IR Instrument Accuracy Required for Atmospheric Temperature and Water Vapor Trend Detection

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Presentation outline

– Introduction and methodology
– Natural variability based on NWP reanalysis and climate model data
– Deriving IR instrument requirement
– Summary and Conclusions

Introduction

- Quantify natural variability and derive the calibration requirement for geophysical constituents observation
  - Methodology outlined in BAMS paper by Wielicki et al.
  - Derive Natural variability of T(p) and H_2O(p) from MERRA and ECMWF reanalysis data
  - Climate model (CMIPS-5) provides additional validation
  - Derive vertical T(p) and H_2O(p) accuracy required for trend detection using natural variability and autocorrelation length
- Derive spectral dependent instrument requirement using fingerprinting method and the required actuary for T(p) and H_2O(p)
  - Frame work of the fingerprint method used
  - Fast radiative transfer model (PCRTM) is suitable for simulation study
  - Null space vertical error minimized by using EOF representation of the vertical profile.

Part I
Natural variability of Temperature and Water Vapor vertical Profiles

Temperature and humidity variability

- Detection of anthropogenic influence requires accounting for natural climate forcing
  - Internal forcing
    - EL Niño-Southern Oscillation (ENSO)
    - Quasi-biennial oscillation (QBO)
  - External forcing
    - Variation of solar irradiation (11 year cycle)
    - Major Volcanic eruption (EL Chichón in April 1982 ,Pinatubo in June 1991)
- Multiple linear regression (MLR) method is used to derive a linear trend term
  - Proxies for ENSO, QBO, volcanic eruption and Solar cycle signal from time series data
- Non-polar globally averaged, de-seasonalized monthly mean values from reanalysis results are used
  - Also done analysis of global and regions average with similar conclusions

Climate forcing proxy indices

- Adopt proxy indices that are widely used for various global and zonal trend studies.

I. Multivariate ENSO index (MEI) is used to represent global ENSO impact.

II. NOAA/ESRL QBO index (from the zonal average of the 30mb zonal wind at the equator as computed from the NCEP/NCAR Reanalysis).

III. Sun spot number (SSN) is obtained from NASA's Marshall Space Flight Center website.

IV. Global stratospheric aerosol optical depth (AOD) data from NOAA is used to estimate Volcanic aerosol effect.

Calibration requirement

Calibration requirement is established base on how the measurement uncertainty affect the climate trend detection uncertainty

$$U_a^2 = 1 + (\sigma_{cal}^2 \tau_{cal} + \sigma_{instru}^2 \tau_{instru} + \sigma_{orbit}^2 \tau_{orbit})/(\sigma_{var}^2 \tau_{var})$$

$$\sigma_{cal} = \sqrt{\frac{(U_a^2 - 1)\sigma_{var}^2 \tau_{var} - \sigma_{instru}^2 \tau_{instru} - \sigma_{orbit}^2 \tau_{orbit}}{\tau_{cal}}}$$

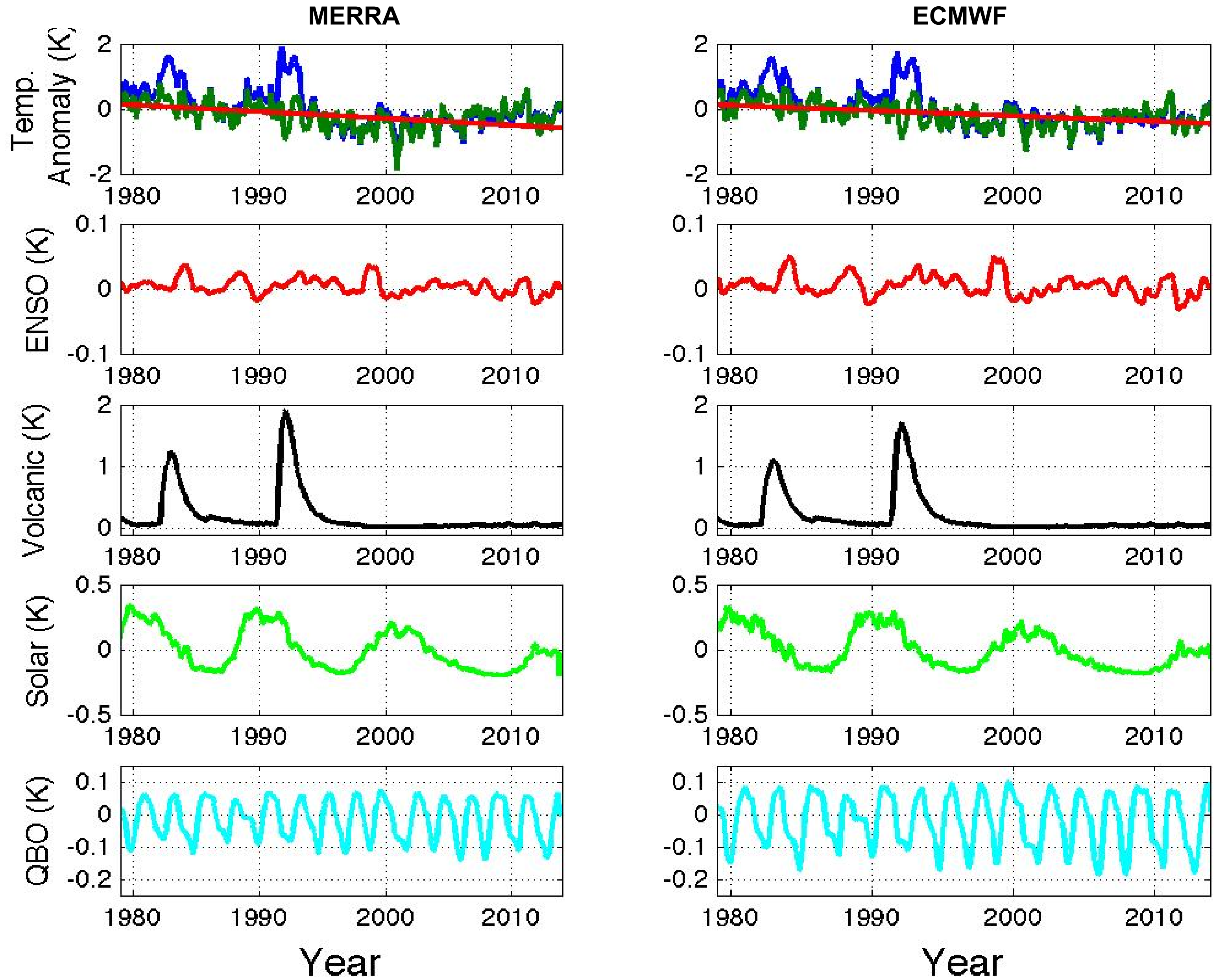
$$\sigma_{cal} = \sqrt{\frac{(U_a^2 - 1)\tau_{var}}{\tau_{cal}}}\ \sigma_{var}$$

- instrument noise contribution σ_{instru}, is small due vertical averaging
- orbit sampling error σ_{orbit}, is also neglected

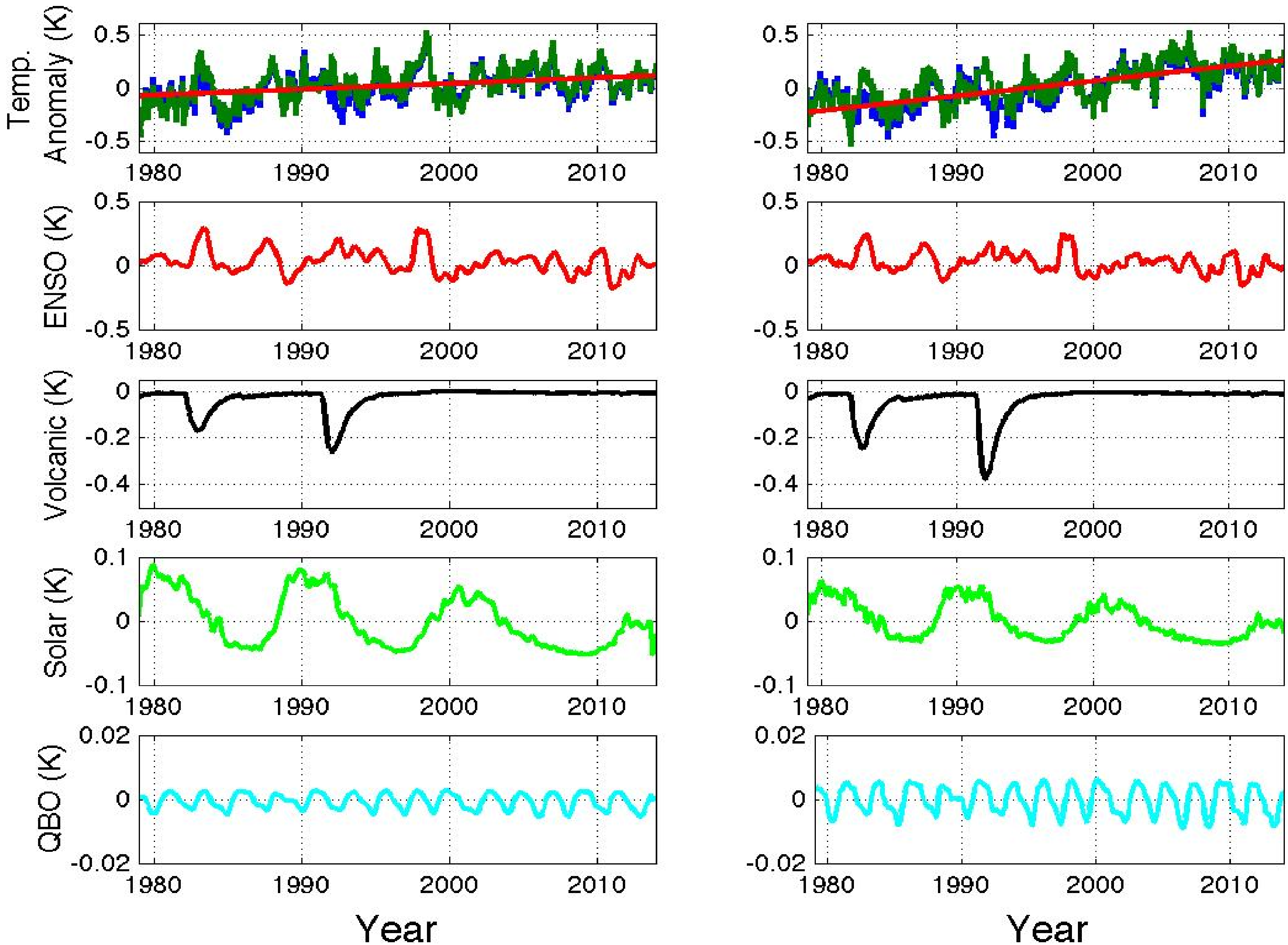
Accuracy uncertainty factor U_a (Wielicki et al. 2013) defines how CLARREO's observation accuracy for climate trends deviates from the accuracy of a perfect system

