

**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

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Welcome and Opening Remarks

William L. Smith, Sr., Hampton University (USA) and University of Wisconsin (USA)

- 1 AIRS: Product Retrieval, Validation, and Application
Thomas S. Pagano, Jet Propulsion Laboratory (USA)
- 2 Atmospheric CO₂ Retrieval and the GOSAT Mission
Tadao Aoki, National Institute for Environmental Studies (Japan)

- 3 GIFTS: Thermal Vacuum Results and Future Spaceborne Science
Hank E. Revercomb, University of Wisconsin, Madison (USA)
 - 4 Radiative Transfer Modelling and Geophysical Parameter Retrieval
Jonathan P. Taylor, United Kingdom Meteorological Office (United Kingdom)
 - 5 Sensor Concepts, Performance, Calibration, and Characterization
William L. Smith, Sr., Hampton University (USA) and University of Wisconsin (USA)
 - 6 Land Surface Classification and Applications: General
Ram Rattan, ISRO Space Applications Centre (India)
 - 7 Land Surface Classification and Applications: Minerals
K. Vinod Kumar, National Remote Sensing Agency (India)
 - 8 Land Surface Classification and Applications: Vegetation
S. Sanjeevi, Anna University (India)
 - 9 Water Property Determination and Applications
A. Sentihil Kumar, National Remote Sensing Agency (India)
 - 10 Image Processing, Corrections, and Classification Approaches I
Manab Chakraborty, Indian Space Research Organisation (India)
 - 11 Image Processing, Corrections, and Classification Approaches II
Manab Chakraborty, Indian Space Research Organisation (India)
- Poster Session
Jianyu Wang, Shanghai Institute of Technical Physics (China)

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Contents

ix	<i>Conference Committee</i>
xi	<i>Symposium Committees</i>

AIRS: PRODUCT RETRIEVAL, VALIDATION, AND APPLICATION

- 640501 **Infrared calibration for climate: a perspective on present and future high-spectral resolution instruments (Keynote Paper)** [6405-01]
H. E. Revercomb, Univ. of Wisconsin, Madison (USA); J. G. Anderson, Harvard Univ. (USA); F. A. Best, D. C. Tobin, R. O. Knuteson, D. D. LaPorte, J. K. Taylor, Univ. of Wisconsin, Madison (USA)
- 640503 **Validation of Atmospheric Infrared Sounder (AIRS) temperature, water vapor, and ozone retrievals with matched radiosonde and ozonesonde measurements and forecasts** [6405-03]
M. Divakarla, Science Applications International Corp. (USA); C. Barnet, M. Goldberg, National Oceanic and Atmospheric Administration (USA); E. Maddy, W. Wolf, QSS Group, Inc. (USA); L. Flynn, National Oceanic and Atmospheric Administration (USA); X. Xiong, J. Wei, L. Zhou, X. Liu, QSS Group, Inc. (USA)
- 640505 **Techniques used in improving the radiance validation of Atmospheric Infrared Sounder (AIRS) observations with the Scanning High-Resolution Interferometer Sounder (S-HIS)** [6405-68]
K. H. Vinson, D. C. Tobin, H. E. Revercomb, R. O. Knuteson, F. A. Best, W. L. Smith, N. N. Ciganovich, S. Dutcher, S. D. Ellington, R. K. Garcia, H. B. Howell, D. D. LaPorte, J. K. Taylor, P. van Delst, M. W. Werner, Univ. of Wisconsin, Madison (USA)

