

# Detection and attribution of externally forced cloud trends

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# Detection and Attribution 101

- Fingerprinting
  - What does external forcing look like?



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- Detection
  - Does a signal emerge from internal climate noise?



# Detection and Attribution 101

- Fingerprinting
  - What does external forcing look like?
- Detection
  - Does a signal emerge from internal climate noise?
- Attribution
  - Is it consistent with forced model results?



What is the signature of external forcing on clouds?

# **FINGERPRINTING**

# Ingredients



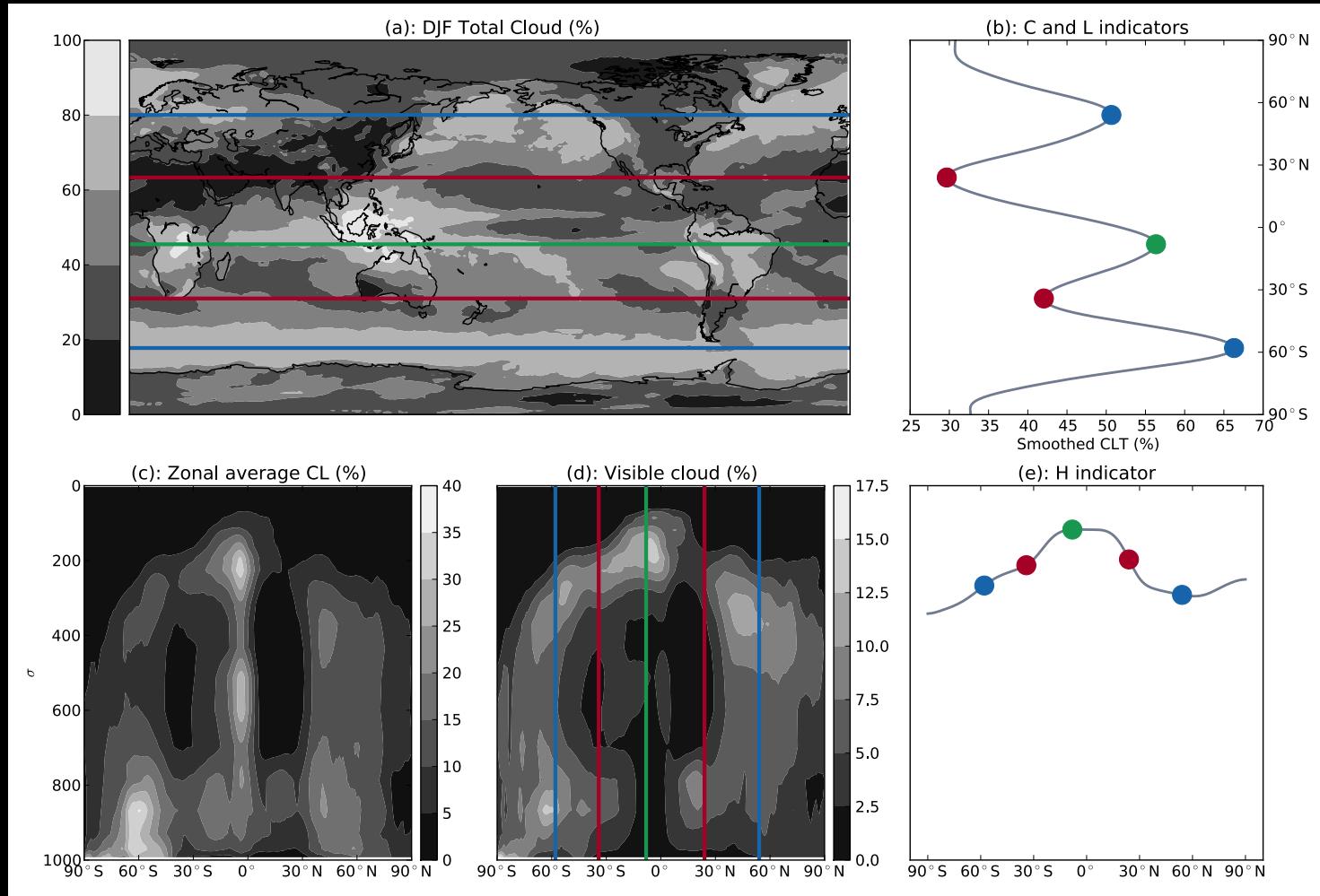
- Model agreement on clouds is notoriously poor
- Need indicators that capture robust processes
- We use three indicators: L, C, H

# Expectations in a warming world

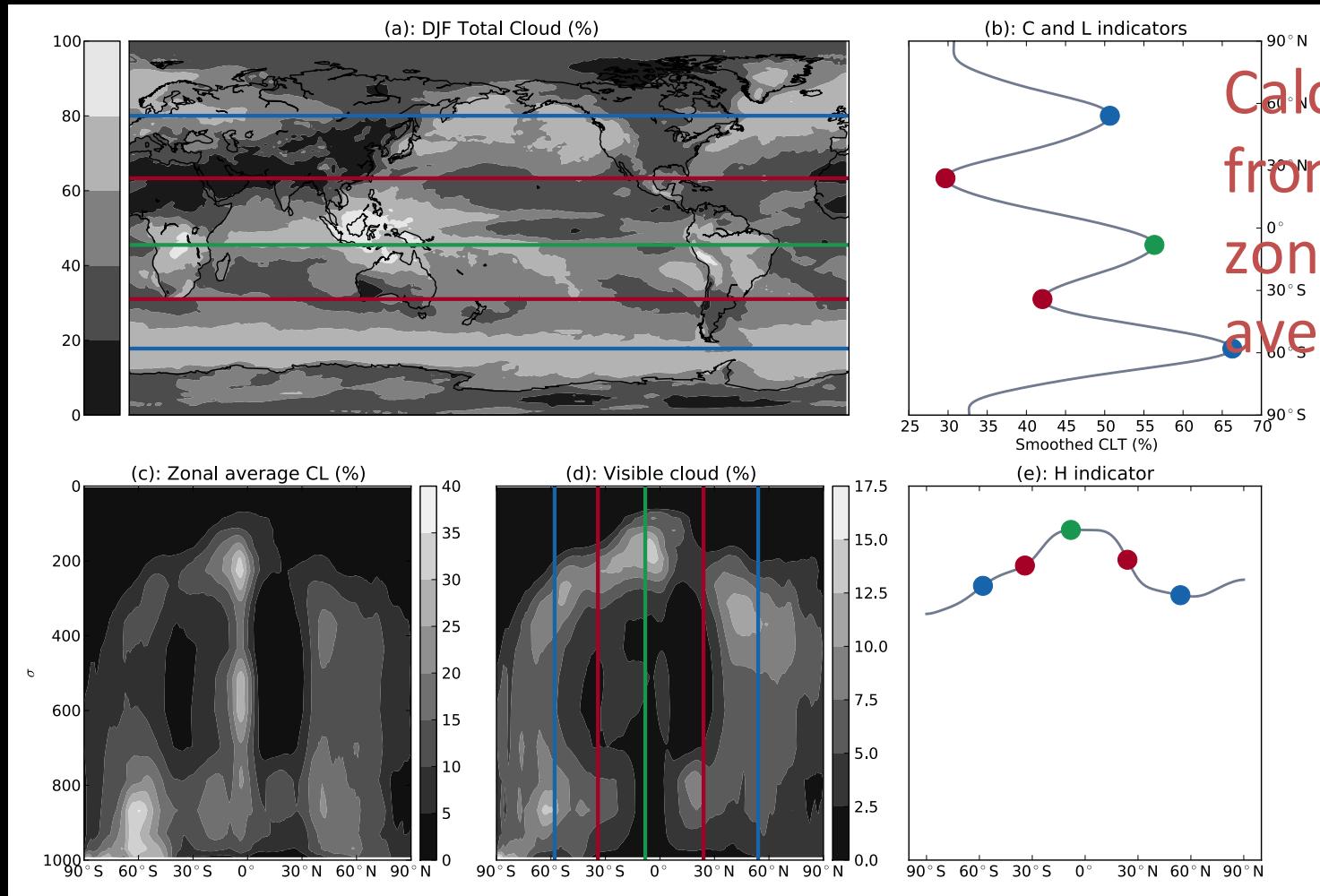
- Poleward shifts in circulation
  - Min *et al*, Johansen and Fu, Seidel, Marvel & Bonfils
- Hydrological cycle intensification
  - Held and Soden, Zhang *et al*, Durack *et al*
- Changing vertical temperature structure
  - Santer *et al*, Hartmann and Lohman, Zelinka and Hartmann



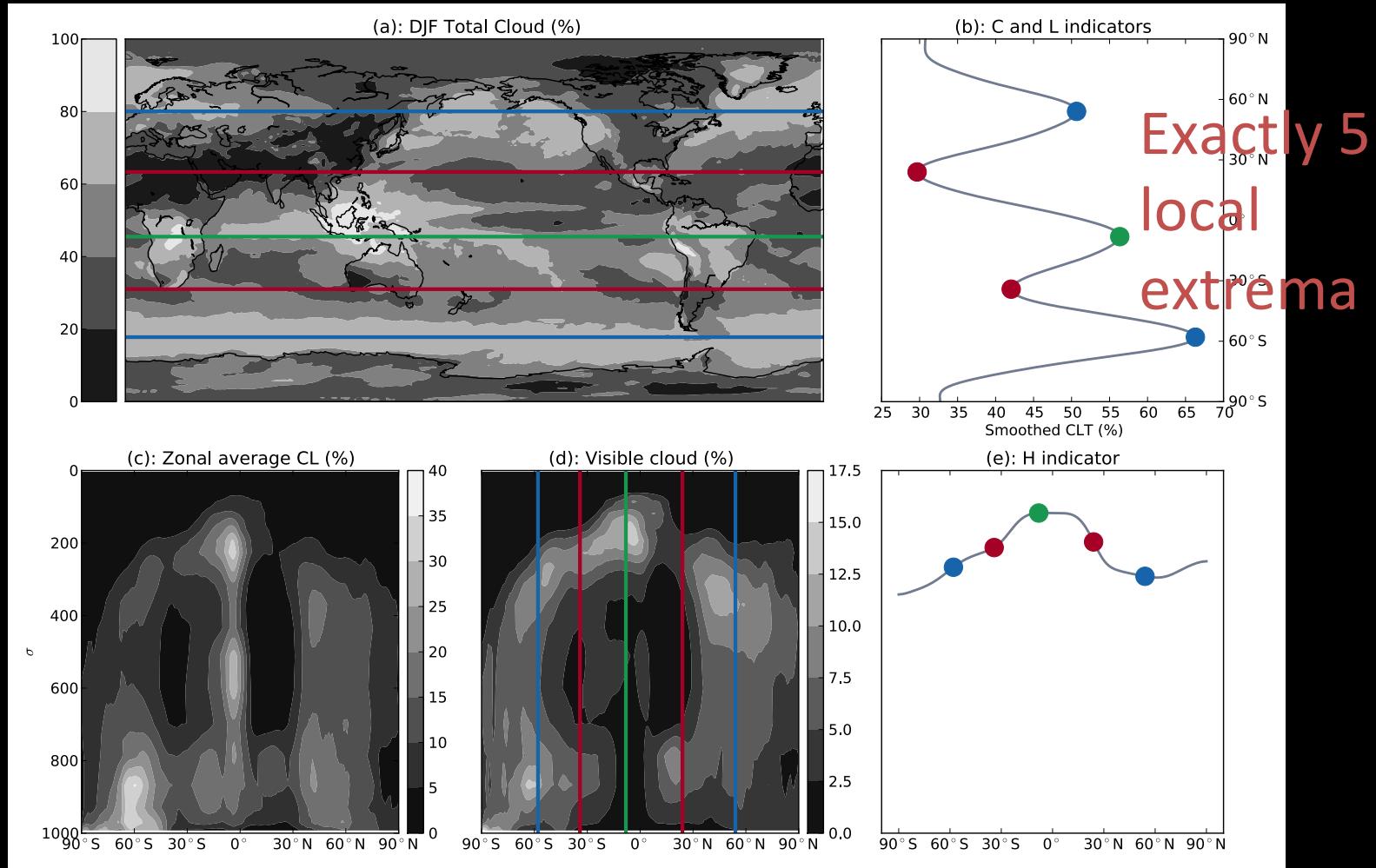
# L,C,H indicators



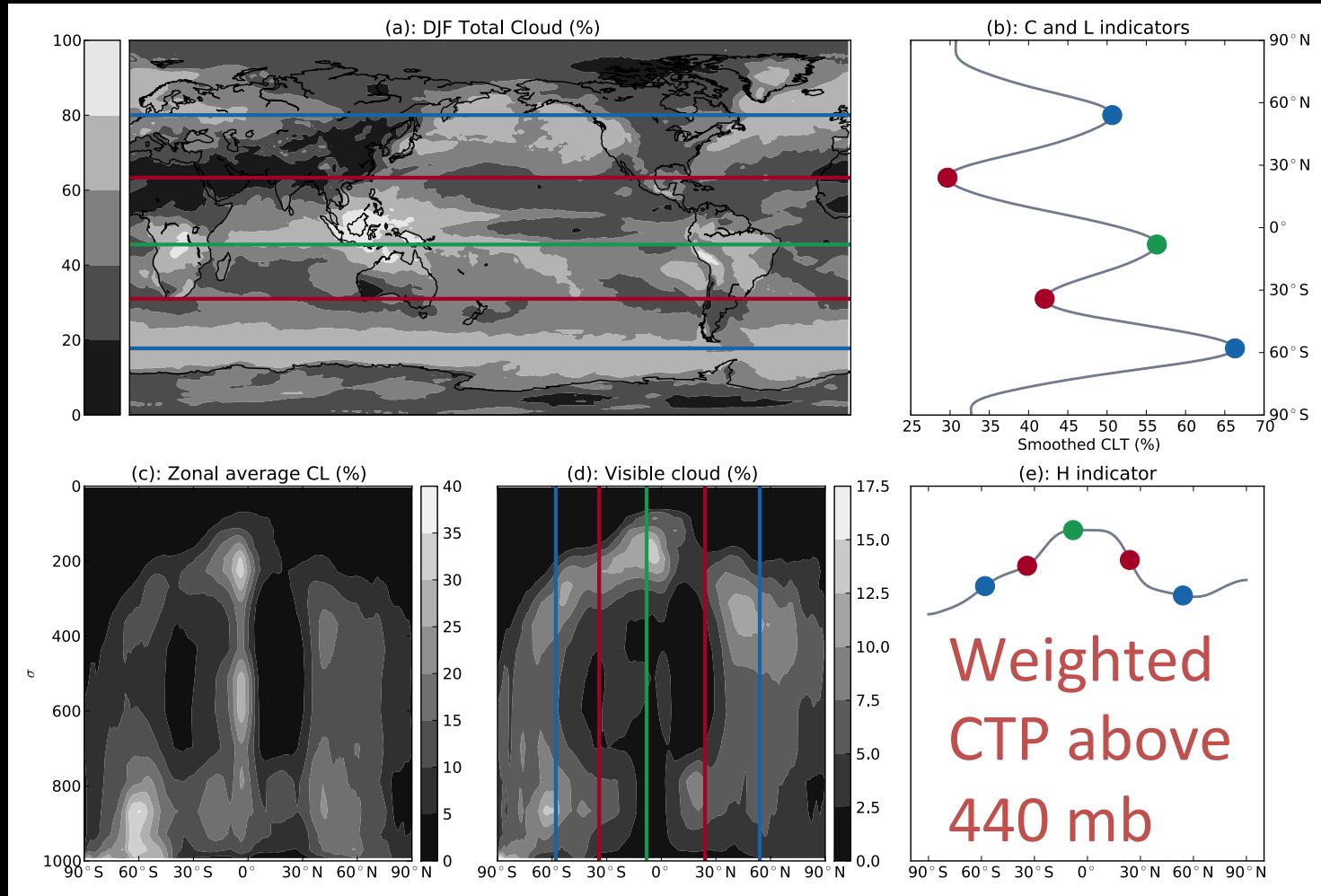
# L,C,H indicators



# L,C,H indicators



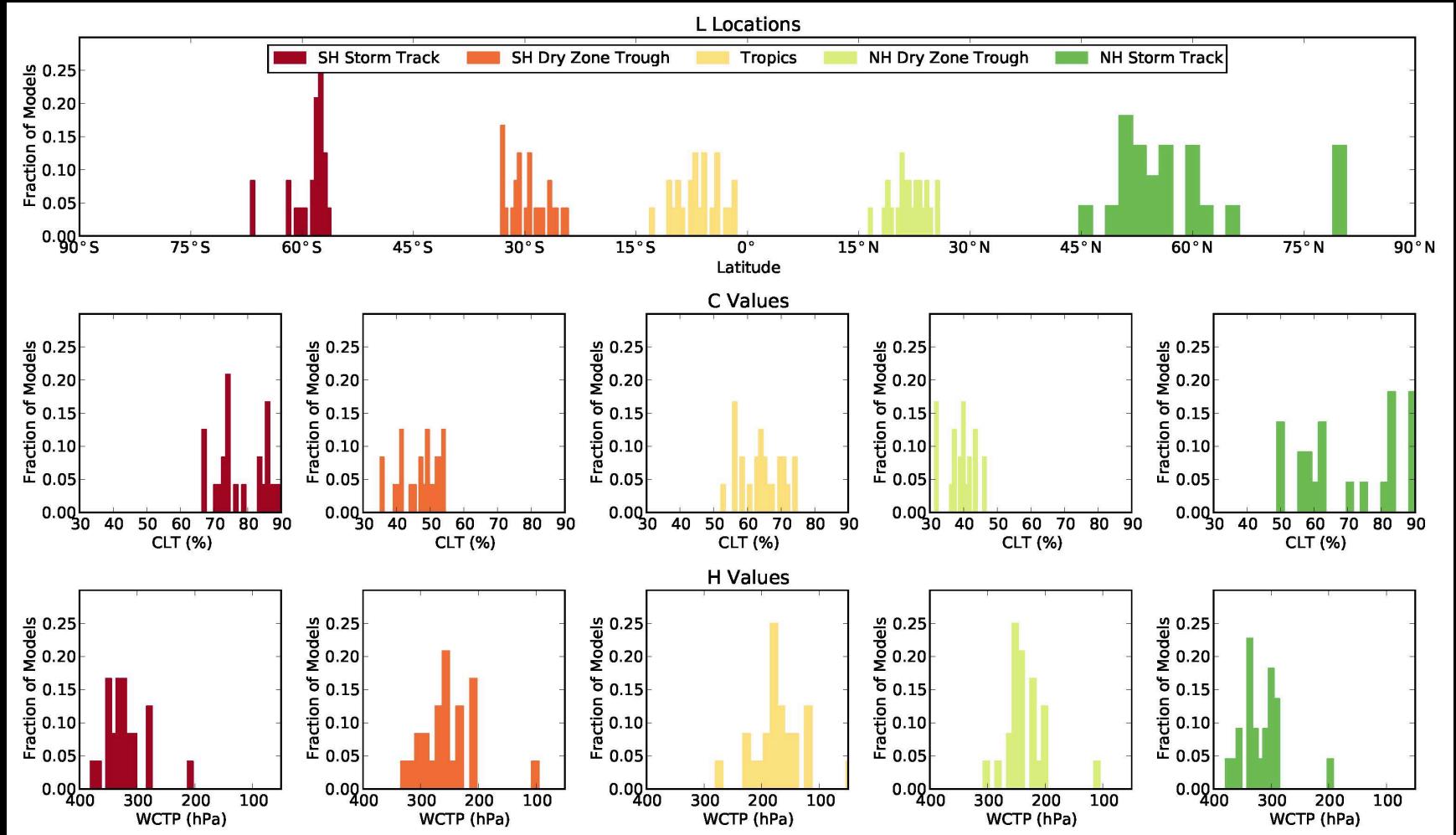
# L,C,H indicators



# L,C,H indicators

- How are the ***locations*** of max/min cloud fraction changing? → “Latitude Indicator”
- How is the ***total cloud fraction*** changing at these locations? → “Cloud Fraction Indicator”
- How is the ***cloud top pressure*** changing at these locations (from 3D CL field)? → “Height Indicator”

