Quantifying the Dependence of Changes in Instrument Calibration on Reflected Solar Satellite Cloud Retrievals
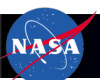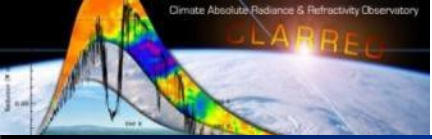
Yolanda Roberts[1], Bruce Wielicki[1], Sunny Sun-Mack[2], Pat Minnis[1], Lusheng Liang[2], Larry Di Girolamo[3]

[1]NASA Langley Research Center, Hampton, VA
[2]Science Systems and Applications, Inc. (SSAI), Hampton, VA
*[3]University of Illinois at Urbana-Champaign*

- **NASA's CLARREO** will provide the first *SI traceable* high accuracy spectral measurements of the reflected shortwave and emitted longwave *to detect* changes in Earth's climate

- CLARREO Intercalibration with other sensors will enable climate change observations of several variables

  – E.g. temperature & water vapor profiles, cloud properties, broadband radiation, ocean & land surface properties

- High *absolute accuracy* necessary for climate change observations

  – For rigorous climate model testing, reliable climate model predictions, and the resulting policy decisions.
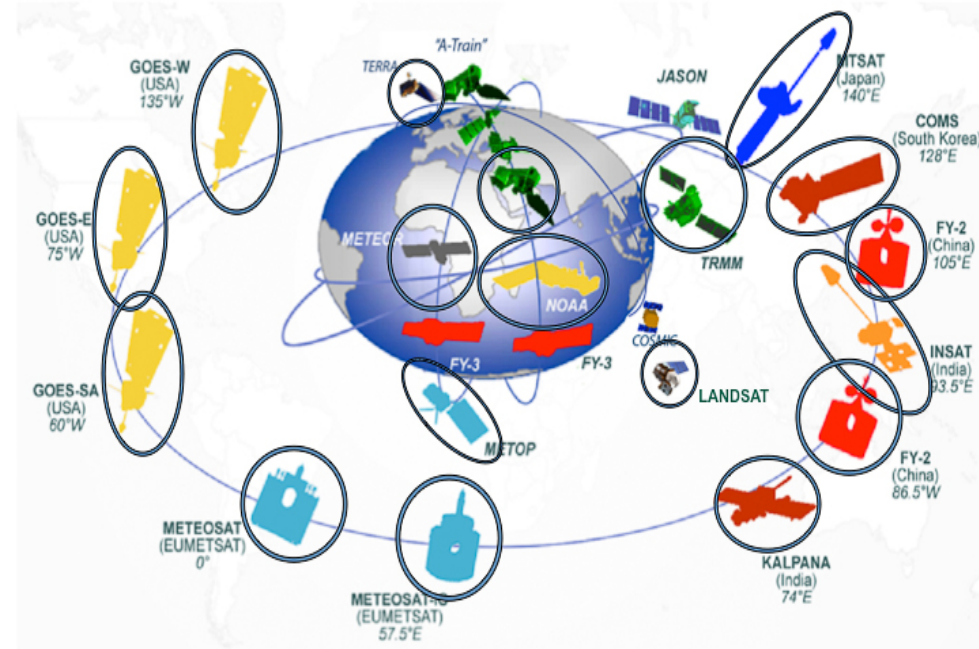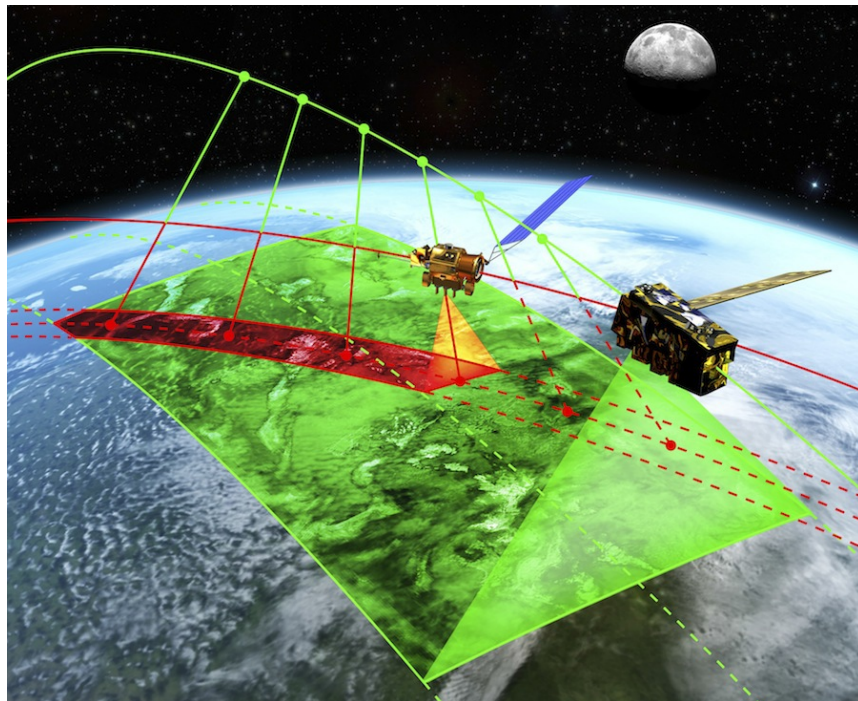
> How do we ensure to design these instruments with the accuracy required to observe changes in the climate system?
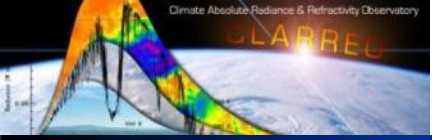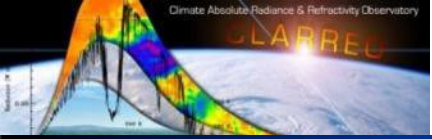
- CLARREO Intercalibration with potentially up to 40 other LEO and GEO sensors would enable climate change observations of several variables

