOCI AOD into a system already assimilating MODIS AOD

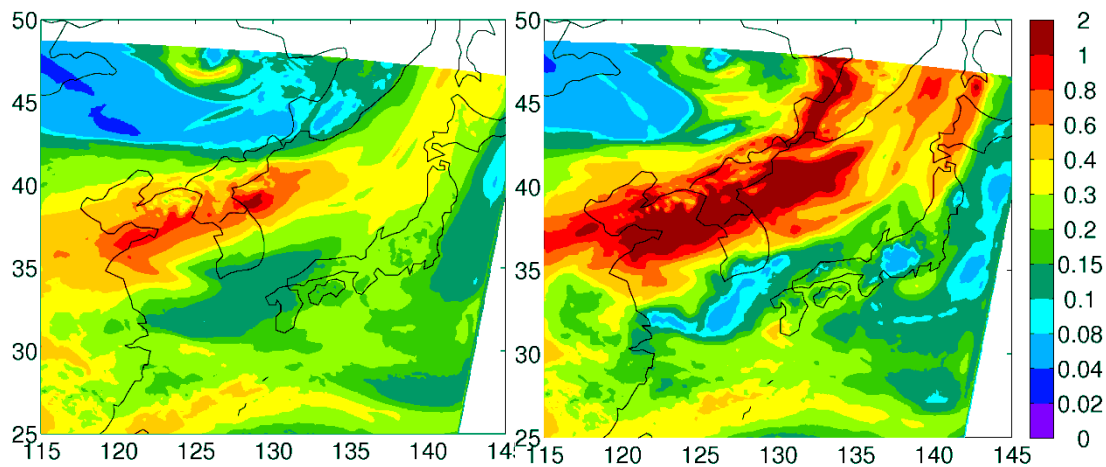
- **System:** WRF-Chem - GSI for MOSAIC sectional aerosol model (Saide et al., ACP 2013) allows assimilation of multiple data

- **Experiments:** GSI AOD assimilation every 3 hours, MODIS only, MODIS+GOCI. (*Only over-sea AOD used)*

