Retrieval of atmospheric and cloud property anomalies from temporally and spatially averaged spectral radiances

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Objective of this study

- Demonstrate that retrieving temperature, water vapor amount, and cloud fraction anomalies using highly averaged spectral radiance (anomaly) is possible
- Quantify the retrieval error in two ways
  - Standard deviation of retrieved anomalies compared to the standard deviation of true anomalies
  - How often the true trend falls within a 95 confidence interval of retrieved trend

MERRA DATA

- 1983 – 2010 : 28 years
  - Global (540,361) (0.66 Lon x 0.50 Lat)
  - 6 Hourly:
    - T, Q, O_3 Profiles at 42 vertical levels
  - Hourly :
    - Tskin, T2m, Q2m, Sfc_emiss
    - Random Overlap Cloud Fraction (High, Mid, Low)
    - Cloud Optical Depth (High, Mid, Low)
    - Cloud Pressure (1st layer seen from space)
    - NO Phase, NO Particle Size, Limited Cloud Height info.
      - No Cloud LWC/IWC profile files
    - Clear and Total Sky OLR (MERRA Rt code)
  - Files used :
    - inst6_3d_ana_Np. , tavg1_2d_slv_Nx, tavg1_2d_rad_Nx
    - On /ASDC_archive

PCRTM

- Principal Component Radiative Transfer Model
  - Xu Liu, William L. Smith, Daniel K. Zhou, and Allen Larar
    - Applied Optics Vol 45, No. 1, 1 Jan 2006
- Spectral longwave radiance (50 -2760 cm^{-1})
- 0.5cm^{-1} effective resolution
  - Obtained using 280 principal components
- Cloud properties (P. Yang)
  - Optical depth, Particle size, Phase ,Effective pressure
- Includes Multiple Scattering
- Variable Gases: **H_2O, O_3**
  - CO_2, CH_4, N_2O, CO can vary in PCRTM but not in this simulation.
  - Other minor trace gas concentrations fixed example: CFC's
- No Aerosol in this simulation

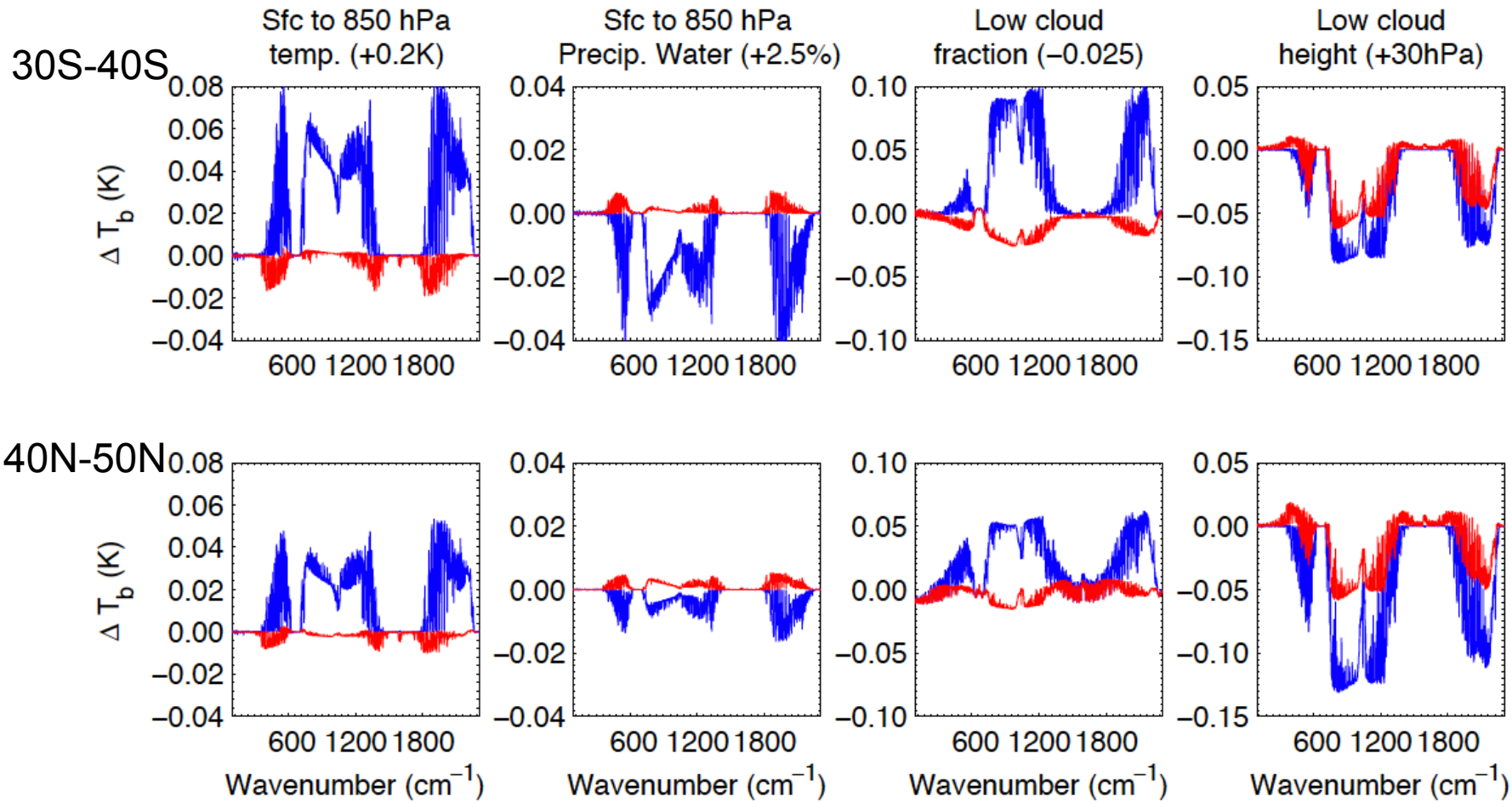
Radiance simulation with MERRA

- 90deg CLARREO ‘like’ Orbit
  - Repeats Annually
- Assuming 30 second sampling interval
- FOV is taken as closest MERRA grid-hour box
- Spectral radiance is computed for every FOV to simulate observation

Monthly mean computations to build spectral radiative kernels

- 10 zonal monthly mean temperature and humidity profiles
- 3 cloud types within a zone
- Emissivity weighted logarithmic mean optical thickness for each cloud type
- Spectral radiances computed with monthly zonal mean properties agree with instantaneous spectral radiance well.

