On the use of spectral observations in climate change studies: a review and an outlook

Xianglei Huang

University of Michigan

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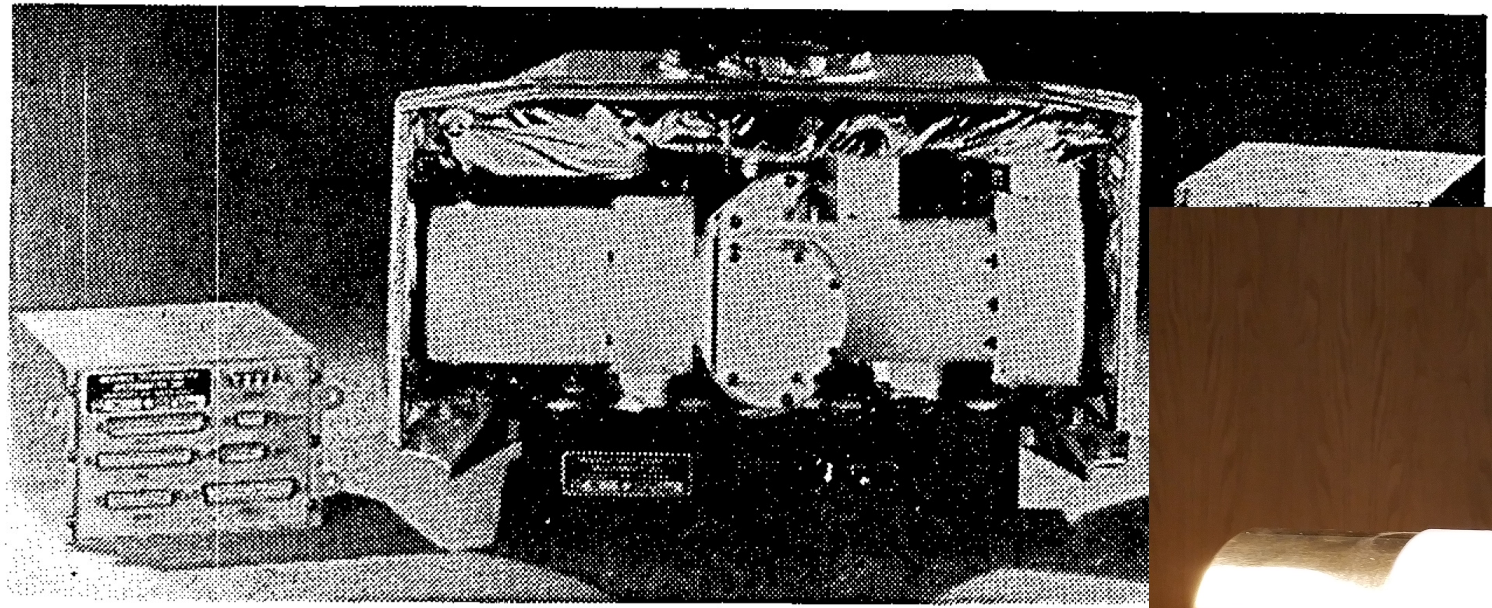
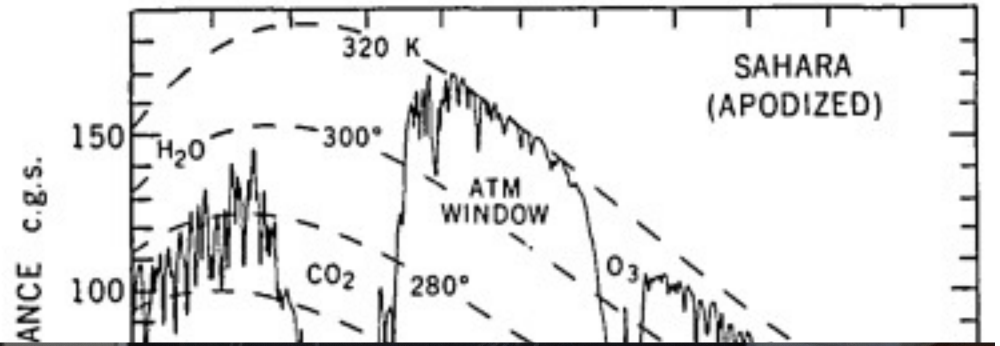
Acknowledgments: CERES team, past and current students and collaborators

A bit more than half a century ago





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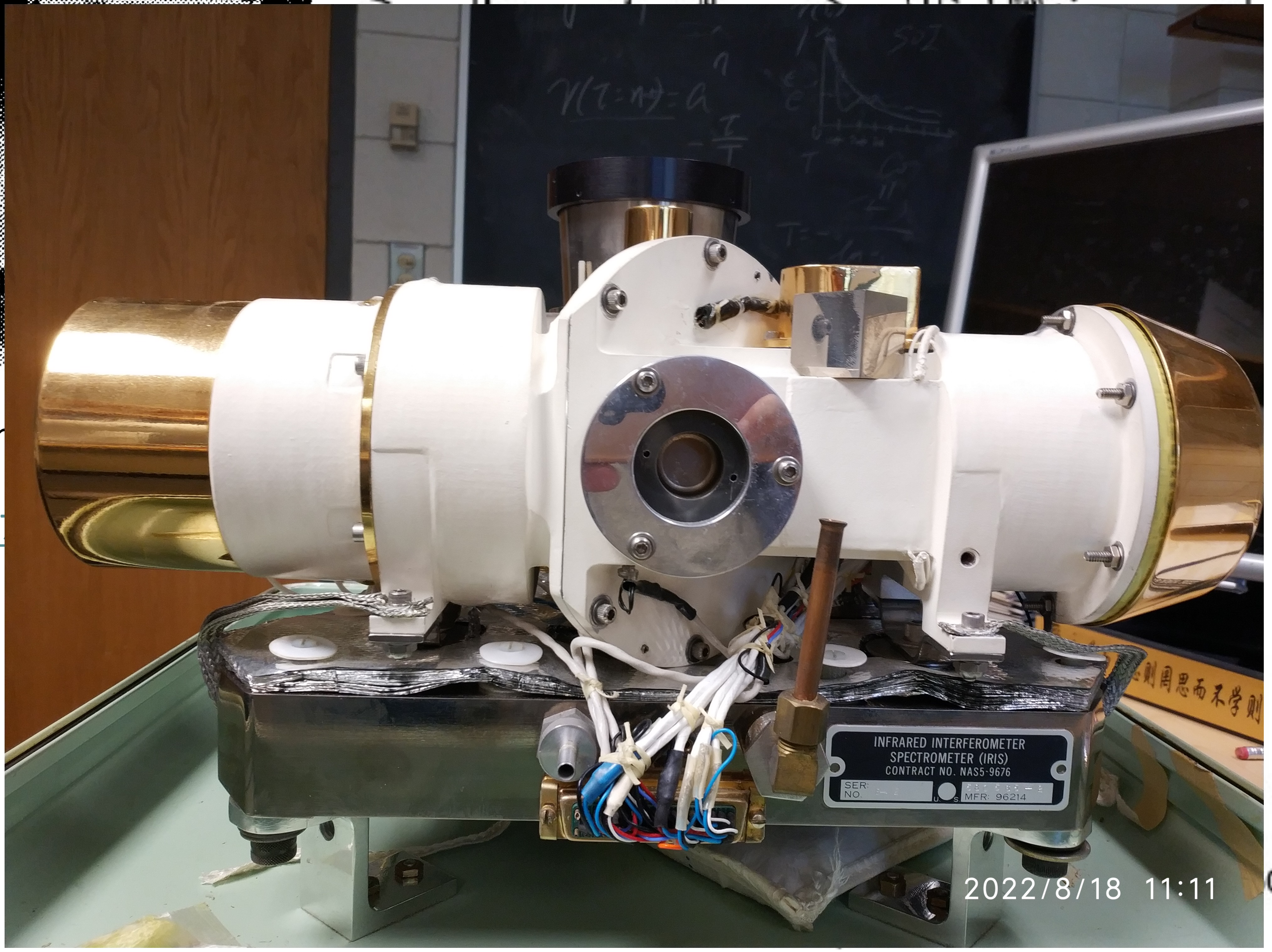

IRIS-D on Nimbus IV: April 1970-January 1971

Quarter a century ago

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A statistical method for testing a general circu with spectrally resolved satellite data

Robert D. Haskins, Richard M. Goody, and Luke Chen
Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Abstract. The motivation for this paper is to understand better t testing climate models. Statistics of observed, outgoing, therm those predicted from a climate model, on the basis of data co approximately 1 year. This is a powerful approach to testing a processes internal to the atmosphere. These processes, which ha less than a year, define the atmosphere's response to external statistics are particularly important for testing model variabilit the results of forcing the atmosphere, for example, by ocean s increase of greenhouse gases, etc. Comparisons are presented from the infrared interferometer spectrometer (IRIS), an orb spectrometer, and spectra calculated using the medium-resolu MODTRAN, applied to the temperature and humidity profile model. Ten months of IRIS data are available, and we have c deviations, skew, and kurtosis of its spectrally resolved brightr tropical regions for individual months and for a range of time comparisons of covariances using Empirical Orthogonal Func frequency space. All data that are presented are based on rad like spectra, which eliminates many of the errors generated by most of the errors due to calibration uncertainties in IRIS. In residuals) between the IRIS and the GCM statistics are found in that the spectral data can provide a severe test of many aspec general circulation model. We discuss some of the residuals a improve model performance in the context of an adjoint form only way to have confidence in the performance of a model is discriminating comparisons with data as are practicable, and v

NOTES AND CORRESPONDENCE

Calibration of Radiances from Space

RICHARD GOODY
Falmouth, Massachusetts

ROBERT HASKINS
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

6 March 1997 and 19 June 1997

ABSTRACT

Radiance Covariance and Climate Models

ROBERT HASKINS,* RICHARD GOODY, AND LUKE CHEN
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

(Manuscript received 7 January 1998, in final form 1 June 1998)

ABSTRACT

Spectral empirical orthogonal functions (EOFs) derived from the covariance of satellite radiance spectra may be interpreted in terms of the vertical distribution of the covariance of temperature, water vapor, and clouds. This has been done for four major geographic regions: the tropical oceans, midlatitude oceans, and three important land areas. The purpose of the investigation is to demonstrate the important constraints that resolved spectral radiances can place upon climate models.

Detect climate change from AIRS radiances

Testing Climate Models: An Approach

Richard Goody,* James Anderson,+ and Gerald North#

ABSTRACT

The scientific merit of decadal climate projections can only be established by means of comparisons with observations. Testing of models that are used to predict climate change is of such importance that no single approach will provide the necessary basis to analyze systematic errors and to withstand critical analysis.

Appropriate observing systems must be relevant, global, precise, and calibratable against absolute standards. This paper describes two systems that satisfy these criteria: spectrometers that can measure thermal brightness temperatures with an absolute accuracy of 0.1 K and a spectral resolution of 1 cm^{-1}, and radio occultation measurements of refractivity using satellites of the GPS positioning system, which give data of similar accuracy.

Comparison between observations and model predictions requires an array of carefully posed tests. There are at least two ways in which either of these data systems can be used to provide strict, objective tests of climate models. The first looks for the emergence from the natural variability of a predicted climate "fingerprint" in data taken on different occasions. The second involves the use of high-order statistics to test those interactions that drive the climate system toward a steady state. A correct representation of these interactions is essential for a credible climate model.

A set of climate model tests is presented based upon these observational and theoretical ideas. It is an approach that emphasizes accuracy, exposes systematic errors, and is focused and of low cost. It offers a realistic hope for resolving some of the contentious arguments about global change.

