SENSITIVITY ANALYSIS OF AEROSOL FEEDBACKS ON CHEMISTRY AND CLIMATE AT URBAN AND REGIONAL SCALES

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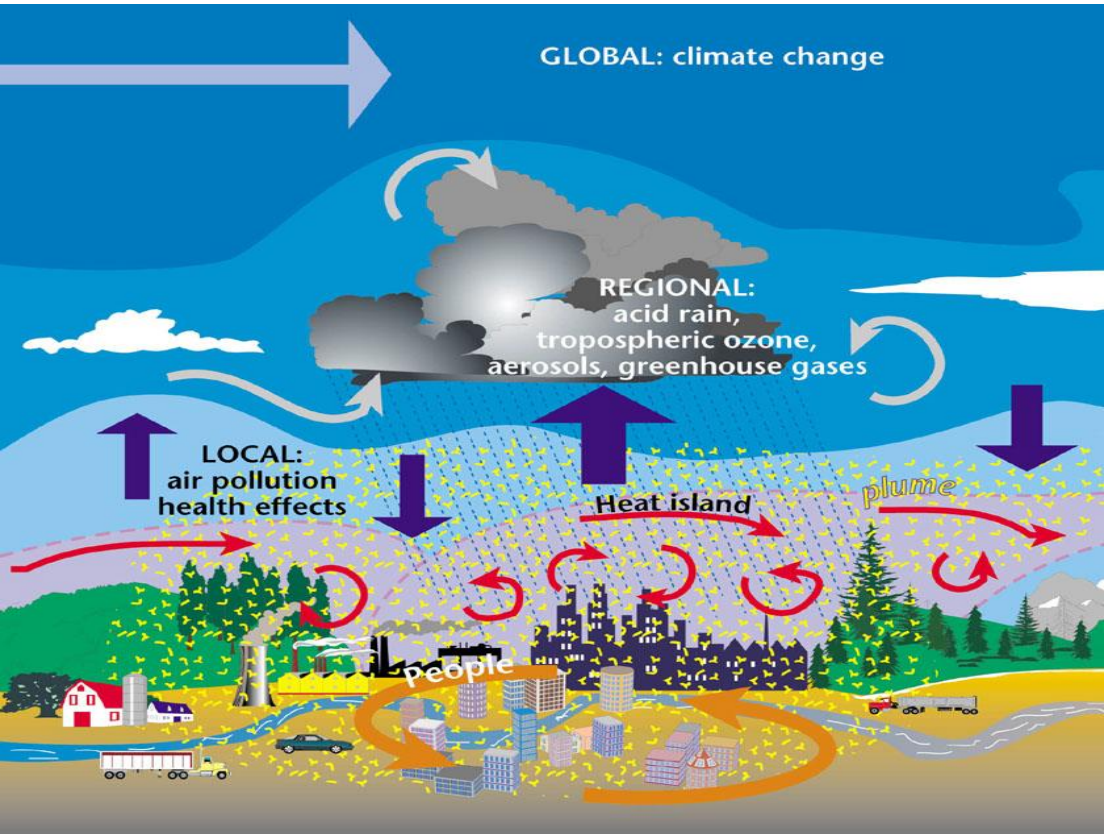


Today's talk -

- Combining air quality and weather forecasting - implications for air quality & NWP predictions.
- Opportunities to improve prediction through assimilation
- Thoughts on moving forward.

Combining Air Quality and Meteorology Modeling

(Radiation)

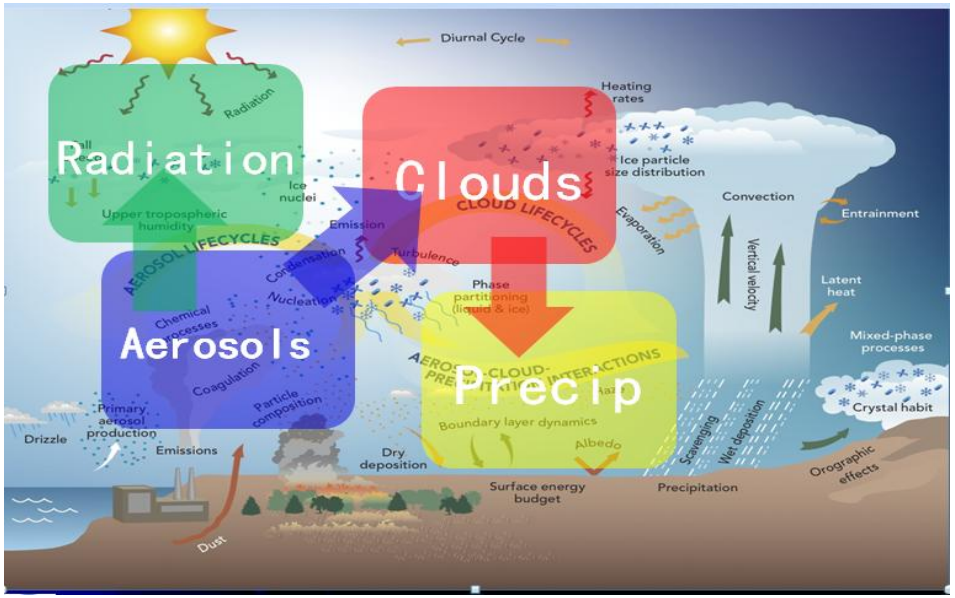
Direct effects

(cloud formation, CCN)

Indirect effects

Aerosols ← **Meteorology**

(transport, physico-chemical reaction rates, biological emissions and wet & dry depositions etc.)



Modeling Aerosol Feedbacks at Local/Regional Scales

(Radiation)

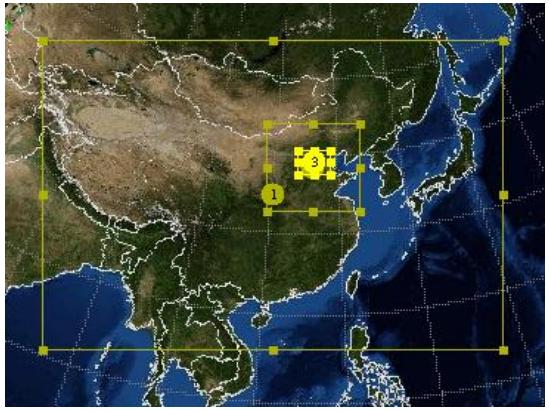
Direct effects

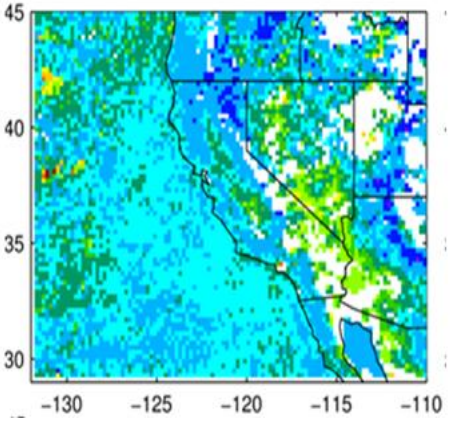
(cloud formation, CCN)

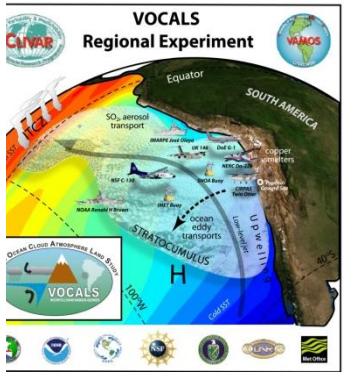
Indirect effects

Aerosols ⟵ **Meteorology**

(transport, physico-chemical reaction rates, biological emissions and wet & dry depositions etc.)

