Shortwave and Pan-Spectral Observing System Simulation Experiments in Support of the CLARREO Science Definition Team

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Outline

- Summary of tasks proposed for the CLARREO SDT.
- Summary of OSSE data in hand.
- SW detection time analysis for a perfect observing system.
- Effect of measurement uncertainty on SW detection times.
- Pan-spectral development update.
- Conclusion and discussion.

Proposed Tasks for the CLARREO SDT

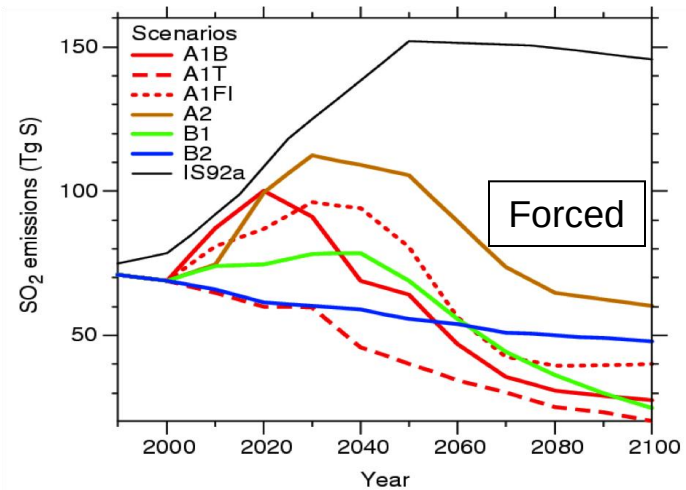
- The Berkeley group has proposed to contribute the following to the CLARREO SDT:
  - Utilization of simulated CLARREO data to estimate change detection time in SW reflectance spectra
  - Production of pan-spectral (SW+IR) OSSE spectra.
  - Interfacing different scenarios (varying forcings and feedbacks) of CCSM3 into the CLARREO OSSE framework.
  - Production and analysis of spectra derived from different orbits.
  - Development and implementation of tools to produce OSSE spectra based on CMIP5 database.

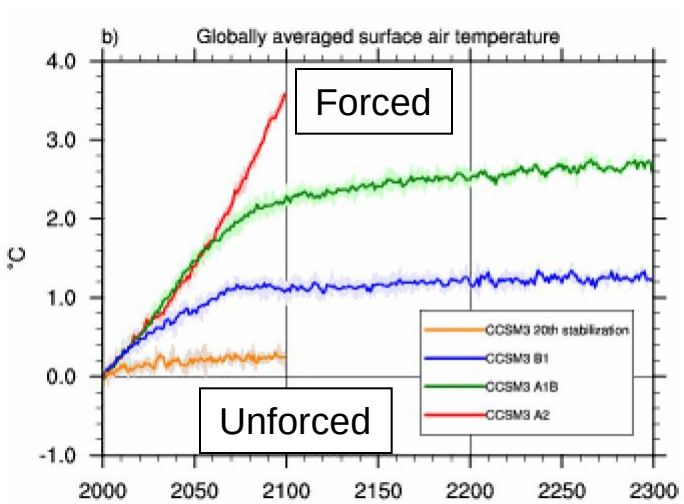
Summary of simulations

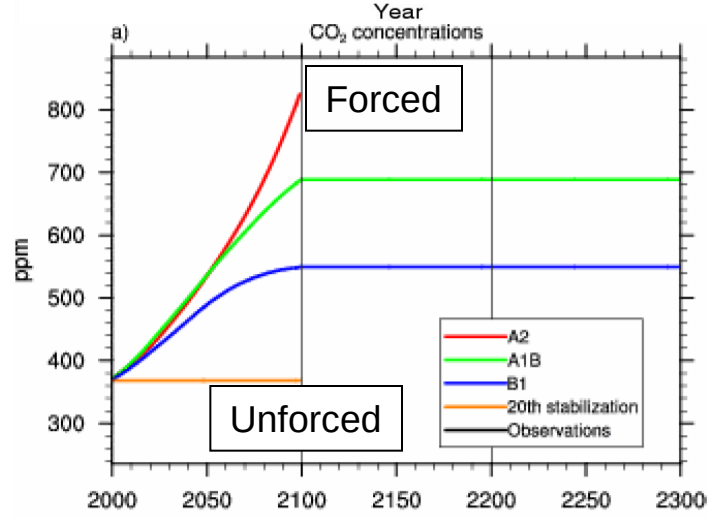
- We have an operational Observing System Simulation Experiment (OSSE) framework as described in Feldman et al, JGR [2011].
- We have simulated SW reflectance spectra based on two CCSM3 integrations of 21st Century
  - Spectra based on monthly-mean fields
  - 1.4° x1.4° horizontal resolution
  - 26 vertical levels
  - Sun-synchronous orbit at 1:30 pm local equator-crossing time.
- We are in the final stages of testing the OSSE to produce SW + LW spectra.

Forcing of Simulations

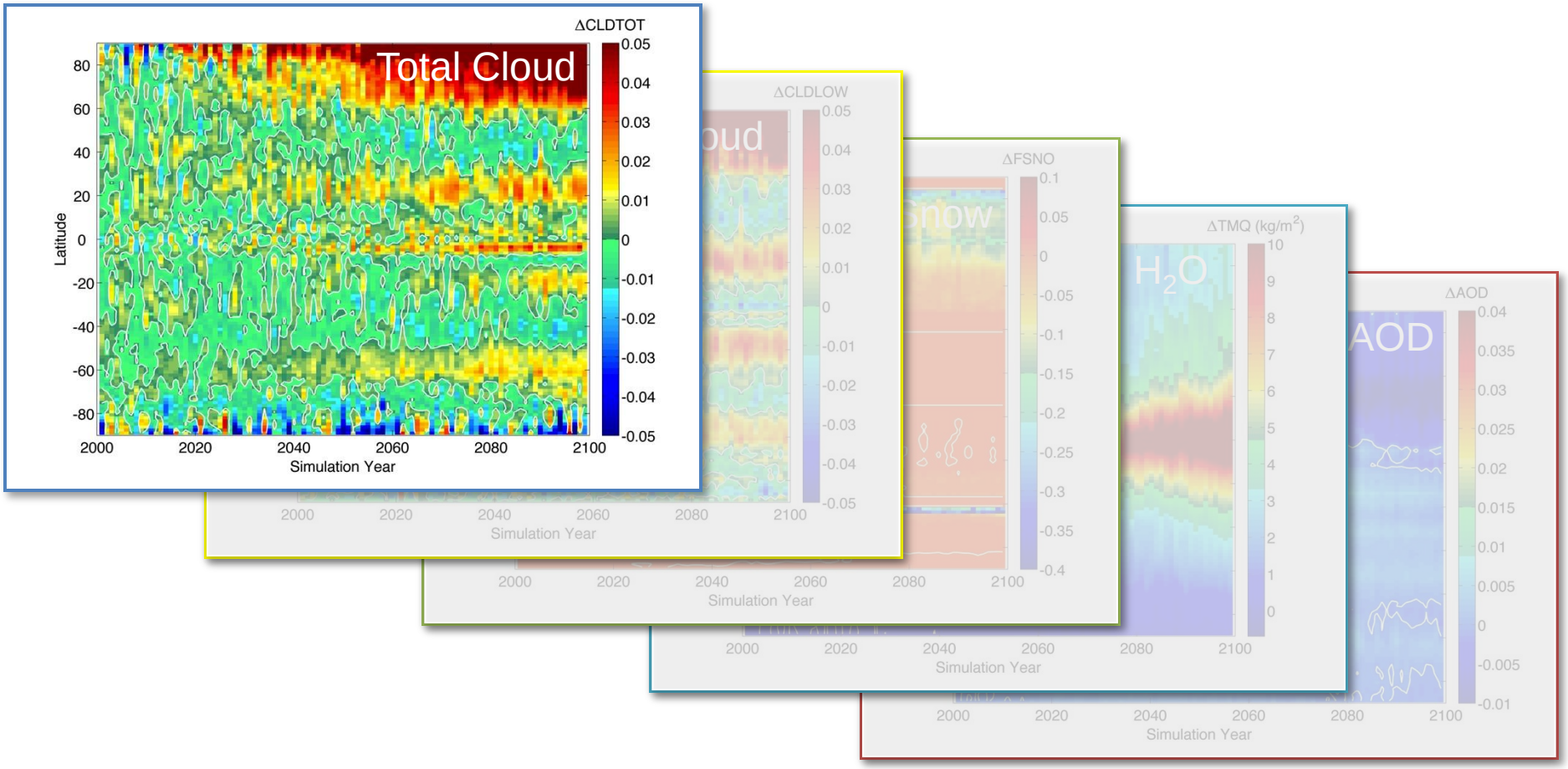
- We have OSSE data from **forced** (SRES A2) & **unforced** (AR4 constant concentration) scenarios.
  - **Forced** scenario prescribes high GHG emissions with aerosols peaking at mid-century.
  - **Unforced** scenario prescribes no new emissions.