- Long-term trend then optimal fingerprinting for detection and attribution
- Second-moment statistics (covariance) for model evaluation

From spectral radiance to climate

Geophysical variables

- T(z)
- $q_{H2O}(z)$, $q_{O3}(z)$, $q_{CH4}(z)$ …
- Cloud, aerosols
- T_{skin}, $\varepsilon_s(v)$

Spectral Radiances

$$I_{TOA}(v;\theta,\phi)$$

Retrieve-then-average
Vs.
Average-then-retrieve

Sounding community

Detect climate change signal from radiances (AIRS, IRIS-D, IASI, …)

Spectral Flux

$$F_v = \int_0^{2\pi} d\phi \int_0^{\frac{\pi}{2}} I_{TOA}(v;\theta,\phi)\cos\theta\sin\theta\, d\theta$$

Spectral Radiative Feedbacks

$$\lambda_{x_v} = -\frac{\delta_x \overline{F_v}}{\delta X}\frac{\delta X}{\delta T_s}$$

Instrument cross calibration

Spectral radiative feedbacks

Broadband *Radiation Budget*

$$F = \int_{\Delta v} F_v\, dv$$

Broadband *Radiative Feedbacks*

$$\lambda_x = -\frac{\delta_x \overline{F}}{\delta X}\frac{\delta X}{\delta T_s}$$

Energy budget and feedbacks community

Assess long-term performance

MICHIGAN

With 21.9 billions of AIRS well-calibrated spectra collected so far

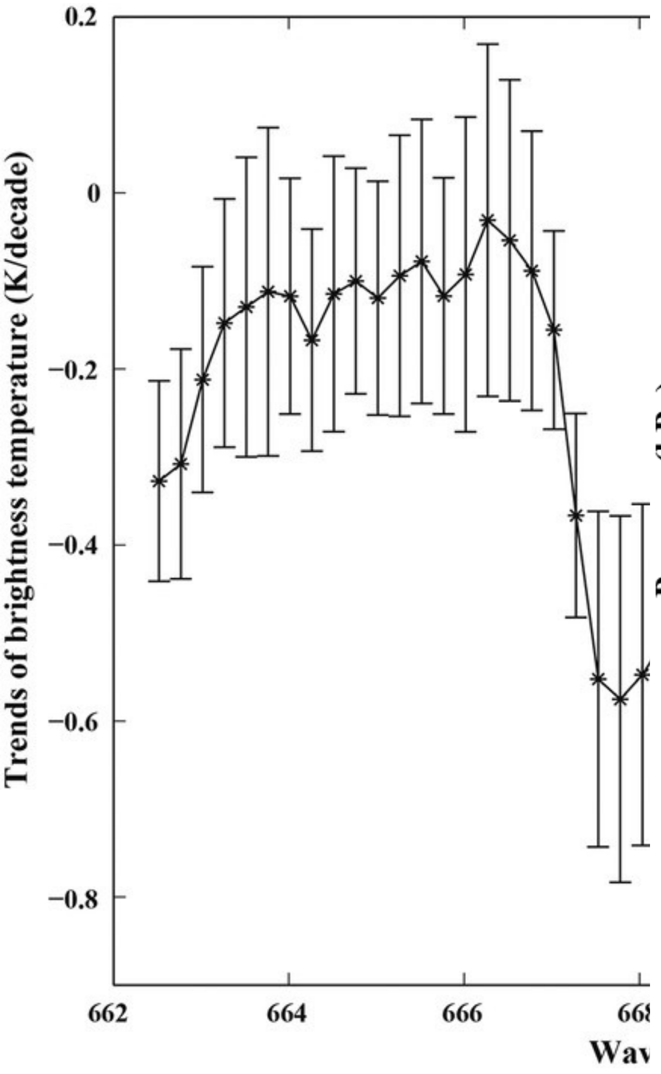
- More can be done with the spectral radiances (trend analysis, signal detection and attribution, etc.), yet complexity with angles and clouds.
- Spectral flux can be derived and used as a bridge to help us understand radiative forcings and feedbacks

  Spectral OLR we derived directly from AIRS radiance now is part of standard AIRS L3 product (AIRSIL3MSOLR_6.1)

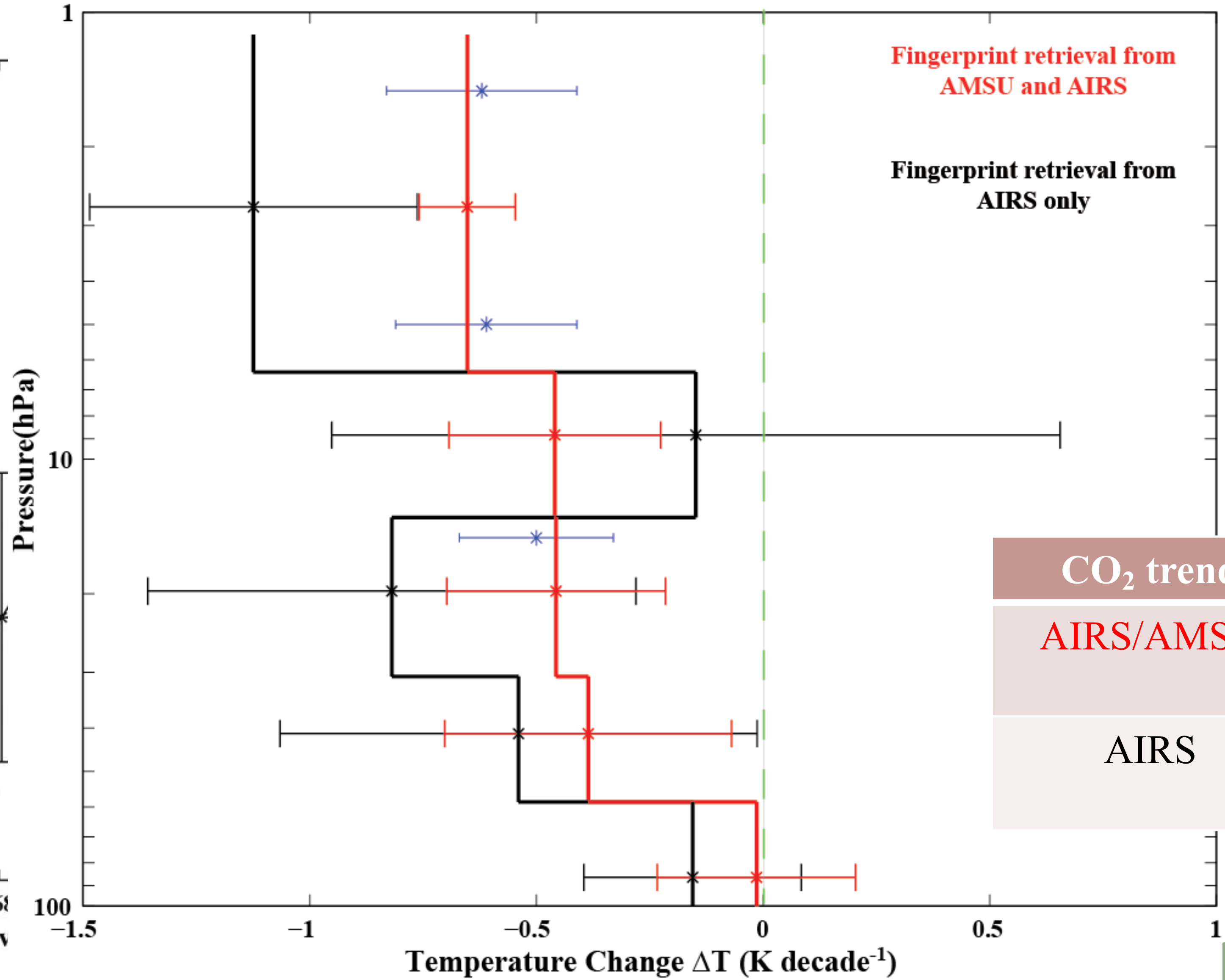
In the rest of this presentation, I will discuss a few studies and efforts in my group for the above two tasks.

AIRS nadir-view radiance trends and inferred stratospheric change (Pan et al., 2017)

Trend of 2003-2013

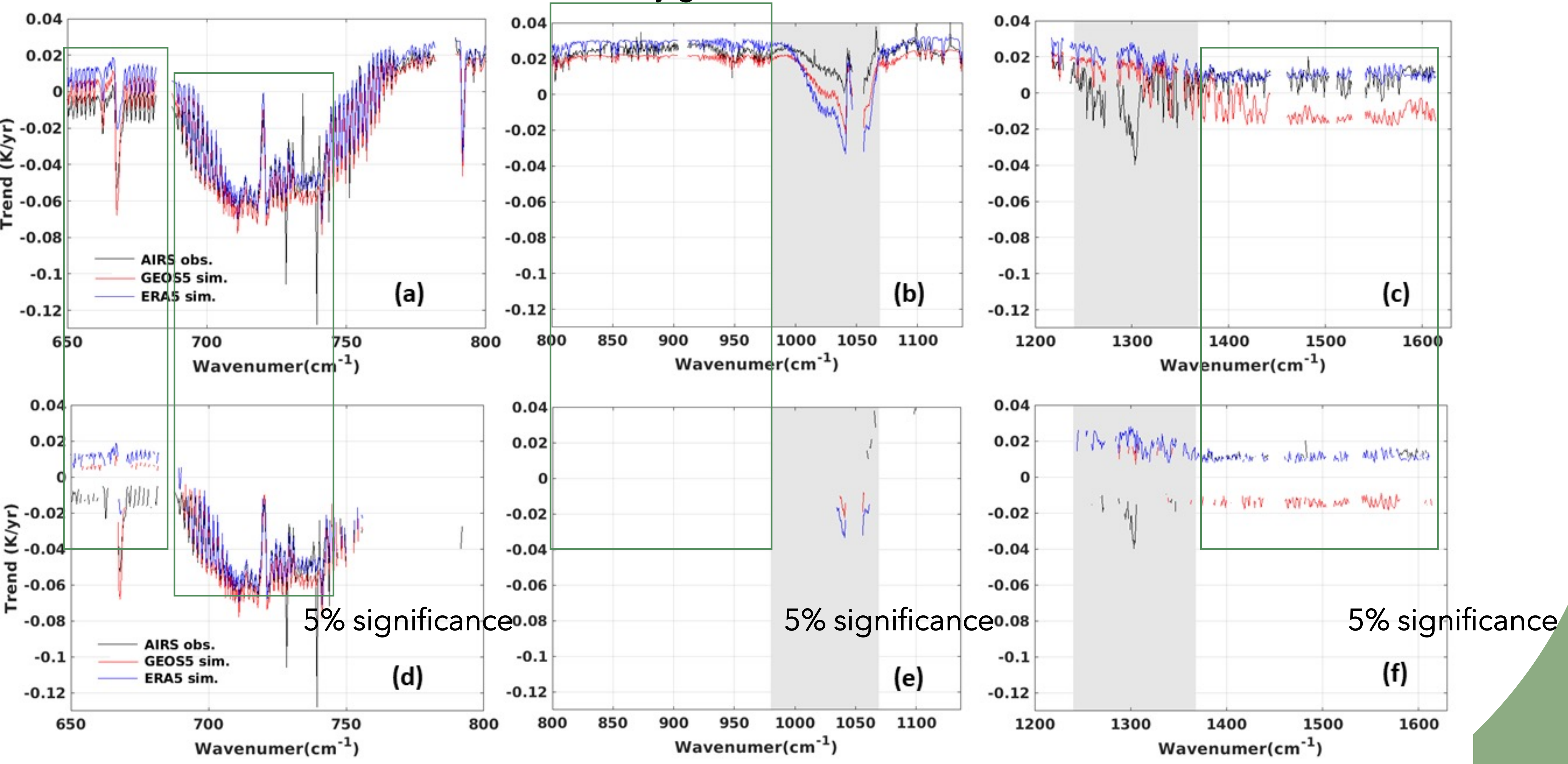


Optimal fingerprint estimation (Hasselmann, 1993;1997)