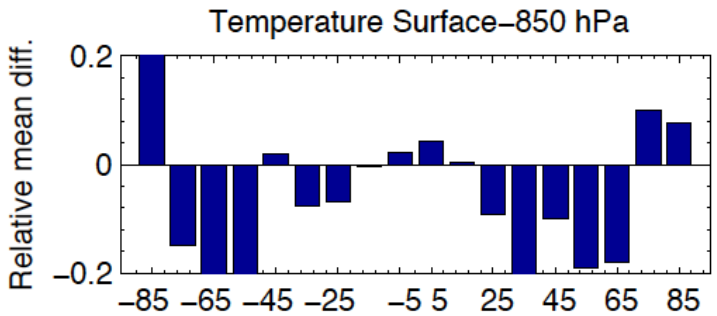
Spectral radiance change difference

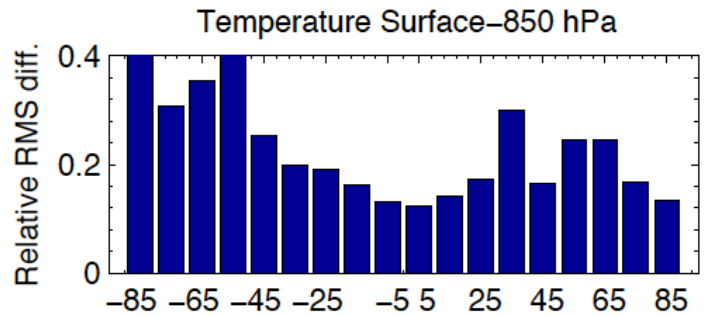


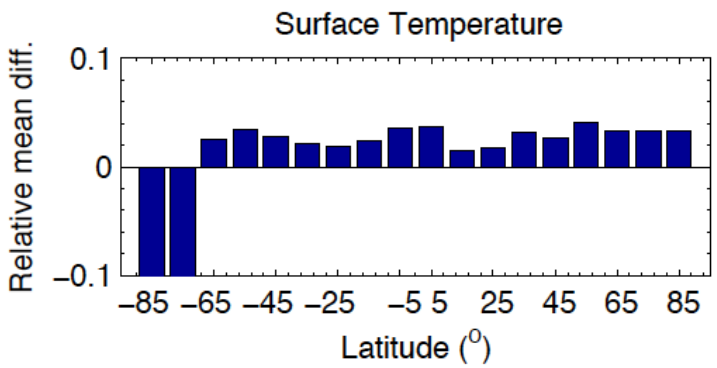
Spectral radiance change computed by perturbing the monthly 10° zonal mean values indicated at the top of each plot and averaging over a year (blue line). The red line indicates the spectral radiance change computed by perturbing monthly 10° zonal value and averaging over a year minus the change computed by perturbing corresponding instantaneous values sampled by a 90° inclined polar orbit.

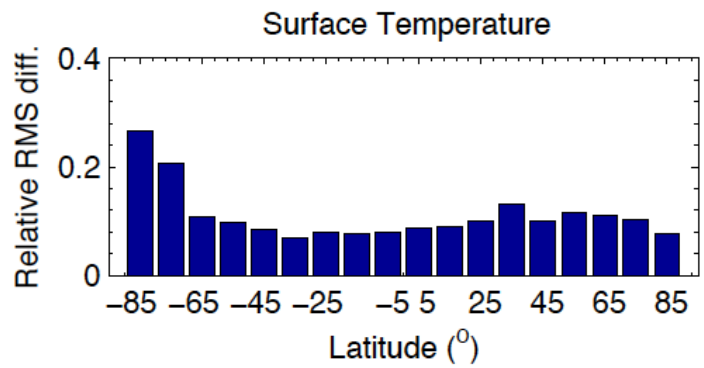
Relative difference

Temperature





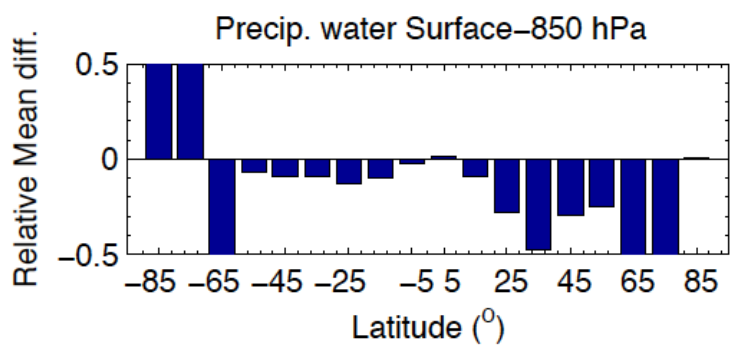


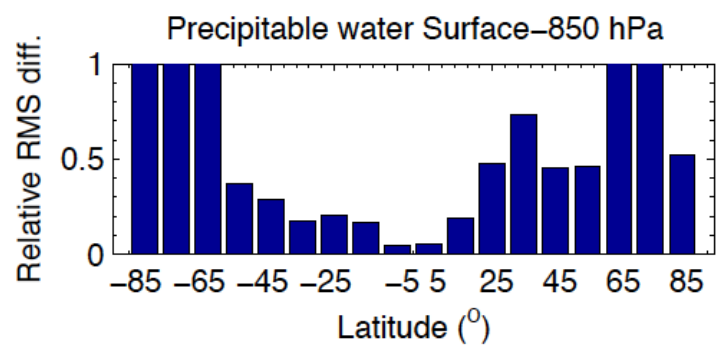


$$\frac{\sum_{\nu}\left[I_{month}(\nu)-I_{inst}(\nu)\right]}{\sum_{\nu} I_{inst}(\nu)}$$

$$\frac{\sqrt{1/n\sum\left[I_{month}(\nu)-I_{inst}(\nu)\right]^2}}{1/n\sum I_{month}(\nu)-I_{inst}(\nu)}$$