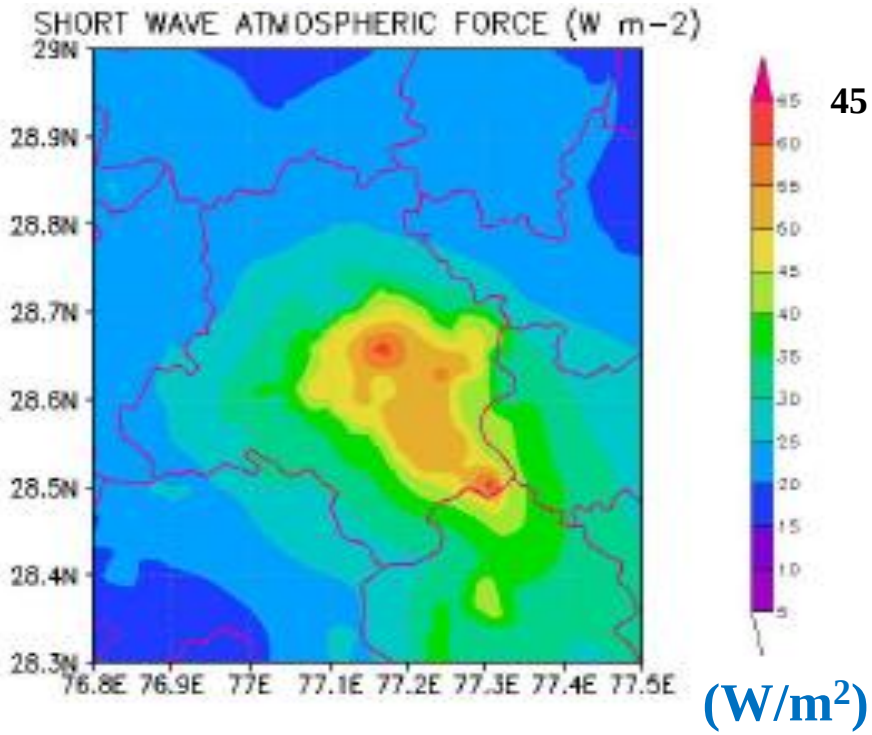


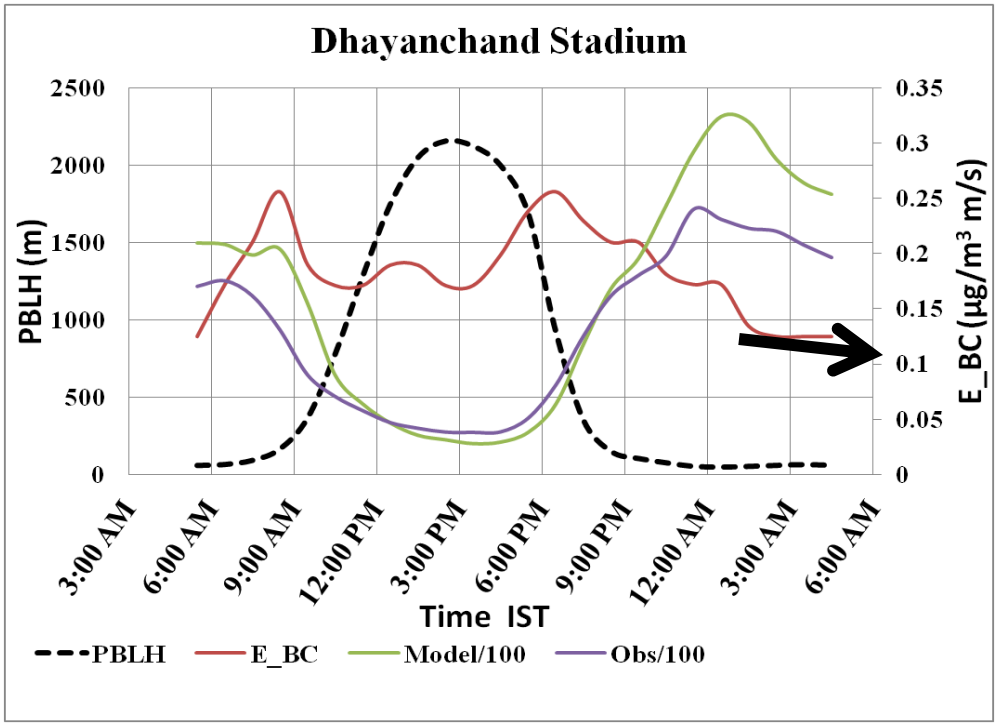




- WRF-Chem model (including aerosol feedbacks)
- Case studies: Delhi, Beijing, California and Chile

High Aerosol Loadings and Strong Radiative Forcings with Diurnal Variations Driven by Emissions and Boundary Layer Dynamics