CO_2 trend	ppmv yr^{-1}
AIRS/AMSU	1.57 ± 0.1
AIRS	1.05 ± 0.6

AIRS nadir-view, clear-sky global-mean trend (2003-2020)



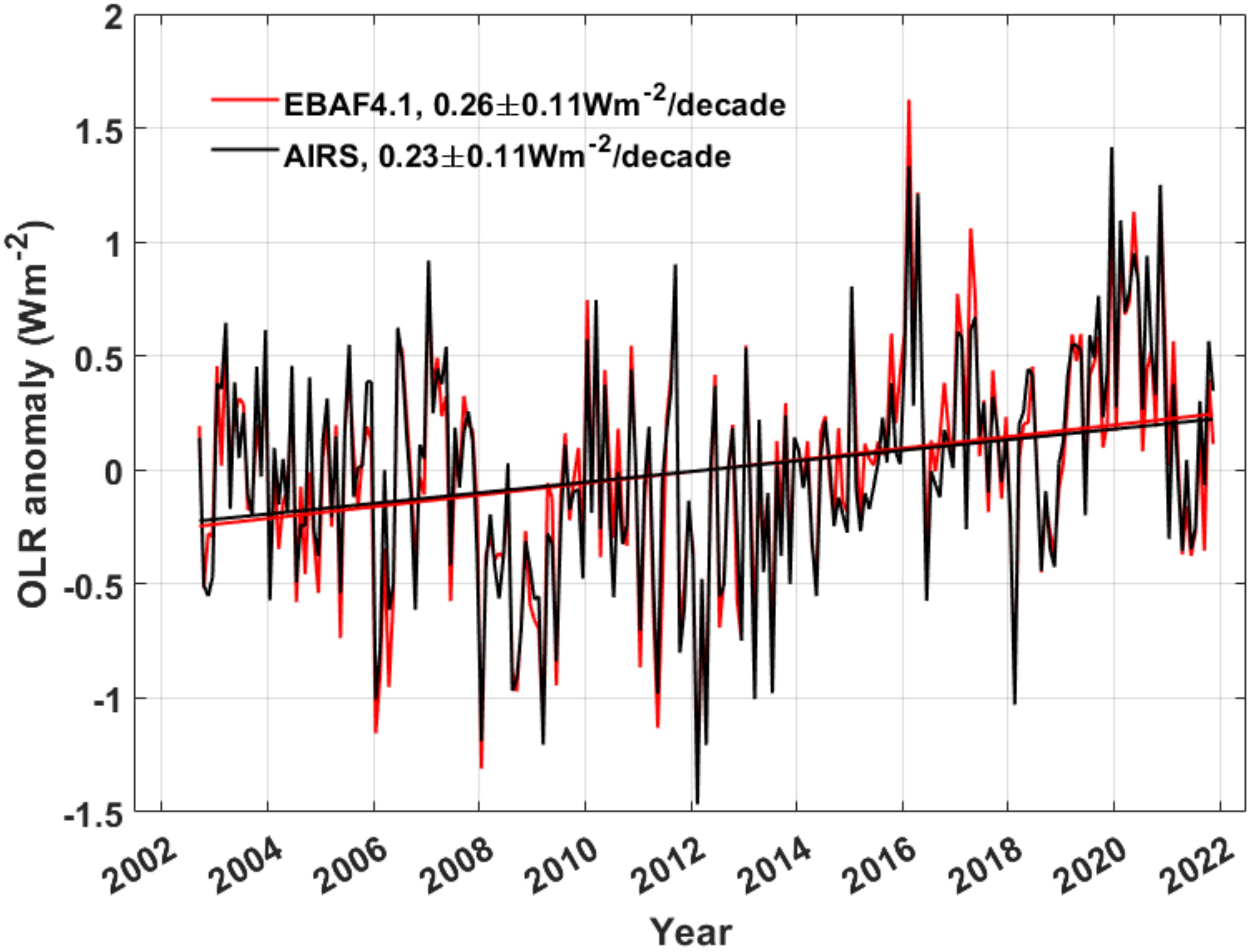
Both reanalyses sampled to AIRS clear-sky footprints before any trend analysis Huang et al. (submitted)

Next, I will use two examples to illustrate the merit of spectral flux diagnostics in feedback studies

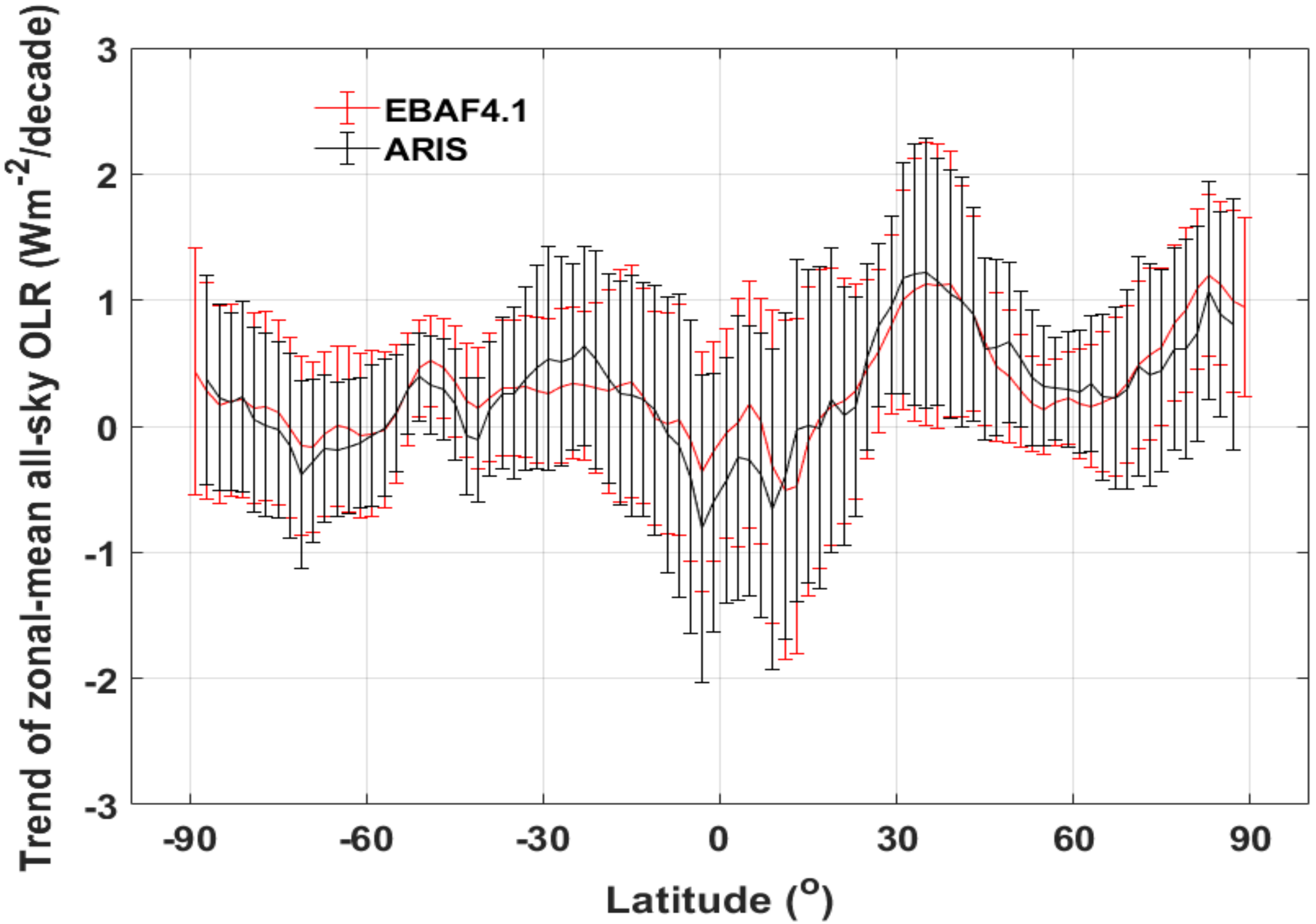
- Trends of AIRS spectra OLR vs. CERES EBAF 4.1 OLR
- Spectrally decomposed lapse-rate and relative humidity feedbacks (LW)

Spectral dimension can reveal the compensating biases that cannot be revealed from broadband diagnostics and evaluation

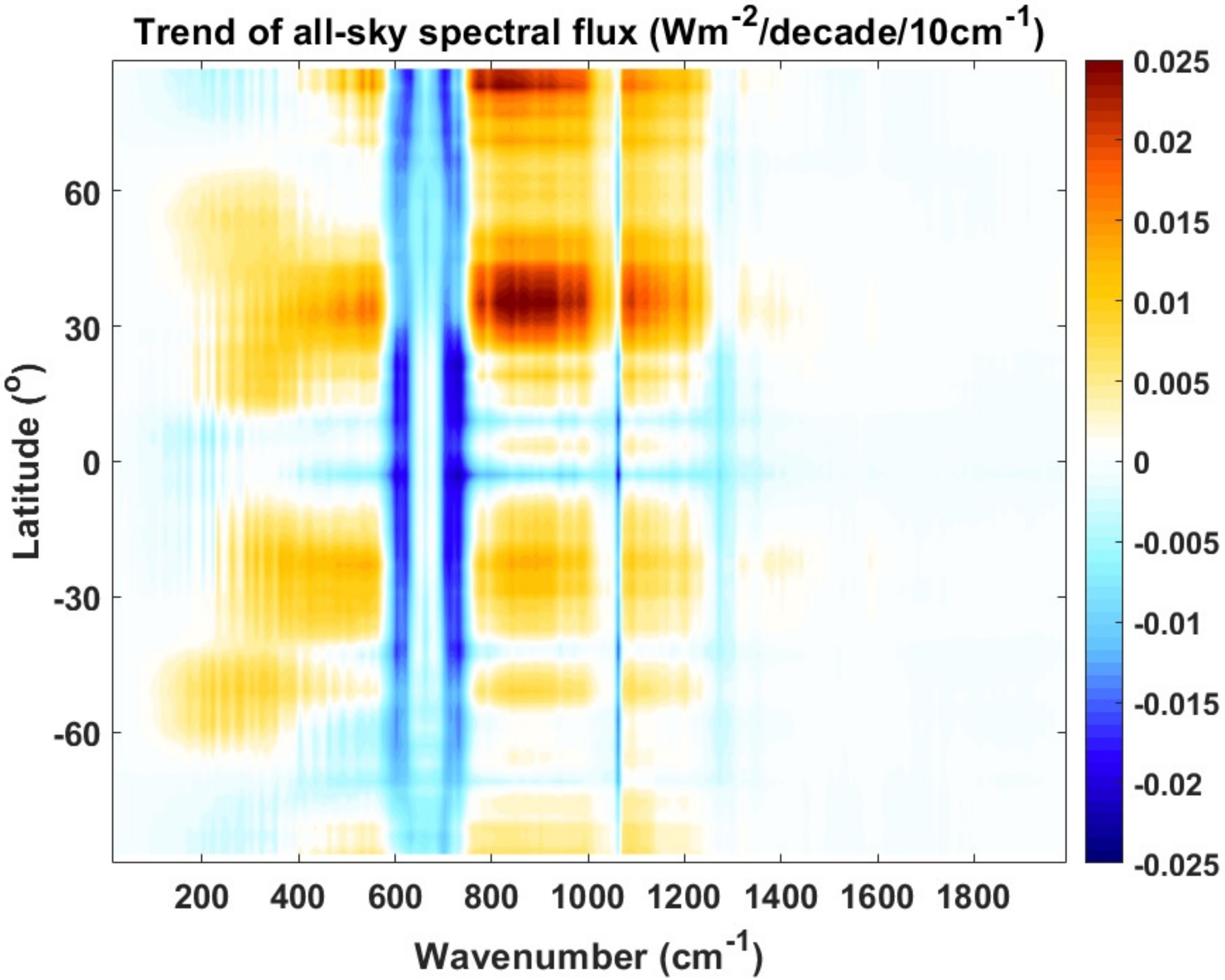
AIRS: sum of spectral OLR directly inferred from AIRS L1 radiances