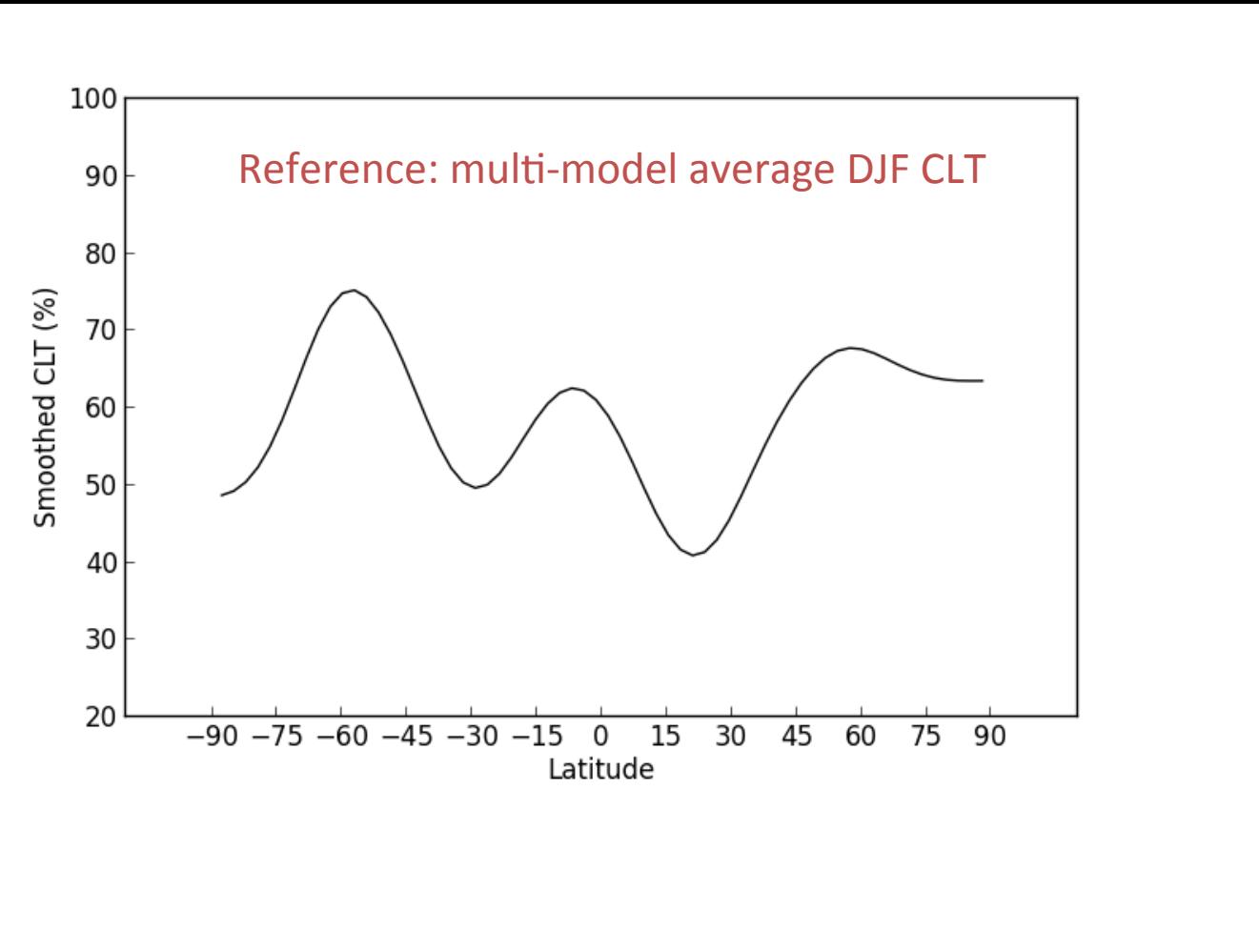
# Anomalies relative to model climatology



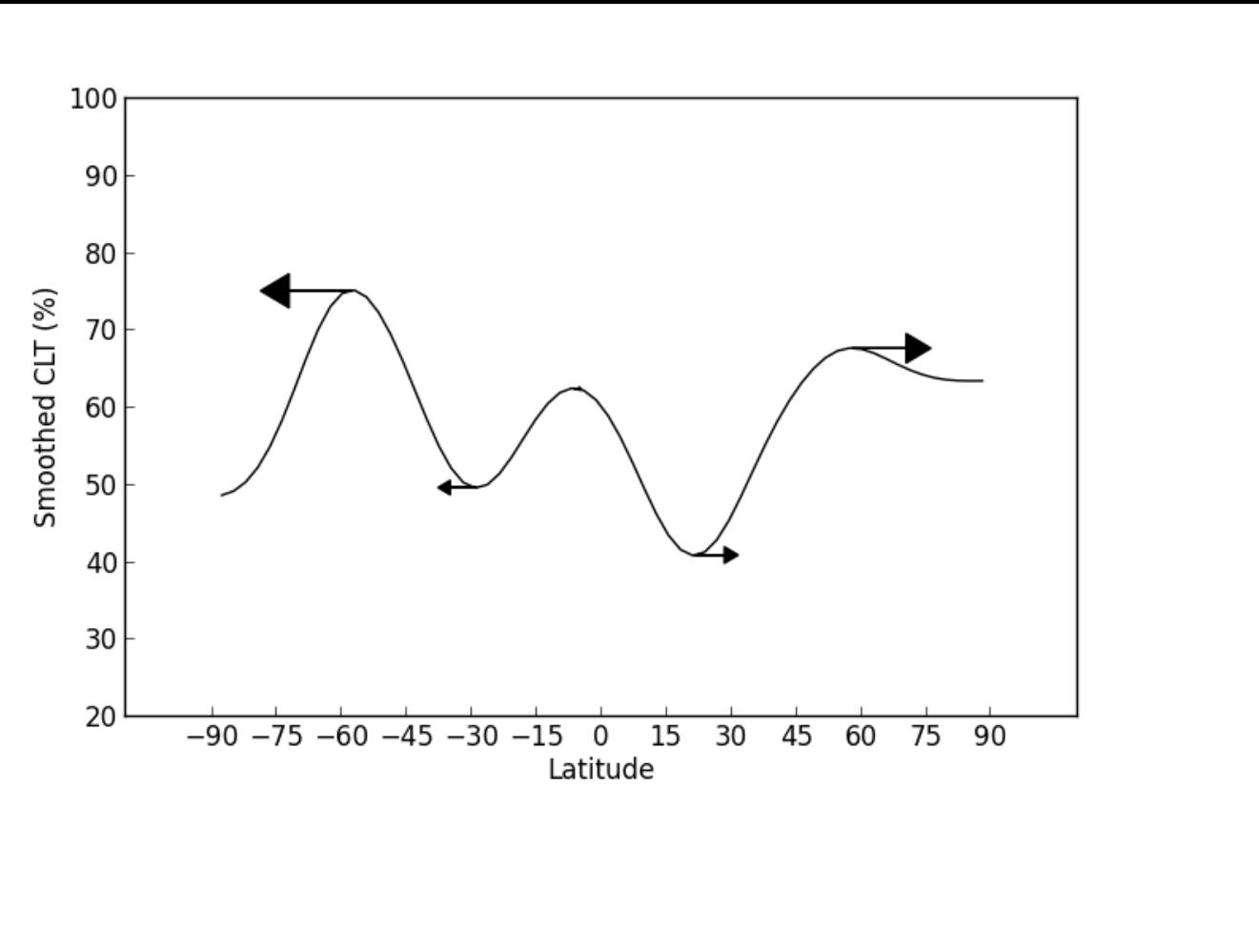
# Multivariate fingerprinting

- Use historical/RCP8.5 experiments 1900-2100
- Take multi-model average to damp internal variability
- Fingerprint is leading EOF of joint covariance matrix of L,C,H
- Explains > 95% of variance

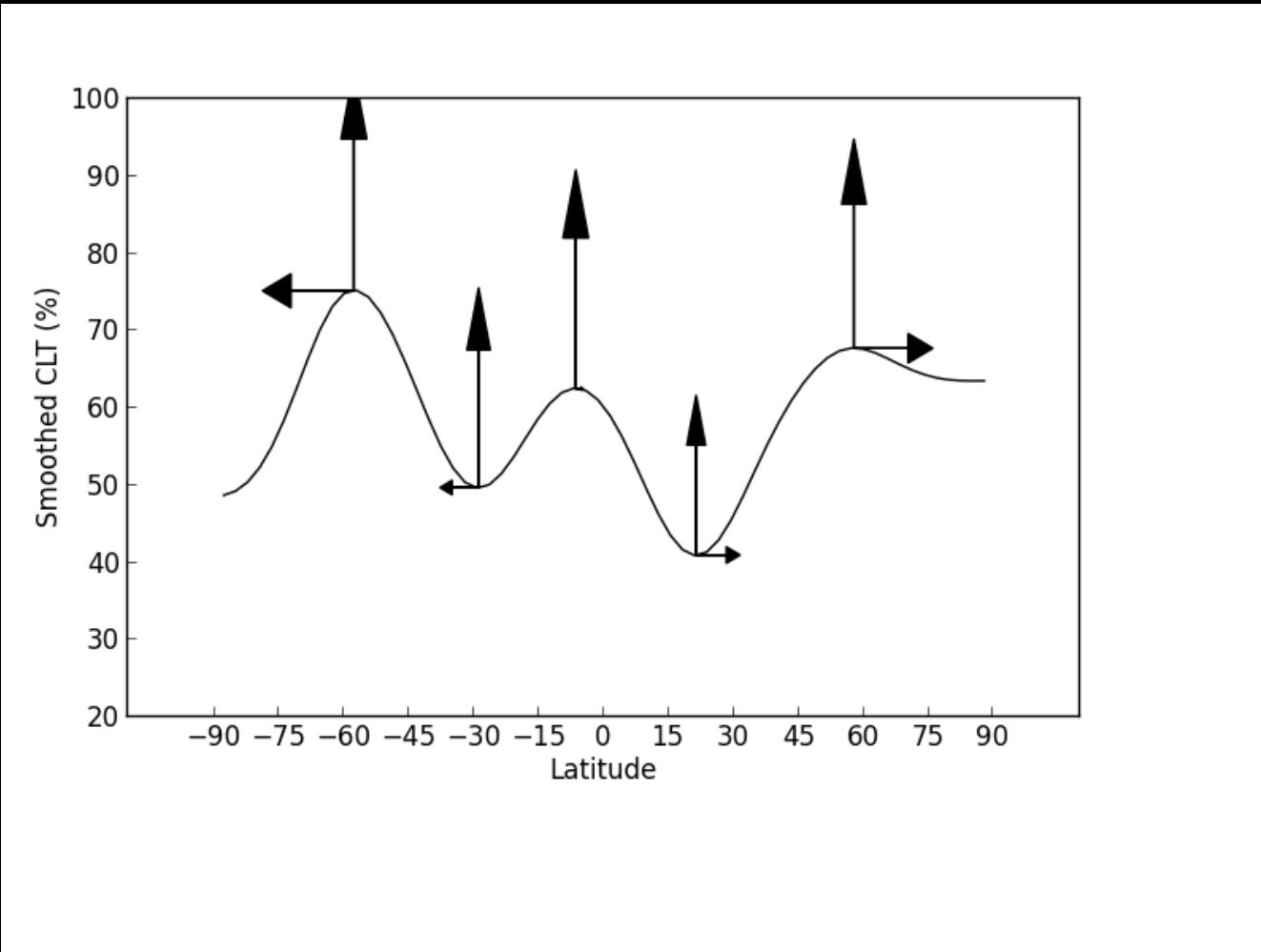
# Multivariate fingerprint



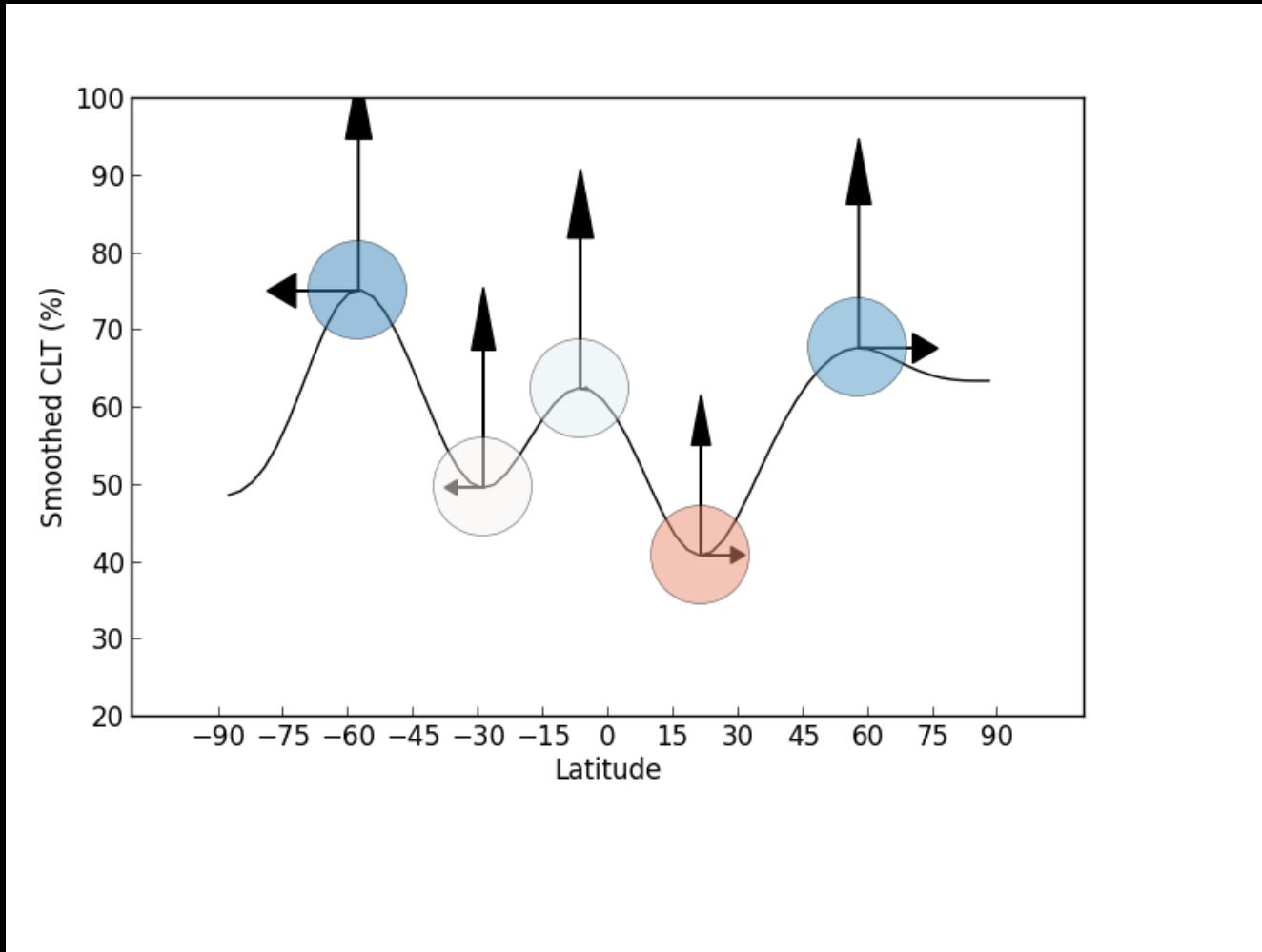
# Multivariate fingerprint



# Multivariate fingerprint



# Multivariate fingerprint



Can we see the signal above the noise?