GOCI AOD



Aug 27-29, 2012

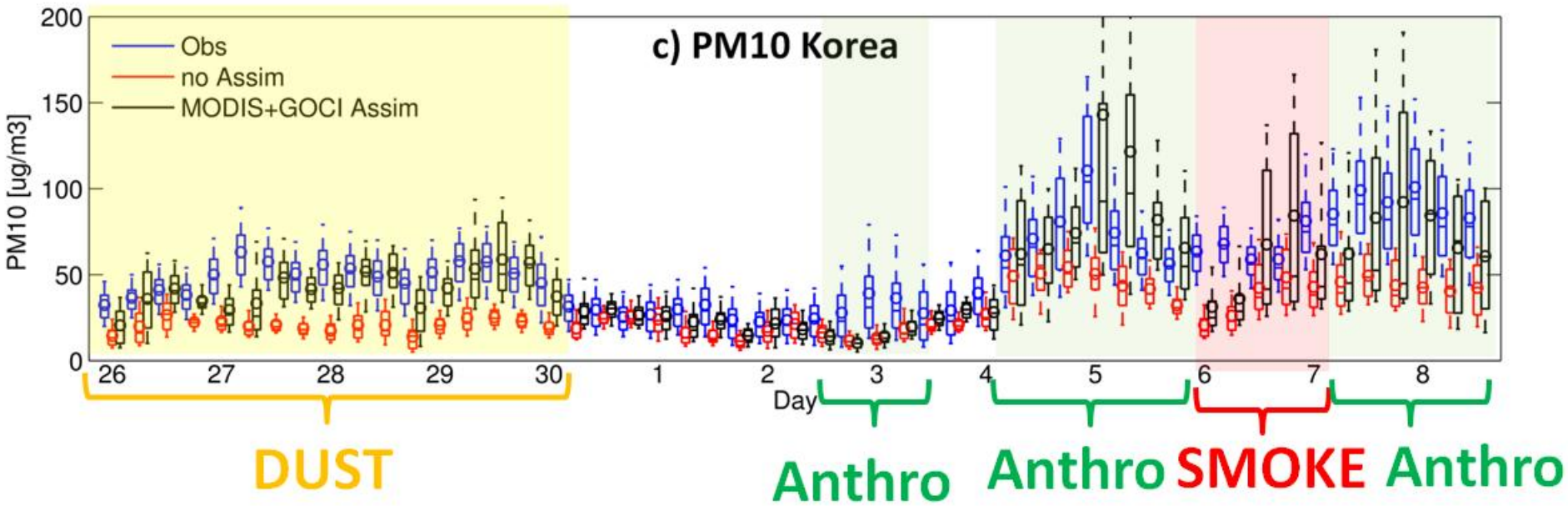


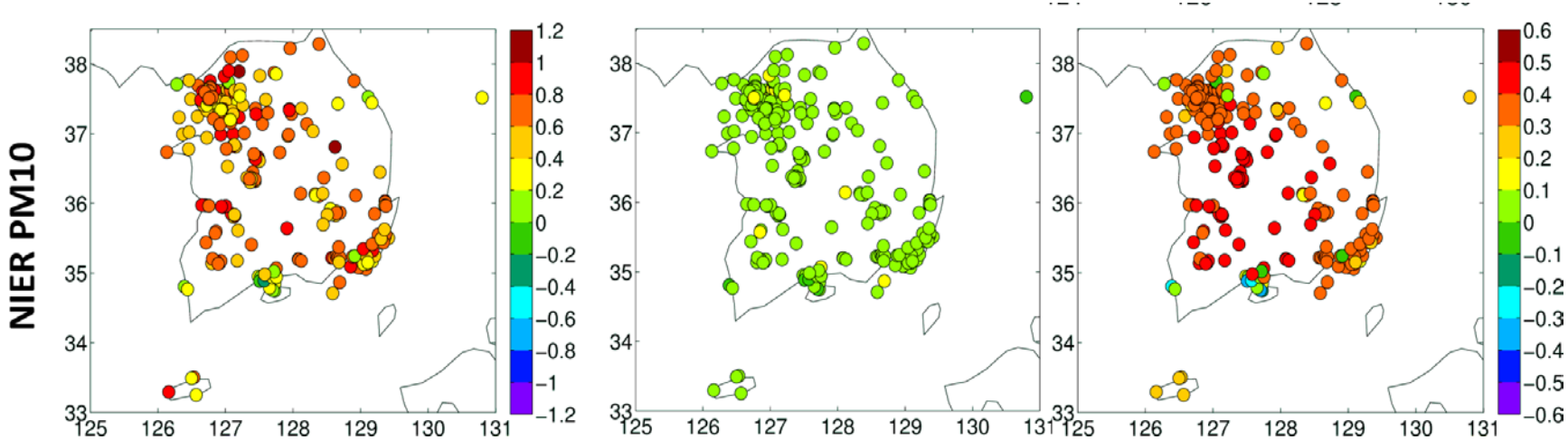
WRF-Chem NO Assim

WRF-Chem MODIS+GOCI Assim

Saide et al., GRL, 2014

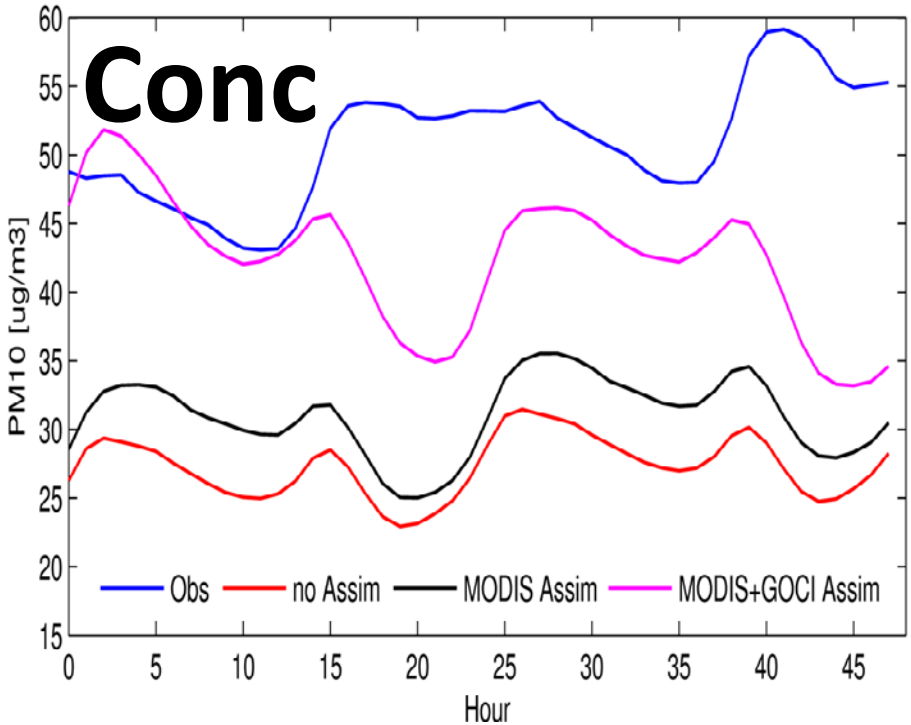
Impact of GOCI on PM10 Prediction





Fractional Bias reduction

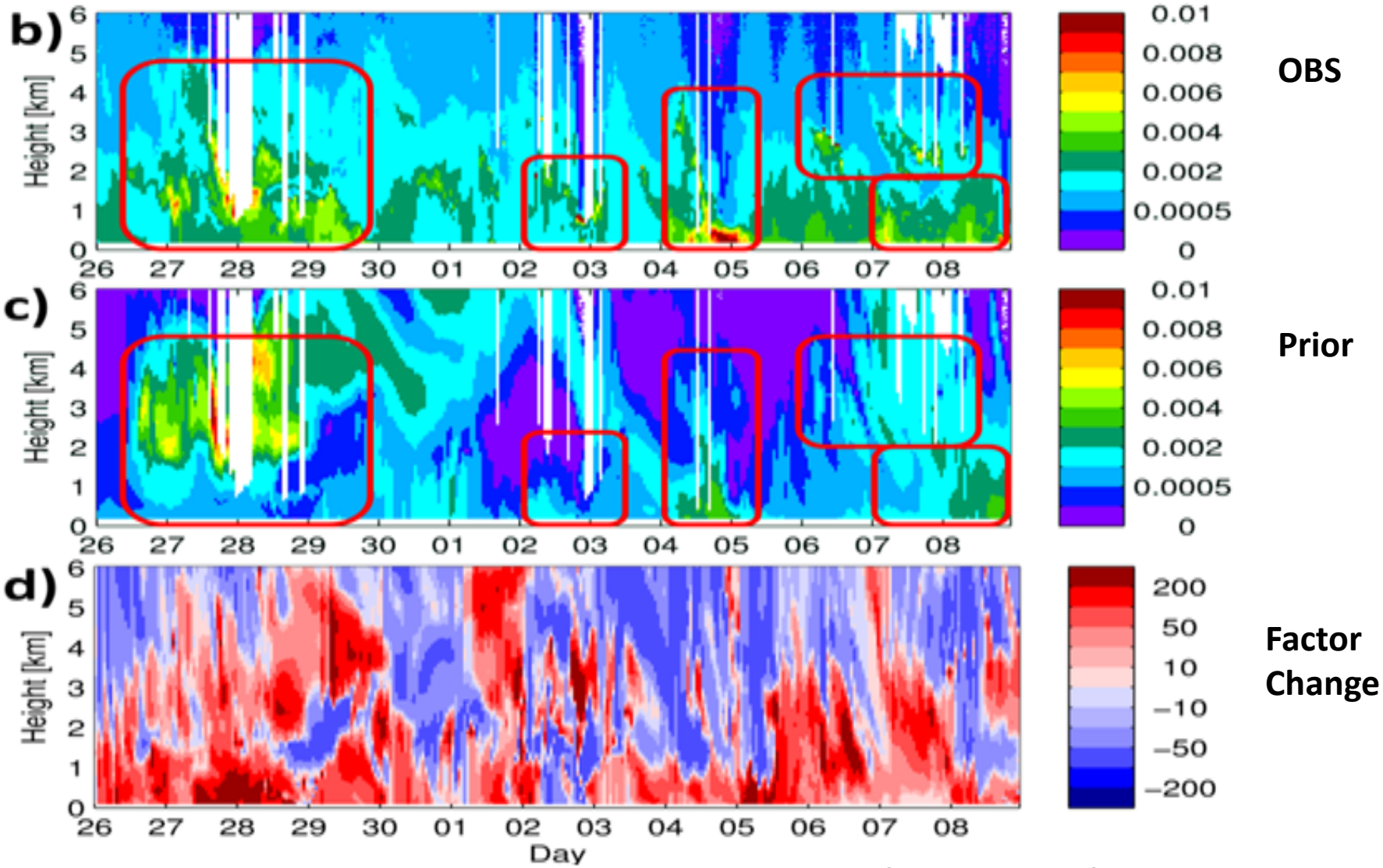
