PROCEEDINGS OF SPIE

Multispectral, Hyperspectral, and Ultraspectral Remote Sensing Technology, Techniques, and Applications

William L. Smith, Sr.
Allen M. Larar
Tadao Aoki
Ram Rattan
Chairs/Editors

13–16 November 2006
Goa, India

Sponsored by
SPIE—The International Society for Optical Engineering • ISRO—Indian Space Research Organization (India) • JAXA—Japan Aerospace Exploration Agency (Japan) • NASA—National Aeronautics and Space Administration (USA) • NOAA—National Oceanic and Atmospheric Administration (USA) • NICT—National Institute of Information and Communications Technology (Japan) • NIO—National Institute of Oceanography (India) NPOESS—National Polar-orbiting Operational Environmental Satellite System, Integrated Program Office (USA) • Science and Technology Corporation (USA)

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Infrared Calibration for Climate: A Perspective on Present and Future High Spectral Resolution Instruments

Henry E. Revercomb[a], James G. Anderson[b], Fred A. Best[a], David C. Tobin[a], Robert O. Knuteson[a], Daniel D. LaPorte[a], and Joe K. Taylor[a]

[a]University of Wisconsin-Madison, Space Science and Engineering Center
1225 West Dayton Street, Madison Wisconsin, 53706
[b]Harvard University, Cambridge, MA 02138

ABSTRACT

The new era of high spectral resolution infrared instruments for atmospheric sounding offers great opportunities for climate change applications. A major issue with most of our existing IR observations from space is spectral sampling uncertainty and the lack of standardization in spectral sampling. The new ultra resolution observing capabilities from the AIRS grating spectrometer on the NASA Aqua platform and from new operational FTS instruments (IASI on Metop, CrIS for NPP/NPOESS, and the GIFTS for a GOES demonstration) will go a long way toward improving this situation.

These new observations offer the following improvements:

1. Absolute accuracy, moving from issues of order 1 K to <0.2-0.4 K brightness temperature,
2. More complete spectral coverage, with Nyquist sampling for scale standardization, and
3. Capabilities for unifying IR calibration among different instruments and platforms.

However, more needs to be done to meet the immediate needs for climate and to effectively leverage these new operational weather systems, including

1. Place special emphasis on making new instruments as accurate as they can be to realize the potential of technological investments already made,
2. Maintain a careful validation program for establishing the best possible direct radiance check of long-term accuracy--specifically, continuing to use aircraft-or balloon-borne instruments that are periodically checked directly with NIST, and
3. Commit to a simple, new IR mission that will provide an ongoing backbone for the climate observing system. The new mission would make use of Fourier Transform Spectrometer measurements to fill in spectral and diurnal sampling gaps of the operational systems and provide a benchmark with better than 0.1K 3-sigma accuracy based on standards that are verifiable in-flight.

Key Words: Infrared, Calibration, Spectrometer, Validation, Spectral radiance

1. INTRODUCTION

The challenge is to provide highly sensitive climate reference observations that can be continued for decades to quantify global and regional climate change. Now that it is evident mankind can and is modifying our atmosphere on a global scale, there is a clear mandate to observe the forcing and the response in a way that quantifies the changes for future generations. The results will form a key part of the basis for planning societal approaches to mitigation and adaptation.

Earth radiation budget observations were the first measurements of the earth from space, performed by Verner E. Suomi's pioneering experiment on Explorer 7 in 1959. In the nearly half century since this visionary start to applying satellites to explore the factors that affect the balance of the earth radiation components, much progress has been made in both understanding this delicate balance and in our capability to observe the earth from space with ever improving spacecraft instruments. Fortunately, as society has advanced to the stage that it can alter the atmosphere, it has also advanced highly accurate tools that can be used to monitor these changes. We need to commit to making a range of carefully selected, highly sensitive climate benchmark observations that apply our most accurate remote sensing techniques to this task. These measurement should include detailed measurements of the solar reflected spectrum and the sun itself, the infrared emission spectrum, and other key measurements that can be made with exceptional accuracy (like atmospheric refraction that is highly sensitive to atmospheric structure and composition).

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This paper advocates adding benchmark measurements of the thermal emission spectrum of the earth that contains information on key factors forcing global change and on the response mechanisms, as well as, the overall radiative cooling of the atmosphere. In the next section, we recommend a general concept, then in Section 3 summarize the need for a new system based on shortcomings of existing and planned systems, and in Section 4 discuss the system requirements and general approach for a benchmark infrared system.