  - E.g. temperature & water vapor profiles, cloud properties, broadband radiation, ocean & land surface properties
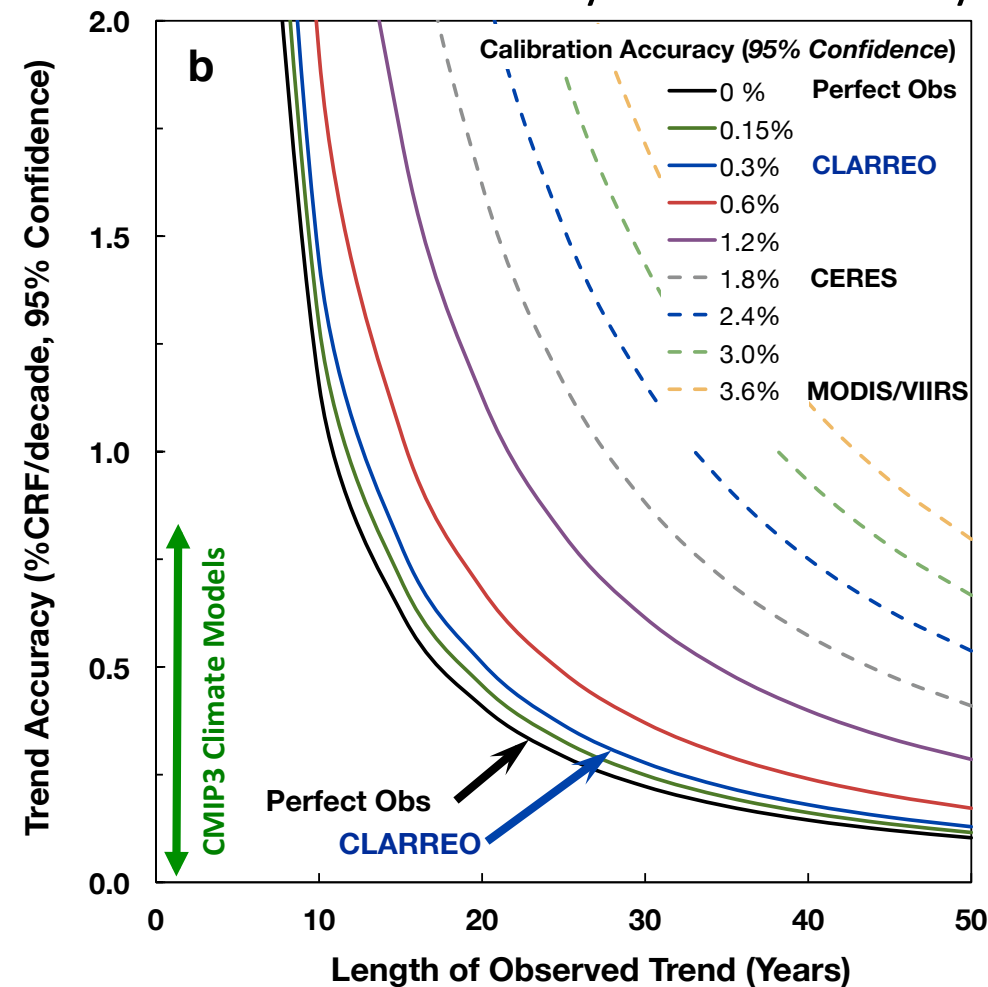
The accuracy of a perfect climate observing system is limited by the natural variability of the climate system [*Leroy et al., 2008*].
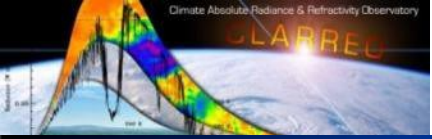

Variable Trend Uncertainty is Dependent Upon:

- Magnitude of natural variability
- How long trend is observed
- Climate Observing System Accuracy

CLARREO *BAMS* Article [*Wielicki et al., 2013*]

We are extending this trend accuracy analysis to cloud properties

Accuracy Uncertainty Factor

$$U_a = \sqrt{1 + \frac{\sigma_{Vcal}^2 \tau_{cal}}{\sigma_{var}^2 \tau_{var}}} = \frac{\text{Variable Trend Uncertainty for } \textbf{\textit{Actual}} \text{ Instrument}}{\text{Variable Trend Uncertainty for } \textbf{\textit{Perfect}} \text{ Instrument}}$$

Calculate natural variability terms from annually and globally (60S-60N) averaged cloud property time series

- σ_{Var}: Standard deviation
- τ_{Var}: Time between independent measurements – dependent on the lag-1 autocorrelation
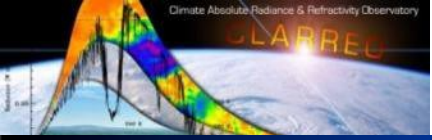
For an instrument **20% from perfect** $\longrightarrow$ $U_a = 1.2$

Estimated instrument lifetime used as calibration autocorrelation time $\longrightarrow$ $\tau_{cal} = 5$ Years
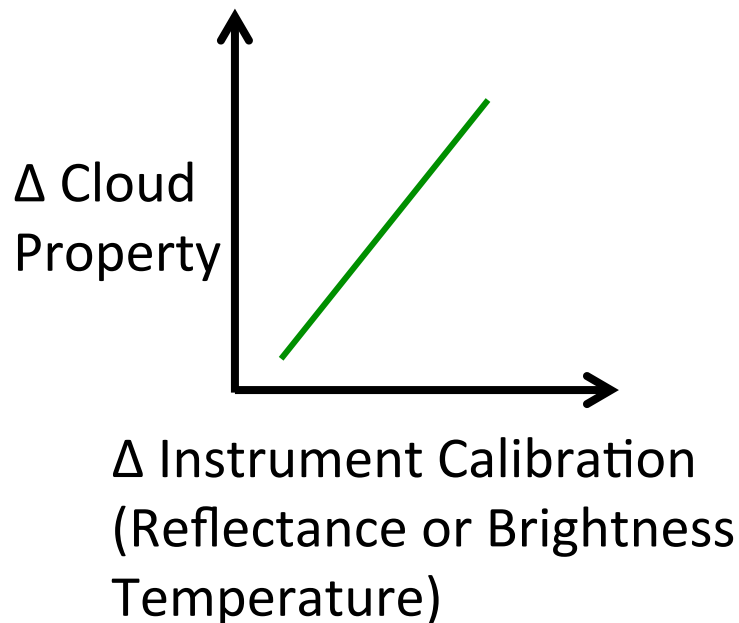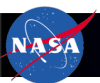
From the *accuracy uncertainty ratio*, we get the calibration uncertainty *as a function of the cloud property* in question.

$$U_a = \sqrt{1 + \frac{\sigma_{Vcal}^2 \tau_{cal}}{\sigma_{var}^2 \tau_{var}}}$$
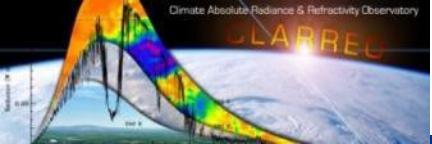
We need the sensitivity of retrieved cloud property to changes in instrument calibration.

