Simulated Shortwave and Longwave Spectra from Models with Different Cloud Feedback Strengths

Daniel Feldman[1]

Bill Collins[1,2], Daniel Coleman[1]

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[1] Lawrence Berkeley National Laboratory, Earth Sciences Division
[2] University of California-Berkeley, Department of Earth & Planetary Science

Outline

- Recap of tasks proposed for the CLARREO SDT.
- Pan-spectral development update.
- Simulations of different cloud feedback strengths
- Conclusion and discussion.

Proposed Tasks for the CLARREO SDT

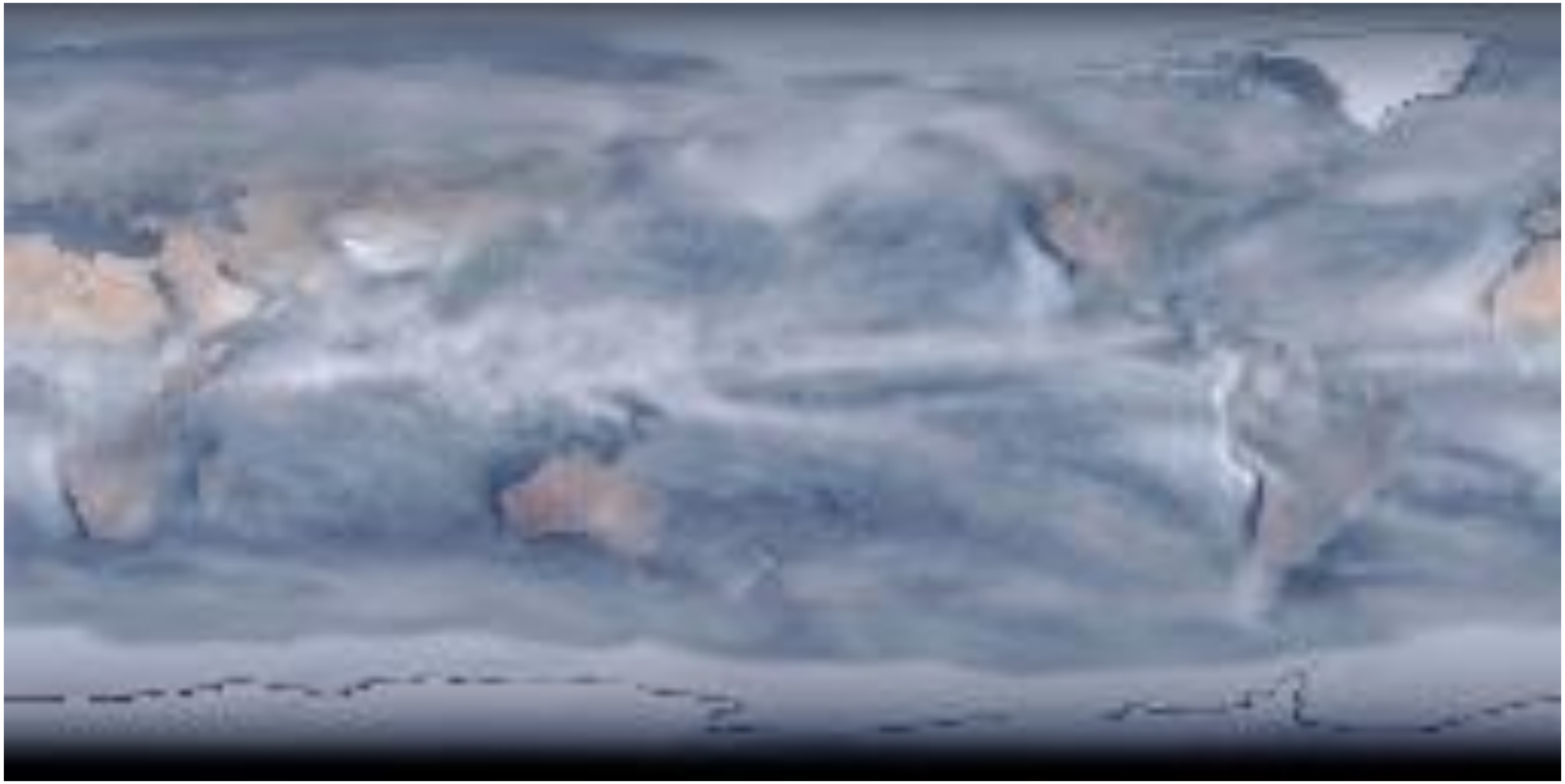
- The Berkeley group has proposed to contribute the following to the CLARREO SDT:
  - Utilization of simulated CLARREO data to estimate change detection time in SW reflectance spectra
  - Production of pan-spectral (SW+IR) OSSE spectra.
  - Interfacing different scenarios (varying forcings and feedbacks) 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 and LW radiance spectra based on an anthropogenically-forced and an unforced CCSM3 integrations of 21st Century.
- Signal analysis on the SW OSSE results indicates spectral measurements can detect climate change faster than broadband measurements [Feldman et al, 2011 accepted].

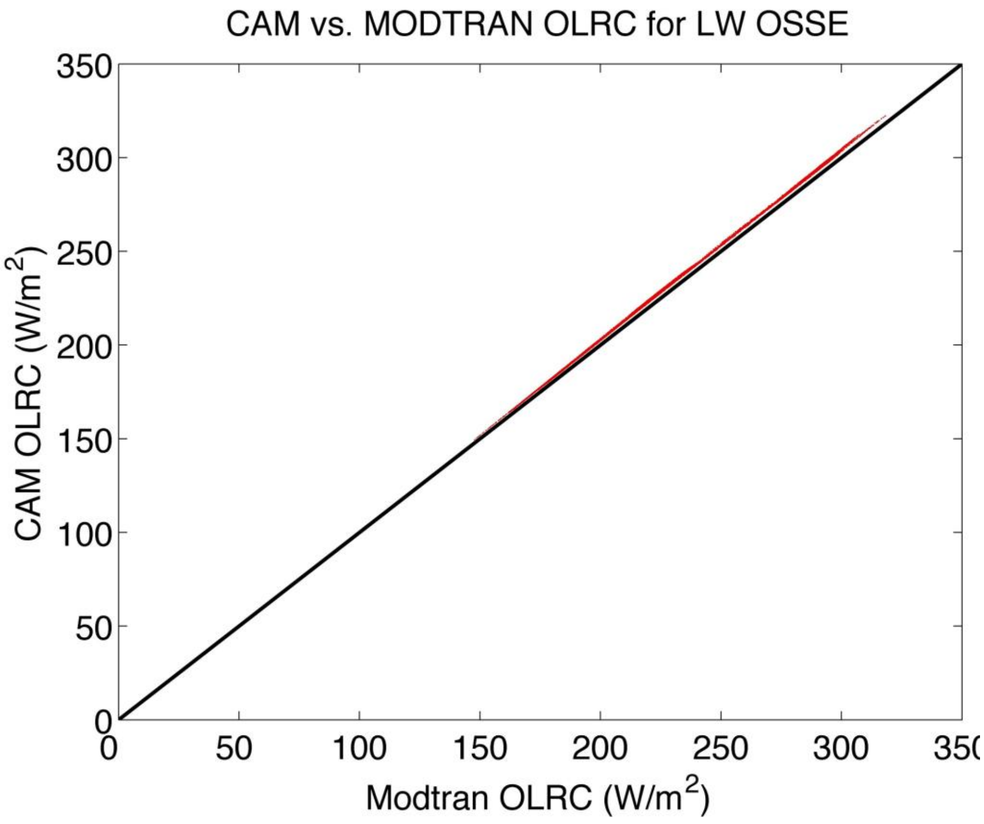
A2 Clear-Sky September Time Series

A2 All-Sky September Time Series



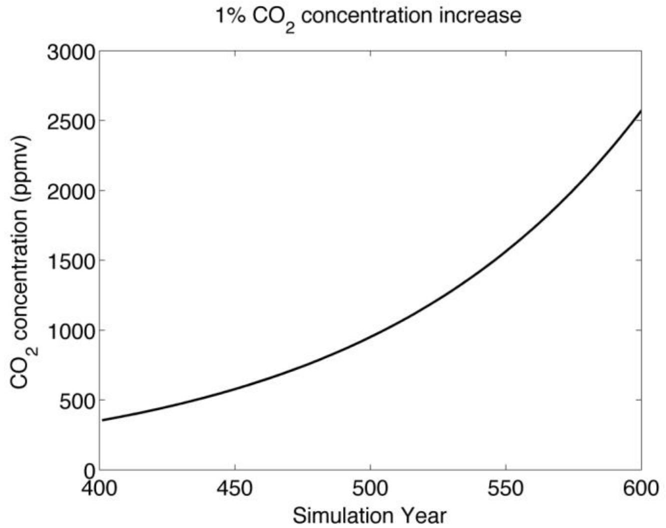
Validation of LW Simulations

- Upwelling TOA broadband fluxes have been validated for the clear-sky LW OSSE simulations against CAM RT.
- LW thin clouds have been validated.
- LW treatment of multi-layer optically thick clouds are a WIP.