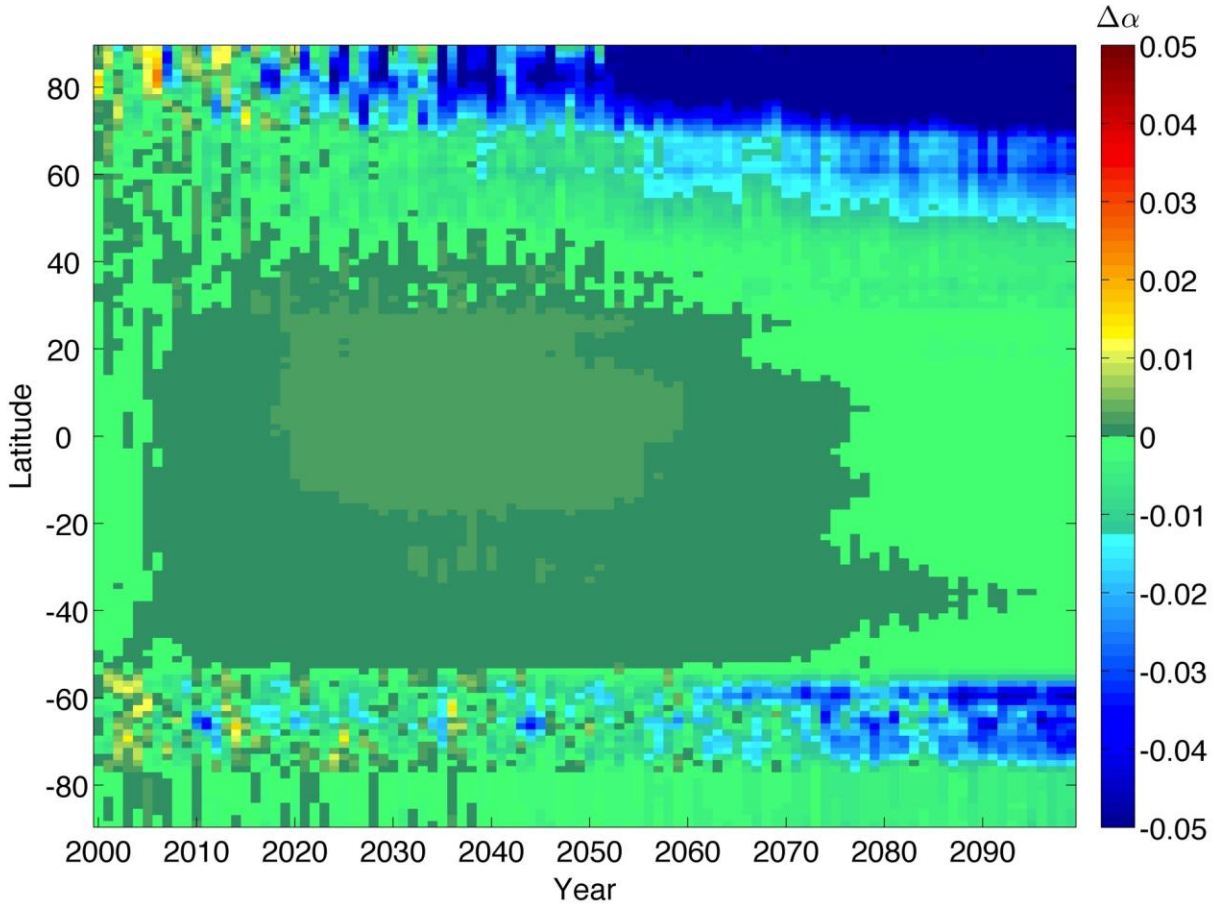




CCSM3 Changes in the Climate System Relative to 2000s from the A2 emissions scenario

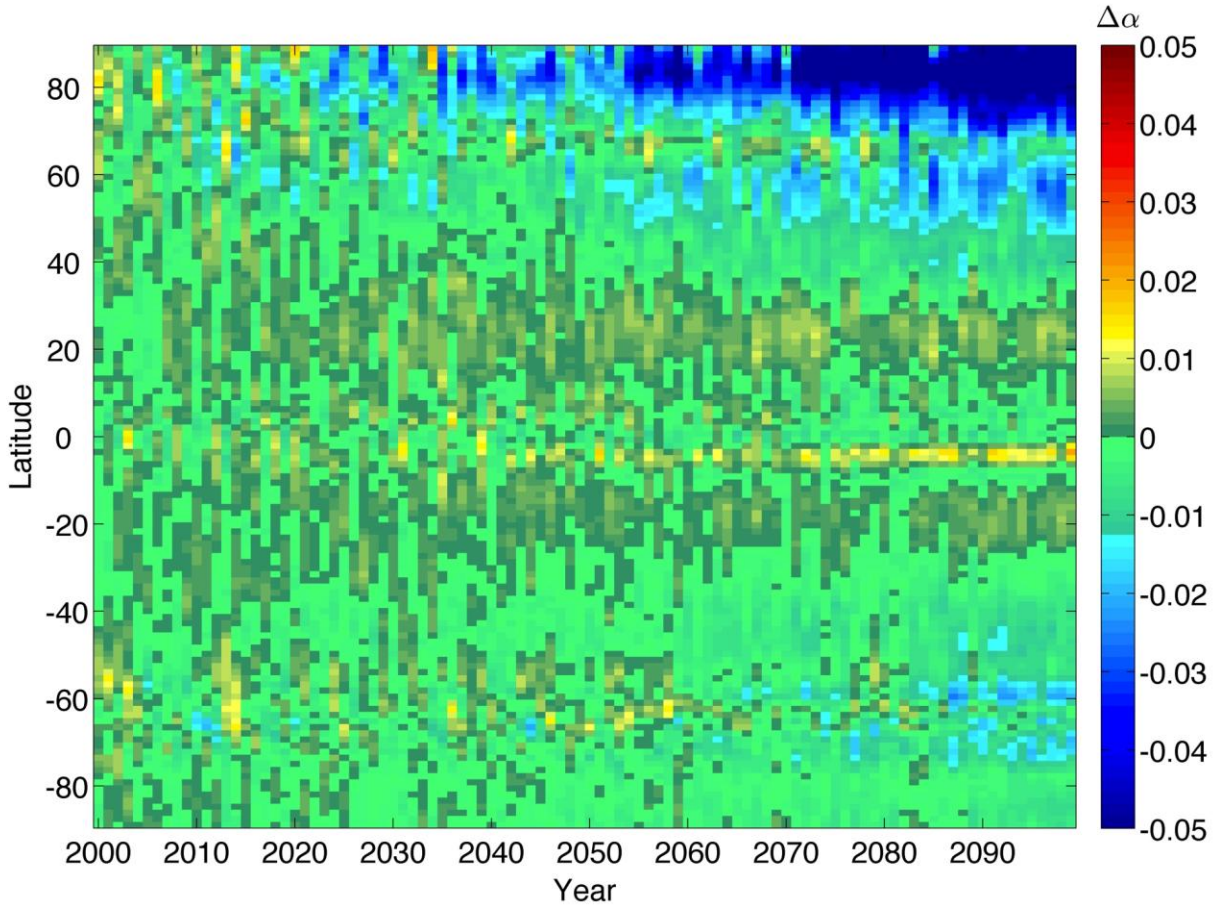


Δ Clear-sky broadband albedo



Largest broadband trends are associated with changes in aerosols, snow, and sea ice.