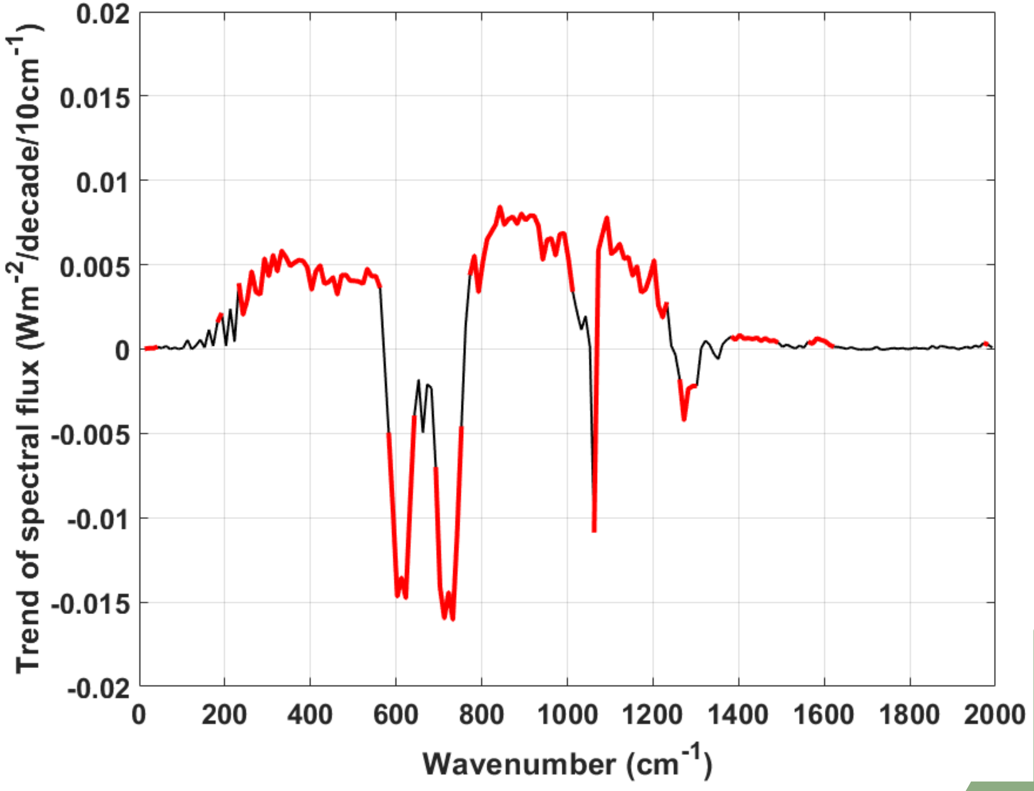


Zonal-mean Trend (2003 to 2021)



Trend of global-mean, all-sky spectral flux (2003-2021)

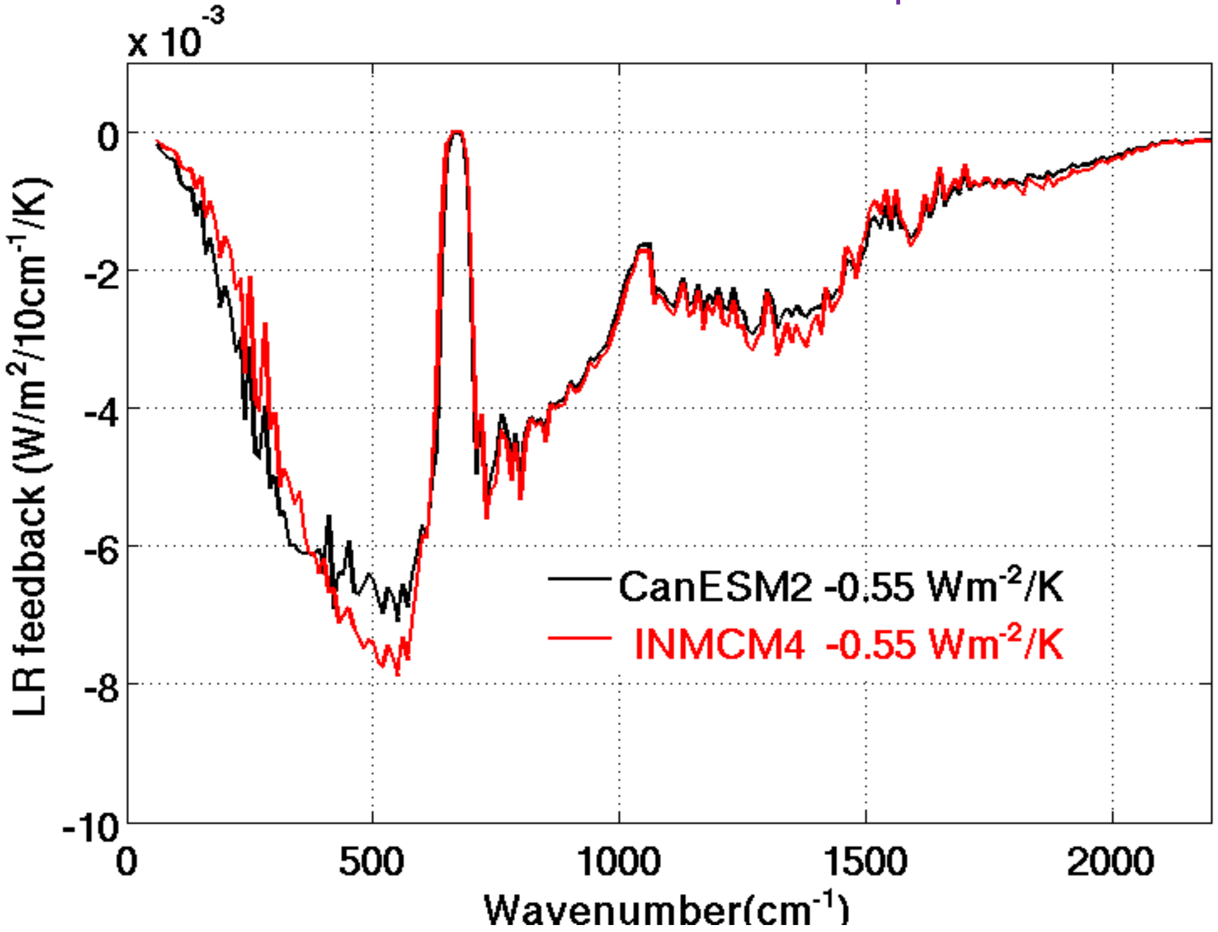


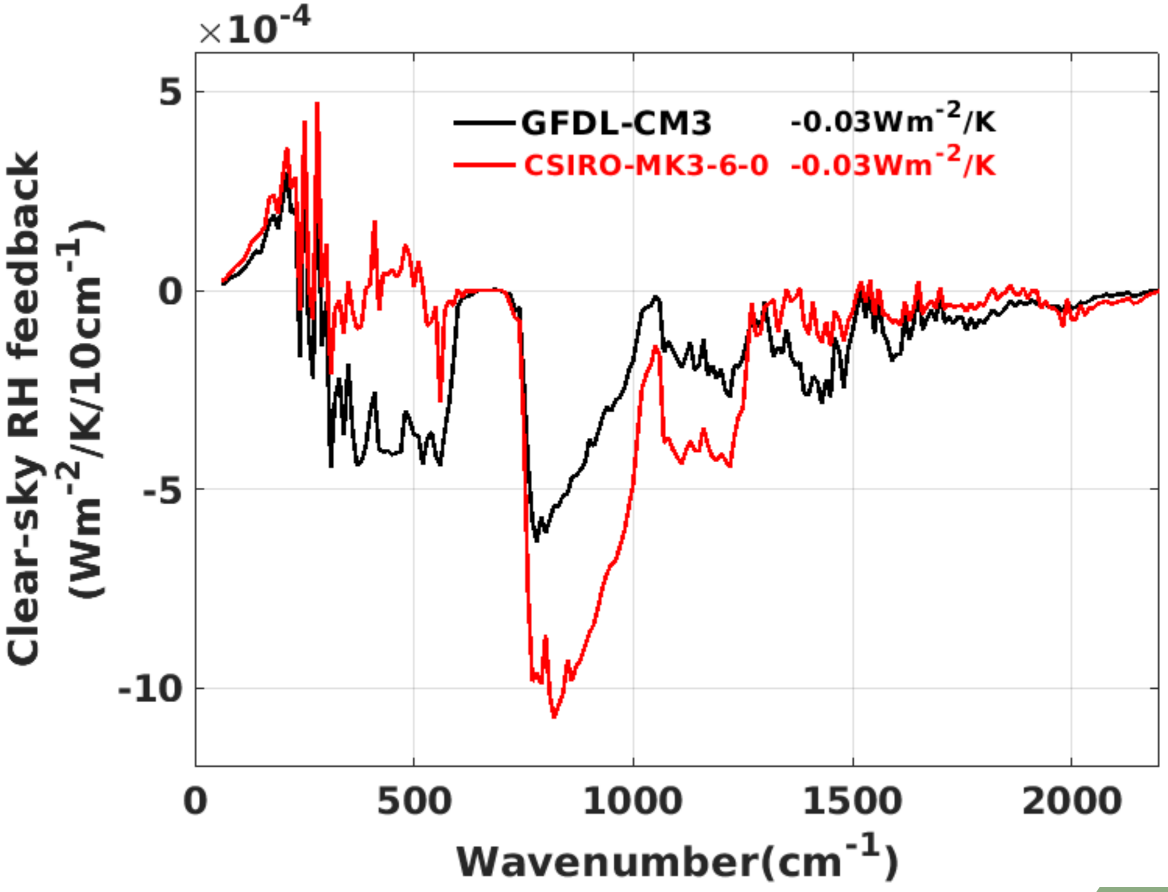


Spectral decomposition of the LW radiative feedbacks

Identical broadband feedback could have different spectral decomposition

spectral interval: $10 cm^{-1}$

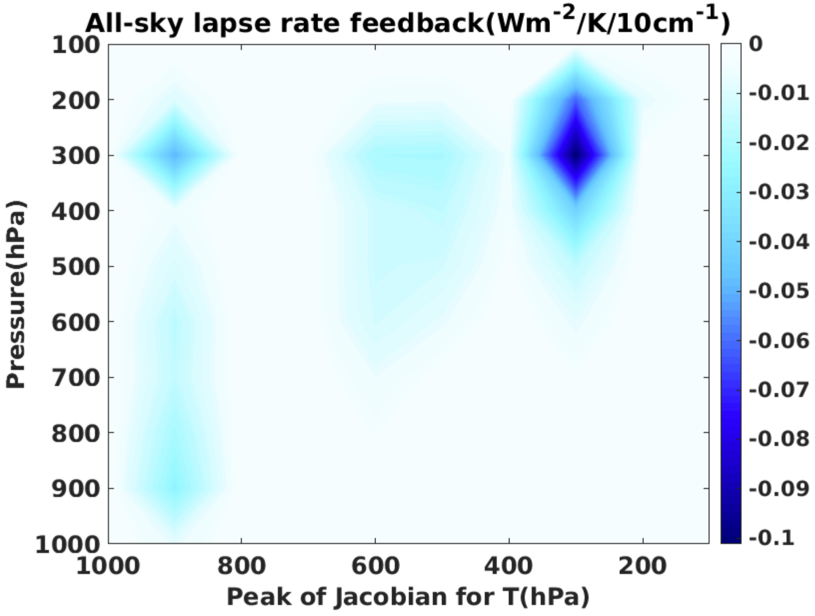




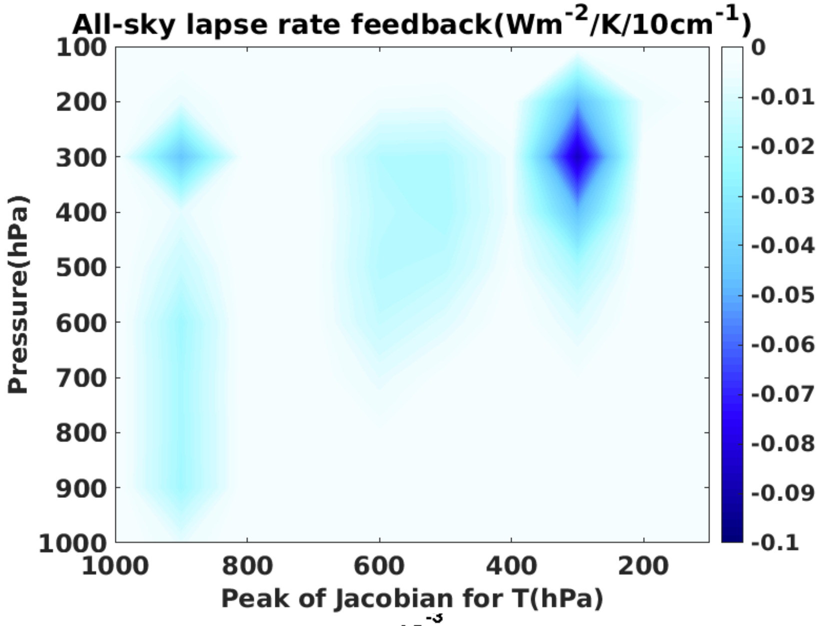
(Huang et al., 2014; Pan & Huang, 2018)