Forcing and Feedback in Simulations

- We have OSSE data from several runs all forced only with CO_2 increasing at 1% per year.
- Simulations are at T31 (~ 3.75°), T42 (~2.8°), and T85 (1.4°) horizontal resolutions.
- Cloud feedbacks are stronger for higher spatial resolution models
  - Due to boundary-layer parameterizations that lead to over-prediction of low-level cloud fraction from inefficient mixing of drier air in the boundary layer.

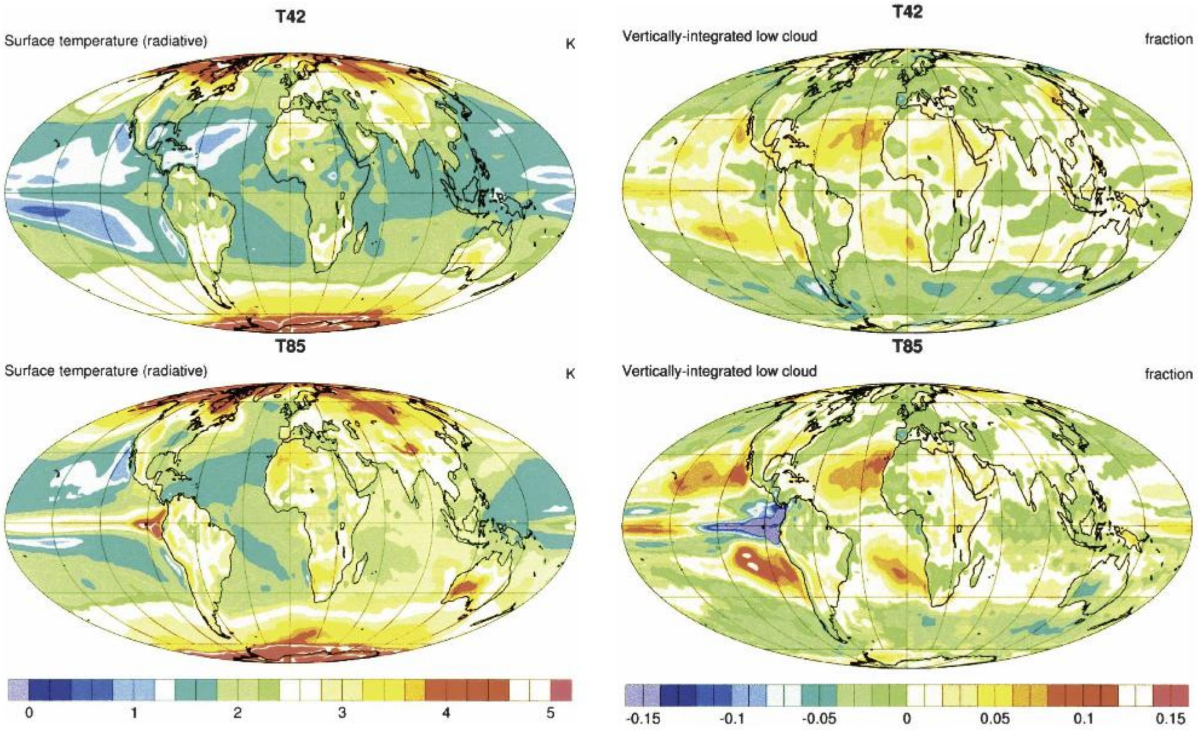


CCSM3 Feedback strengths (W/m²/°C)				
Model	λ lw clr	λ lw cld	λ sw clr	λ sw cld
T31	1.5	-0.32	0.7	-0.63
T42	1.52	-0.33	0.87	-0.61
T85	1.62	-0.41	0.83	-0.41

Kiehl et al 2006

Results arising from differing feedbacks

- Identical physics modulo low-cloud feedback.
- Changes in radiative surface temperature and low-cloud amount arise solely from a change in low-cloud feedback strength.

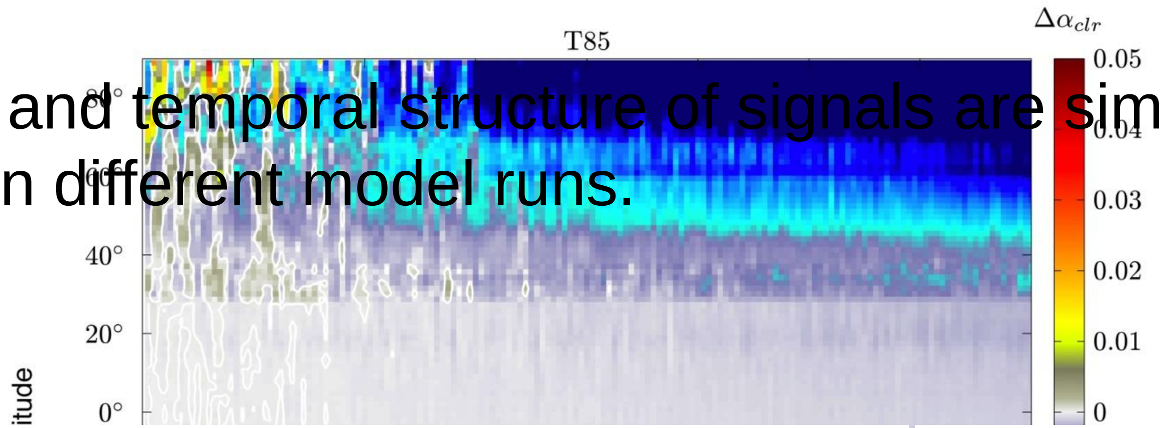


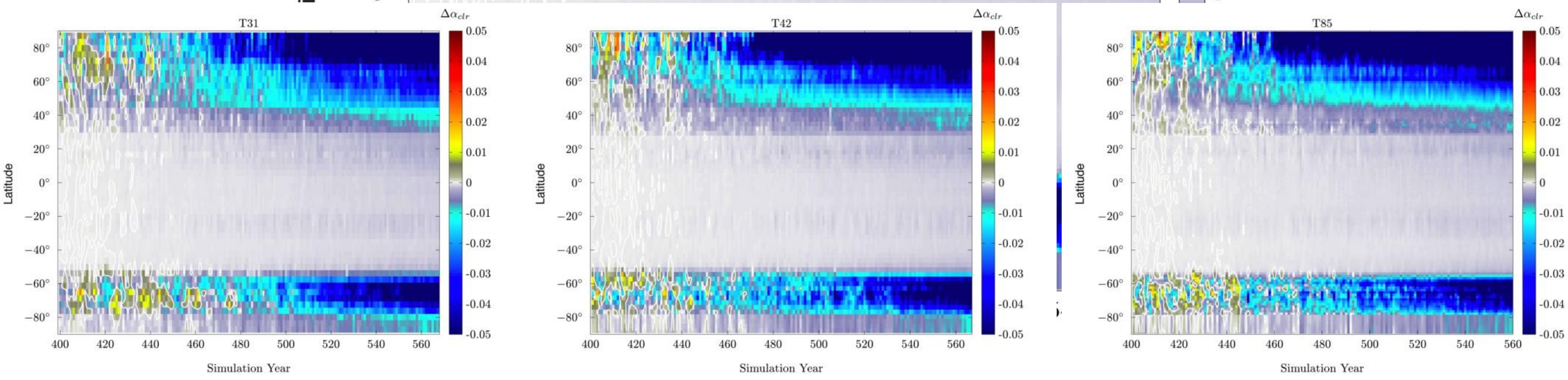
Kiehl et al 2006

Δ Clear-sky broadband albedo

Broadband trends are associated with changes in snow, and sea ice and H_2O.