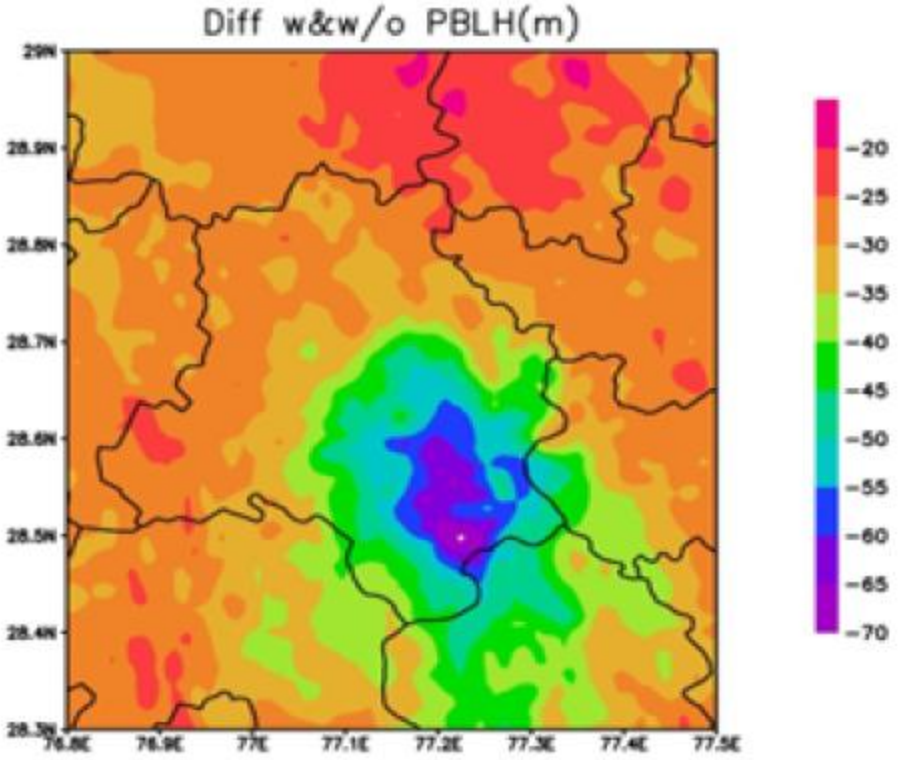


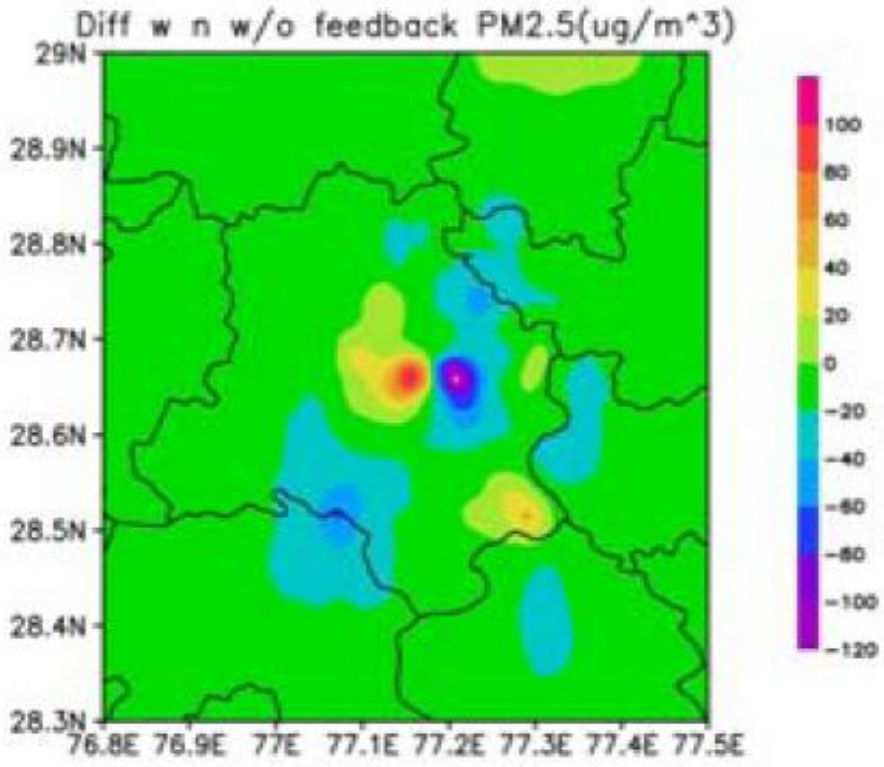


Strong surface dimming due to primary and secondary aerosols are found (> 60 W/m^2)

Mean diurnal variation in boundary layer height, emissions and BC concentrations from model and observations at the Dhyanchand Stadium site.

Strong Sensitivity of Surface Concentrations to Feedbacks



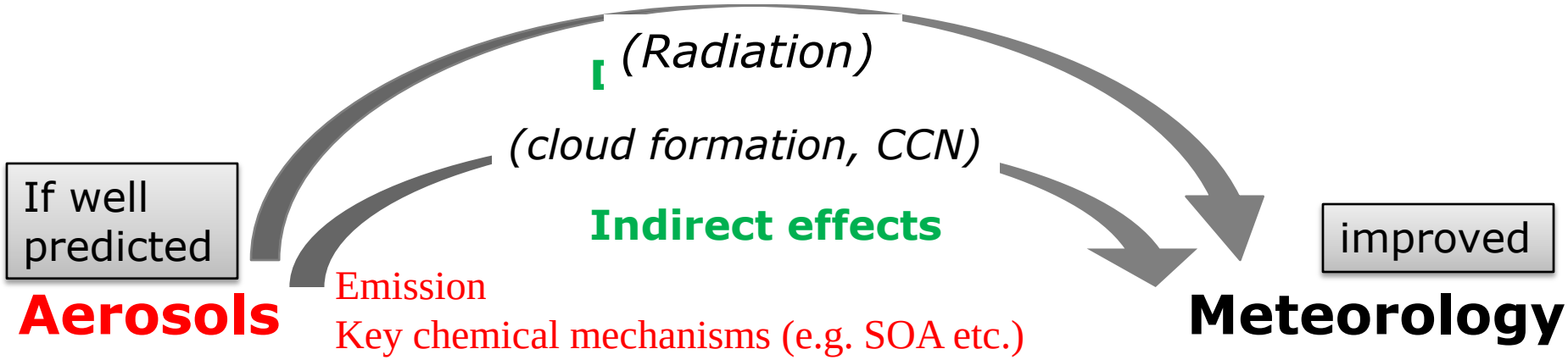


Δ **Day-time Mixing Heights**

Δ **Mean surface PM2.5**

(With – Without Feedbacks)

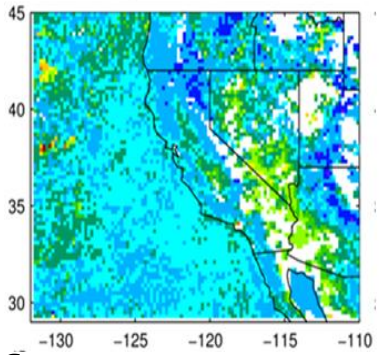
A Growing Number of Case Studies Suggest Including Feedbacks Improve Predictions



But large uncertainties in prediction of aerosols

- ***Improving predictions requires better forward models and constraining models with observations***
- ***Not a great amount of experience in chemical data assimilation in coupled AQ/Met Prediction***
- **Our approach develop techniques in the on-line WRF-Chem model with feedbacks (direct & indirect) between aerosols and meteorology**
  - **First step embed in operational 3d-Var system --- GSI (*Gridpoint Statistical Interpolation)***

