Effects of Boundary Layer depth, stability, precipitation, and droplet concentration on stratocumulus evolution using a Lagrangian approach

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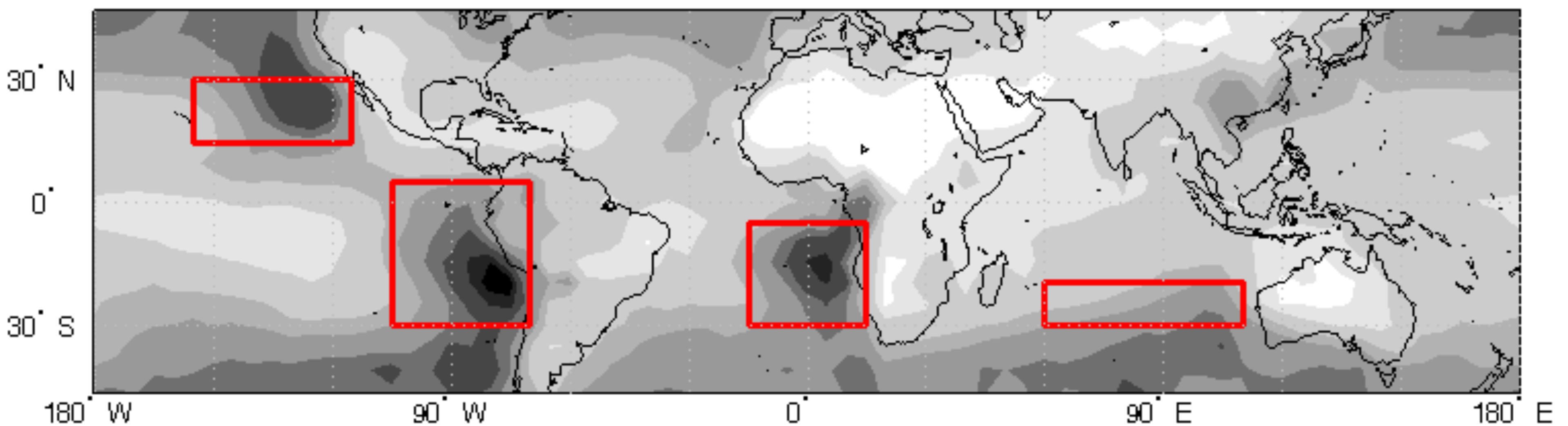
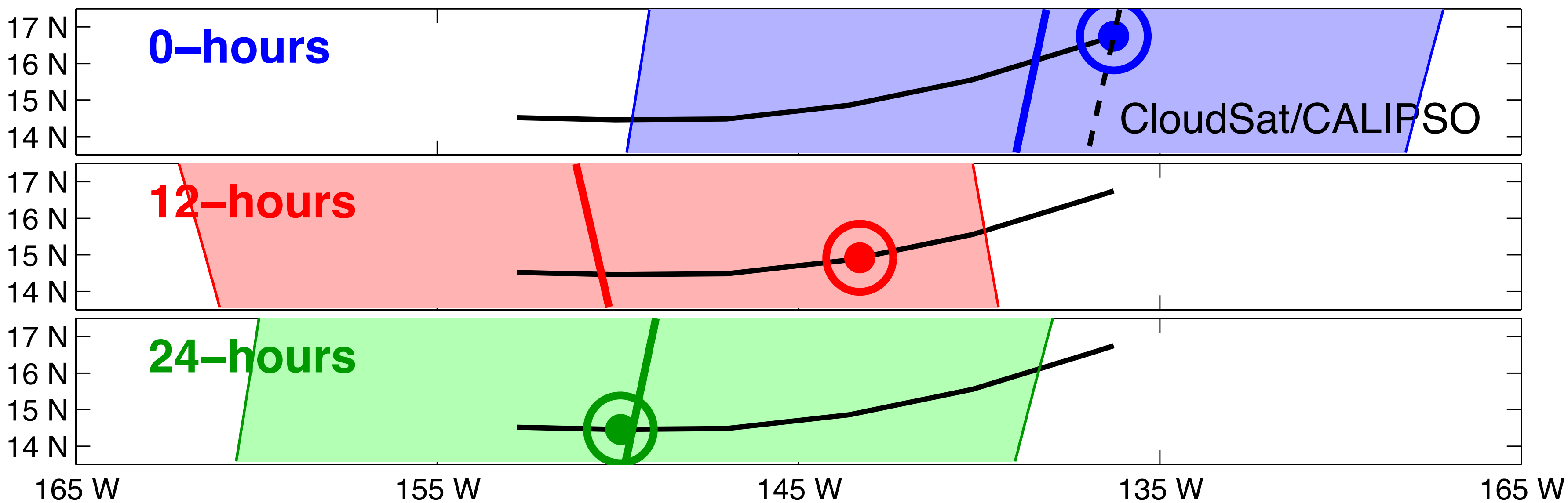
Subsidence Regions with Abundant Sc

- Regions chosen based on annual average Sc amounts from surface observations
- Chose large boxes to capture Sc maxima and regions of strong gradient (Sc ➔ Cu)



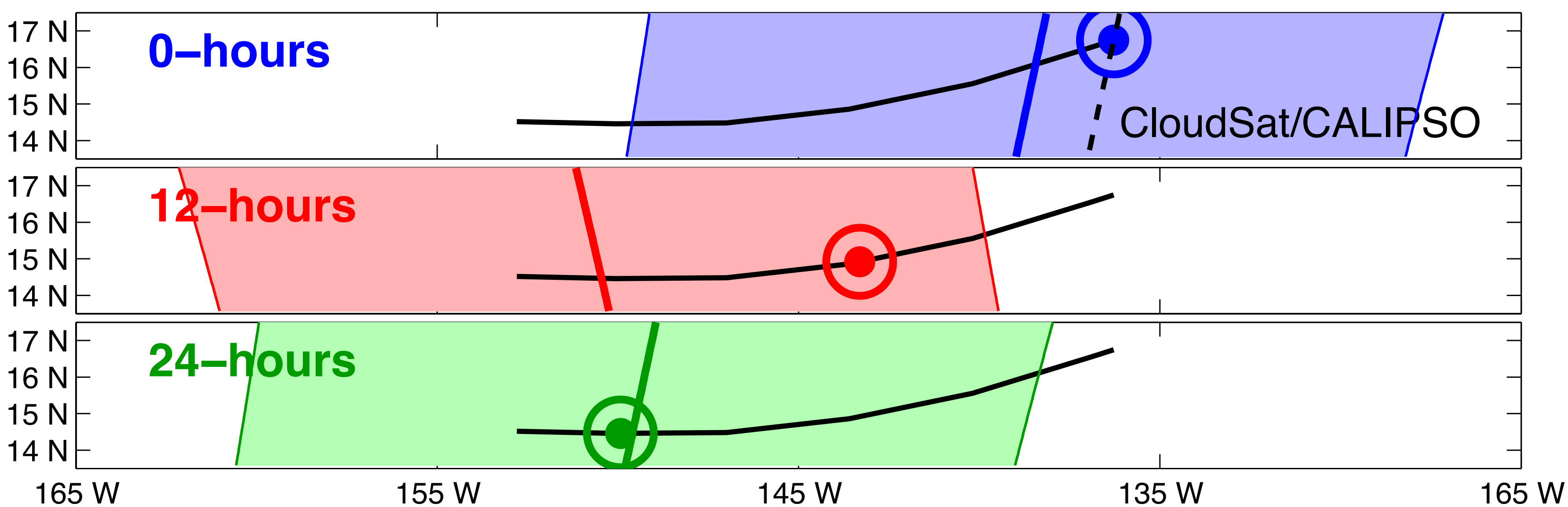
The Lagrangian Approach

- Follow the same 100km-radius sample for 48 hours, observing with every A-Train flyover at 12-hour intervals (~1:30 and ~13:30 local time)
- We use ~62,000 individual trajectories (2007-2008)