- Spatial and temporal structure of signals are similar between different model runs.

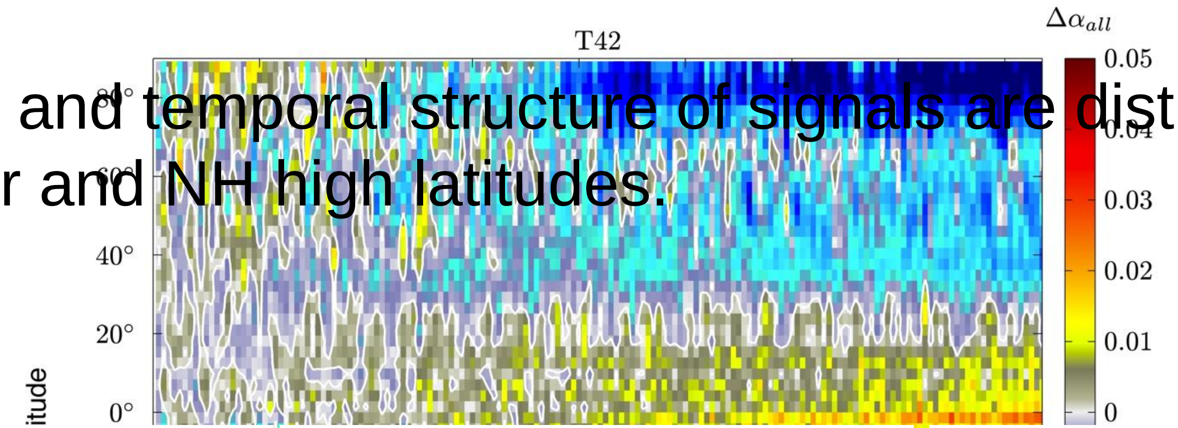


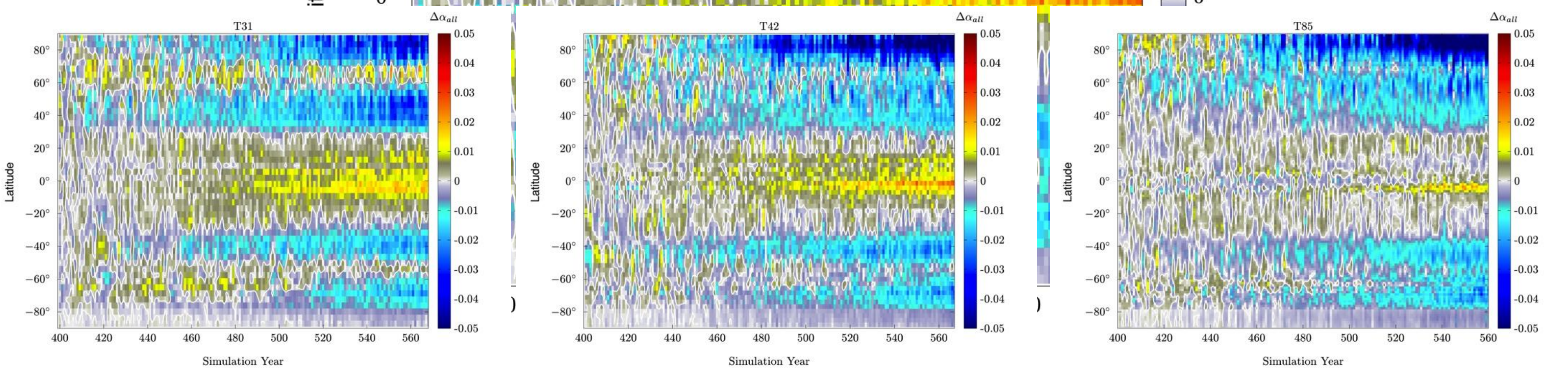


Δ All-sky broadband albedo

Broadband trends are associated with changes in clouds, snow, and sea-ice.

- Spatial and temporal structure of signals are distinct at equator and NH high latitudes.

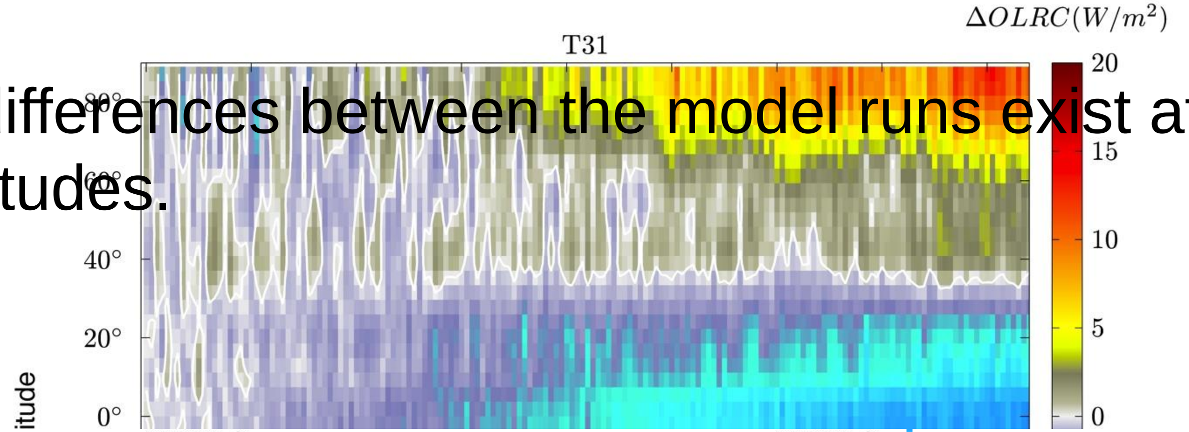


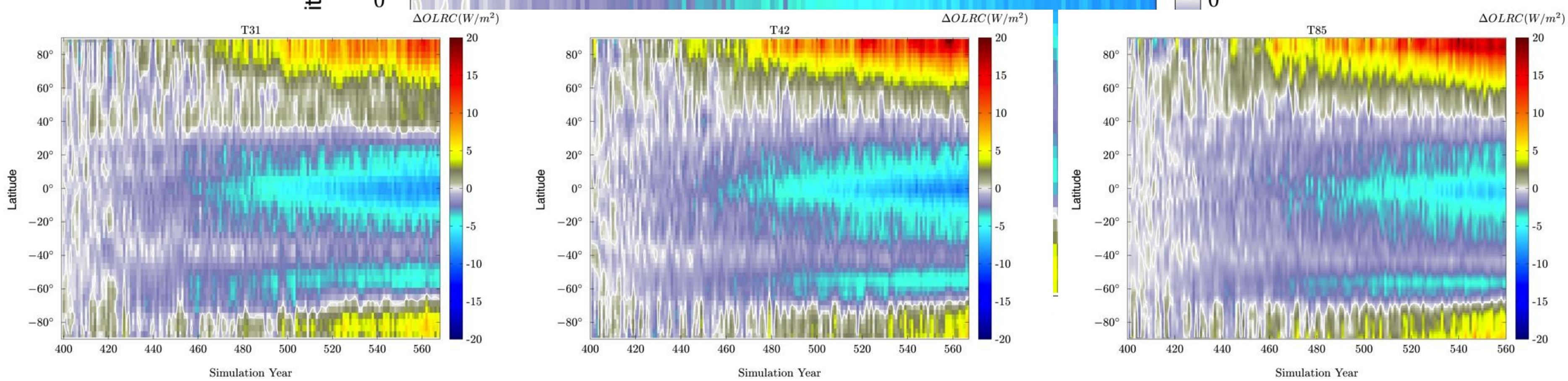


Δ Clear-sky OLR

Broadband trends are associated with water vapor and temperature.

- Small differences between the model runs exist at NH mid-latitudes.