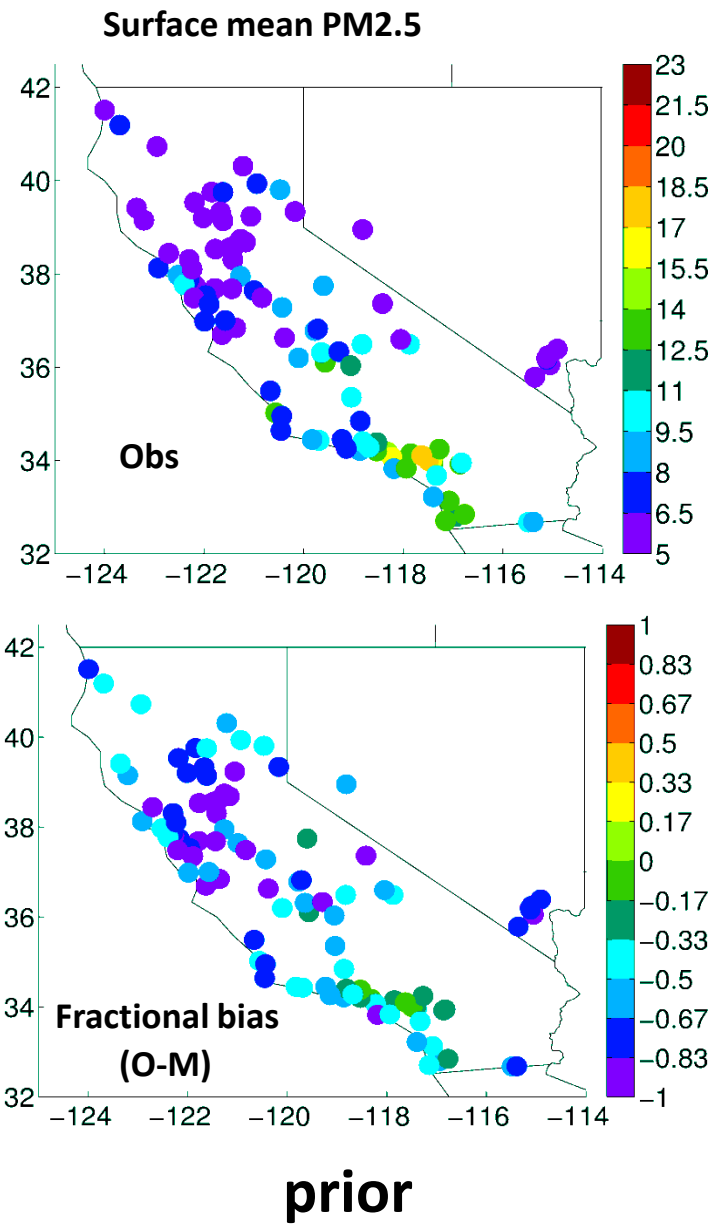
Adding AOD assimilation

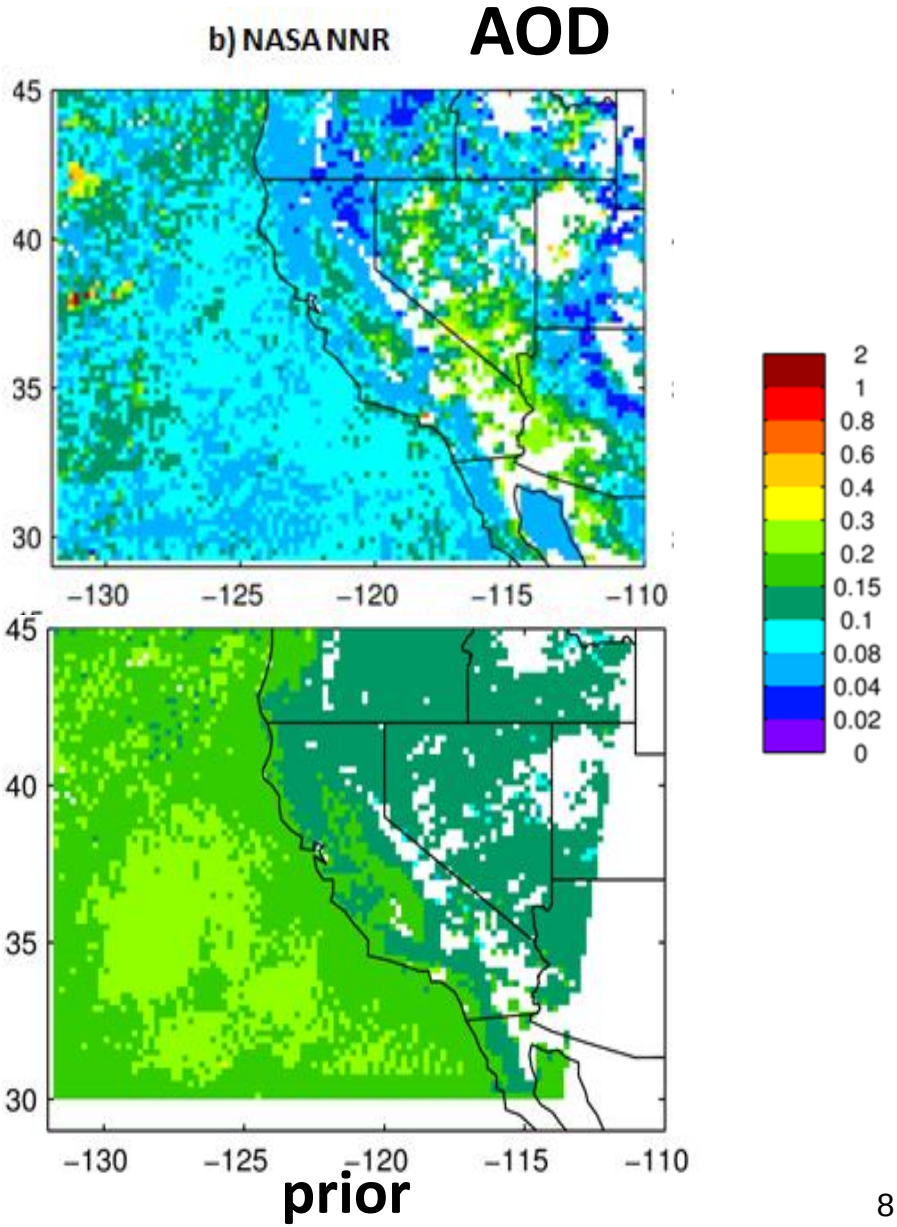


- Gridpoint Statistical Interpolation (GSI) can perform simultaneous DA of different datasets (e.g. ground PM2.5 and AOD)
- First, need to add MOSAIC (sectional) AOD assimilation (just GOCART before) in GSI:
  - AOD and sensitivities computed with WRF-Chem optical averaging routine (Mie code + Internal Mixture) and its adjoint (TAPENADE)
  - Aerosol water computed as in MOSAIC (use electrolytes)
  - Add correlation between bins sizes by using smoothing filters
  - Simultaneous assimilation of various AOD products (total and fine AOD **OR** AOD at multiple wavelengths)

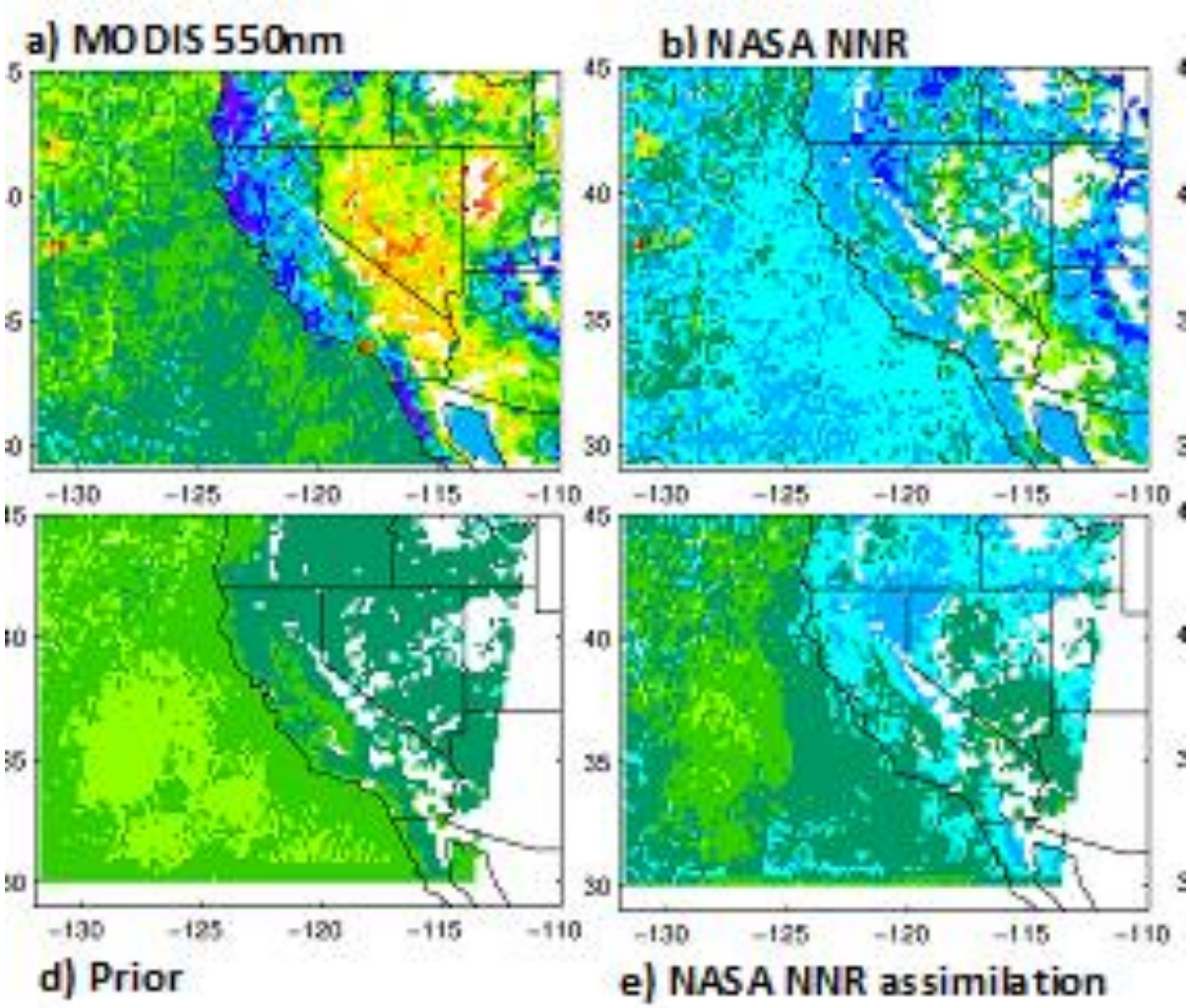
Ref: Schwartz et al., JGR 2012, Liu et al., JGR 2011, Fast et al., JGR 2006