The Lagrangian Approach

- Use ERA-Interim u, v wind fields at 925 mb
- Observe initially with CloudSat, CALIPSO, MODIS
- Observe again with MODIS



Data Products

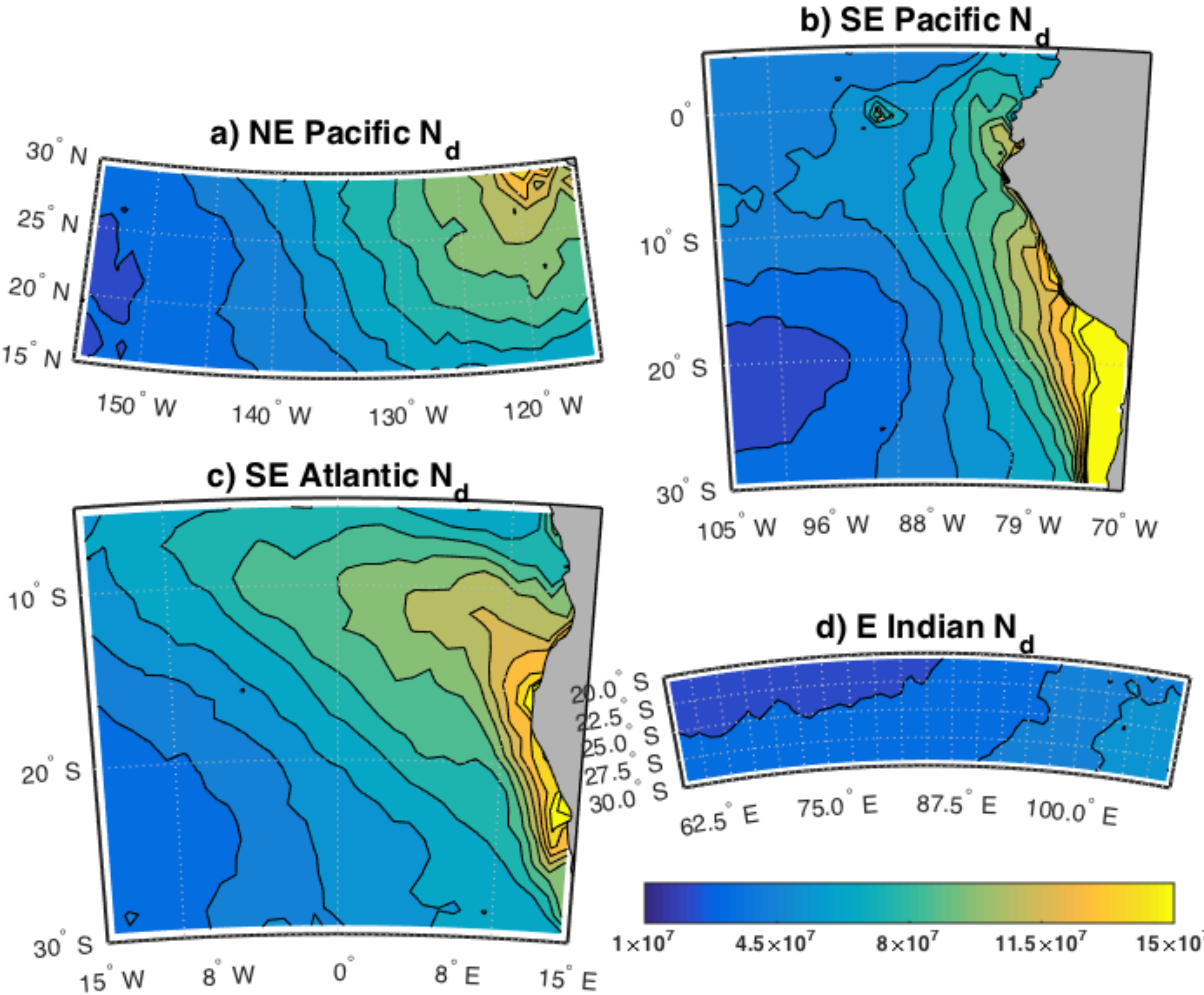
- Cloud Cover from MODIS level 3 cloud mask
  - 1x1 degree lat/lon grid
  - Day and night
  - Release 5
- Lower Tropospheric Stability (LTS)
  - Difference in θ between 700mb and 2 meters
  - From ERA-Interim reanalysis

Data Products

- Droplet Concentration (N_d) from two MODIS products:
  - Effective Radius (r_e), Liquid Water Path (LWP)
  - Daytime only, from Optical Properties dataset
  - $N_d = N_{eff}/k$ ($k = 0.8$) for marine stratiform clouds

$$N_{eff} = \sqrt{2}\,\frac{3}{4}\pi\rho_w\Gamma_{eff}^{\frac{1}{2}}\,\frac{LWP^{\frac{1}{2}}}{r_e(h)^3}$$

