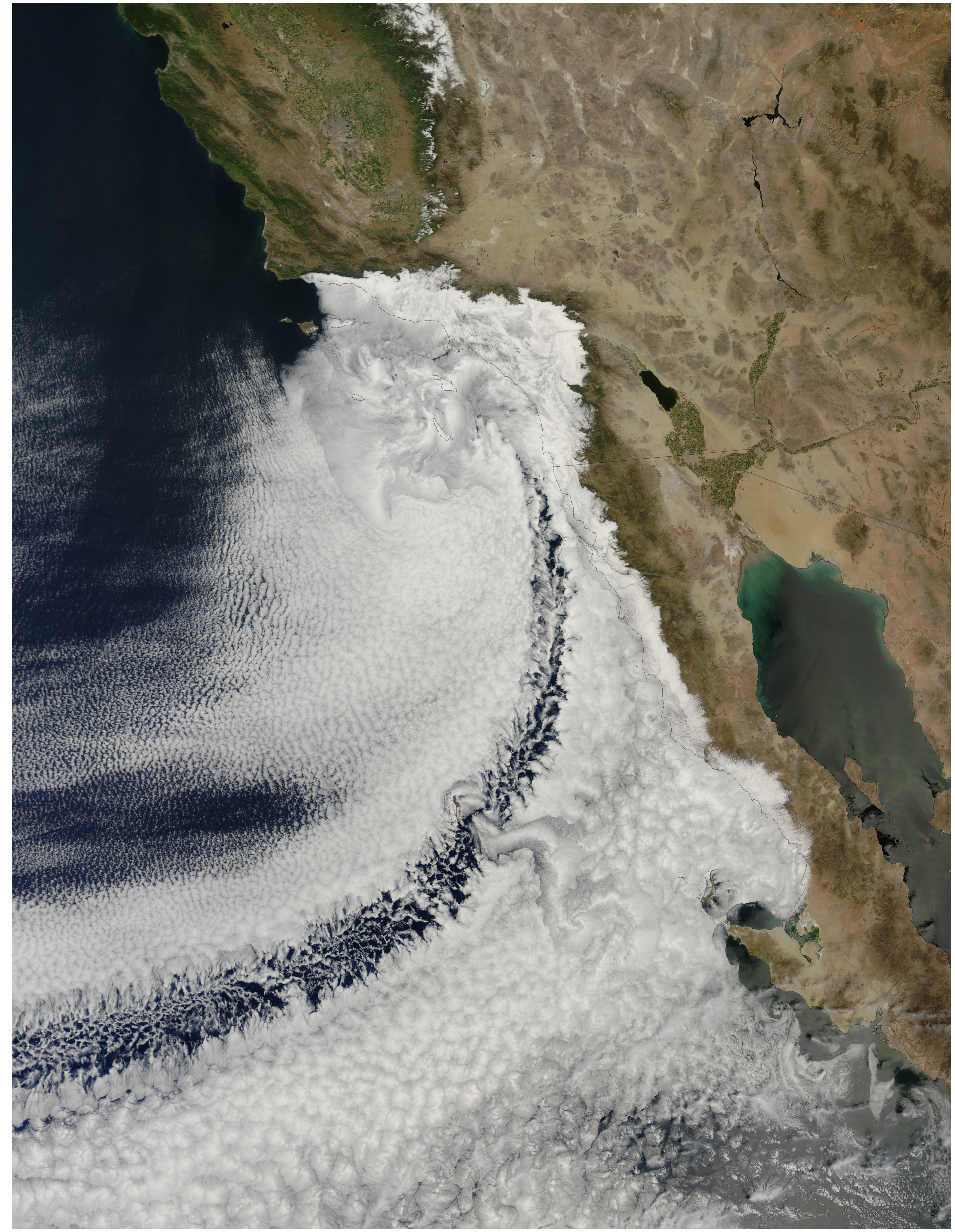
Factors leading to the breakup of marine Sc, a Lagrangian perspective using the A-Train

Ryan Eastman
Robert Wood

University of Washington
2014

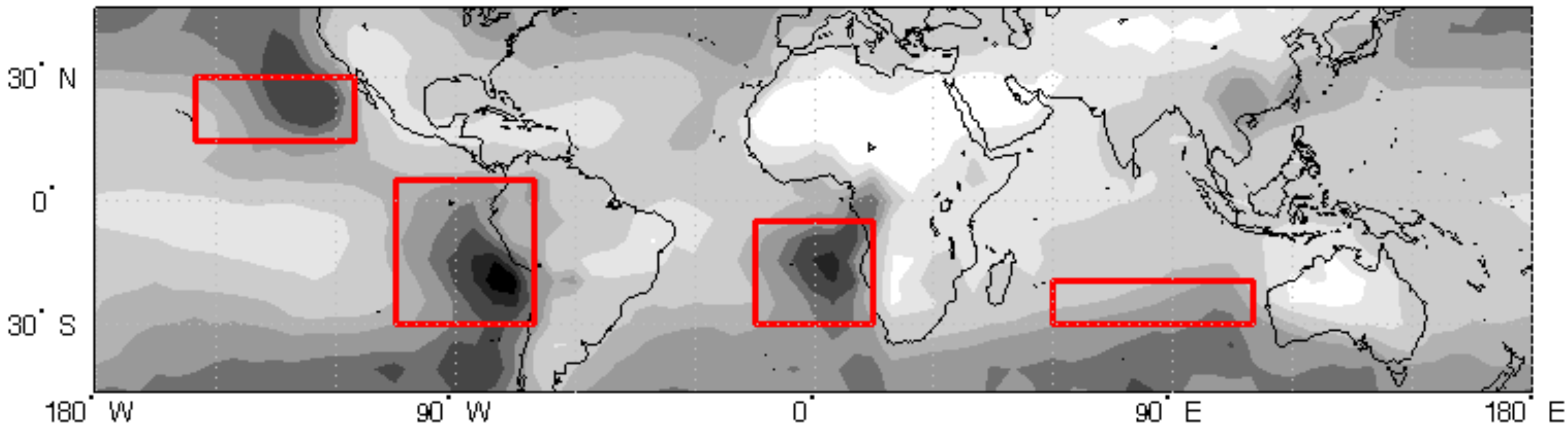
The role of Sc decks in the climate

- Form in stable environments on large and small scales
  - In stable regions around midlatitude cyclones
  - Continent-sized cloud decks in the subtropics
- Act to cool the climate
  - Reflect an enormous amount of sunlight
  - Radiate LW similar to the surface



MODIS image courtesy Jeff Schmaltz

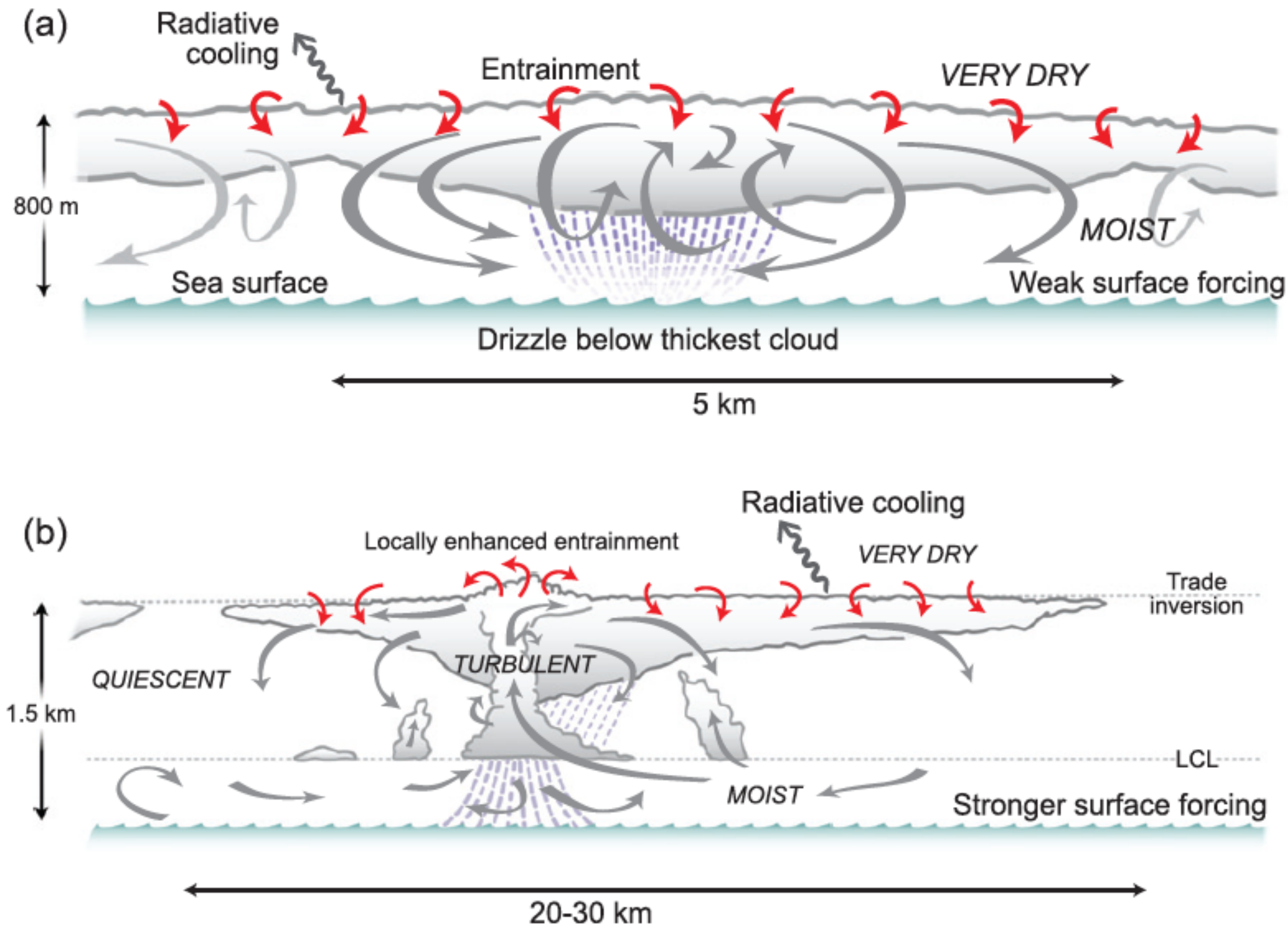
Sc climatology from surface obs



Hahn & Warren Cloud Atlas: www.atmos.washington.edu/CloudMap

- Study Sc in eastern sub-tropical ocean basins, in regions of subsidence, offshore flow, and cool SST
- Looking for maxima near continents and declining Sc gradient offshore