Water vapor

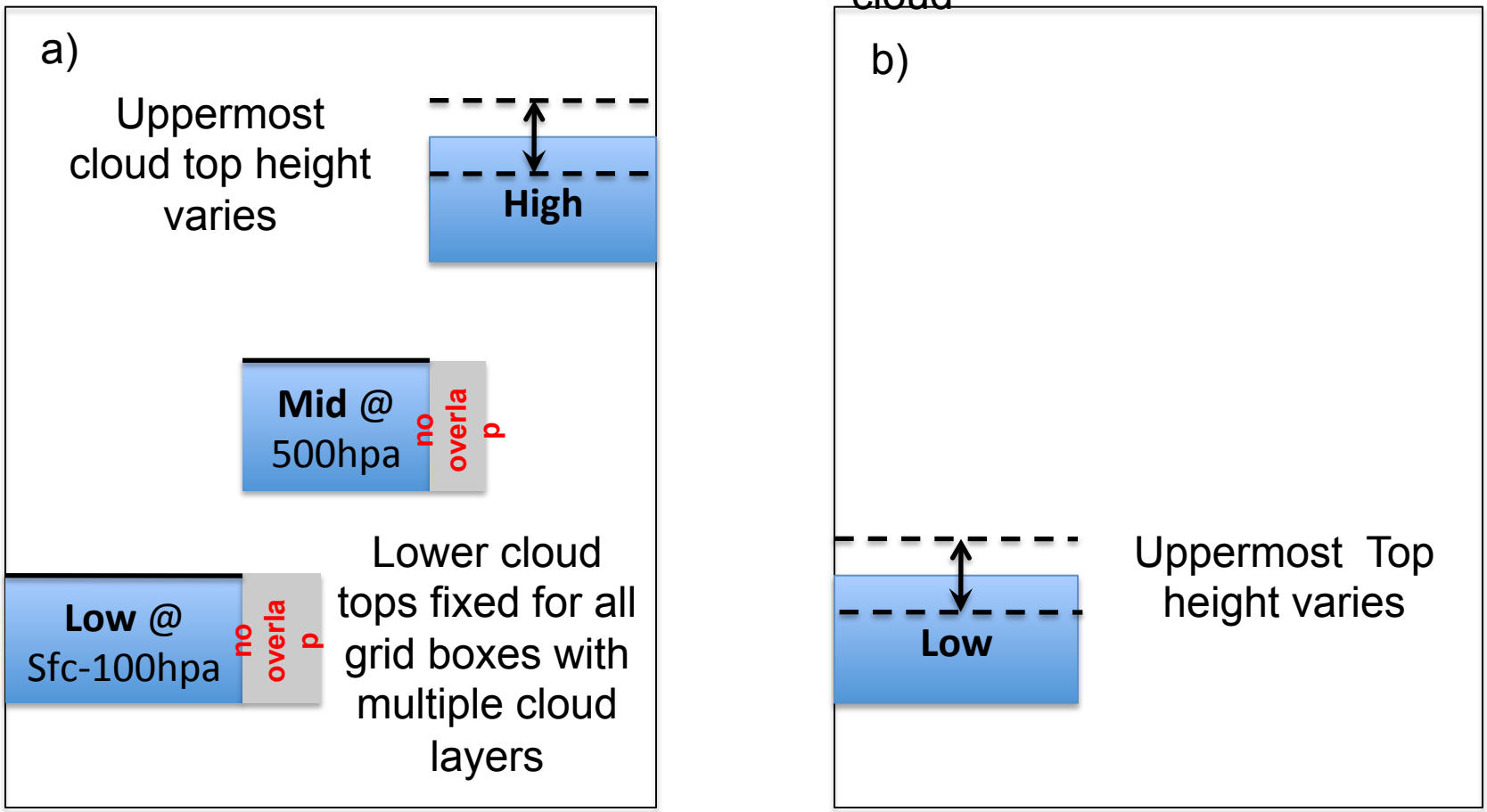




Simlification applied to cloud height

0.66°× 0.5° grid box that has all three cloud types

0.66°× 0.5° grid box that only contains a single level cloud

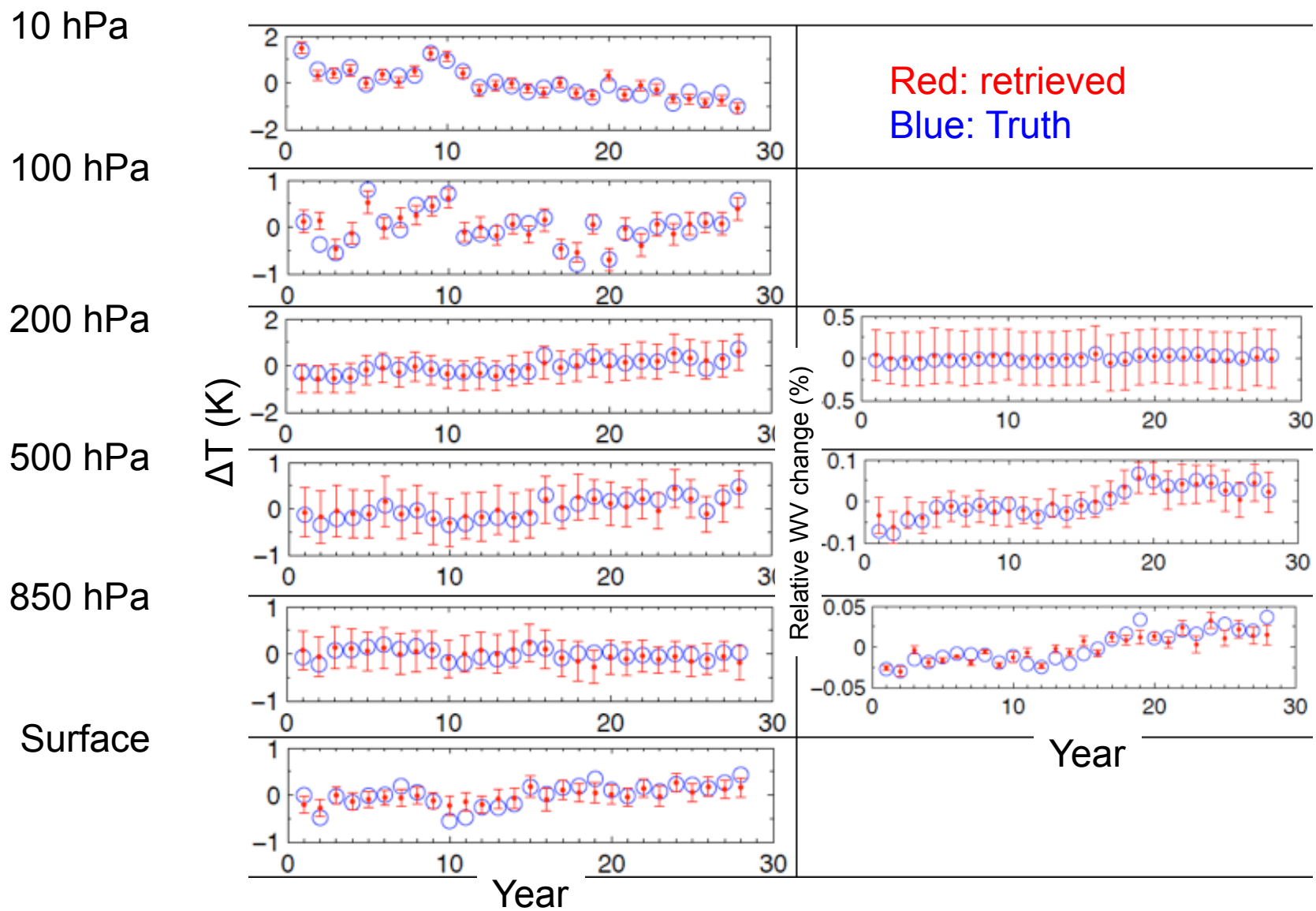


MERRA provides high-, mid-, and low-level clouds fraction assuming random overlap and the highest cloud top height in 0.66°× 0.5° grids every hour. For this PCRTM simulation cloud fractions are converted to fraction viewed from space assuming no overlap. Clouds exposed to space are placed in PCRTM separated by cloud type, i.e. PCRTM is run with single layer high-, mid-, and low-level clouds in addition to clear-sky. Effective cloud-top for all cloud can vary due to the optical depth / emissivity input.

