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


IRIS-D on Nimbus IV: April 1970-January 1971
Quarter a century ago

A statistical method for testing a general circu spec 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 testing climate models. Statistics of observed, outgoing, thermal energy predictions from a climate model, on the basis of data collected over approximately 1 year. This is a powerful approach to testing processes internal to the atmosphere. These processes, which place constraints on the atmosphere’s response to external forcing, are particularly important for testing model variability in the results of forcing the atmosphere, for example, by oceanic processes, such as the increase of greenhouse gases, etc. Comparisons are presented from the infrared interferometer spectrometer (IRIS), an orbiter spectrometer, and spectra calculated using the medium-resolution MODTRAN, applied to the temperature and humidity profile of air. Ten months of IRIS data are available, and we have deviations, skew, and kurtosis of its spectrally resolved brightness temperature for individual months and for a range of frequency space. All data that are presented are based on radiances like spectra, which eliminates many of the errors generated by calibration uncertainties in IRIS. In residuals between the IRIS and the GCM statistics are found that the spectral data can provide a severe test of many aspects of climate models. We discuss some of the residuals and improve model performance in the context of an adjoint model. Only one way to have confidence in the performance of a model is to discriminate comparisons with data as are practicable, and so

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

May 1999

Haskins et al.

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

- $T(z)$
- $q_{H_2O}(z)$
- $q_{O_3}(z)$
- $q_{CH_4}(z)$
- Cloud, aerosols

- $T_{skin}, \varepsilon_s(v)$

Spectral Radiances

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

Spectral Flux

$F = \int_{0}^{2\pi} d\phi \int_{0}^{\pi} I_{TOA}(v; \theta, \phi) \cos \theta d\theta$

Broadband Radiation Budget

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

Broadband Radiative Feedbacks

$\lambda_x = \frac{\delta_x F_v \delta X}{\delta X \delta T_s}$

Spectral Radiative Feedbacks

Energy budget and feedbacks community

Energy budget and feedbacks community

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

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

Instrument cross calibration

Sounding community

Assess long-term performance

Spectral radiative feedbacks
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)

<table>
<thead>
<tr>
<th>CO₂ trend</th>
<th>ppmv yr⁻¹</th>
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<tbody>
<tr>
<td>AIRS/AMSU</td>
<td>1.57 ± 0.1</td>
</tr>
<tr>
<td>AIRS</td>
<td>1.05 ± 0.6</td>
</tr>
</tbody>
</table>
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

- EBAF4.1, $0.26 \pm 0.11 \text{Wm}^{-2}/\text{decade}$
- AIRS, $0.23 \pm 0.11 \text{Wm}^{-2}/\text{decade}$
Zonal-mean Trend (2003 to 2021)
Trend of all-sky spectral flux (Wm$^{-2}$/decade/10cm$^{-1}$)

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: 10cm⁻¹**

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

(Huang et al., 2014; Pan & Huang, 2018)
CanESM2: -0.55 Wm$^{-2}$/K

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

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
References


Thank You!
Backup
Annual means of clear-sky and cloudy-sky $\text{OLR}_{\text{CrIS}} - \text{OLR}_{\text{CERES-FM5-Ed1}}$ over the globe for 2012 to 2020.
Range of the annual-mean $\text{OLR}_{\text{CrIS}} - \text{OLR}_{\text{CERES-FM5-Ed1}}$ (Wm$^{-2}$) from 2012 to 2020

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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: $10\,\text{cm}^{-1}$

(Huang et al., 2014)
(Pan and Huang, 2018)
Using RH as a state variable
Spatial compensation

(Pan & Huang, 2018)