Using WRF-Chem to understand interactions between synoptic and microphysical variability during VOCALS

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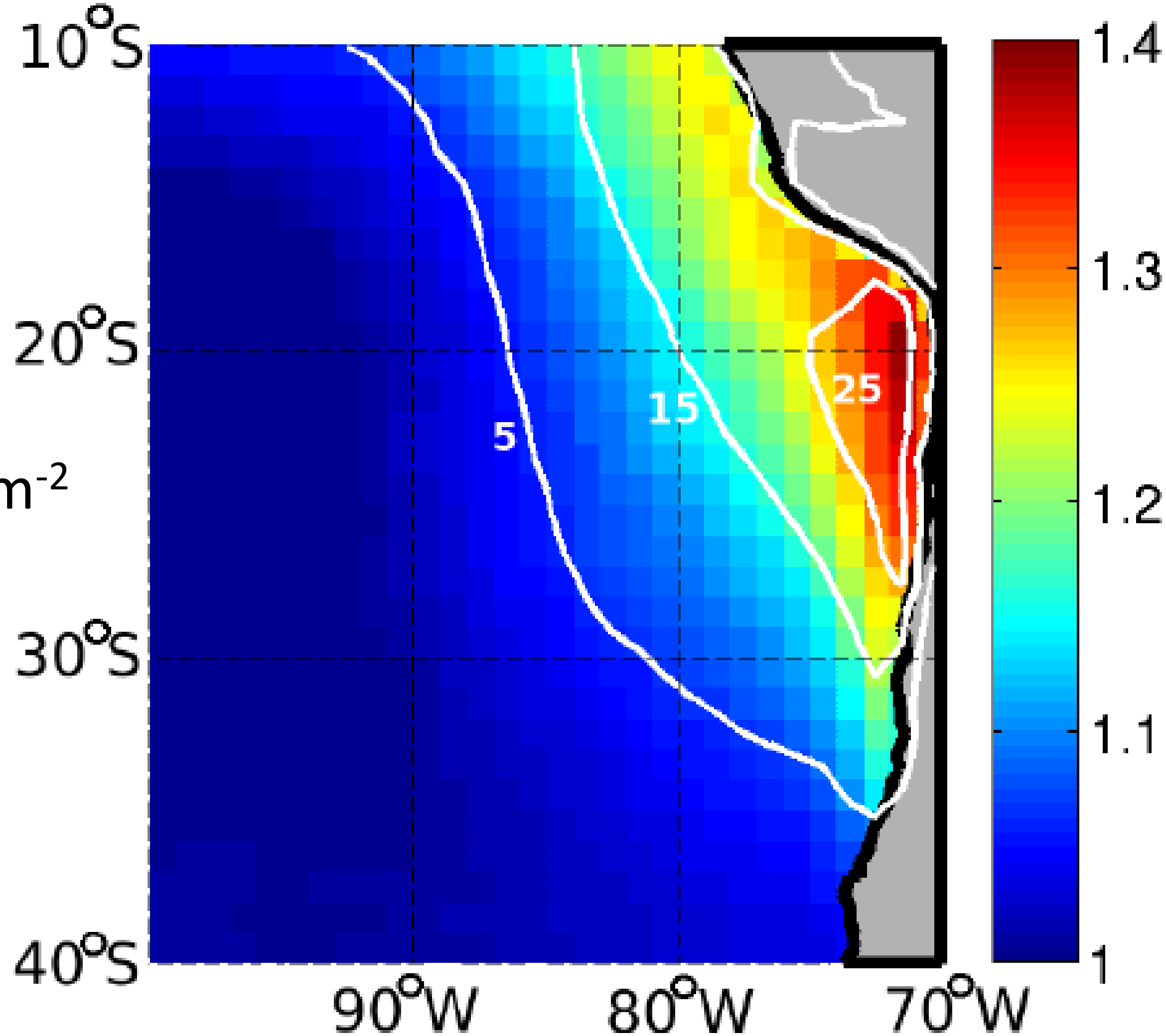
Motivation

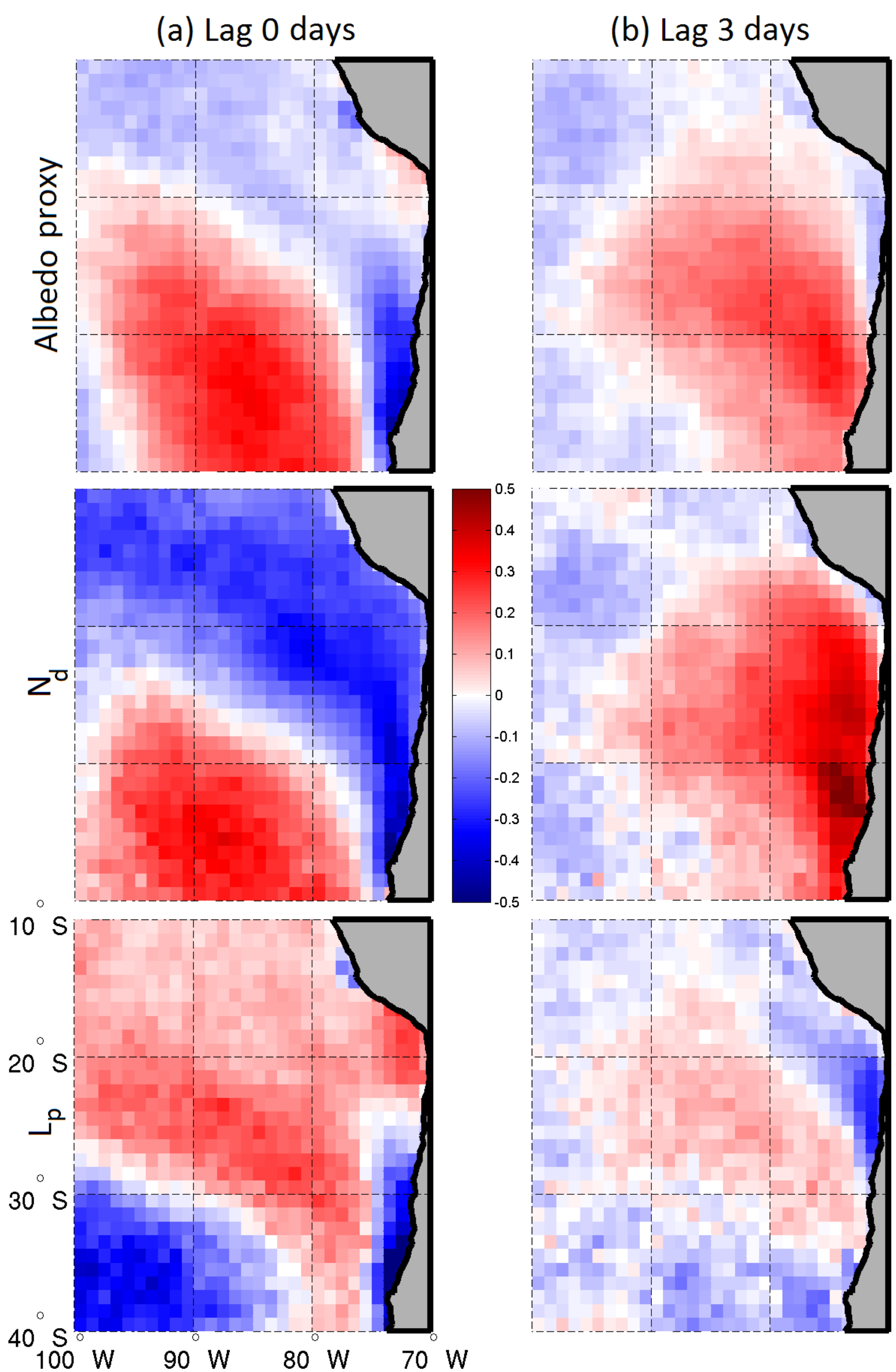
N_d = droplet concentration
Colored contours:

$$\frac{\text{Mean albedo (observed } N_d)}{\text{Mean albedo(remote } N_d)}$$

White contours:
Δ(reflected solar flux) in W m^{-2}

- Aerosol Indirect Effects (AIEs) remain a large source of uncertainty in the anthropogenic contribution to climate change





-Fractional composite difference plots of MODIS fields on index of the strength of the Subtropical High, 2001-2008. (George and Wood 2009)

To what extent are these associations due to

-aerosol effects on clouds and aerosol transport

-direct dynamical mechanisms independent of aerosol changes

?