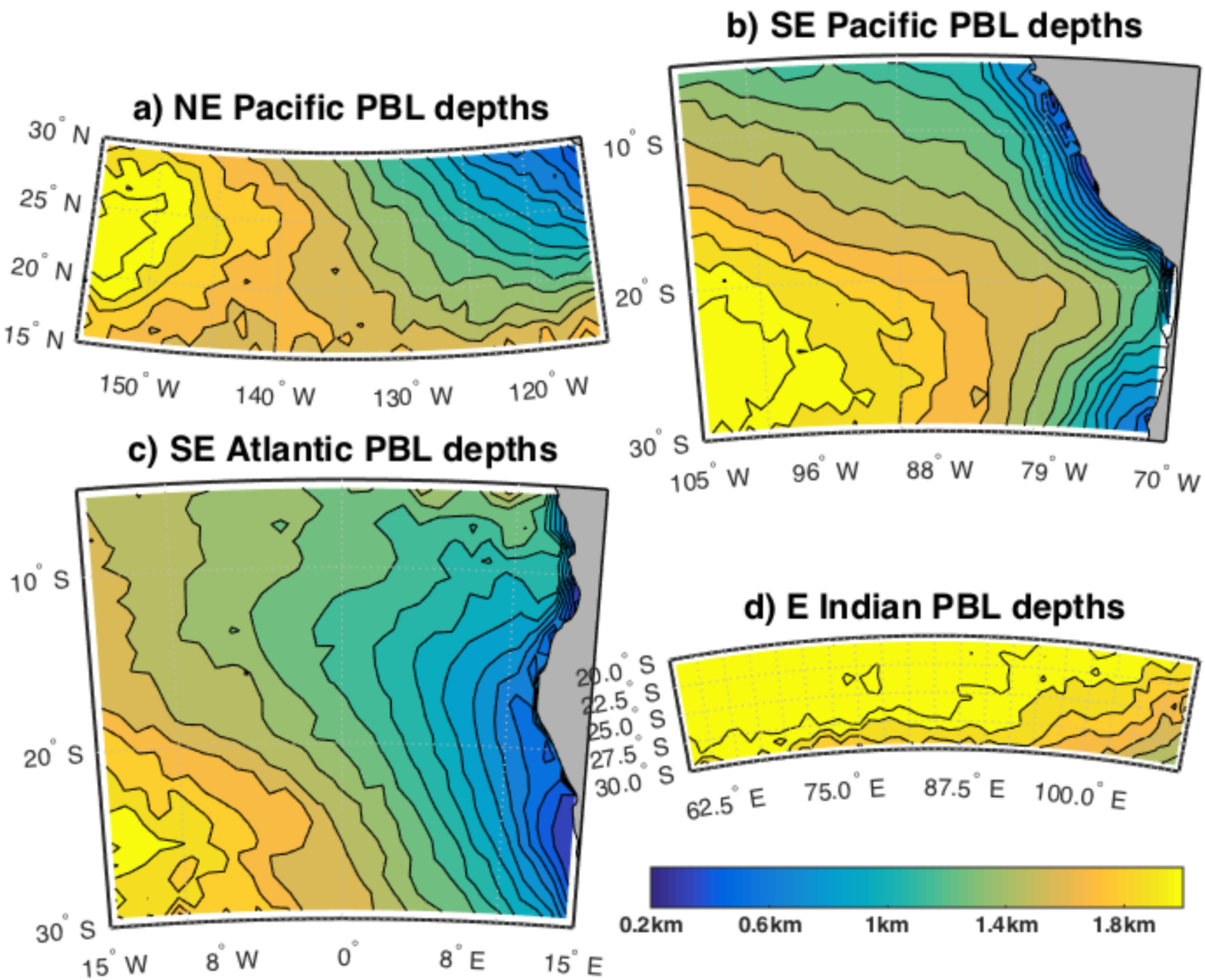
MODIS Droplet Concentration N_d



Data Products

- PBL depth from CALIPSO (Eastman and Wood 2016) based on highest cloud tops from VFM
- PBL depth from MODIS using:
  - Temperature contrast between cloud tops (from MODIS cloud top temperature histograms) and reanalysis SST
  - Using parameterized lapse rate from Wood and Bretherton 2004 (Figure 4)

MODIS Planetary Boundary Layer Depth

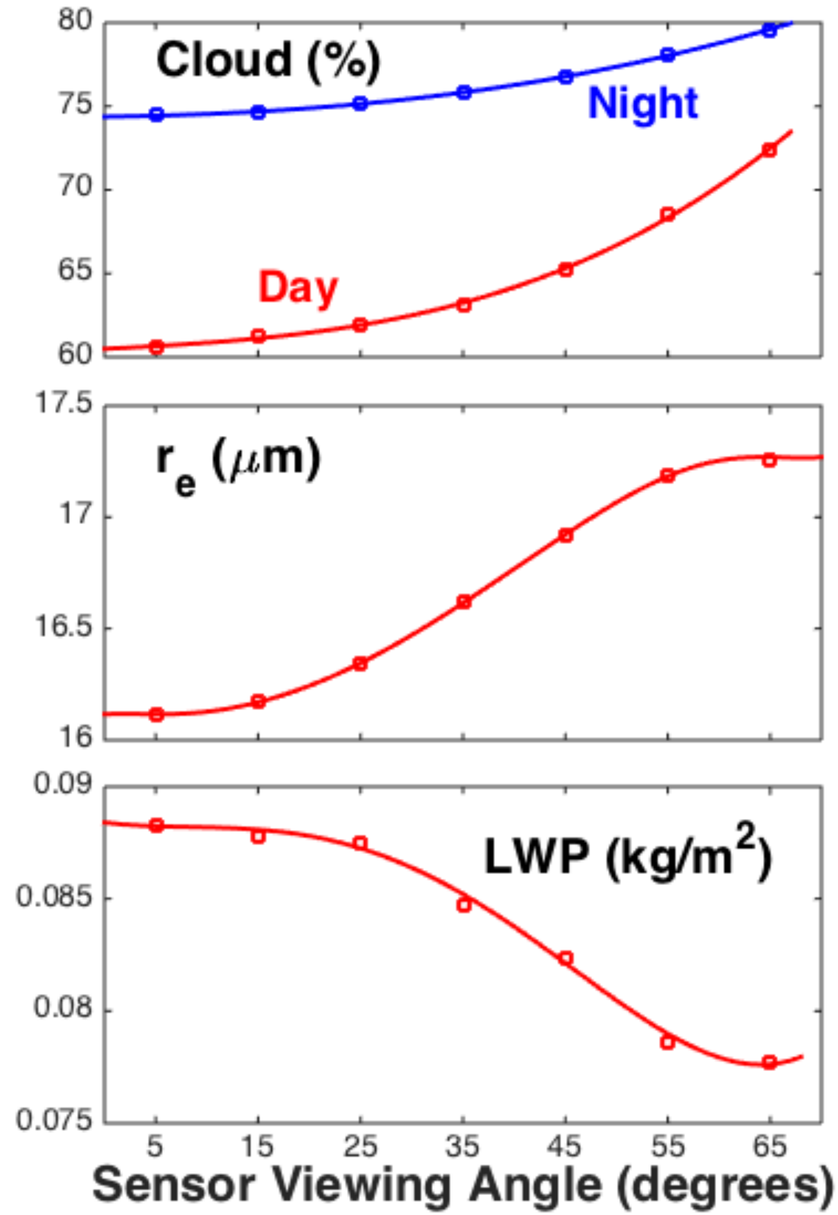


All Lagrangian Variables converted to Anomalies

- All variables tracked in this Lagrangian study are anomalies:
  - Diurnal cycle removed
  - Seasonal cycle removed
- This was necessary to avoid any geographic biases produced by uneven trajectory distances and distributions

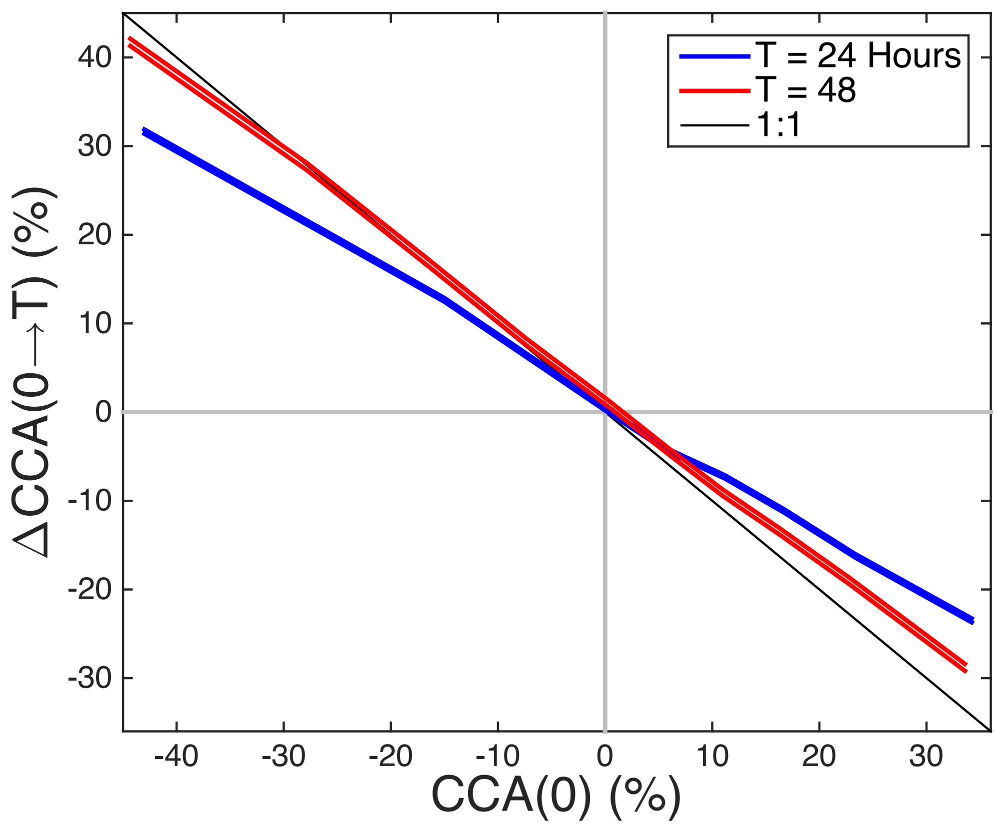
Zenith Angle Bias

- The wide sensor viewing angle on MODIS (~67°) makes a zenith angle bias likely
  - Bias was observed in cloud cover, effective radius and LWP
  - Bias is removed from all data using the polynomial fits shown