ATMOSPHERIC CO₂ RETRIEVAL AND THE GOSAT MISSION

- 640506 **Information and disturbances contained in the reflected solar radiation spectra measured with space-borne Fourier transform spectrometer for greenhouse gas mapping (Invited Paper)** [6405-06]
T. Aoki, T. Yokota, National Institute for Environmental Studies (Japan); G. Inoue, Nagoya Univ. (Japan); K. Nobuta, A. Kotani, Fujitsu FIP Corp. (Japan)
- 640508 **Assessment of uncertainty in CO₂ concentrations retrieved from thermal infrared spectra of GOSAT satellite** [6405-08]
N. Saitoh, The Univ. of Tokyo (Japan); Y. Ota, National Institute for Environmental Studies (Japan); S. Taguchi, National Institute of Advanced Industrial Science and Technology (Japan); R. Imasu, The Univ. of Tokyo (Japan)
- 640509 **Application of the equivalence theorem to simulate GOSAT observation data under cirrus-present condition** [6405-09]
S. Oshchepkov, A. Bril, T. Yokota, National Institute for Environmental Studies (Japan); G. Inoue, Nagoya Univ. (Japan) and National Institute for Environmental Studies (Japan)

- 64050C **Application of hyperspectral remote sensing in monitoring chlorophyll a concentration in Dianshan Lake** [6405-83]
L. Song, Y. Qiu, H. Zhang, J. Zhao, Tongji Univ. (China)

GIFTS: THERMAL VACUUM RESULTS AND FUTURE SPACEBORNE SCIENCE

- 64050E **Geostationary Imaging Fourier Transform Spectrometer (GIFTS): science applications (Invited Paper)** [6405-10]
W. L. Smith, Hampton Univ. (USA) and Univ. of Wisconsin, Madison (USA); H. E. Revercomb, Univ. of Wisconsin, Madison (USA); D. K. Zhou, NASA Langley Research Ctr. (USA); G. E. Bingham, Utah State Univ. (USA); W. F. Feltz, H. L. Huang, R. O. Knuteson, Univ. of Wisconsin, Madison (USA); A. M. Larar, X. Liu, R. Reisse, NASA Langley Research Ctr. (USA); D. C. Tobin, Univ. of Wisconsin, Madison (USA)
- 64050F **Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) engineering development unit (EDU) overview and performance summary** [6405-11]
G. E. Bingham, R. E. Anderson, G. W. Cantwell, Utah State Univ. (USA); D. K. Zhou, NASA Langley Research Ctr. (USA); D. K. Scott, R. W. Esplin, G. B. Hansen, S. M. Jensen, M. D. Jensen, S. B. Brown, L. J. Zollinger, V. A. Thurgood, M. P. Esplin, Utah State Univ. (USA); R. J. Huppi, ZEL Technologies, LLC (USA); H. E. Revercomb, F. A. Best, D. C. Tobin, J. K. Taylor, R. O. Knuteson, Univ. of Wisconsin, Madison (USA); W. L. Smith, Hampton Univ. (USA); R. A. Reisse, NASA Langley Research Ctr. (USA); R. Hooker, NASA Headquarters (USA)
- 64050G **Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) thermal vacuum testing: aspects of spectral characterization** [6405-12]
D. C. Tobin, H. E. Revercomb, J. K. Taylor, F. A. Best, R. O. Knuteson, W. L. Smith, Univ. of Wisconsin, Madison (USA); J. Elwell, G. Cantwell, G. Bingham, J. Tansock, Utah State Univ. (USA); R. A. Reisse, D. K. Zhou, NASA Langley Research Ctr. (USA)
- 64050I **Performance verification of the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) on-board blackbody calibration system** [6405-14]
F. A. Best, H. E. Revercomb, D. C. Tobin, R. O. Knuteson, J. K. Taylor, D. J. Thielman, D. P. Adler, M. W. Werner, S. D. Ellington, Univ. of Wisconsin, Madison (USA); J. D. Elwell, D. K. Scott, G. W. Cantwell, G. E. Bingham, Utah State Univ. (USA); W. L. Smith, Hampton Univ. (USA)
- 64050J **The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS): noise performance** [6405-15]
J. K. Taylor, H. E. Revercomb, D. C. Tobin, F. A. Best, R. O. Knuteson, Univ. of Wisconsin, Madison (USA); J. D. Elwell, G. W. Cantwell, D. K. Scott, G. E. Bingham, Utah State Univ. (USA); W. L. Smith, Hampton Univ. (USA); D. K. Zhou, R. A. Reisse, NASA Langley Research Ctr. (USA)