# DETECTION

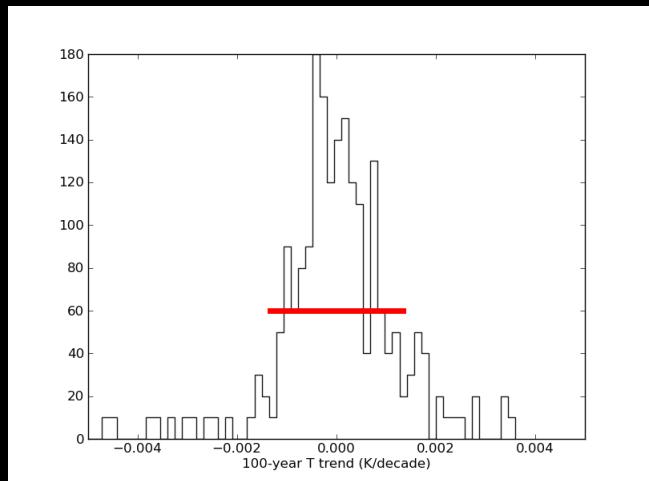
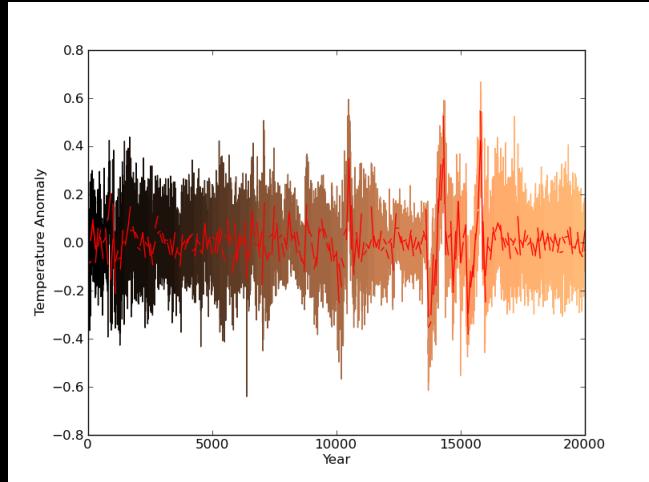
# Signal

- Derive Lobs,Cobs,Hobs indicators from observations
- Project [Lobs,Cobs,Hobs] onto fingerprint
- The signal is the linear trend in the projection time series



# Noise

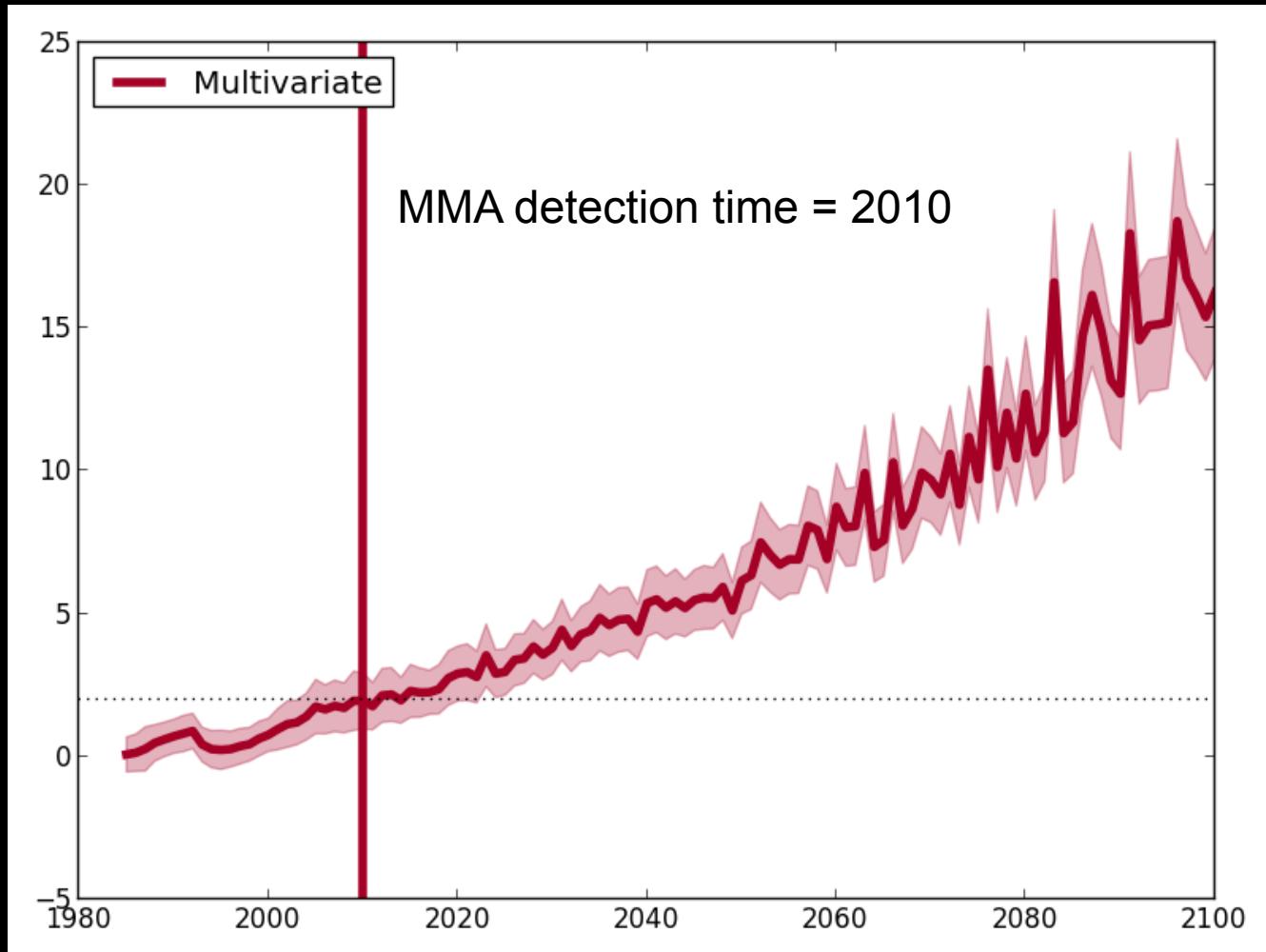
- Get  $L_c$ ,  $C_c$ ,  $H_c$  from concatenated pre-industrial control runs
- Project onto fingerprint
- Calculate trends in non-overlapping segments
- Noise term = width of distribution



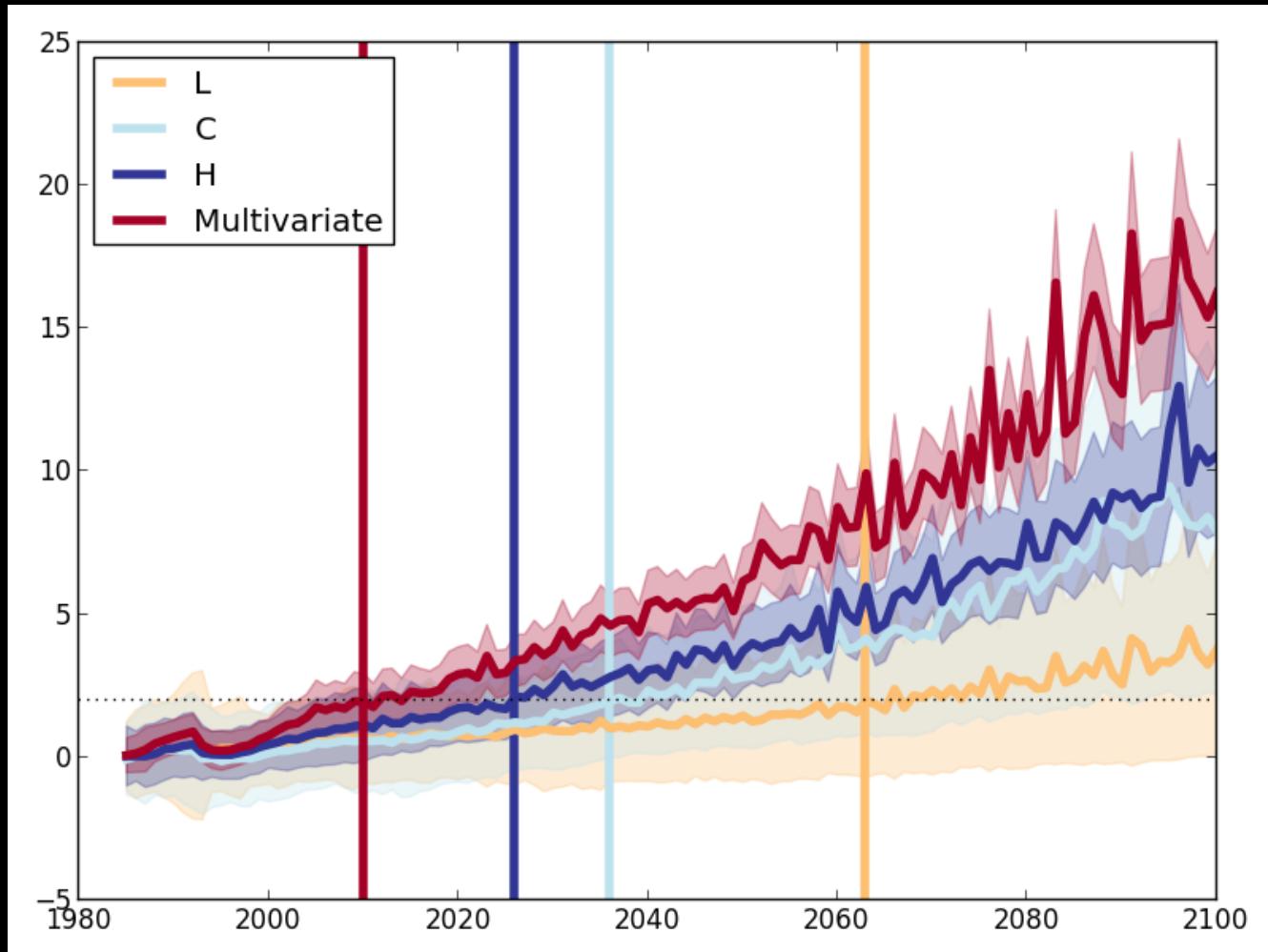
# Signal-to-noise

- When SN ratio  $> 1.96$ , signal is detectable at 95% confidence.
- Satellite datasets begin in the mid-1980s
- Is it reasonable to start looking for a detectable signal? If not, how long must we wait?

# Multivariate S/N



# Univariate S/N



# Detection time

- Models predict the multivariate signal to be detectable NOW
- Univariate signals are weaker; models say they aren't detectable yet
- Rising high clouds produce the strongest signal in CMIP5 models
- Poleward expansion of subtropical clear zones and midlatitude storm tracks produces the weakest signal



Confronting the models

# OBSERVATIONS

# Observations

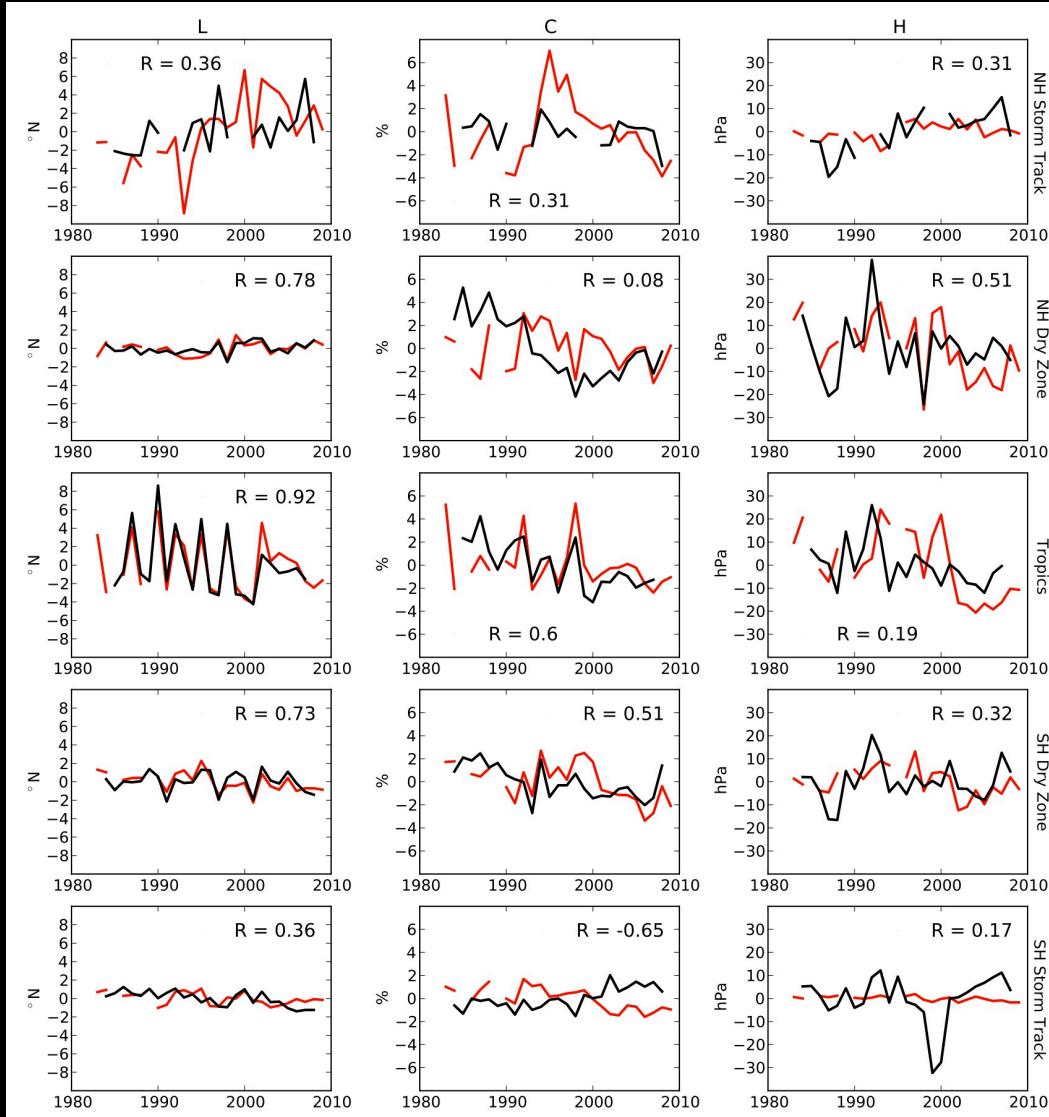


**PATMOS-x**

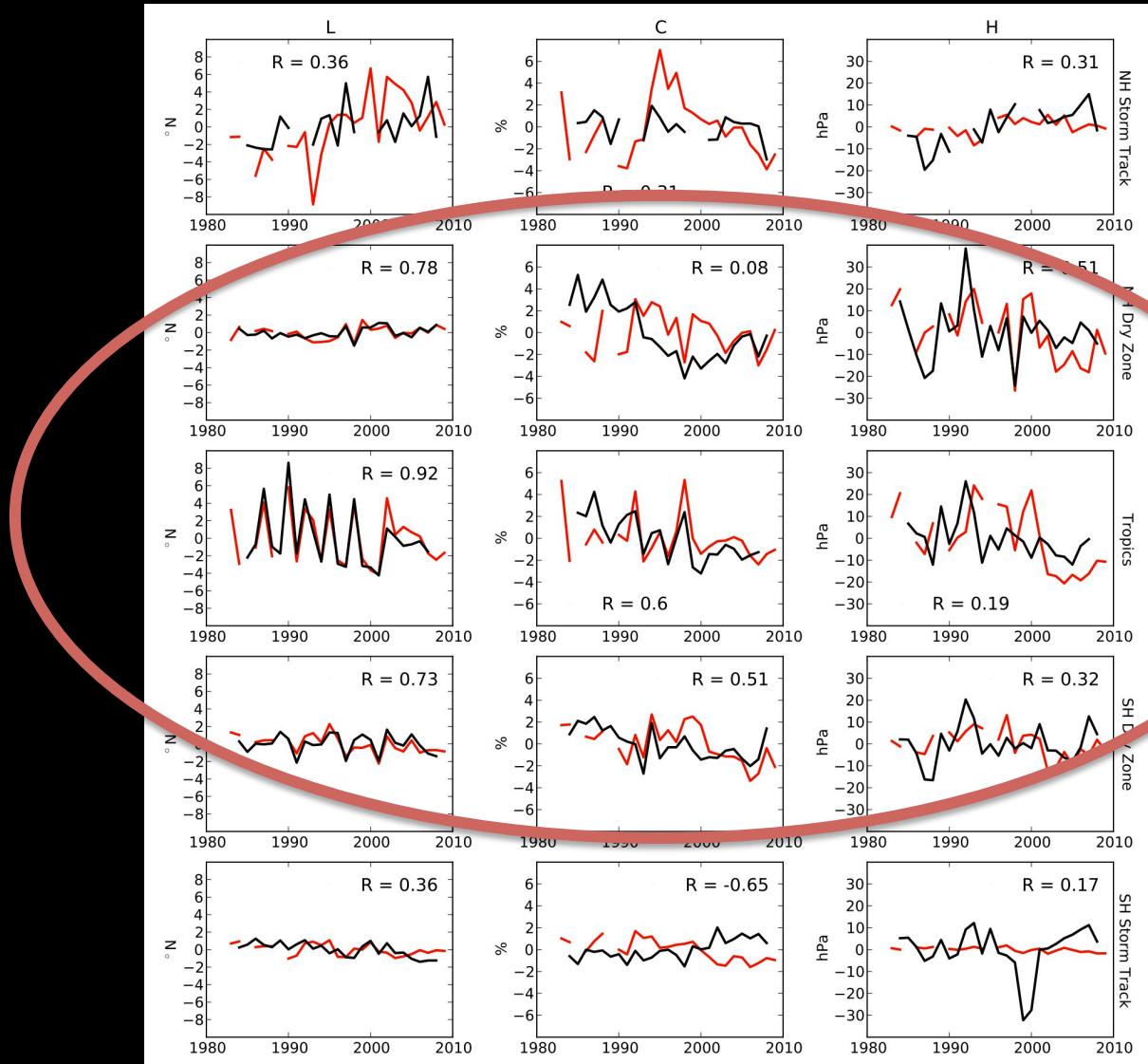
*Pathfinder Atmospheres - Extended*

- International Satellite Cloud Climatology Project (**ISCCP**)
  - GCM simulator-oriented ISCCP cloud product
  - July 1983-June 2008
- Pathfinder Atmospheres Extended (**PATMOS-x**)
  - GEWEX Cloud Assessment
  - January 1982-December 2009