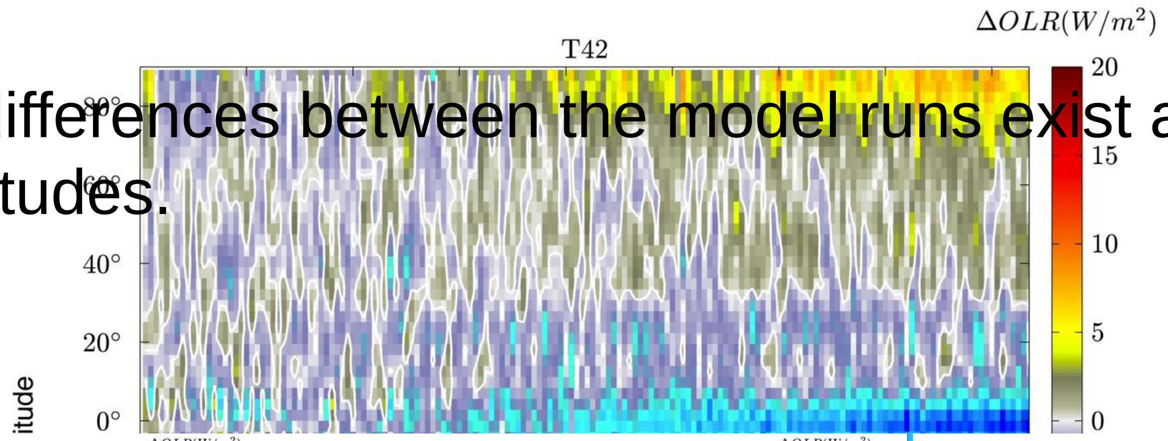


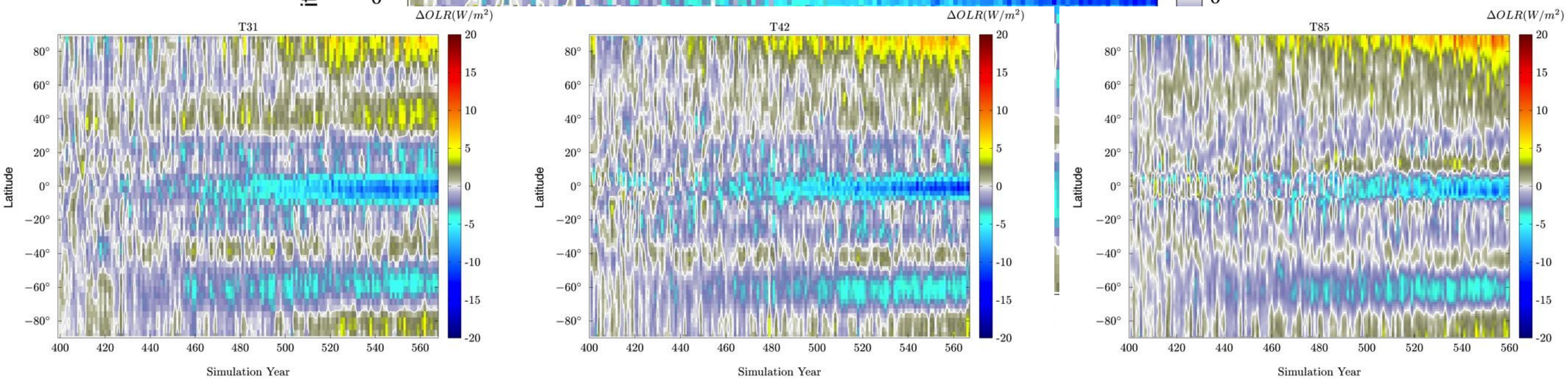


Δ All-sky OLR

Broadband trends from water vapor, temperature, and, to a lesser extent, low clouds.

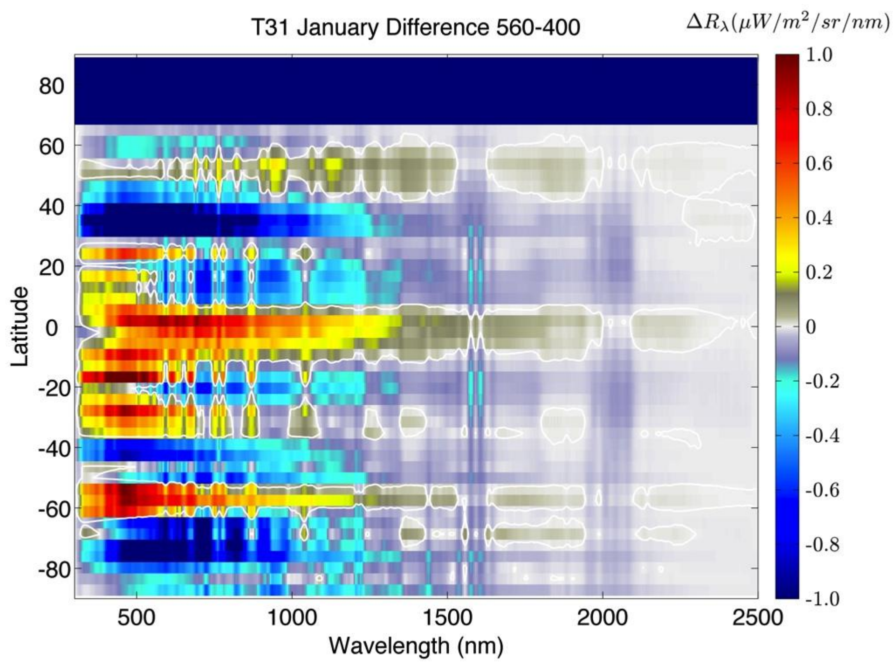
- Small differences between the model runs exist at NH mid-latitudes.

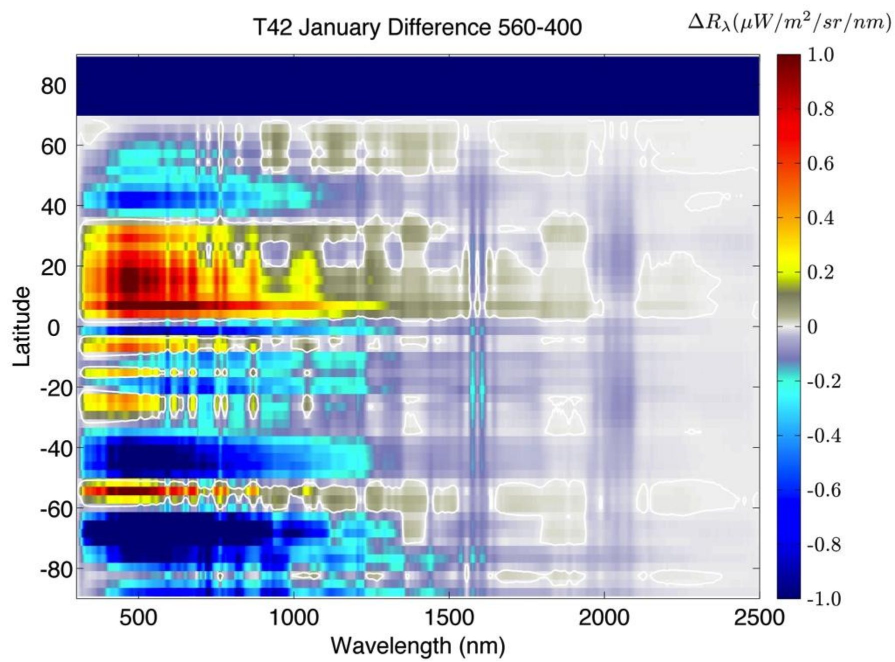




Spectral Signatures of Cloud Feedbacks

- As with previous OSSE results, the spectral signatures of cloud feedbacks are broadband, but H_2O overtone lines and VIS vs NIR contain significant information.