Shallow vs Deep Boundary Layers



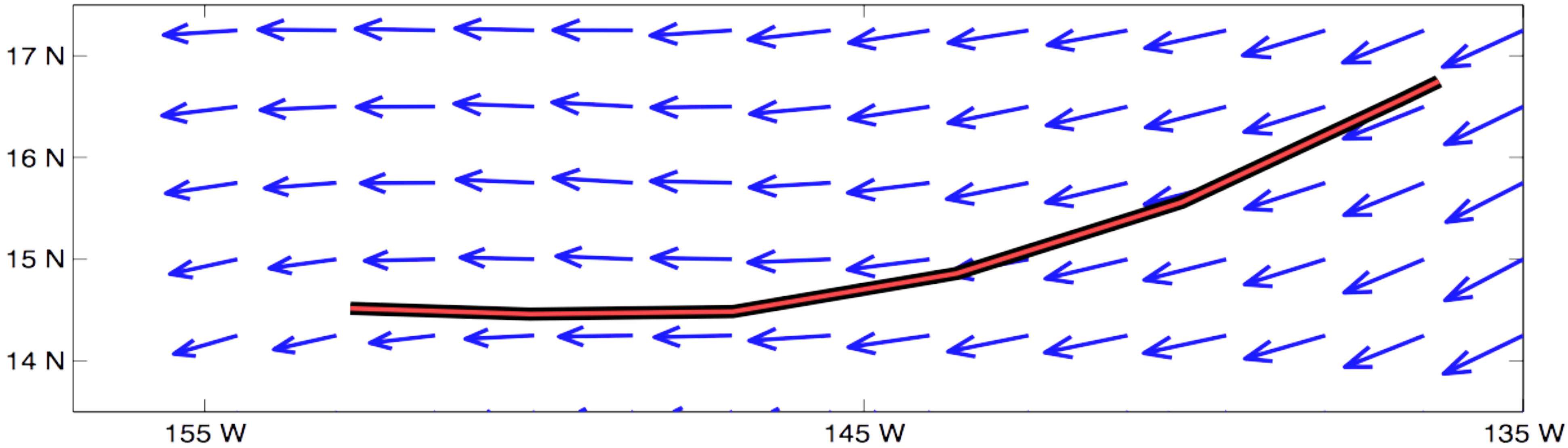
Wood 2012

Uncertainties concerning Sc breakup

- Many factors may contribute to Sc breakup over the remote ocean
  - Precipitation stabilizing the boundary layer
    - Condensation at cloud level, evaporation below
    - Removing CCN, encouraging precip, positive feedback
  - Weakening divergence offshore
  - Warming SSTs weakening the inversion
    - Boundary layer deepens, Sc layer decouples from surface
- Most of these things are correlated with one-another

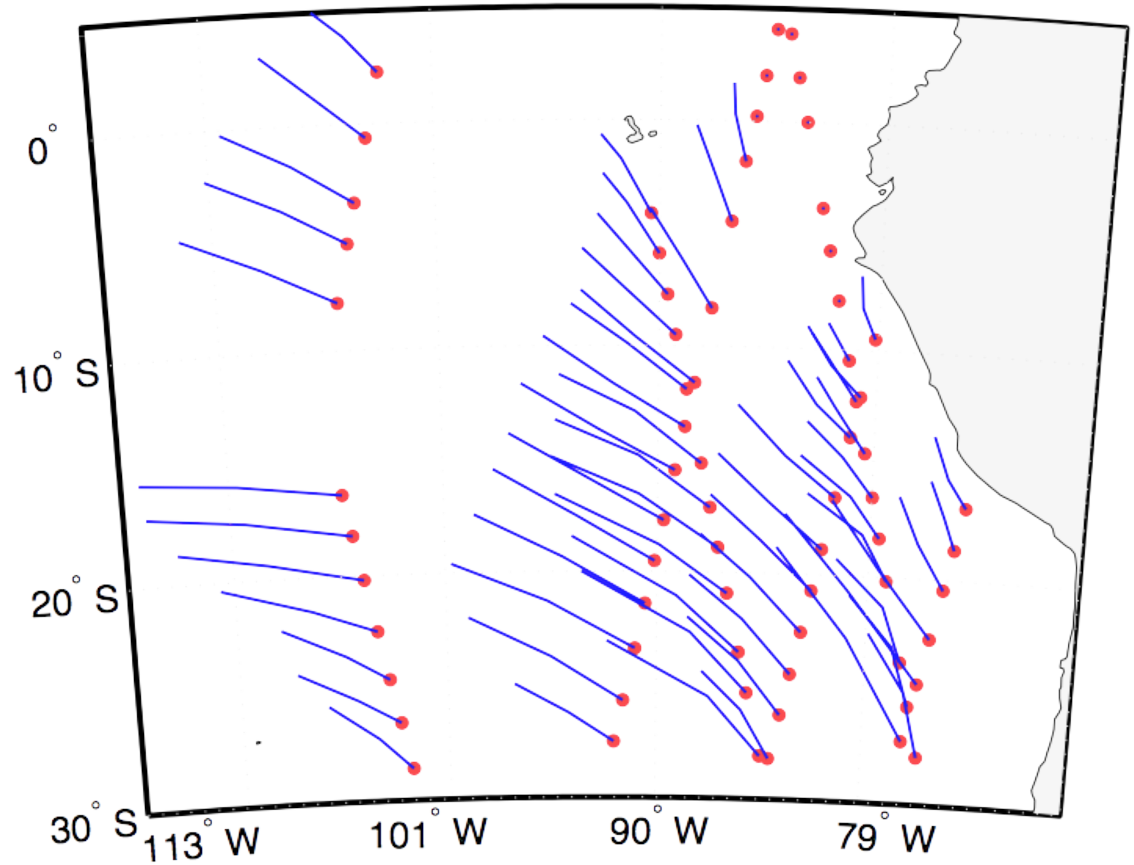
24-hour Lagrangian Study

- Compute 24-hour trajectories from reanalysis data
  - ERA-Interim reanalysis U and V fields, 0.75° at 925 mb
  - For years 2007 & 2008 only for now



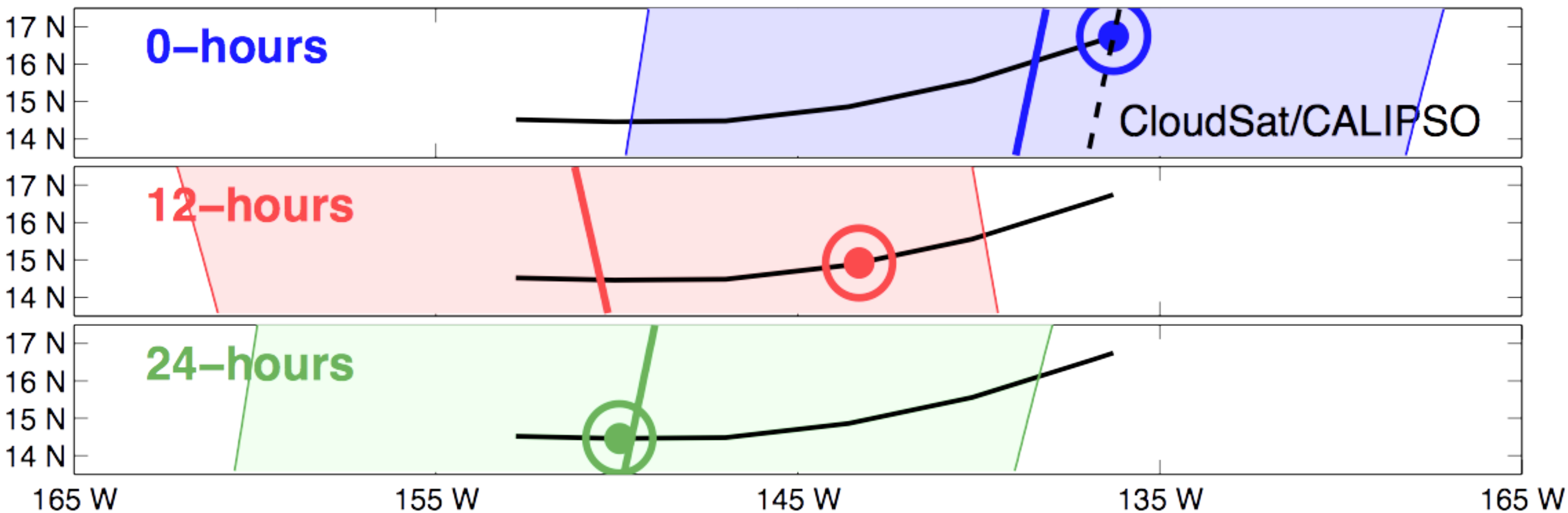
24-hour Lagrangian Study

- Start at randomly chosen points along A-Train swath, at least 200 km apart, Day and Night,
  - Over 60,000 individual trajectories
  - Only study trajectories moving east-to-west