2. THE RECOMMENDED INRARED CONCEPT

Driven by applications for vertical temperature and water vapor sounding and atmospheric chemistry, high spectral resolution spacecraft instruments have been developed for infrared observing. Advanced techniques capable of resolving atmospheric absorption lines not only offer higher information content, but also offer significant advantages for accurate calibration. The fundamental advantage over lower spectral resolution measurements for radiometric calibration is discussed in Goody and Haskins (1). In addition, these techniques greatly reduce the uncertainty associated with spectral calibration (2,3). Fourier Transform Spectrometer (FTS) techniques that provide well defined and stable spectral Instrument Line Shape (ILS) and carry onboard laser spectral references are especially effective for delivering high absolute accuracy (4-7). Now we have the opportunity to apply these advantages to characterize climate change.

The key elements of the recommended concept are

1. Monitor thermal emission spectra with a resolution that resolves absorption lines,
2. Extend spectral coverage into the far infrared,
3. Emphasize absolute radiometric & spectral calibration (Stability is not enough),
4. Provide reference sources with in-orbit verification and incorporate measurement redundancy for heightened credibility, and
5. Improve global, temporal coverage using satellites in non-sun-synchronous orbits, which also provides orbit overlaps for calibration transfer.

Although measurement continuity will also be a goal, achieving high absolute accuracy is the best way to guarantee a continuously useful climate record.

The considerations that justify making spectrally resolved IR measurements a high priority for climate are

1. The IR constitutes a fundamental component of the energy budget of the earth,
2. High Accuracy for establishing small trends is relatively easy to achieve, because especially hot or cold reference sources are not needed and highly accurate spectral calibration is possible, and
3. High information content to characterize complex climate change is possible using spectrally resolved radiances.

Included in the high information content category, is the independent information about climate forcing from trace gas changes (CO_2, N_2O, CFCs), and the response (e.g. warming, moisture changes, cloud changes).

The wide range of complex conditions represented by spectrally resolved radiance observations is illustrated in Figure 1 that shows example spectra from the NASA Atmospheric Infrared Sounder (AIRS) instrument, launched on the Aqua platform on 2 May 2002 (8,9). Examples that serve as reminders of the high information content of IR spectral radiances include the sensitivity to vertical structure and atmospheric stability that motivate atmospheric sounding applications (Figure 2), sensitivity to cloud phase and microphysical properties (Figures 3 and 4), information about land surface properties (Figure 5), as well as sensitivity to trace gas distributions.

3. SHORTCOMINGS OF EXISTING AND PLANNED OBSERVATIONS

Infrared observations with climate applications fall into three basic categories: 1) Total, Solar, or IR integrated radiance or flux (e.g. ERB, ERBE, CERES), 2) Multi-channel imaging or sounding filter radiometers (e.g. AVHRR, HIRS, GOES radiometers, MODIS), and 3) High spectral resolution, down-looking sounders (AIRS, TES, IASI, CrIS, GIFTS, future GOES sounders). Only instruments in the first category were originally designed for climate applications, although there is growing use of the other types of measurements. Each has shortcomings that the new system described here would address.

The major problem with relying on spectrally integrated radiance or flux is that spectral integration obscures information content. It is not possible to separate changes in forcing from changes in response, because everything is lumped together. In addition, significant changes can create opposite effects that cancel, thereby masking the changes from detection. For example, one can envision a lapse rate change coupled with a surface warming, such that the total outgoing longwave flux does not change. Therefore, the information content of these integrated observations is quite limited and even for basic detection of change the accuracy requirement must be very high.