Δ All-sky broadband albedo

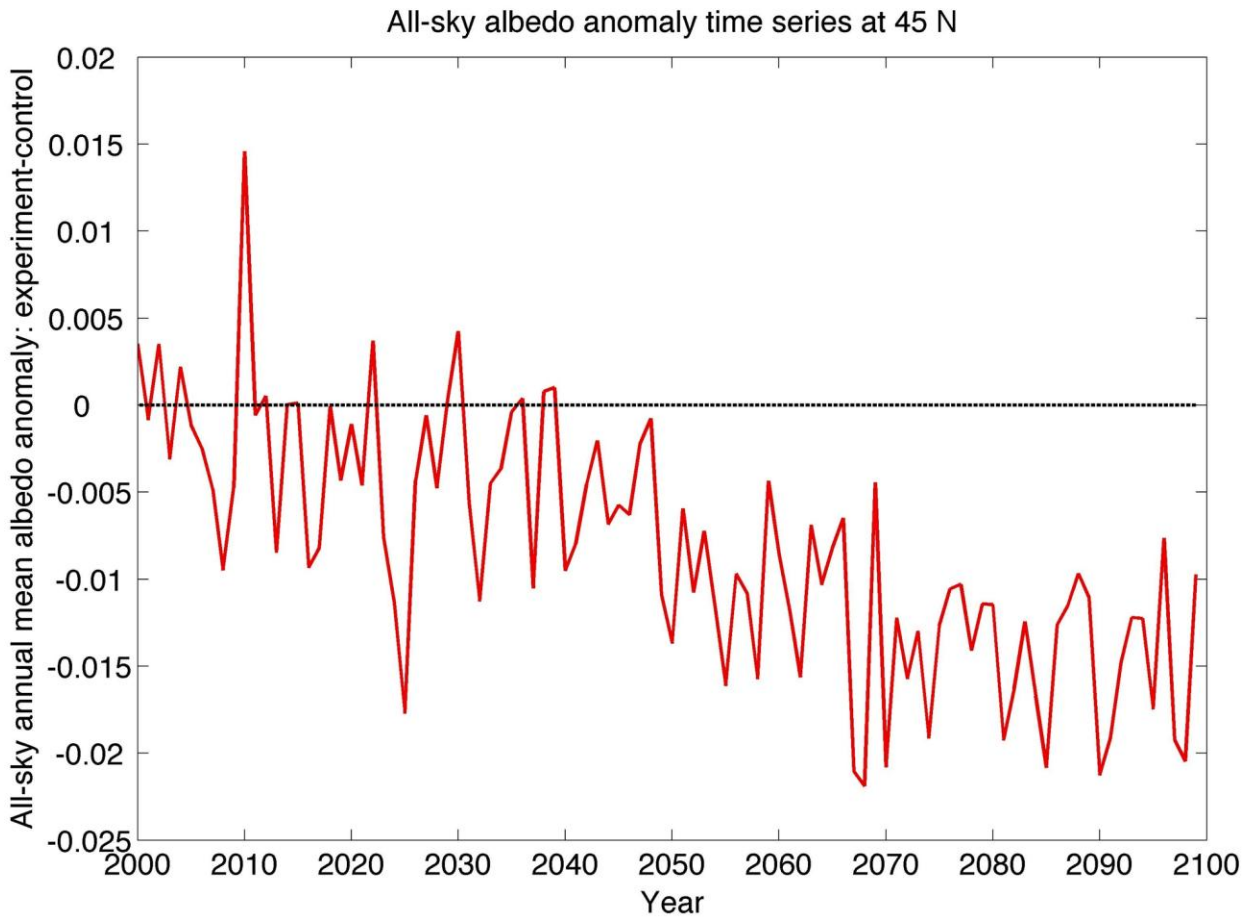


Differences between all-sky and clear-sky due to increase in stratus cover, movement of the ITCZ and increases in polar clouds

Time Series Analysis for Change Detection

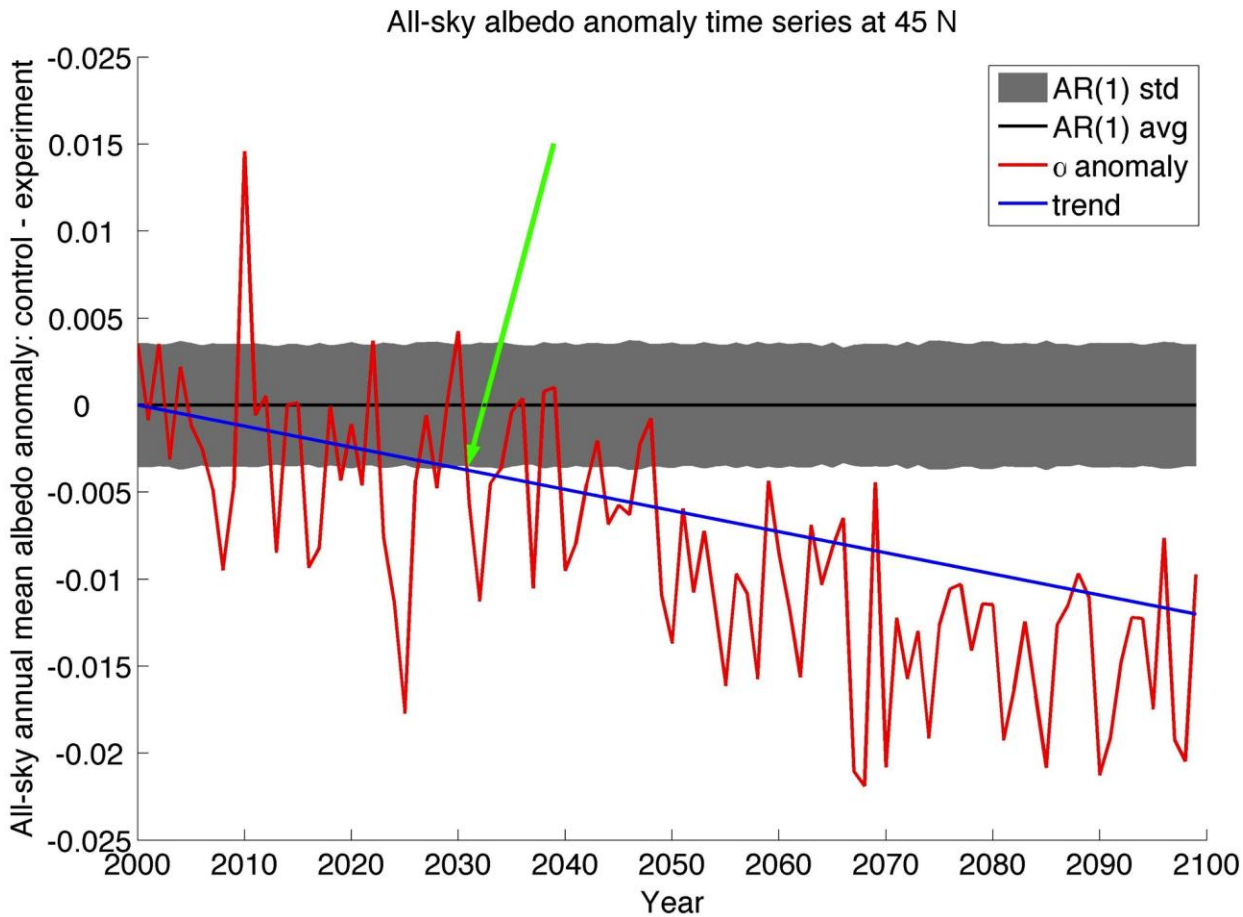
- We utilize the formulae from Weatherhead et al [1998] to estimate a secular change in a time series with natural variability.
  - AR(1) noise process.
  - Linear secular trend.
  - Trend and noise assumed to be stationary.
- We calculate annual (flux- and/or radiance-based) and zonal-averages to produce time series of 100 data records each.

Time to detection for climate change



Trends in albedo and reflectance are superimposed on natural variability.