RADIATIVE TRANSFER MODELLING AND GEOPHYSICAL PARAMETER RETRIEVAL

- 64050L **A physical retrieval algorithm for IASI using PCRTM** [6405-17]
X. Liu, D. K. Zhou, A. Larar, NASA Langley Research Ctr. (USA); W. L. Smith, Hampton Univ. (USA); P. Schluessel, EUNETSAT (Germany)
- 64050M **The development of a fast radiative transfer model based on an empirical orthogonal functions (EOF) technique** [6405-18]
S. Havemann, United Kingdom Meteorological Office (United Kingdom)

- 64050P **Remote sensing new model for monitoring the East Asian migratory locust infections based on its breeding circle** [6405-84]
X. Han, China Meteorological Administration (China); J. Ma, Institute of Remote Sensing Applications (China); Y. Bao, Inner Mongolian Key Lab. of Remote Sensing (Mongolia)
- 64050Q **A new remote sensing model for retrieving snow depth within 30 centimeters using MODIS data** [6405-85]
S. Li, Y. Liu, China Meteorological Administration (China); Z. Huang, H. Fu, Xinjiang Province Meteorological Bureau (China)

SENSOR CONCEPTS, PERFORMANCE, CALIBRATION, AND CHARACTERIZATION

- 64050R **Testing and characterization of a multispectral imaging Fabry-Perot interferometer for tropospheric trace species detection** [6405-22]
A. M. Larar, W. B. Cook, C. S. Mills, M. A. Flood, NASA Langley Research Ctr. (USA); E. E. Burcher, Swales Aerospace (USA); C. M. Boyer, NASA Langley Research Ctr. (USA); J. J. Puschell, Raytheon Space and Airborne Systems (USA)
- 64050S **Spaceflight instrument study for tropospheric ozone measurement** [6405-23]
J. J. Puschell, M. Cox, Raytheon Space and Airborne Systems (USA); A. M. Larar, W. B. Cook, C. S. Mills, M. A. Flood, NASA Langley Research Ctr. (USA)
- 64050T **New technology sensors for correcting satellite imagery for earth curvature effects** [6405-24]
D. B. Johnson, National Ctr. for Atmospheric Research (USA)
- 64050U **Compact hyperspectral imager with selectable bands** [6405-25]
A. R. Chowdhury, K. R. Murali, ISRO Space Applications Ctr. (India)
- 64050V **Update on in-flight performance of the Japanese Advanced Meteorological Imager** [6405-26]
J. J. Puschell, R. Osgood, J. Auchter, W. T. Hurt, Raytheon Space and Airborne Systems (USA); M. Hitomi, M. Sasaki, Y. Tahara, Japan Meteorological Agency (Japan); A. Tadros, K. Faller, M. McLaren, J. Sheffield, J. Gaiser, Space Systems, Loral (USA); A. Kamel, Kamel Engineering (USA); M. Gunshor, Univ. of Wisconsin (USA)
- 64050W **On-orbit spatial resolution estimation of IRS: CARTOSAT-1 cameras with images of artificial and man-made targets — preliminary results** [6405-27]
A. S. Kumar, A. S. Manjunath, K. M. M. Rao, National Remote Sensing Agency (India); A. S. K. Kumar, R. R. Navalgund, Space Applications Ctr. (India); K. Radhakrishnan, National Remote Sensing Agency (India)
- 64050X **AWiFS camera for Resourcesat** [6405-28]
H. Dave, C. Dewan, S. Paul, S. S. Sarkar, H. Pandya, S. R. Joshi, A. Mishra, M. Detroja, ISRO Space Applications Ctr. (India)
- 64050Y **LISS-3* camera for Resourcesat** [6405-29]
C. Dewan, S. Paul, H. Dave, S. S. Sarkar, S. Singh, P. J. Shah, R. Bisht, ISRO Space Applications Ctr. (India)