Δ Cloud
Property

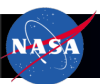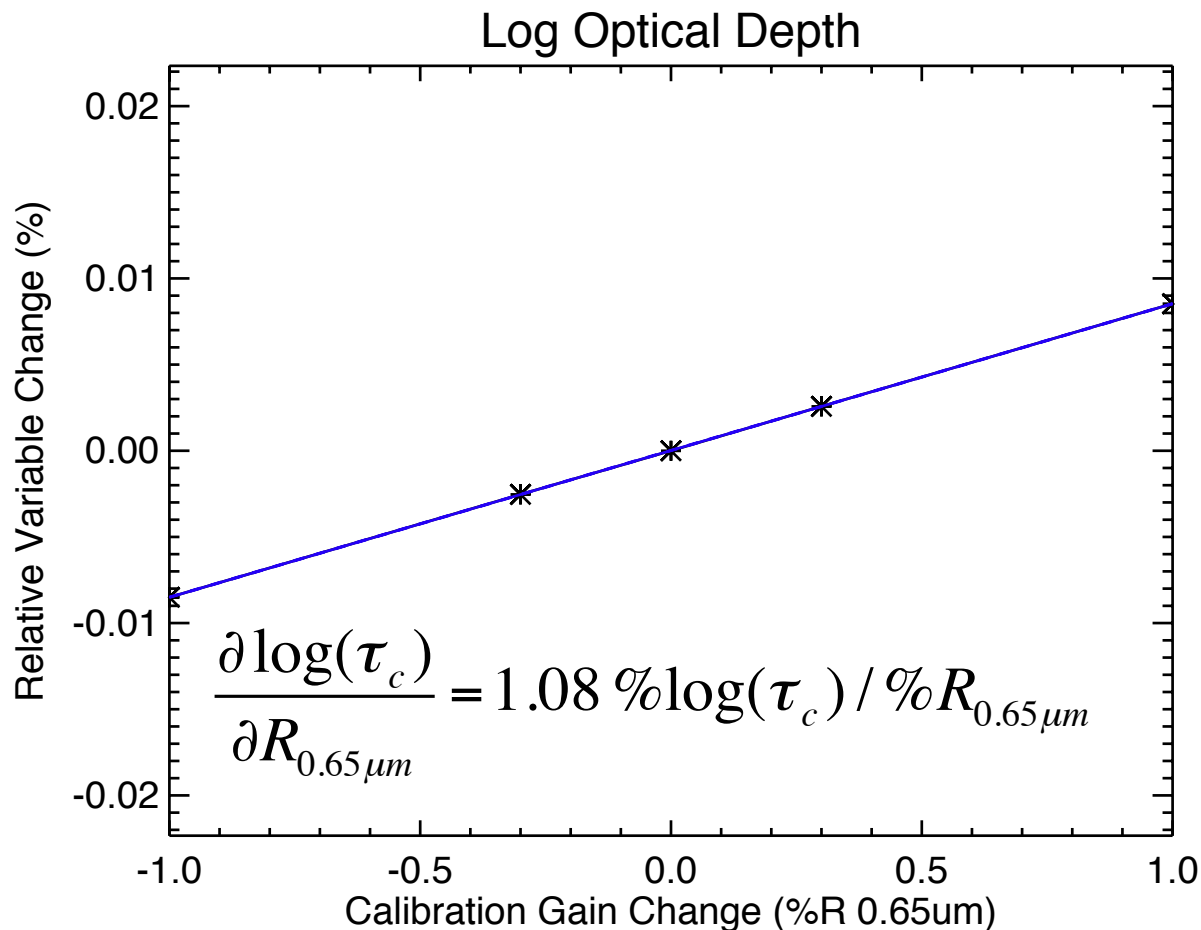$$\frac{\partial(\text{Cloud Property})}{\partial(\text{Instrument Calibration}_\lambda)}$$

Δ Instrument Calibration
(Reflectance or Brightness
Temperature)

CERES-MODIS algorithm primarily uses 0.65 μm MODIS
Reflectance to retrieve Cloud Optical Thickness (τ_c)

Log Optical Depth

$$\frac{\partial \log(\tau_c)}{\partial R_{0.65\mu m}} = 1.08 \, \% \log(\tau_c) / \% R_{0.65\mu m}$$

How sensitive is log(τ_c) trend uncertainty to different calibration uncertainties?

0.65 µm Calibration Uncertainty
(95% Confidence)

Perfect: 0.00%
0.15%
0.21%
CLARREO: 0.30%
0.60%
1.20%
1.80%
2.40%
3.00%
MODIS/VIIRS: 3.60%
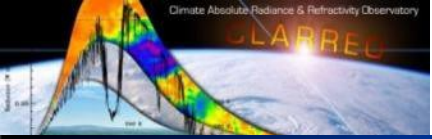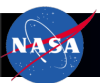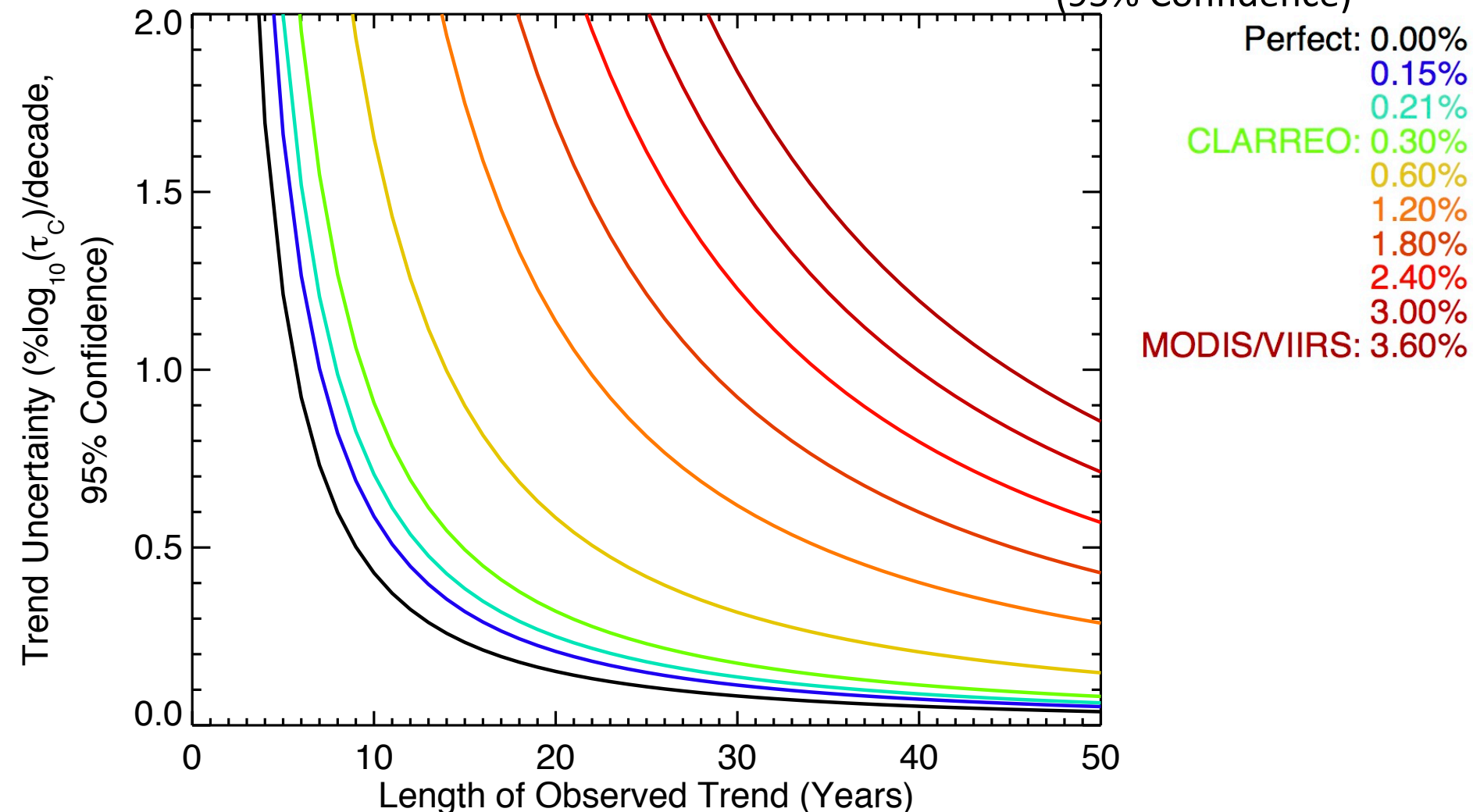
How does this compare to the time to detect trends in CRF?