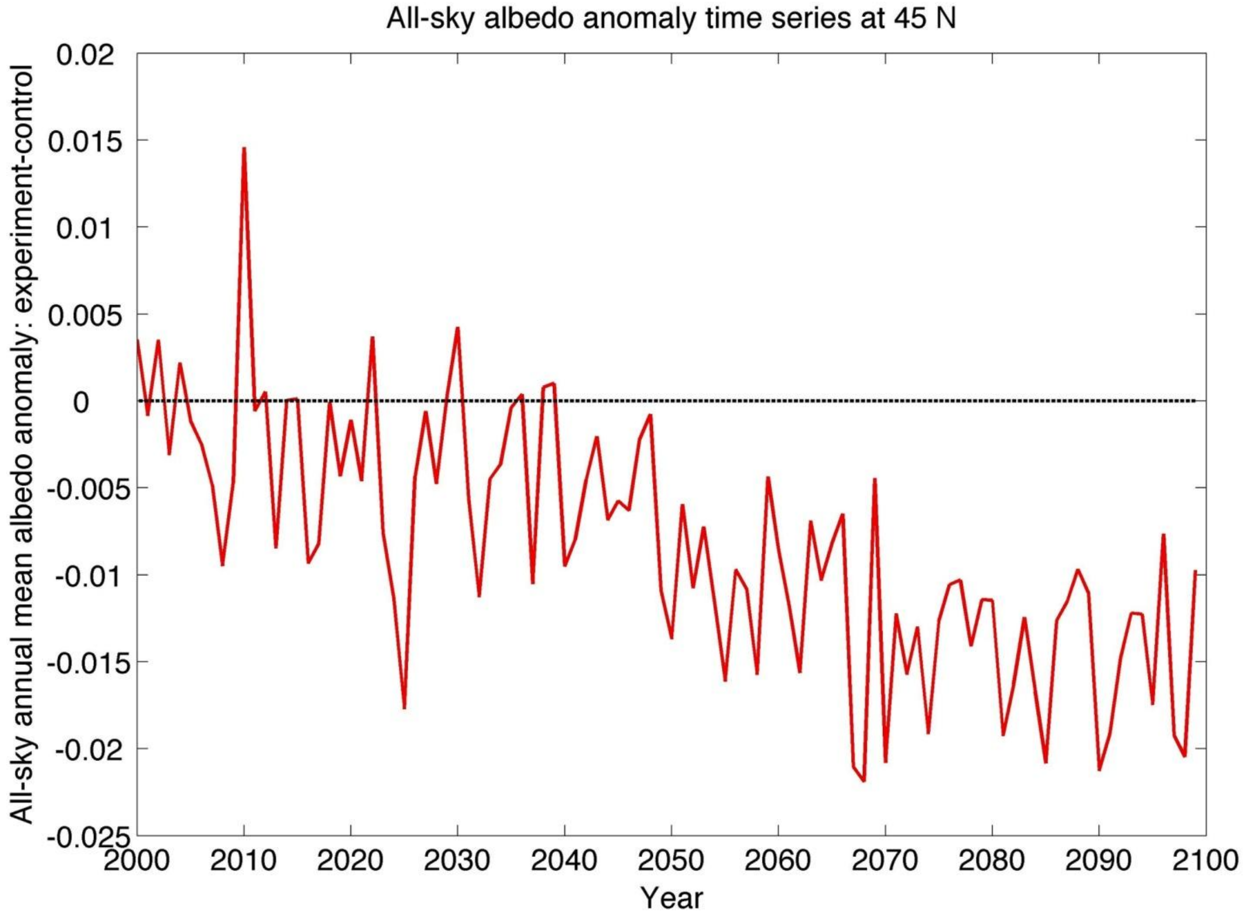




Time Series Comparison Analysis

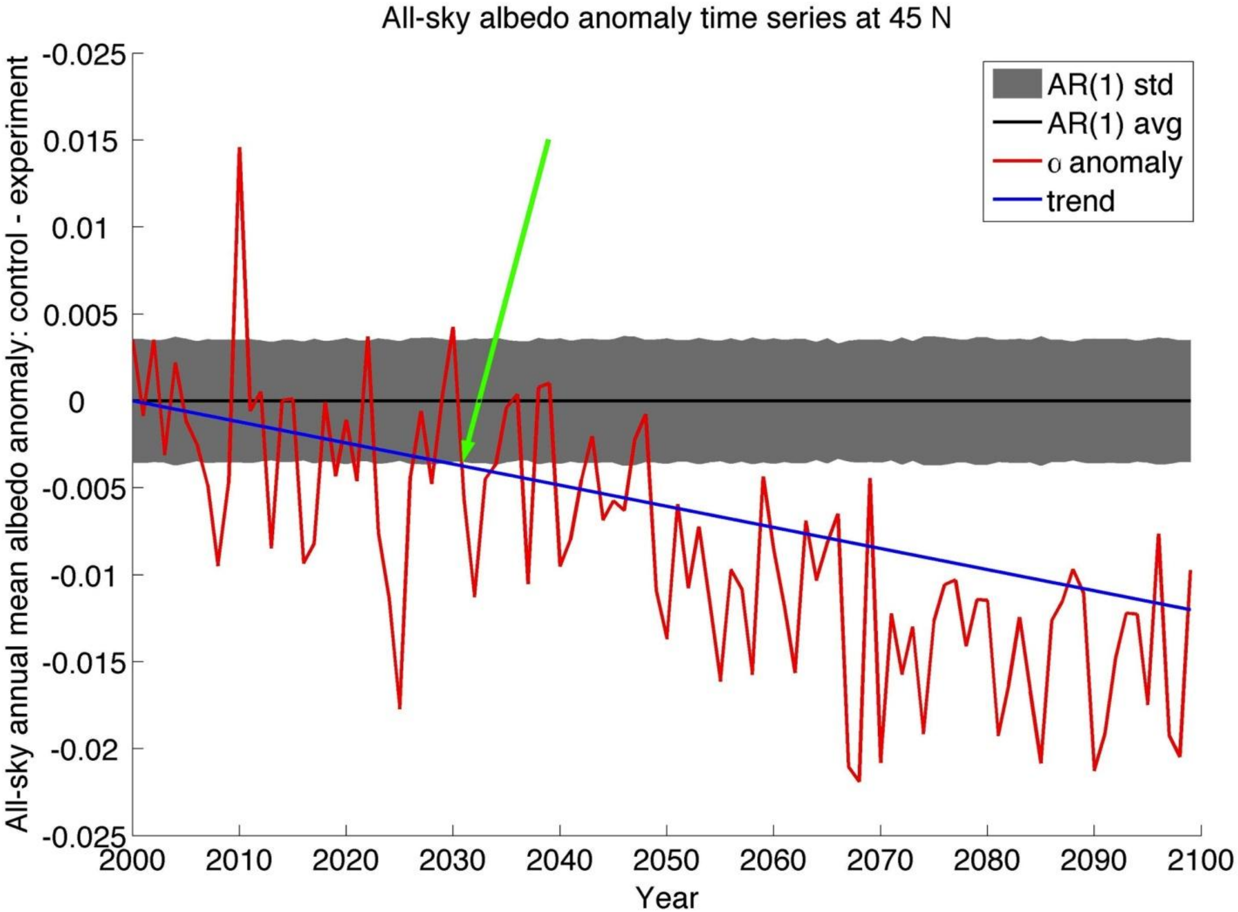
- We utilize the formulae from Weatherhead et al [1998] and described in Feldman et al [JGR, accepted] to estimate the time required to differentiate **two** time series.
  - Autocorrelation of noise process from constant (1x) CO_2 simulation.
  - Linear secular trend derived from the difference of the two time series.
  - Trend and noise assumed to be stationary.
- The goal is to quantify how quickly we could distinguish climate systems with higher/lower sensitivity using spectral vs. broadband measurements.

Time to detection for climate change



Trends in albedo and reflectance are superimposed on natural variability.