Bruce A. Wielicki, et al., 2013: Achieving Climate Change Absolute Accuracy in Orbit. *Bull. Amer. Meteor. Soc.*, 94, 1519–1539.

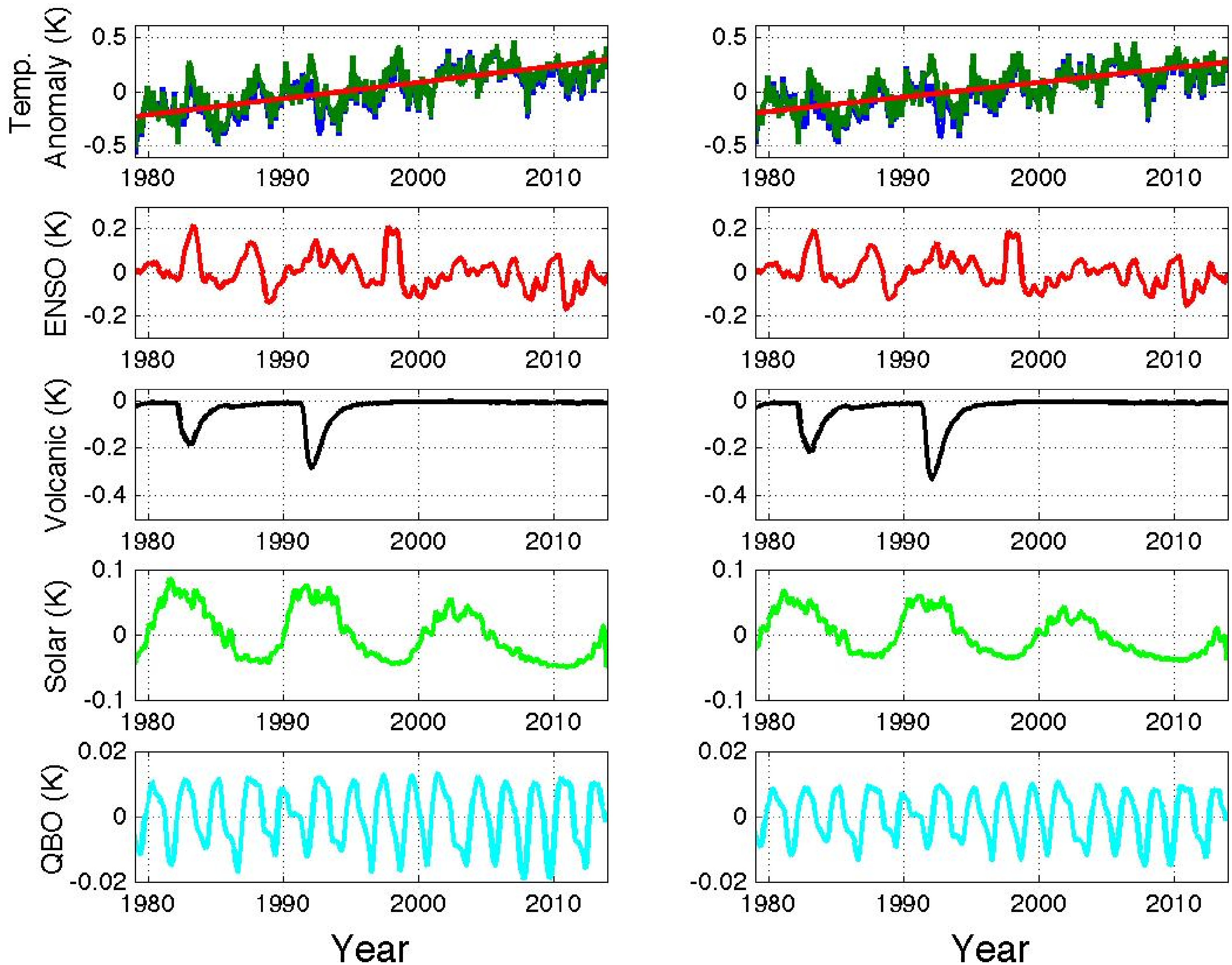
Temperature anomaly and linear trend @ 70hPa from MERRA and ECMWF



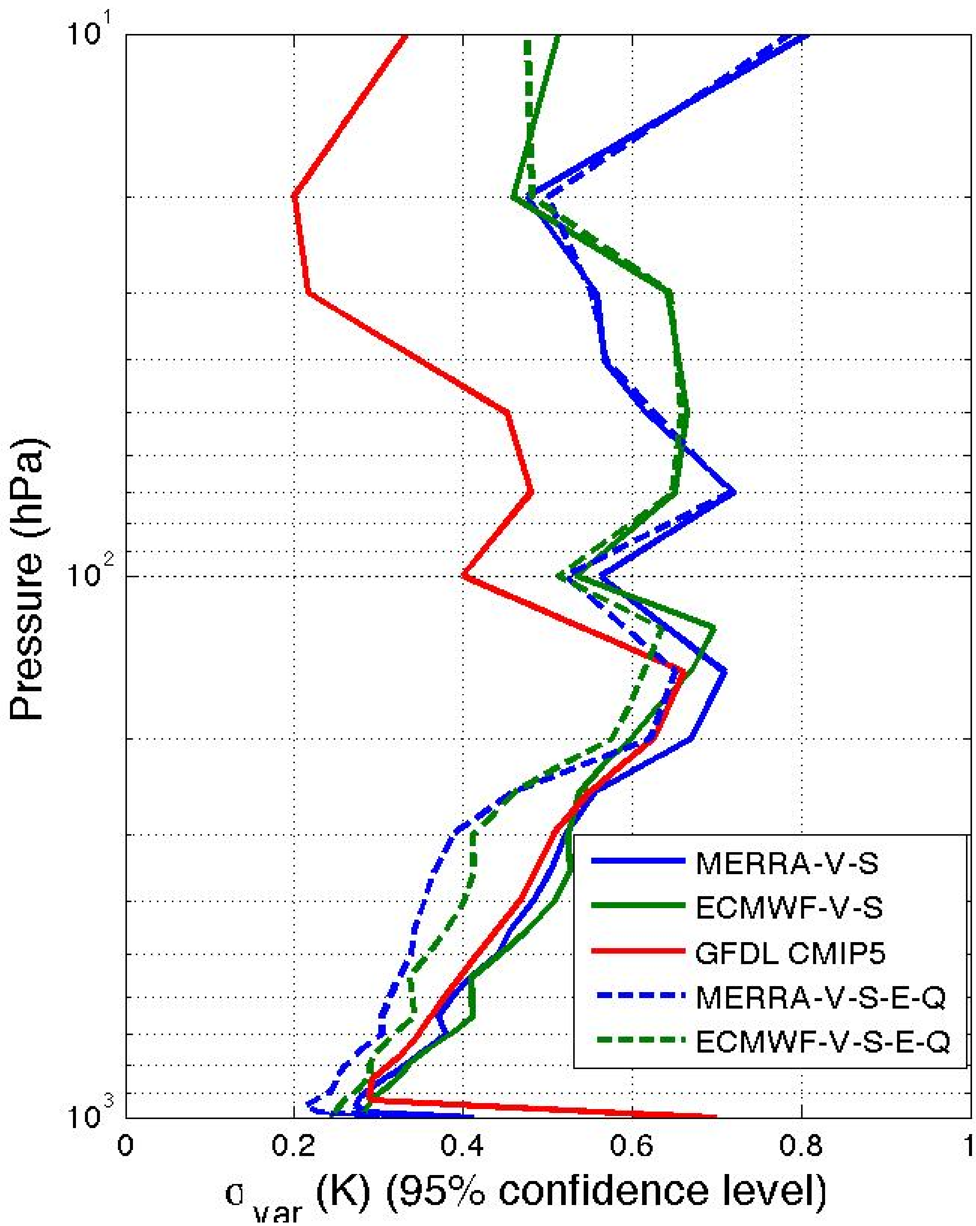
Temperature anomaly and linear trend @ 975hPa from MERRA and ECMWF