More was done, and more could be done with satellite data alone, but fundamental problem of **attributing causality** to physical mechanisms and separating meteorology from aerosol impacts remains.

Goals (not for today)

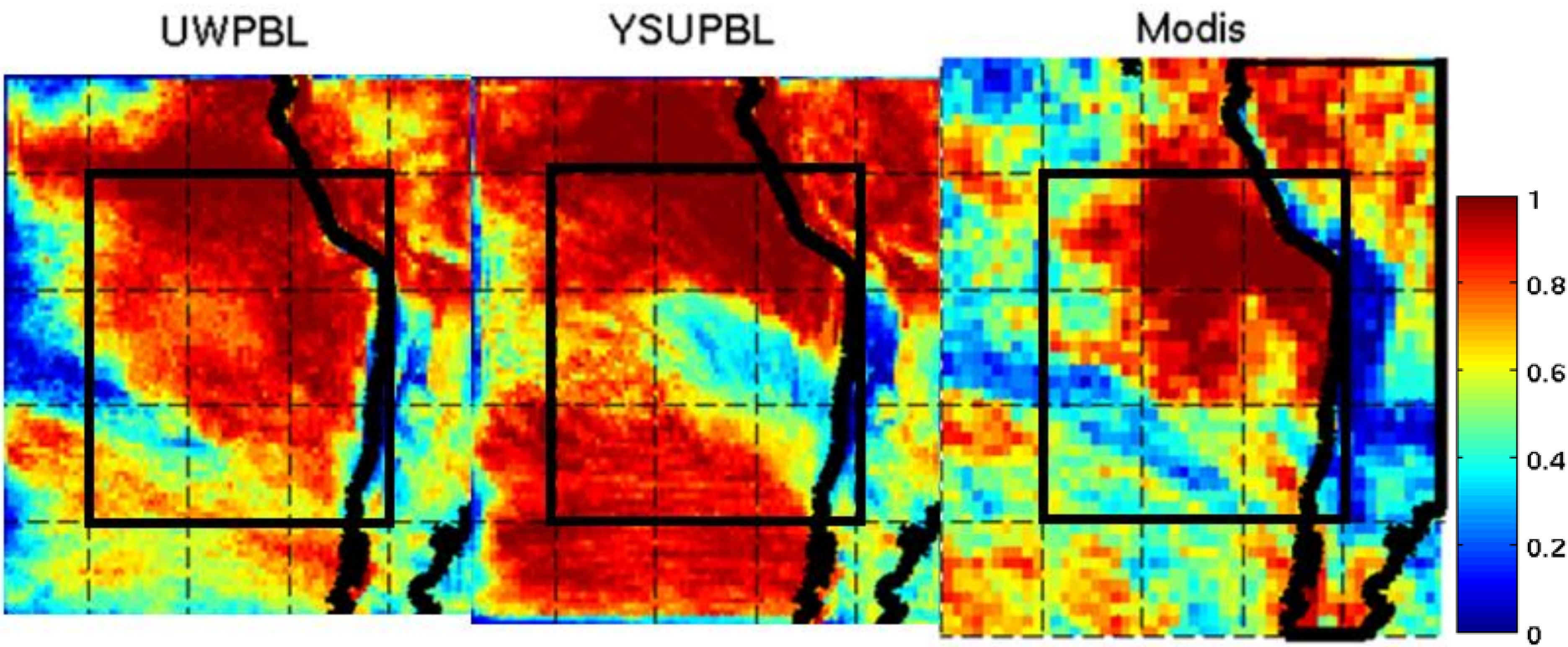
- Run a regional model that can reproduce the mean and variability of meteorology (easy), clouds (hard), and aerosols (hard) seen in satellite and VOCALS flight data.
- Determine dominant mechanisms influencing cloud microphysical and macrophysical variability, including radiatively relevant quantity albedo.
- Ultimately attempt to constrain indirect effect in SEP

WRF-CHEM Model Specs used

- Simulation domain 60 -110 ^{o} W, 0-50 ^{o} S, dt = 3 minutes, data saved every 2 hours, dx=0.5^{o}, 27 vertical levels ~10-12 in the boundary layer
- Forced with NCEP FNL meteorological data
- Lin et al. microphysics scheme
- Implemented UW PBL scheme from CAM (modified code from Xin-Zhong Liang)
- Regional Acid Deposition Model, 2nd generation (RADM2) chemical mechanism)
- Modal aerosol scheme (aitken, accumulation, coarse modes)[MADE/SORGAM aerosols]
- Some aqueous reactions- cloud chemistry, wet scavenging Fast-J photolysis, subgrid convective transport
- Emissions: VOCA Emissions inventory compiled by Scott Spak and Marcelo Mena
- MOZART4 initial and boundary conditions (Emmons et al. 2010)
- Sea salt only Na and Cl (no DMS)

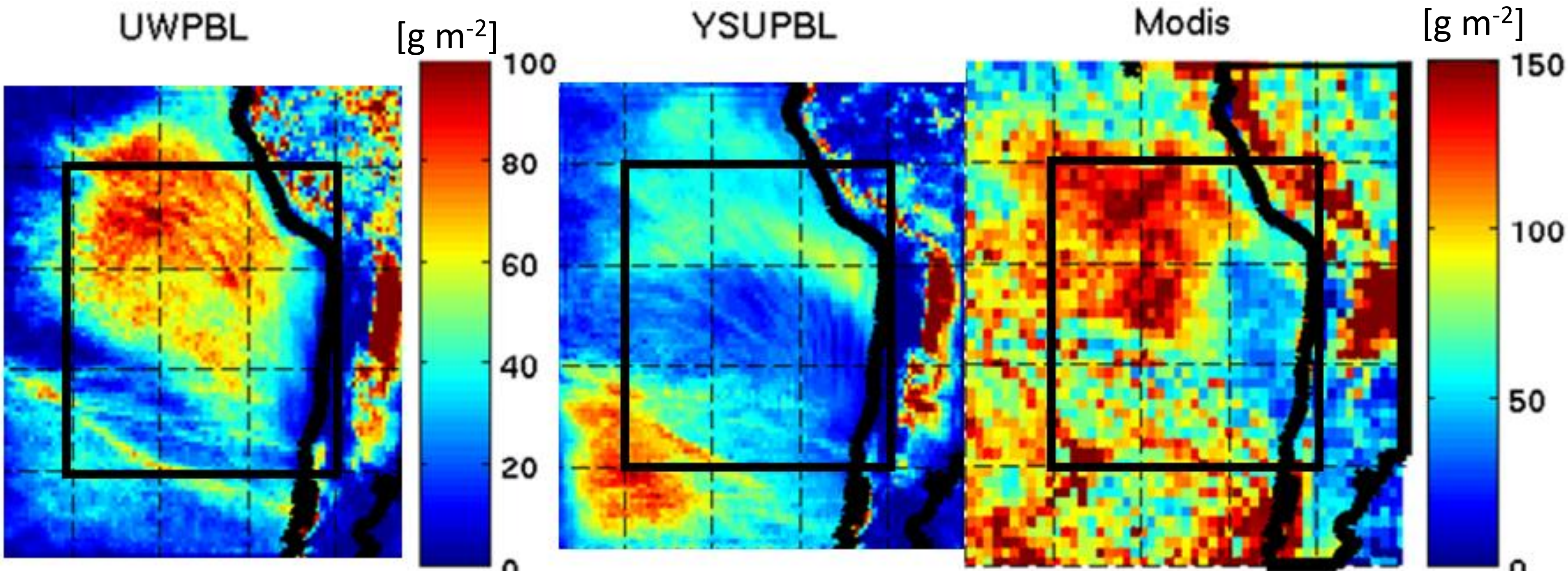
UW PBL vs YSU PBL vs MODIS
CF=cloud fraction