Case Study – California CALNeX: Forward Model Prediction (Monthly Mean) May 2010



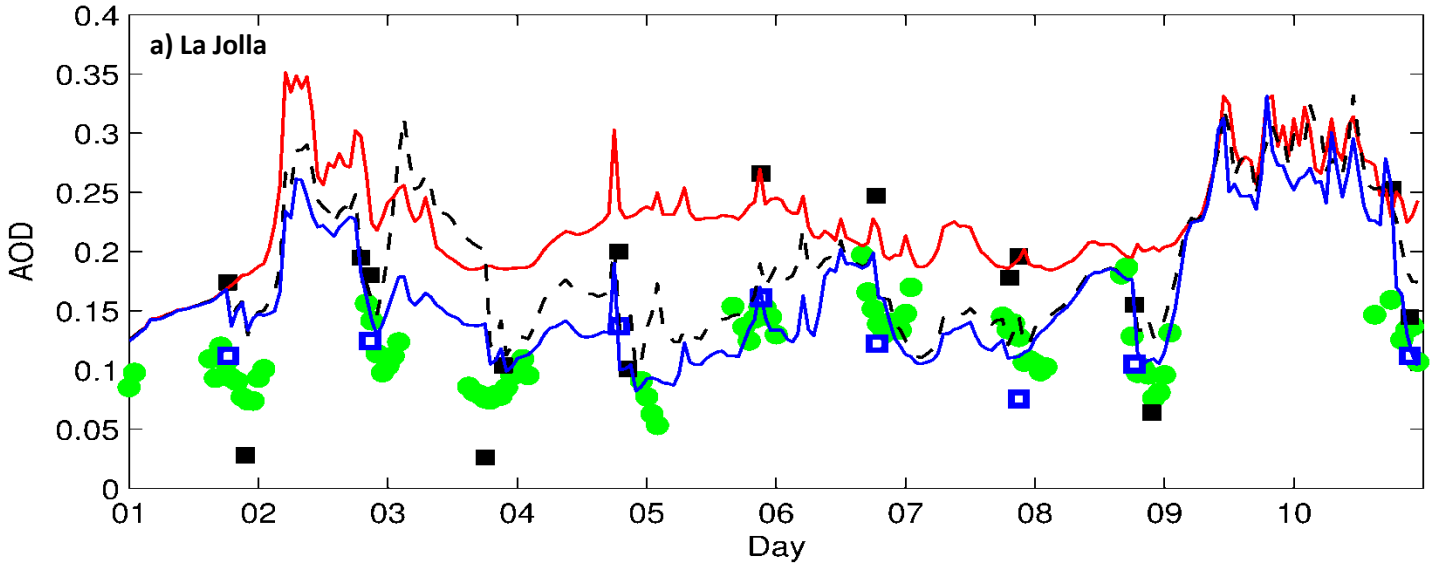


Assimilating Different AOD Products



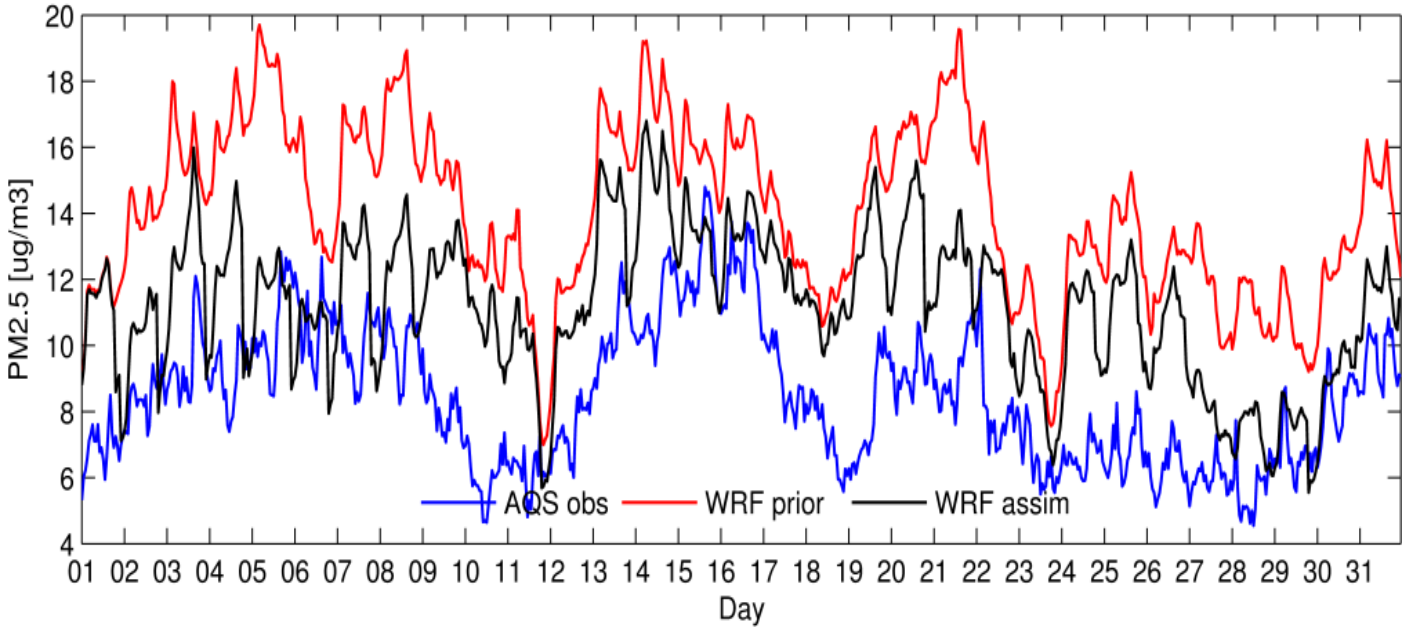
Saide et al., APCD, 2013

Impact of Assimilation on Forecast (i.c. only)