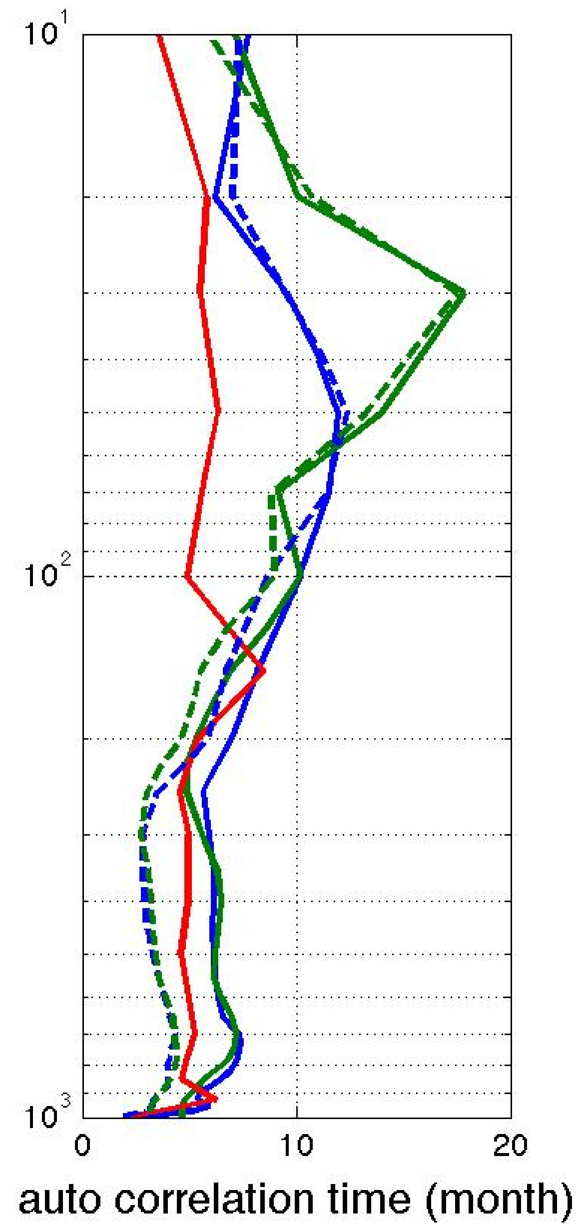


Surface skin temperature anomaly and linear trend from MERRA and ECMWF

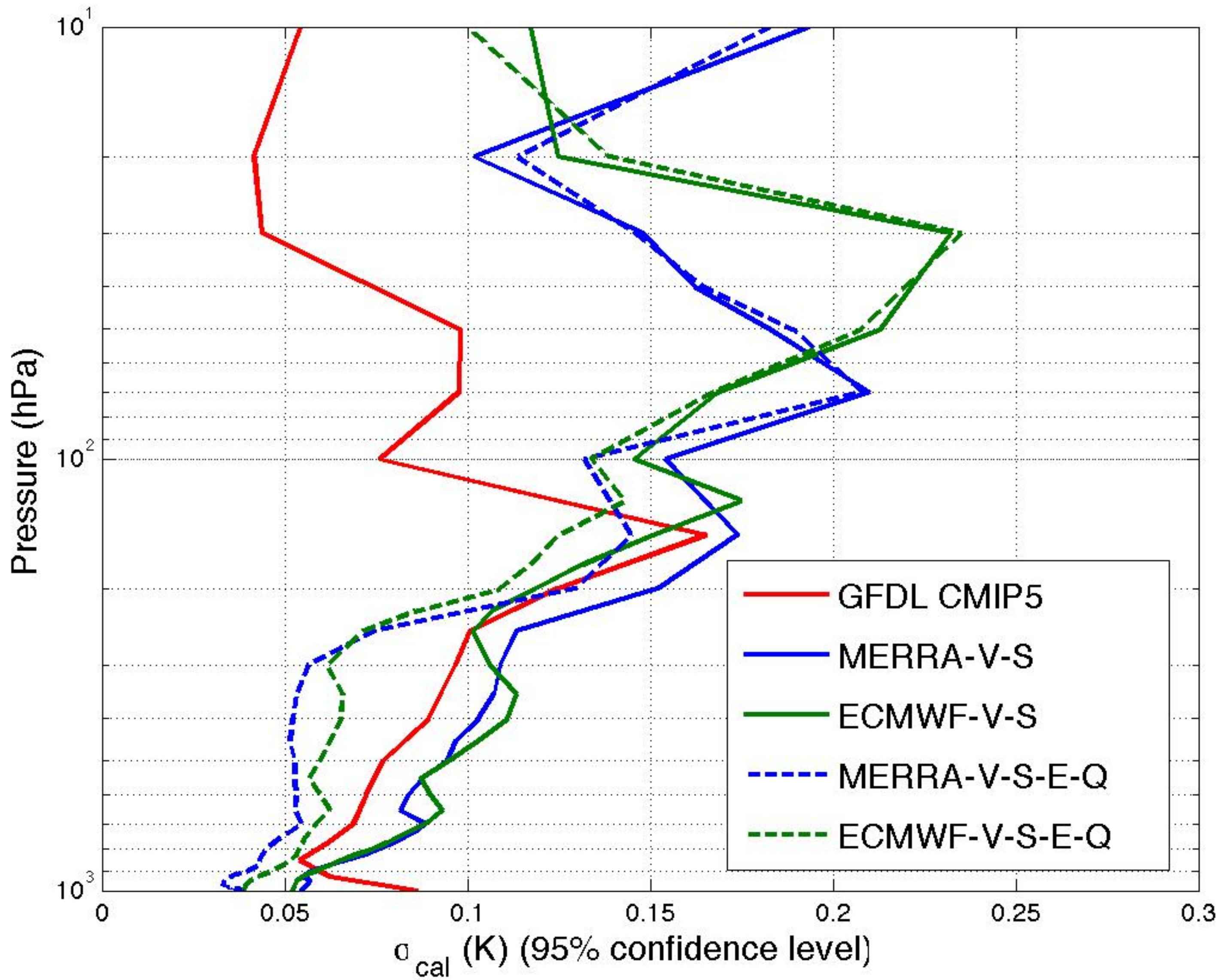


Temperature variability derived from MERRA, ECMWF and GFDL CMIP5





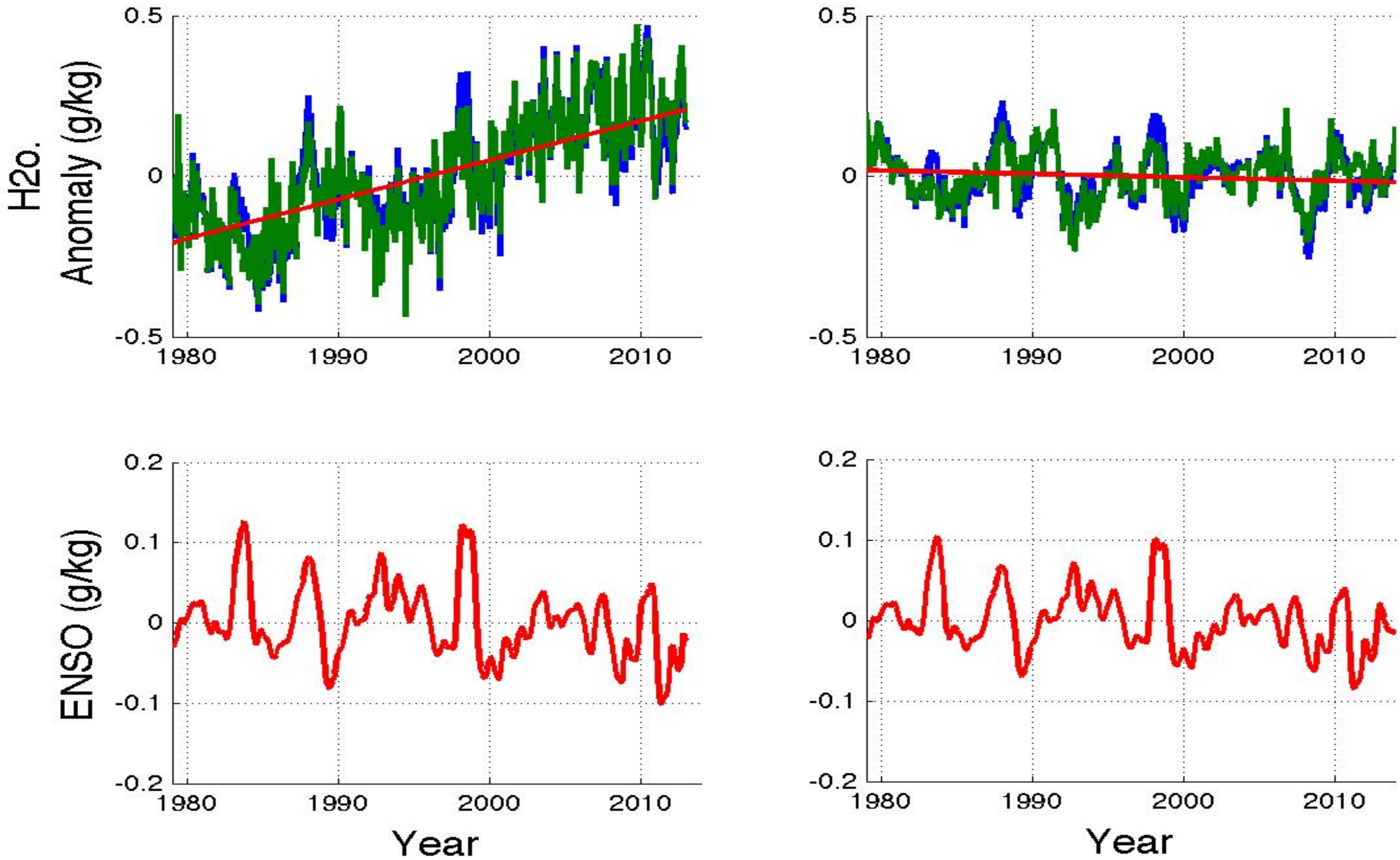
Temperature calibration requirement $U_a = 1.2$, $\tau_{cal} = 5$ years