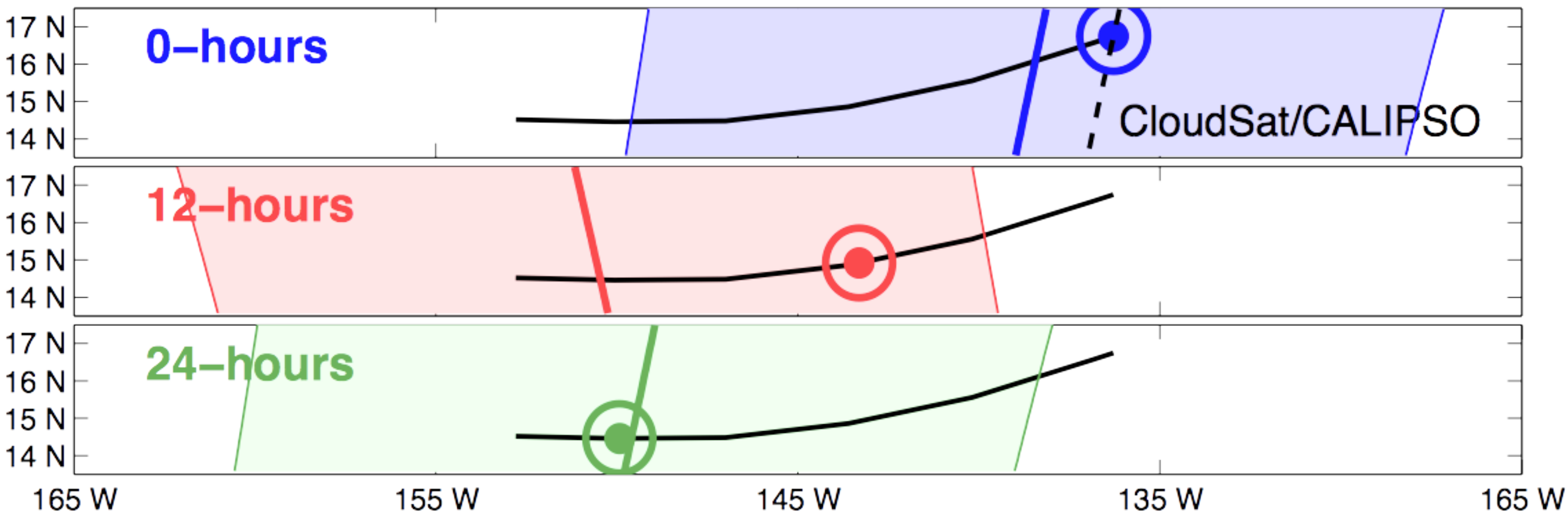
24-hour Lagrangian Study

- Look at the A-train sounding at the first point
  - Sample Precip using CloudSat 'Rain Profile' product
    - Determines whether precipitation reaches the surface
  - A sample with any precip is considered 'precipitating'

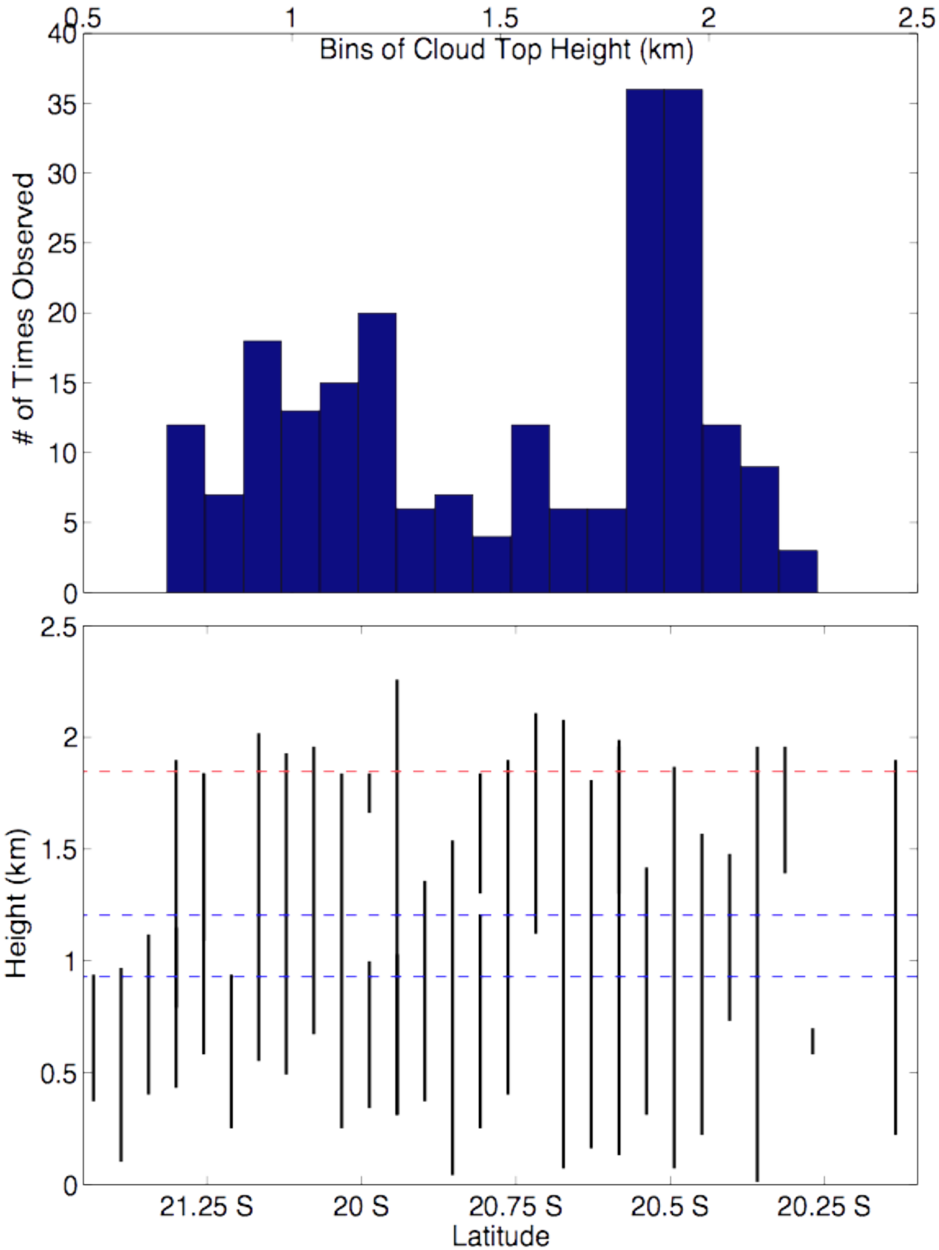


24-hour Lagrangian Study

- Use CALIPSO Vertical feature mask for boundary layer depth
  - Look at the lowest 3 km of the atmosphere
  - Assign a boundary layer depth using cloud-top returns