We can rearrange spectral frequency w.r.t. the peak of clear-sky Jacobian
&
Examine the contribution from different vertical layers

CanESM2: -0.55 Wm^{-2}/K

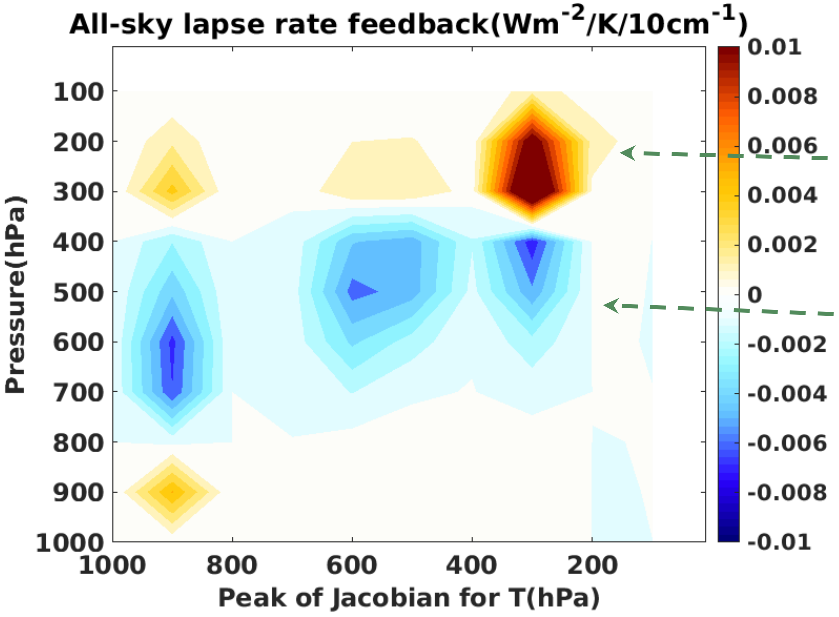


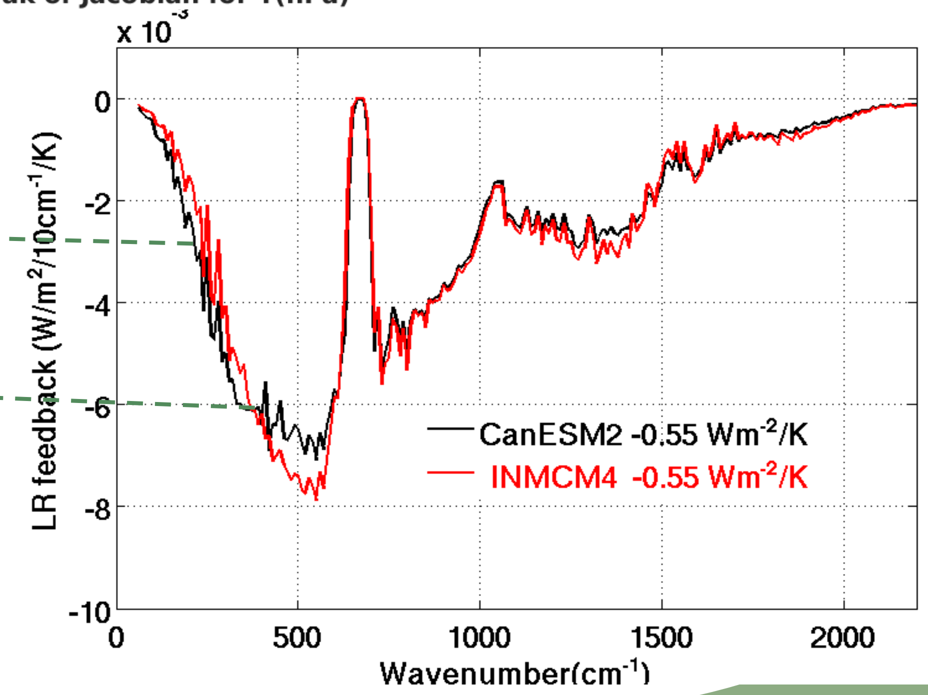
INMCM4: -0.55 Wm^{-2}/K



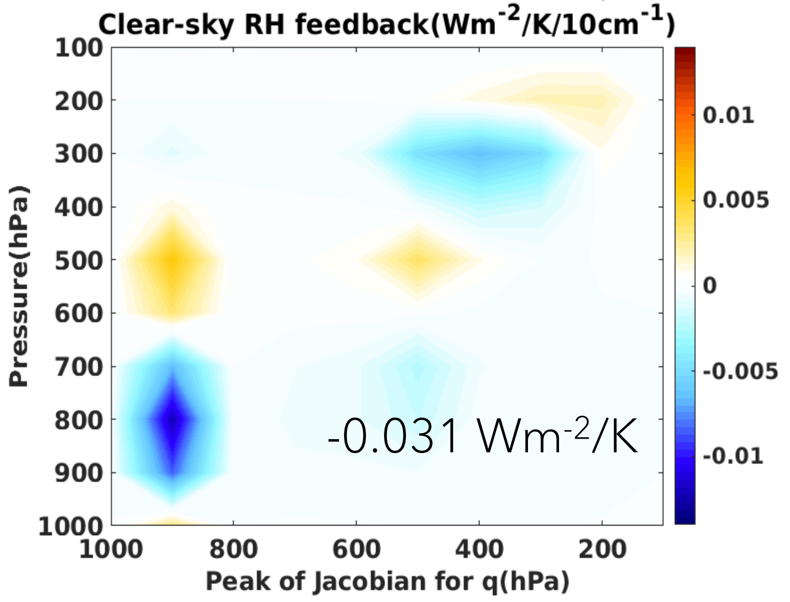
spectral interval: $10cm^{-1}$

INMCM4 – CanESM2

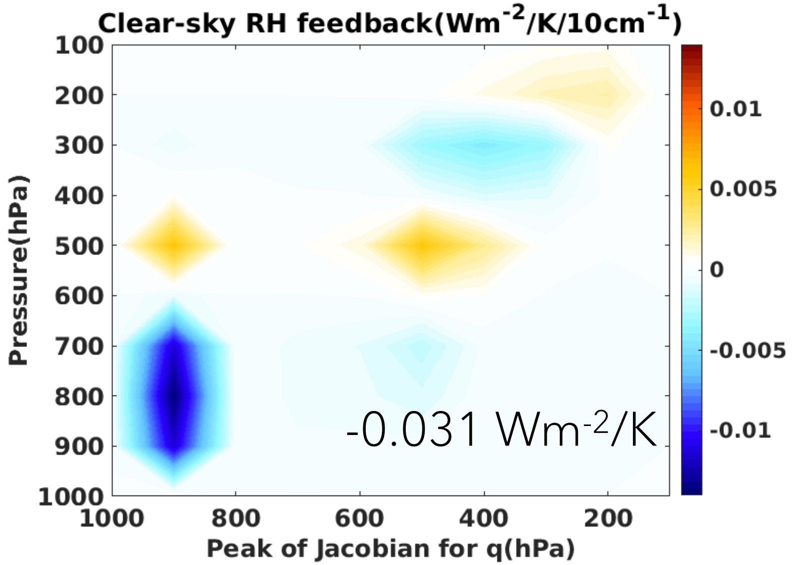




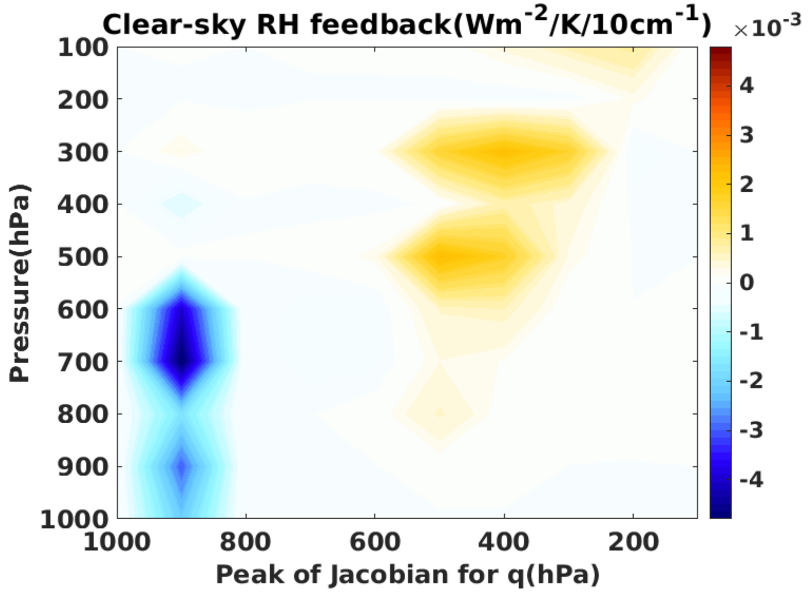
GFDL CM3 (clear-sky)



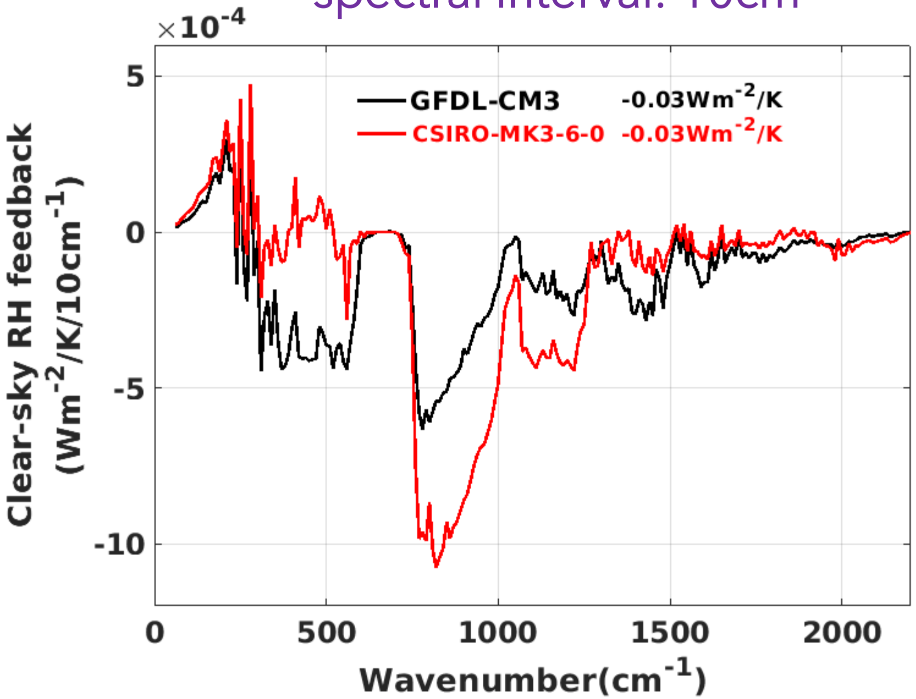
CSIRO-MK3-6-0(clear-sky)



CSIRO-MK3-6-0 – GFDL CM3



spectral interval: $10cm^{-1}$



Summary and Reflections

- Complement to broadband analysis, spectral dimension can reveal the compensating biases
- However, for the longwave spectral obs: vertical information is encoded in the spectral dimension in a *complicated* way (thermal contrast, clouds, etc)
- Unscramble such vertical information is not trivial, other obs can help
- We have enough data now to seriously look at spectral radiative forcing and feedback details from the observations

Thank You!