Statistics of surface skin temperature variability
(U_a=1.2, τ_{cal}=5 years)

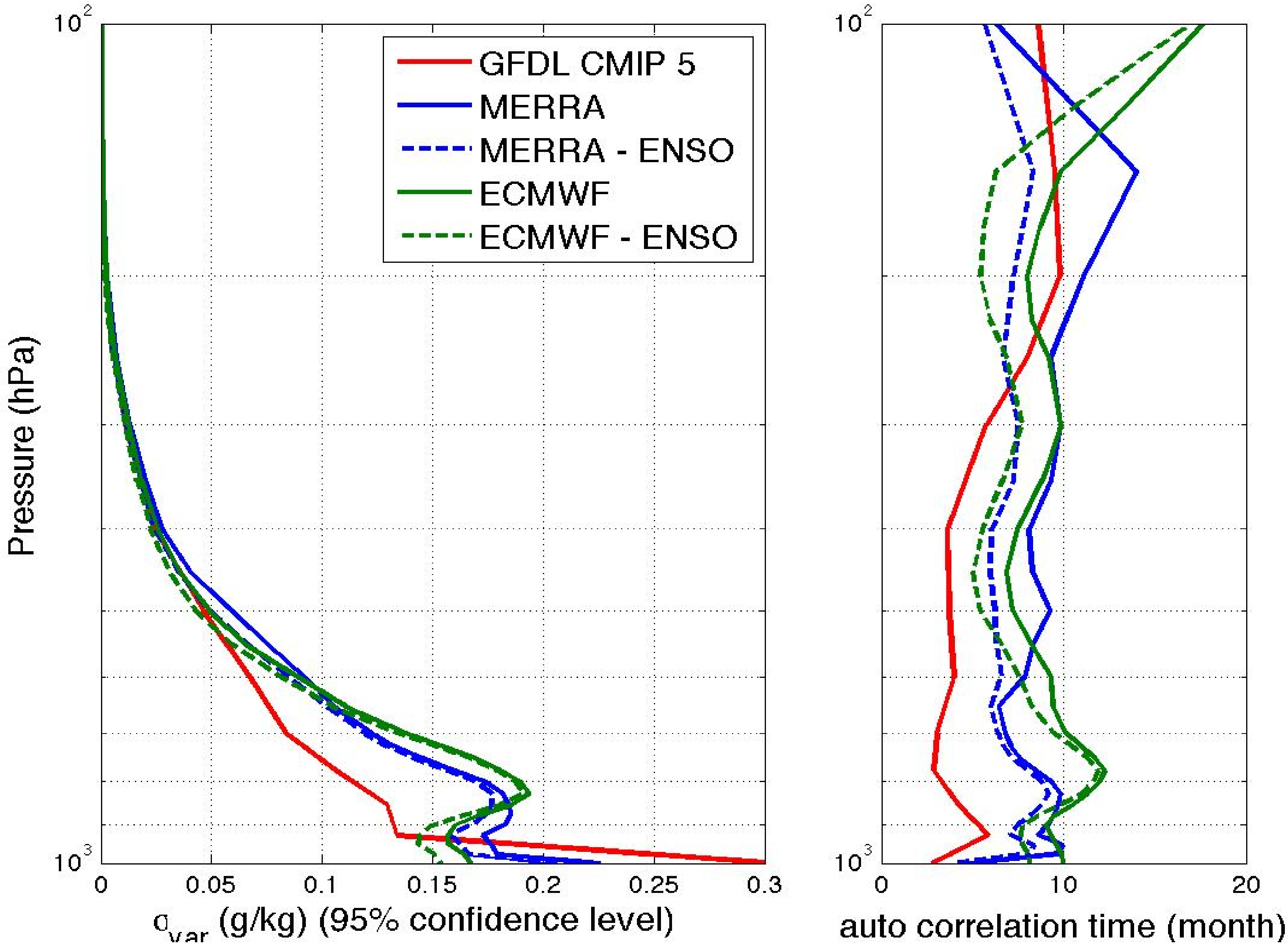
Tskin anomaly	σ_{var} (K)	τ_{var} (month)	σ_{cal} (K)
ECMWF (free of external forcing)	0.27	4.4	0.045
MERRA (free of external forcing)	0.28	5.1	0.054
GFDL CMIP5 (pi-Control run)	0.31	8.6	0.078
ECMWF (free of all forcing)	0.24	3.1	0.041
MERRA (free of all forcing)	0.24	3.4	0.045

Global humidity anomaly @ 1000 hPa

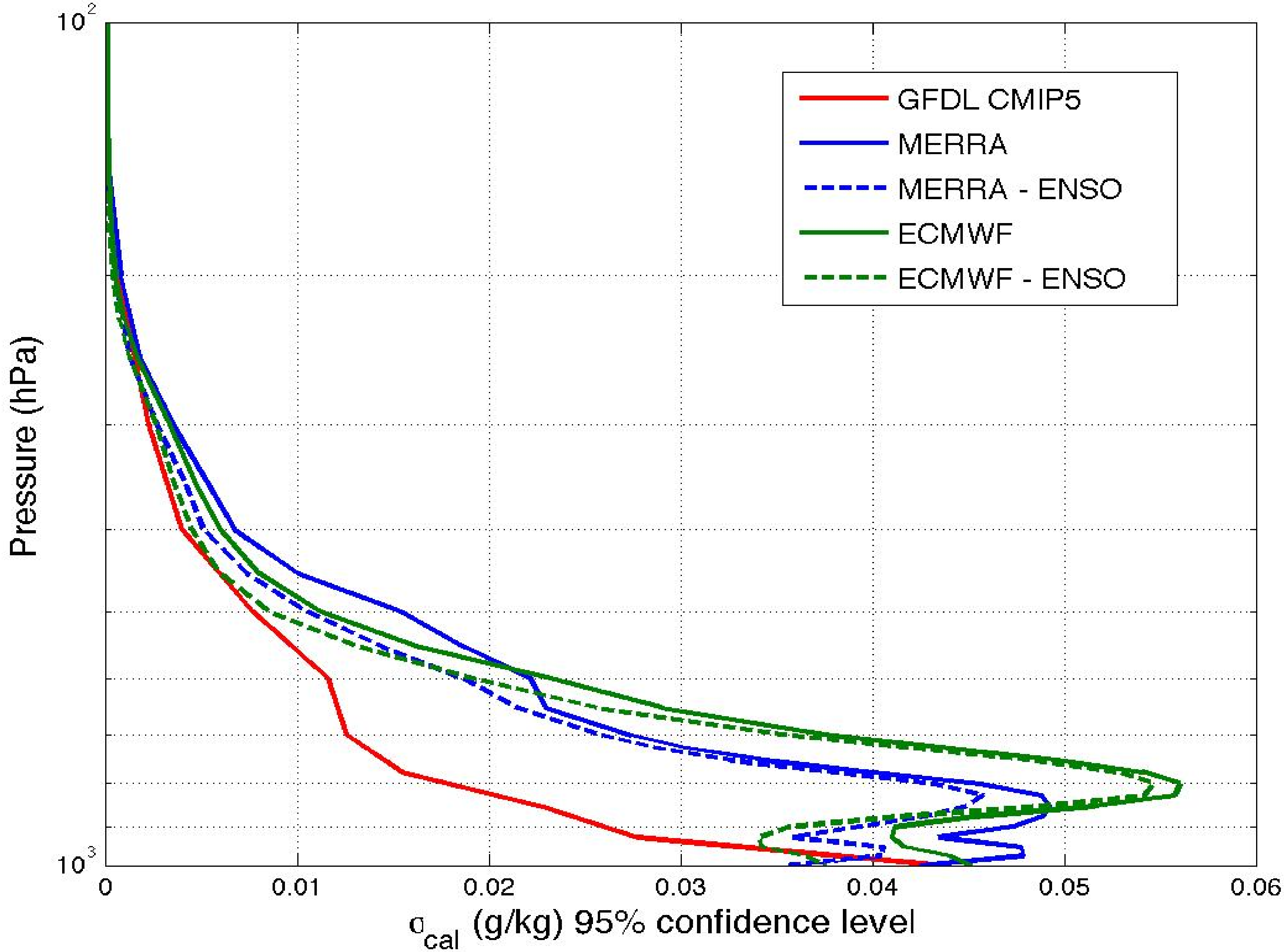


Humidity trend established from MERRA and ECMWF are very different, but magnitude of the internal variation are similar

Humidity variability derived from MERRA, ECMWF and GFDL CMIP5



Humidity calibration requirement $U_a = 1.2$, $\tau_{cal} = 5$ *years*



Summary for natural variability study

- The temperature and the specific humidity variability derived from the long term ECMWF data and that from the long term MERRA data are in similar scale.
- The humidity trend derived from the ECMWF data and that from MERRA data are very different, but the derived variability are similar
- The small natural variability near surface puts a stringent instrument calibration requirement
- Skin temperature requirements derived using MERRA, ECMWF data generally agree with each other