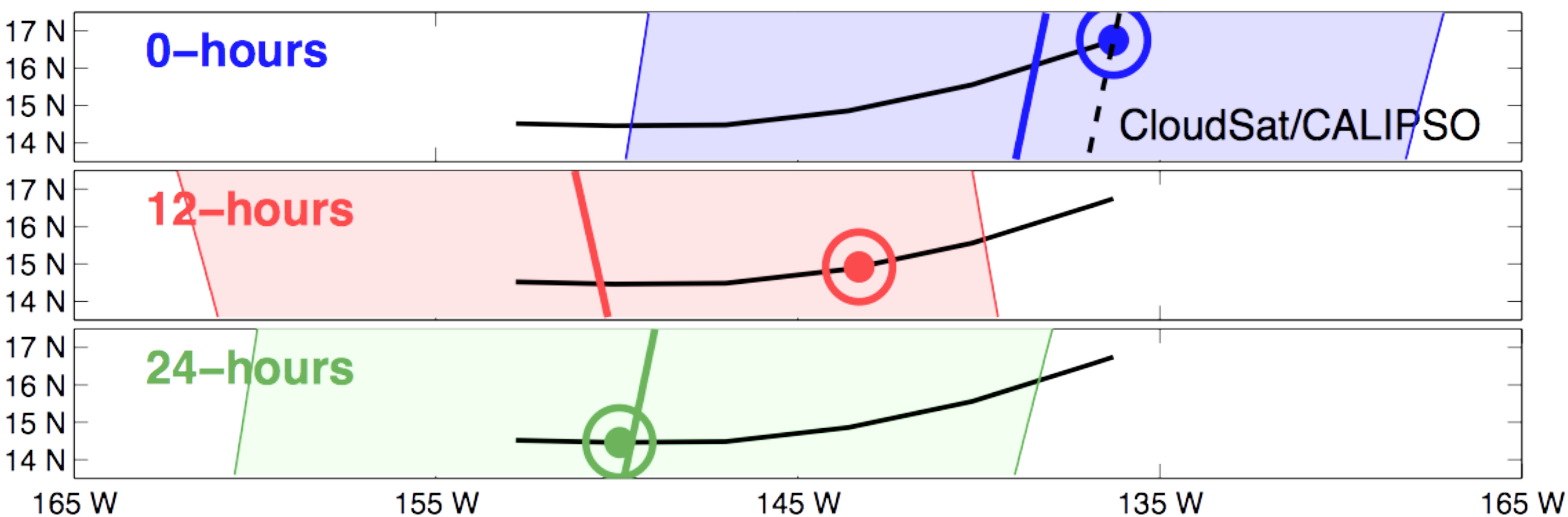
CALIPSO Cloud Top Height



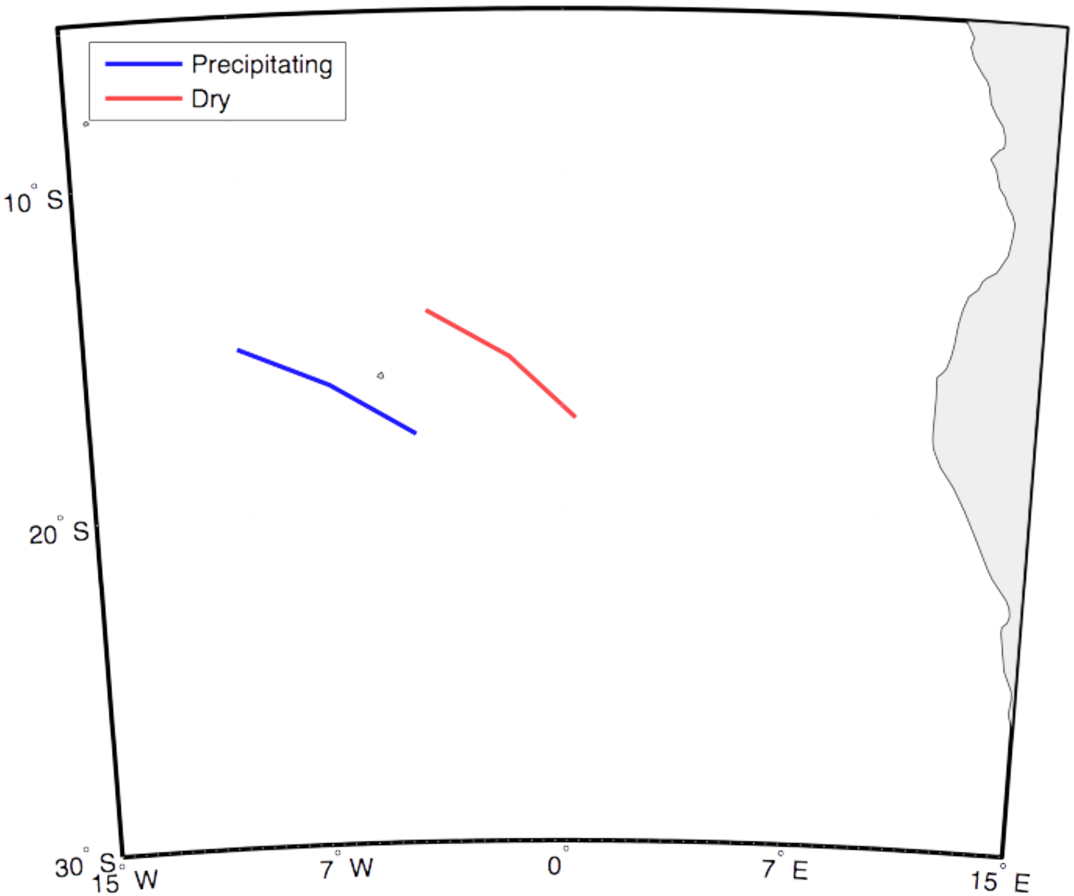
- Cloud top is not always obvious
  - Use histogram to find peaks in the frequency distribution of cloud tops below 3km
  - Peaks in the distribution are considered relevant if they are at least 40% as high as the highest peak
  - Choose the highest altitude relevant peak

24-hour Lagrangian Study

- Use MODIS at **0**, **12**, and **24** hours
  - MODIS cloud mask day or night for 100 km radius
  - Level 3 data on a 1x1 lat-lon grid



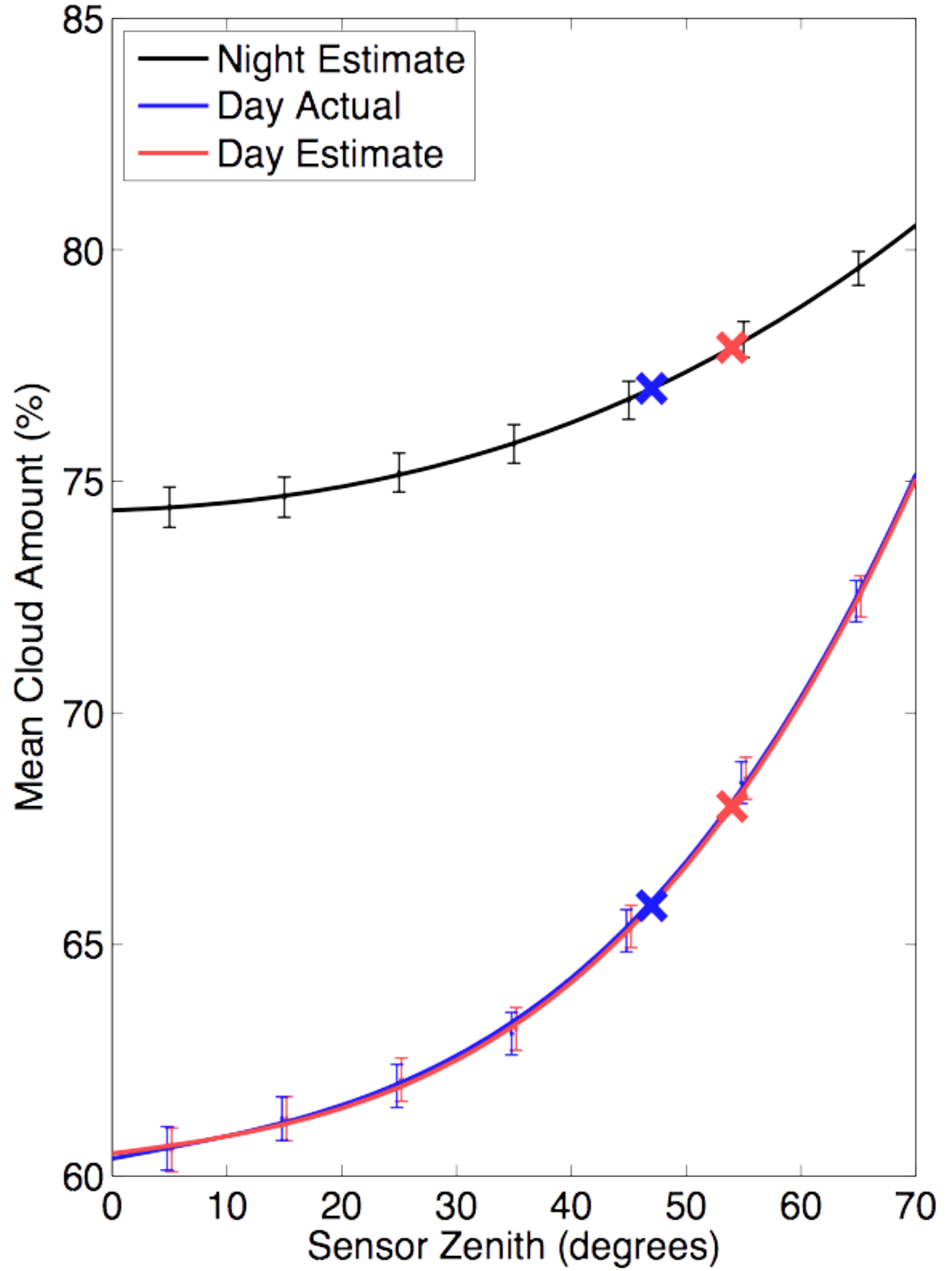
Precipitating versus dry trajectories



- Dry and precipitating trajectories should not be directly compared
  - Mean locations and distance travelled of dry and precipitating trajectories are different
  - Precip trajectories tend to go farther, and cover more CC gradient offshore
- We use seasonal cloud anomalies instead of actual amounts

MODIS Zenith Angle Bias

- MODIS senses more clouds at the edge of the swath due to:
  - Thin clouds appearing more opaque at high angles
  - Vertically developed clouds filling up more pixel
- Estimate day and night bias, and represent them as a polynomial, subtract from data