--- Prior

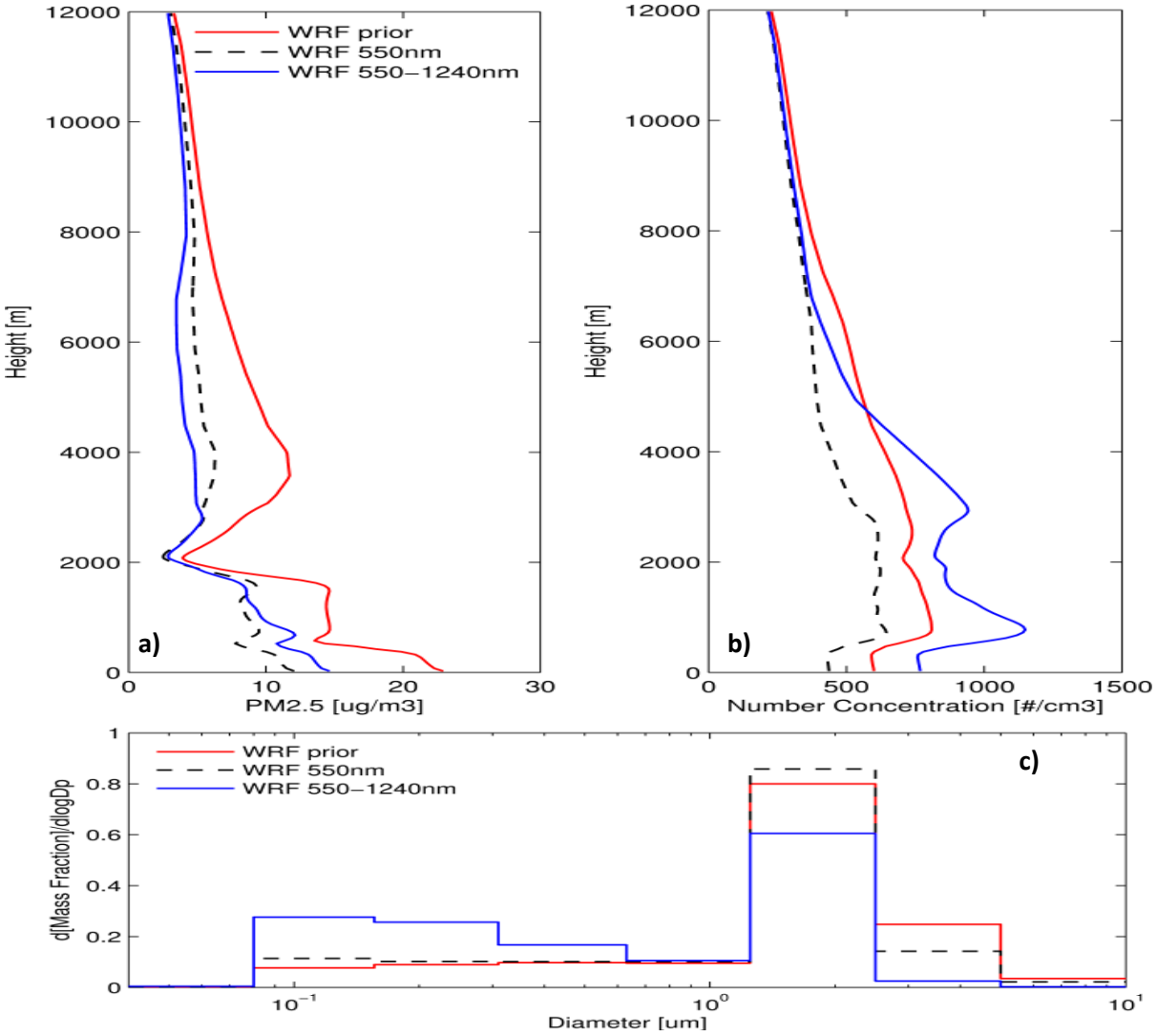
--- Assim



All CA Sites

Assimilation using this Method affects Vertical Profile and Size Distribution

(May 6th, 2010 at 21 UTC)

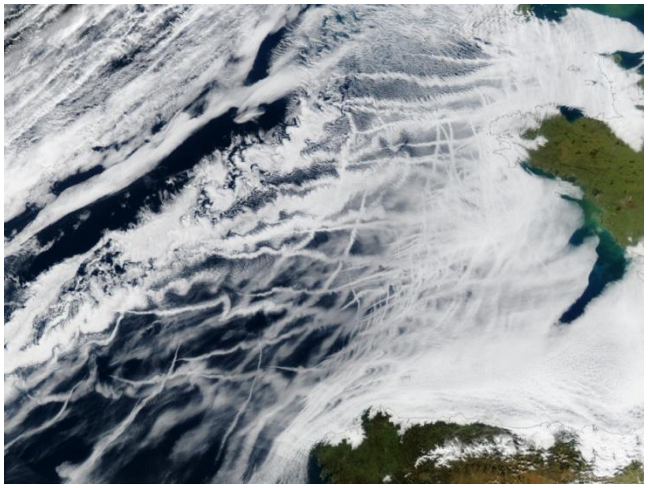


Diff between assimilation of single and multiple wavelengths

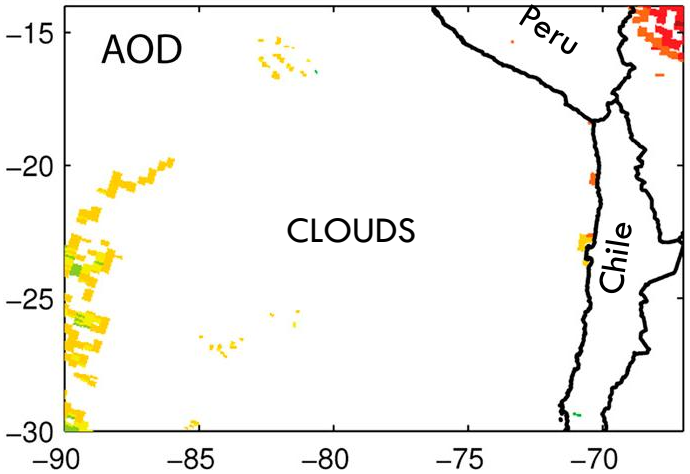
Next Steps

- AOD retrievals provide information to constrain aerosol mass.
- **But** in many regions there is a lack of AOD information.
- **However** cloud retrievals contain information on aerosols.

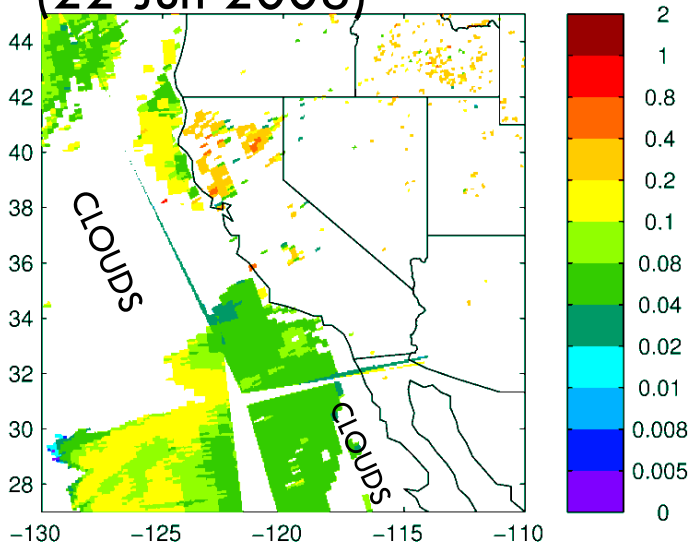
Cloud "Ship tracks"



MODIS fine AOD SE Pacific

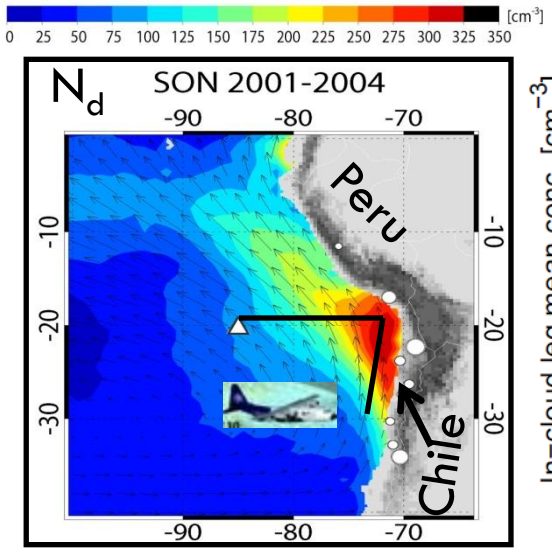


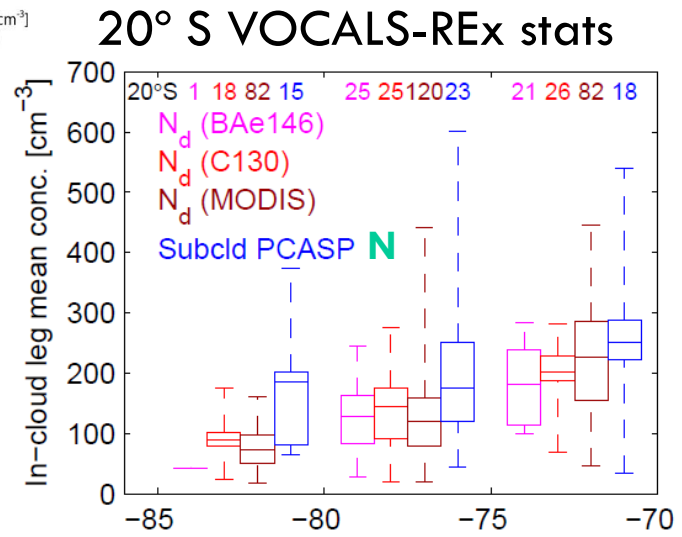
MODIS fine AOD CA (22 Jun 2008)



Opportunity

- SEP marine Sc N_d satellite retrievals show evidence of aerosol load and agree with observations
- Aerosol indirect effects simulated with some skill in WRF-Chem (in coastal marine environemnts)
- **Hypothesis:** variational assimilation with N_d retrievals can improve below-cloud aerosols in models