Part II
Spectral calibration requirement

Attribution of spectral calibration error to geophysical parameters

Optimal fingerprint attribution

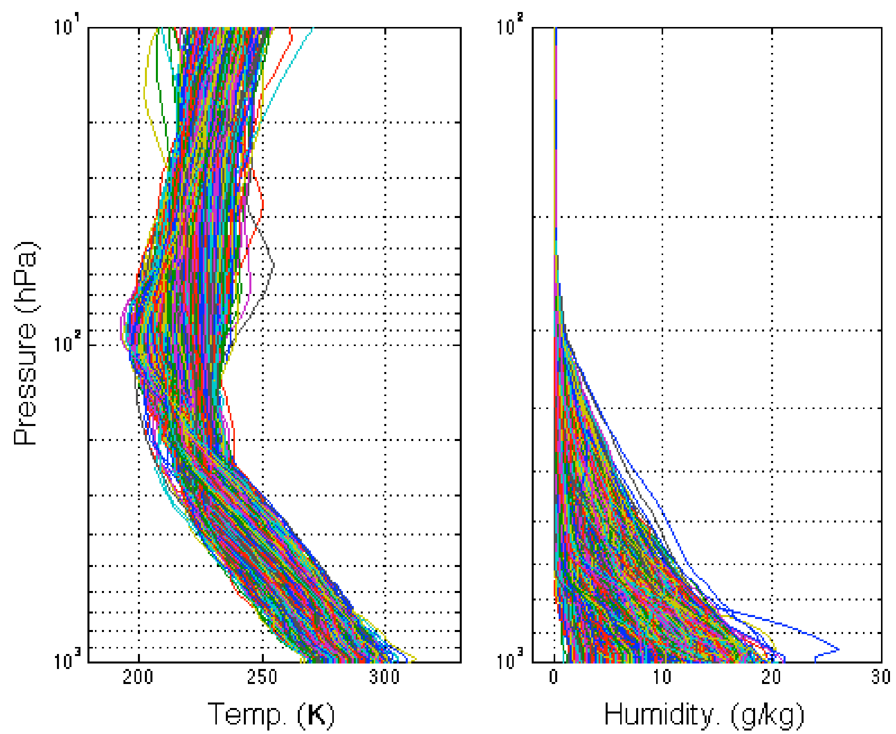
$$\overline{\Delta X} = (\overline{K}^T \Sigma_s^{-1} \overline{K} + \lambda H)^{-1} \overline{K}^T \Sigma_s^{-1} \overline{\Delta R}$$

Σ_s the covariance matrix that accounts for various error sources

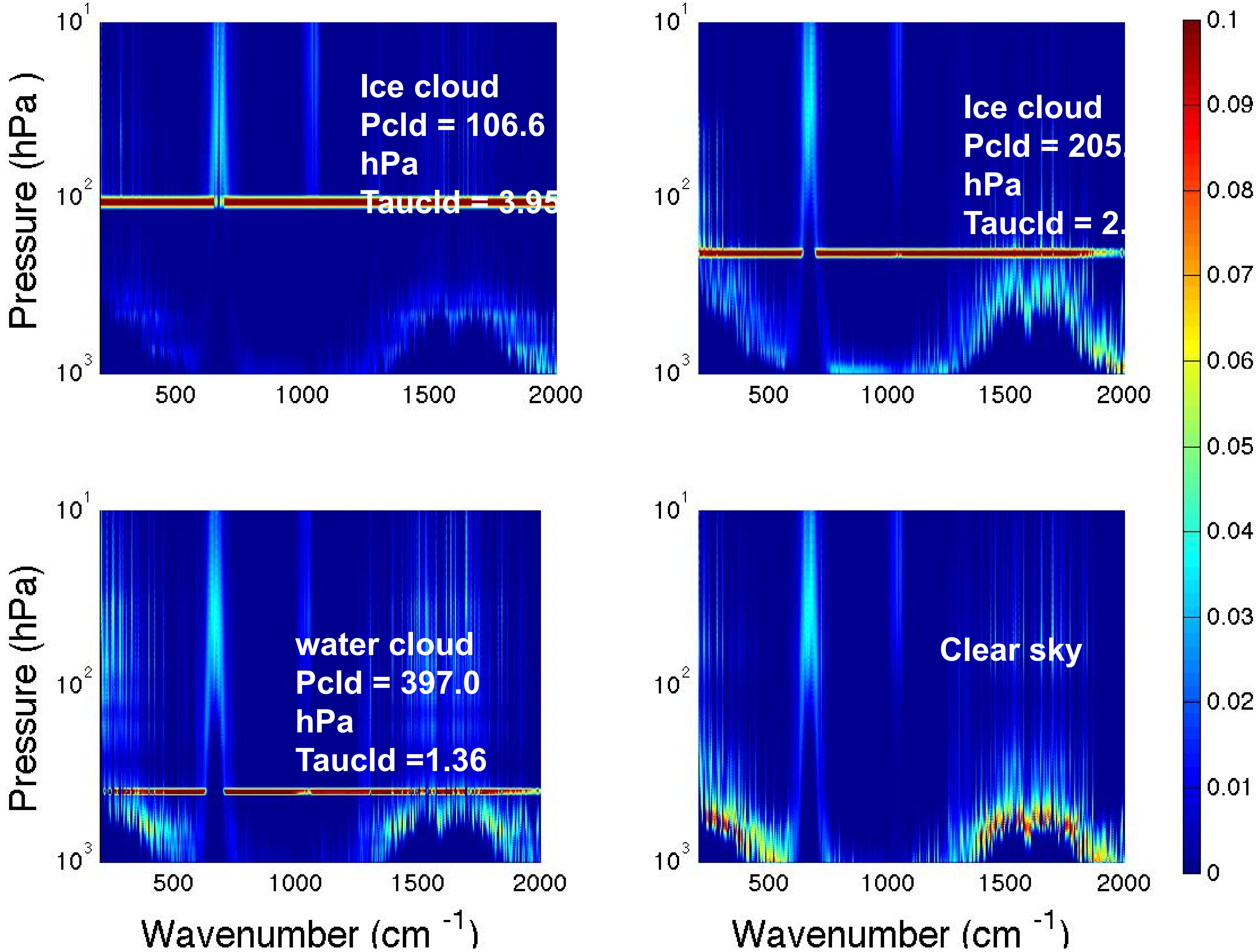
Attribution of spectral calibration error

$$\Delta X_{cal} = (\overline{K}^T \Sigma_s^{-1} \overline{K} + \lambda H)^{-1} \overline{K}^T \Sigma_s^{-1} \Delta R_{cal}$$

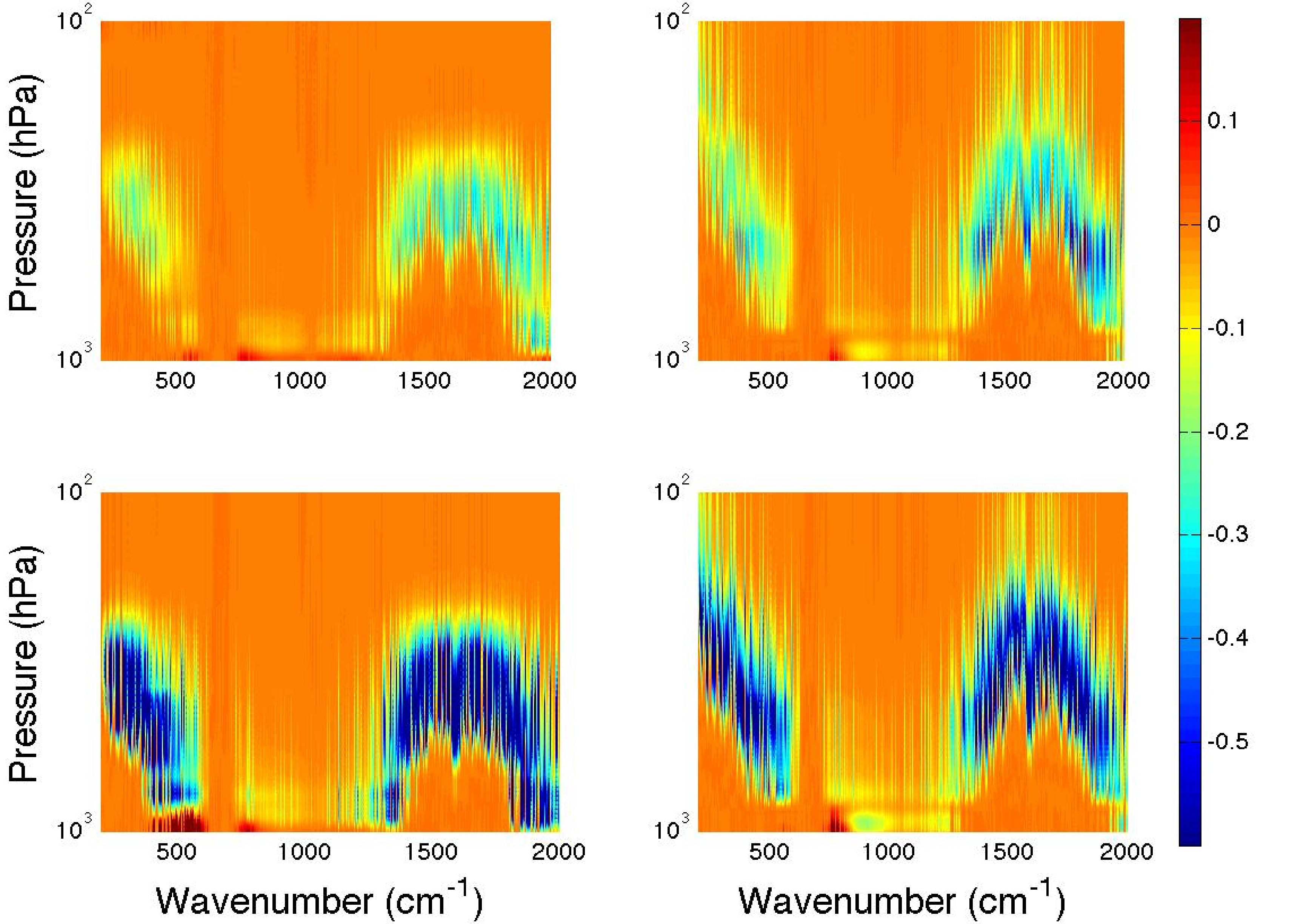
Globally distributed atmospheric profiles are use in the simulation study