Retrieval of annual anomalies

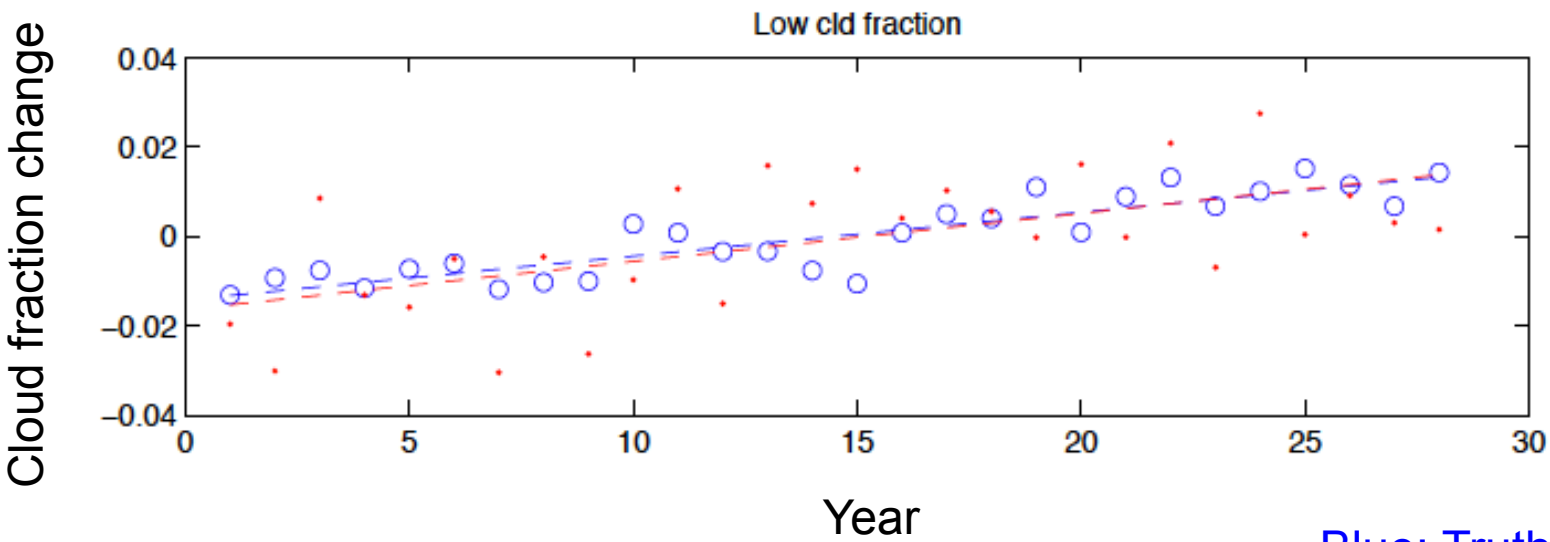
- Use spectral radiance computed at a high resolution (simulating CLARREO observations)
- Compute ΔI by taking annual mean spectral radiance minus the 28-year mean
- Retrieve cloud and atmospheric property anomalies (deviation from the 28-year mean) from annual 10° zonal radiance anomalies using spectral kernels computed by perturbing monthly mean properties averaged over 28 years
- Compare retrieved atmospheric and cloud properties with true annual property anomalies
- Compare trends computed from truth and retrieved anomalies

Retrieved T and Q anomalies (10° zone of 40°S to 30°S)



Retrieved from all-sky spectral radiance anomalies

Cloud fraction retrieval

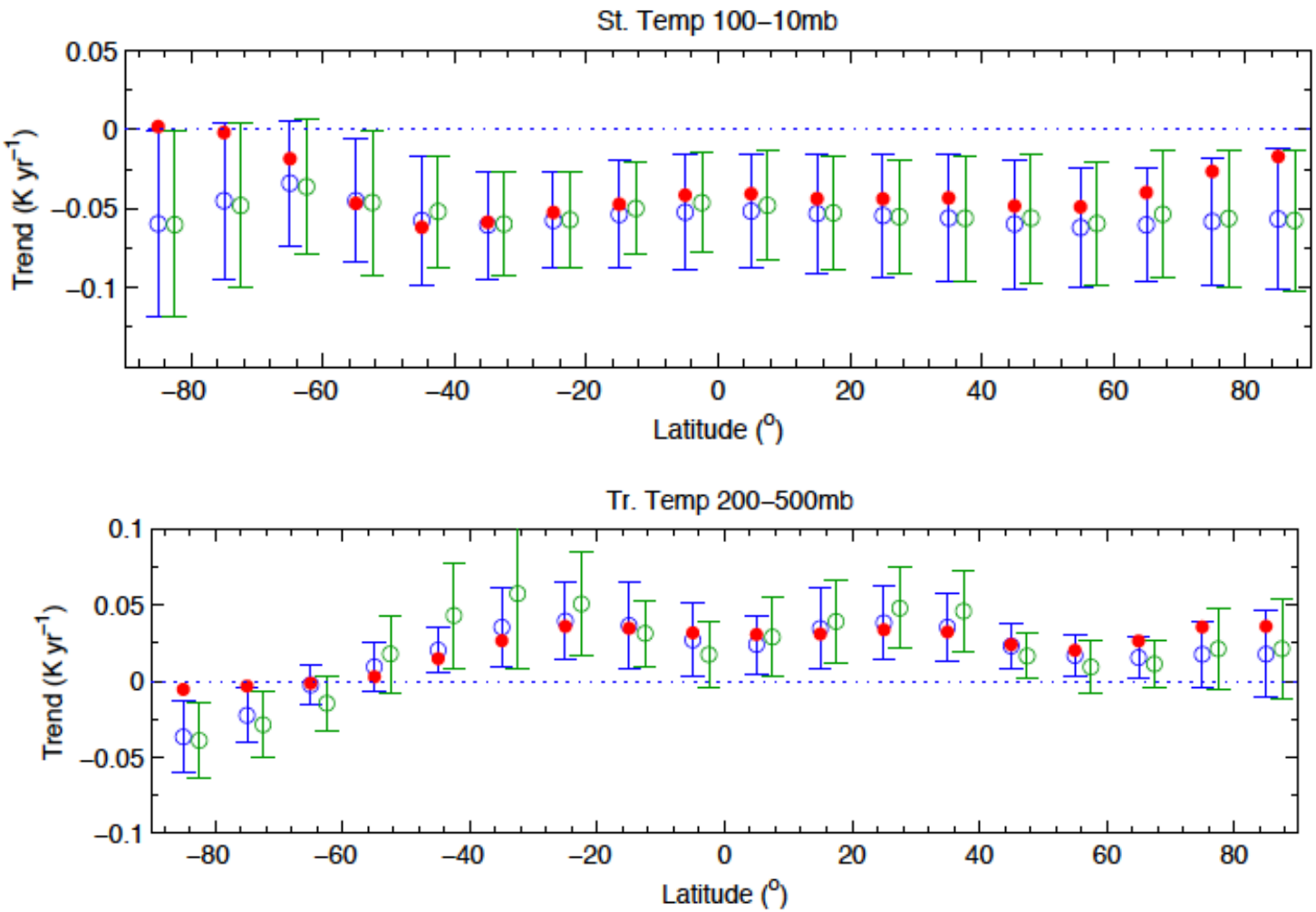


Blue: Truth
Red: retrieved

$$\mathbf{a}_c = (\mathbf{S}^T\mathbf{S} + \lambda\mathbf{H})^{-1}\mathbf{S}^T\Delta\mathbf{I},$$

S: Spectral signature matrix containing distinguishing spectral radiances
H: smoothing matrix that minimizes variability, i.e. forcing toward climatological values
λ: Lagrange multiplier
Increasing λ reduces the standard deviation of retrieved anomalies
Uncertainty estimate of the trend of retrieved values is difficult
Is the good trend estimate fortuitous?