Impact of Observations on Improving "Forecasts" of PM – *assessing time influence of a single assimilation*



Forecast time

Daily simulations starting from each 09 UTC performed for 48 hours over the period of April 26th to May 6th, resulting in eleven simulations. The data shown represents the average performance of the eleven simulations.

Assimilation Technique along with GOCI Assimilation Changes 4-d Fields --



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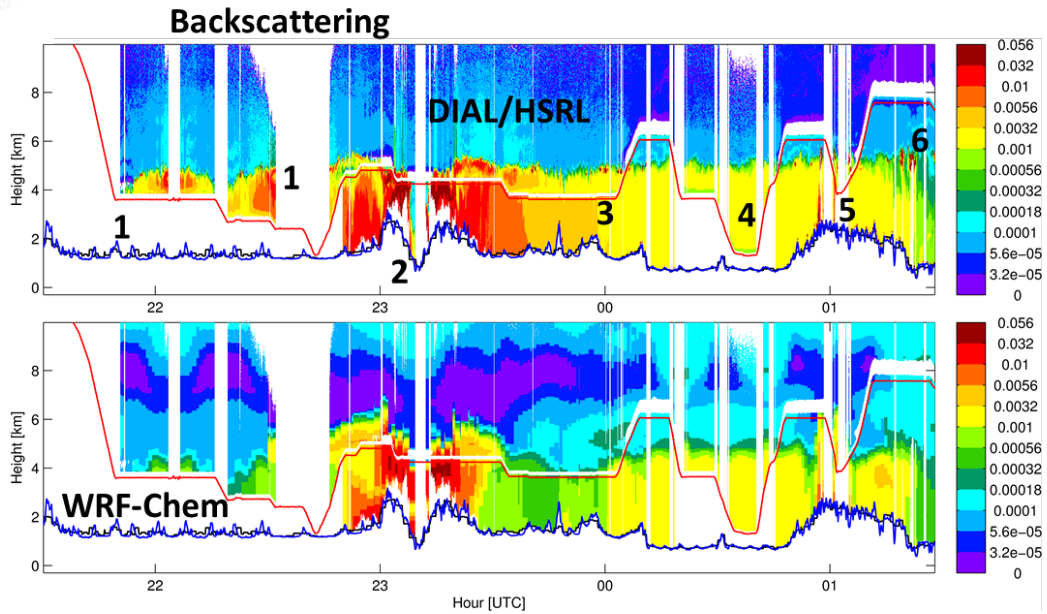
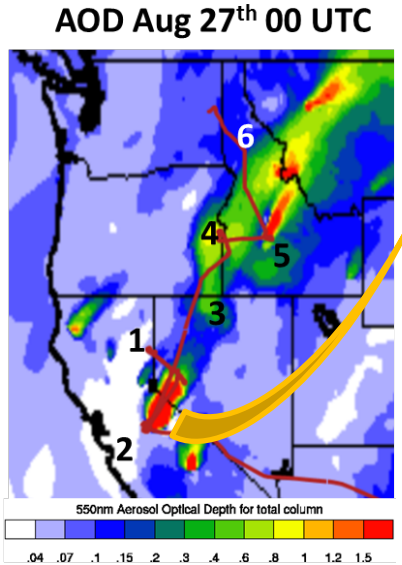
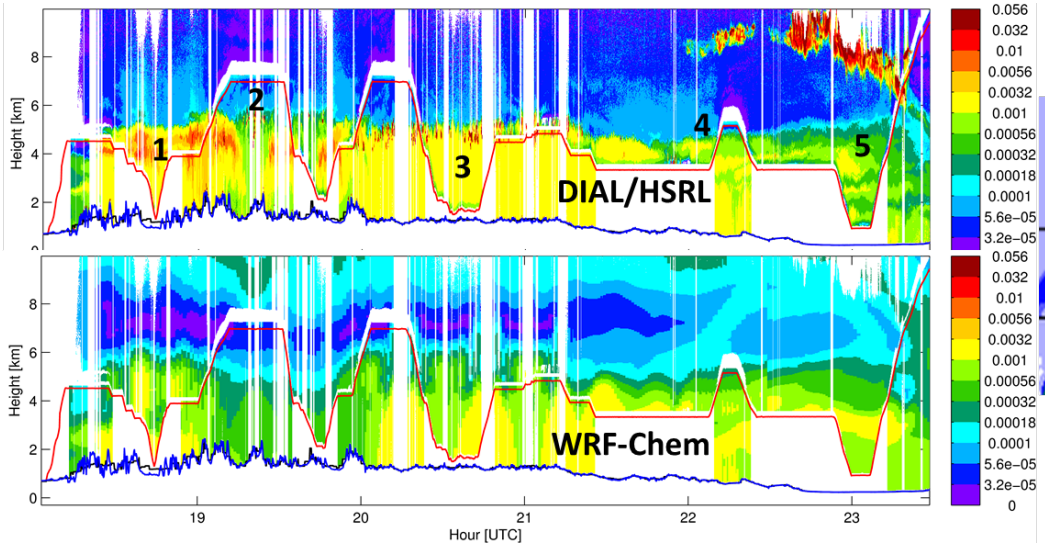
RIM fire during SEAC4RS