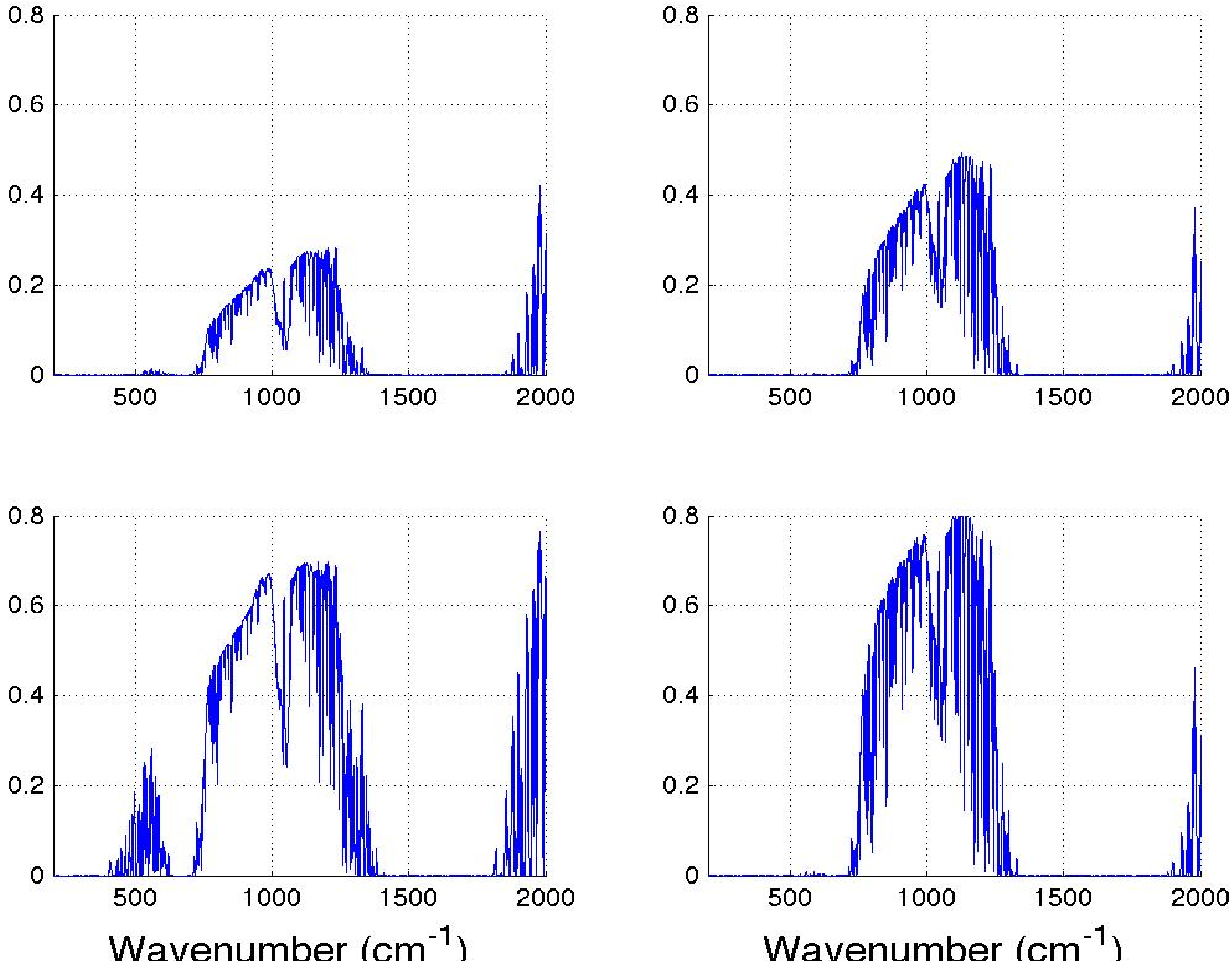
Temperature kernel matrix (Jacobian)



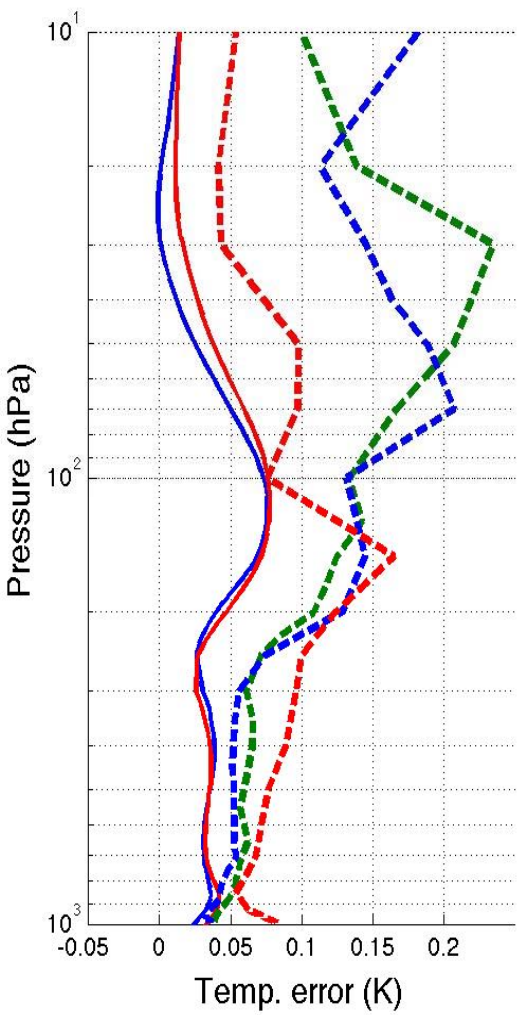
Humidity kernel matrix (Jacobian)