Trend estimte



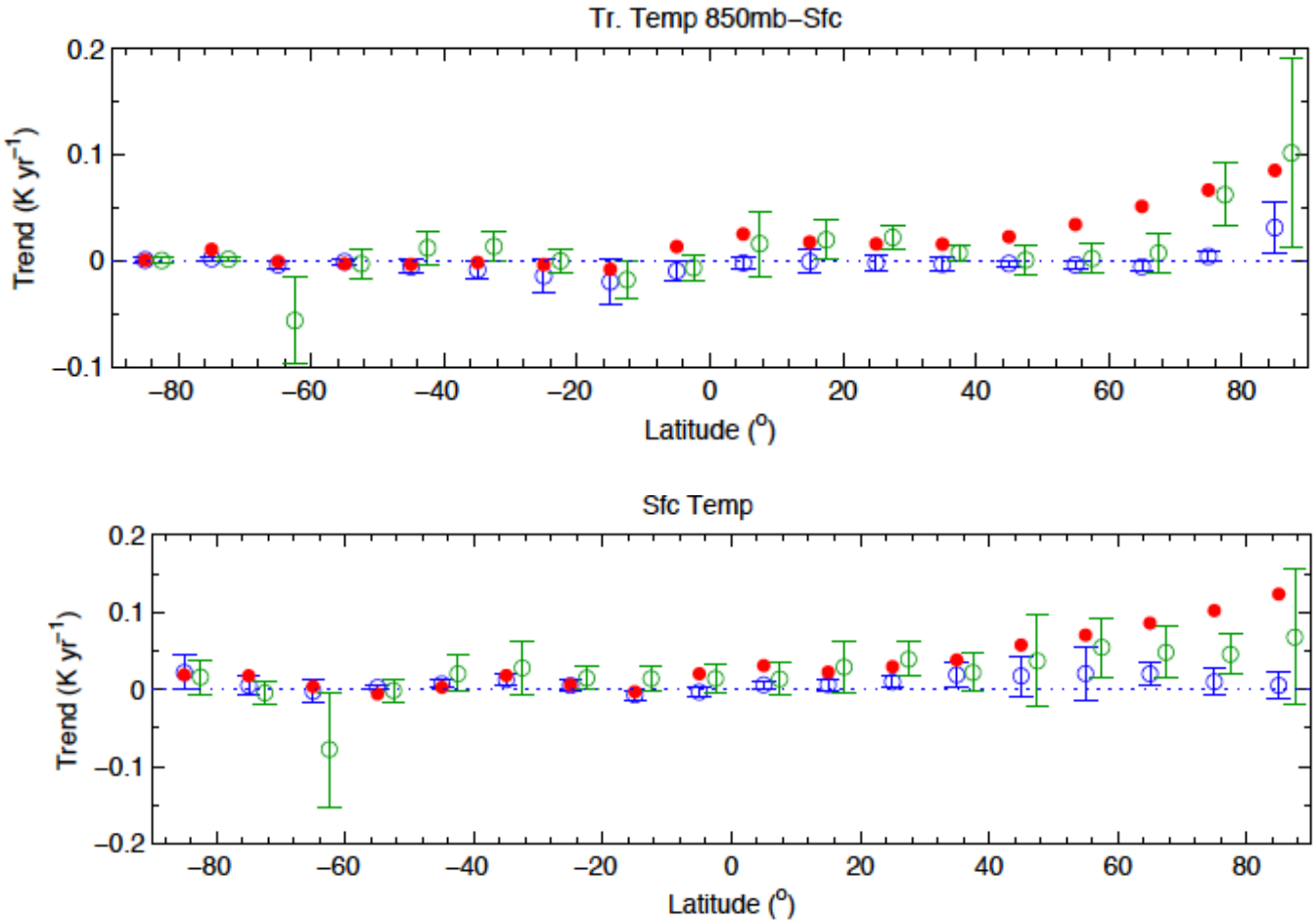
Blue: Retrieved from all-sky

Red: Truth

Green: Retrieved from clear-sky (cloud removed)

Error bars: trend uncertainty (95% confidence level)

Trend (near surface temperature)