Mean 10/16/2008-10/20/2008

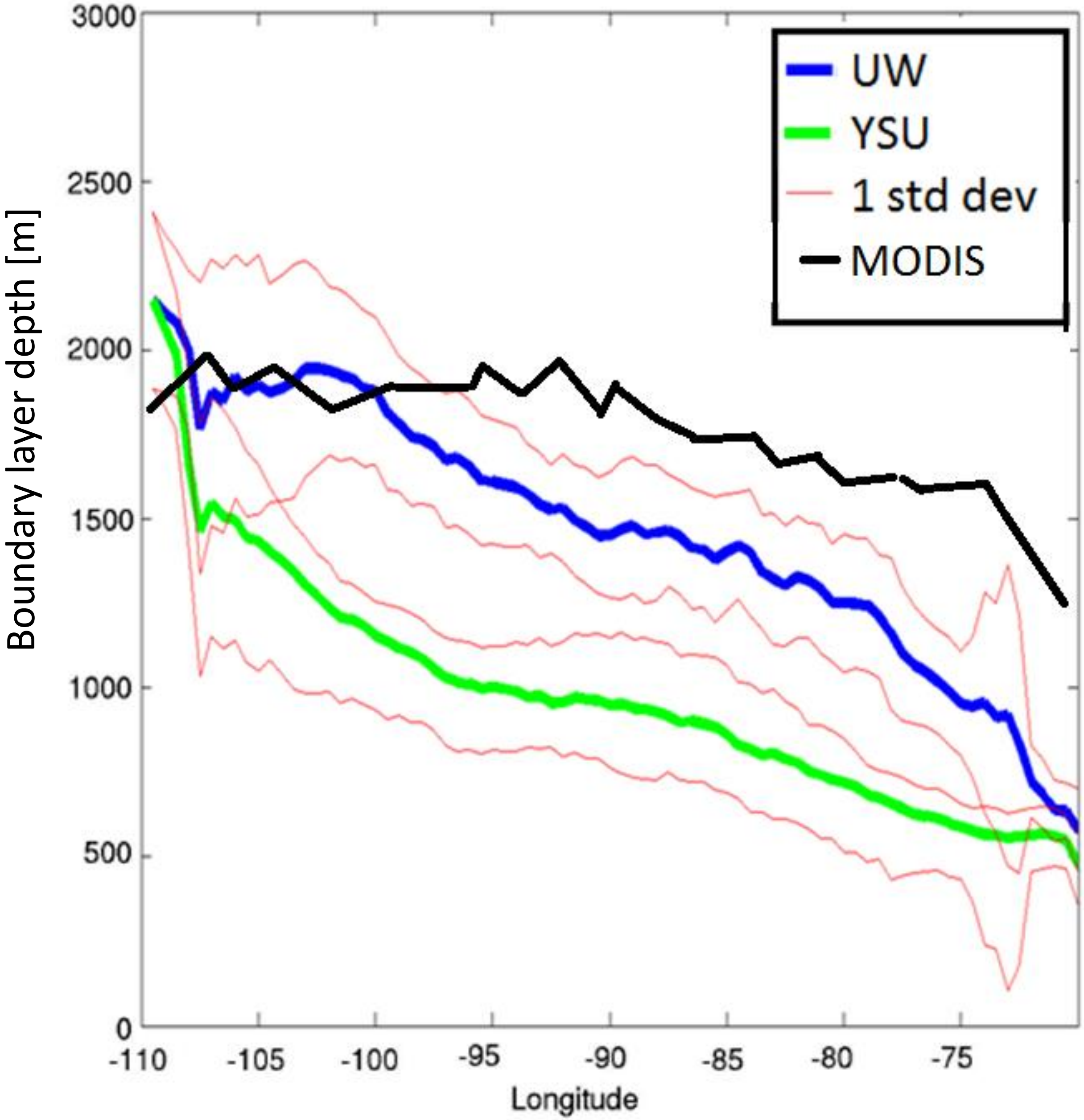


UW PBL vs YSU PBL vs MODIS
LWP=Liquid Water Path

Mean 10/16/2008-10/20/2008

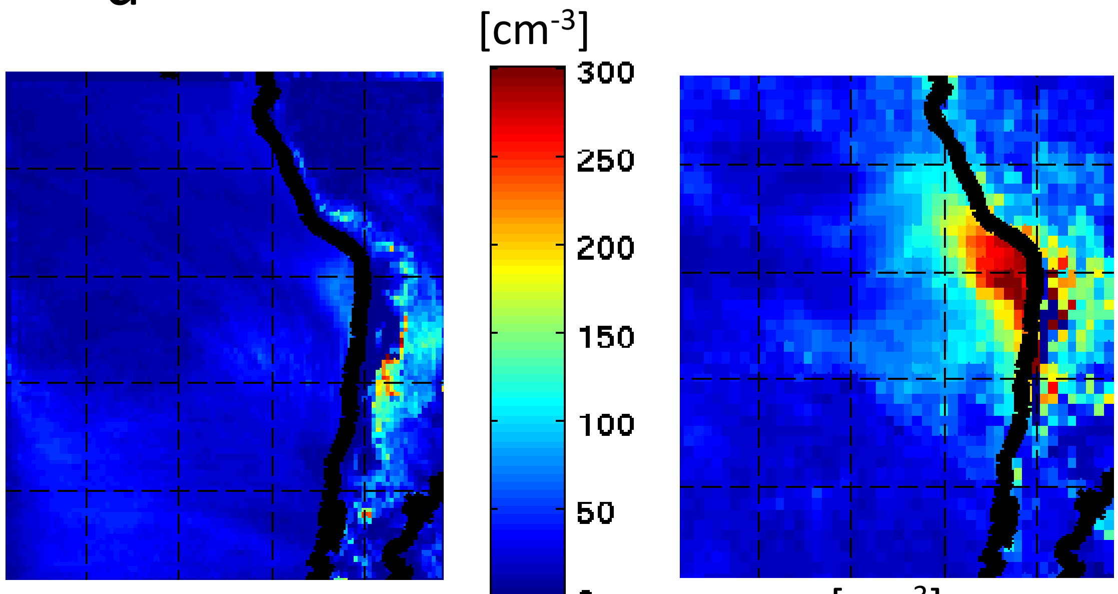


WRF-Chem Nov 16-20, 2008



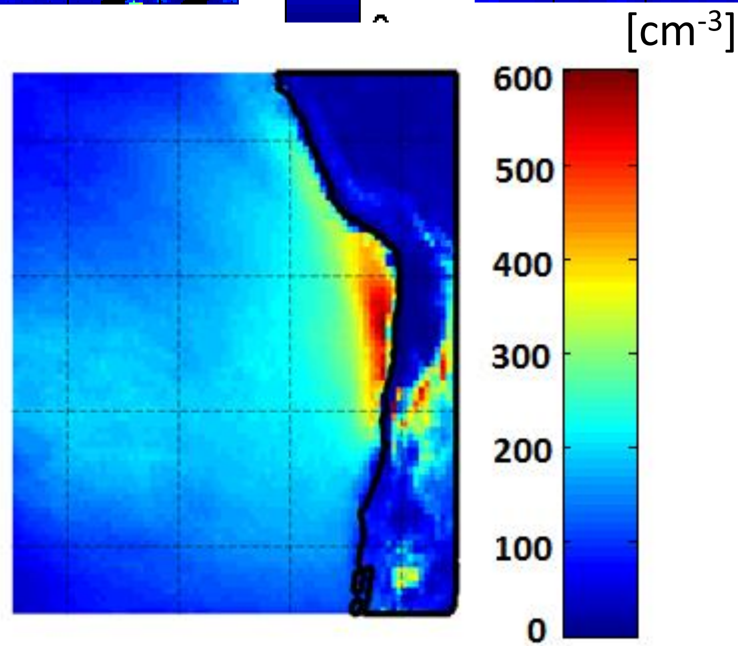
UW PBL vs YSU PBL vs MODIS
N_d = droplet concentration