Red Noise Considerations

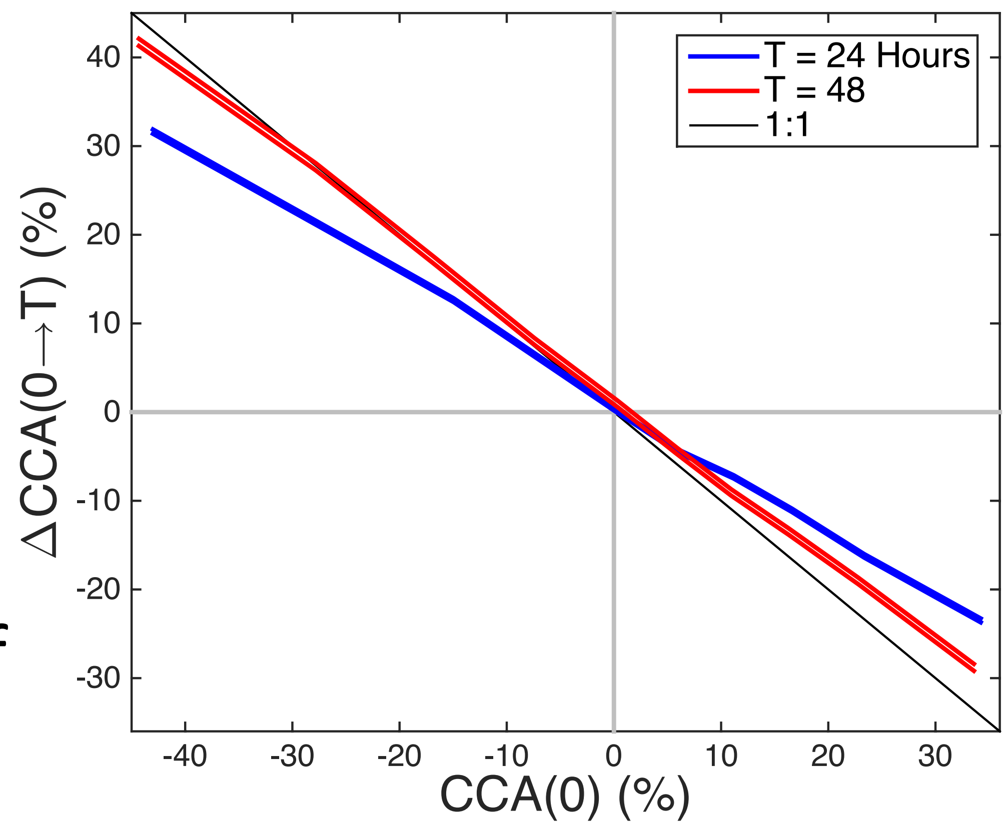
- Cloud Cover Anomalies (CCA) tend to regress to the mean (anomaly = 0)
- Linear relationship between CCA and ΔCCA shows ΔCCA to partially be a linear function of CCA
- Is well modeled as a red noise process



$$\Delta CCA = \Delta CCA(CCA_{T=0}) + \Delta CCA(Environment)$$

Red Noise Considerations

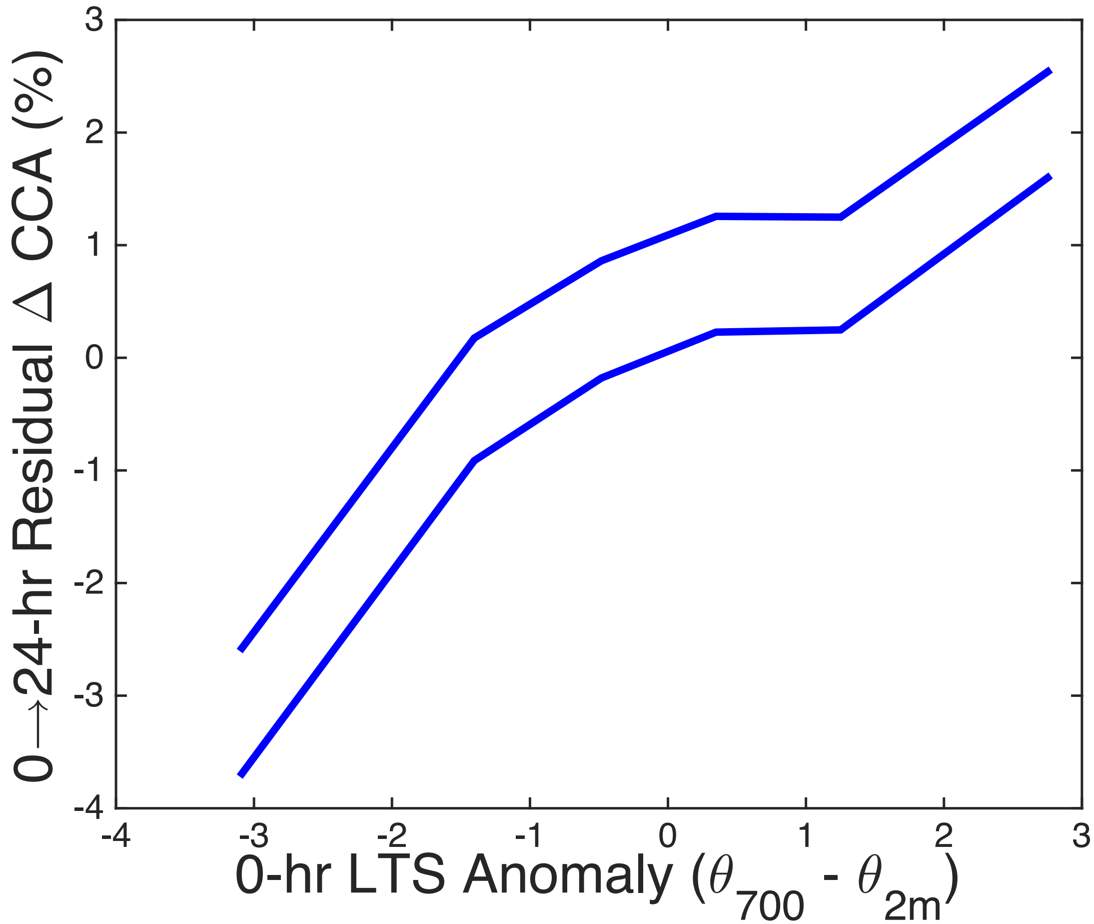
- We calculate the slope between CCA and ΔCCA
- Remove the ΔCCA that is a function of CCA(T=0) to produce a "Residual ΔCCA", which is a function of the surrounding environment



$$Residual\ \Delta CCA = \Delta CCA - \Delta CCA(CCA_{T=0})$$
$$= \Delta CCA(Environment)$$