0.65 µm Calibration Uncertainty
(95% Confidence)

Left plot axes: Trend Uncertainty (%log$_{10}$(τ_c)/decade, 95% Confidence) vs. Length of Observed Trend (Years)

- Perfect: 0.00%
- 0.15%
- 0.21%
- CLARREO: 0.30%
- 0.60%
- 1.20%
- 1.80%
- 2.40%
- 3.00%
- MODIS/VIIRS: 3.60%

Right plot (b) axes: Trend Accuracy (%CRF/decade, 95% Confidence) vs. Length of Observed Trend (Years)

Calibration Accuracy (*95% Confidence*)
- 0 %   Perfect Obs
- 0.15%
- 0.3%   CLARREO
- 0.6%
- 1.2%
- 1.8%   CERES
- 2.4%
- 3.0%
- 3.6%   MODIS/VIIRS

CMIP3 Climate Models

Perfect Obs
CLARREO
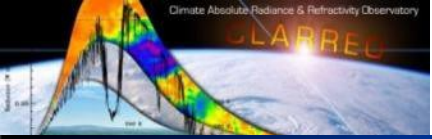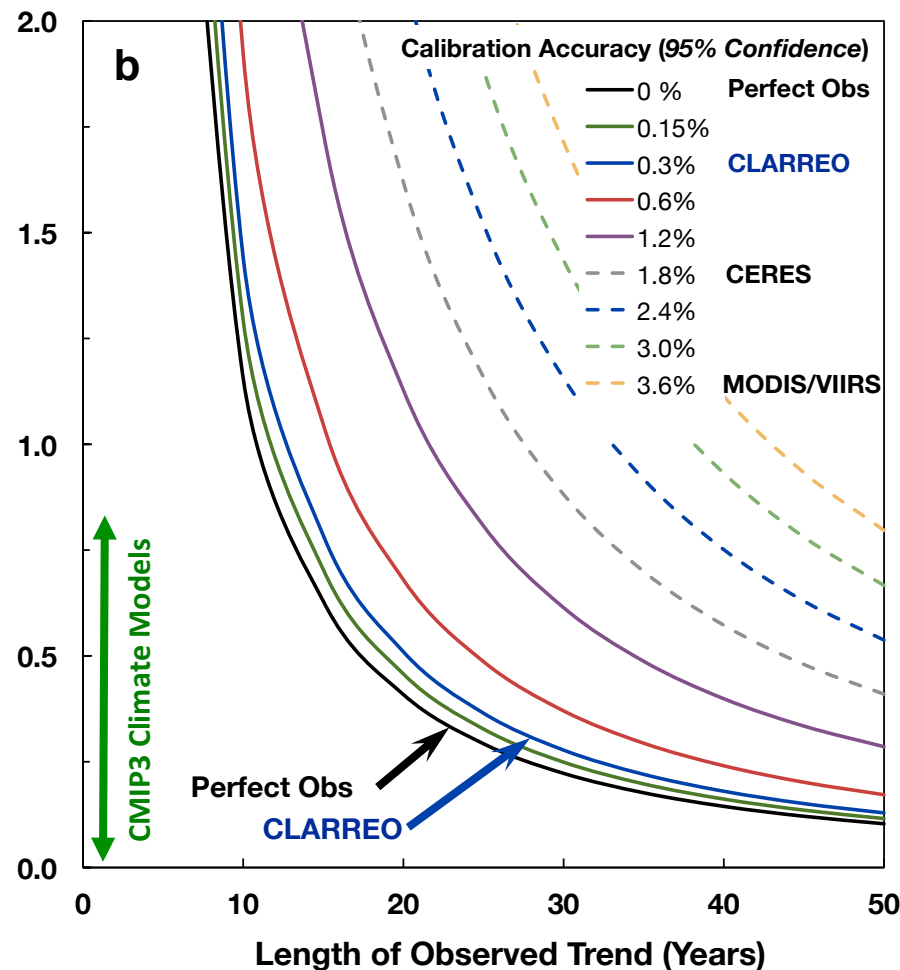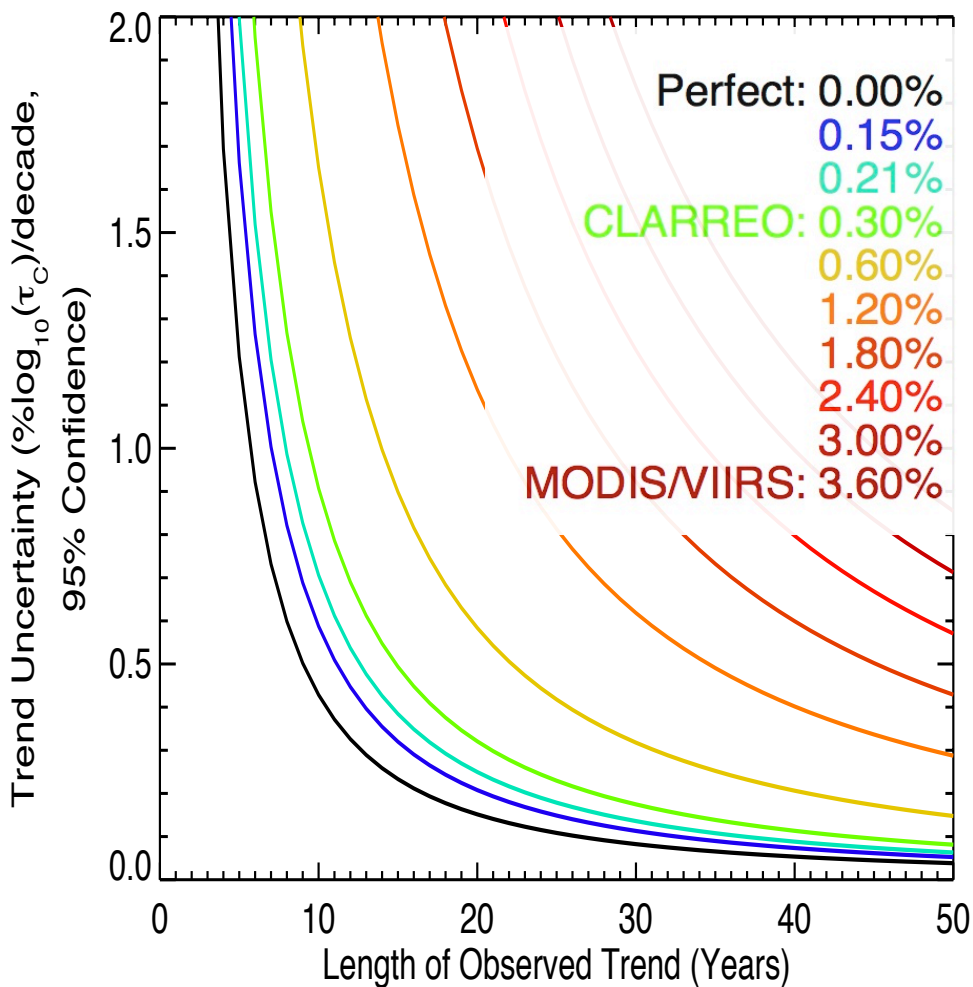
May be able to detect trends in τ_c faster than in CRF.
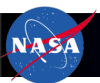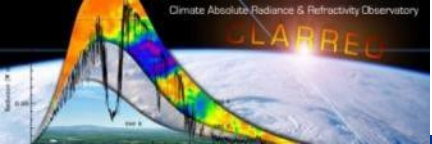
CERES-MODIS algorithm primarily uses 0.65 μm MODIS
Reflectance to retrieve Cloud Optical Thickness (τ$_c$)