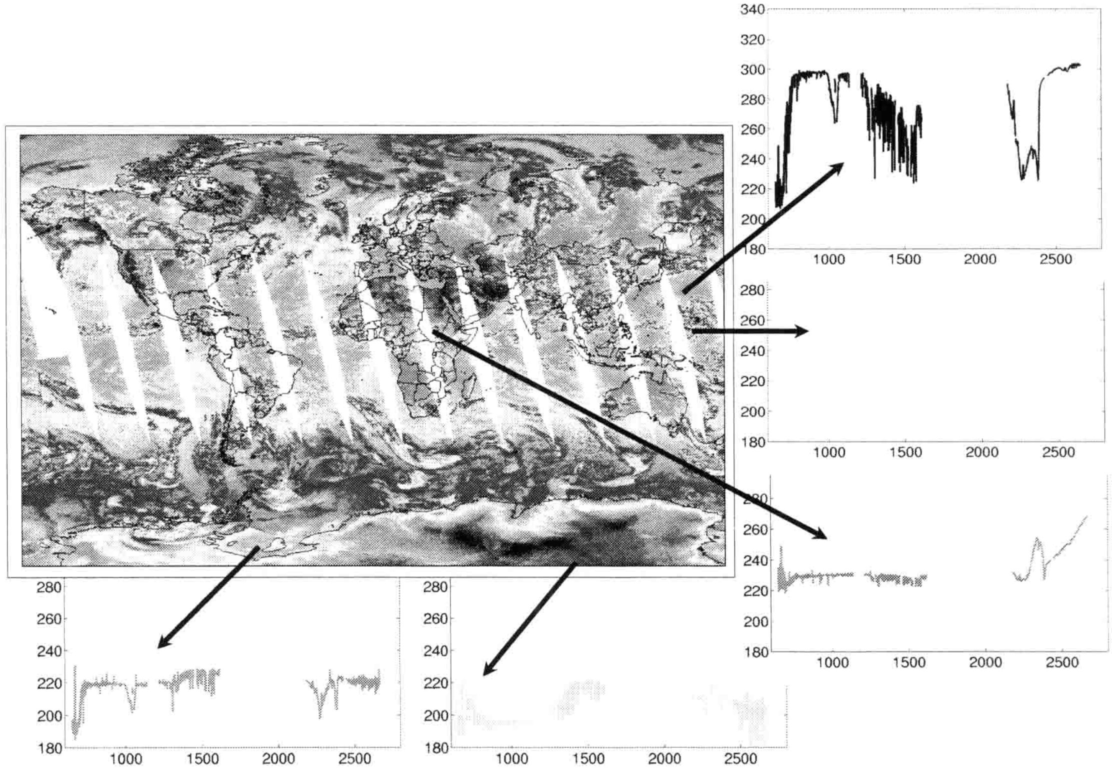


Figure 1. Sample brightness temperature spectra as a function of wavenumber from AIRS (20 July 2002), illustrating the complexity captured by high resolution IR emission spectra.

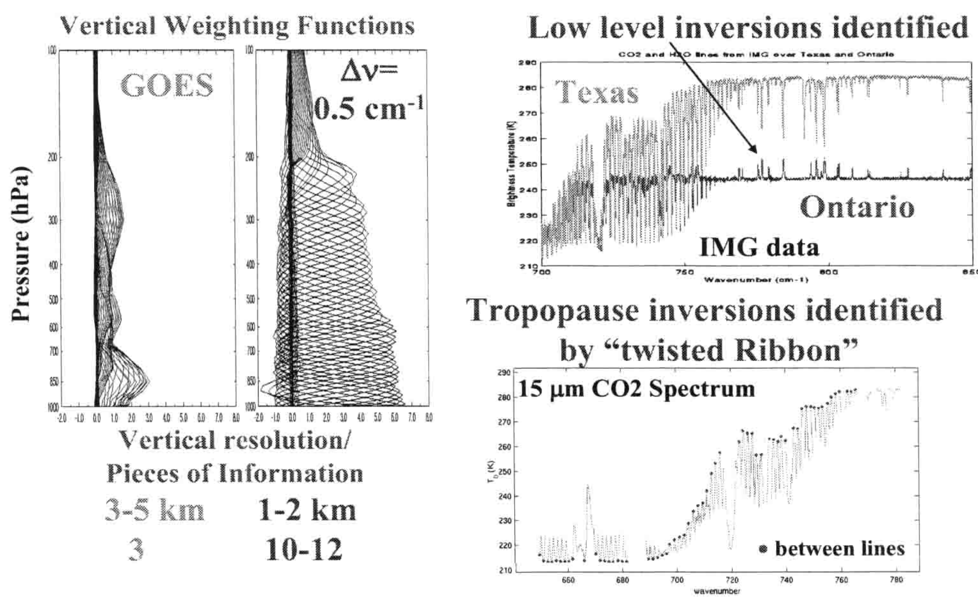
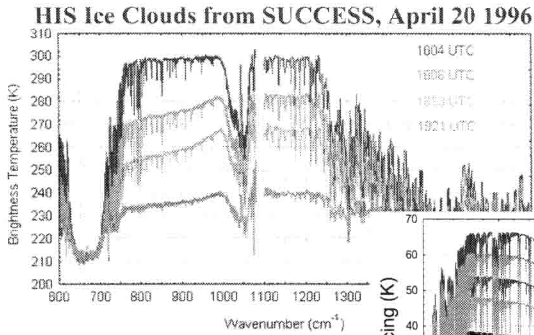


Figure 2. Examples illustrating the sensitivity to vertical structure of IR spectra with resolution capable of resolving individual spectral lines. This sensitivity is important to the characterization of climate change.