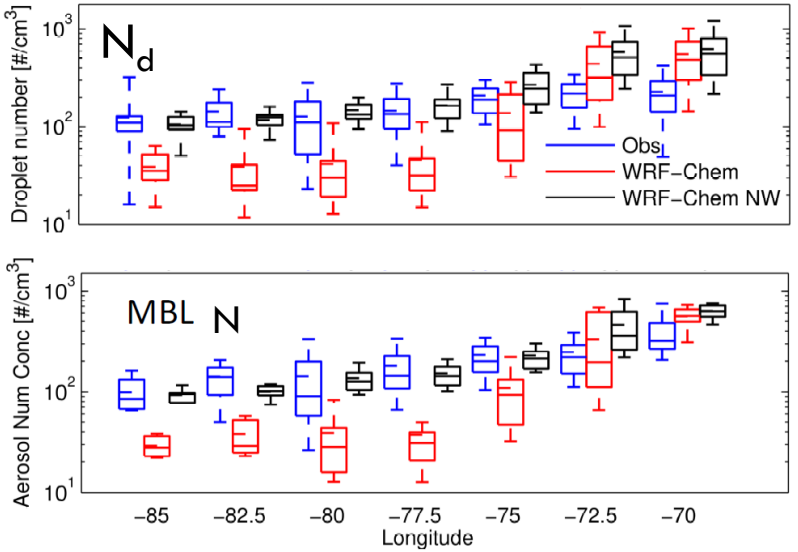
$$N_d = K \tau^{1/2} r_e^{-5/2}$$

T: Cloud optical depth

r_e: Cloud effective radius

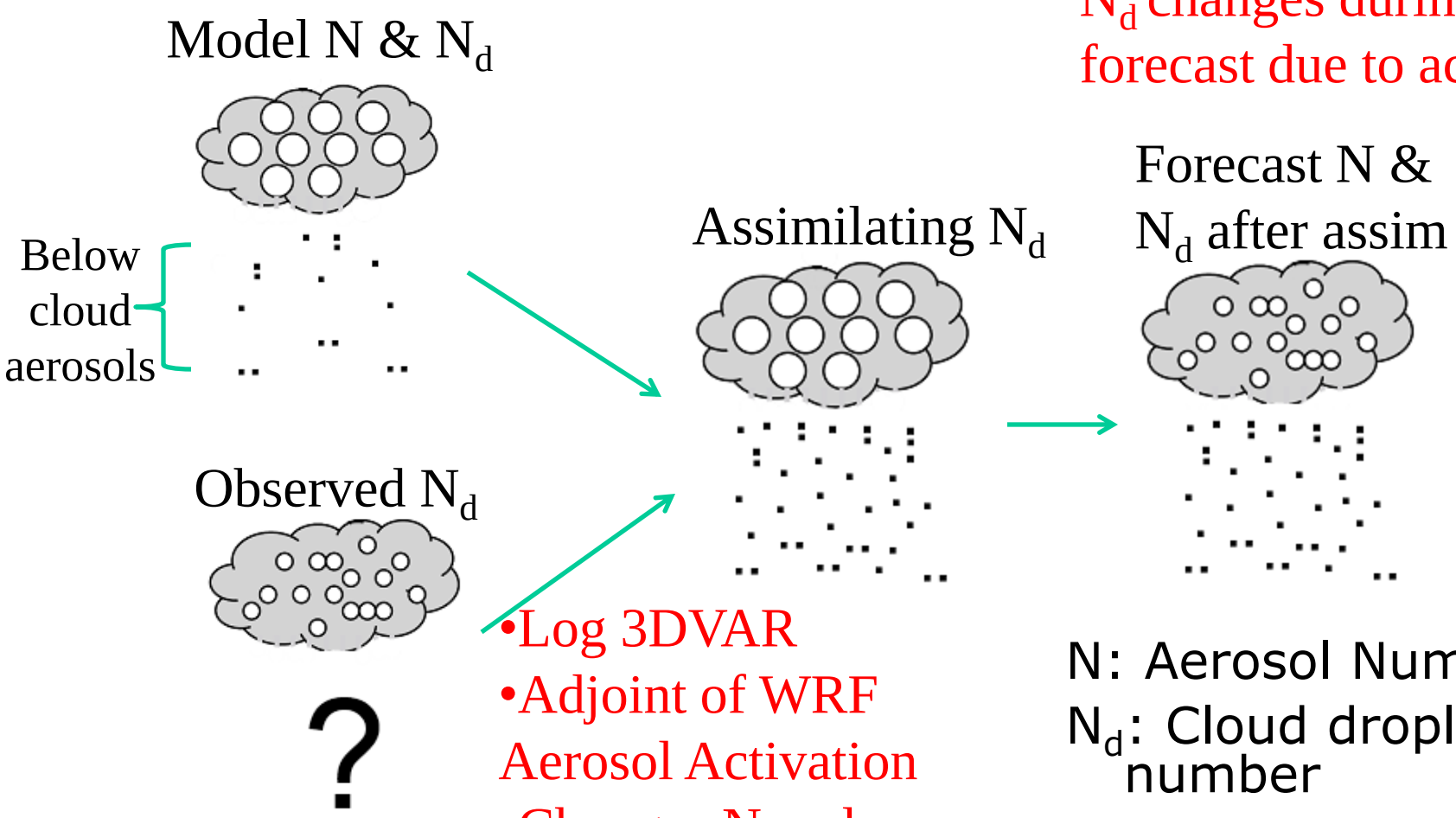
N_d: Cloud droplet #

N: Aerosol # conc.



Refs: Saide et al., ACP 2012, Bretherton et al., ACP 2010, Painemal and Zuidema, ACP 2011

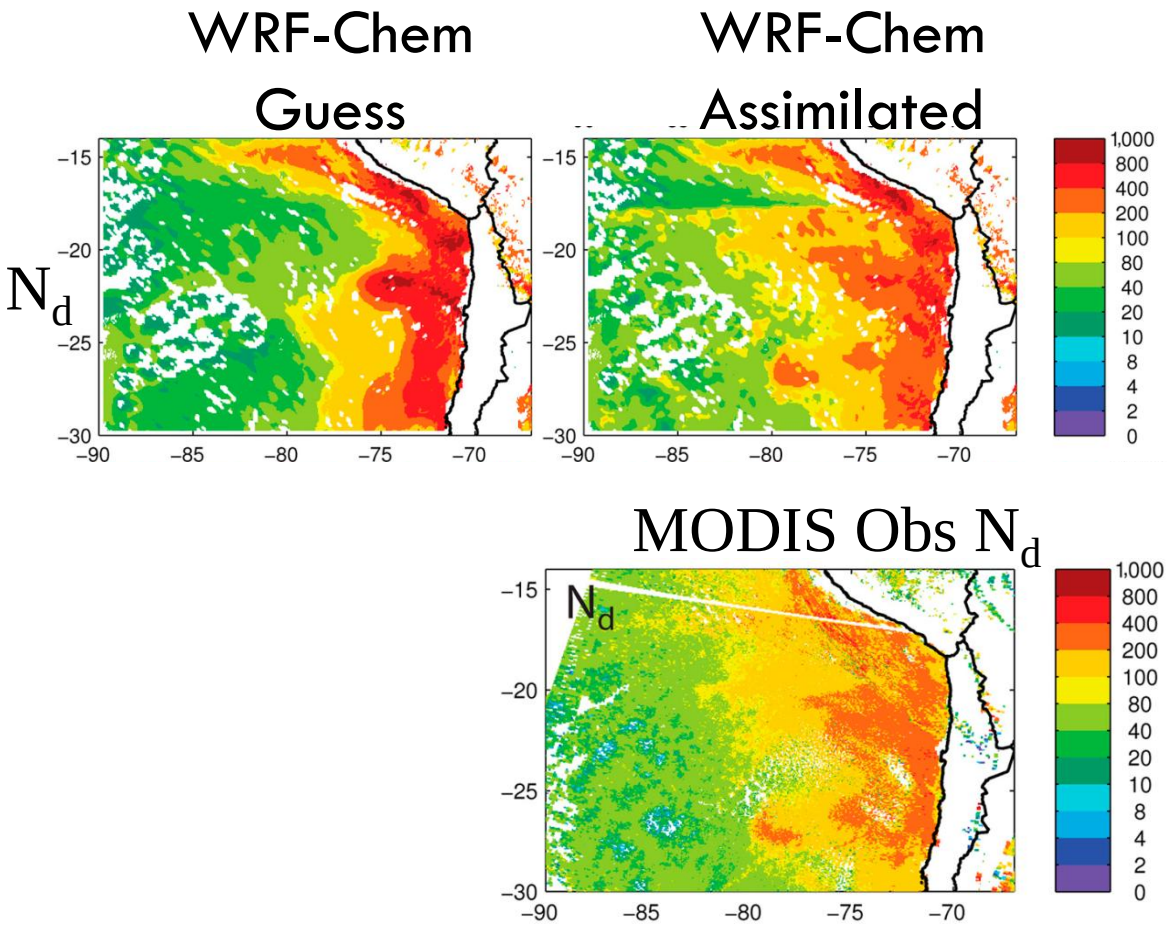
We've developed a technique to assimilate cloud satellite retievals to constrain aerosol distributions