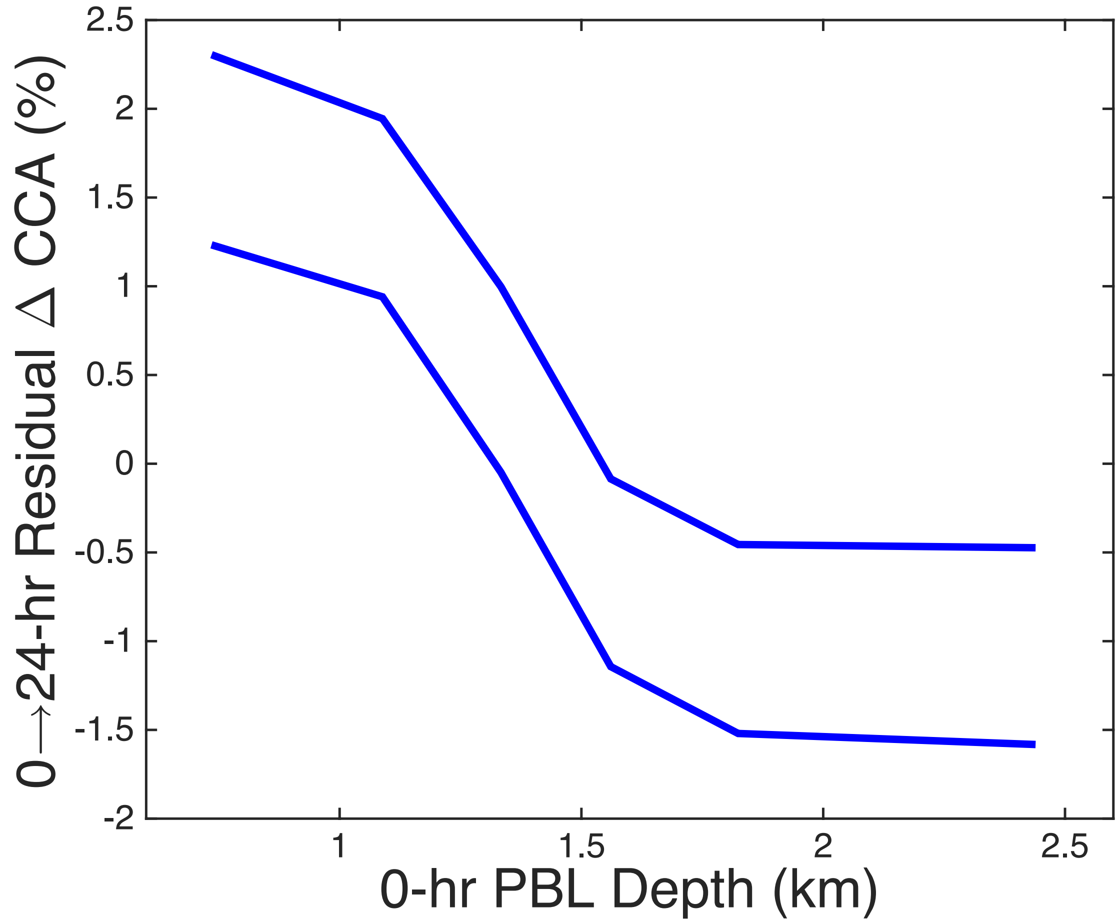
Stability and Cloud Cover

- High stability associated with longer-lived clouds
- Low stability associated with cloud breakup

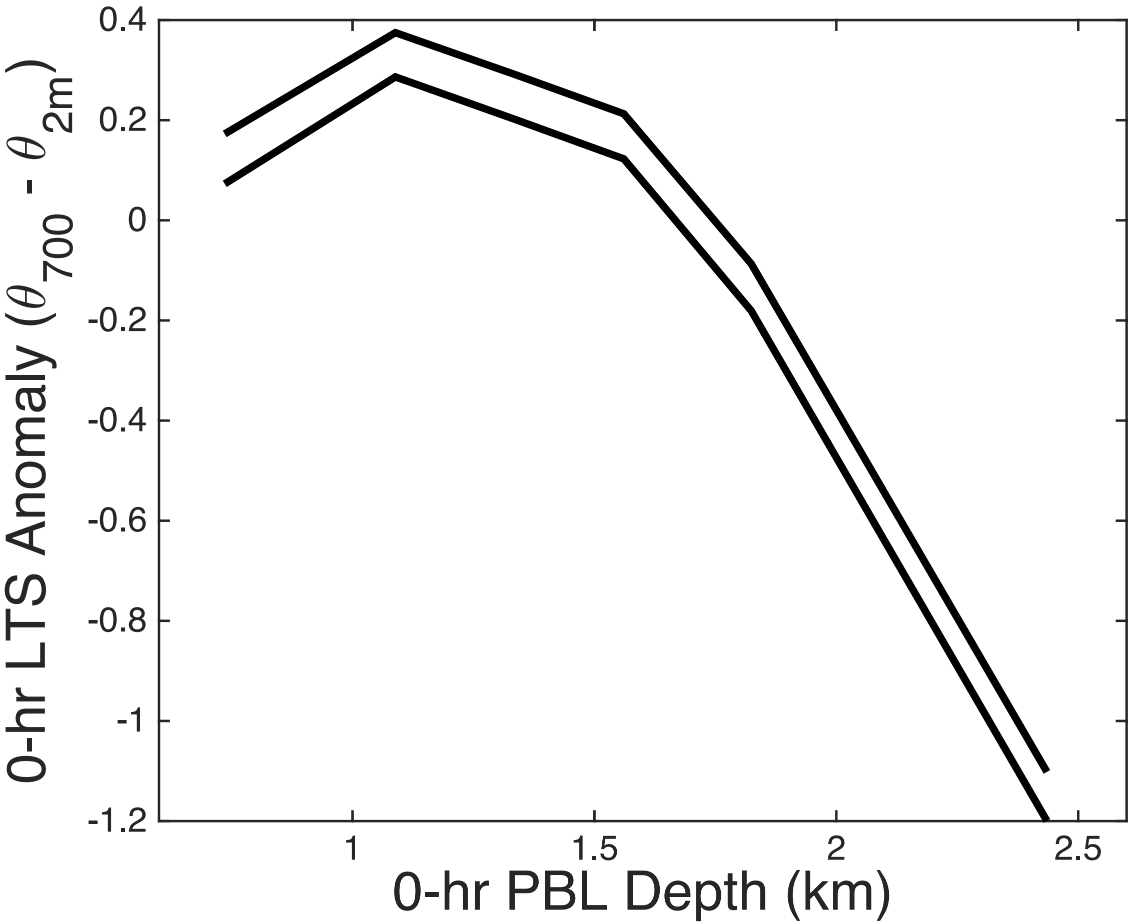


PBL Depth and Cloud Cover

- Clouds in shallow boundary layers persist
- Clouds in deeper boundary layers tend to break up more quickly