Time to detection for climate change

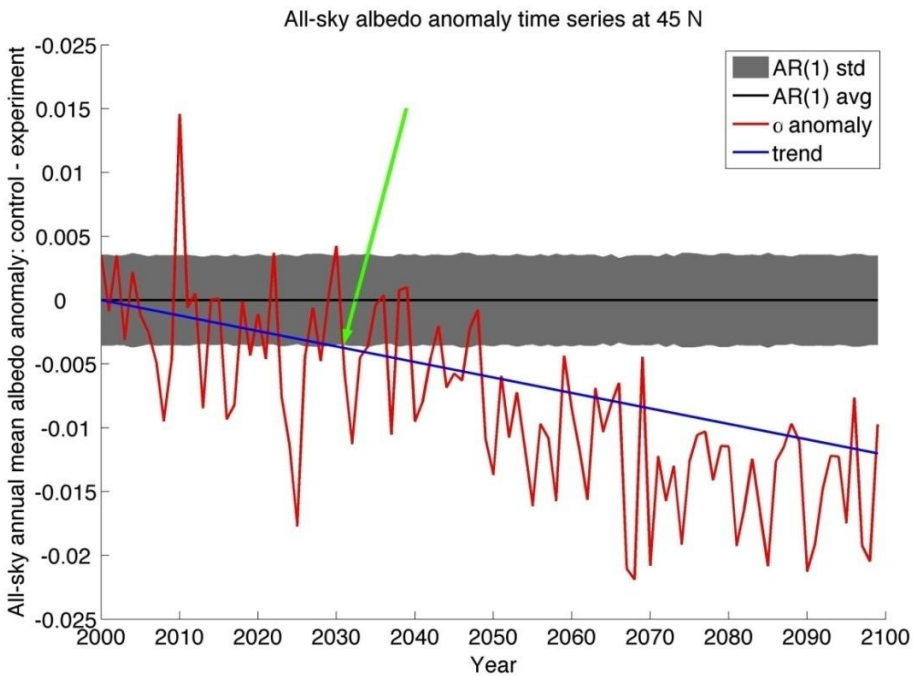


Trends in albedo and reflectance are superimposed on natural variability.

Time to detection = time to exceed 95% of variability

Formula for Change Detection

- The time required to detect changes in an observation increases from:
  - Natural variability
  - Measurement uncertainty
  - Uncertainty in noise and trend estimation from a short time series.



Detection time

Scaling factor for length of record

Std dev of noise process

$$n^* \approx e^{b/\sqrt{M}} \left[\frac{3.96 s_e}{w_o (1-j)} \right]^{2/3} \left(1 + \frac{s_{meas}^2}{s_v^2} \right)^{1/3}$$

Measurement uncertainty

Secular trend

AR(1) of noise process

Correlated natural variability

Rapid and confident change detection

- We are interested in knowing the record length required to declare confidently that a change has occurred.
  - Analysis performed with a partial time series beginning with the first record.
  - This condition is satisfied where:

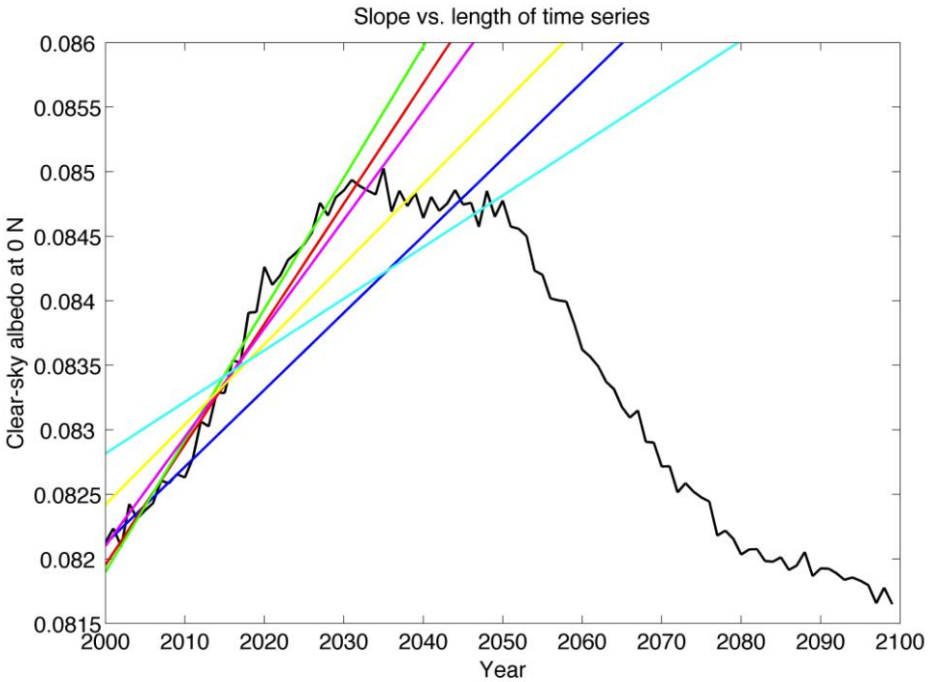
$$n^*(t) \text{ £ } t$$

  - This approach can be problematic where:

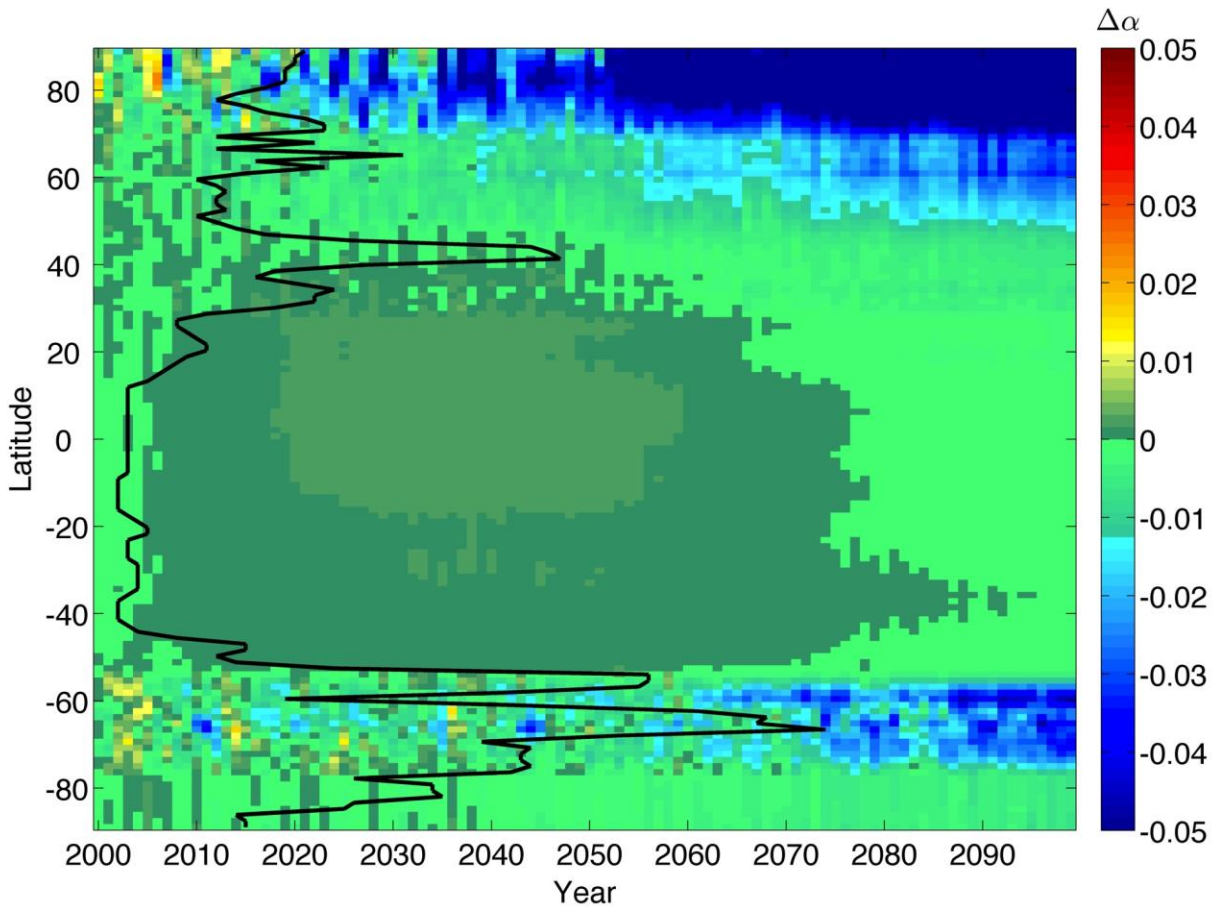
$$\frac{\text{¶}|w_o|}{\text{¶}t} < 0$$

    e.g., clear-sky albedo time-series at low-latitudes
  - Detection time is indeterminate where:

$$n^*(t) > t \text{ " } t$$



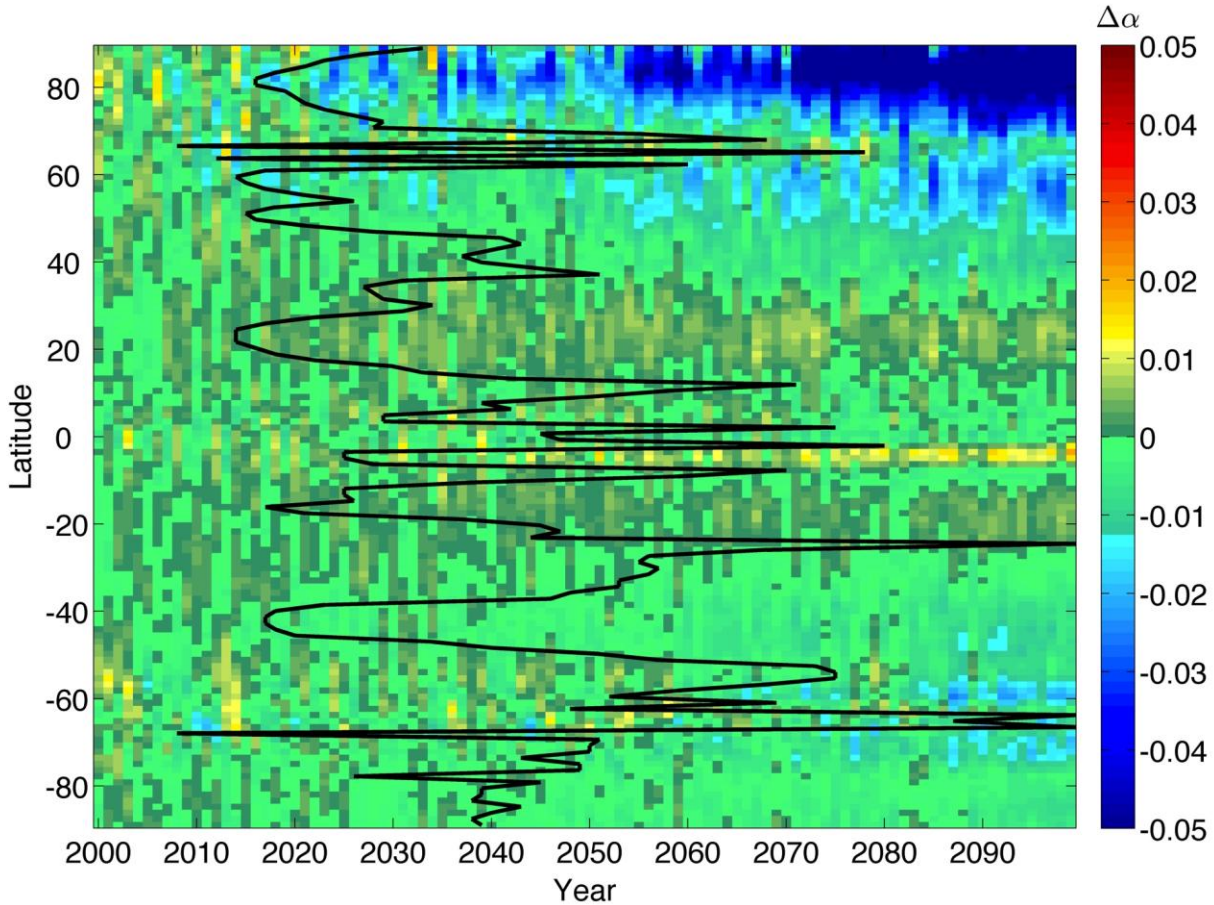
Δ Clear-sky broadband albedo: Time to detect



Largest broadband trends are associated with changes in aerosols, snow, and sea ice.

These trends can be detected by a perfect observing system with high confidence in <10 years at low latitudes and 15-30 years at higher latitudes.