References

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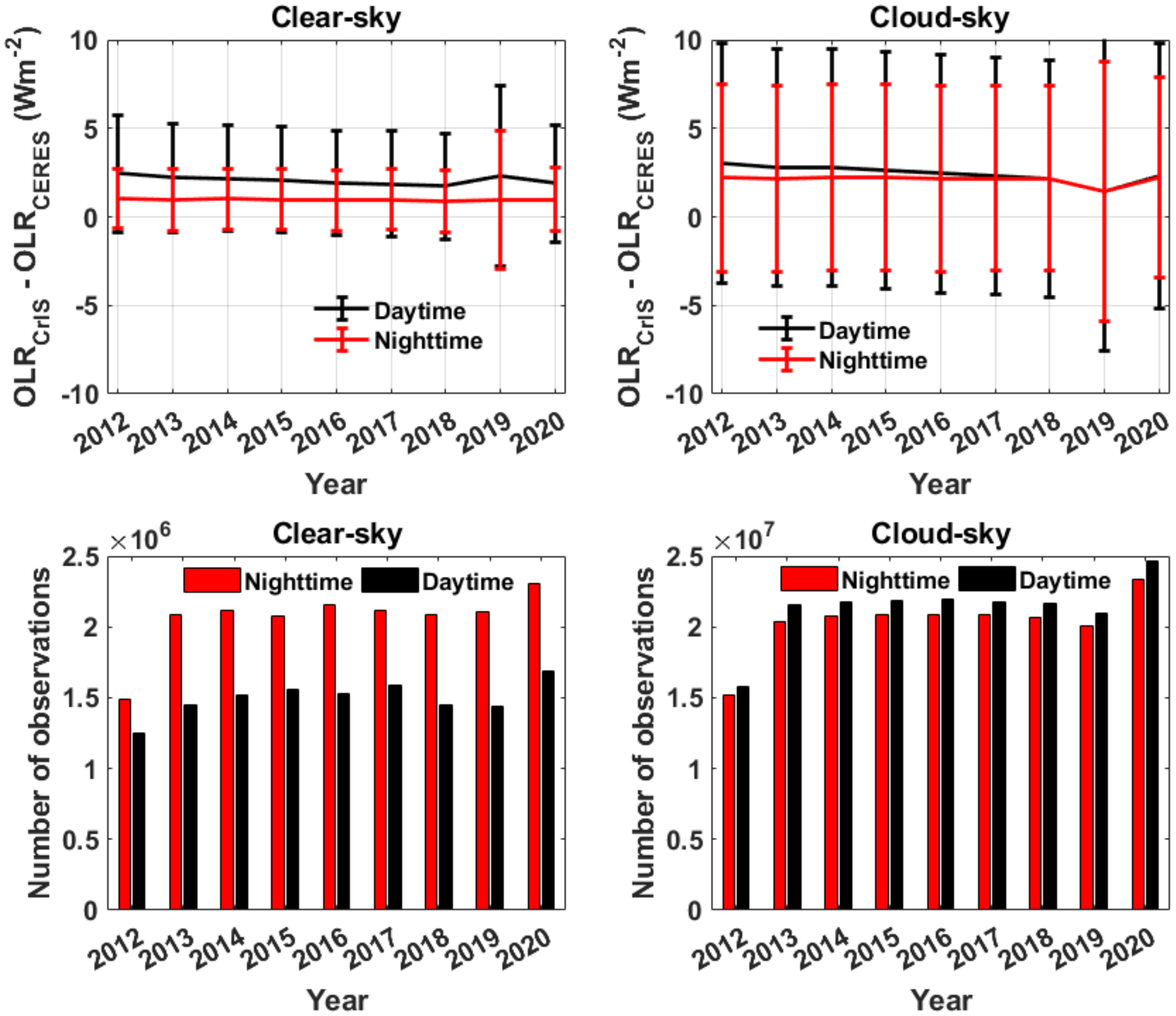
Backup

Annual means of clear-sky and cloudy-sky OLR_{CrIS} – $OLR_{CERES-FM5-Ed1}$ over the globe for 2012 to 2020



Range of the annual-mean OLR_{CrIS} – $OLR_{CERES\text{-}FM5\text{-}Ed1}$ (Wm^{-2}) from 2012 to 2020

	Clear-sky	Cloudy-sky
Daytime	[1.71,2.43]	[1.42, 3.02]
Nighttime	[0.88,1.03]	[1.45, 2.23]

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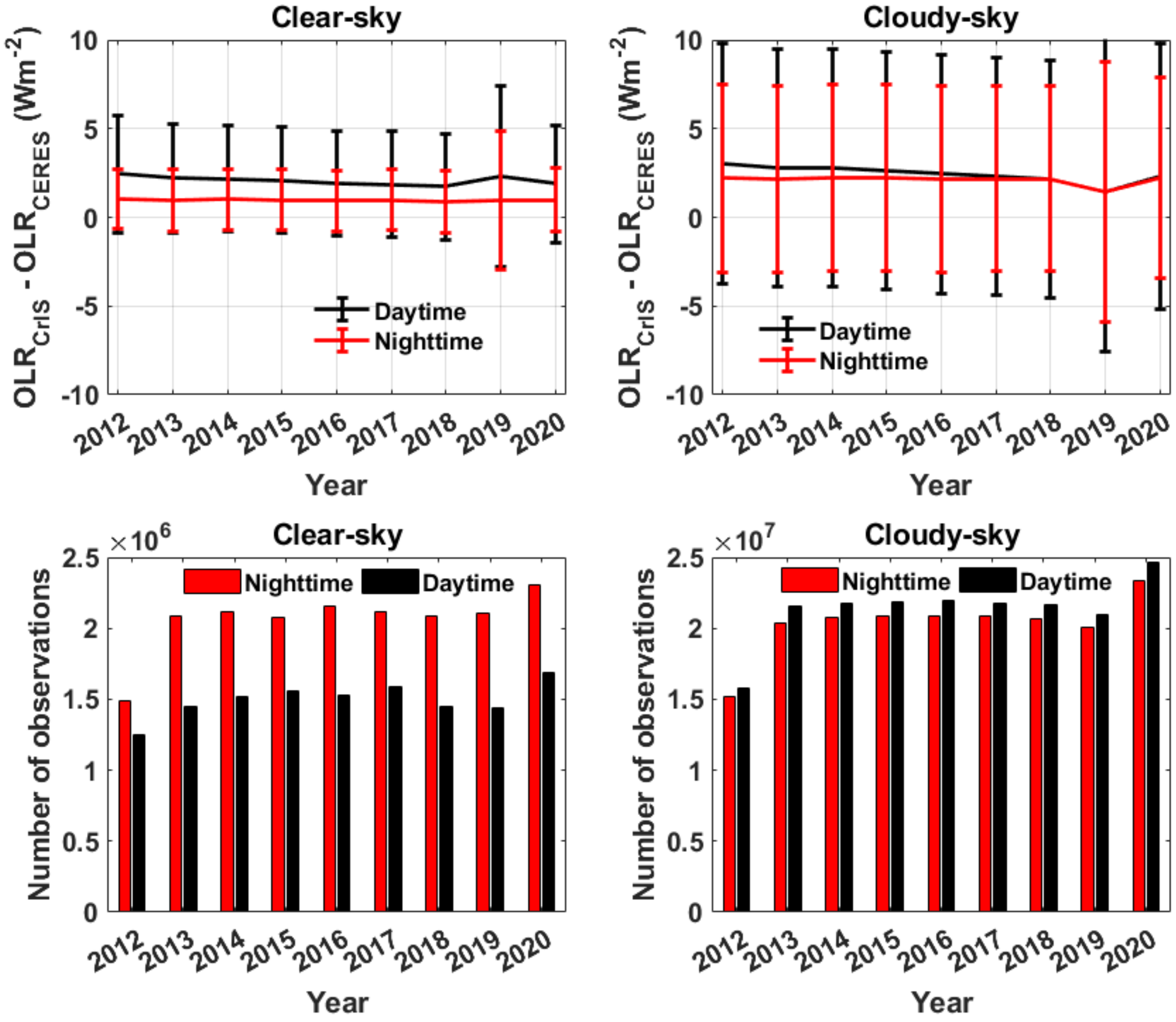
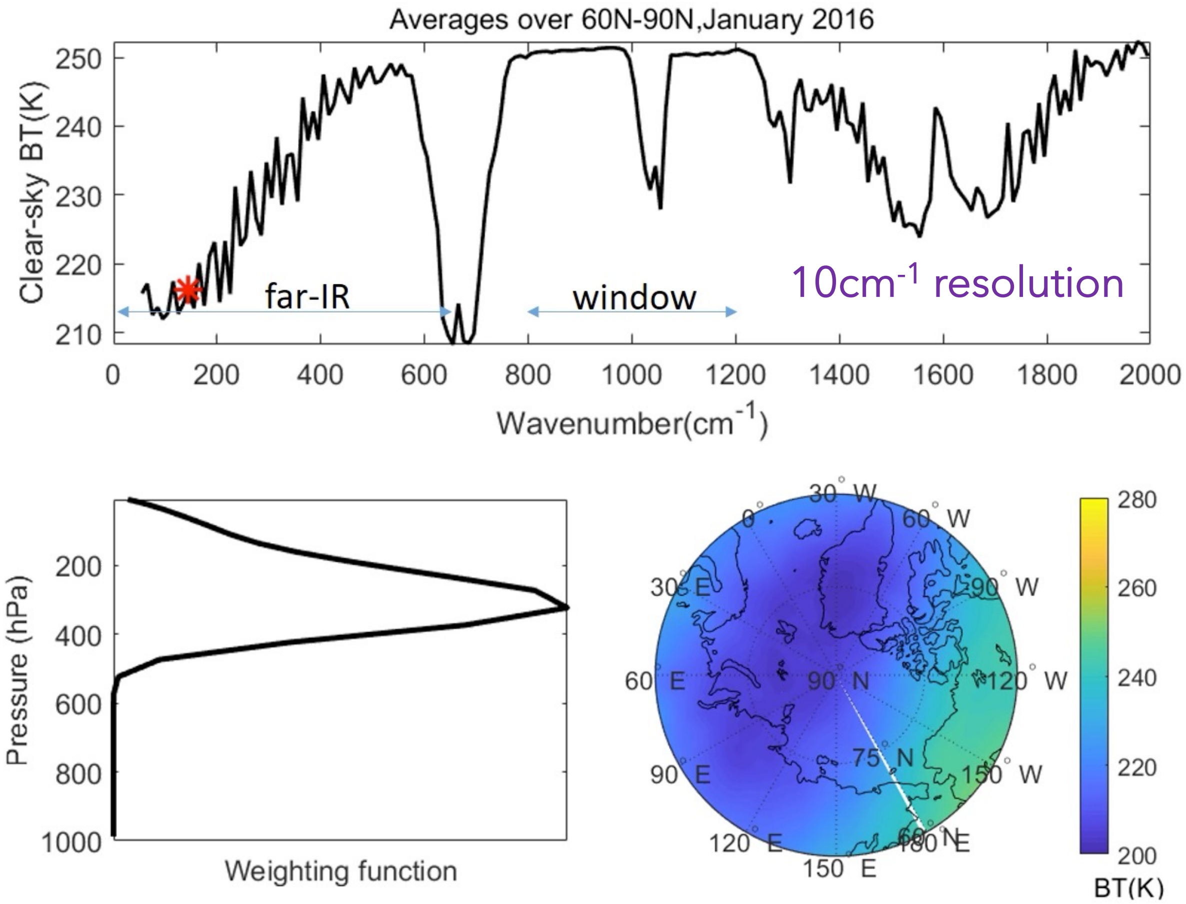