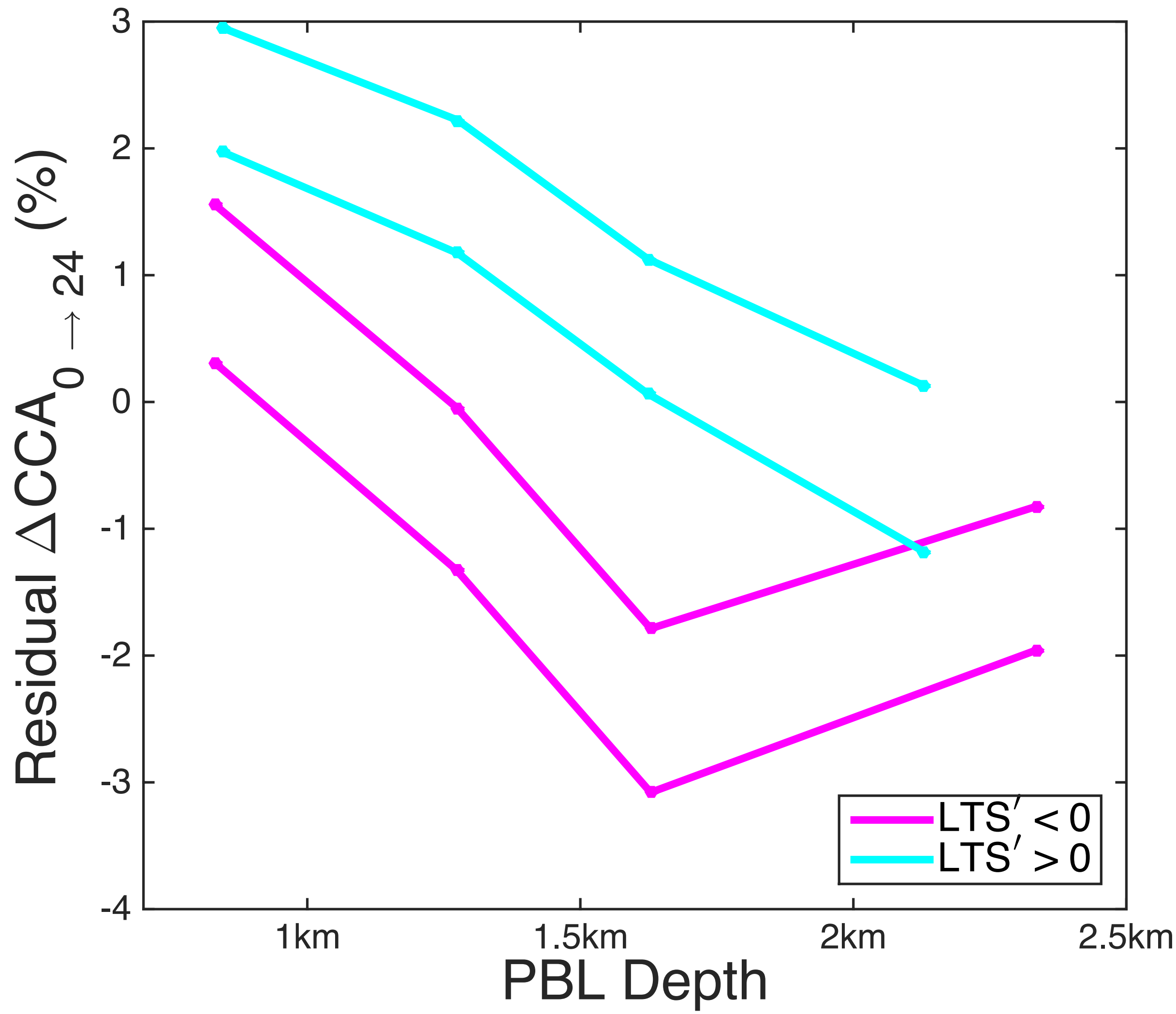
Correlation among Variables



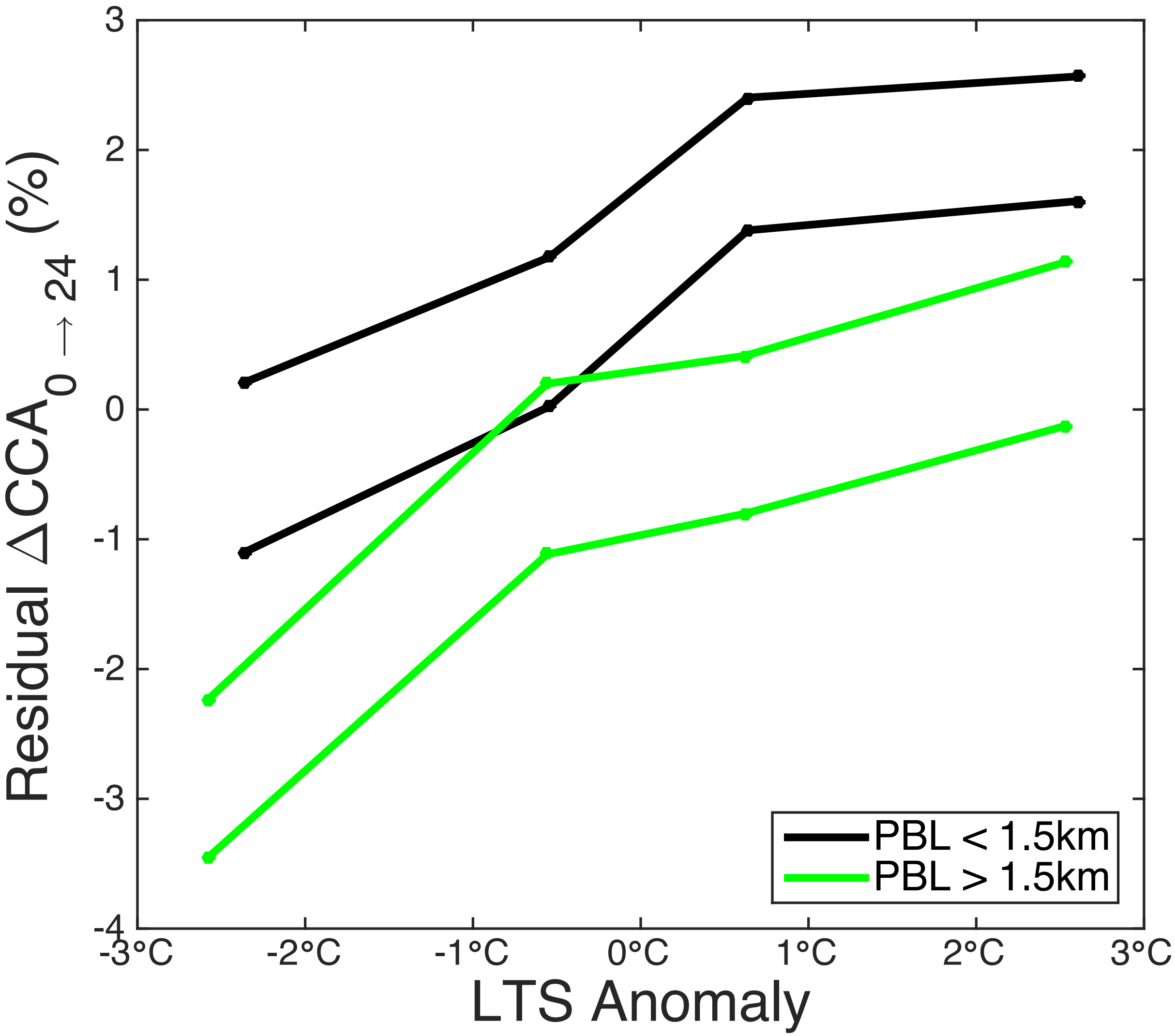
- Low stability is associated with deeper PBLs
  - r = -0.20
- Need a method to untangle which variable drives cloud breakup

PBL Depth, Stability, and Cloud Cover

- When we control for PBL depth, LTS still shows a clear effect
- Clouds in less stable environments tend to break up