Log Optical Depth

$$\frac{\partial \log(\tau_c)}{\partial R_\lambda}$$

Absolute Variable Change (y-axis, left): 0.02, 0.01, 0.00, -0.01, -0.02

Relative Change (%) (y-axis, right): 2, 1, 0, -1, -2

Calibration Gain (%R) or Bias (K BT) Change (x-axis): -1.0, -0.5, 0.0, 0.5, 1.0

Legend:
- 0.65 μm
- 3.8 μm
- 11 μm
- 12 μm
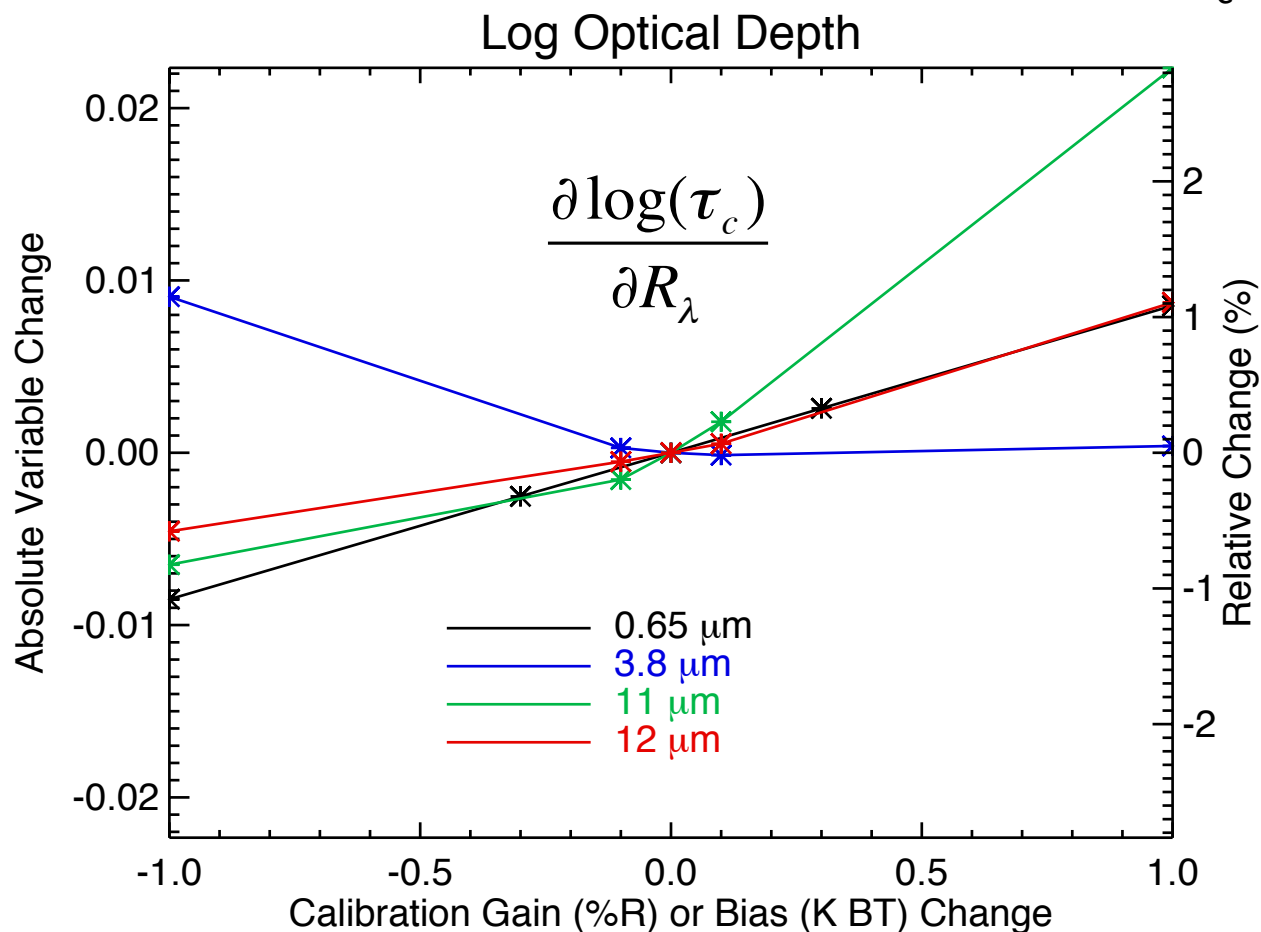
Cloud Fraction changes from imposed calibration changes feed into τ$_c$ changes
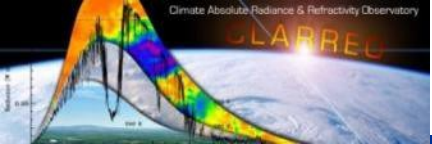
Sensitivity between calibration changes and variable change with and without clear-sky updating.

Clear-Sky Updating vs Start-up Maps 0.65μm

Sensitivity between calibration changes and variable change with and without clear-sky updating.