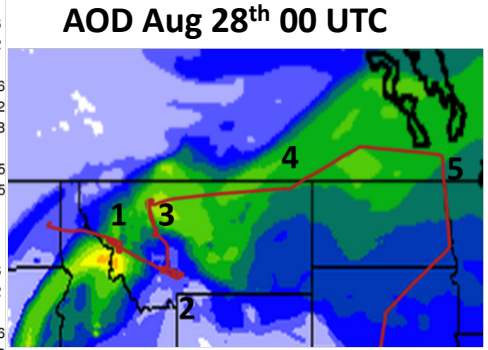
August 26th



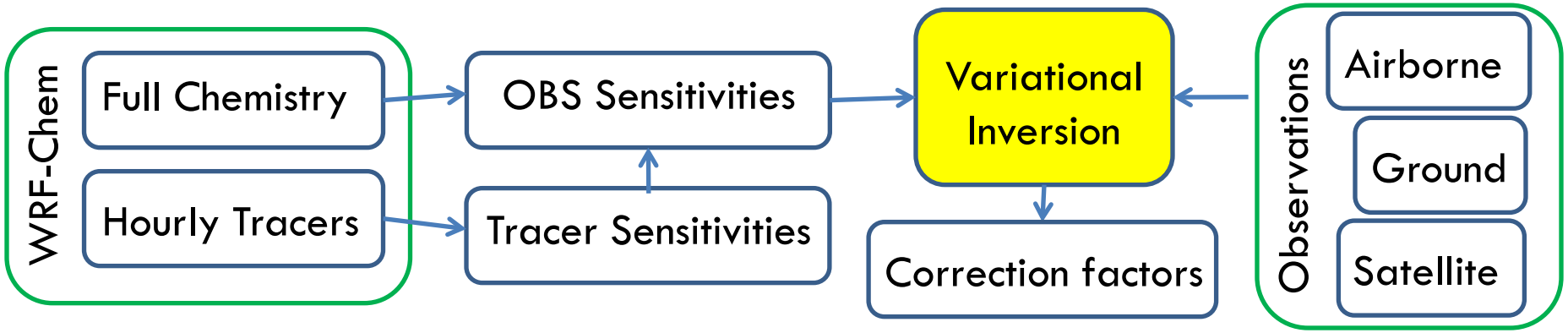


August 27th

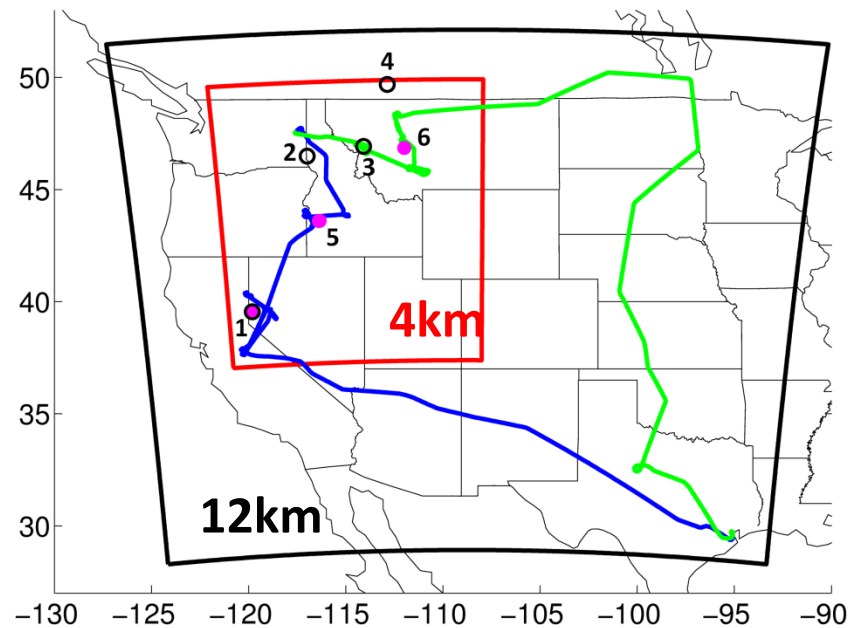




Emission Inversion method



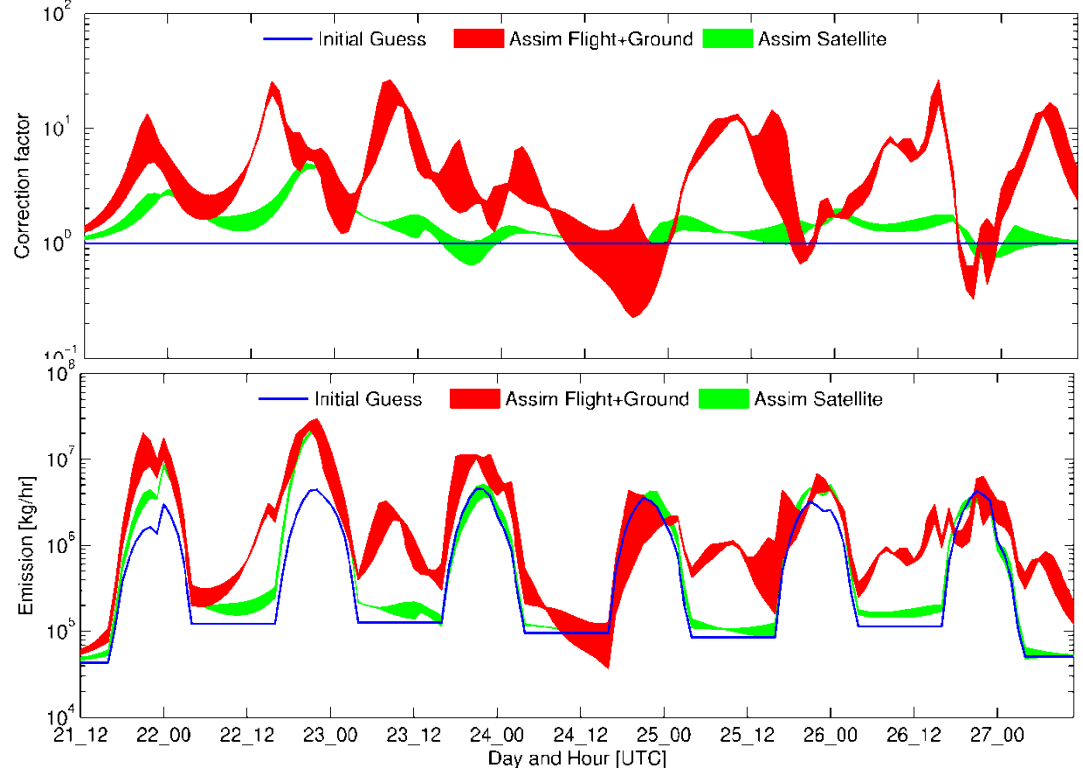
- Simultaneously improve the model fit to various measurements:
  - SEAC4RS in-situ (OA, CO, extinction) and remote sensing (DIAL-HSRL Extinction) from 2 flights
  - AERONET AOD
  - Ground based CO
  - Satellite AOD
- Constrain hourly RIM fire emissions
- Performed at 4km resolution, for 2 met boundary conditions (FNL, NARR)