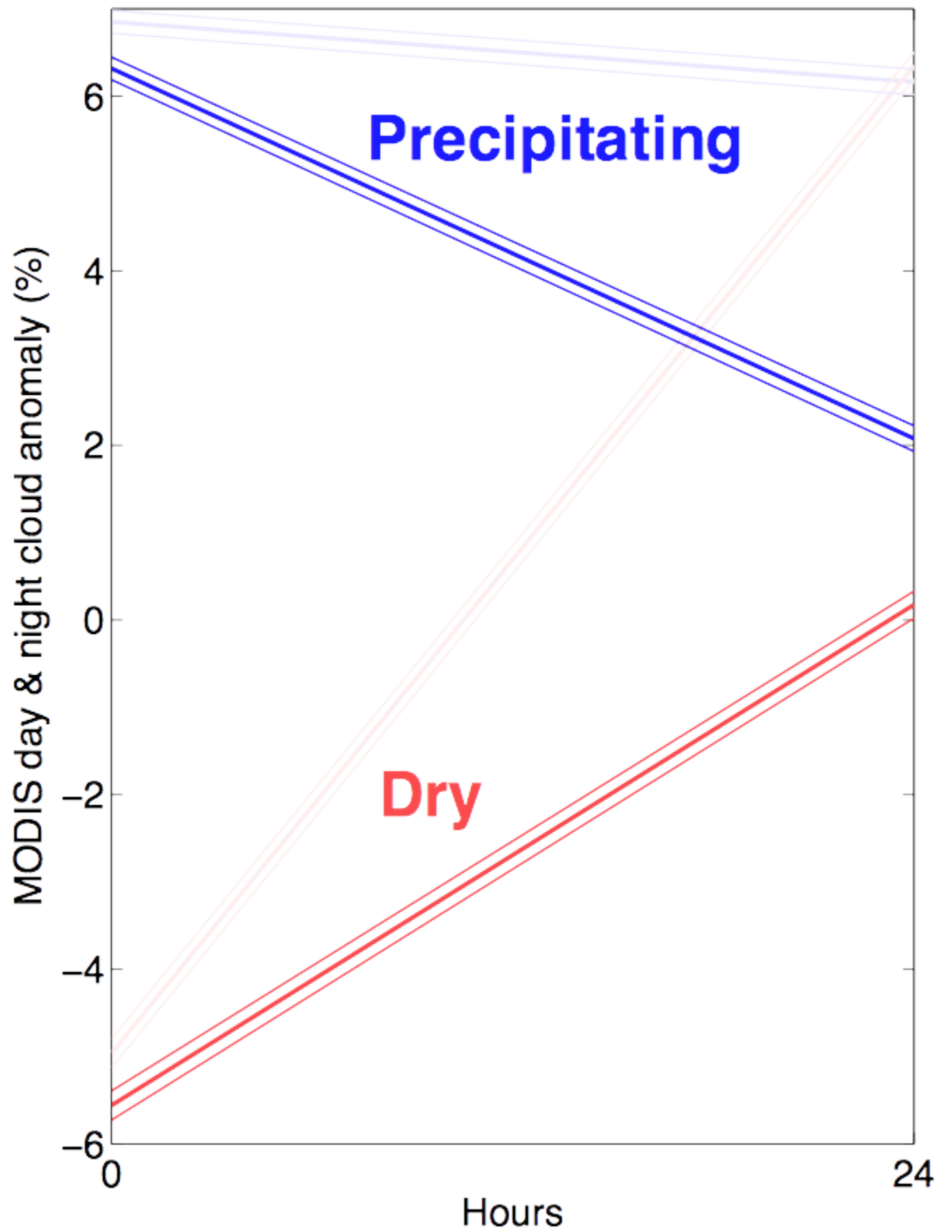


Biases in a Lagrangian study

- Most significant: A bias due to the differing initial cloud-cover anomaly distributions between precipitating and non-precipitating environments
- Clouds are necessary for precipitation to occur, therefore:
  - Precipitating trajectories must start off with some cloud cover (usually lots of clouds)
  - Dry trajectories can start cloud-free
  - Dry trajectories can show larger cloud cover increases than precipitating

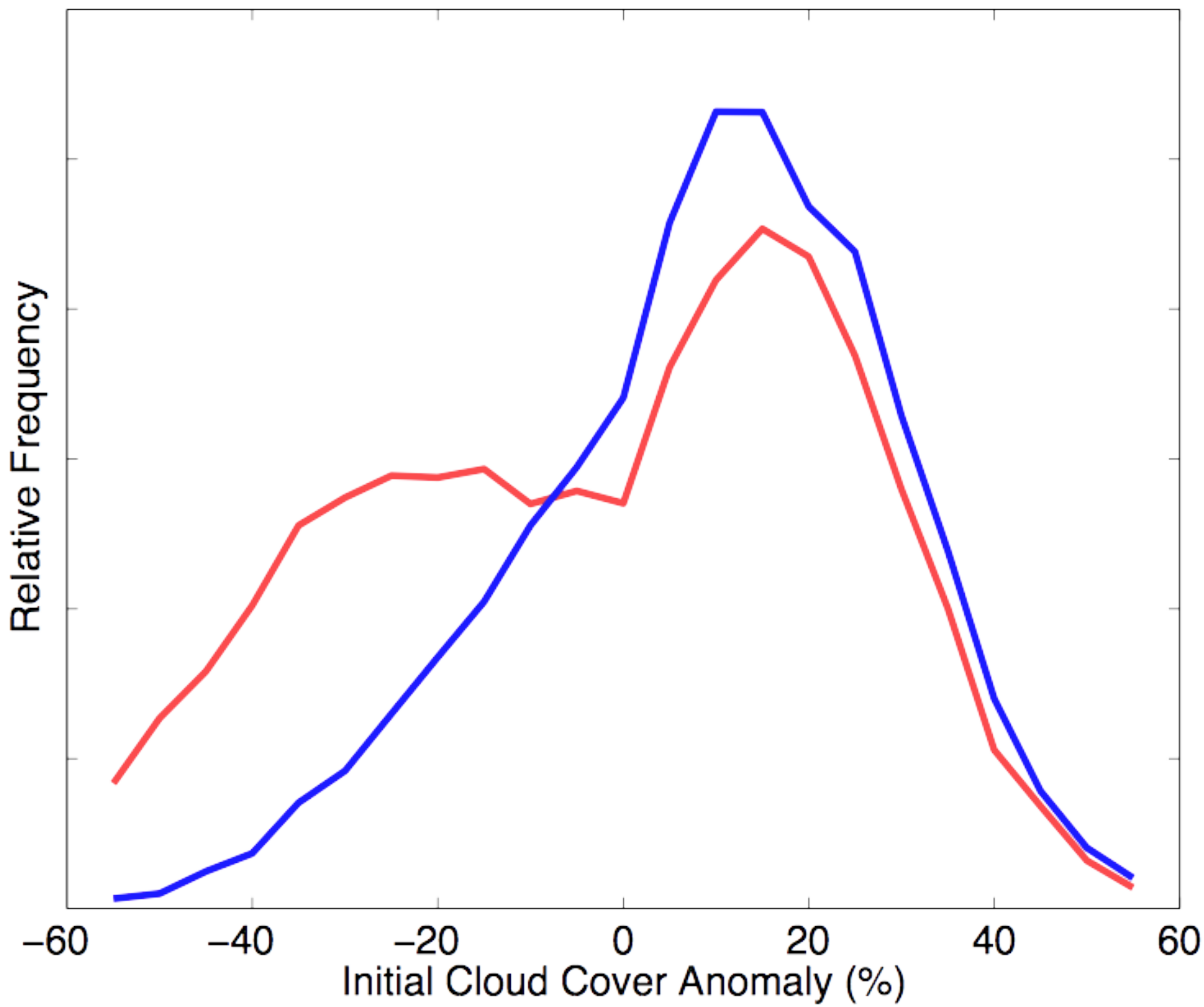
Biases in a Lagrangian study

- Directly comparing Delta Cloud Cover Anomaly (ΔCCA) is misleading
- Not comparing samples that evolve in the same way, regardless of precip
  - Dry trajectories can show a larger ΔCCA, due to 0% Cloud Cover values are only possible for dry