YSU PBL



MODIS

UW PBL



UWPBL scheme

- More mixing than most other schemes → vertical diffusivity coefficient (K) large-> maximum subgrid vertical velocity always used for activation
- TKE = $\frac{1}{2}(u'^2+v'^2+w'^2)$ → assume $u'^2 \sim v'^2 \sim w'^2$ → $w'^2 = \sqrt{\frac{2}{3}TKE}$
- Redefine w'^2 = K/dz = lengthscale*Stabilityfunction*$\sqrt{TKE}$ /dz

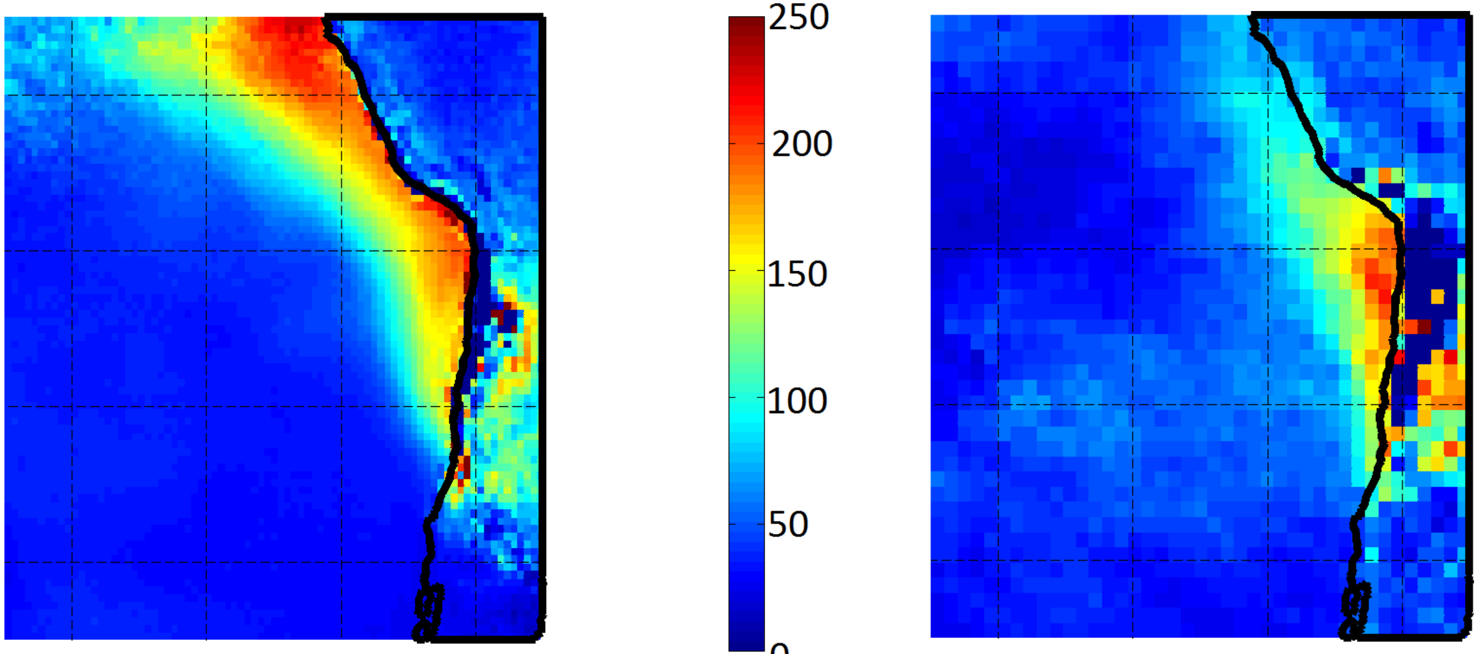
  to $w'^2 = \sqrt{\frac{2}{3}TKE}$

Mean over REx period

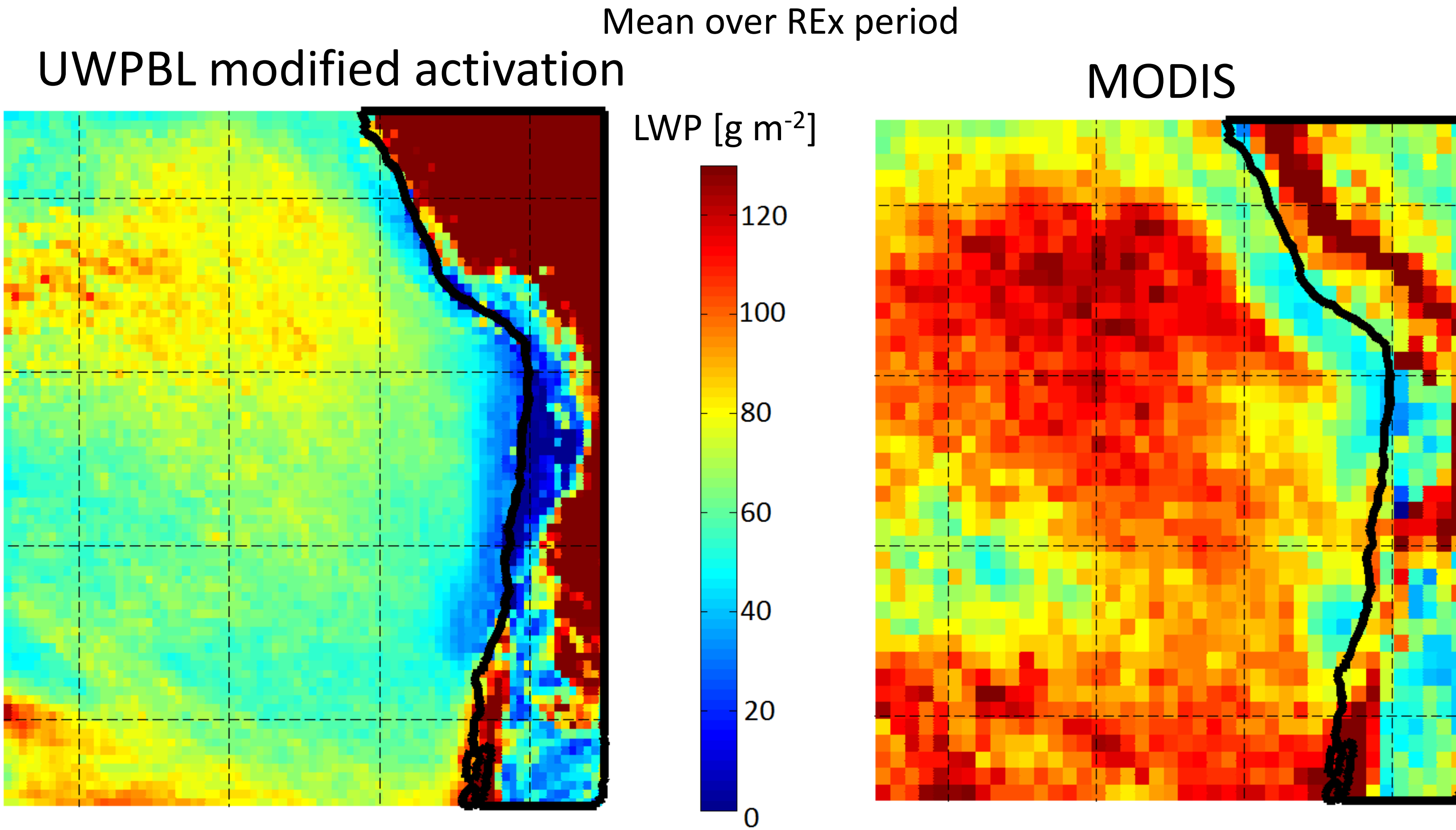
UWPBL modified activation

N_d [cm^{-3}]