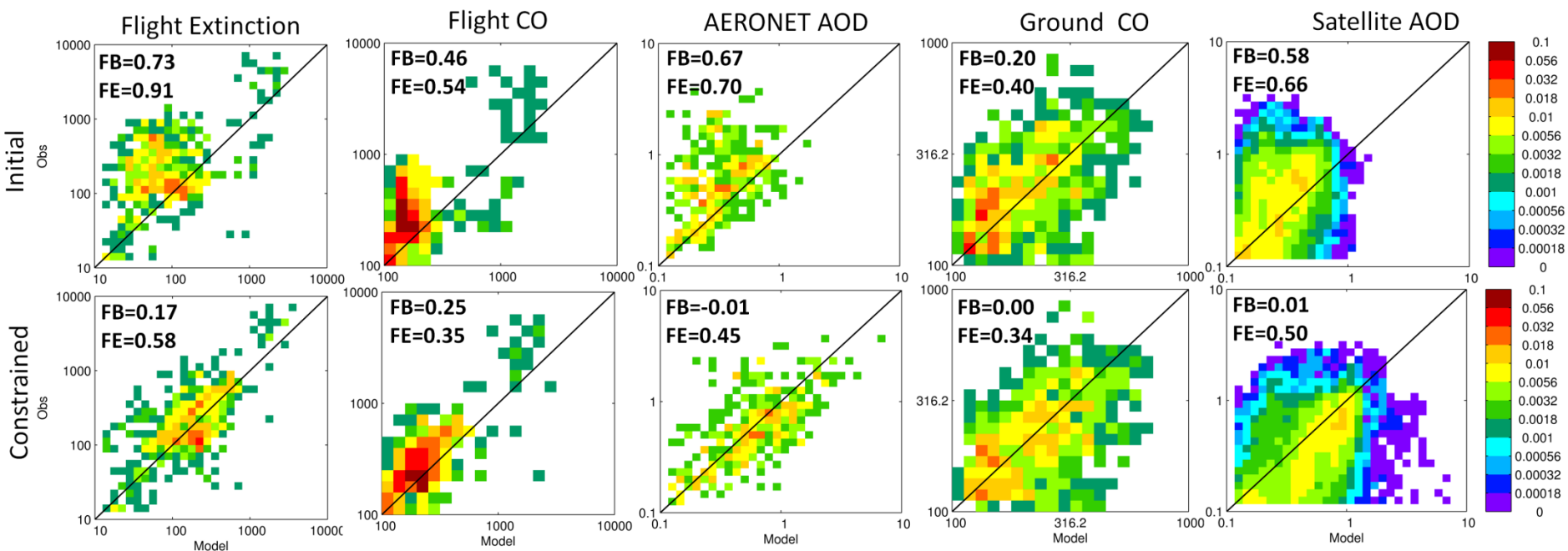


Saide et al., GRL, 2015

Inversion Results

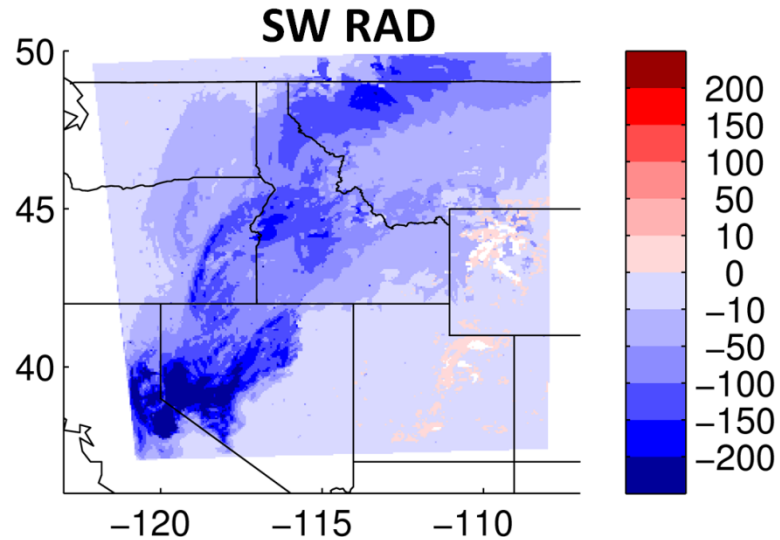
- Total constrained emission are factor ~3 higher
- FNL and NARR inversions generally consistent

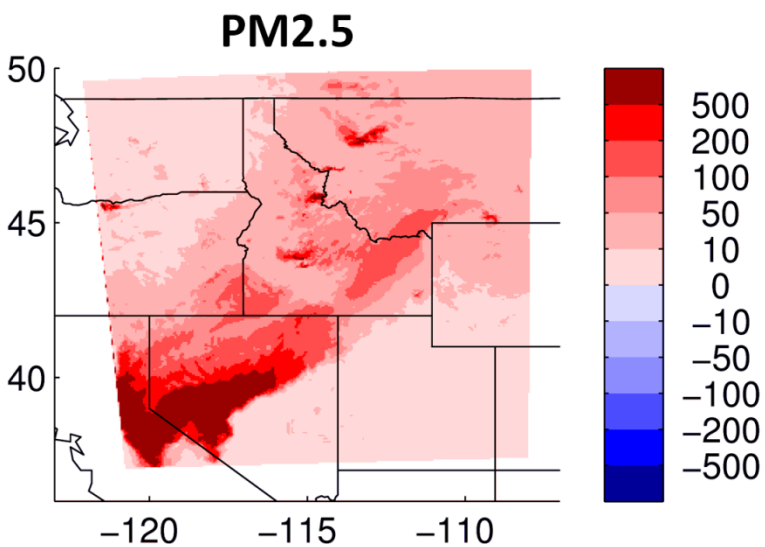


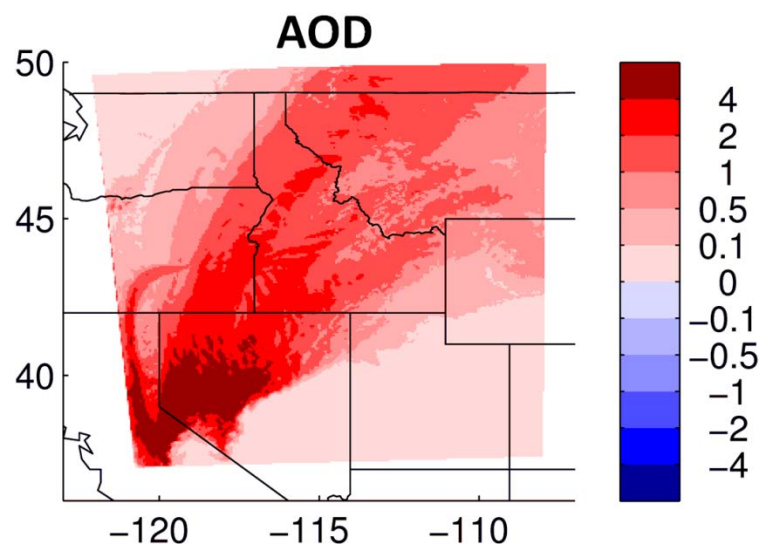


Impacts of constrained emissions

- Maximum changes shown comparing simulation with initial and constrained emissions
- Impacts can be substantial