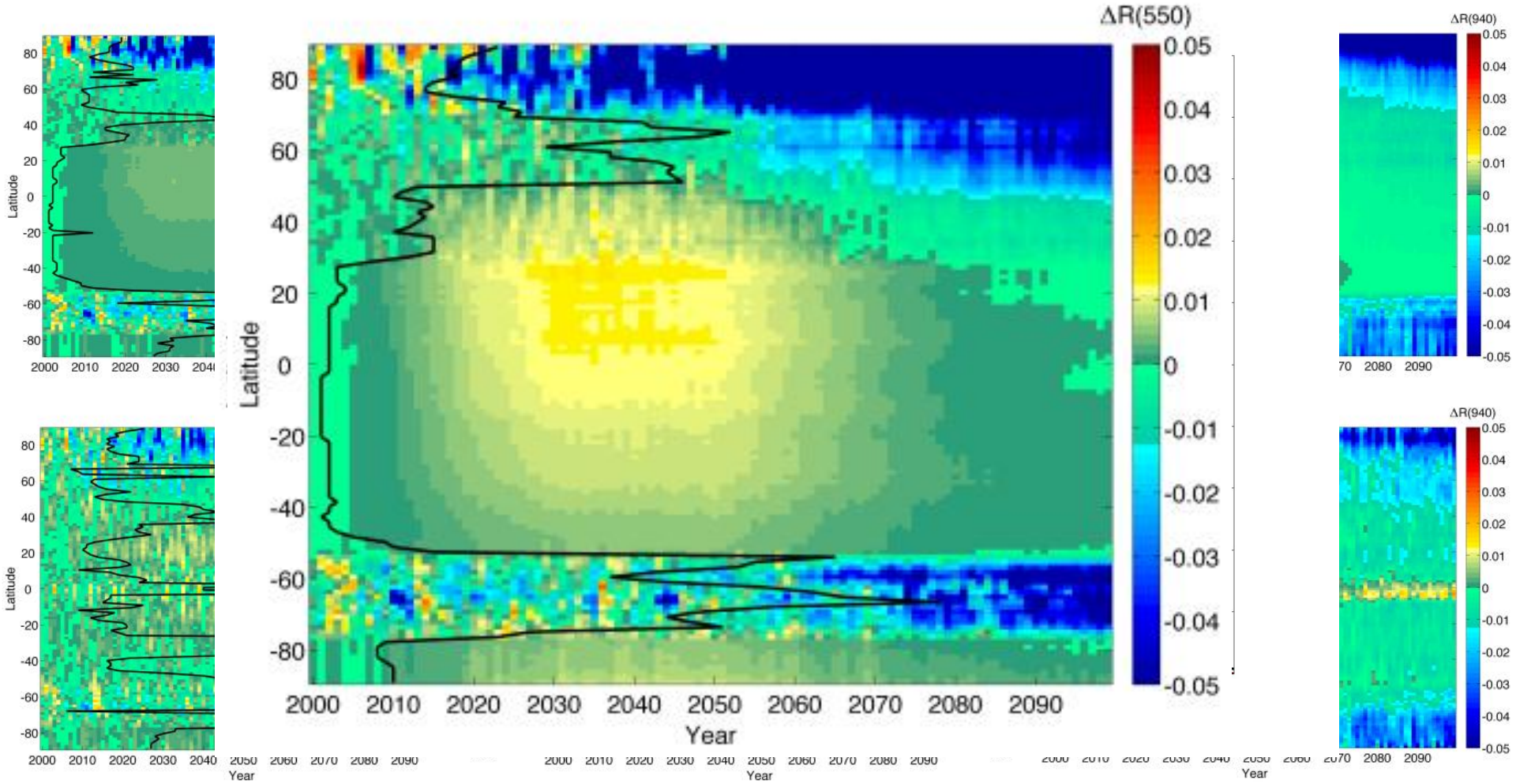
Δ All-sky albedo



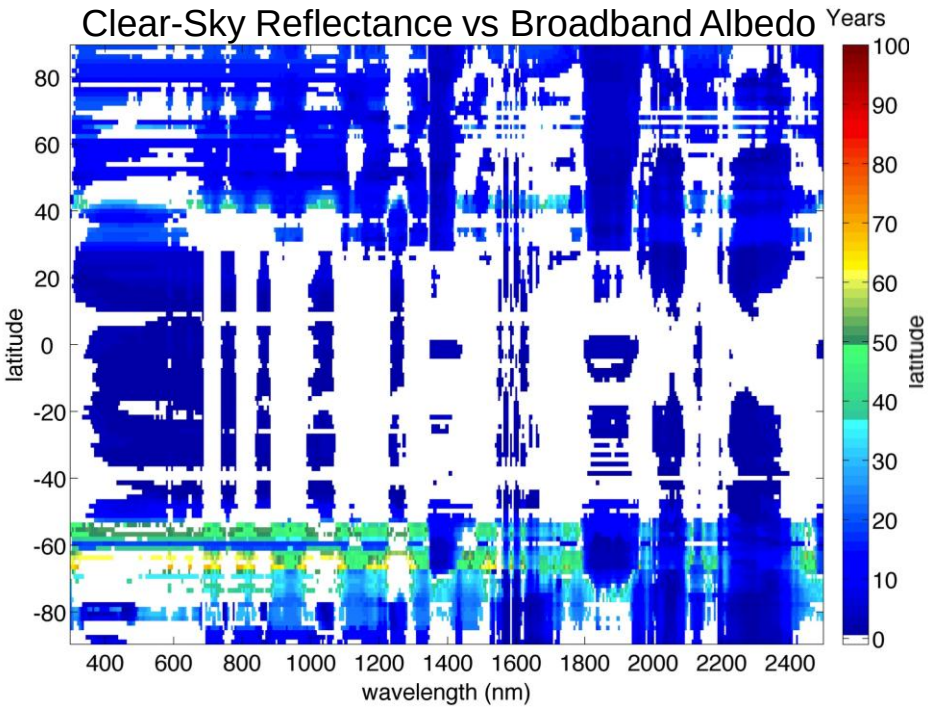
Differences between all-sky and clear-sky due to increase in stratus cover, movement of the ITCZ and increases in polar clouds

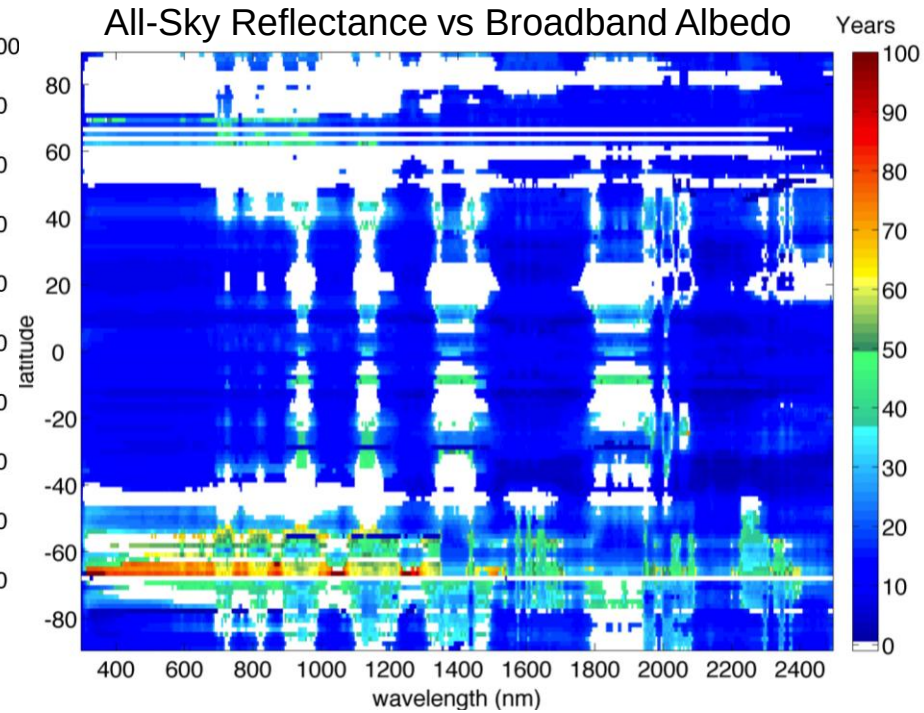
These trends can be detected by a perfect observing system with high confidence in 15-20 years at mid latitudes with high meridional variability.

Time Series and Change Detection with Spectral channels



Change Detection Value Added From Spectra





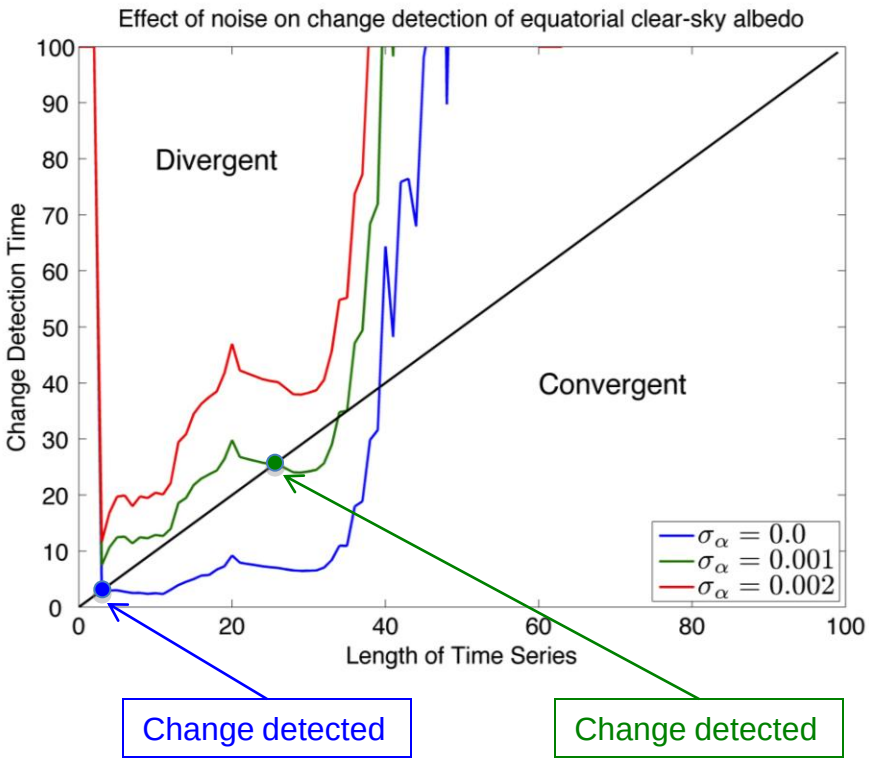
- Spectral albedo or radiance add value to change detection where plots are NOT shaded white.

Change Detection with Measurement Uncertainty

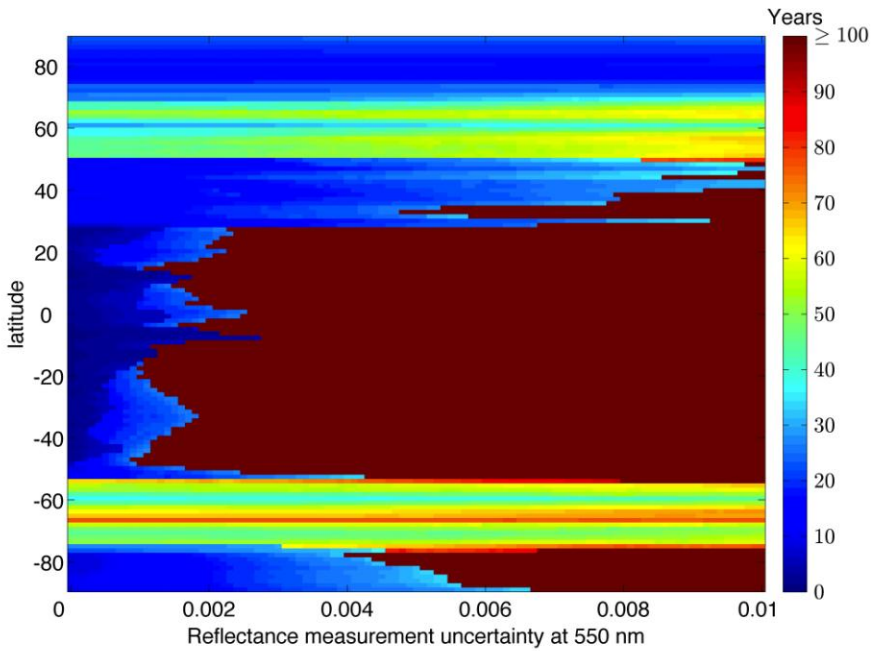
- Measurement uncertainty increases change detection time
- Particularly under conditions where