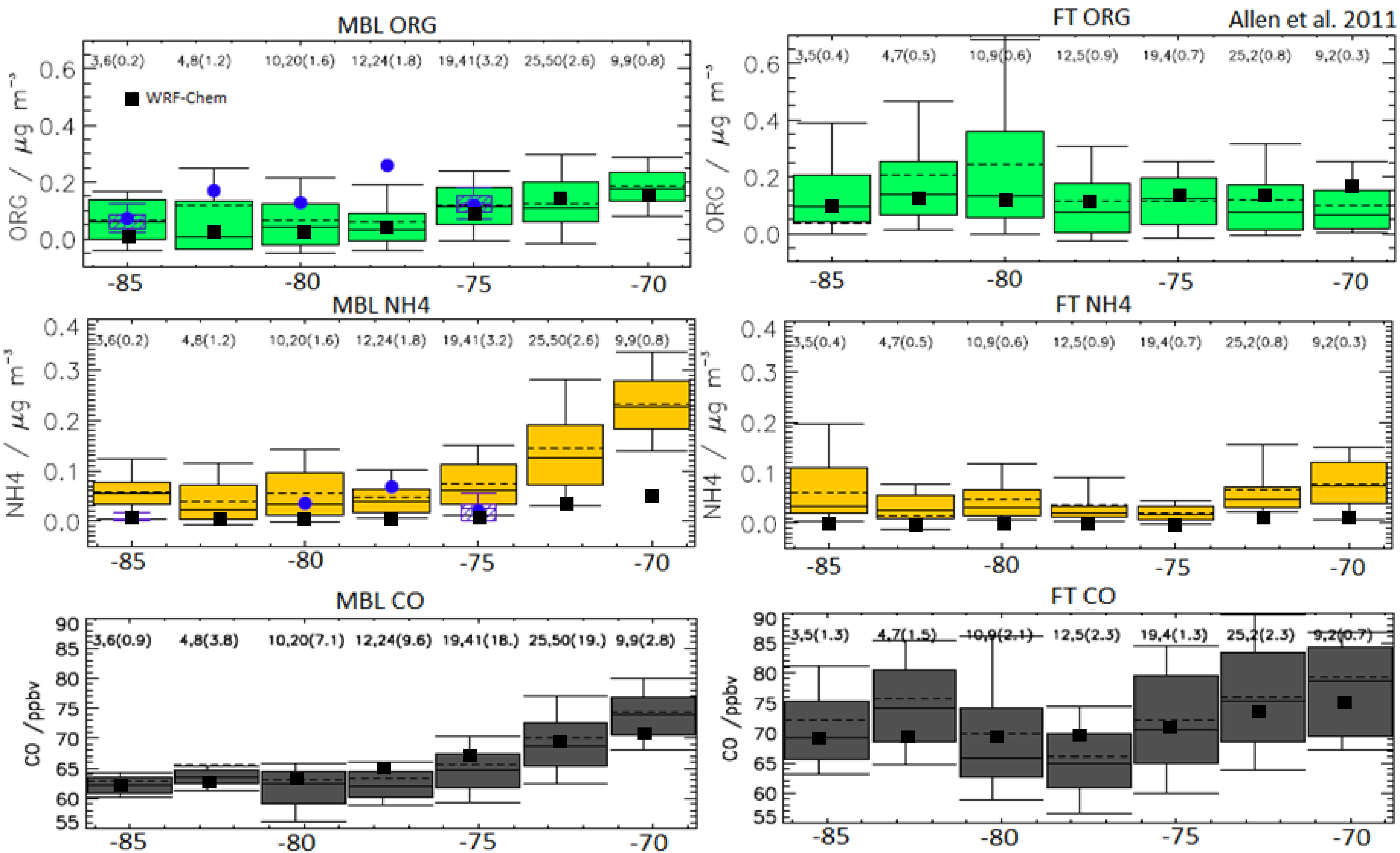
MODIS

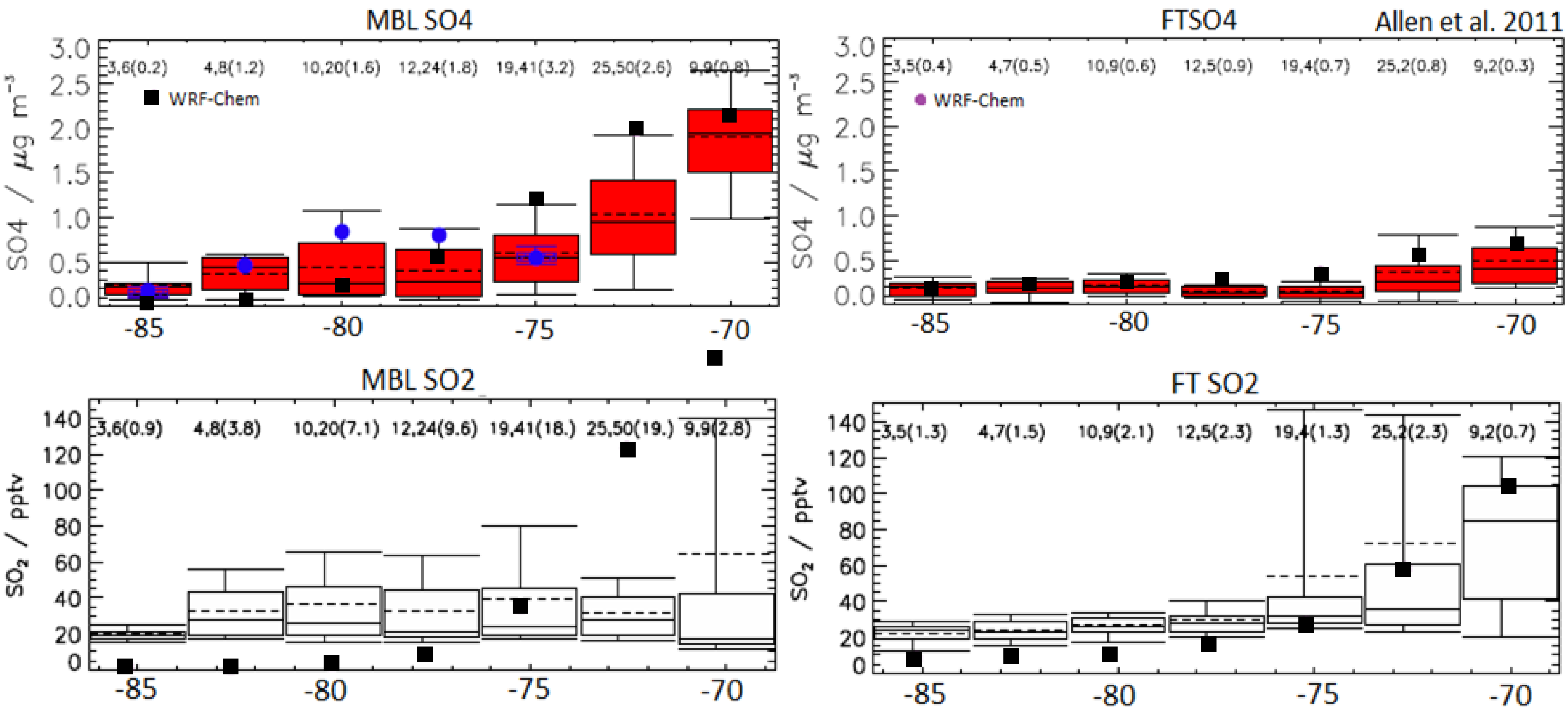


LWP is somewhat low, though that is a common model issue…



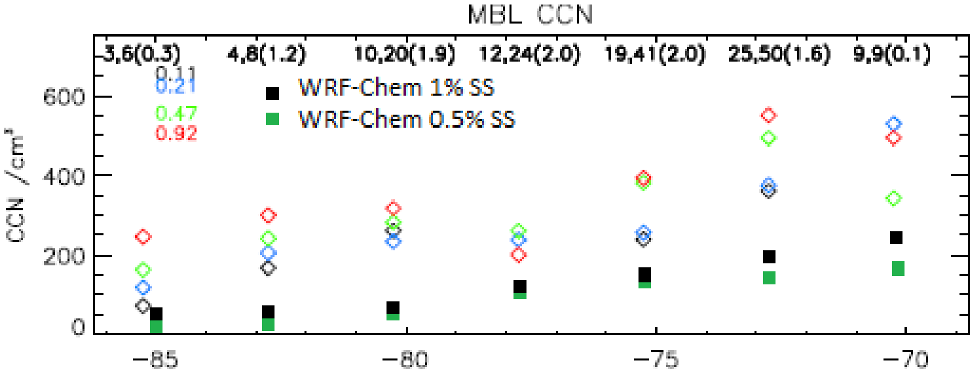
Compare flight data from Allen et al. 2011 to REx mean WRF-Chem fields, binned via similar algorithm:

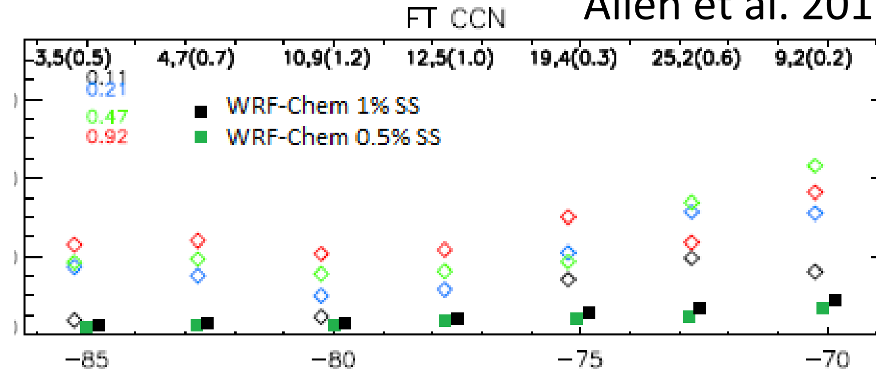


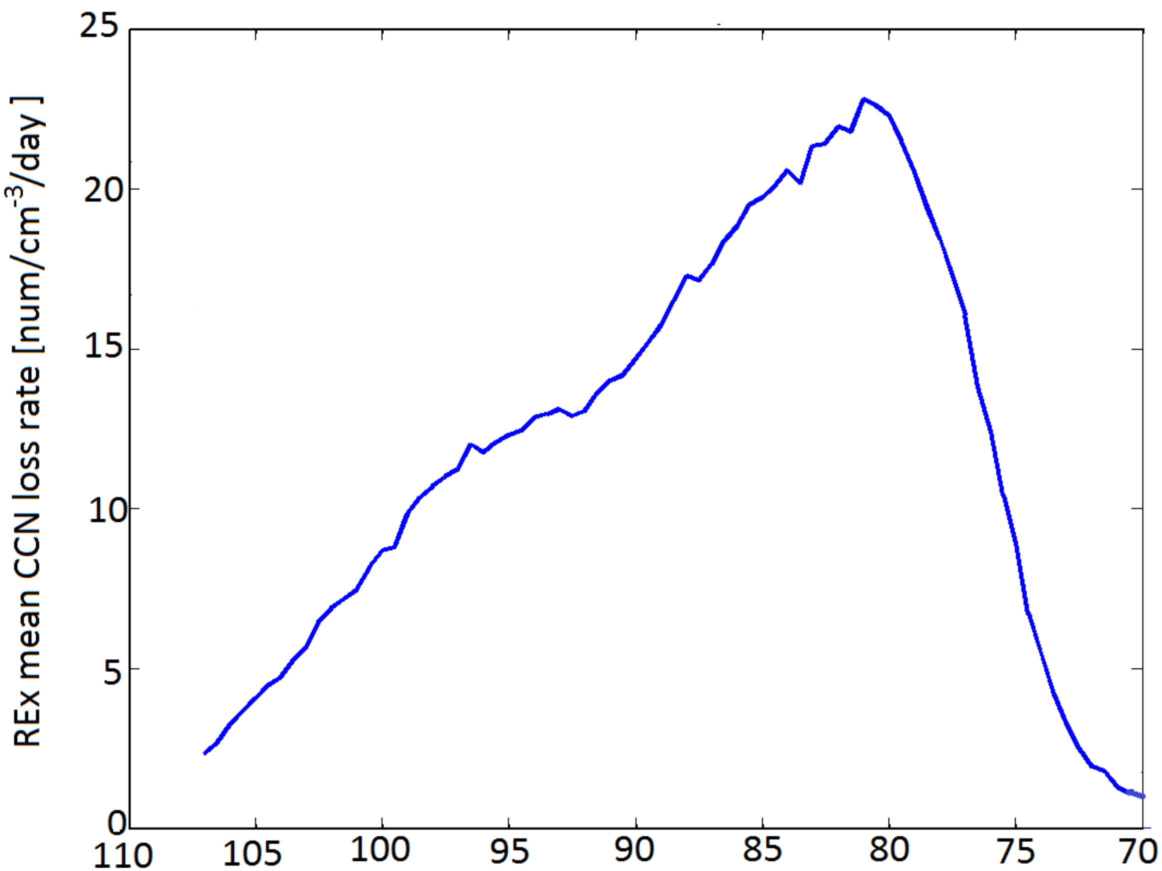


- Offshore low SO2 and SO4 aerosol in MBL – no model DMS
- Much larger SO2 near shore (grid box includes regions/times unsampled by aircraft, model lack of cloud nearshore-SO2 not processed fast enough?, error in emissions translation?)
- In general encouraging result