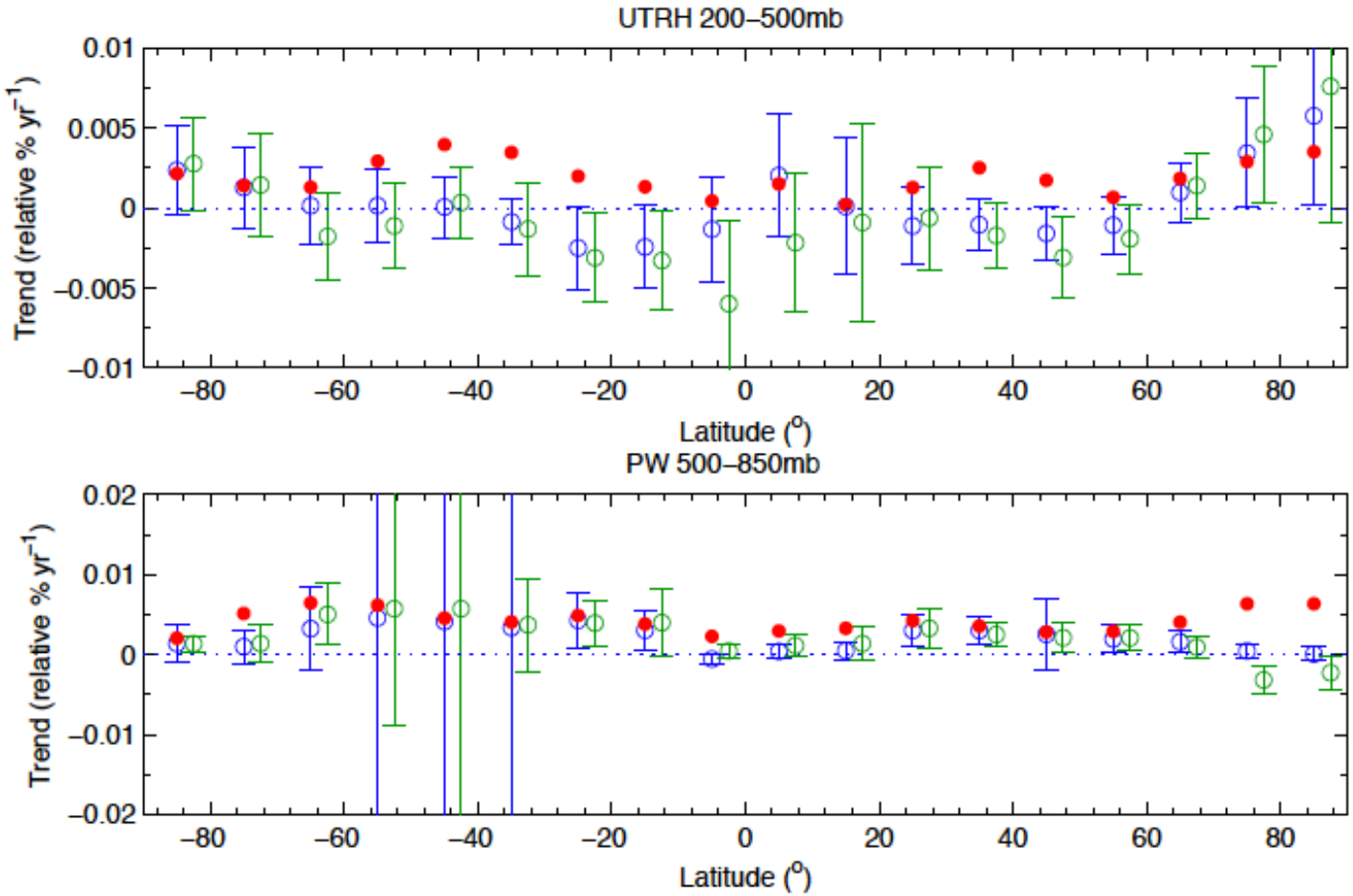
Blue: Retrieved from all-sky

Red: Truth

Green: Retrieved from clear-sky (cloud removed)

Error bars: trend uncertainty (95% confidence level)

Water vapor (relative change)



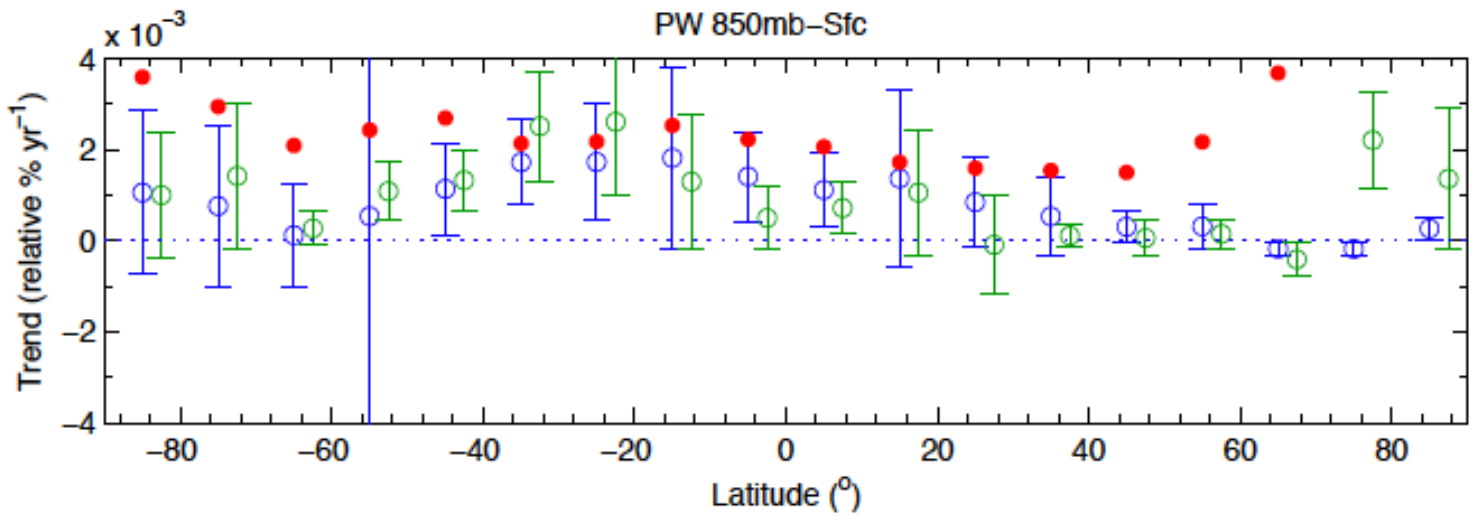
Blue: Retrieved from all-sky

Red: Truth

Green: Retrieved from clear-sky (cloud removed)

Error bars: trend uncertainty (95% confidence level)