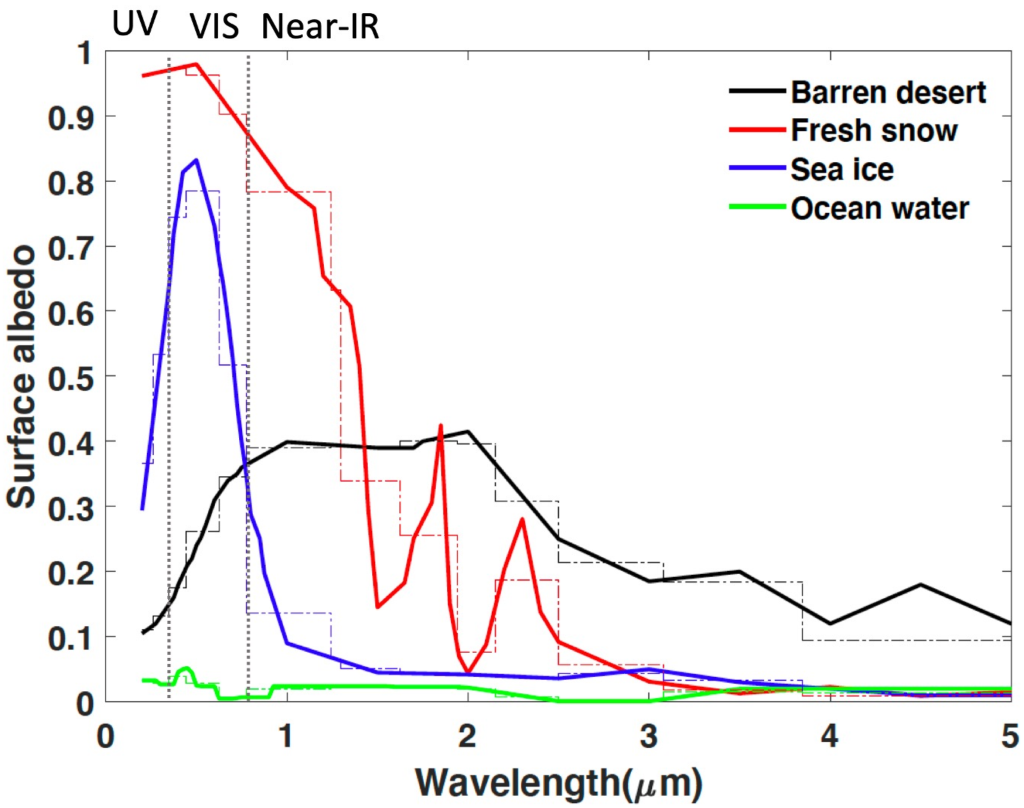
Range of the annual-mean OLR_{CrIS} – $OLR_{CERES\text{-}FM5\text{-}Ed1}$ (Wm^{-2}) from 2012 to 2020

	Clear-sky	Cloudy-sky
Daytime	[1.71,2.43]	[1.42, 3.02]
Nighttime	[0.88,1.03]	[1.45, 2.23]

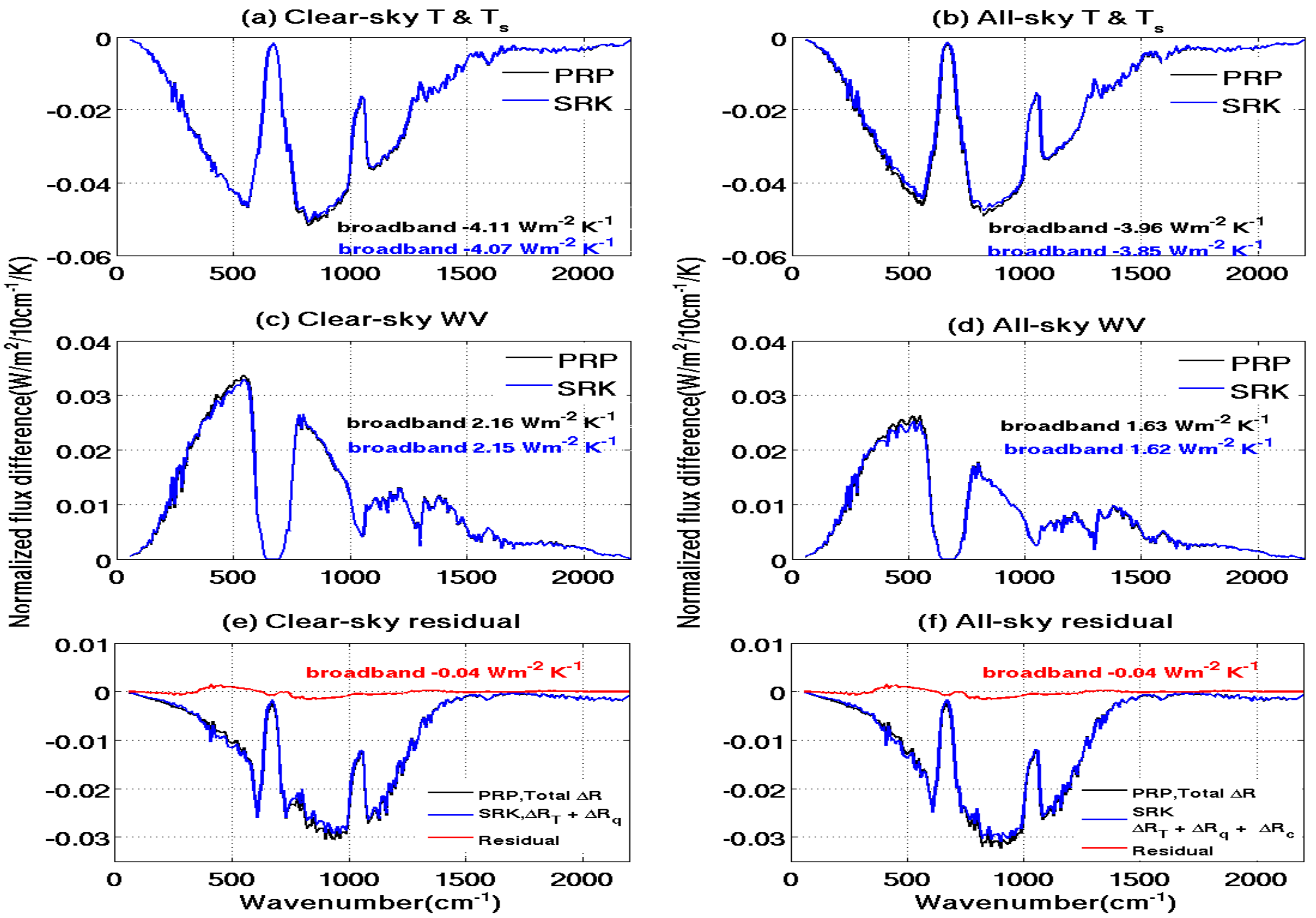
Spectral (band-by-band) flux can be more revealing than the broadband flux

- LW spectral channel/band: sensitive to different part of the atmosphere (cloud can "mess" it up)
- SW spectral channel/band: dichotomy between visible and near-IR (surface albedo, gas absorption)