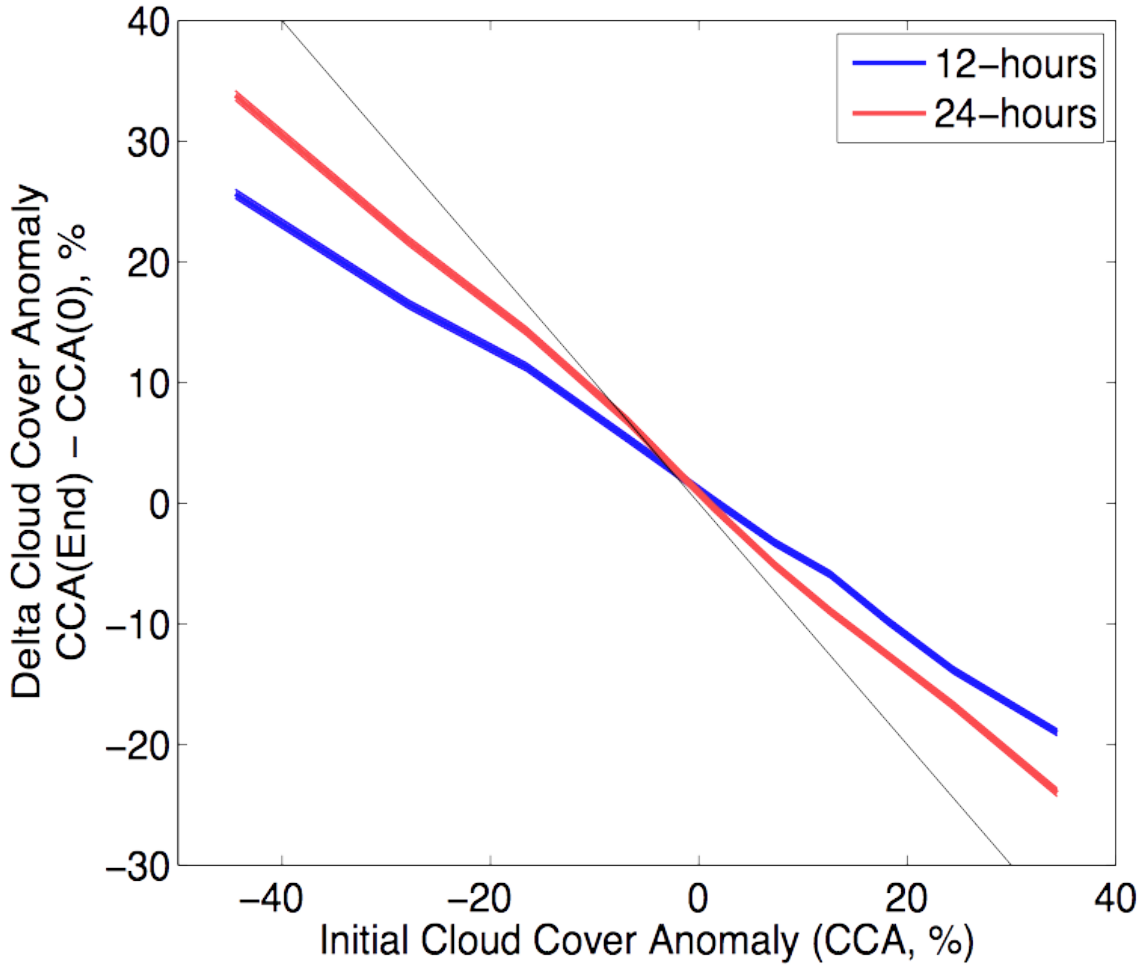
Biases in a Lagrangian study

- More **positive** precipitating initial cloud cover anomalies (CCA)
- More **negative** dry initial CCA
- ΔCCA must (in part) be a function of initial CCA



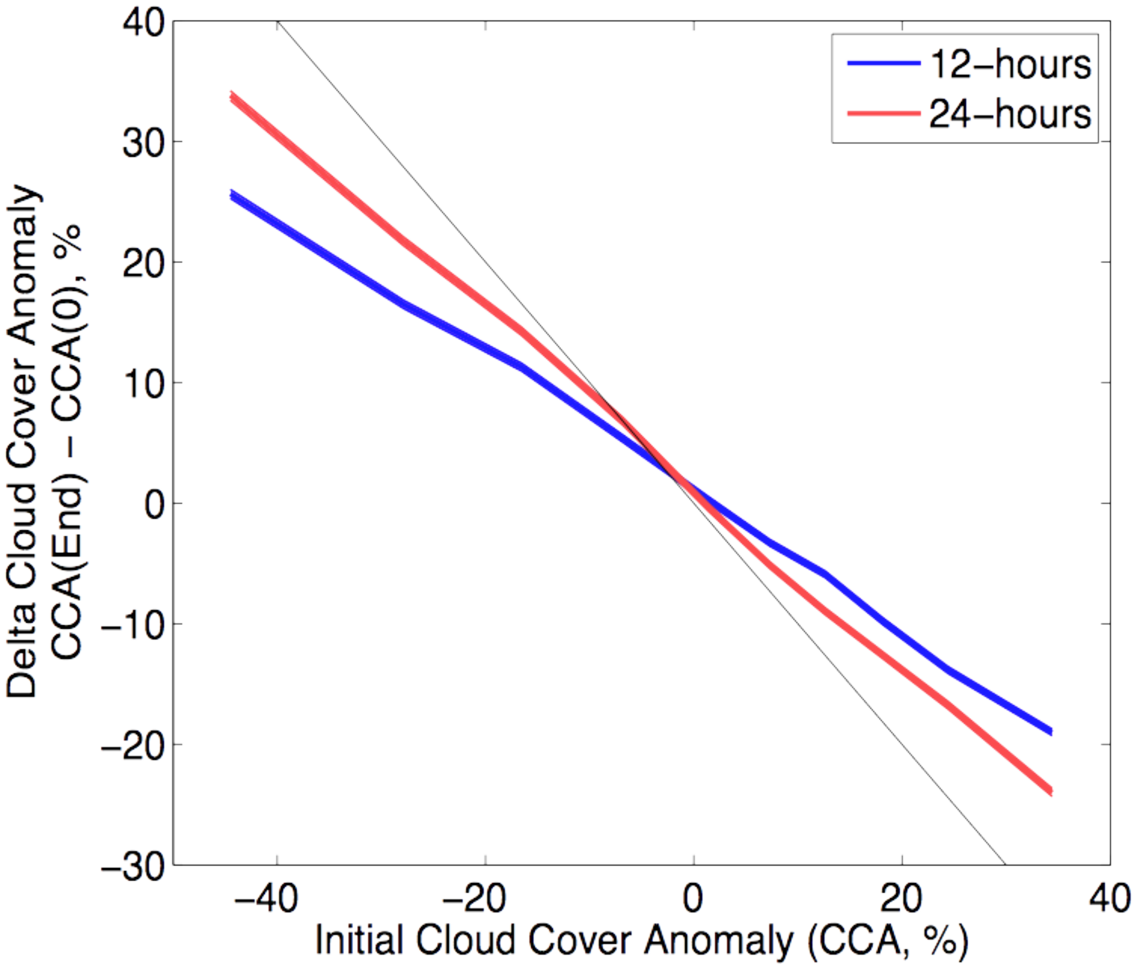
Predicting Δ Cloud Cover Anomaly

- ΔCCA(CCA(0)) for 12- and 24-hour trajectories
- Linear relationships, with the slope steepening over time
- ΔCCA can be represented as a function of initial CCA and time
- We can predict ΔCCA



Predicting Δ Cloud Cover Anomaly

- We now can use this linear relationship to compare the evolution of two samples with differing starting distributions of CCA
- Compare the observed change with the predicted change for each trajectory

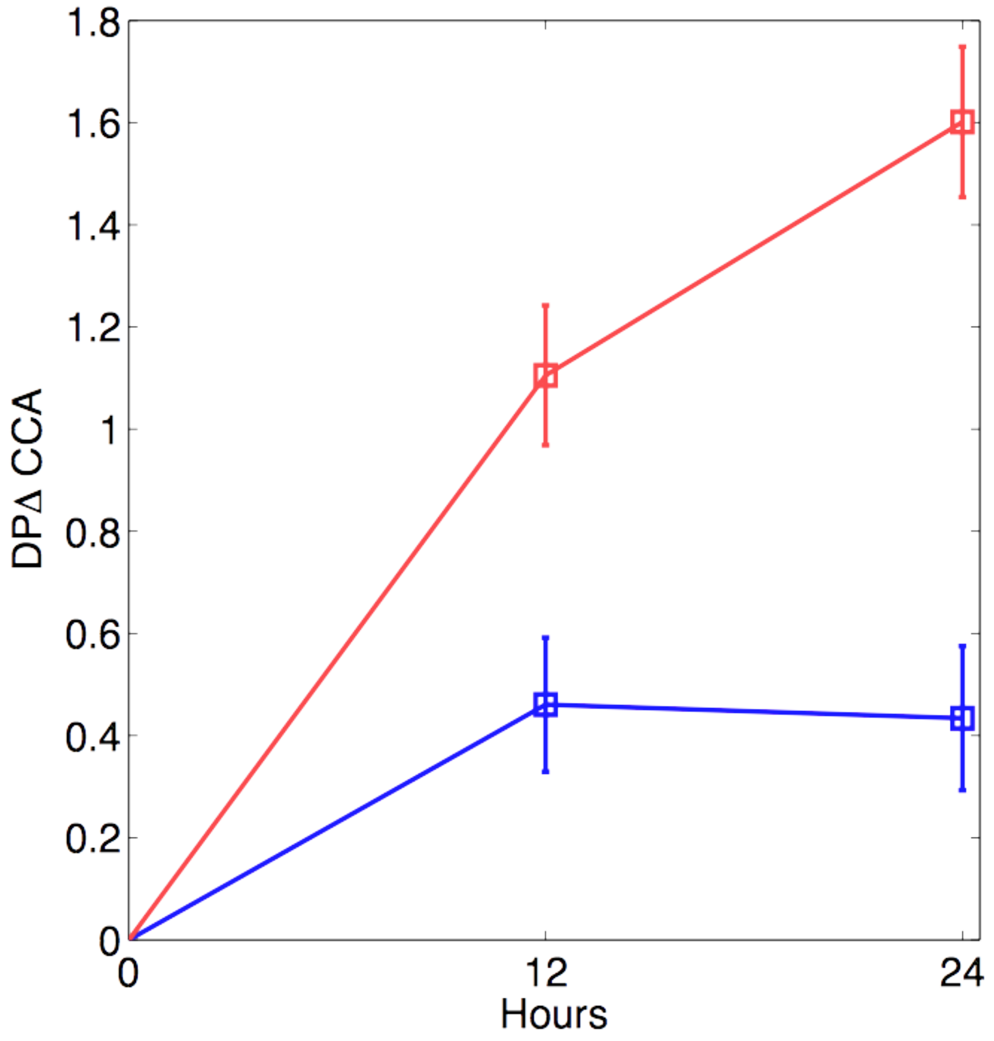


Random vs. Actual ΔCCA

- eg: A trajectory begins with a cloud anomaly of +10 %.
  - Using the previous figure, we predict a ΔCCA of -5% in 12 hours and -8% in 24 hours
  - Compare the actual ΔCCA to the predicted ΔCCA
    - Subtract the predicted ΔCCA from the actual ΔCCA to get DPΔCCA, the **difference from predicted ΔCCA**
    - Actual ΔCCA is -20%, for 12 hours, -25% for 24 hours
    - DPΔCCA(12) = -15%, DPΔCCA(24) = -17%
- Look for variables that significantly alter the DPΔCCA, with no initial distribution bias