Water vapor (near surface) relative change



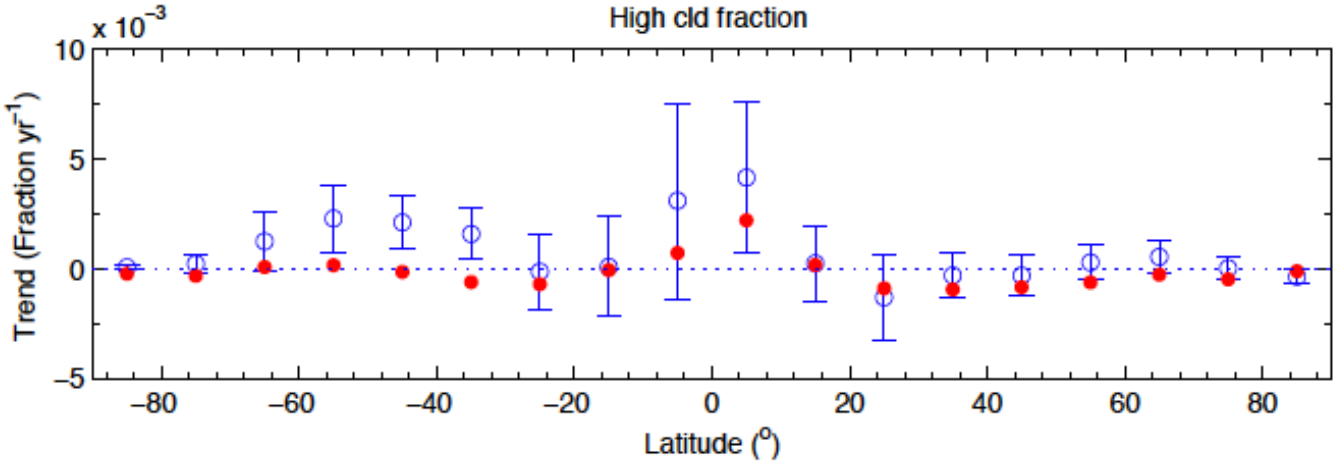
Blue: Retrieved from all-sky

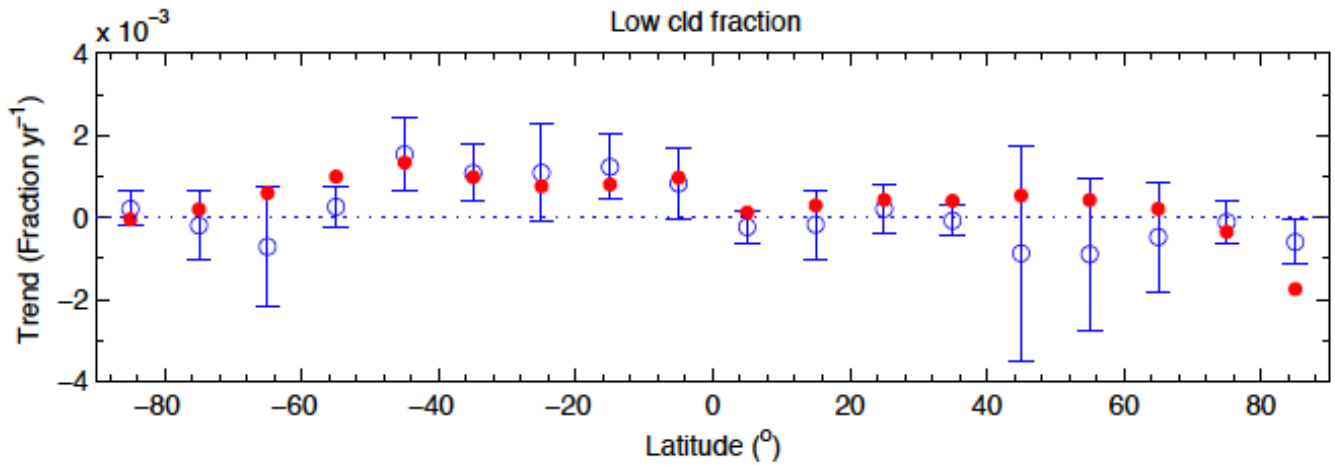
Red: Truth

Green: Retrieved from clear-sky (cloud removed)

Error bars: trend uncertainty (95% confidence level)

Cloud fraction
(all-sky retrieval only)

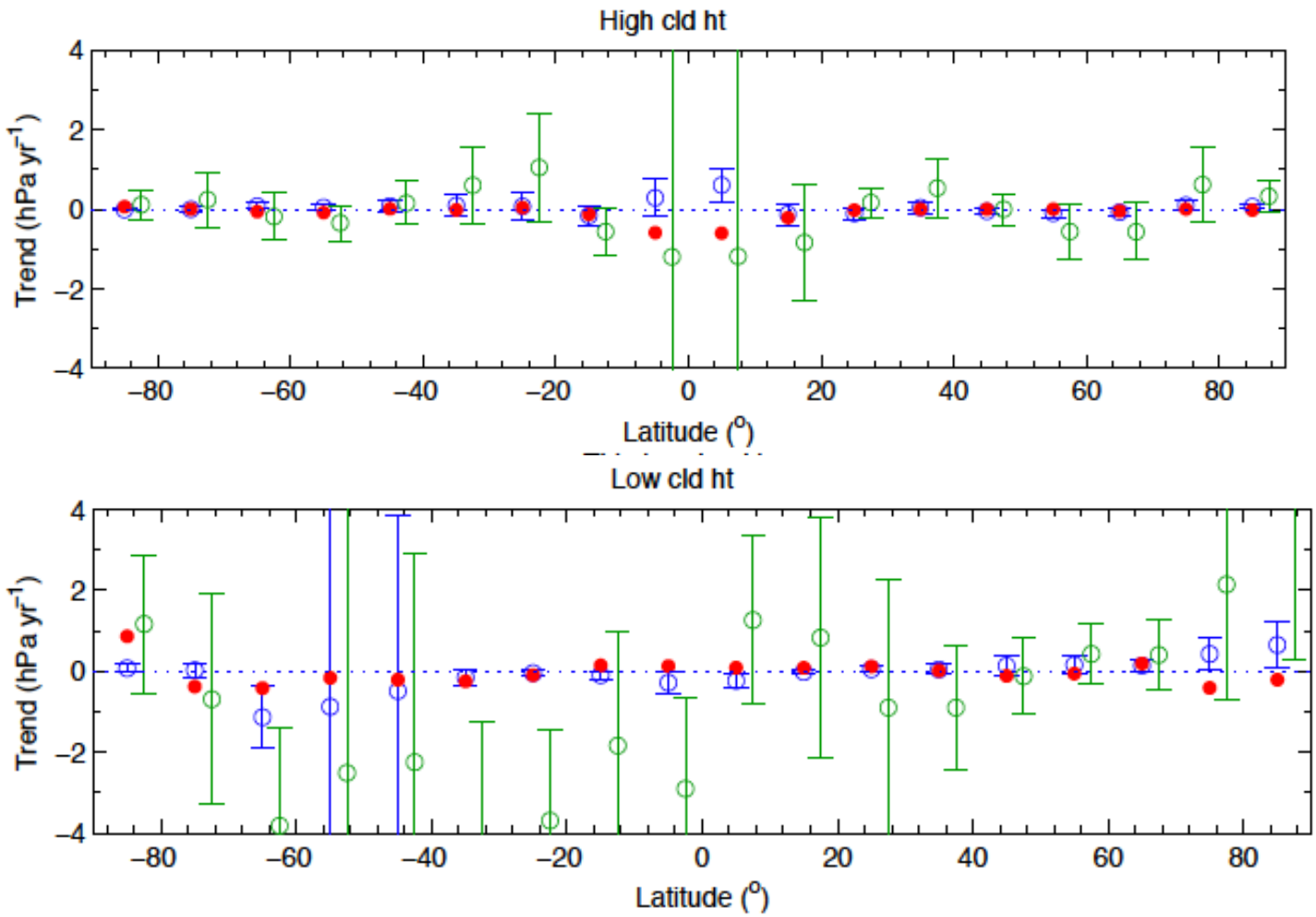




Blue: Retrieved from all-sky Red: Truth

Error bars: trend uncertainty (95% confidence level)

Cloud height



Blue: Retrieved from all-sky

Red: Truth

Green: Retrieved from overcast (cloud forcing)

Need to include T and Q because T and Q for all-sky are different from T and Q for clear-sky

Retrieved variability relative to truth

$$\mathbf{a}_c = (\mathbf{S}^T\mathbf{S} + \lambda\mathbf{H})^{-1}\mathbf{S}^T\Delta\mathbf{I},$$