# Lobs, Cobs, Hobs

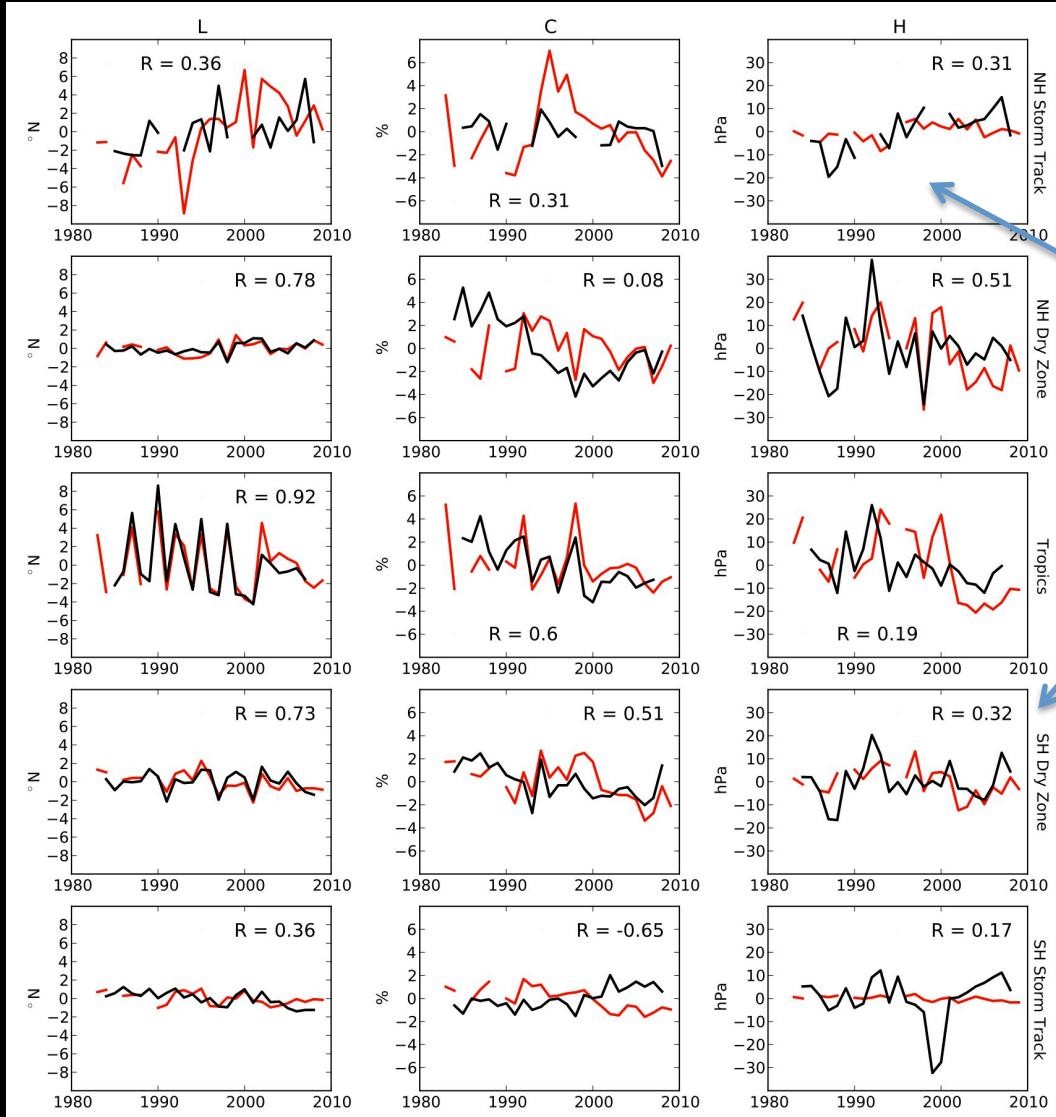


# Lobs, Cobs, Hobs



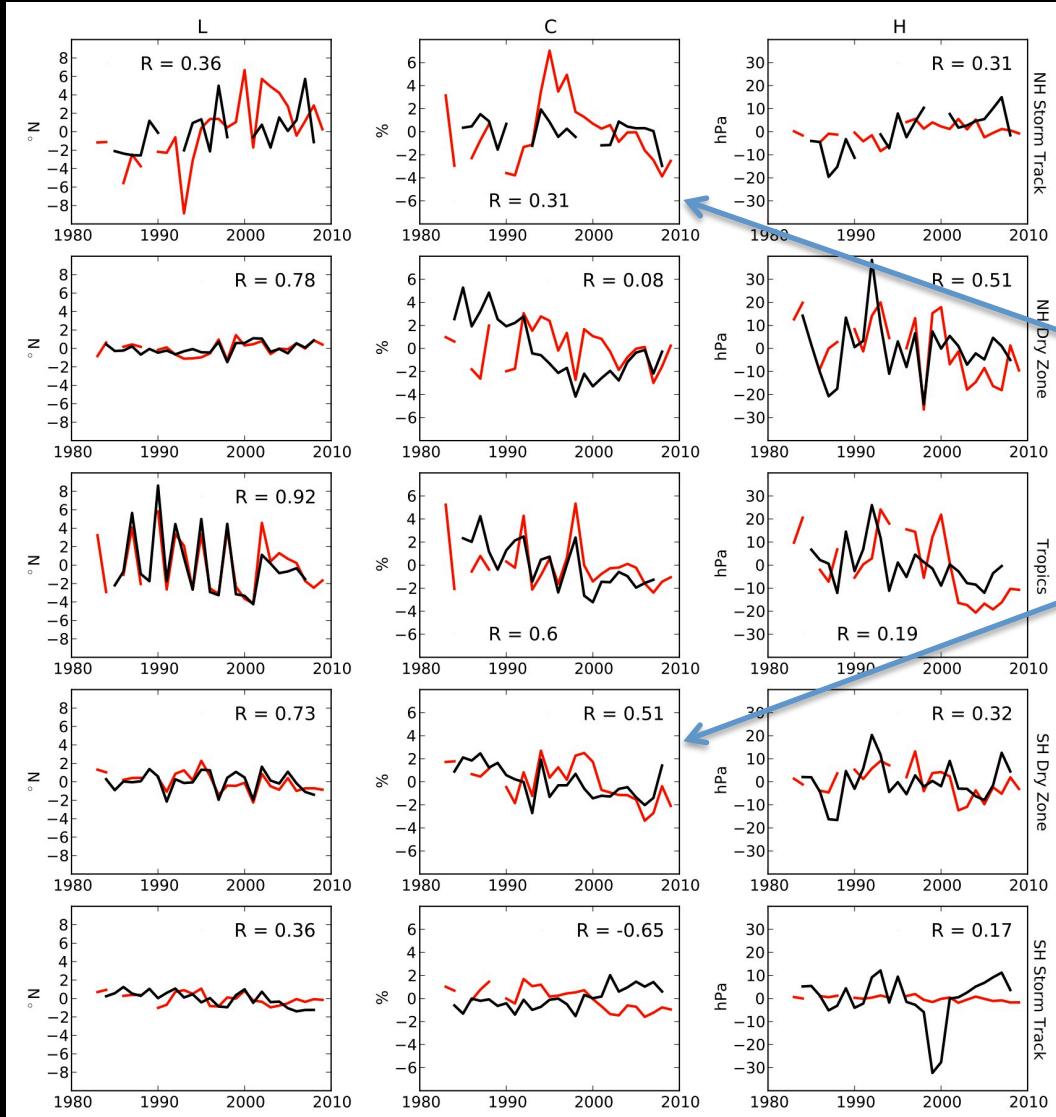
Agreement is  
better in tropics/  
subtropics

# Lobs, Cobs, Hobs



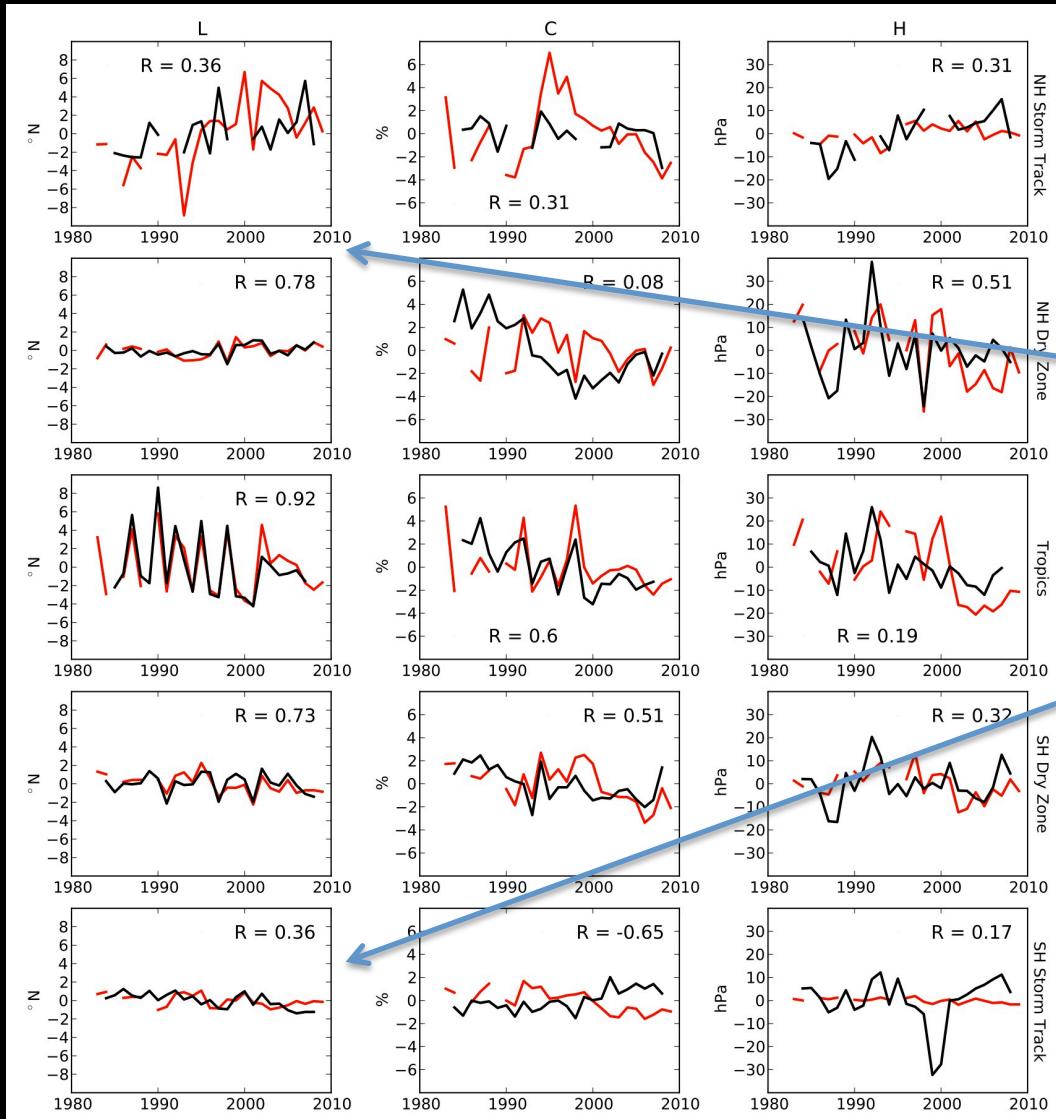
Obs disagree  
on high CTP

# Lobs, Cobs, Hobs



Obs disagree  
on cloud  
amount

# Lobs, Cobs, Hobs

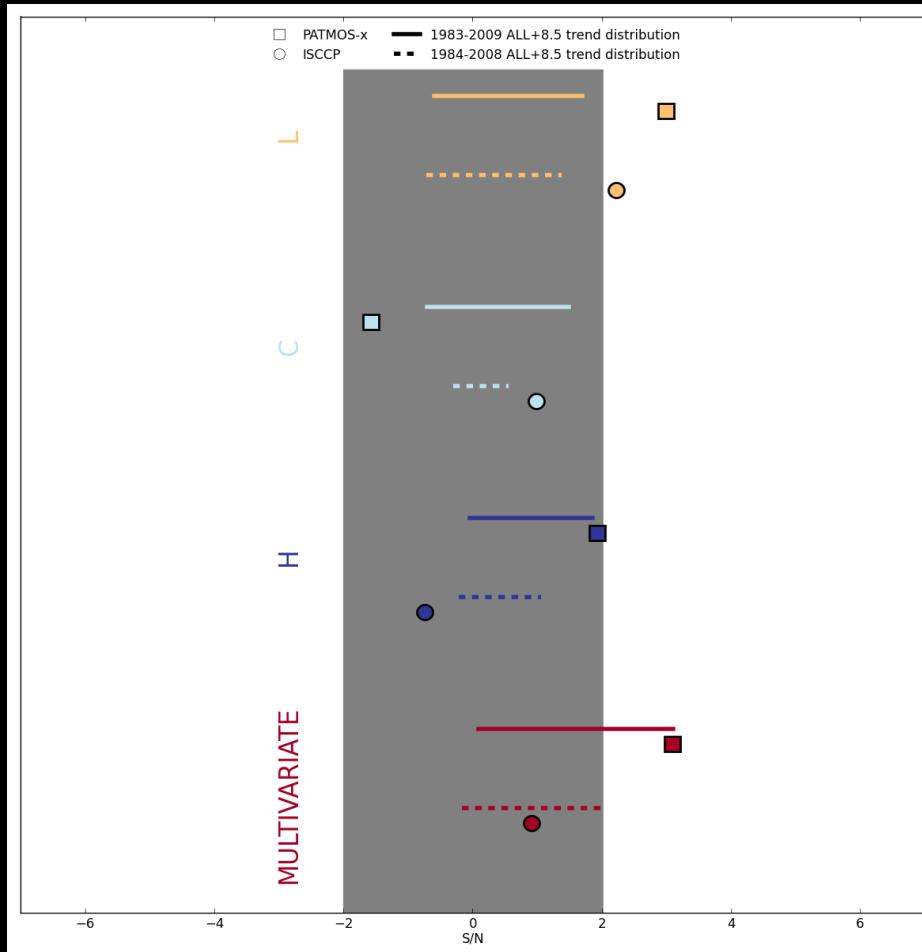


Obs agree on  
the locations  
of cloudy  
and clear  
regions

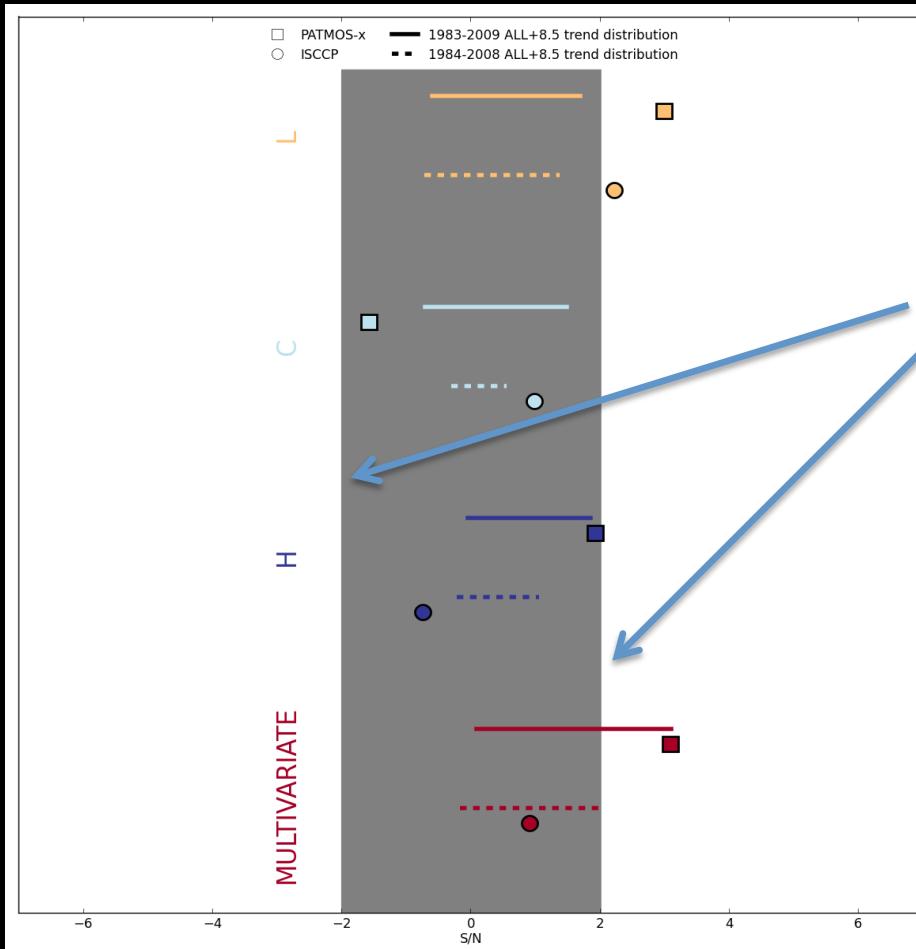
# Detection and attribution

- Calculate 25-year (ISCCP) or 27-year (PATMOS-x) trends in projection time series
- For **detection**: calculate distribution of 25- or 27-year non-overlapping piControl trends
- For **attribution**: calculate historical/RCP8.5 model trends over 1984-2008 (ISCCP) or 1983-2009 (PATMOS-x)
- Normalize all trends by standard error of piControl 25 or 27-year trend distribution