Allen et al. 2011



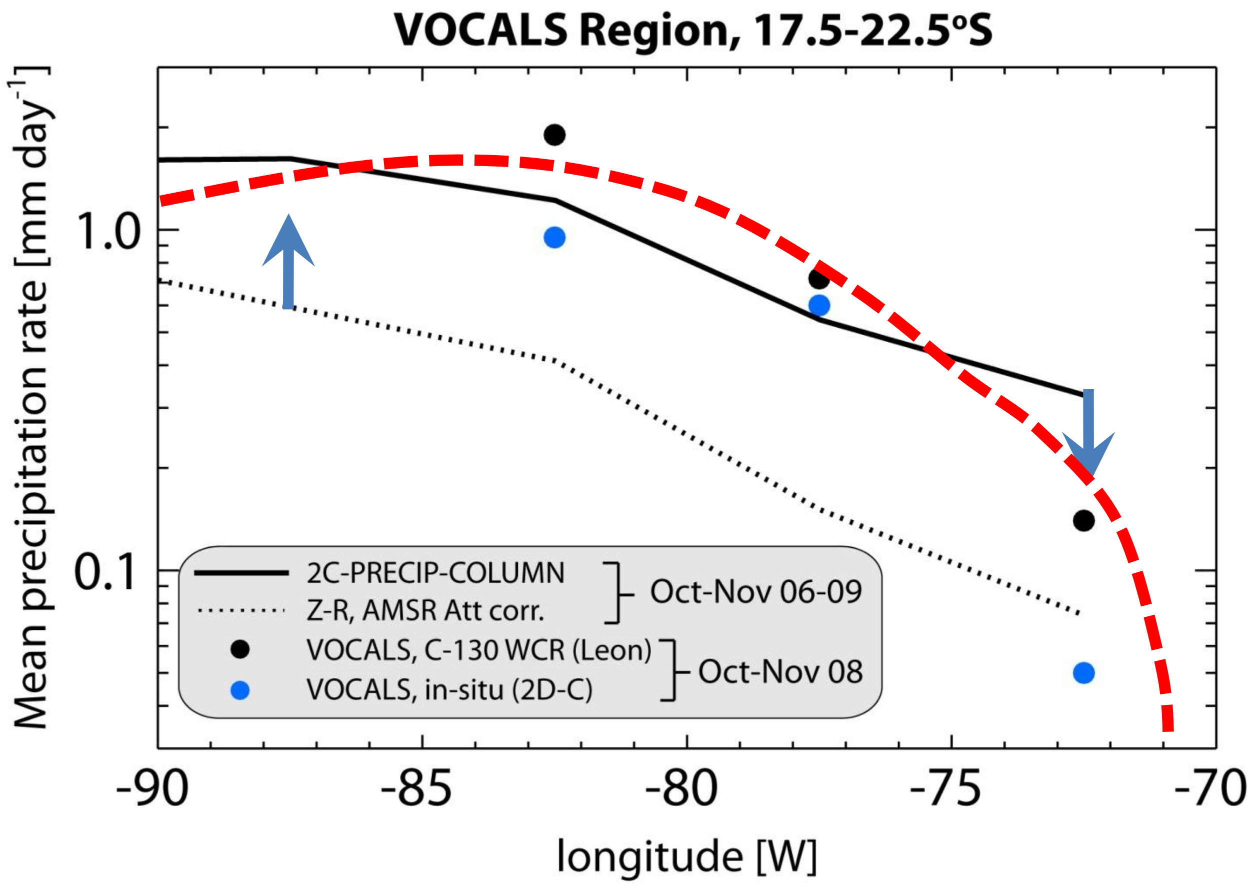




- Reasonable aerosol mass, N_d (at 20S), but very low CCN
- Not limited to this model(VOCA)
- Possibly CCN definition, assumed size of mode, missing DMS, etc.
- Mean CCN loss rate (coalescence scavenging) ?

Precipitation over the VOCALS region

- **CloudSat**
  Attenuation and Z-R methods
- **VOCALS**
  Wyoming Cloud Radar and in-situ cloud probes