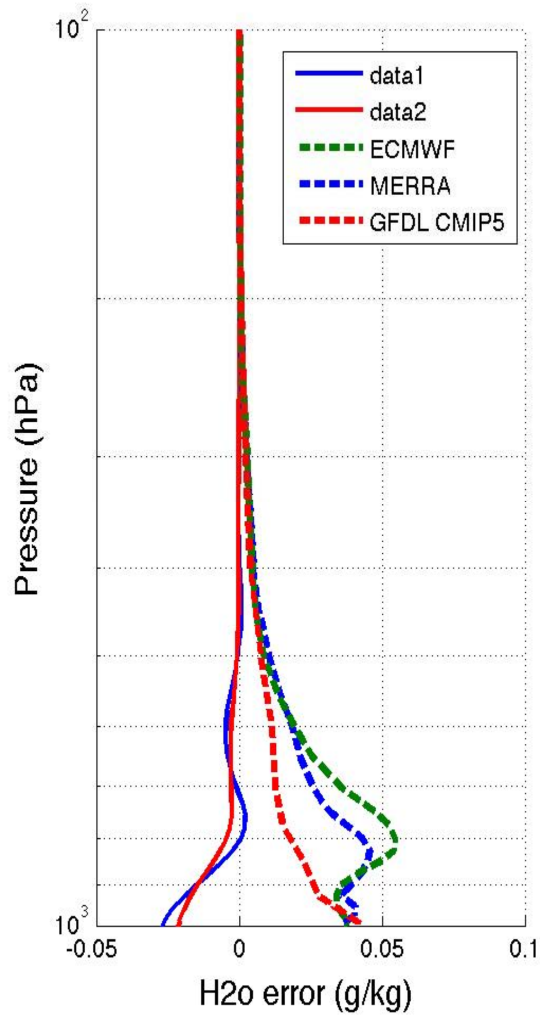


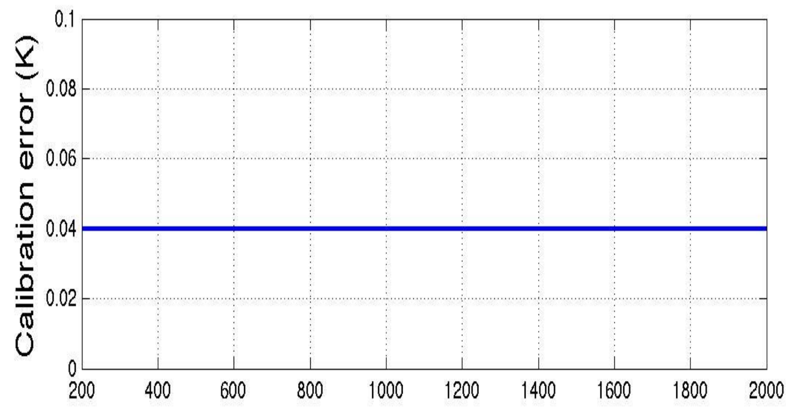
Surface skin temperature Jacobian

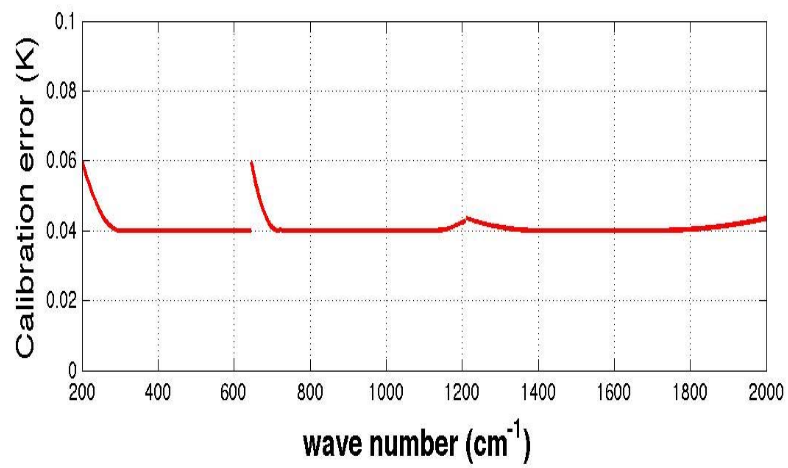


Spectral calibration errors and the associated error in temperature and humidity observation