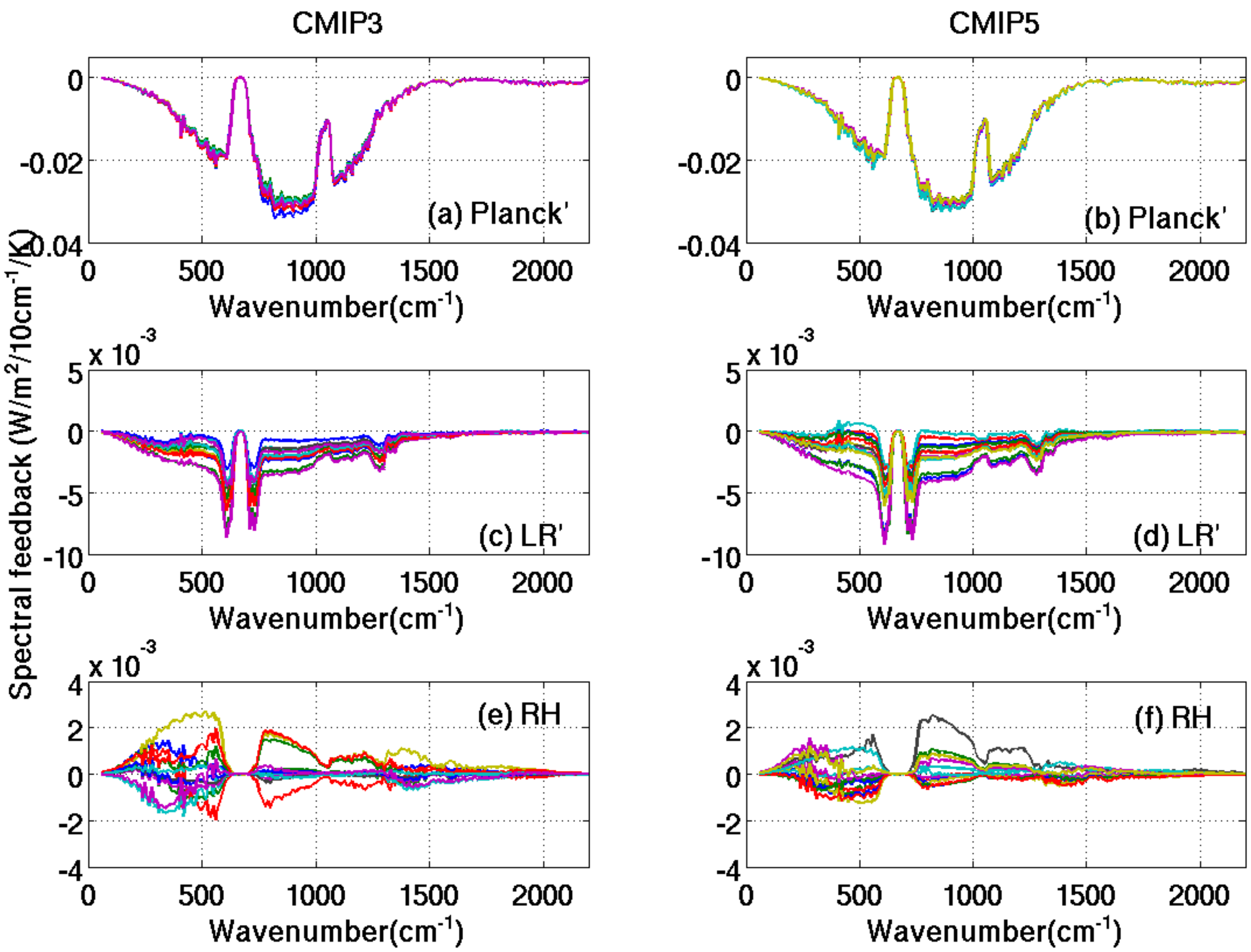




Validation: comparisons with the PRP results



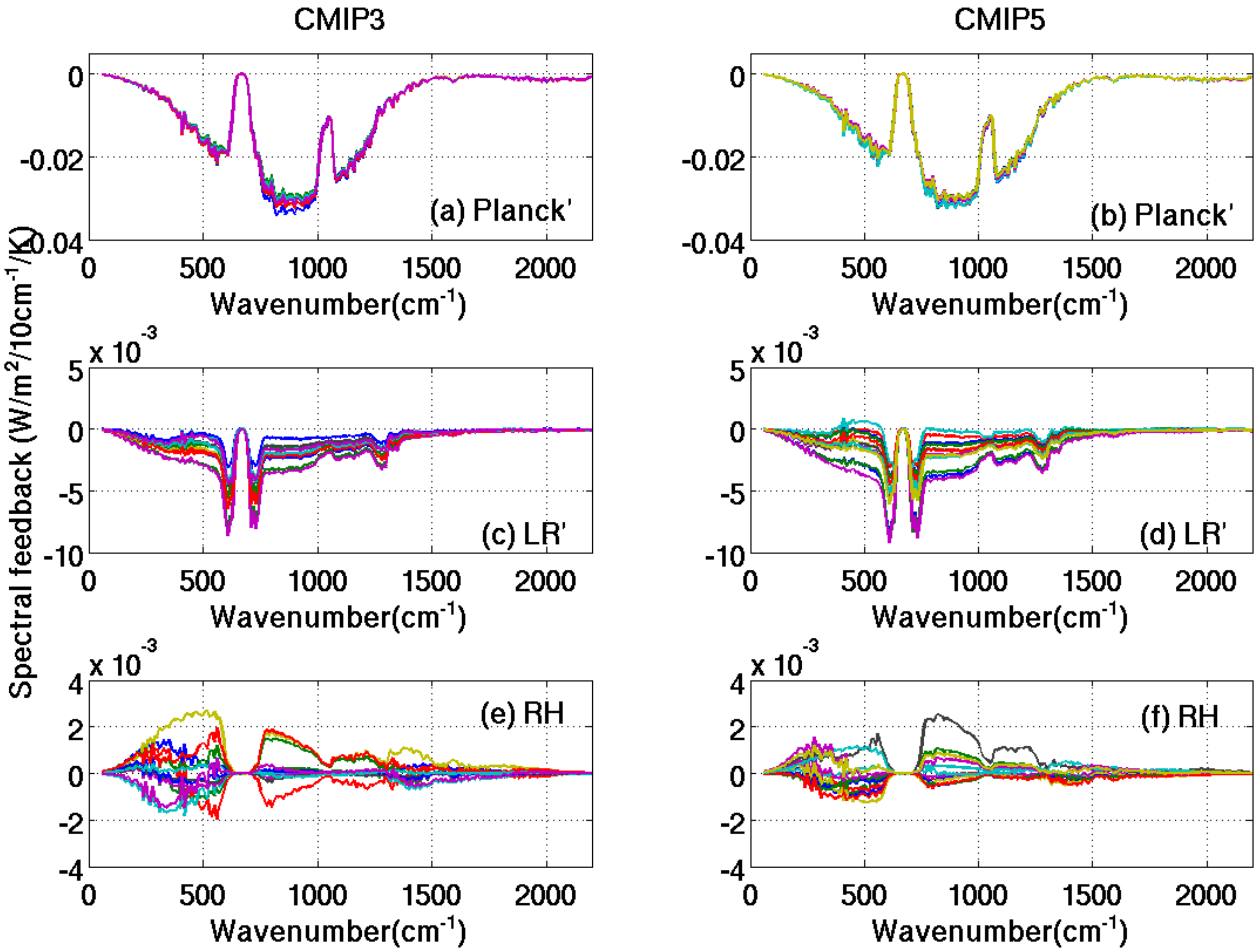
(Huang et al., 2014)

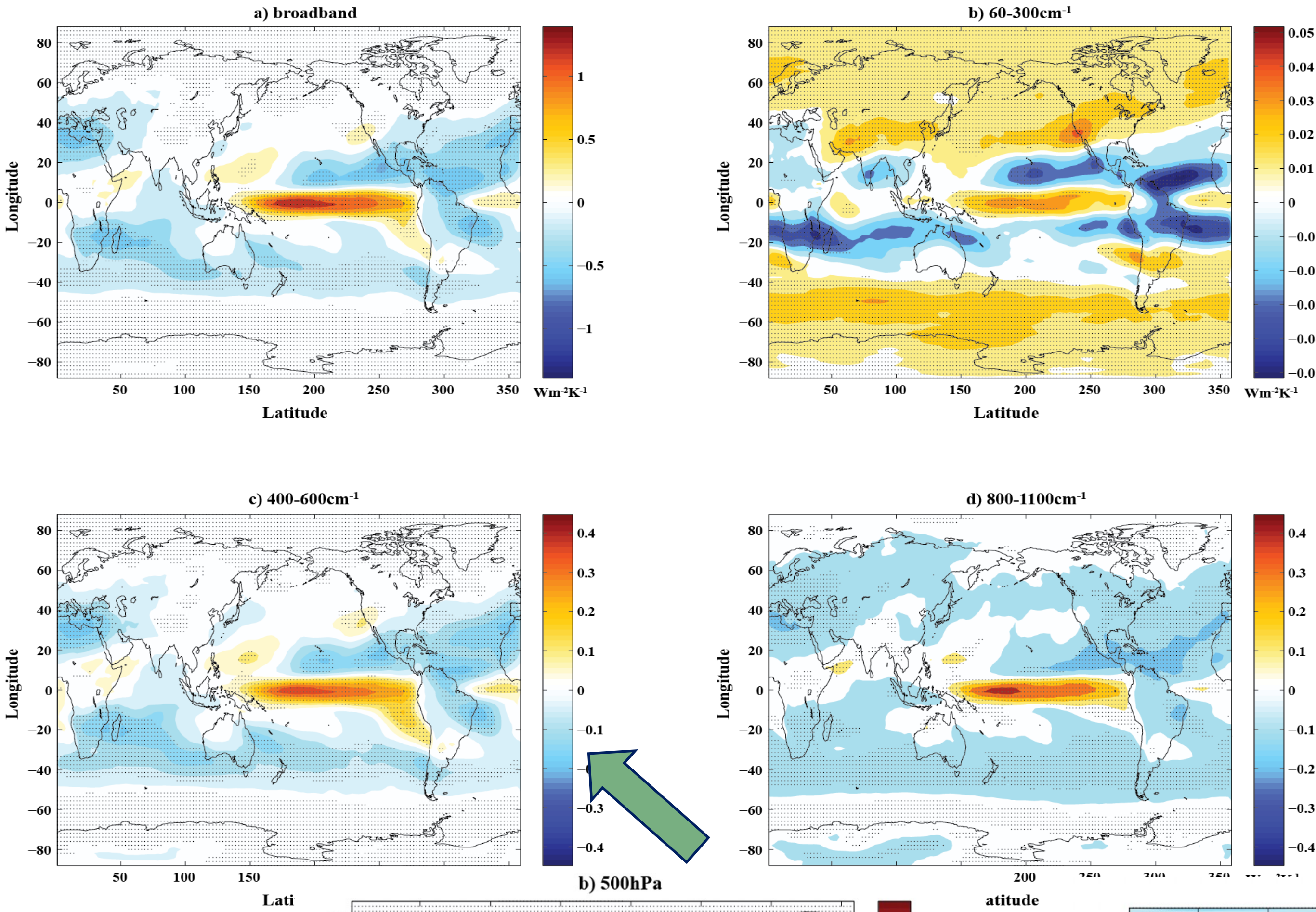


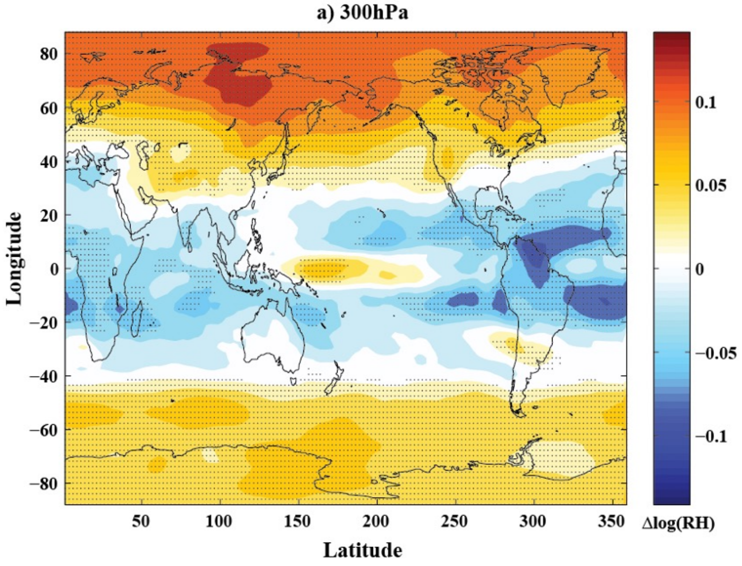
spectral interval: 10cm^{-1}

(Huang et al., 2014)
(Pan and Huang, 2018)

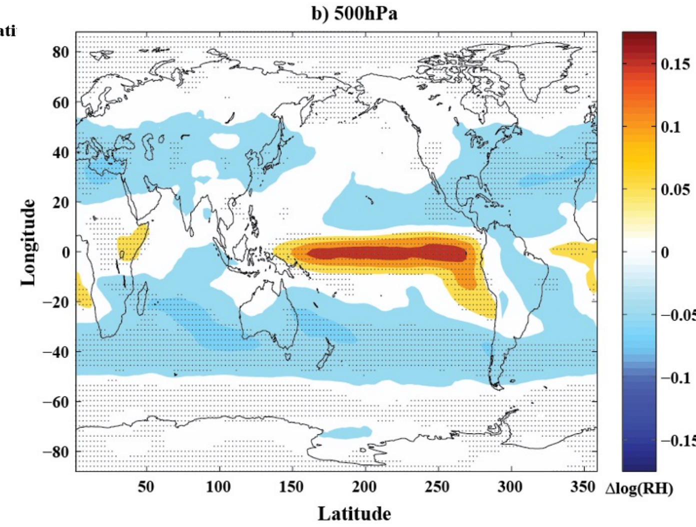
Using RH as a state variable

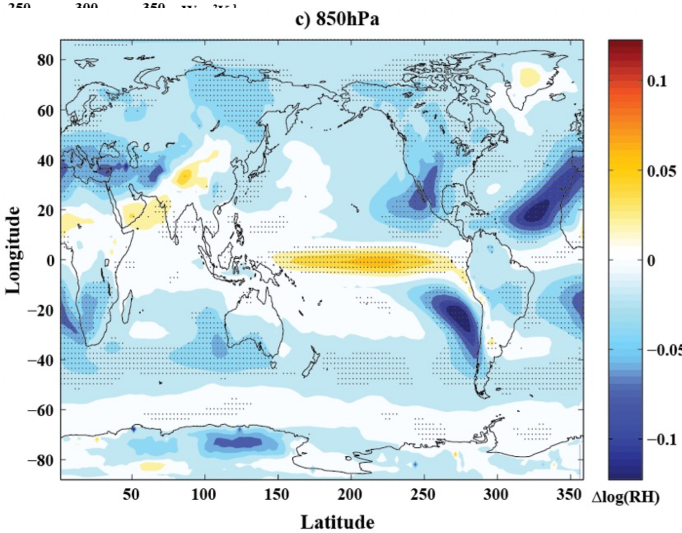






Spatial compensation





(Pan & Huang, 2018)