DPΔCCA and Precipitation

- Precipitation still appears to have an effect, though smaller
  - Difference of only 0.7 or 1.2%
  - Significant at 12 and 24 hours
- Both are positive
  - Due to residual zenith angle bias
  - Selection Bias (westward trajectories only)

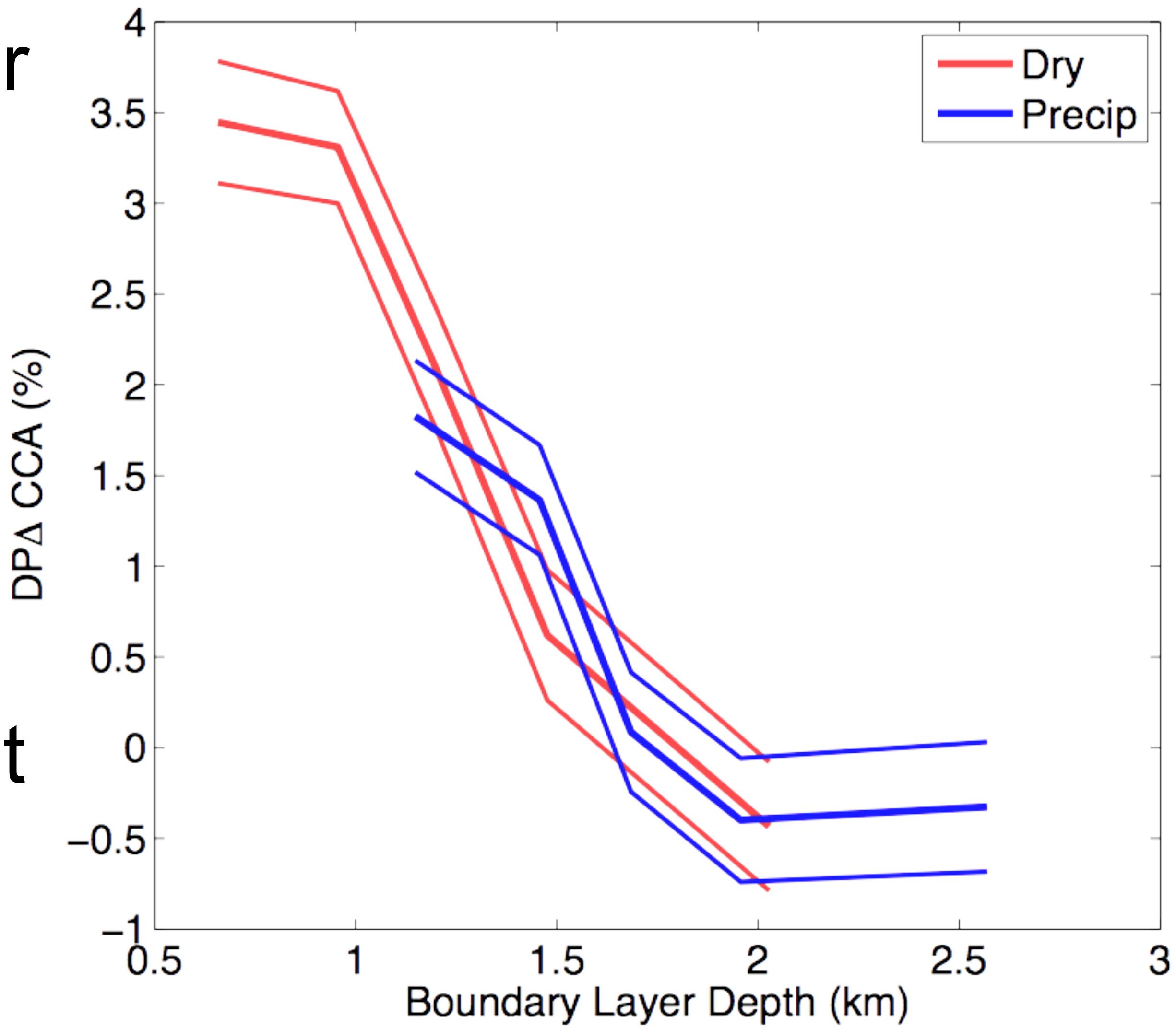


Factors aside from precipitation

- Precipitation is correlated with other variables, which, in turn, are correlated with each other eg...
  - Precipitation tends to occur in deeper boundary layers (r = 0.35), and is slightly correlated with lower-tropospheric stability ($\theta_{700} - \theta_{1000}$, r = -0.12)
    - Derived from CloudSat Auxiliary reanalysis from ECMWF
  - Lower tropospheric stability values correlate negatively with boundary layer depth (r = -0.45)
- What is actually producing this result? Is precipitation the driving variable, or is it something correlated with precipitation?

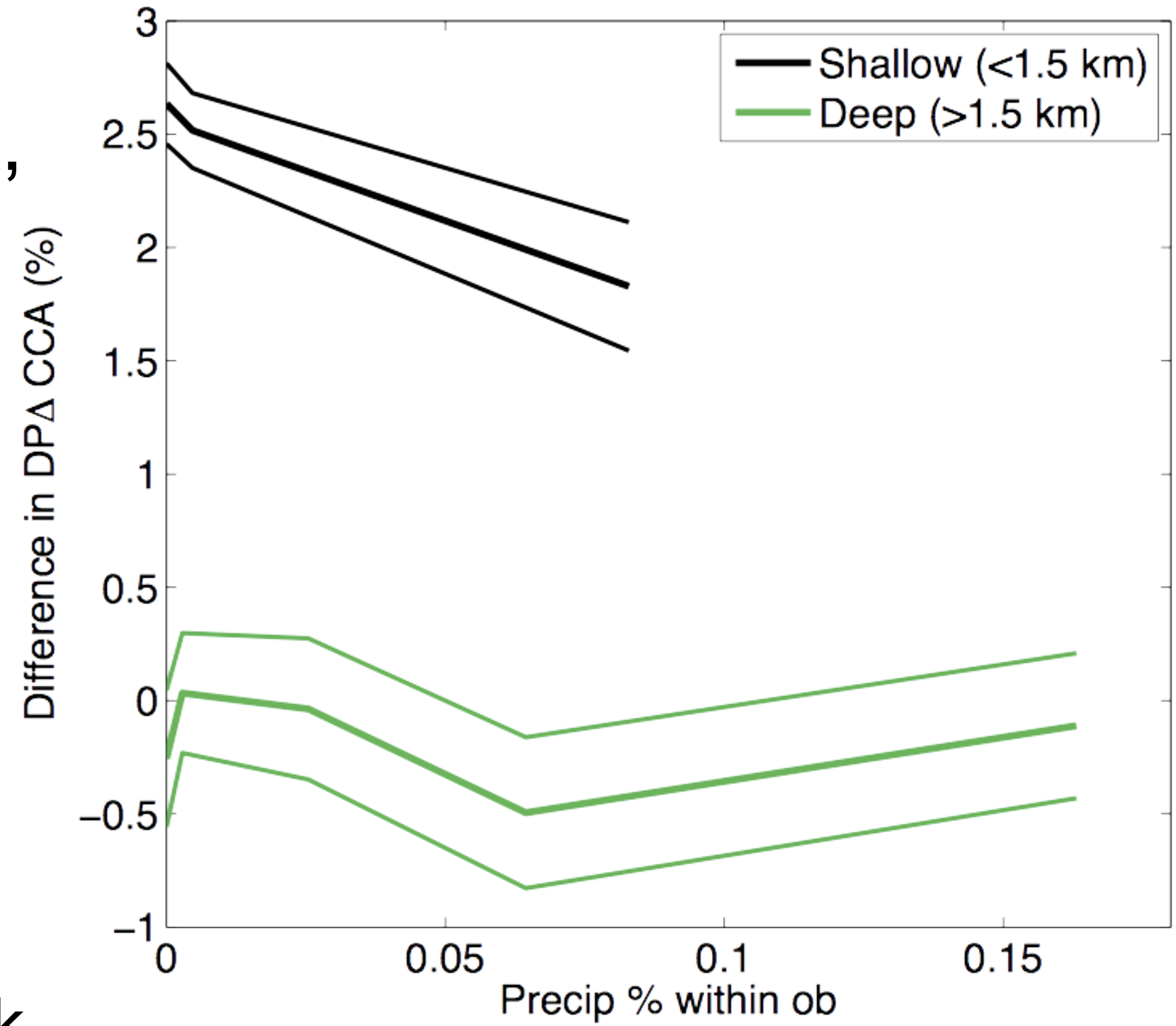
Binning DPΔCCA for constant boundary layer depths