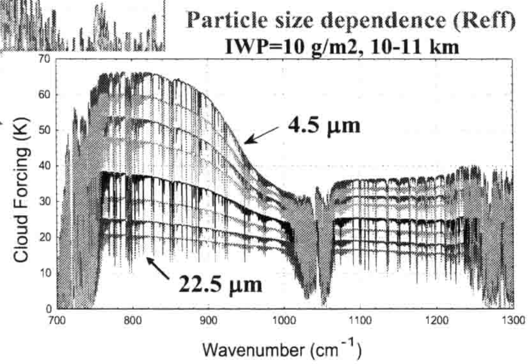


Figure 3. Examples illustrating the sensitivity to cloud phase and particle size, key climate parameters.

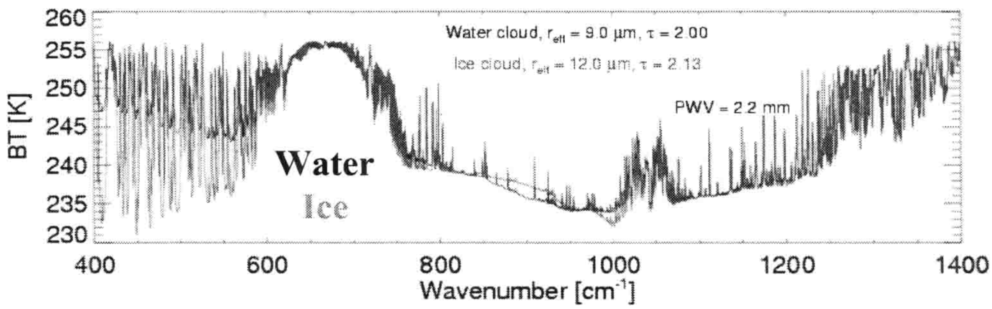


Figure 4. Calculated up-looking brightness temperature spectra illustrating the added information provided by extending the longwave limit of the IR spectrum beyond the normal 15 micron limit. The difference between these two cloud spectra, one for ice cloud and one for water, are hard to identify without the region between 400 and 600 cm^{-1}.

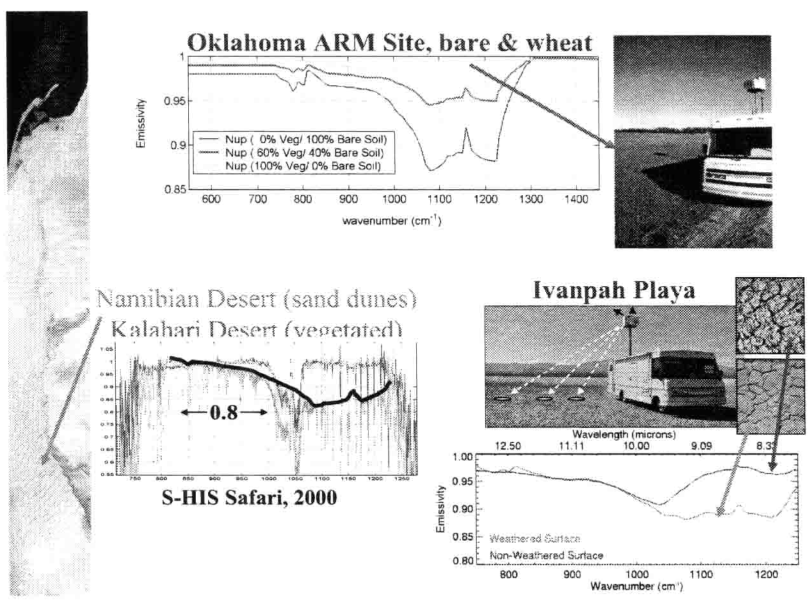


Figure 5. Illustration of land surface emissivity spectral properties that convey information about the effects of climate change on the land surface.