Ref: Saide et al., PNAS 2012

Assimilation results: + & - biases reduced

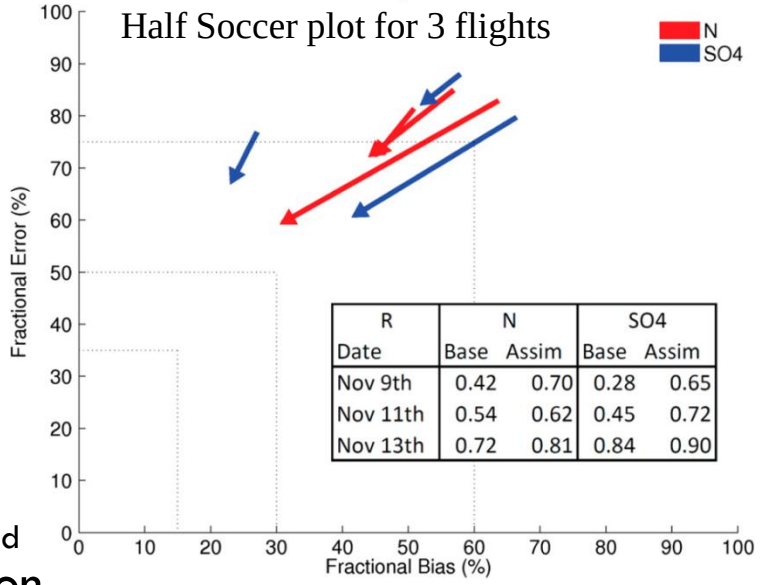
- Assimilate MODIS Terra N_d
- Aerosol mass and number are changed



Ref: Saide et al., PNAS 2012

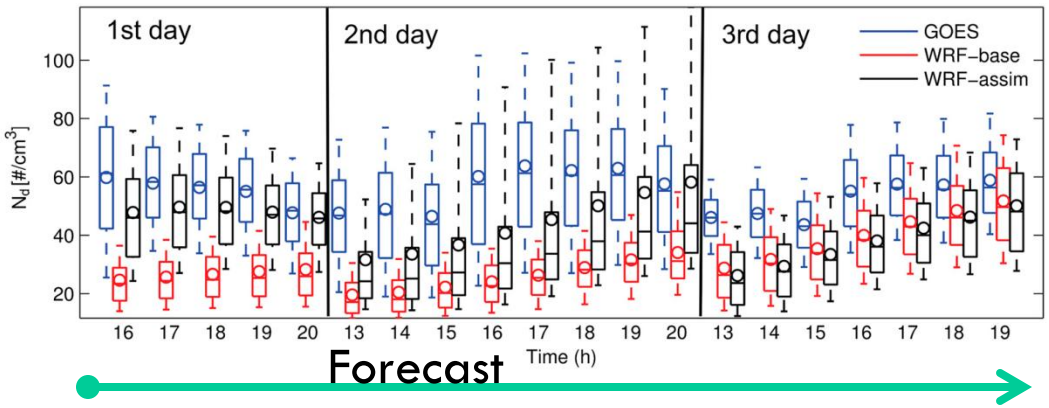
Daytime N_d after assimilation vs GOES and in-situ aerosol

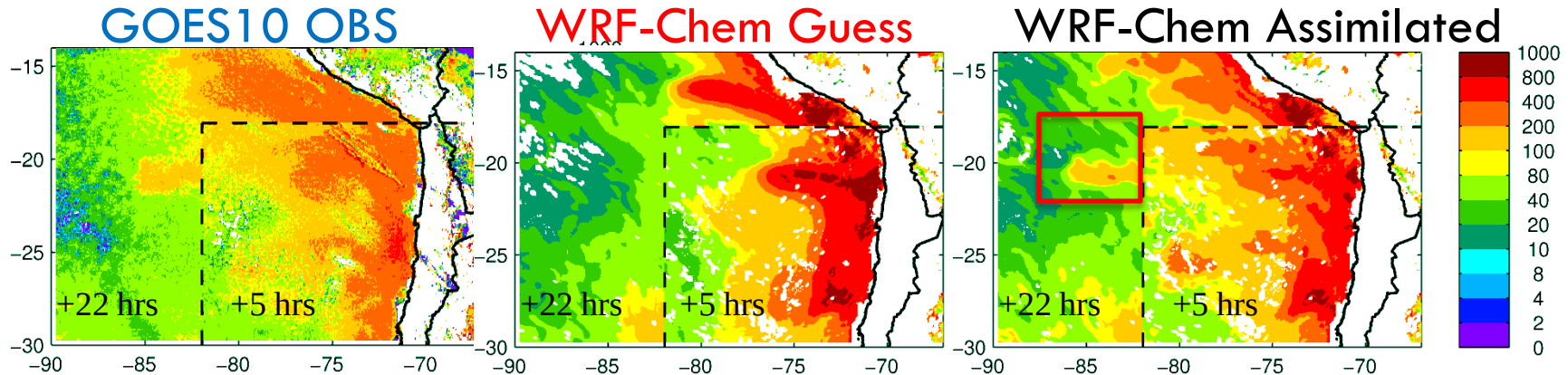
- Large improvements during the first 2 days for all domain
- GOES Assimilation improves agreement with VOCALS-REx C130 aerosol number and mass observations



Date	R N Base	R N Assim	R SO4 Base	R SO4 Assim
Nov 9th	0.42	0.70	0.28	0.65
Nov 11th	0.54	0.62	0.45	0.72
Nov 13th	0.72	0.81	0.84	0.90

A single MODIS N_d Assimilation





Ref: Saide et al., PNAS 2012

Conclusions and future work

- Cloud (N_d) assimilation
  - A data assimilation method to improve below-cloud accumulation aerosol using cloud retrievals is developed and tested, showing improvement vs. satellite and in-situ observations with up to 48 hours influence
  - This technique can be now used within the GSI assimilation system
- Coupling cloud (N_d) and AOD assimilation
  - Development of GSI MOSAIC AOD with positive results, incorporating fine AOD OR total AOD at different wavelengths
- Future work
  - Include surface aerosol information in the assimilation (e.g., PM2.5) – use in SAFAR & include assimilation of surface winds
  - Compare N_d +AOD assimilation to in situ data (ARCTAS-CARB, CALNEX)
  - Include products from other platforms (other LEO and GEO AOD, AAOD)
  - Analyze effect of assimilated aerosol on meteorology and chemistry through WRF-Chem aerosol feedbacks
  - Moving forward with full adjoint WRF-Chem for use in 4dVar applications including emission estimates.