# Signal-to-noise

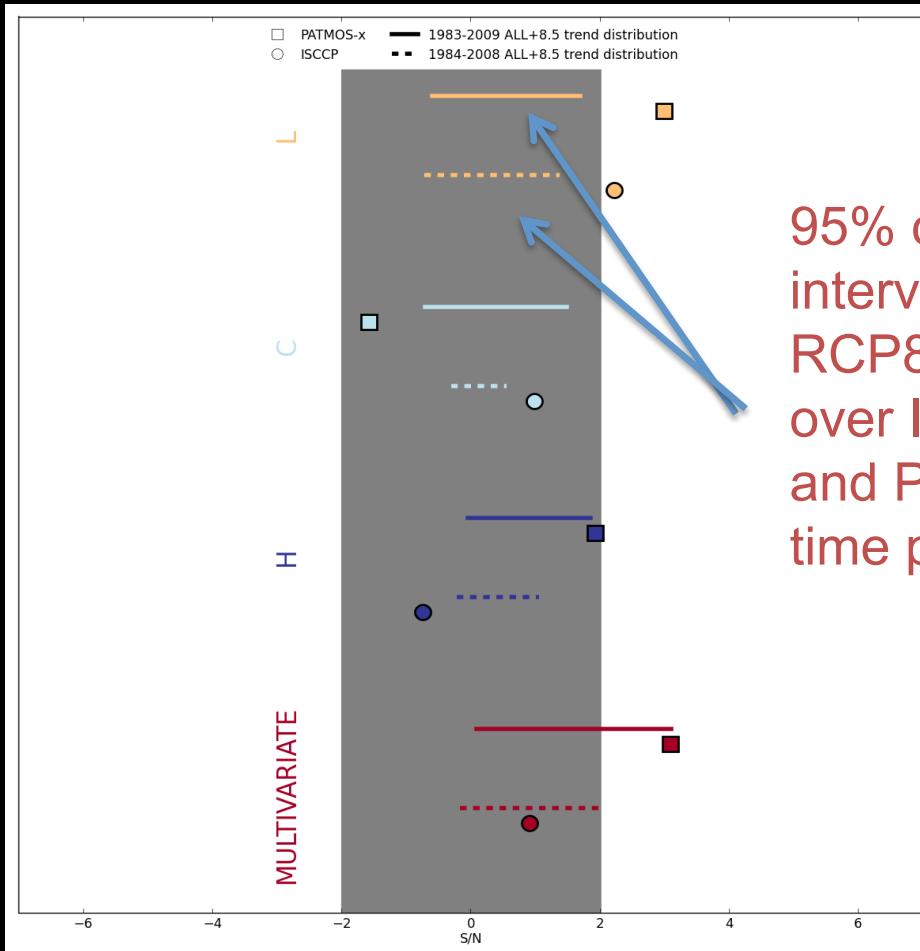


# Signal-to-noise



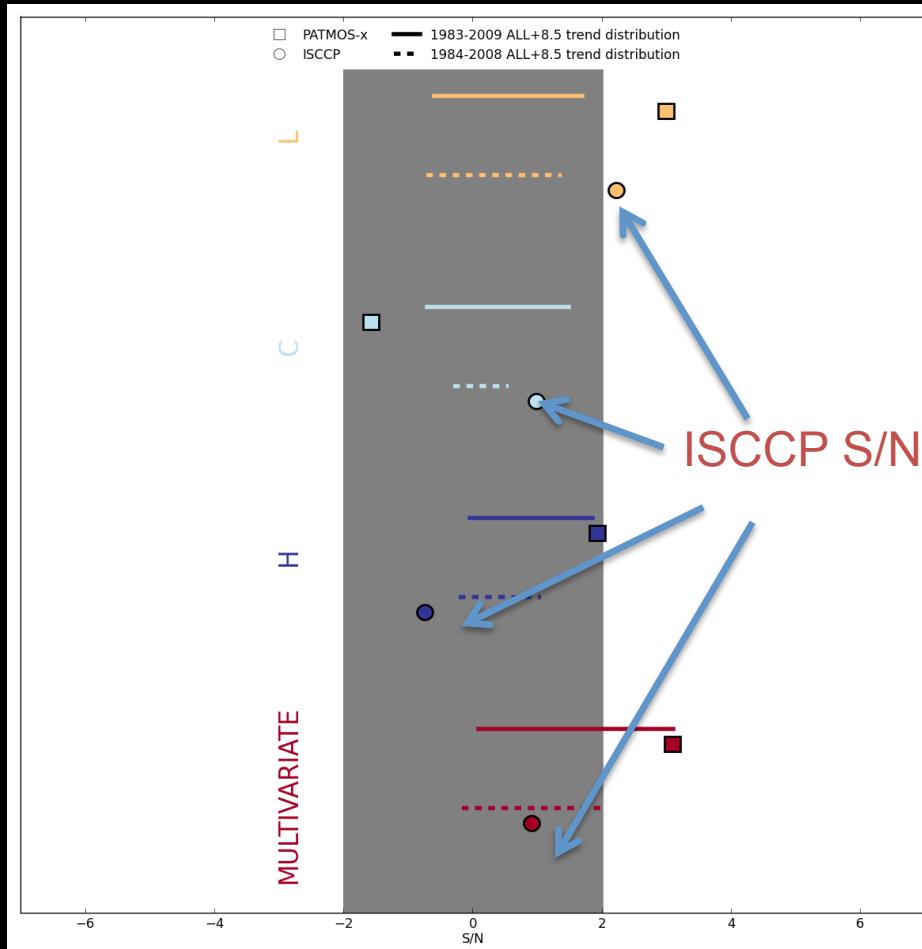
95% confidence  
interval for noise

# Signal-to-noise

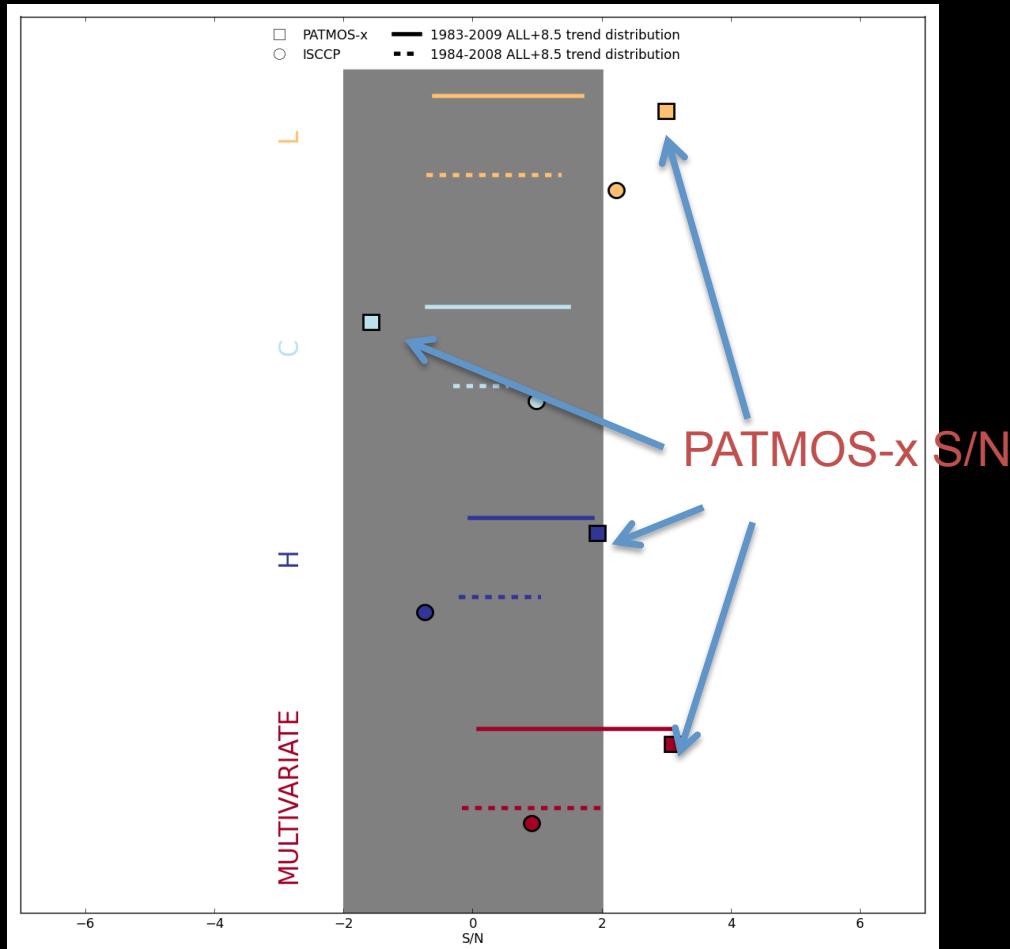


95% confidence intervals for historical/RCP8.5 model trends over ISCCP (dashed) and PATMOS-x (solid) time periods

# Signal-to-noise



# Signal-to-noise



# Results

- Both observational datasets show detectable signals in the L indicator alone (poleward expansion, eg Bender 2008). These signals are incompatible with model trends (see Qu and Johanssen, Min and Song, Allan et al).
- ISCCP shows a strong C signal- may be spurious and attributable to satellite view angle
- Both datasets show positive multivariate signal
- In PATMOS-x, this is **DETECTABLE** at 95% confidence and compatible (just) with forced models.

# Next steps

- Repeat with artifact-corrected datasets (Norris and Evan 2015)
- Focus on L indicator to investigate detectable, non-attributable poleward shift in clouds
- Beyond DJF: other seasons, changes in seasonal cycle
- Fingerprinting with CMIP5 single-forcing experiments
- Sensitivity and signal: are stronger signals associated with higher TCR/ECS?

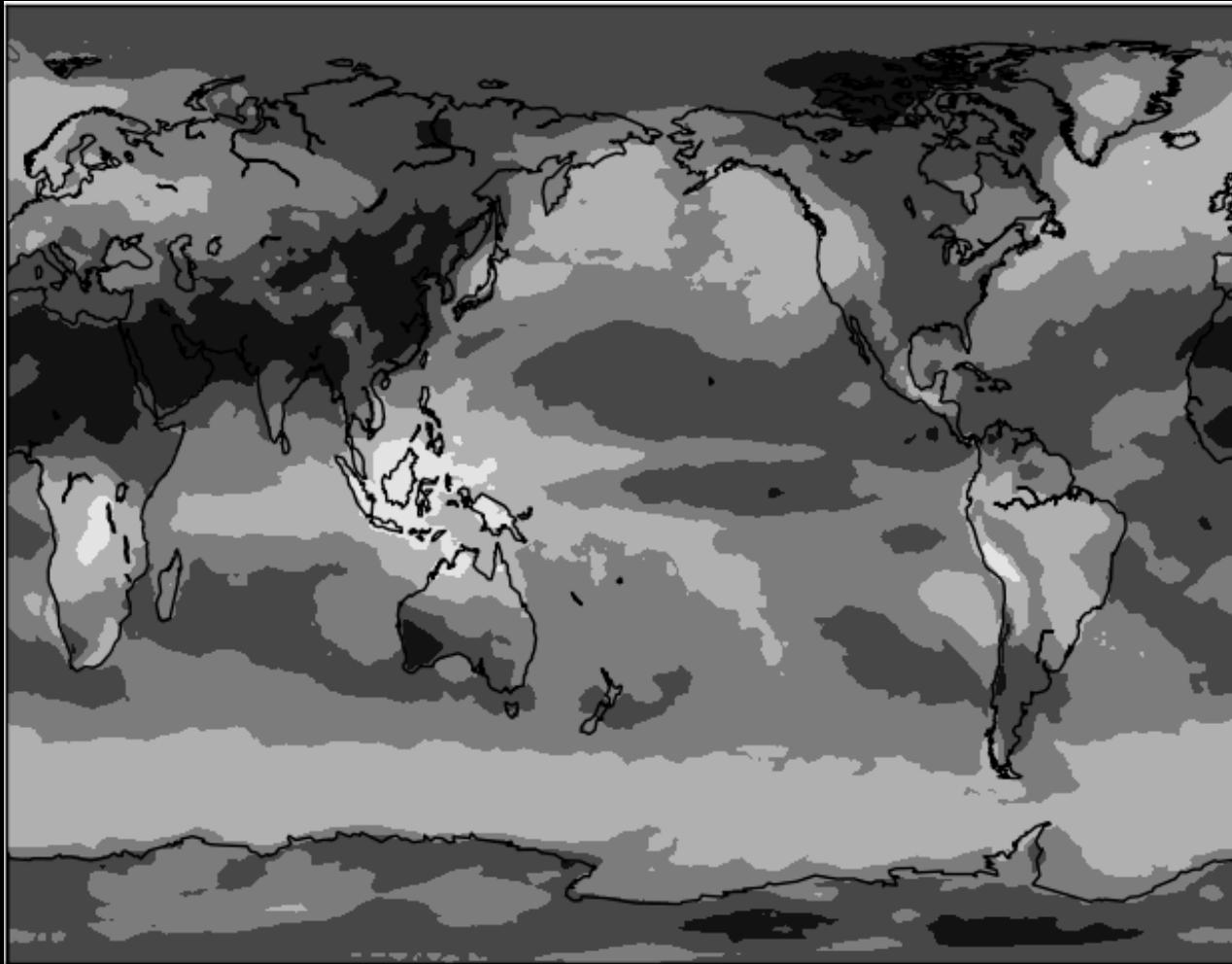
# Conclusions

- Robust cloud fingerprints emerge from the CMIP5 multimodel average
- Considering multiple coherent processes leads to a larger signal-to-noise ratio and shorter detection time
- Observational uncertainty is large, but datasets both show large poleward shifts