Time to detection for climate change

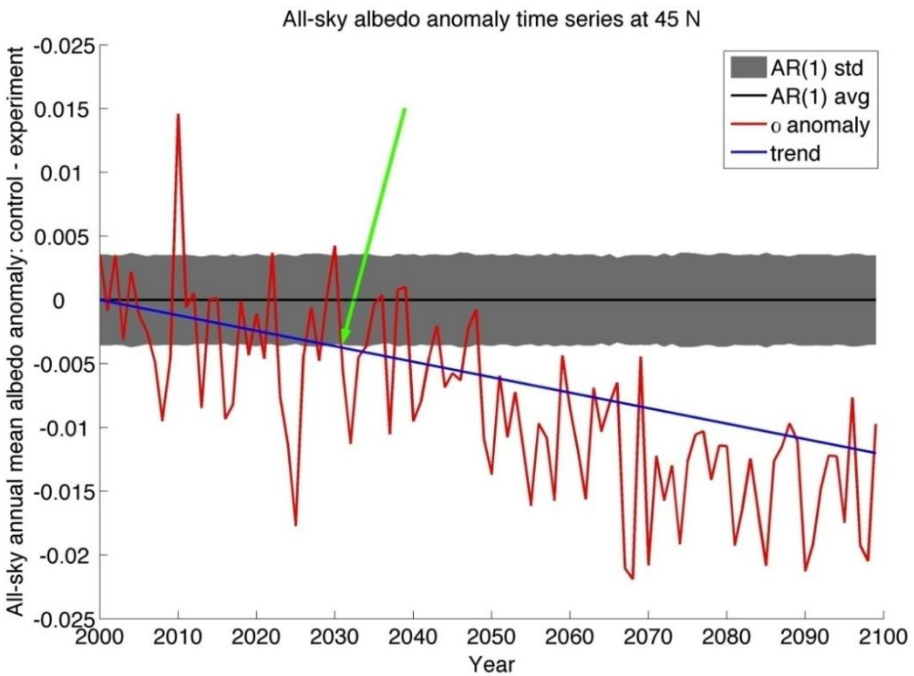


Trends in albedo and reflectance are superimposed on natural variability.

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.



$$n^* \approx e^{b/\sqrt{M}} \left[\frac{3.96\sigma_e}{|\omega_o|(1-\phi)}\right]^{2/3} \left(1+\frac{\sigma_{meas}^2}{\sigma_v^2}\right)^{1/3}$$

Detection time

Scaling factor for length of record

Std dev of noise process

Measurement uncertainty

Difference trend

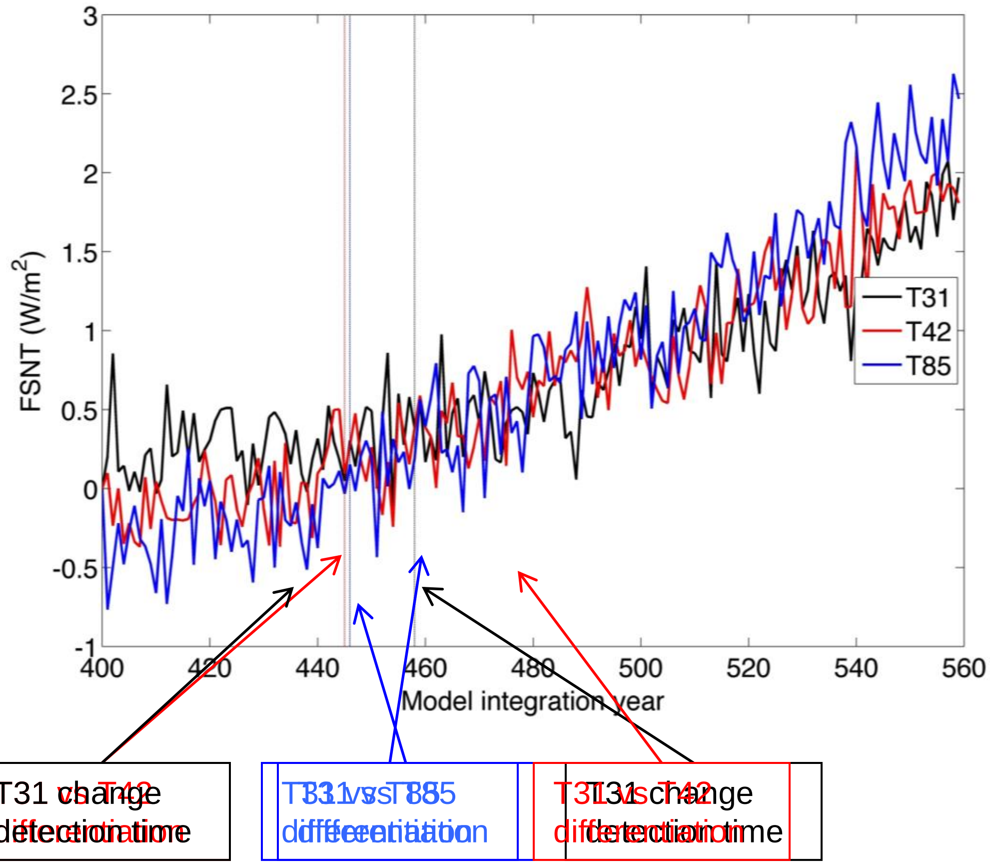
AR(1) of noise process

Correlated natural variability

Detecting change vs differentiating feedbacks

- We start by analyzing the times required to differentiate climates of different sensitivities using broadband data.

CCSM3 Differentation (years)				
Model	OLR	OLRC	α_{all}	α_{clr}
T31	35	35	58	31
T42 vs T31	75	74	45	48
T85 vs T31	58	59	46	46



Conclusions

- With more OSSE simulations, we will be able to evaluate the utility of spectral measurements vs. broadband time-series to differentiate among climates of varying sensitivities.
- This method could identify whether climate models with low/high sensitivity best match the observational record.
- We have begun to use OSSEs to isolate the spectral signatures of low-cloud feedbacks from a set of CCSM simulations.
  - Time records of broadband albedo and OLR for models with different low-cloud feedbacks only begin to diverge after several decades.

- Acknowledgements:
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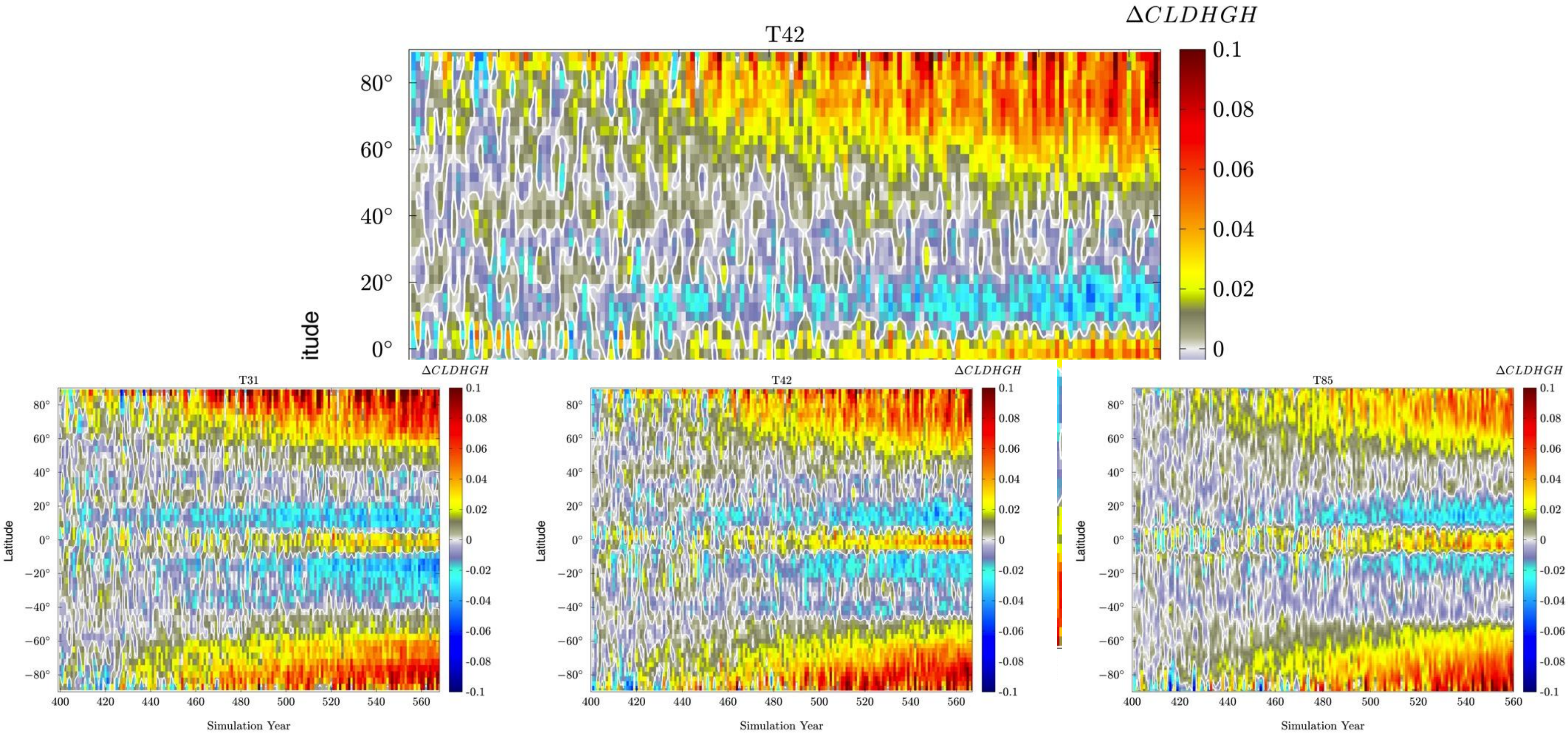
Future Directions

- Finish validation of MODTRAN LW clouds with CAM RT.
- High throughput of OSSE calculations for spectral comparison of T31, T42, and T85 simulations.
- PC methods for faster change detection.
- Joint analysis of long-term SCIAMACHY record
- Lay the groundwork for OSSE simulations using the reporting framework for CMIP5.