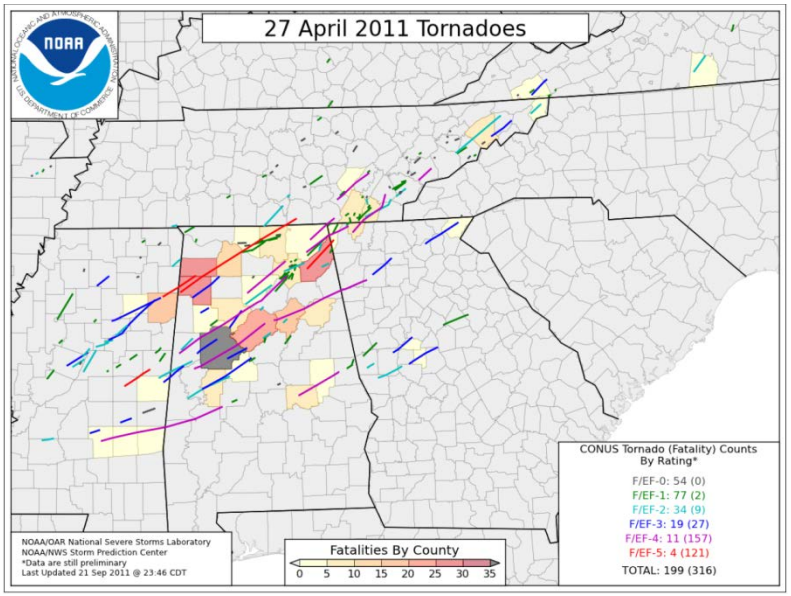






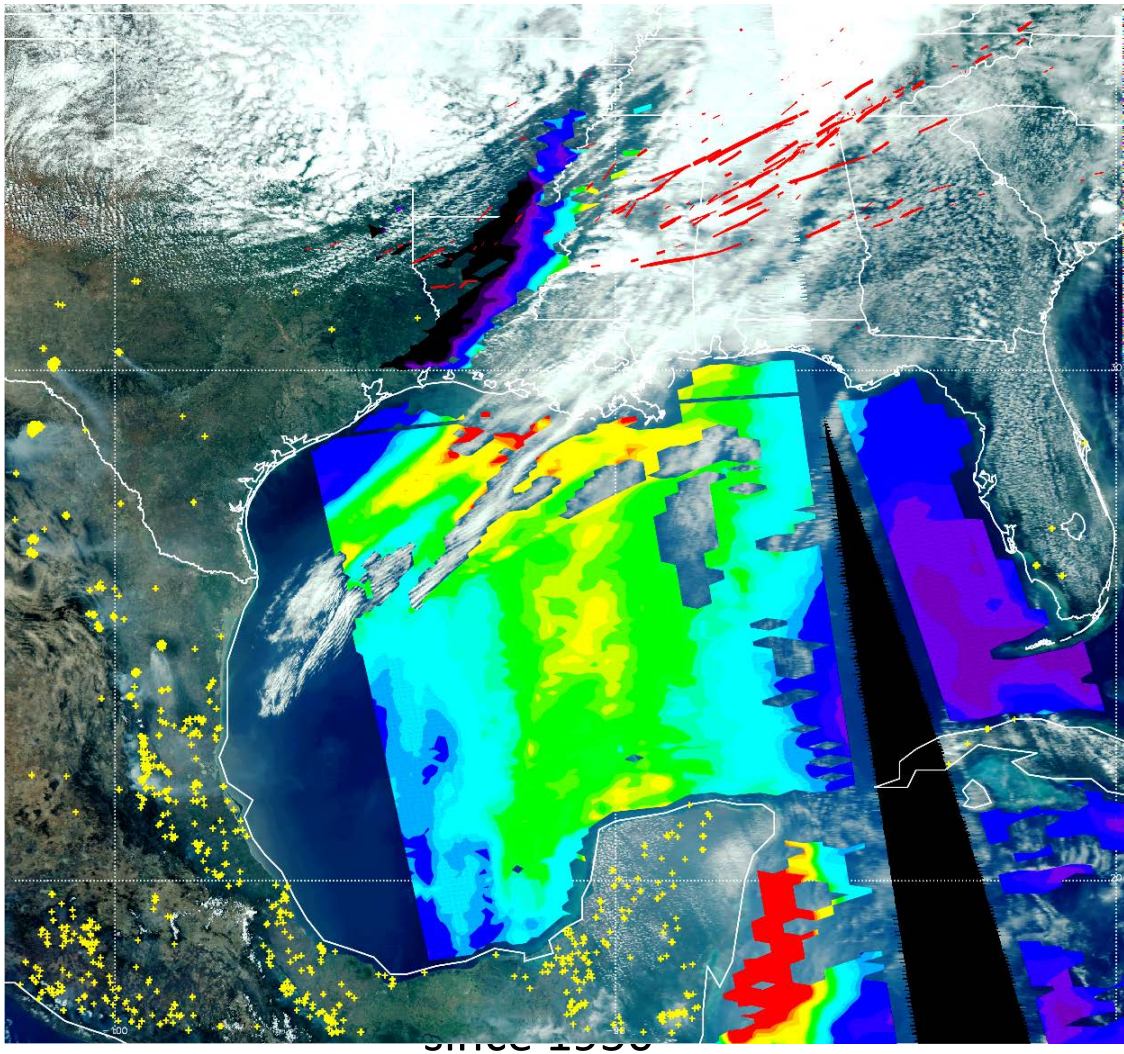
Tornado outbreak on April 27th, 2011- Role of Smoke