- Hold boundary layer depth constant in separate bins for precipitating and dry trajectories
  - Bins with equal N
- See if precipitation still has a significant affect
- Appears not to



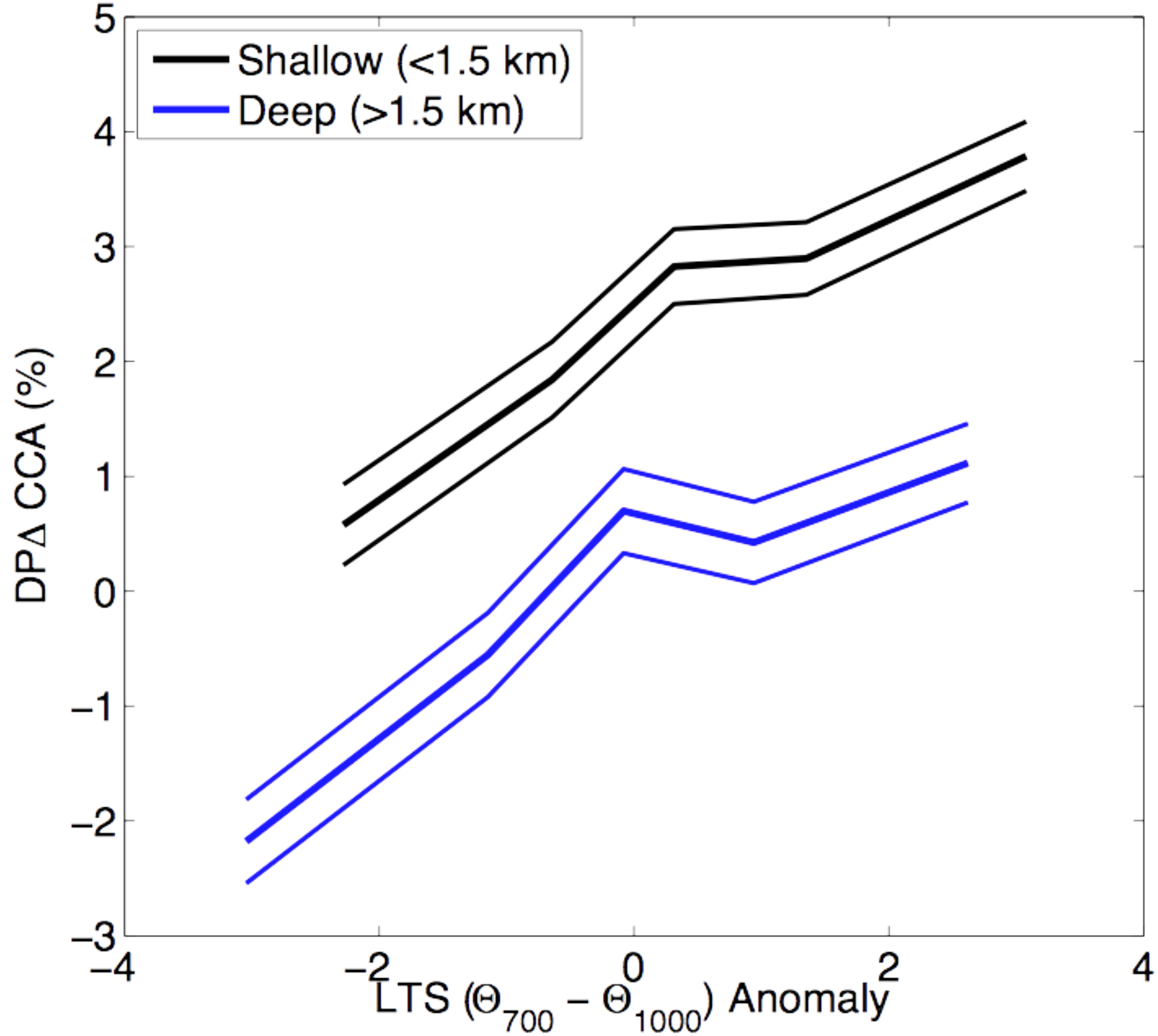
Binning DPΔCCA for constant precipitation frequency (inverse)

- Hold precipitation frequency constant, see if shallow and deep boundary layers evolve differently
- They do
  - Shallow boundary layers persist
  - Deep boundary layers tend to break up



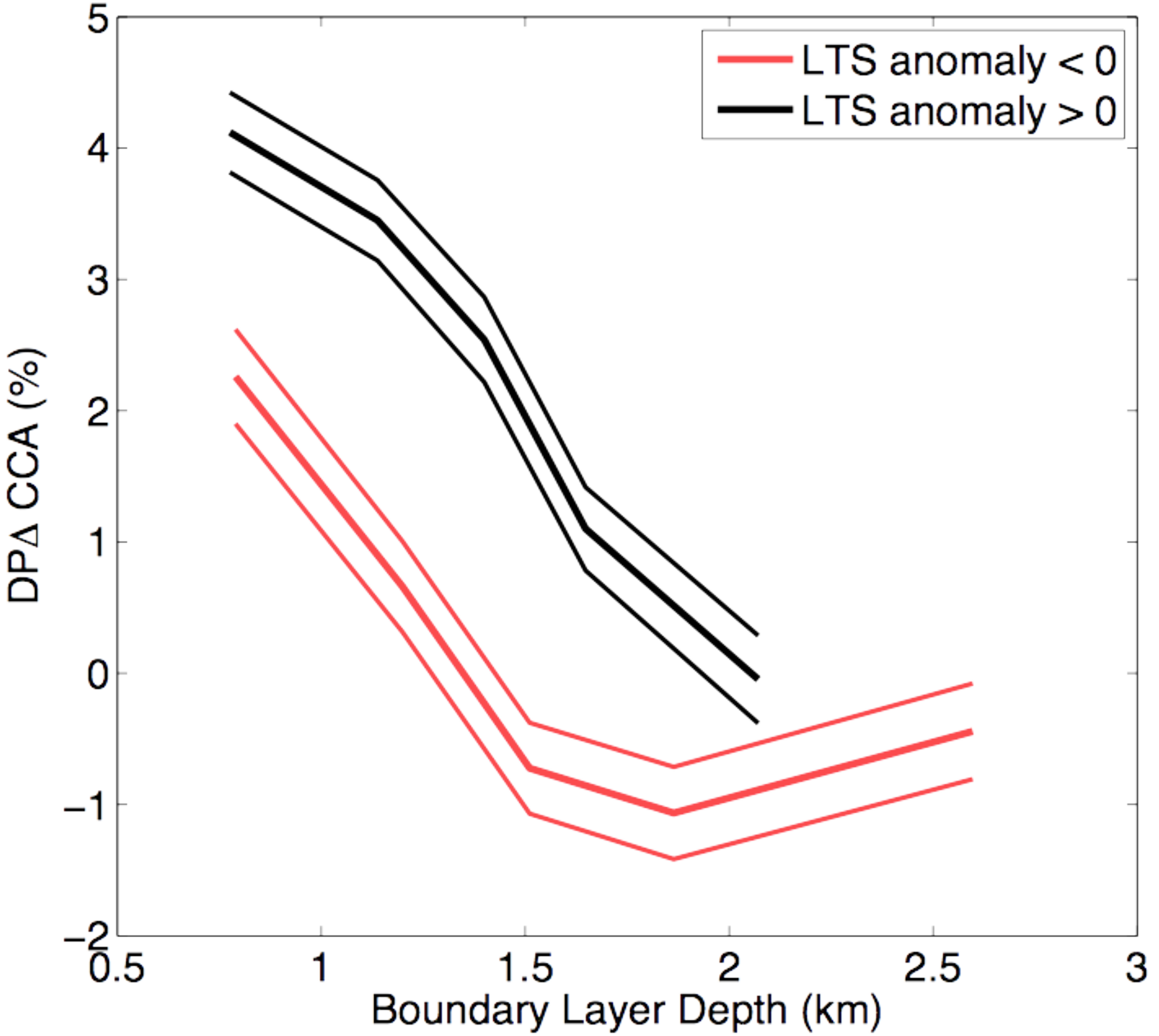
Binning DPΔCCA for constant LTS ($\theta_{700} - \theta_{1000}$) Anomalies

- Boundary layer depth is well correlated with LTS
- Deep boundary layers break up more readily for bins of constant LTS
- Slopes suggest that LTS may also have an influence



Binning DPΔCCA for constant boundary layer depths (inverse)

- Invert the previous figure to see if LTS has an effect for bins of constant boundary depth
- Appears to have a significant effect
  - High LTS (strong inversion) allows clouds to persist
  - Low LTS associated with breakup



Results for binning DPΔCCA

- Precipitation does not appear to be a driver of cloud breakup
- Instead LTS and boundary layer depth both seem to matter more
- Strong inversions tend to maintain cloud cover independent of boundary layer depth
- Deep boundary layers tend to break up more readily independent of inversion strength