Extra Slides

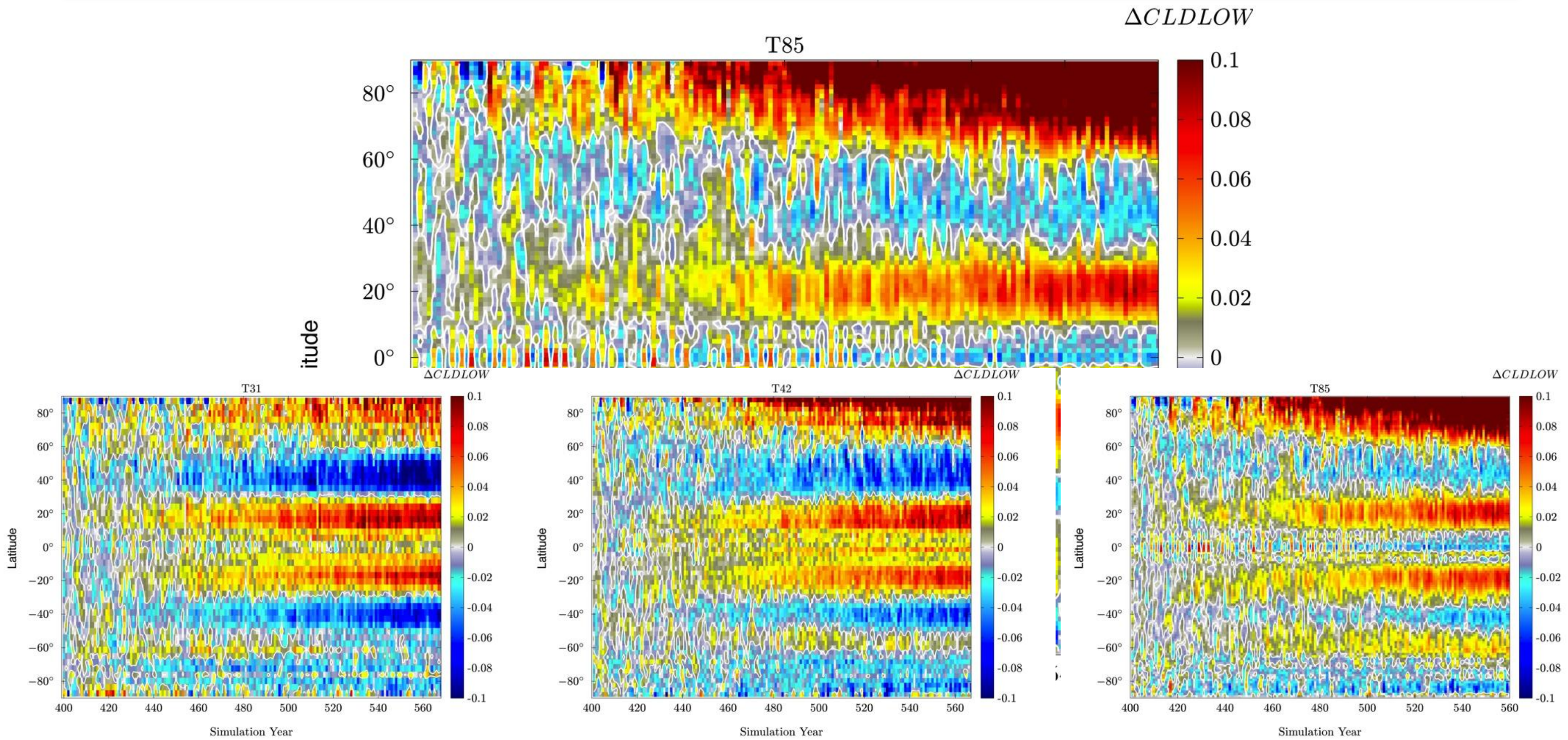
Δ CLDHGH

Similar trends between model resolution runs except at high latitudes.



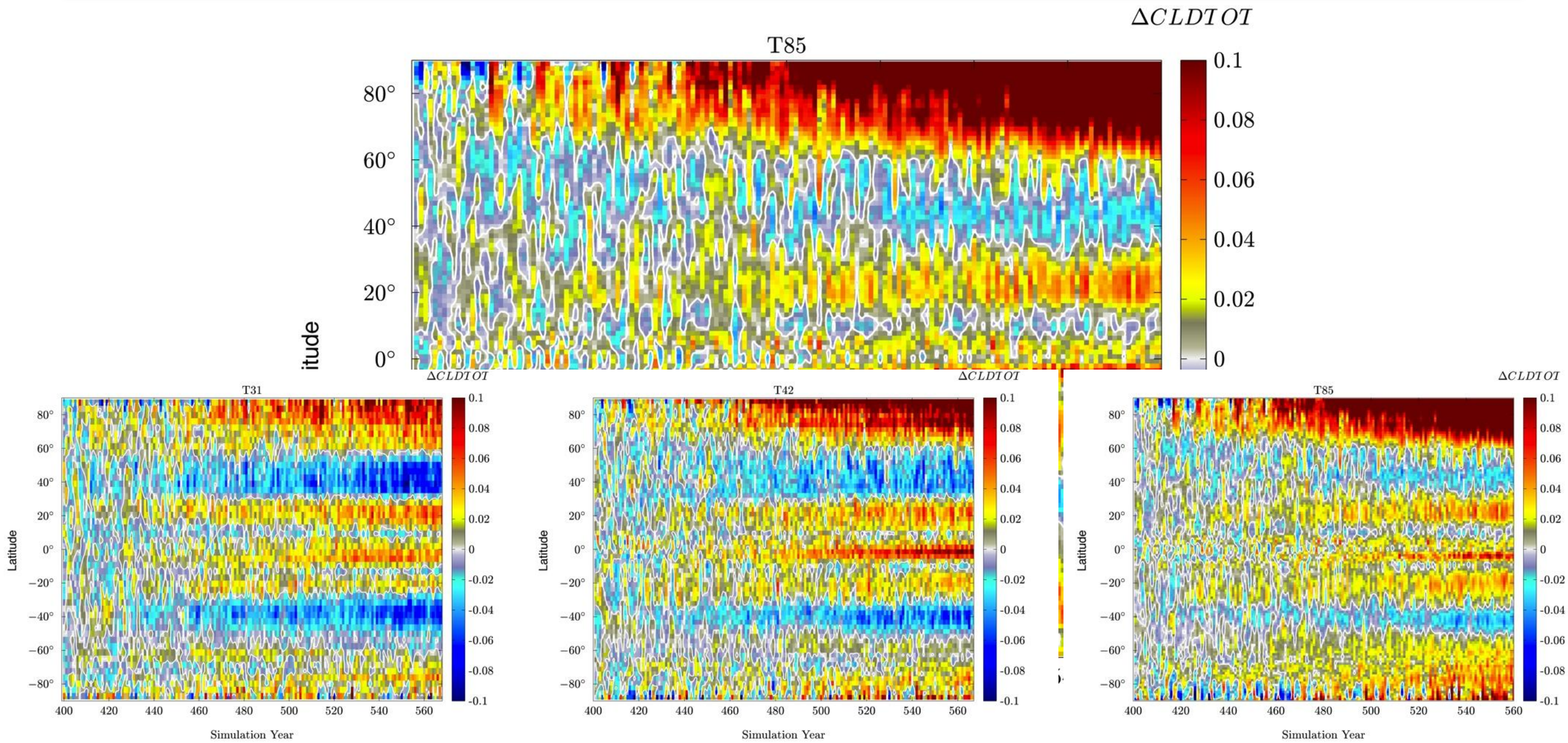
Δ CLDLOW

Differences exist at most latitudes.