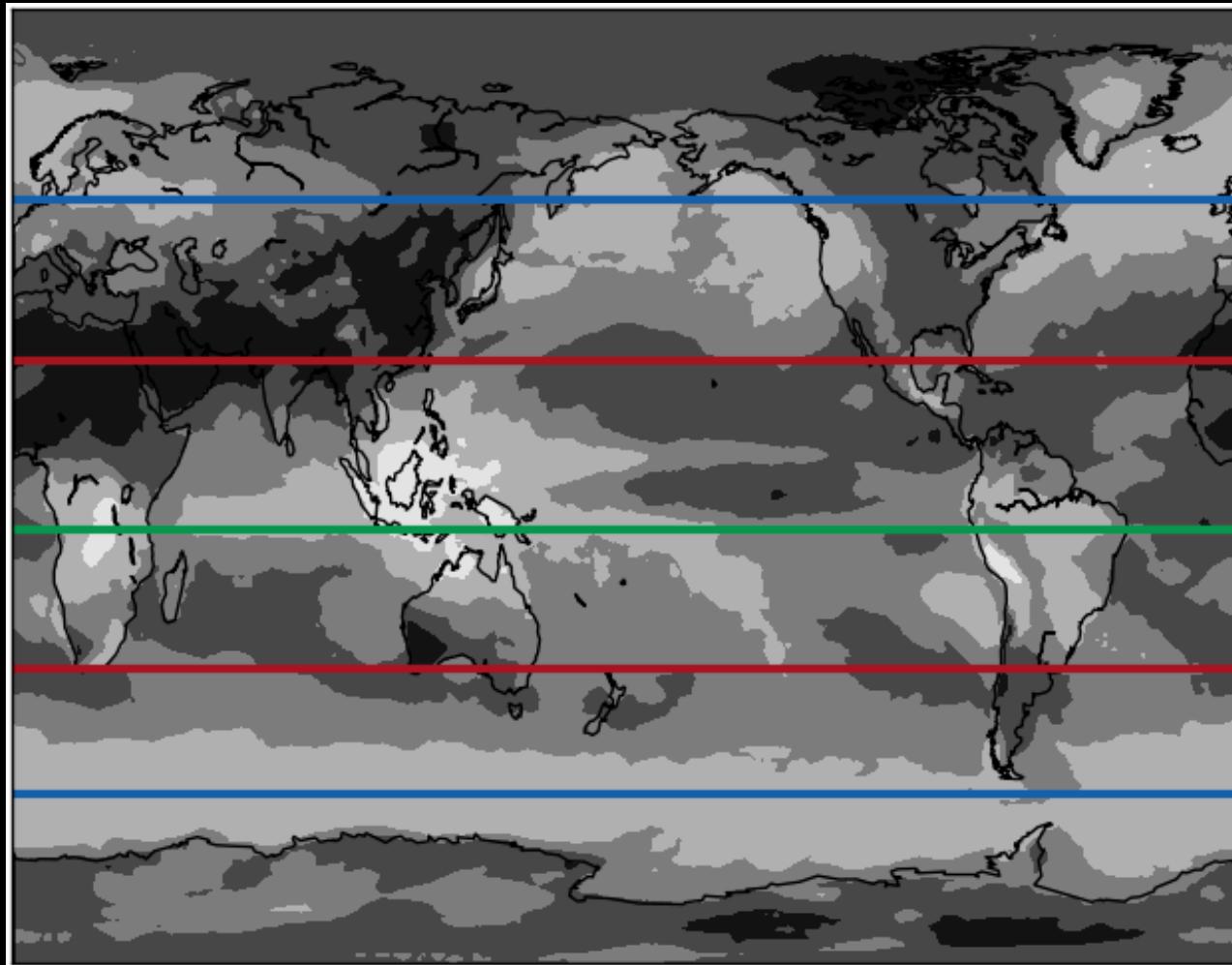
Extra slides

# HOW TO CALCULATE INDICES

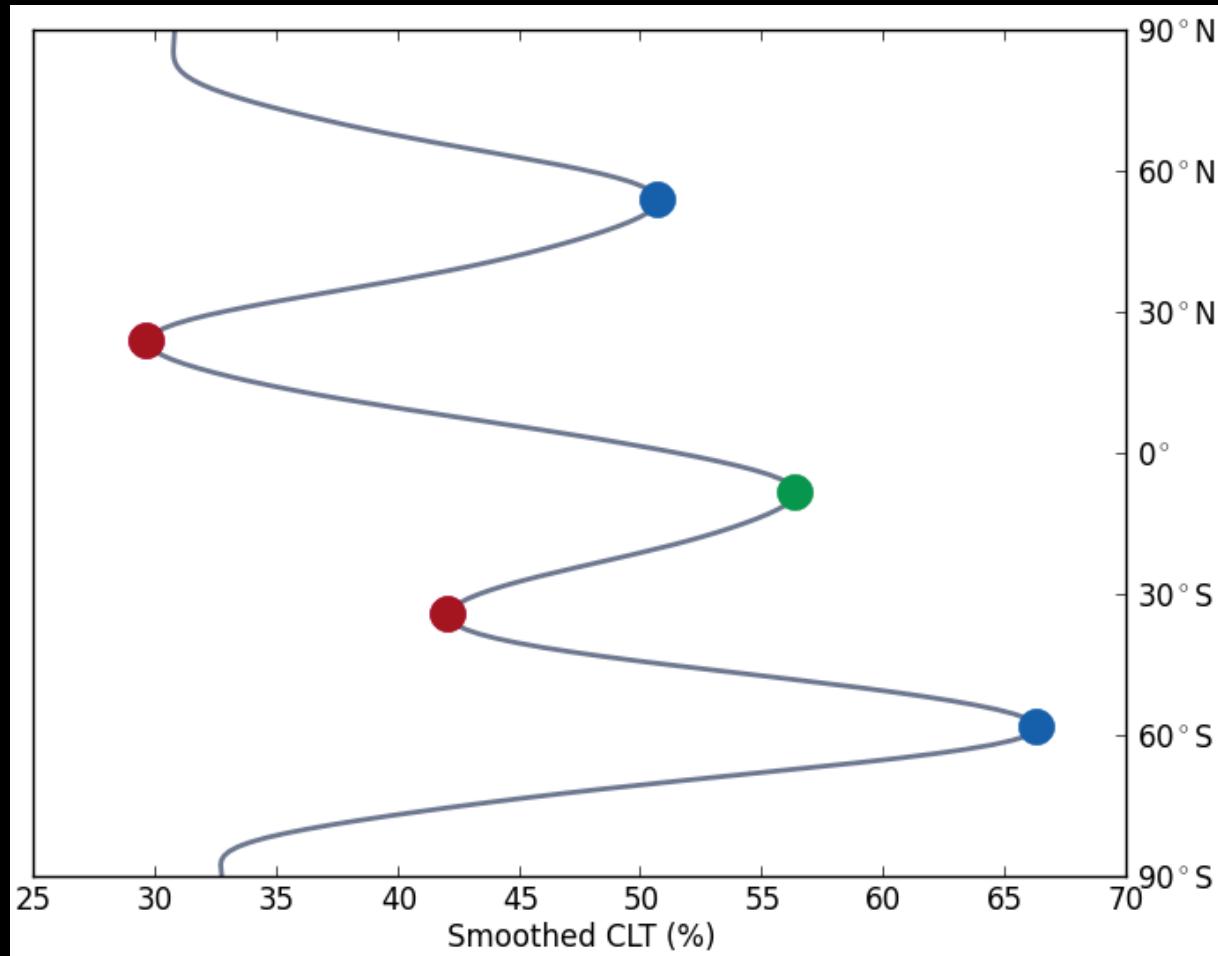
# DJF total cloud fraction



# DJF total cloud fraction

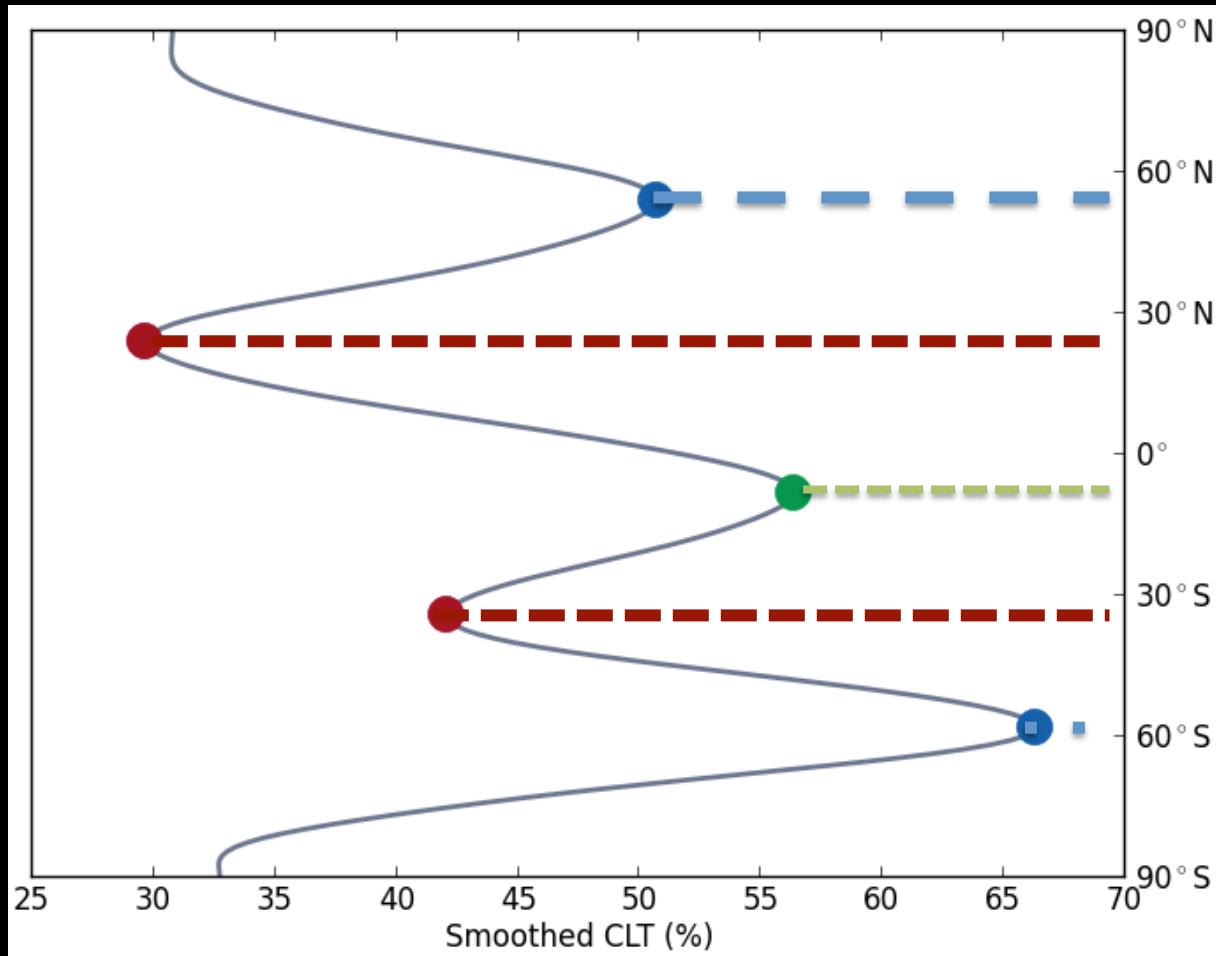


# Exactly 5 local extrema



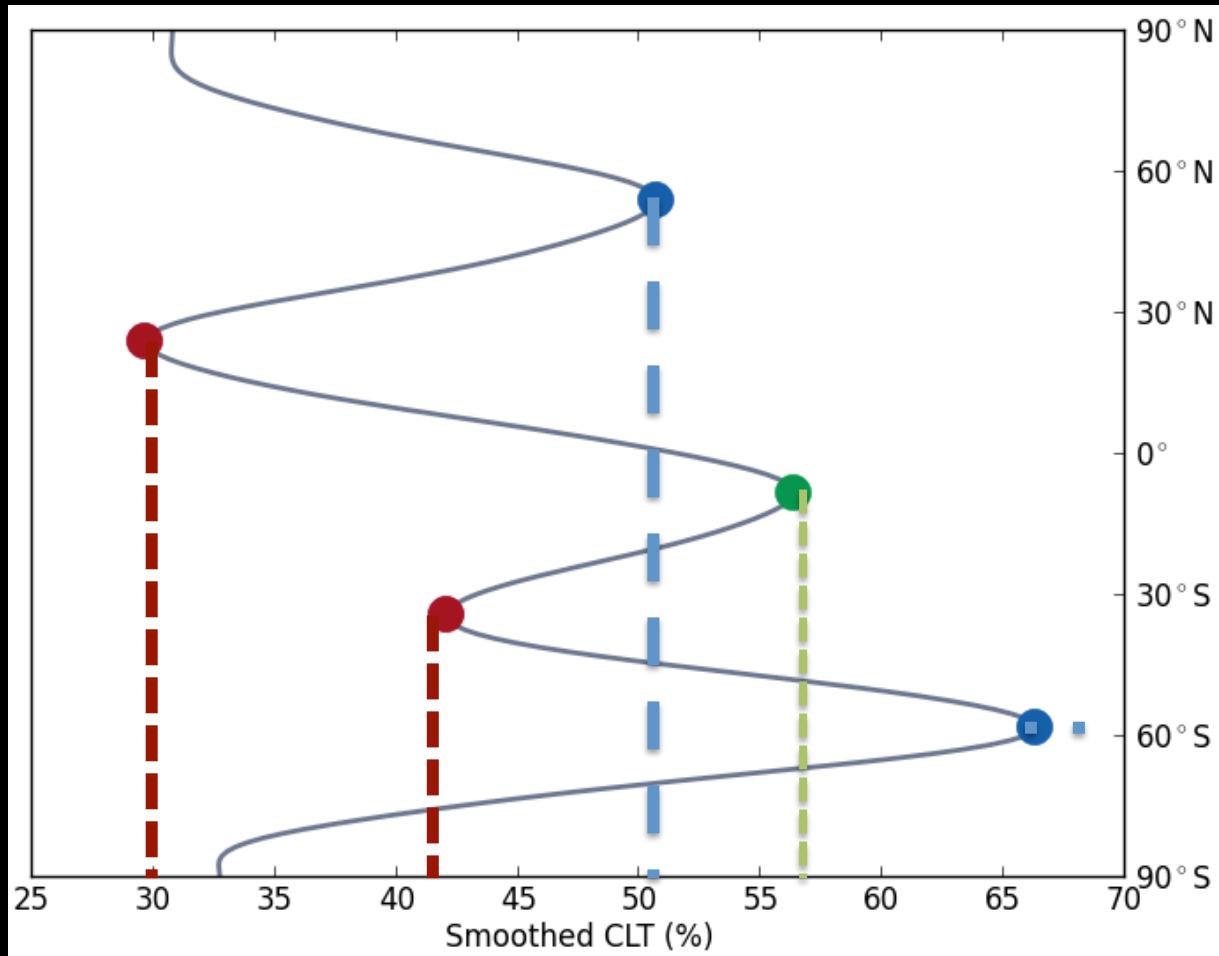
# L and C indicators

L: where are the cloudiest/clearest latitudes?

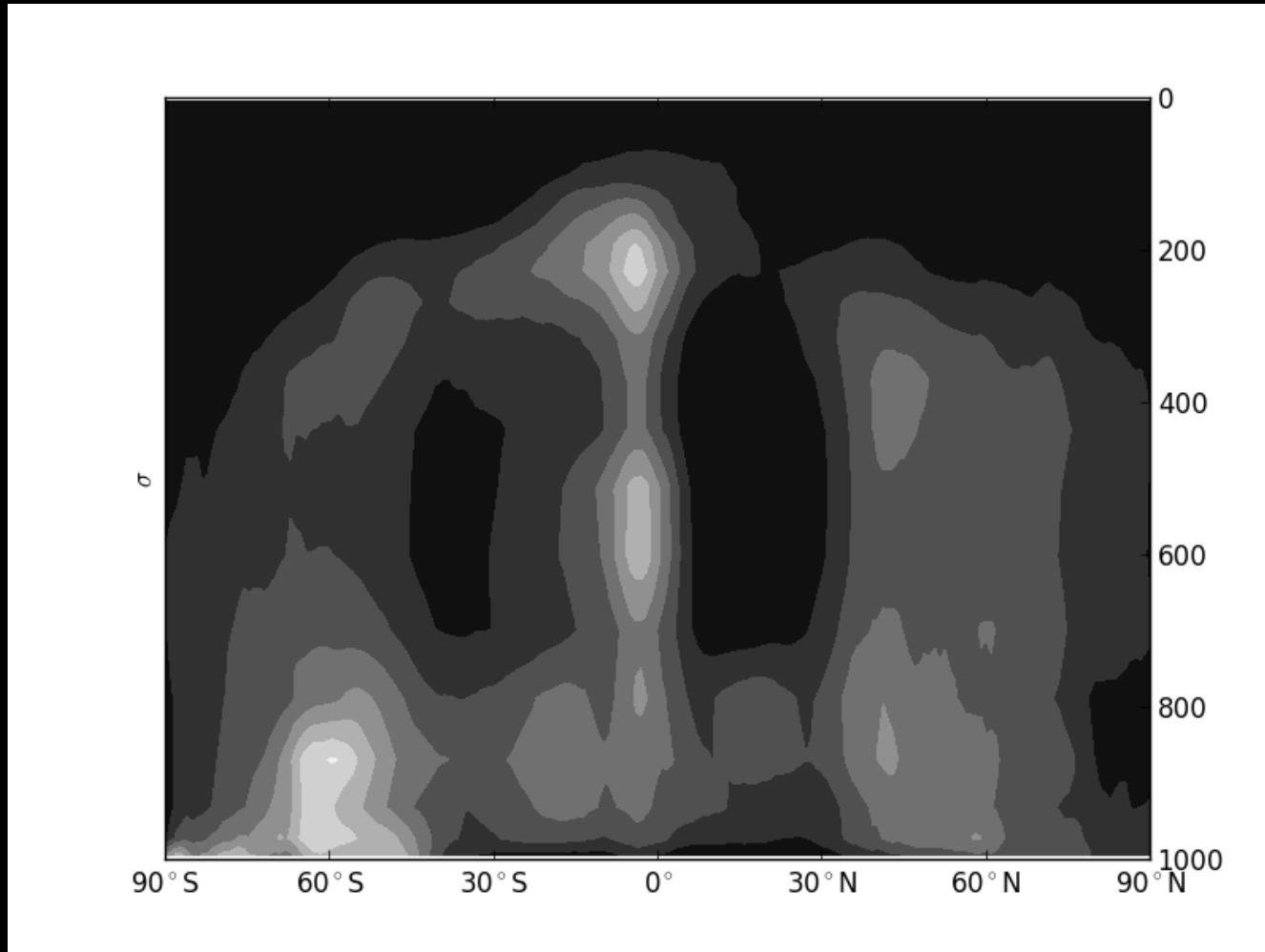


# L and C indicators

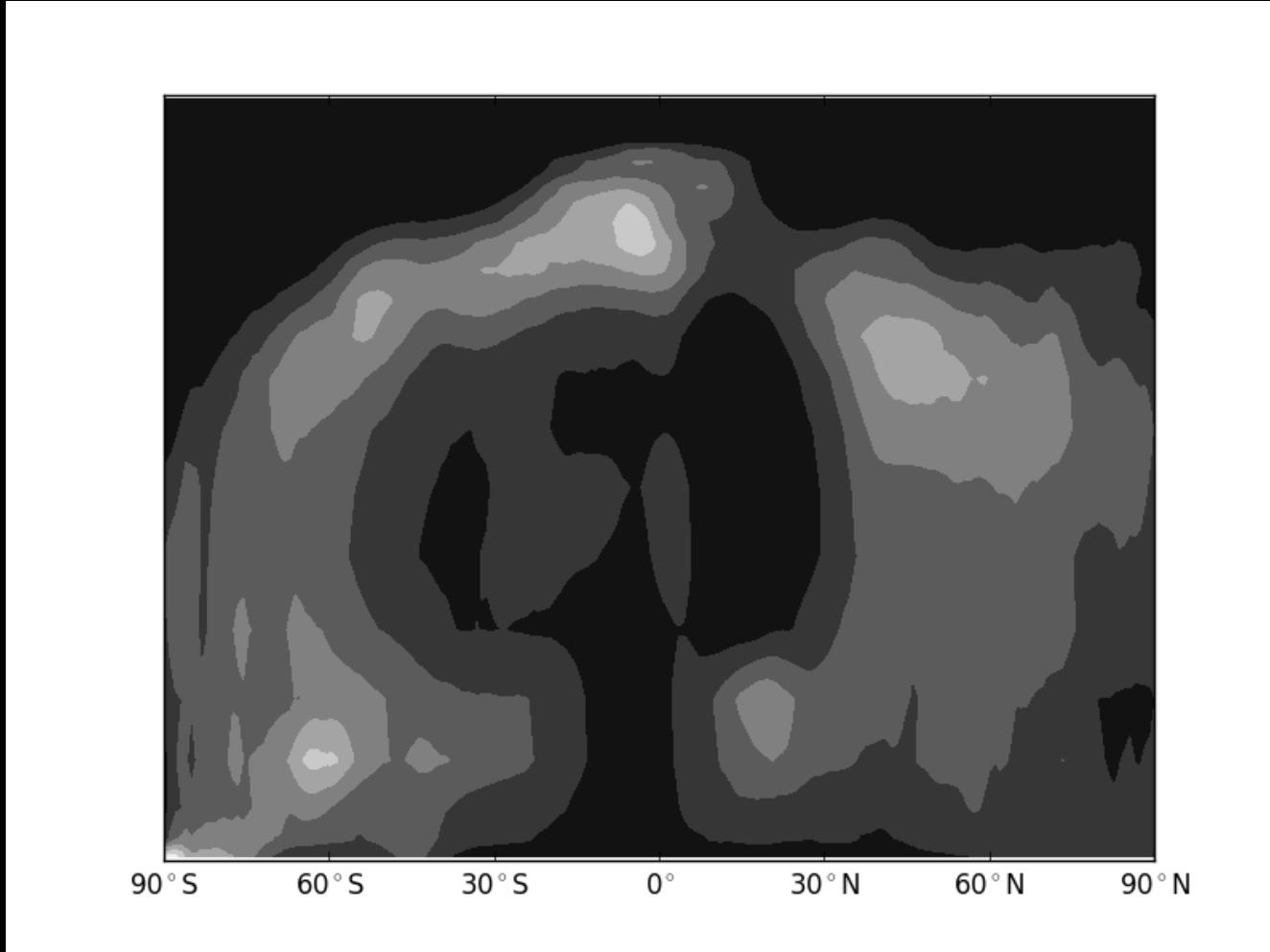
C: how cloudy are the cloudiest/clearest latitudes?