Clear-Sky Updating vs Start-up Maps 0.65μm
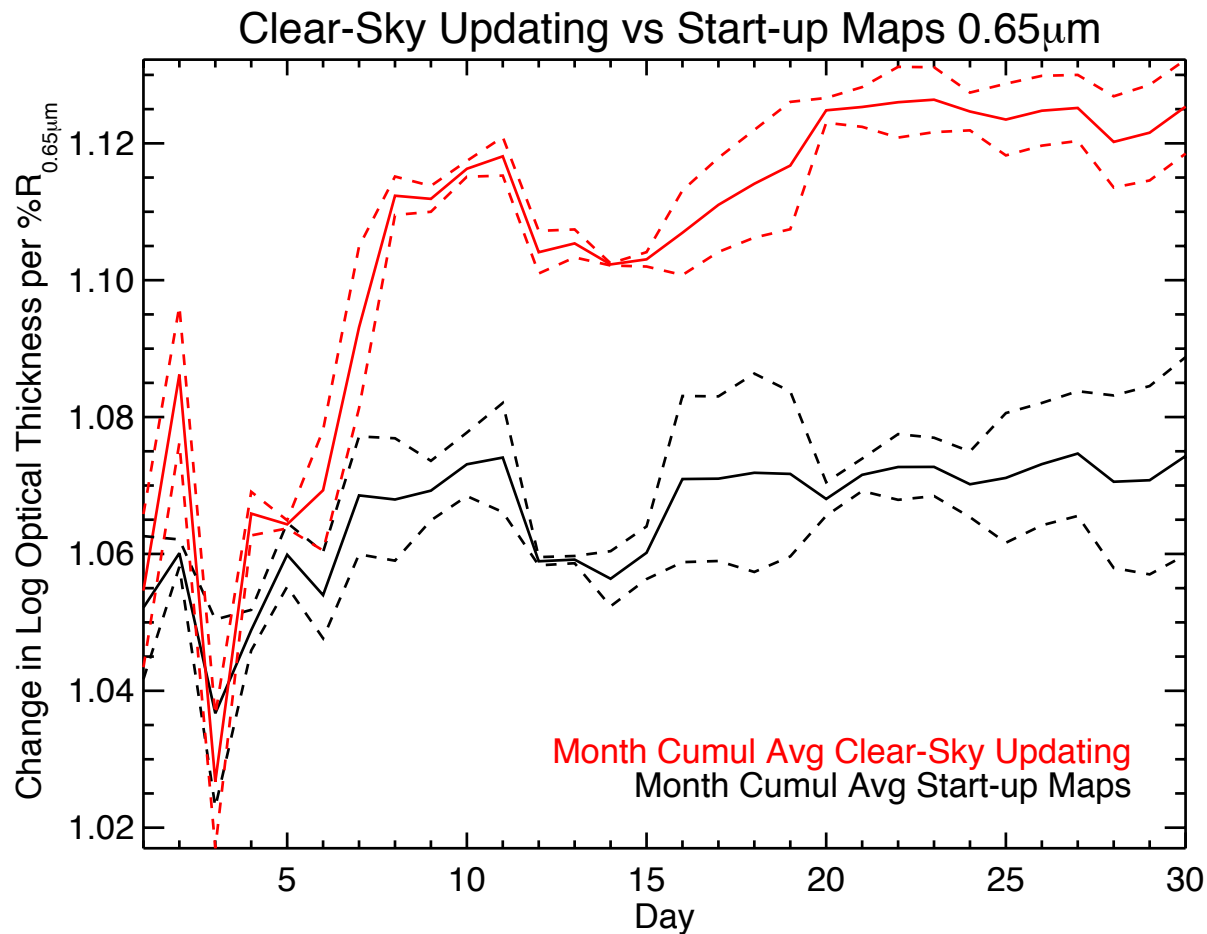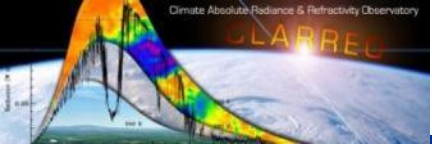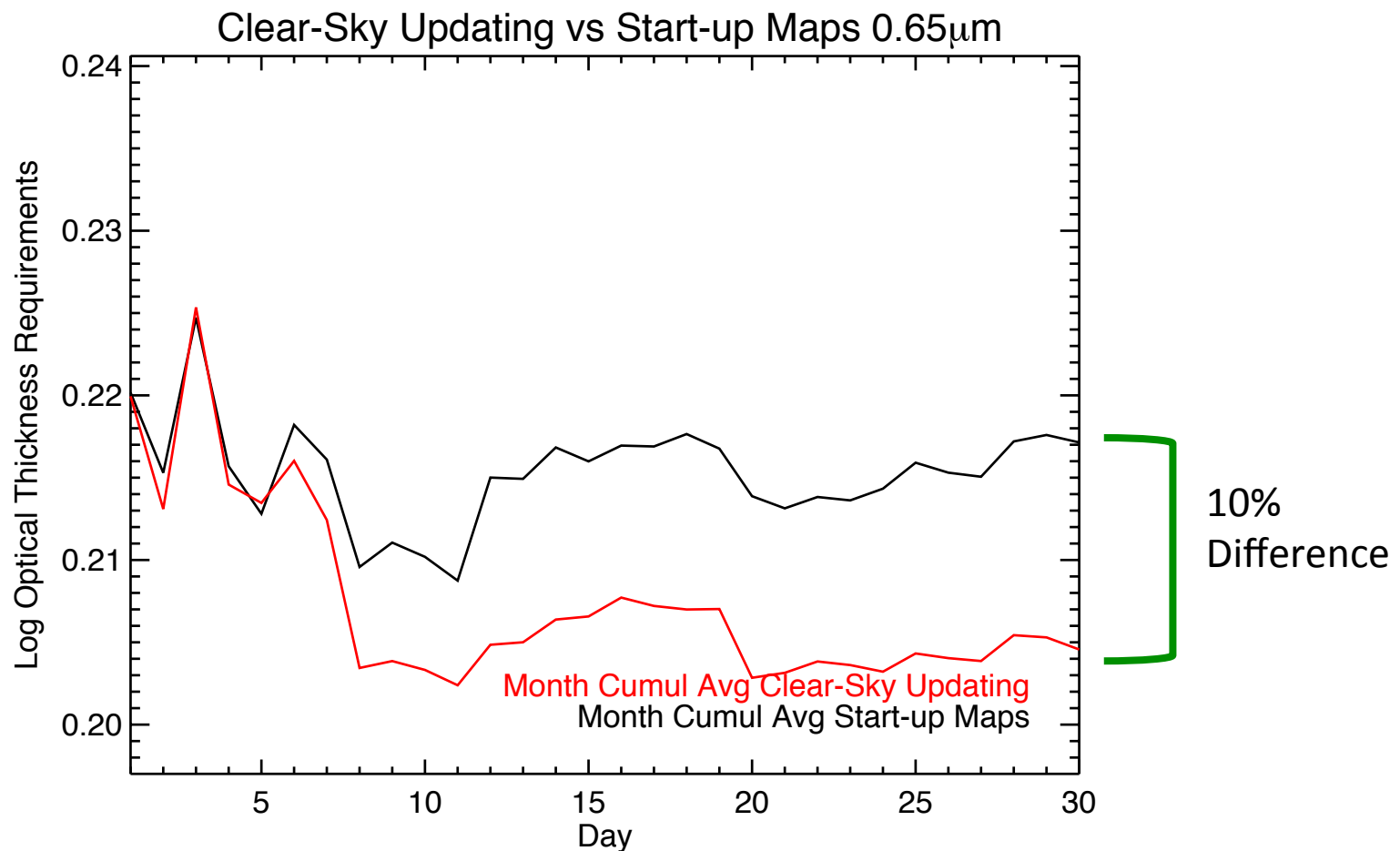
We will add the clear-sky updating error as additional error to requirements.
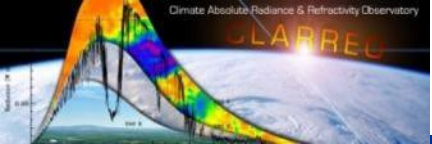
CERES CPRS primarily uses 11 µm MODIS Brightness Temperature to retrieve Cloud Effective Temperature