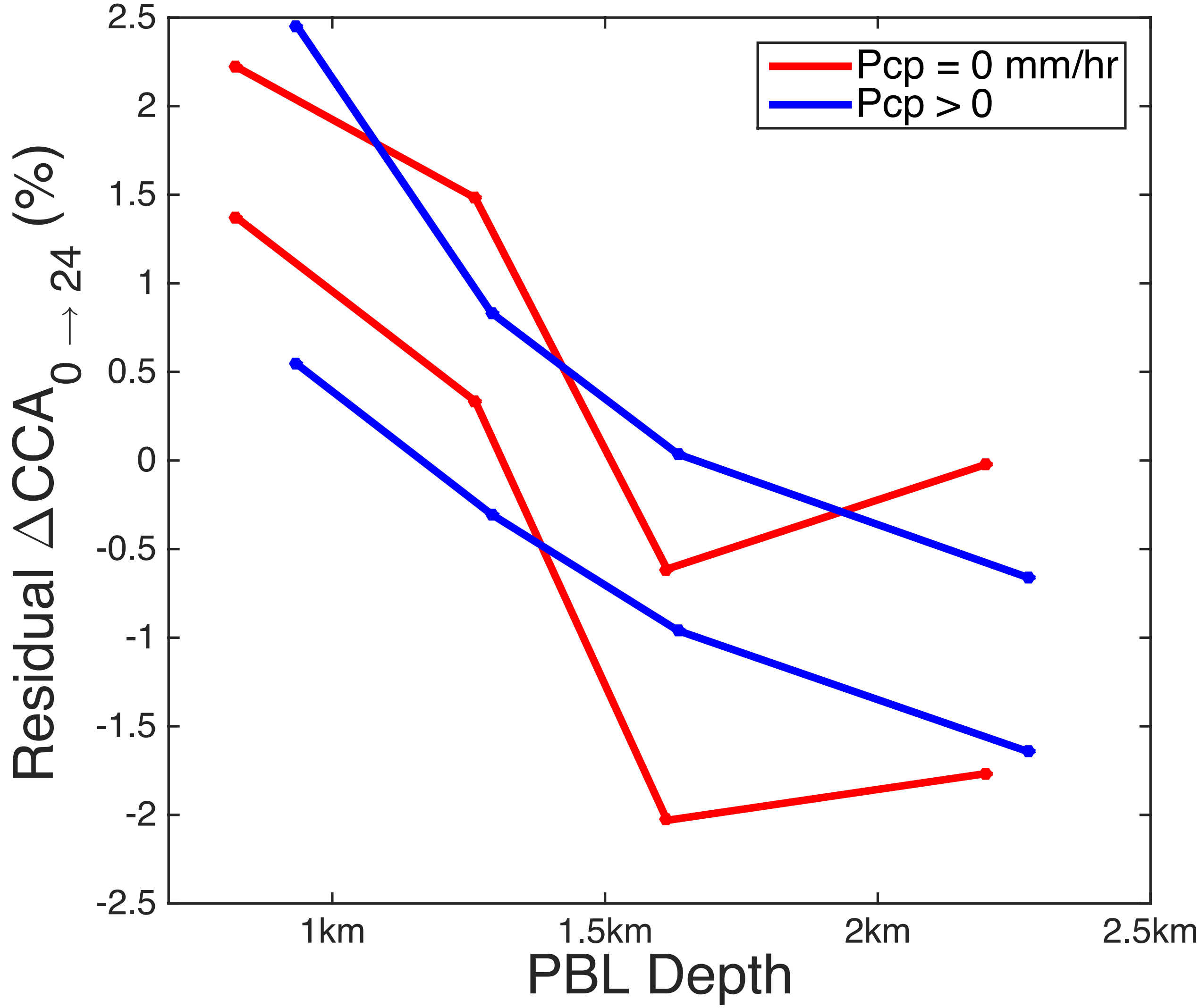
PBL Depth, Stability, and Cloud Cover



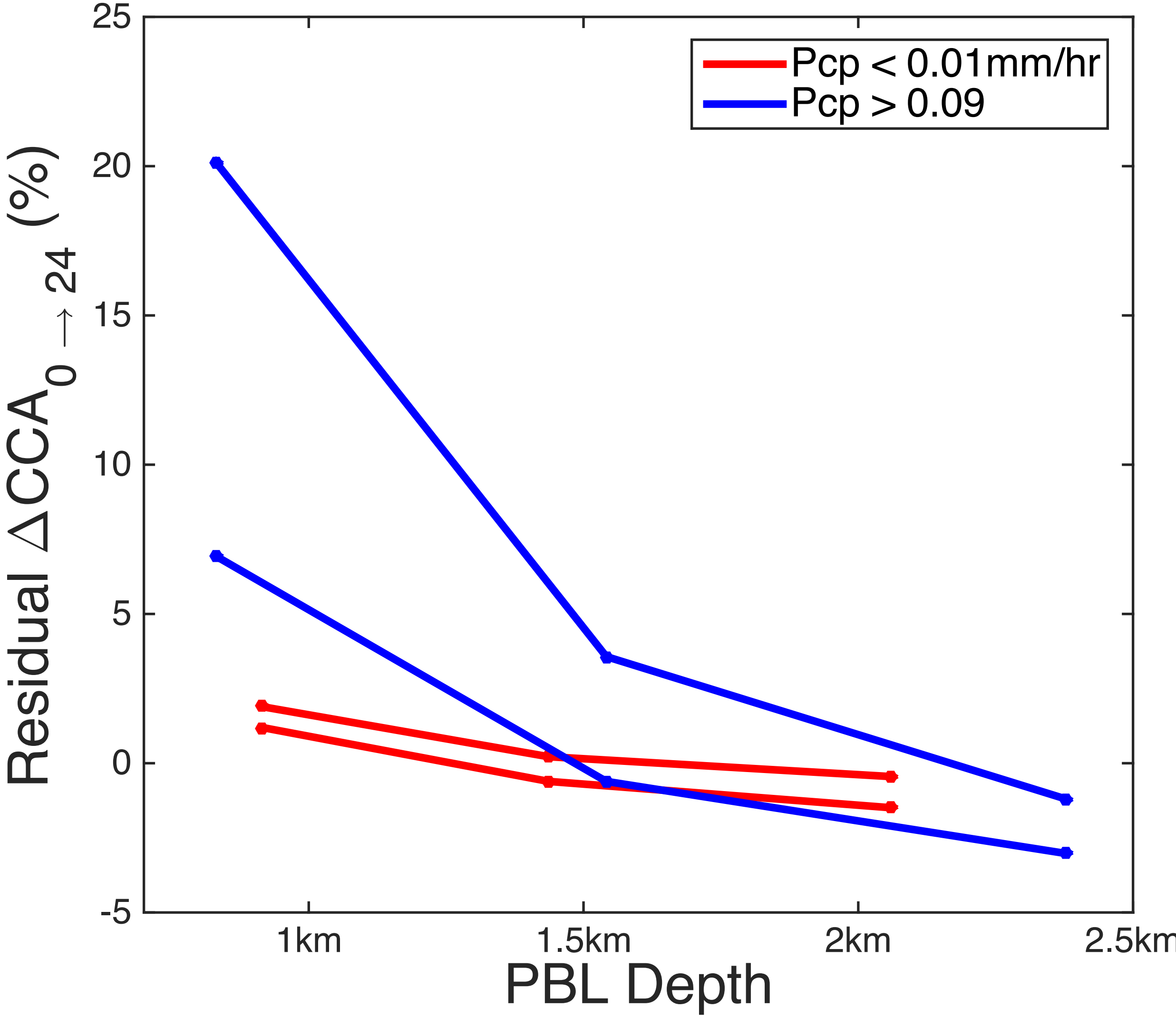
- When we control for LTS, PBL depth also still shows an effect
- Clouds in deep boundary layers tend to break up regardless of LTS

Rain, PBL Depth, and Cloud Cover

- When we control for PBL depth, rain shows minimal effects
- Since rain occurs preferentially in deep PBLs, failure to account for this would produce spurious results