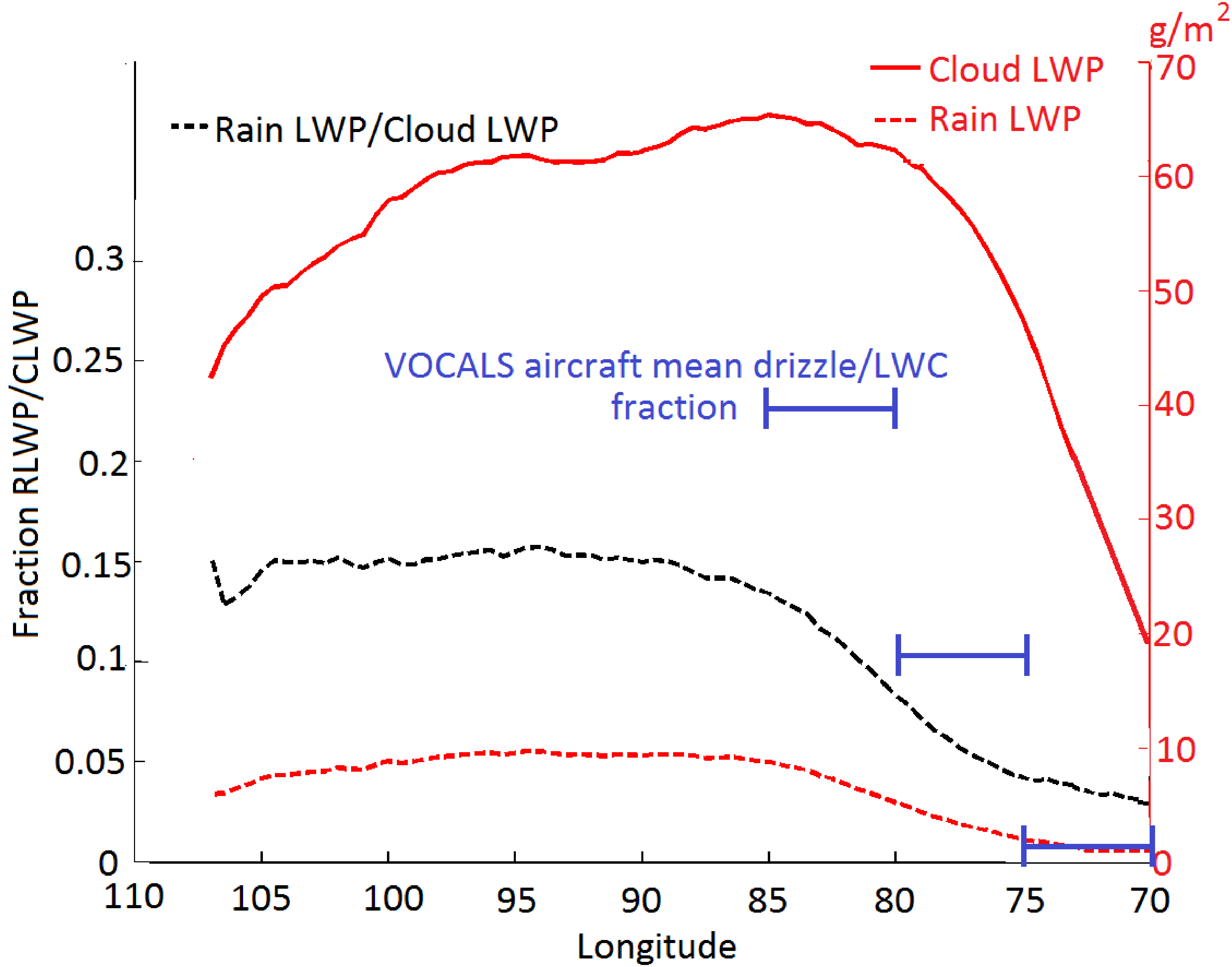


Significant drizzle at 85°W

Very little drizzle near coast

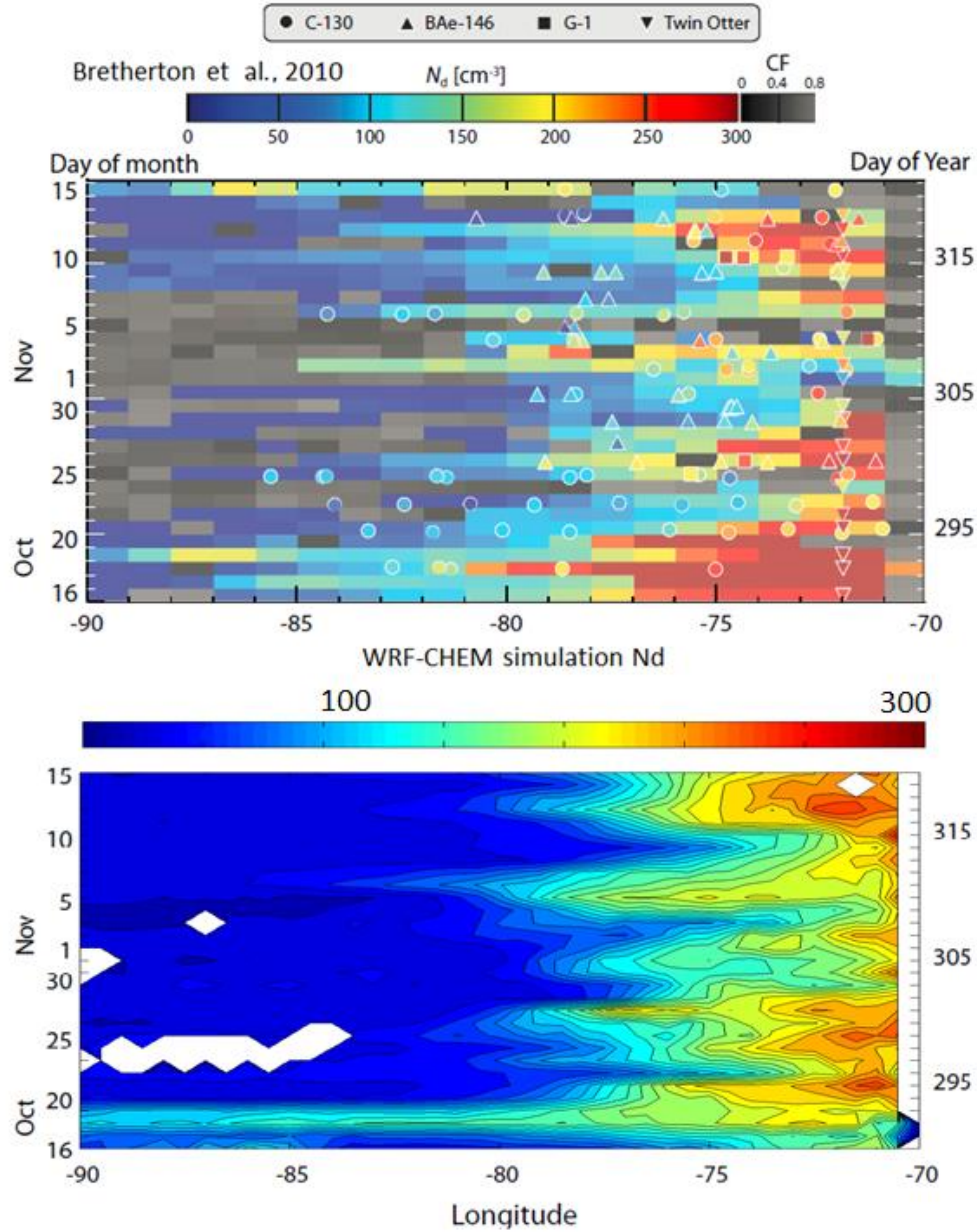
Slide from Robert Wood

WCR data courtesy Dave Leon



g/m2
Cloud LWP
Rain LWP
Rain LWP/Cloud LWP
VOCALS aircraft mean drizzle/LWC fraction
Fraction RLWP/CLWP
0.3
0.25
0.2
0.15
0.1
0.05
0
70
60
50
40
30
20
10
0
110
105
100
95
90
85
80
75
70
Longitude

-N_d variability over VOCAL Rex seems reasonable → model microphysical response to synoptic forcing is encouraging – WRF-Chem should be good tool for interpreting meteorological versus aerosol effects.



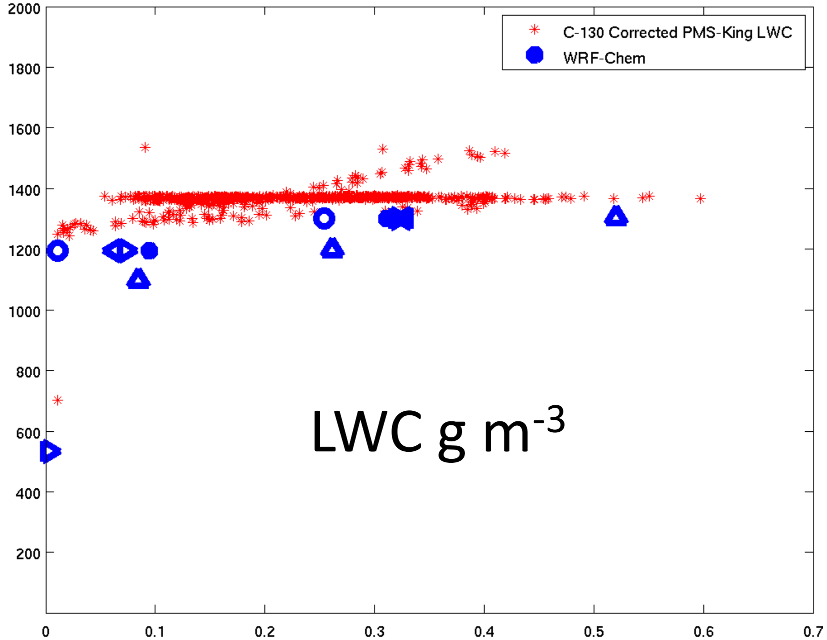
Summary

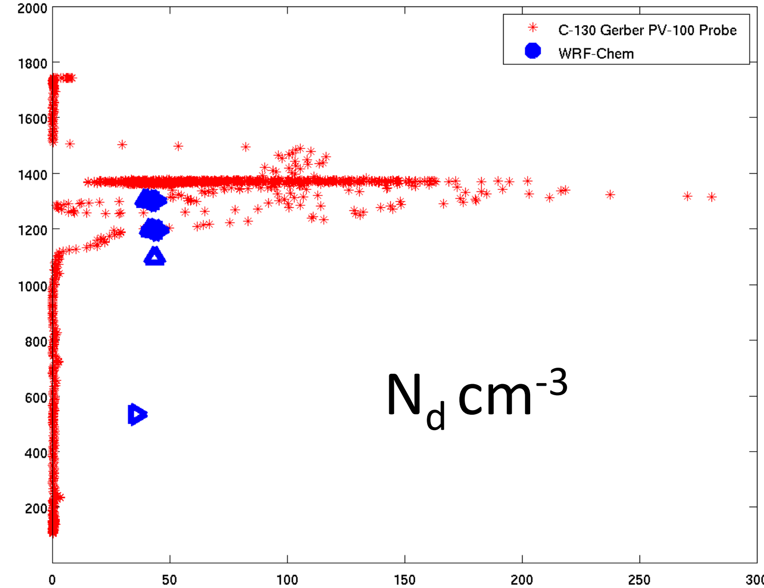
- WRF-Chem is a useful tool for investigating Aerosol Indirect Effects
- The UWPBL scheme written for CAM improves representation of cloud properties such as LWP and CF, but work is still needed on microphysical effects
- Along 20S averaged over the REx time period aerosol, and chemical species agree to an extent with flight measurements.
- Precipitation rate, CCN loss rate to coalescence scavenging, and the amount of rain liquid water versus cloud liquid water are consistent at 20S with observations – thus are useful tools for investigating aerosol/precip/cloud processes.
- Nd variability consistent with satellite/flight data

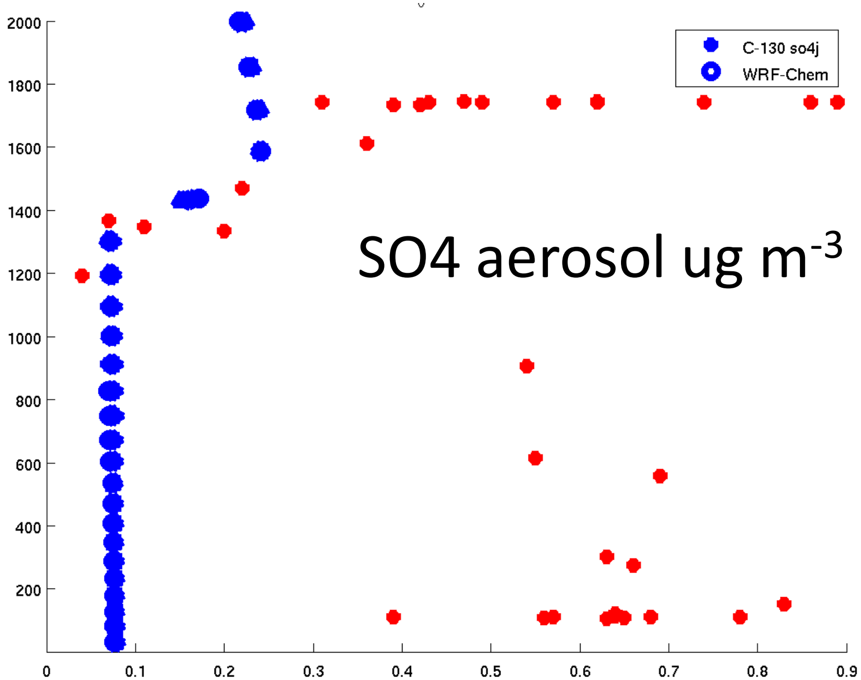
Future Work

- Resolve/explain remaining model mysteries (e.g. low CCN, large amount of aerosol and activation 0-10S near coast, PM2.5 boundary conditions, too much SO2)
- Use the model for good: investigate aerosol indirect effects
    - Impact of sulfate/anthropogenic influence
    - Role of precipitation in aerosol effects (with great model fields to explore– 3D precip rate, CCN loss rate, etc)
    - Identify role of meteorology – are cloud changes associated with the synoptic high due to aerosol impacts and aerosol transport, or thermodynamic/dynamic mechanisms?

A snapshot in time to take with a grain of salt…







81-82 W during
RF03, 10-21-2008