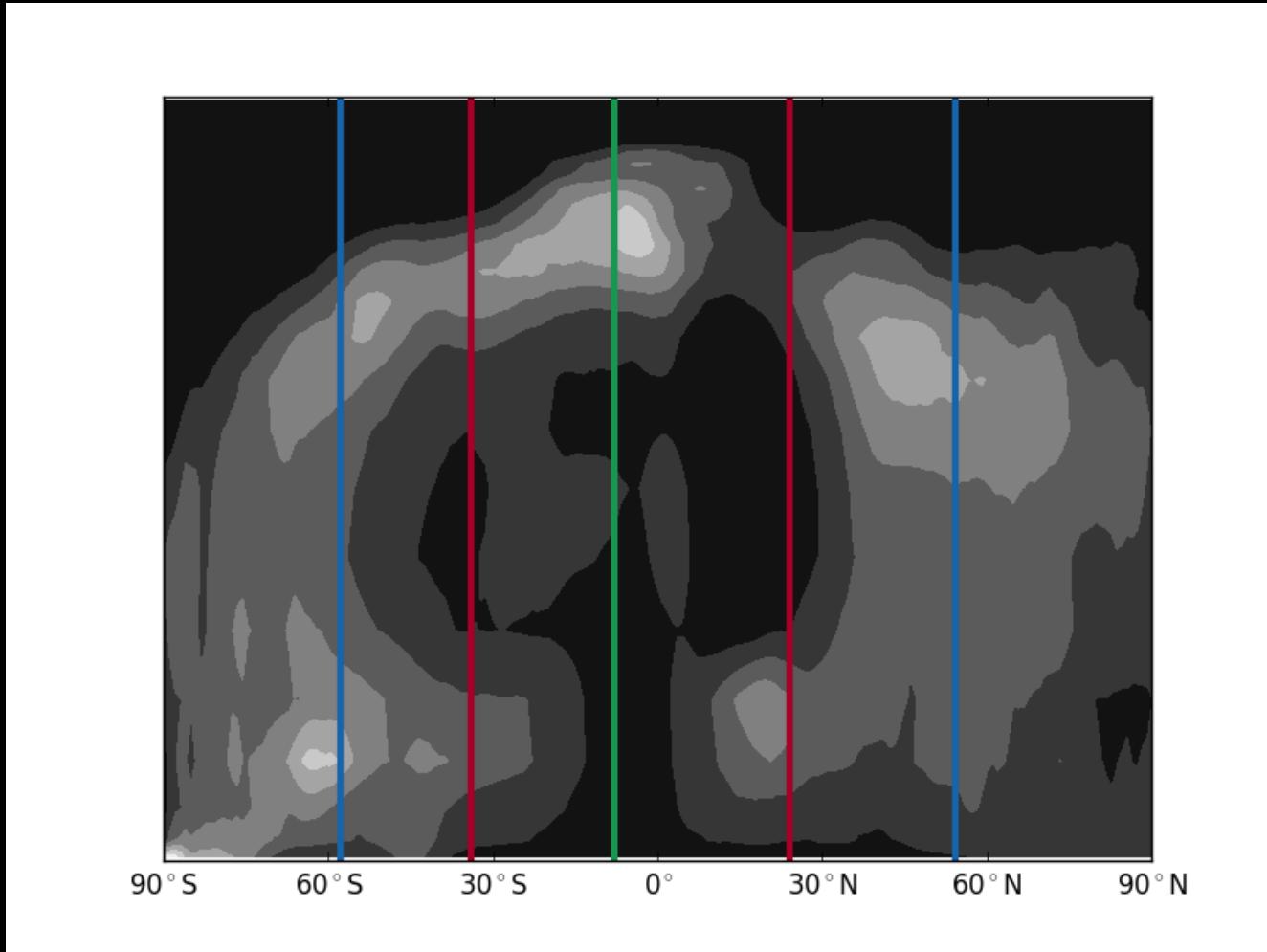
# DJF Cloud Fraction on Model Layers



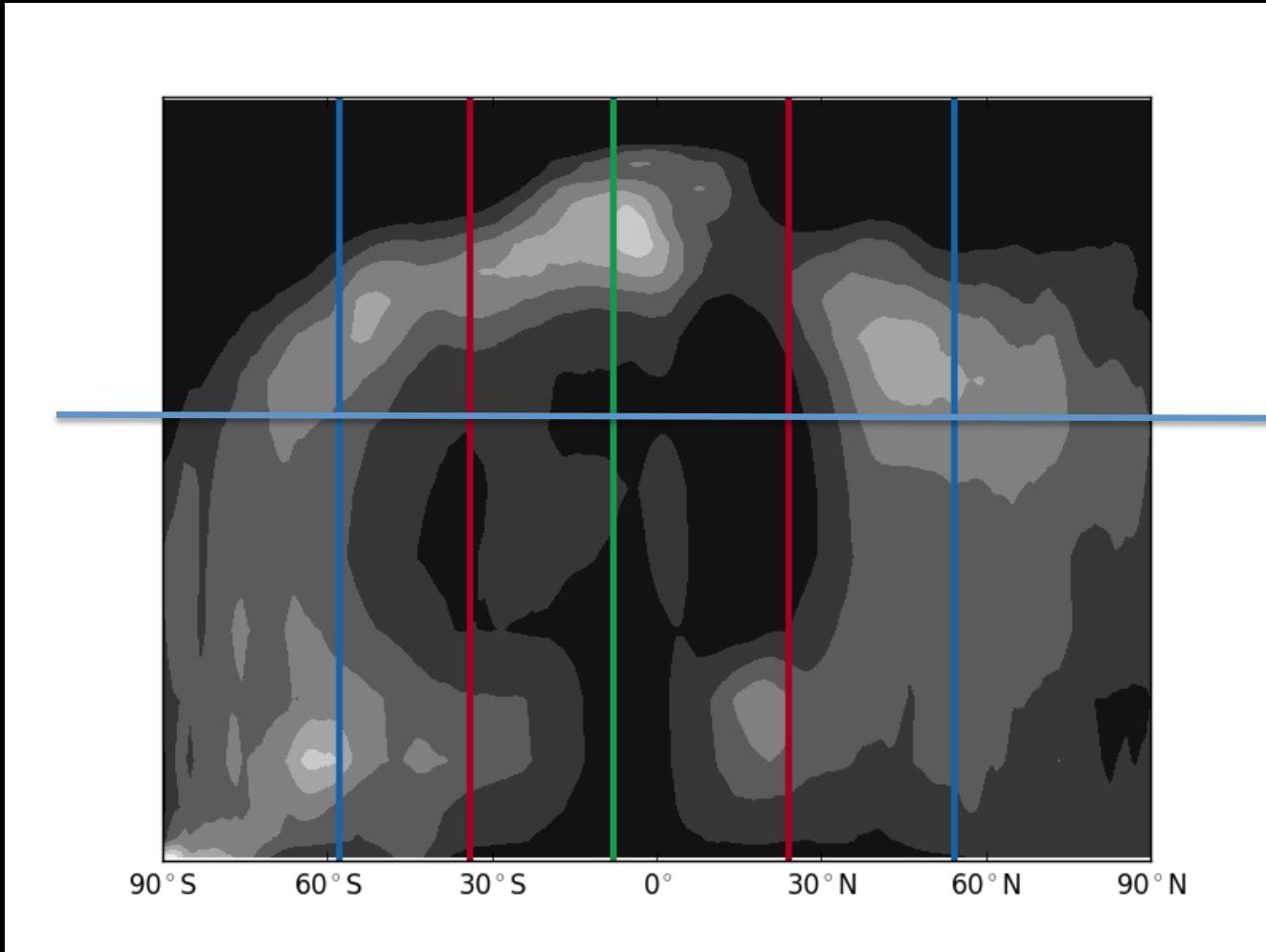
# Visible Cloud



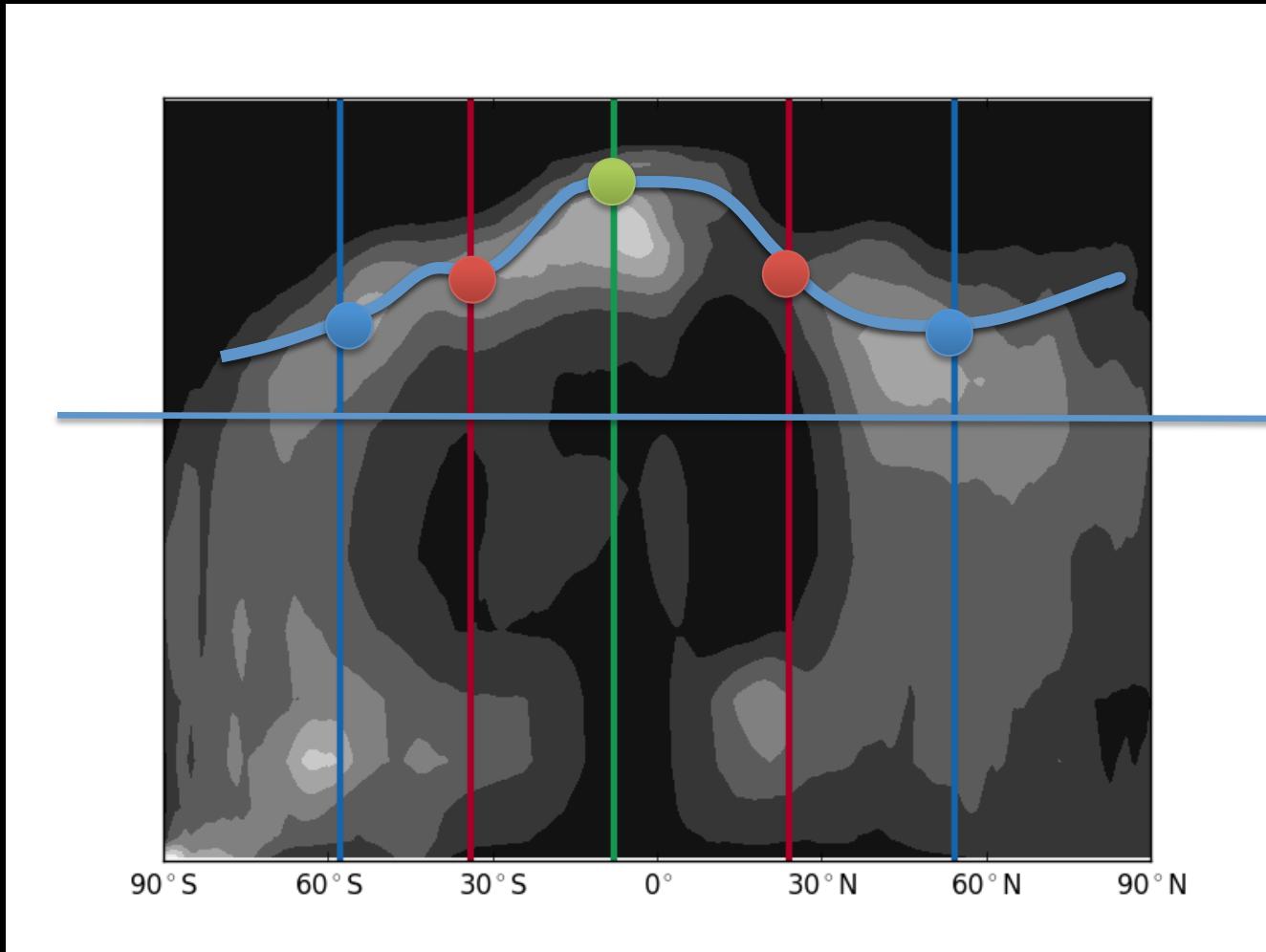
# Visible Cloud at L latitudes



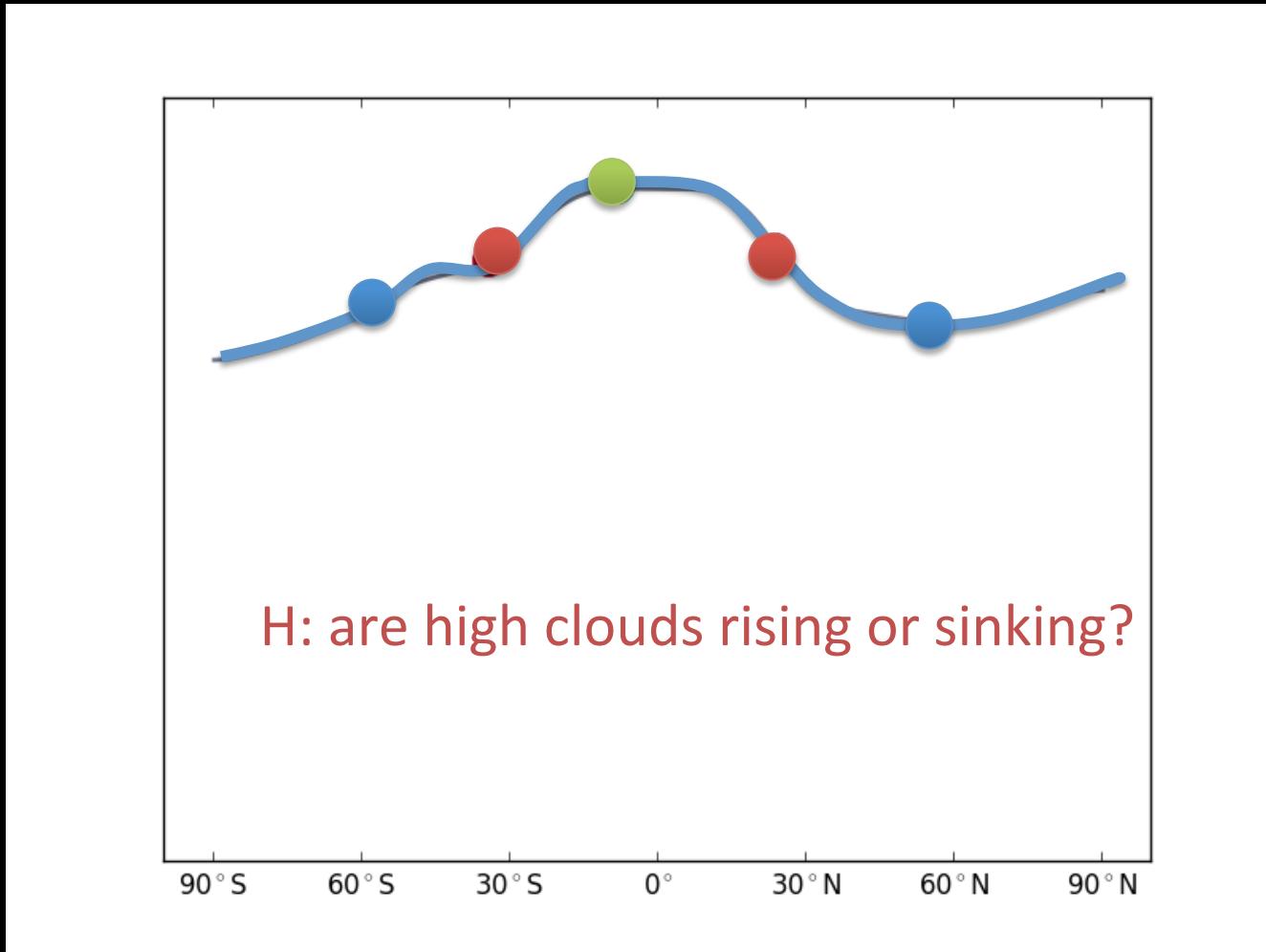
# Visible Cloud at L latitudes



# Visible Cloud at L latitudes



# Weighted cloud top pressure

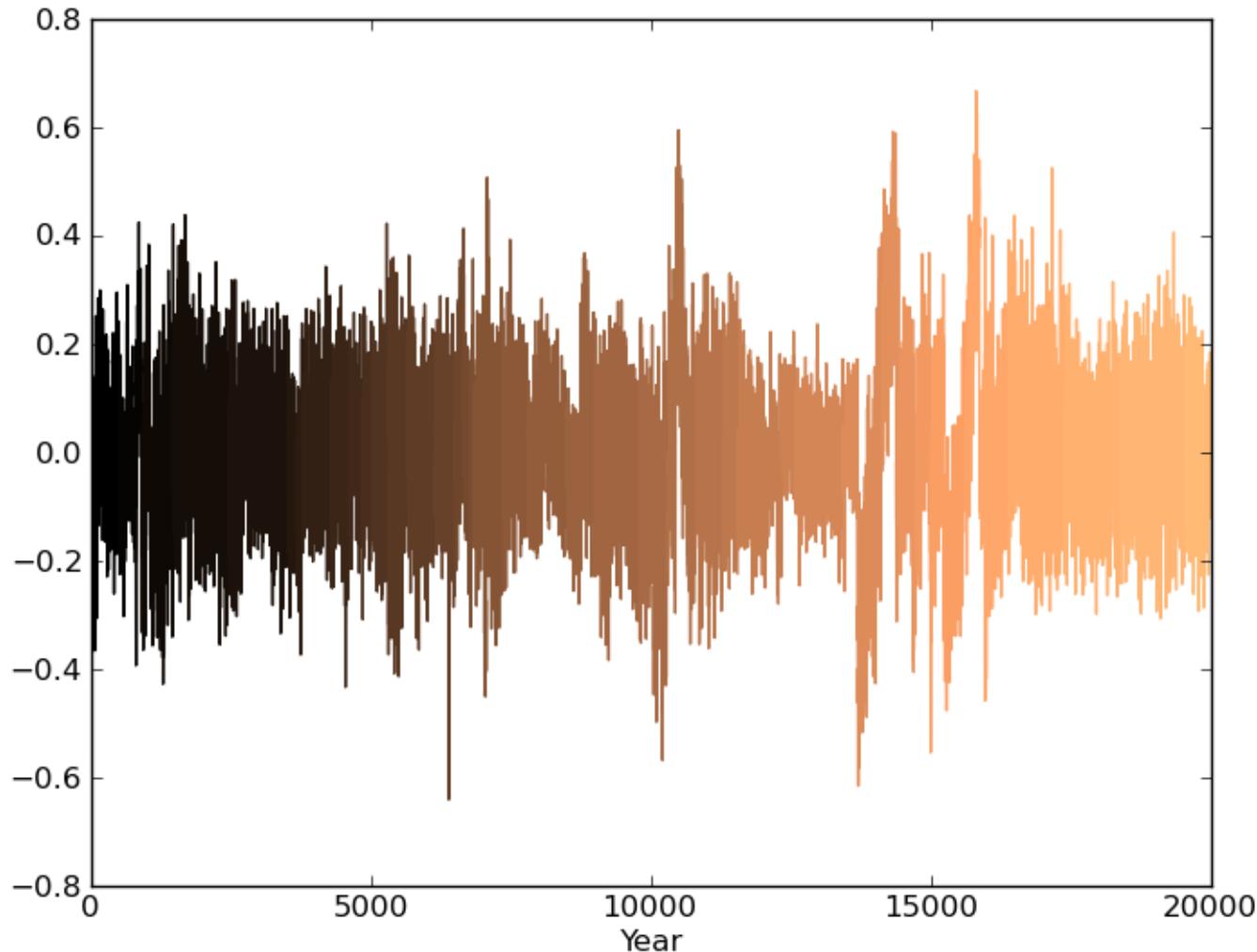


Extra slides

# HOW TO CALCULATE NOISE

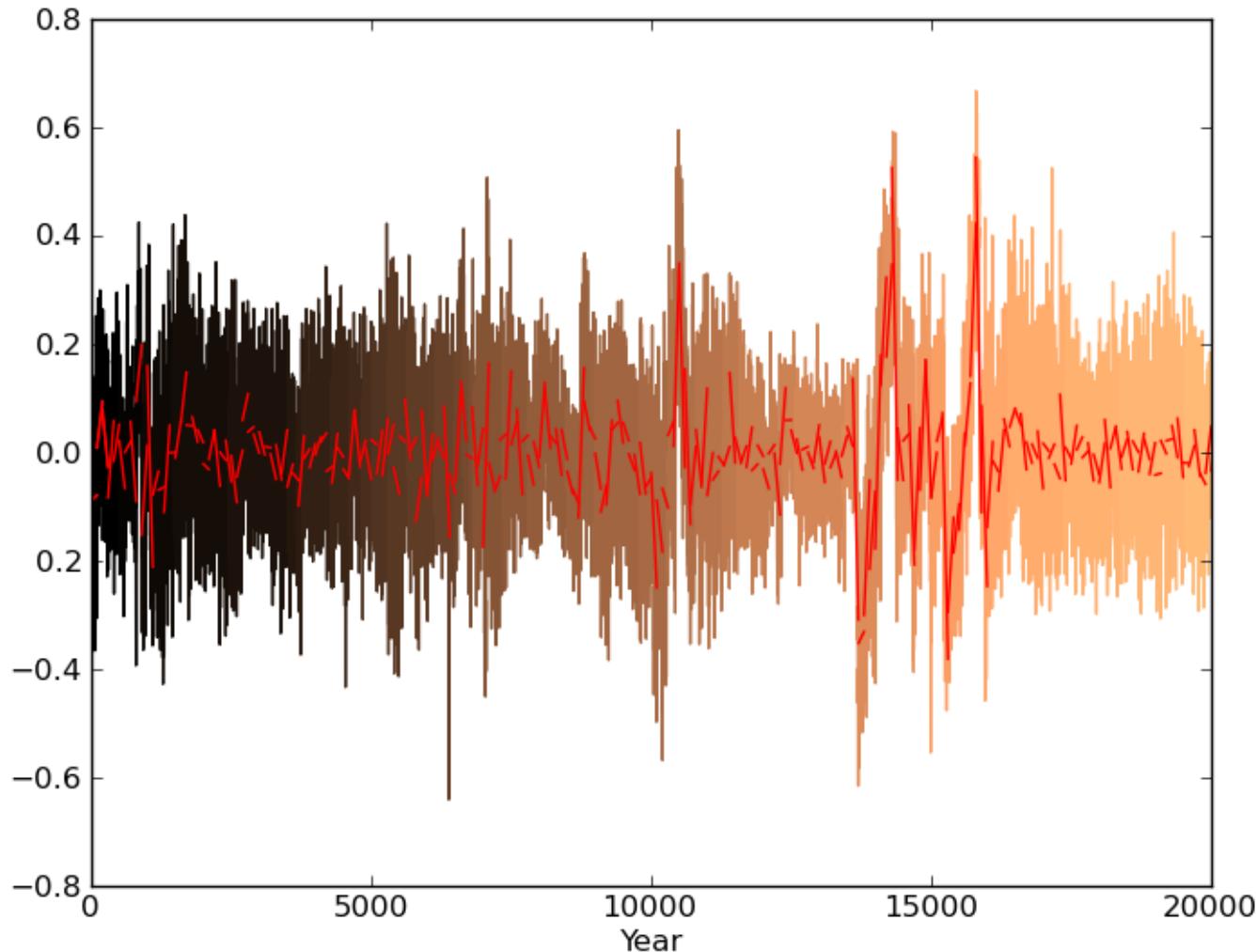