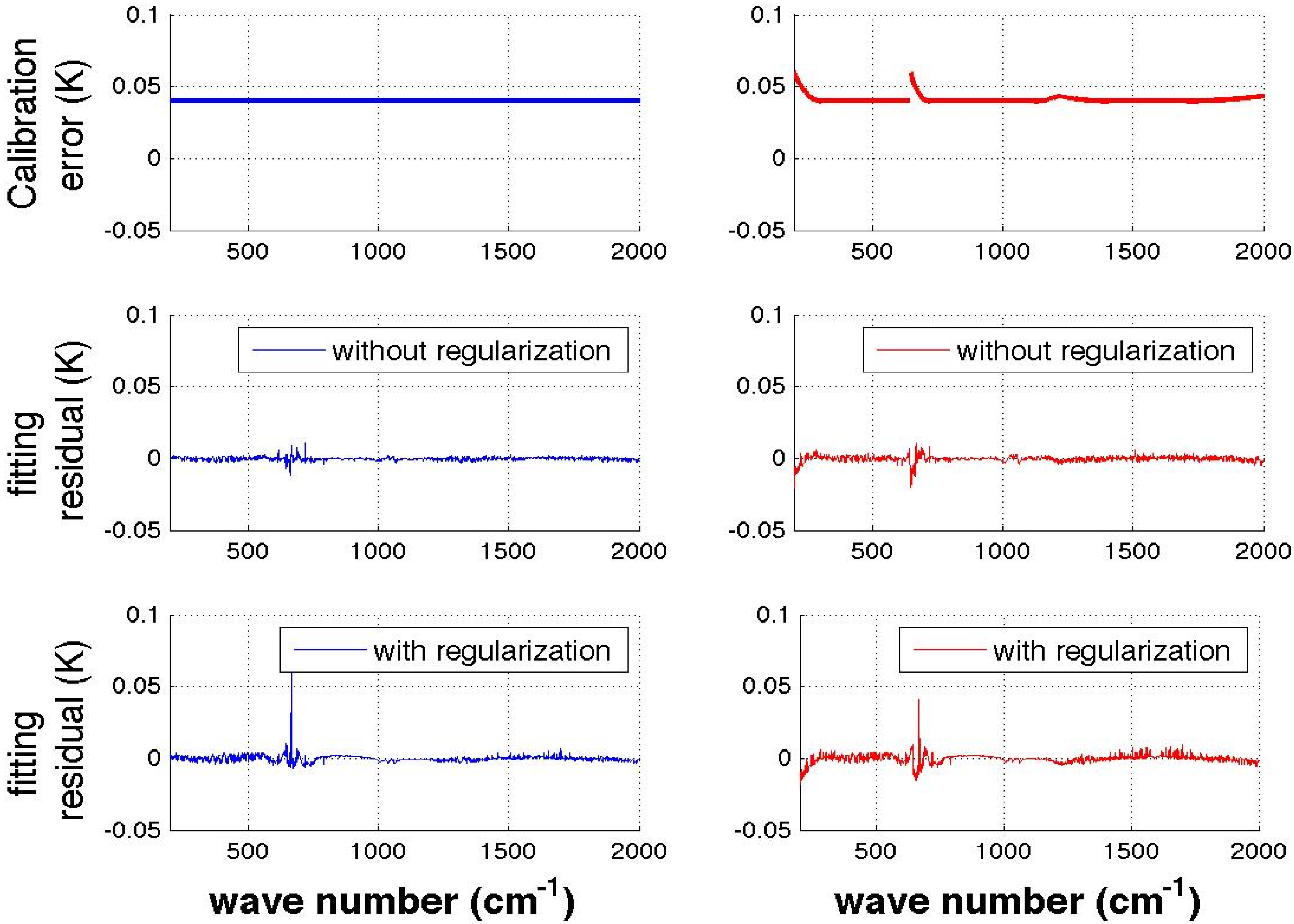




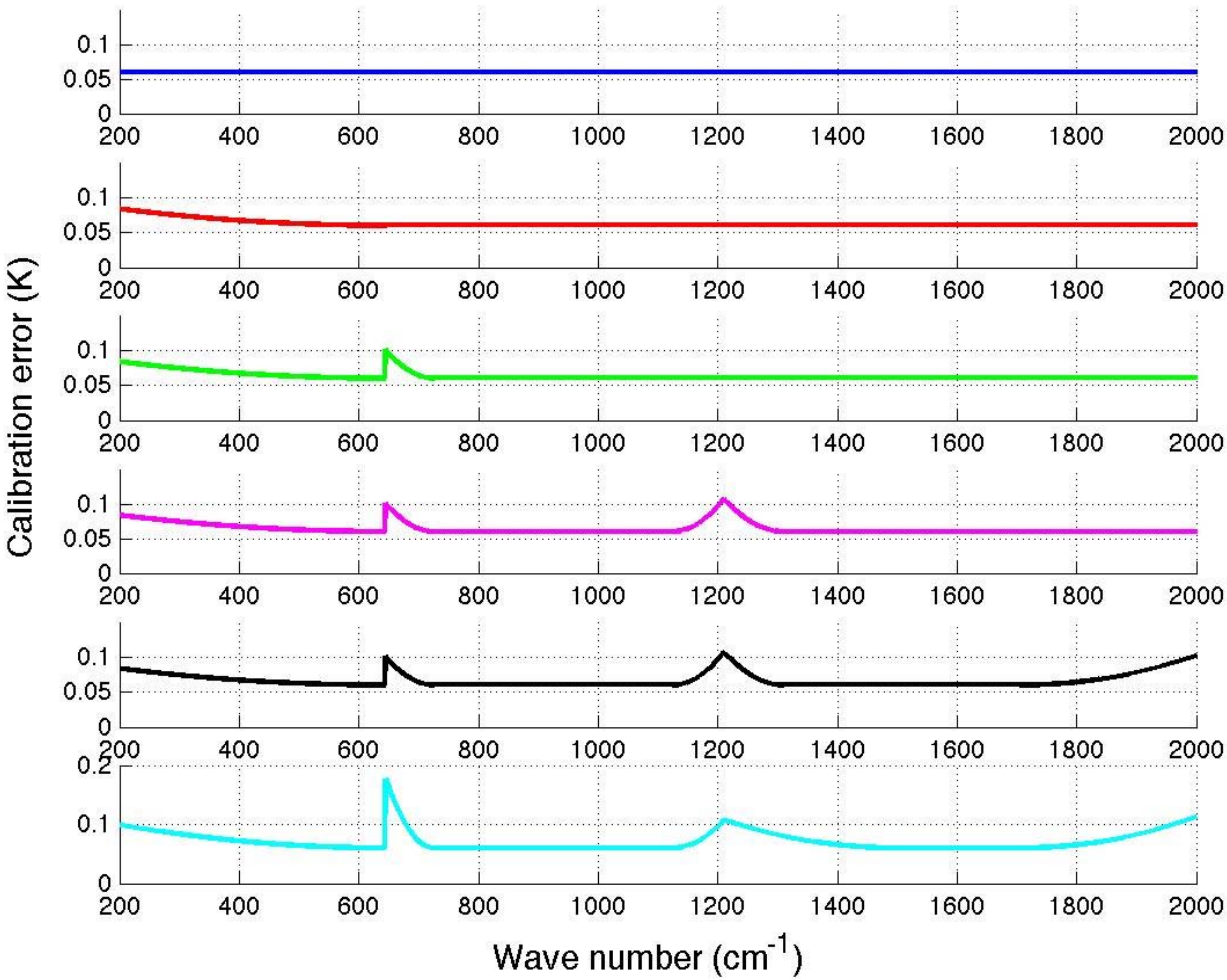




Radiance fitting residue



Calibration error tested

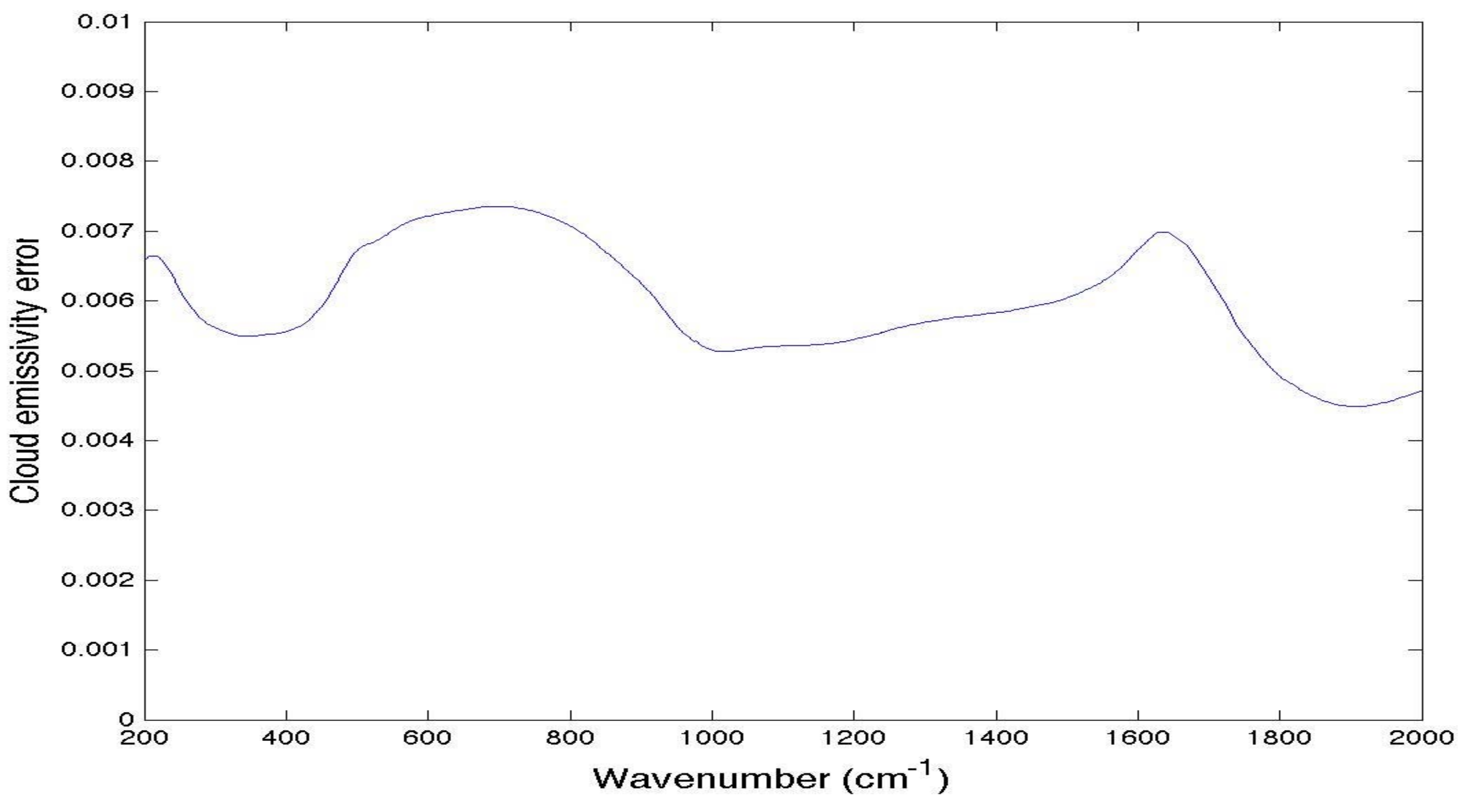


Spectral information of CLARREO

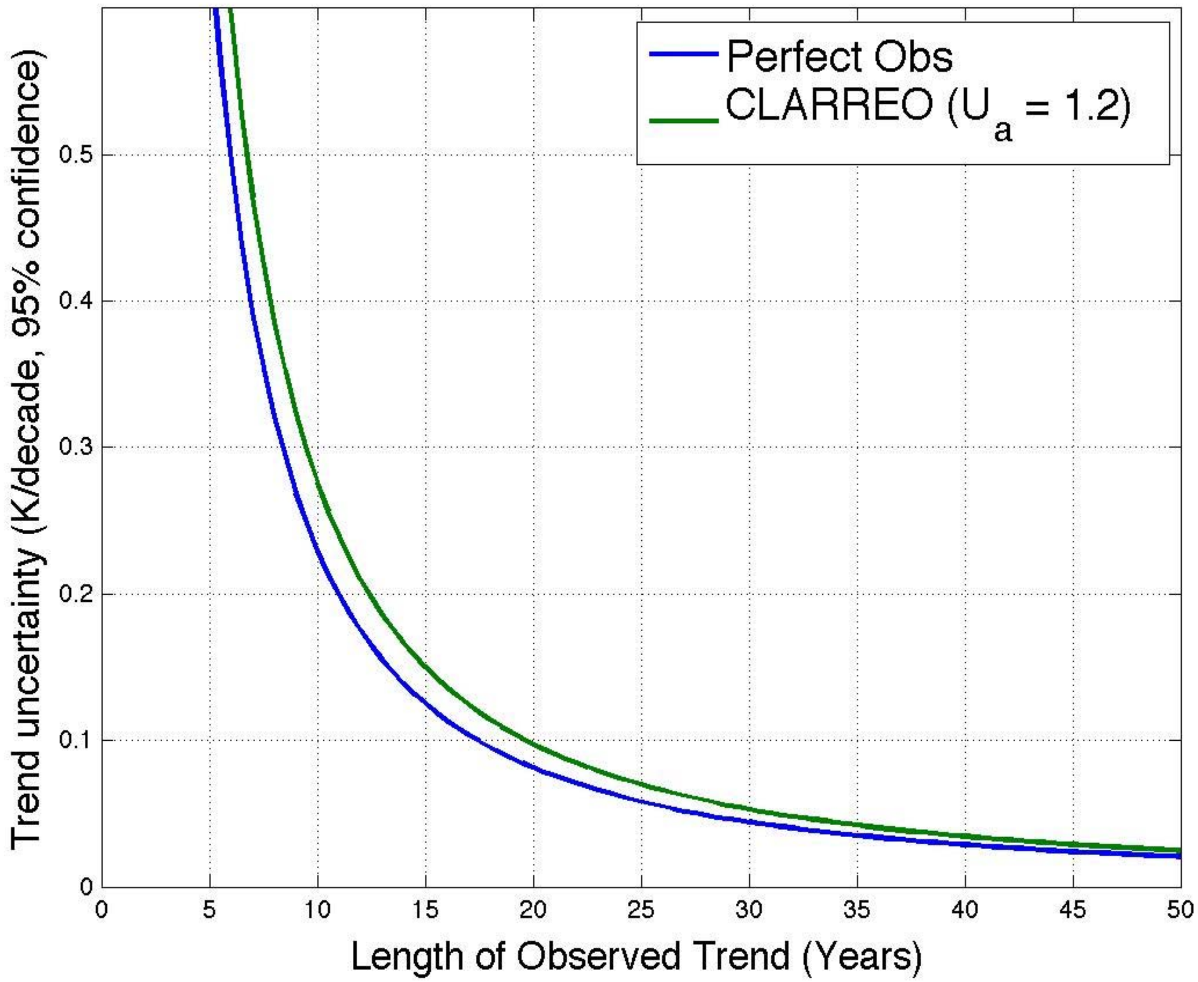
- Similar information is provided by three different spectral regions (in band 1 and band 3) 200 cm^{-1} ~645 cm^{-1}, 1210 cm^{-1} ~1600 cm^{-1}, 1600 cm^{-1} ~2000 cm^{-1}.
- Stratosphere temperature observation accuracy is determined by the spectral accuracy of CO_2 region (645 cm^{-1}~700 cm^{-1}).
- Information redundancy means the calibration requirement for certain channels can be relaxed, if we de-weight or eliminate the information contribution from the associated channels.
- IR detector tend to have larger calibration error near the band edge. The error around 200 cm^{-1}, around 1210 cm^{-1}, around 2000 cm^{-1} will affect surface to low altitude observation accuracy for both temperature and humidity, depending on how broad the noise spectra extend.

Error associated with other Parameters introduced by a 0.06K calibration error

	Skin temp. (K)	Cloud optical depth	Cloud particle size (μm)	Cloud top temp. (K)
σ_{cal}	0.06K	< 0.001	< 0.001	0.06K



1000 hPa Trend uncertainty based ECMWF natural variability and CLARREO instrument requirement



$$\delta m_P = \sqrt{\frac{12\sigma_{\text{var}}^2 \tau_{\text{var}}}{t^3}}$$

Summary

- 34 years MERRA and ECMWF reanalysis data provide a consistent evaluation of the natural variability for T(p) and H_2O(p)
- GFDL CMIP5 climate model gives similar natural variability in the troposphere
- The 0.04K (k=2) calibration accuracy is imposed by the requirement of observing the small variation of near surface air temperature
- The 0.04K calibration baseline will serve the purpose of observing the natural variability of
  - Temperature and water vapor vertical profiles
  - cloud properties
  - Surface temperature
- For climate fingerprinting application
  - Larger errors can be tolerated those spectral regions with redundant information
  - Potential larger calibration error at IR detector band edges can be well accommodated thanks to the rich information provided by the hyper-spectral sensor
- For intersatellite calibration and TOA flux calculations
  - It's better to keep spectral dependent calibration error small