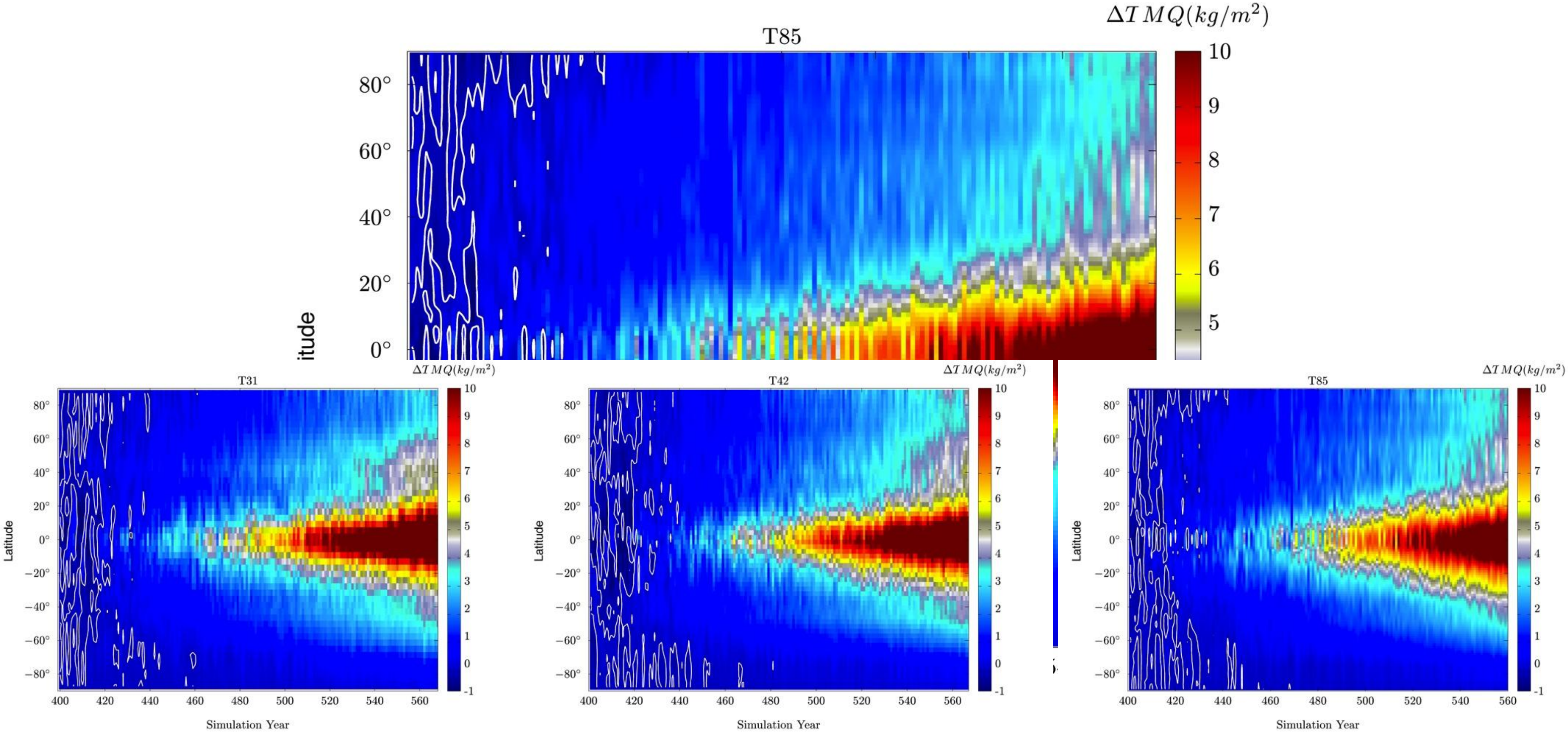
Δ CLDTOT

Similar trends between model resolution runs except at high latitudes.



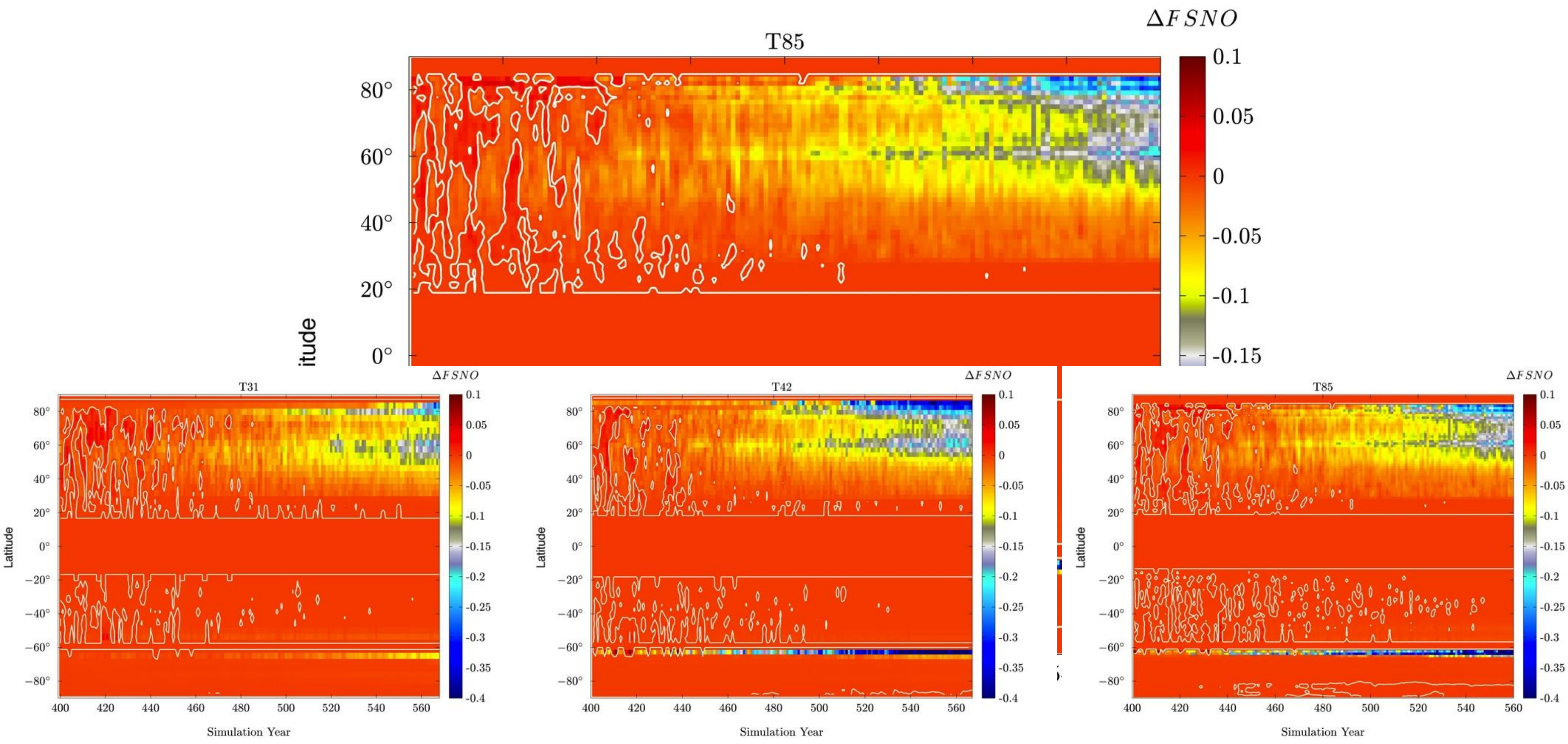
Δ TMQ

Similar trends between model resolution runs except in mid-lat NH.



Δ FSNO

T42 resolution shows the largest trends at high latitudes.



Δ ICEFRAC

Ice fraction decrease is stronger with higher-resolution runs.