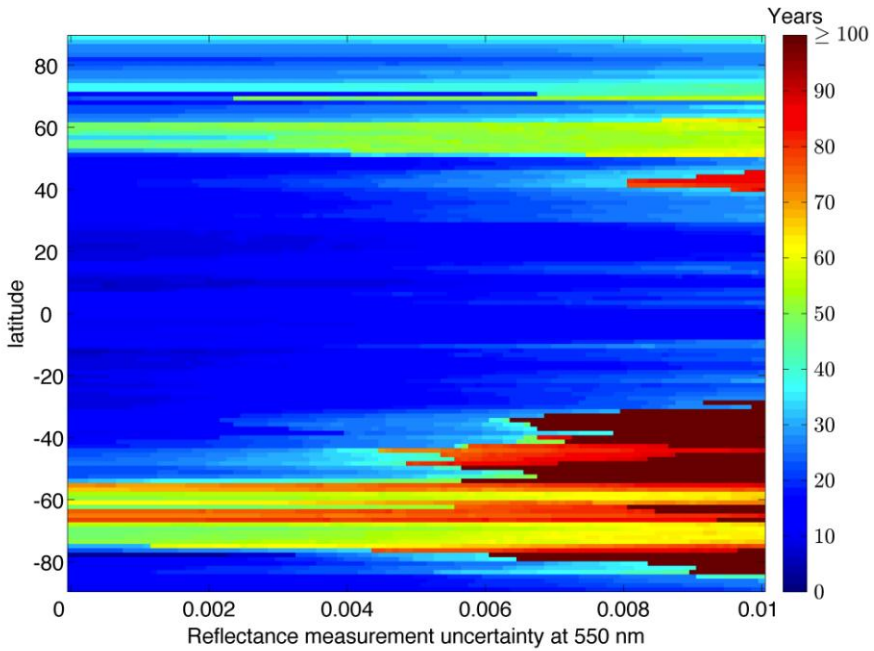
$$\frac{\P|W_o|}{\P t} < 0$$

measurement uncertainty may make change detection estimation indeterminate



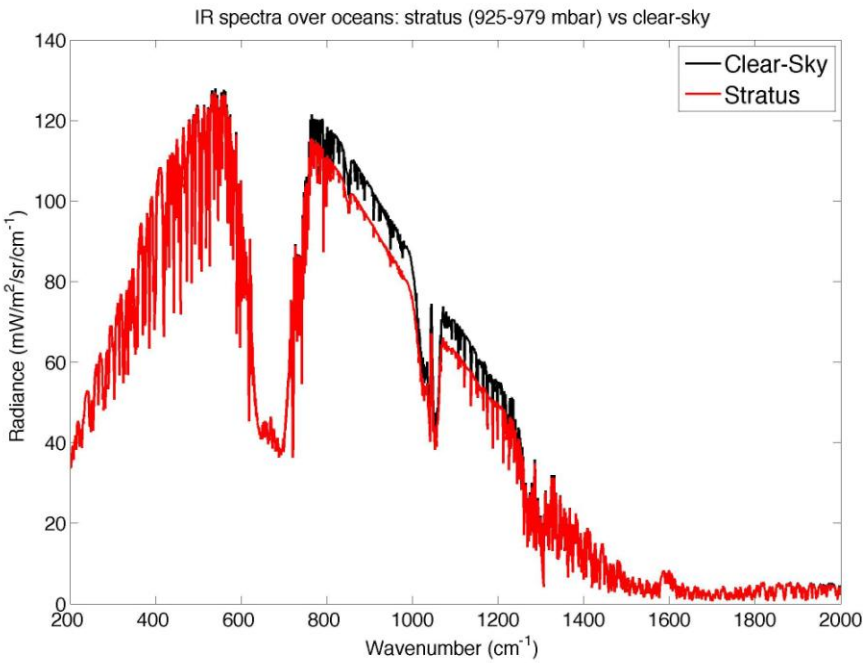
Change Detection with Measurement Uncertainty

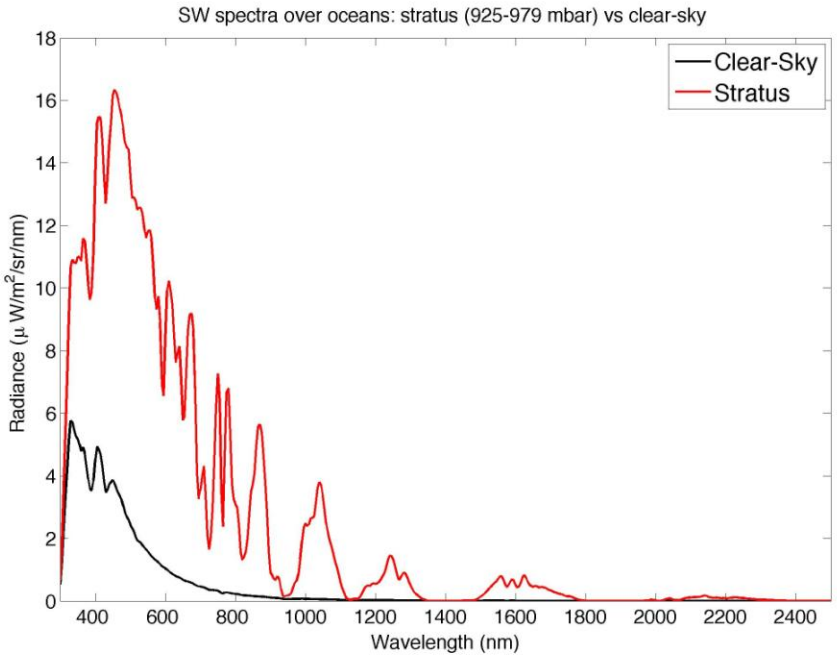




- Measurement uncertainty >0.002 leads to indeterminate change detection time for most clear-sky reflectance measurements.
- Measurement uncertainty >0.006 leads to indeterminate change detection for some all-sky reflectance measurements.