Saide et al., GRL, 2015



CONUS Tornado (Fatality) Counts By Rating*

F/EF-0: 54 (0)
F/EF-1: 77 (2)
F/EF-2: 34 (9)
F/EF-3: 19 (27)
F/EF-4: 11 (157)
F/EF-5: 4 (121)
TOTAL: 199 (316)



WRFPLUS-Chem Current Capabilities

Guerette and Henze GMD, 2015

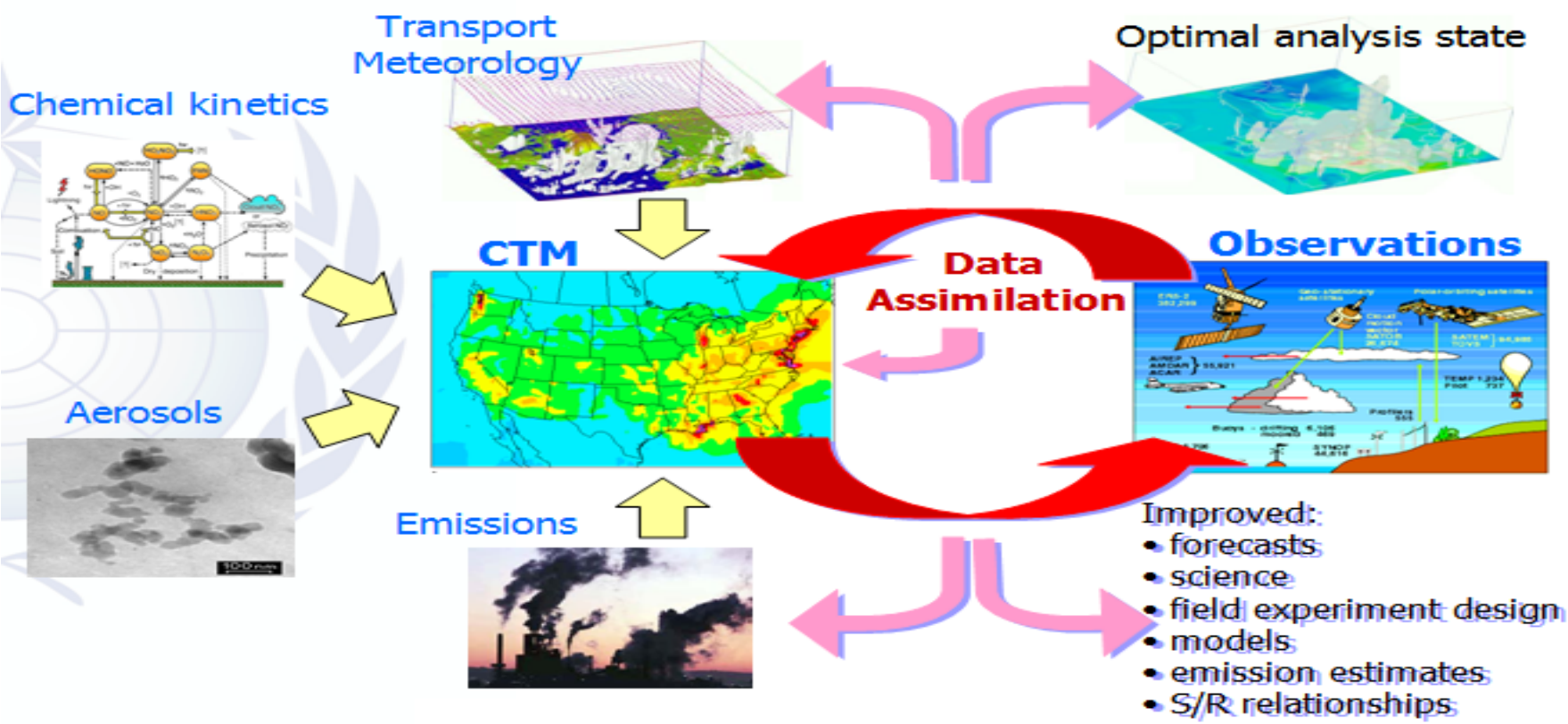
- AD and TL developed for:
  - Emissions (Anthropogenic and Biomass Burning for GOCART)
  - ACM2 PBL (Pleim et al. 2007) w/ integrated tracer transport (2013)
  - Pleim-Xiu and SFCLAY surface layer schemes
  - Pleim-Xiu and SLAB LSMs
  - Wesely Dry Deposition
  - Chem advection (similar to tracer advection by Xin Zhang in 2012)
  - GOCART Aerosols
    - BC aging
    - PM summation
    - Sulfate chemistry (pending testing)

- 2nd-order checkpointing for long duration (> 6 hr) AD/TL simulations

- New adjoint forcing scheme for in-situ chemical observations

- Standalone AD and TL:
  - Grell-Freitas Convection (2013) [chemical tracers in development]

Models Constrained With Observations Play Increasing Important Roles In Research and Applications



Need more tools and experiences with coupled models! AND enhanced atmospheric composition observations