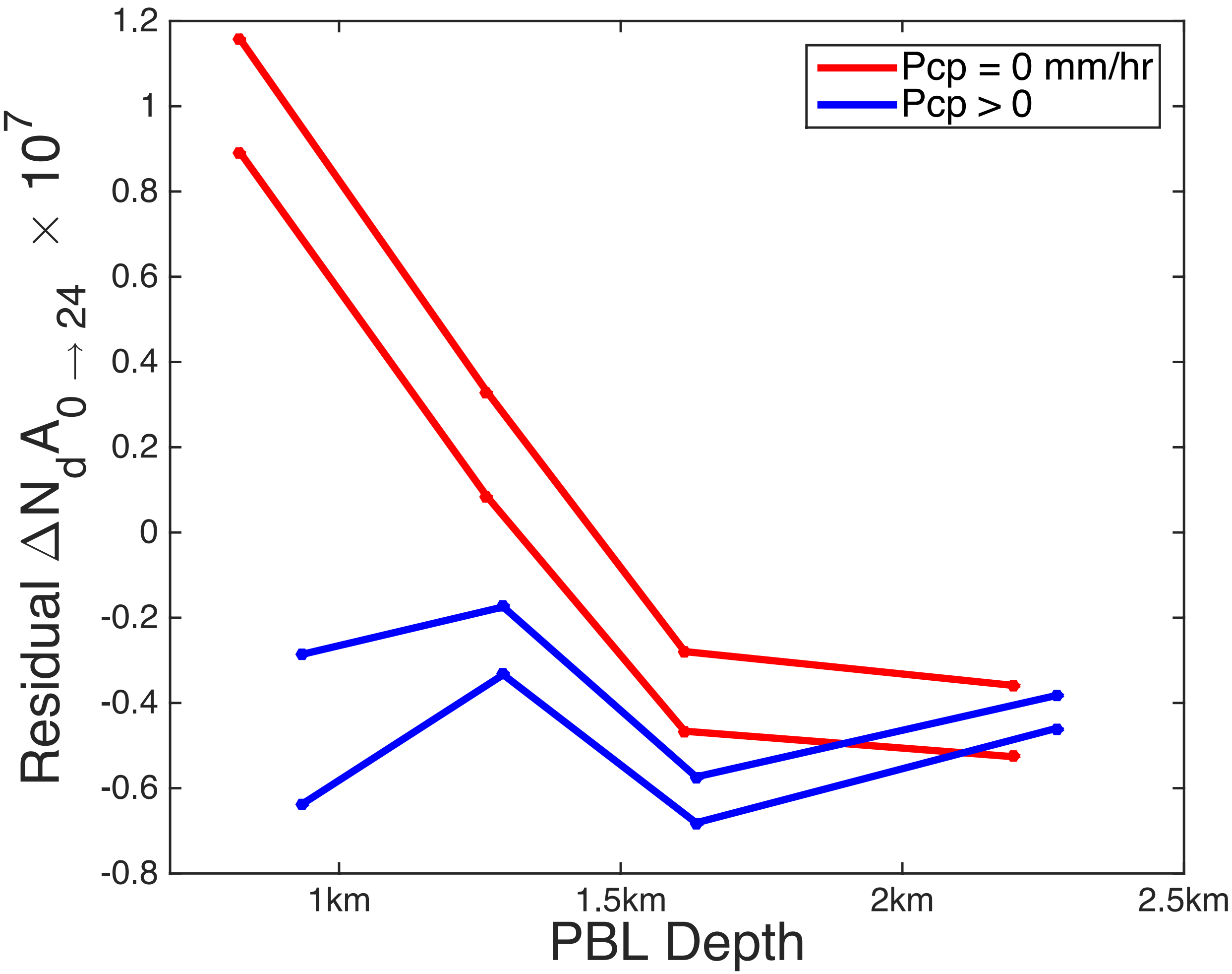
Rain, PBL Depth, and Cloud Cover



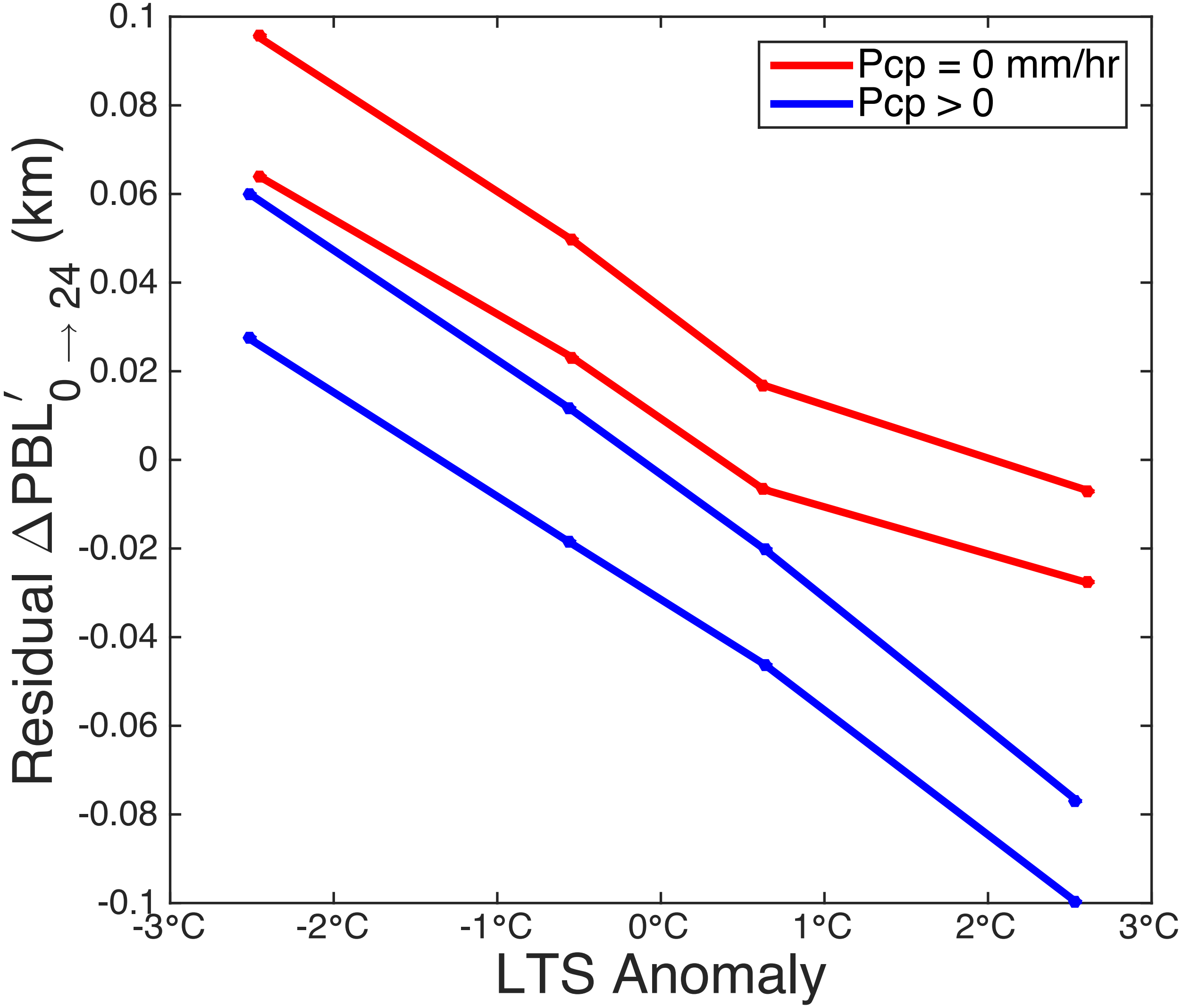
- Changing the rain rate threshold hints at a possible precipitation effect
  - In shallow PBLs heavy rain is associated with persistent clouds
  - Possibly an effect rather than a cause?
  - Stronger well-mixed circulations could produce more rain

PBL Depth, Rain and Droplet Concentration

- Rain appears to affect N_d in shallow PBLs much more than deep
  - Deep PBLs tend to lose N_d regardless of precipitation
  - Shallow PBLs with no precip tend to sustain greater droplet concentration



Rain, Stability, and PBL deepening



- The PBL appears to deepen more readily with lower LTS
  - Less entrainment of dry, warm air with high stability
- Precipitating PBLs deepen less than dry ones for strong and weak LTS

Conclusions

- Lagrangian studies of this magnitude require careful consideration of instrument biases and red noise processes
- We support many prior results and assumptions about cloud breakup, with cloud breakup more prevalent in deep PBLs and with lower LTS
  - Effects appear independently
  - Effects of rain are more subtle, and may depend upon PBL
- The effect of rain on N_d is dependent on PBL depth
- Changes in PBL depth are likely affected by LTS and precipitation processes
  - PBL deepens more with lower LTS
  - PBL deepens less with precipitation