Pan-spectral analysis

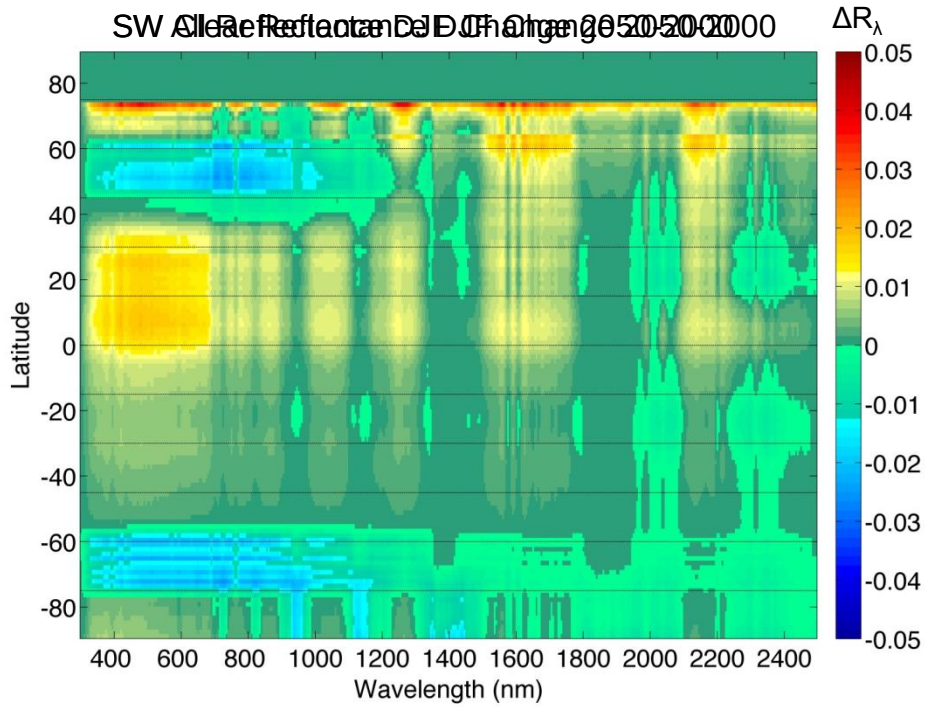


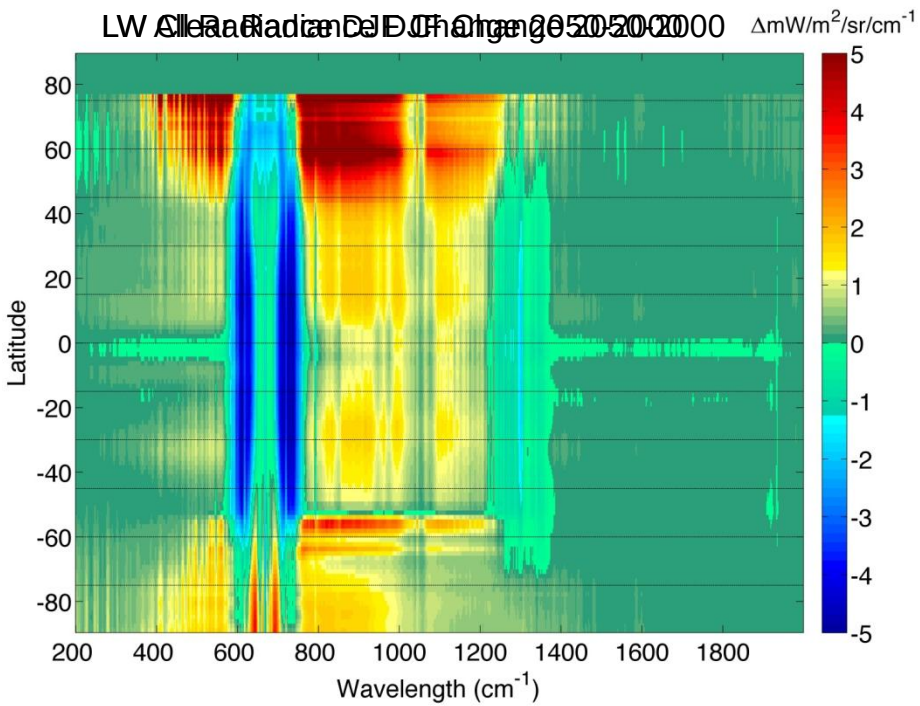


- CLARREO's SW reflectance + IR radiance spectra may be complementary.
- IR measurements are sensitive to H_2O, lapse rate, T_{surf} but less sensitive to low clouds.

Preliminary Pan-Spectral Climate Change Signals: 2050s-2000s

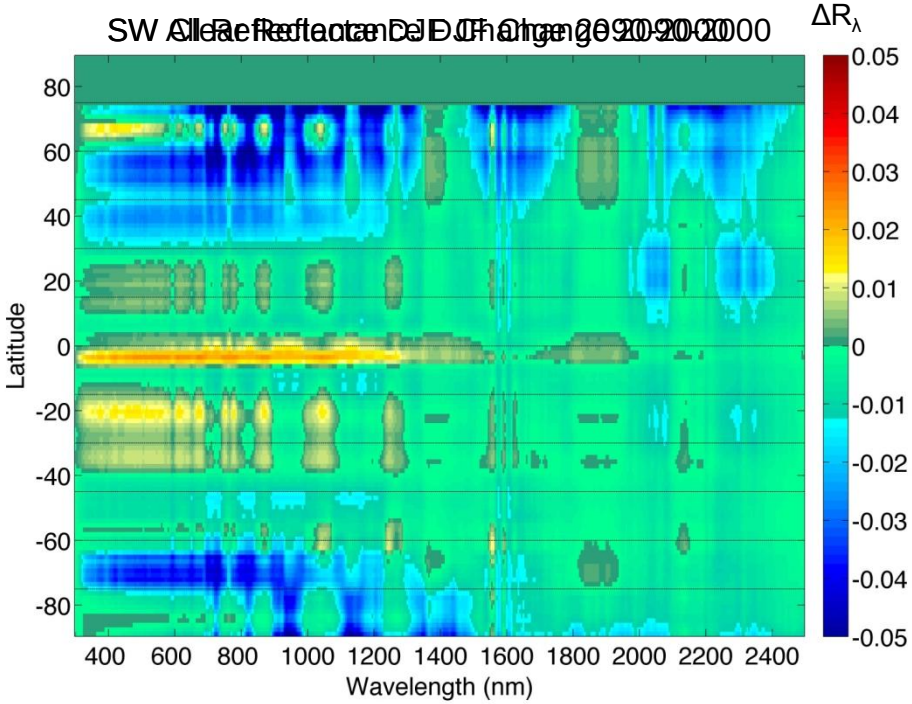
- Clear-sky signals of aerosols, T_{surf} increases, T_{strat} decreases and water-vapor loading are easily detectible by pan-spectral measurements
- Signals from clouds are most apparent in the SW, though upper-trop cloud changes can be seen in the LW.

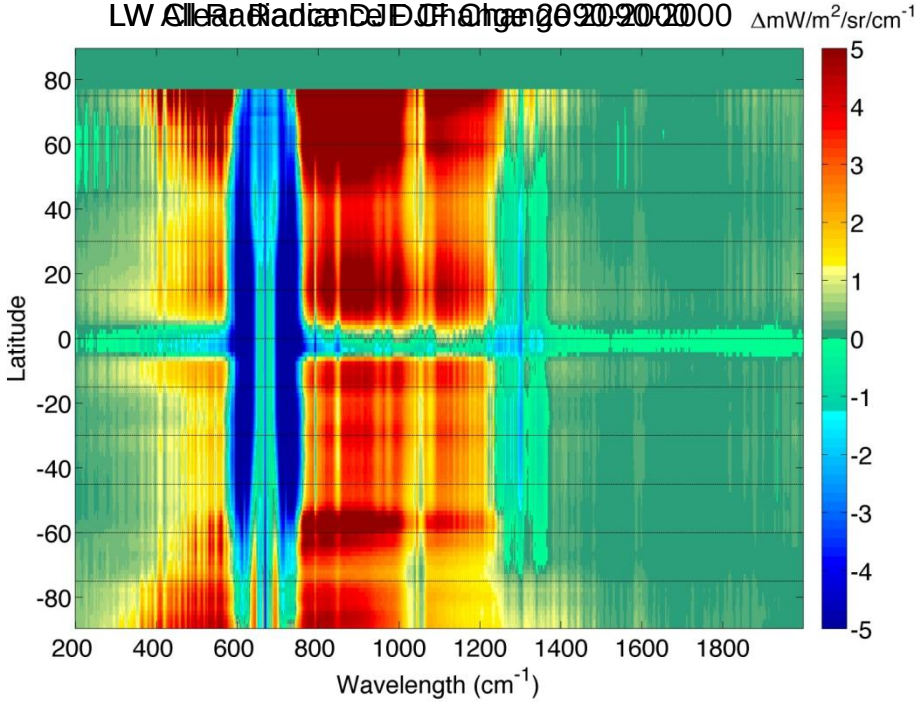




Preliminary Pan-Spectral Climate Change Signals: 2090s-2000s

- Clear-sky signals of T_{surf} increases, T_{strat} decreases and water-vapor loading are easily detectible by pan-spectral measurements
- Signals from clouds are most apparent in the SW, though upper-trop cloud changes can be seen in the LW.





Conclusions

- Earth's reflected solar spectrum will change due to anthropogenic global warming.
- Measurements of broadband albedo or spectral reflectance will detect this change on decadal time-scales.
  - Spectral measurements generally detect change faster than broadband measurements.
  - Measurement uncertainty can confound the change-detection algorithms and make detection indeterminate even on centennial time-scales.
- We have preliminary pan-spectral OSSE simulations that may be useful to the SDT, but they have not been analyzed.

- Acknowledgements:
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