Eff. Temperature (Day) (K)

$$\frac{\partial T_{Eff}}{\partial BT_{11\mu m}} = 1.02 \; K \, / \, K_{11\mu m}$$
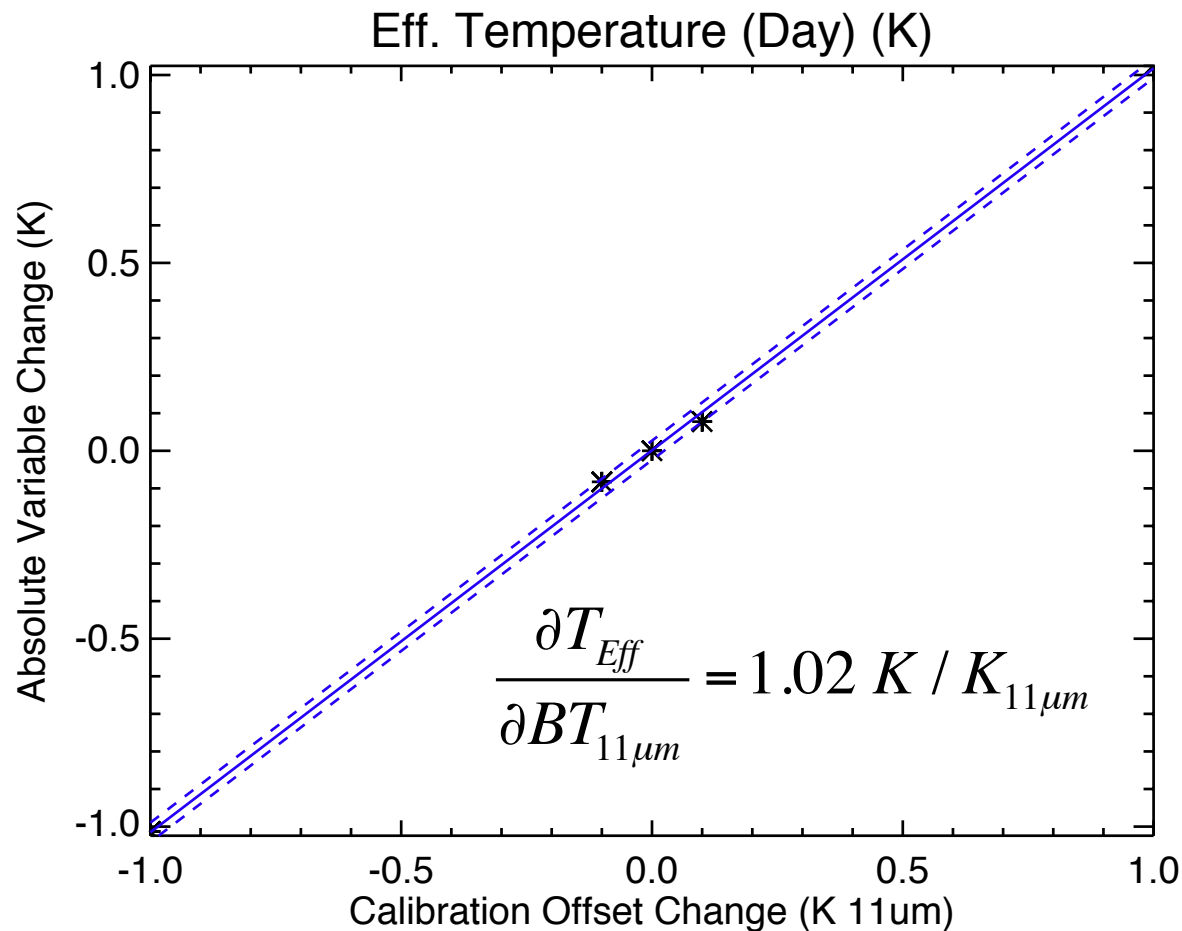
How sensitive is T$_{Eff}$ trend uncertainty to different calibration uncertainties?

11 μm Calibration Uncertainty
(95% Confidence)