# Noise

Concatenated control projection on fingerprint

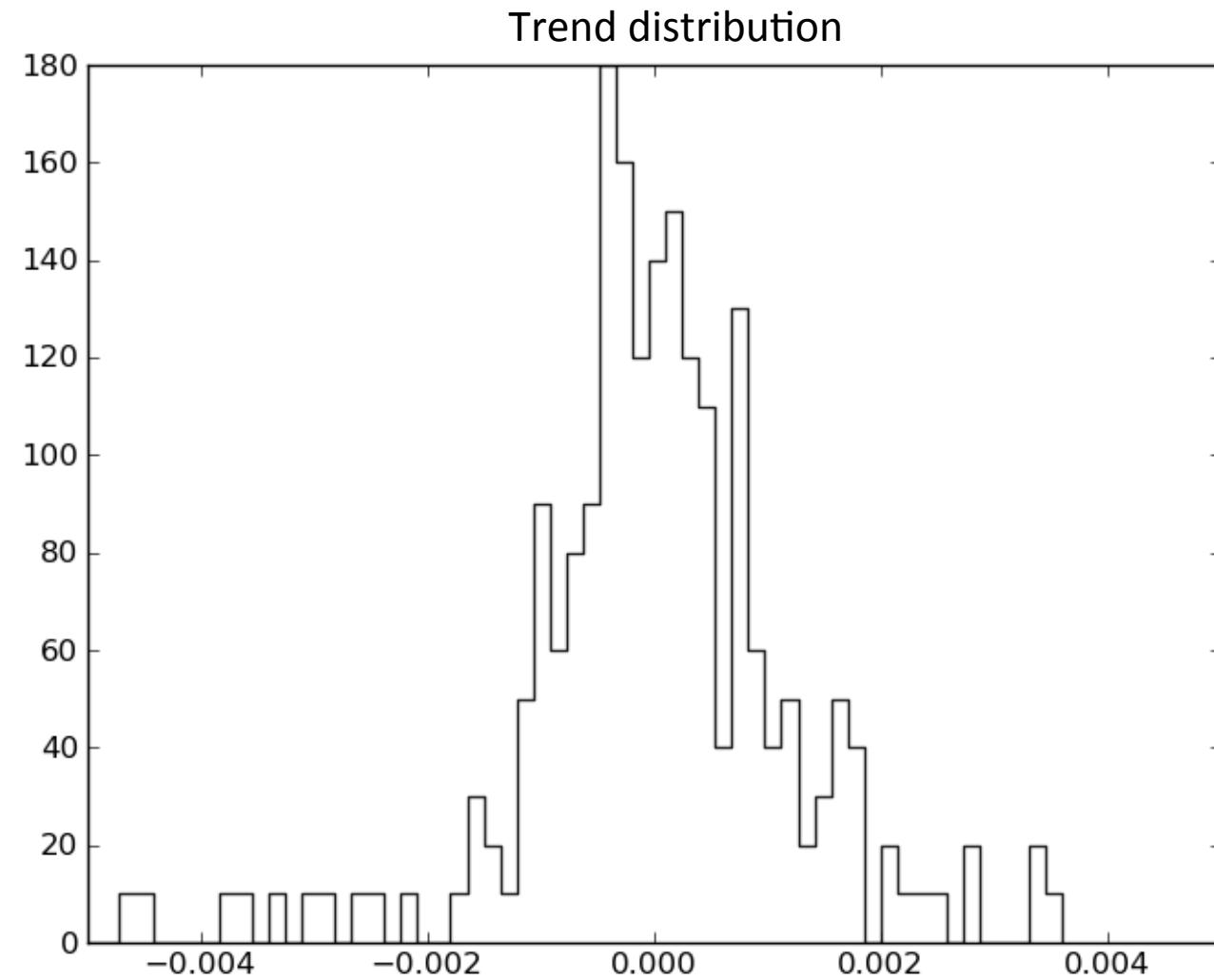


# Noise

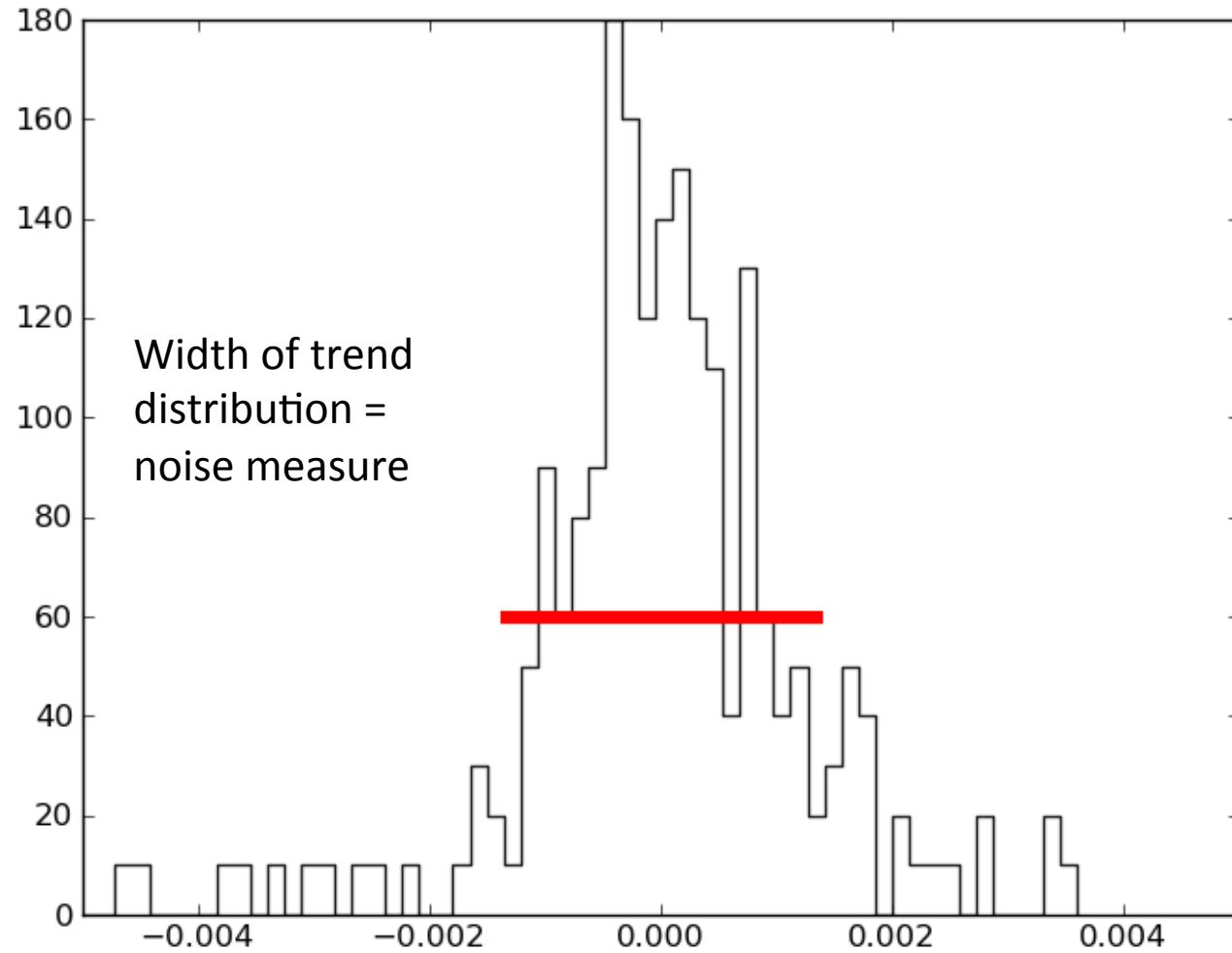
Non-overlapping NT-length trends



# Noise



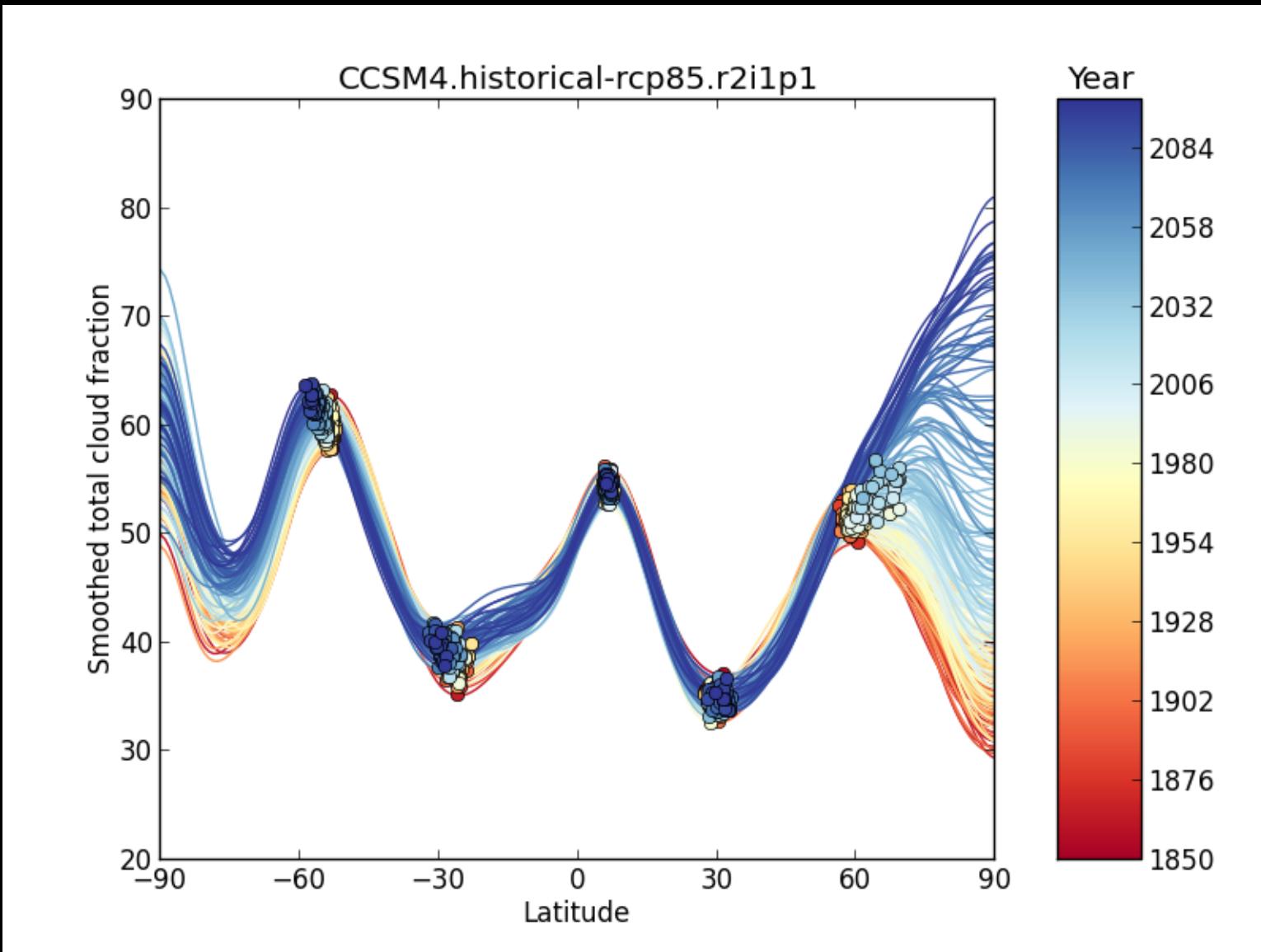
# Noise



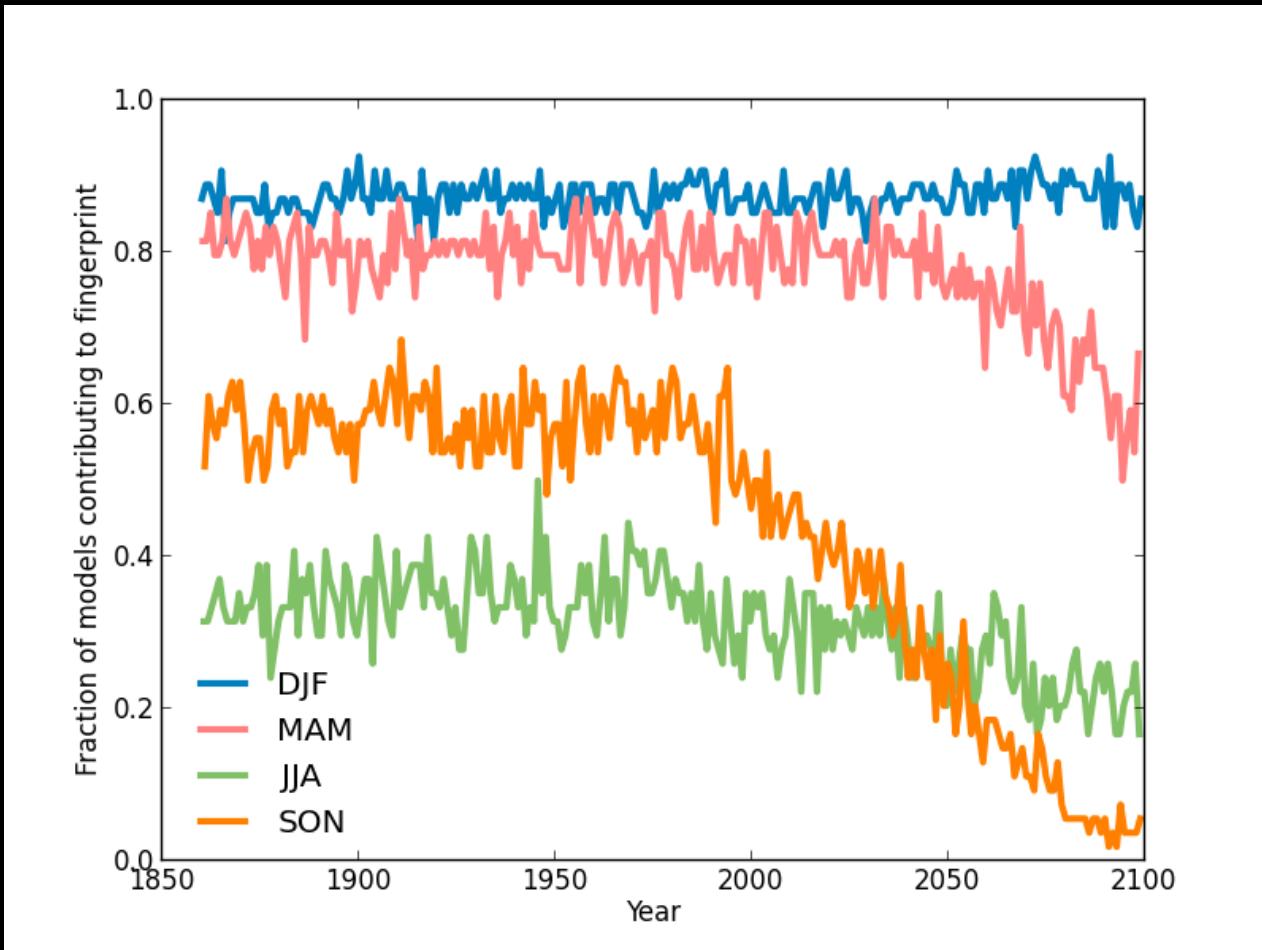
Extra slides

# **OTHER SEASONS**

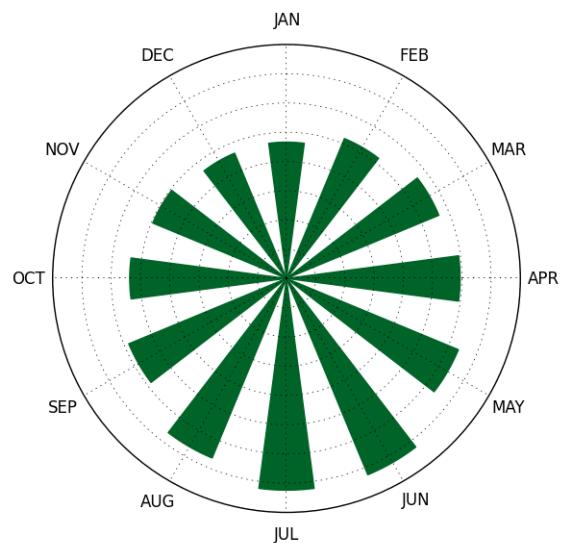
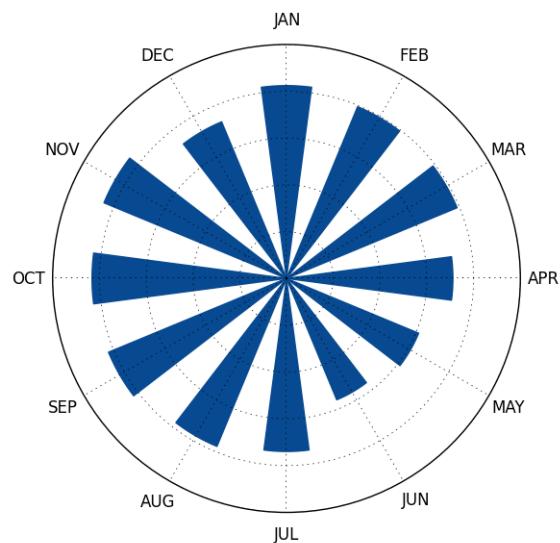
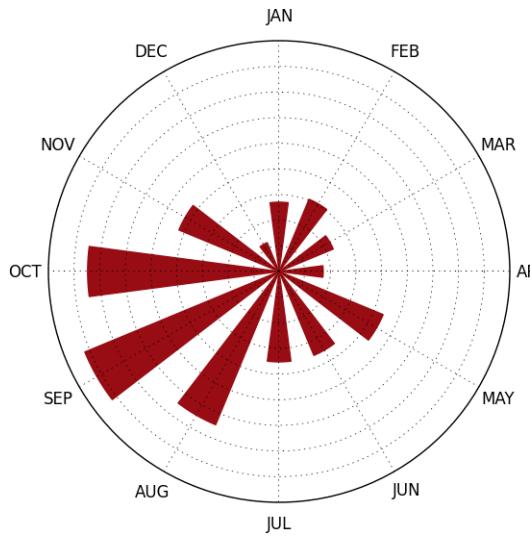
# Why DJF?



# Why DJF?



# Seasonality of signals



L

C

H