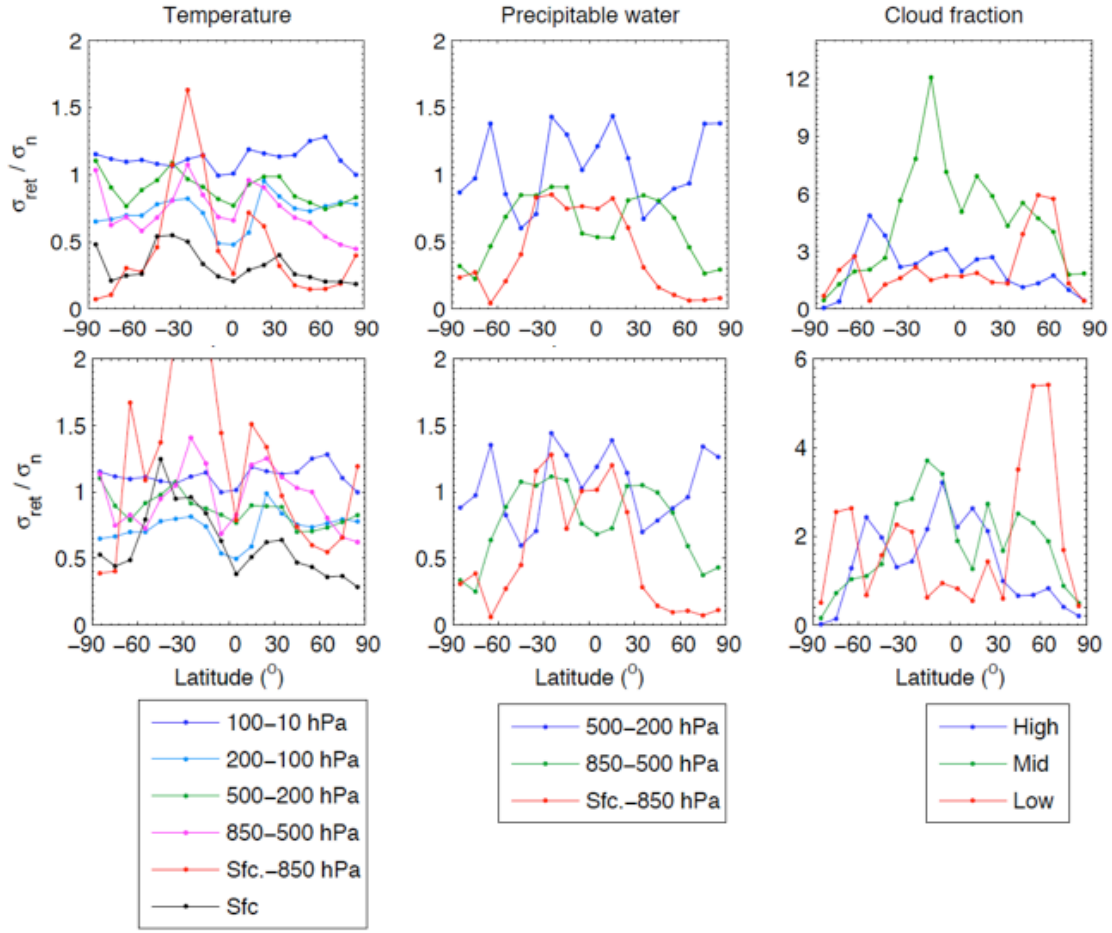


Figure 12: Ratio of the standard deviation of retrieved annual 10° zonal anomalies σ_{ret} to the standard deviation of true annual 10° zonal anomalies σ_n as a function of latitude. Values for upper three plots are derived by using an identity matrix for **H**. Values for lower three plots are derived changing diagonal elements of **H** to values indicated in the first column of Table A1.

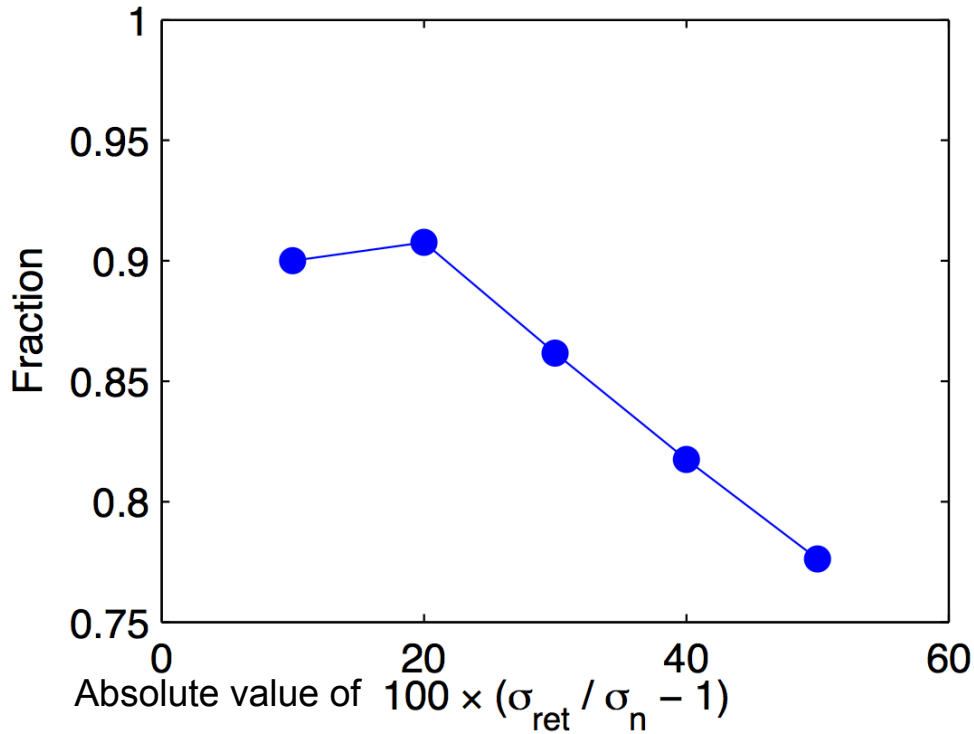
H is an identity matrix.

When the ratio is less than 1, the weight for the climatological values might be too large.

Diagonal elements of **H** depends on variables

Same **H** for all zones

Fraction of the true trend that are within the 95% confidence interval of retrieved trend



Percentage of retrieved standard deviation to true standard deviation

Including all temperature, water vapor, cloud property retrievals for all zones

When σ_{ret}/σ_n -1 is less than ±0.2, 91% of the true trends fall within the 95% confidence level of corresponding retrieved trend.

Summary

- Approximately 30% of the ratio of temperature and water vapor over 10° regions meet the condition that the ratio is within ±1.2 and the true trends fall within the 95% confidence interval of retrieved trends.
- When σ_{ret}/σ_n -1 is less than ±0.2, 91% of true trends fall within the 95% confidence level of the corresponding retrieved trend.

Conclusions

- Retrieving annual anomalies using climatological mean kernels makes the error random so that the trend can be retrieved.
- The weight of climatological mean (H) can be determined by comparing the standard deviation of retrieved anomalies to known natural variability.
- Instantaneous or regional kernel might improve the retrieval.