Perfect: 0.00K
0.03K
CLARREO: 0.06K
0.12K
0.18K
0.24K
AIRS/IASI/CrIS 0.30K
0.36K
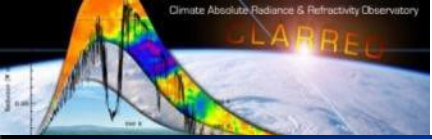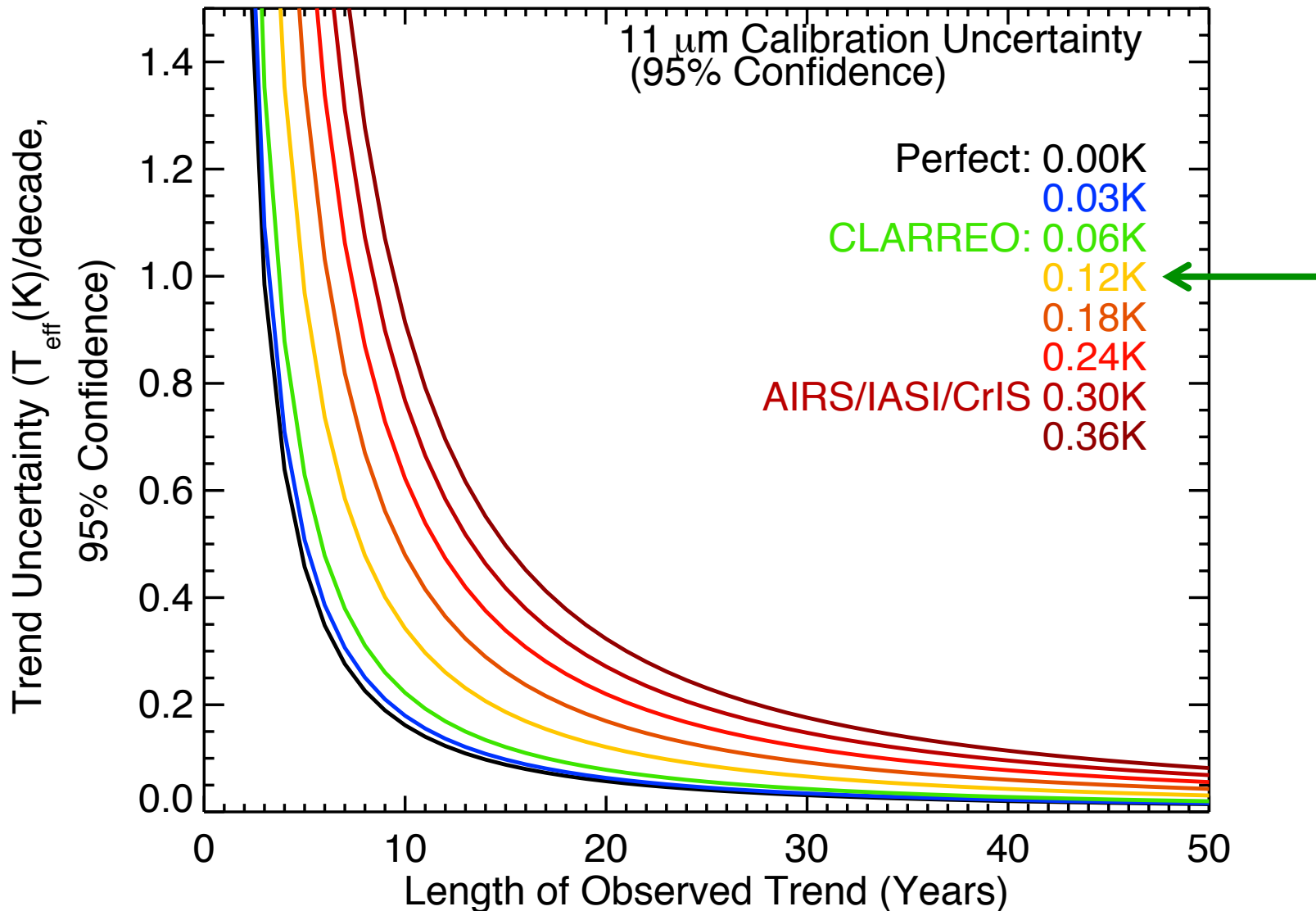
How do changes in other bands impact Cloud Effective Temperature?
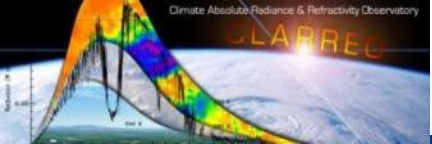
CERES CPRS primarily uses 11 μm MODIS Brightness
Temperature to retrieve Cloud Effective Temperature

Eff. Temperature (Day) (K)
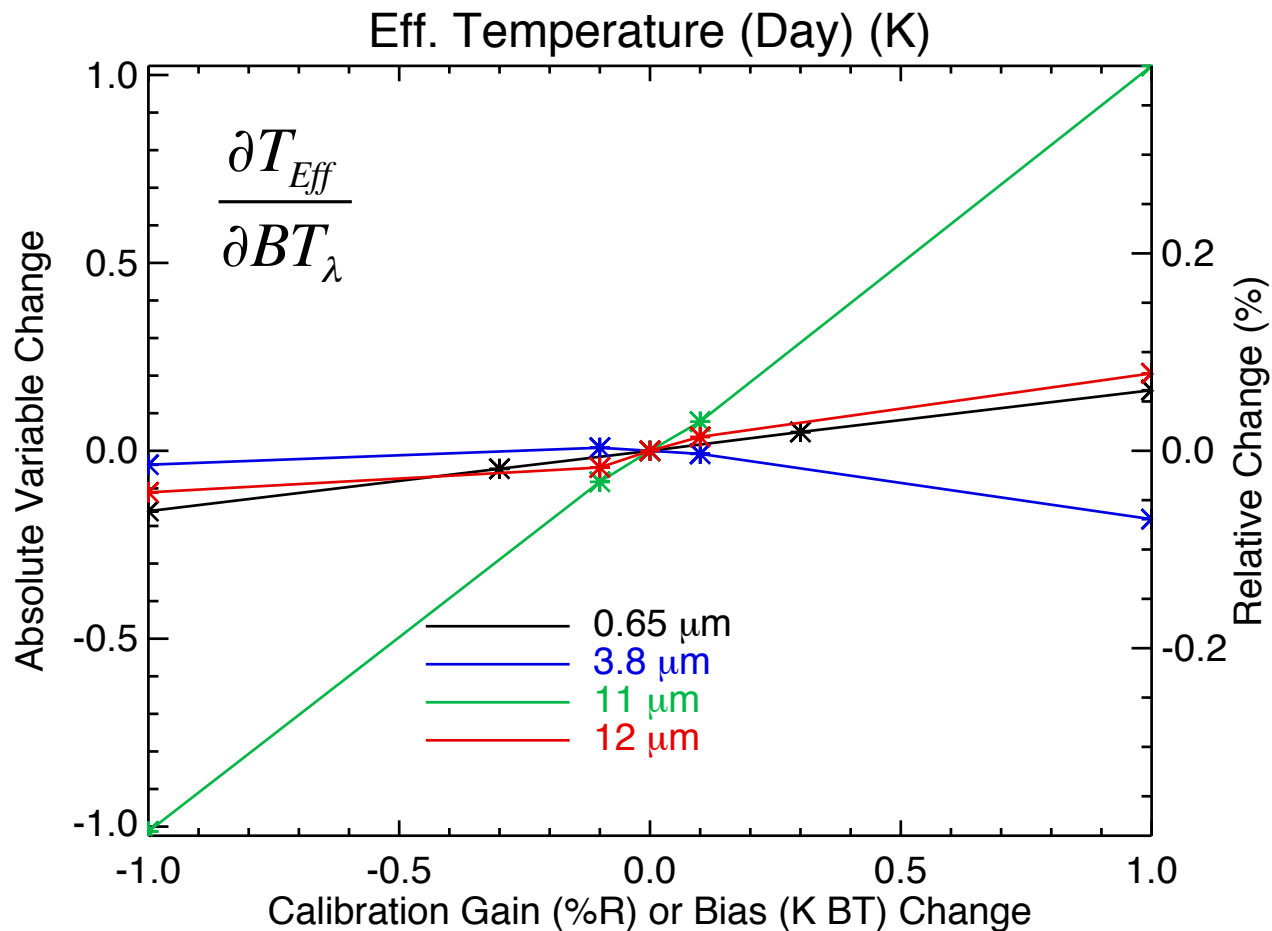
- *Accuracy Uncertainty Ratio* rigorous and universal method to determine observing system accuracy requirement & time to detect trends

- Further investigating CLARREO requirements based on natural variability of cloud properties

- These results depend on cloud retrieval algorithm (MODIS, CERES/MODIS, VIIRS, etc)

- Thus far we have investigated the requirements based on changes in individual MODIS wavelength bands.
  - **Next Step:** Determine requirements based on changes in multiple bands

- **Next Steps:** Are the biases in cloud retrievals due to algorithm assumptions stable over climate scales?
  - Starting Point: Quantifying how much the 3D Optical Depth Bias changes over multiple decades?