- 64050Z **Cross-calibration of A.M. constellation for long-term monitoring of land surface processes** [6405-30]
D. Meyer, Science Applications International Corp. (USA) and U.S. Geological Survey (USA);
G. Chander, U.S. Geological Survey (USA)
- 640510 **LISS-4 camera for Resourcesat** [6405-31]
S. Paul, H. Dave, C. Dewan, P. Kumar, S. S. Sansowa, A. Dave, B. N. Sharma, A. Verma, ISRO
Space Applications Ctr. (India)
- 640513 **Wavelet-modified fringe-adjusted joint transform correlator** [6405-90]
A. Bhagatji, N. K. Nishchal, A. K. Gupta, Instruments Research and Development
Establishment (India); B. P. Tyagi, DBS (PG) College (India)
- 640514 **Fluorescence quenching of 7-Diethylamino-4-trifluoromethyl Coumarin in presence of acetone** [6405-92]
A. Pattanaik, M. Nanda, Defence Research and Development Organisation (India);
P. D. Sahare, Univ. of Delhi (India)
- 640515 **Estimation of soil pH at Mount Beigu Wetland based on visible and near infrared reflectance spectroscopy** [6405-93]
Y. Hu, P. Li, H. Mao, B. Chen, X. Wang, Jiangsu Univ. (China)
- 640516 **Design and development of the multispectral payload for TWSAT mission** [6405-106]
S. A. Kuriakose, D. Subrahmanyam, S. S. Sarkar, V. D. Patel, N. Mathur, Space Applications
Ctr. (India)
- 640517 **Design and development of the Cartosat payload for IRS P5 mission** [6405-107]
D. Subrahmanyam, S. A. Kuriakose, P. Kumar, J. Desai, B. Gupta, B. N. Sharma, Space
Applications Ctr. (India)

LAND SURFACE CLASSIFICATION AND APPLICATIONS: GENERAL

- 64051C **Land use, land cover change analysis with multitemporal remote sensing data** [6405-35]
K. Suzanchi, R. N. Sahoo, N. Kalra, Indian Agricultural Research Institute (India); S. Pandey,
CIMMYT (India)
- 64051D **High-latitude land surface retrieval using high-spectral resolution sensors** [6405-66]
R. O. Knuteson, S. C. Moeller, D. C. Tobin, H. E. Revercomb, Univ. of Wisconsin, Madison (USA)
- 64051F **Analysis of urban reflectance and urban sprawl in China using TM/ETM+ imagery** [6405-98]
H. Zhang, Y. Qiu, L. Chen, J. Zhao, Tongji Univ. (China)
- 64051H **Surface emissivity effects on thermodynamic retrieval of IR spectral radiance** [6405-105]
D. K. Zhou, A. M. Larar, NASA Langley Research Ctr. (USA); W. L. Smith, Hampton Univ. (USA);
X. Liu, NASA Langley Research Ctr. (USA)

LAND SURFACE CLASSIFICATION AND APPLICATIONS: MINERALS

- 64051I **Perpixel and subpixel endmember separation using hyperion data** [6405-37]
K. V. Kumar, National Remote Sensing Agency (India)

- 64051K **Fast searching of spectral library database using variable interval spectral average method** [6405-40]
A. S. Kumar, S. Jayabharathi, A. S. Manjunath, K. M. M. Rao, National Remote Sensing Agency (India)
- 64051N **Spectral unmixing of hyperspectral data to map bauxite deposits** [6405-44]
S. Shanmugam, P. V. Abhishekh, Anna Univ. (India)
- 64051O **Study on environment detection and appraisalment of mining area with RS** [6405-45]
F. Yang, P. Hou, G. Zhou, Q. Li, J. Wang, J. Cheng, Shandong Univ. of Science and Technology (China)

WATER PROPERTY DETERMINATION AND APPLICATIONS

- 64051V **Remote sensing of vegetation based on band-spectral and hyperspectral studies at canopy and pigment level within visible range of wavelength** [6405-51]
B. RayChaudhuri, Presidency College (India); S. Bhaumik, B.E.S. College (India)
- 64051W **Assessment of apparent and inherent optical properties in the northeastern Arabian Sea using in situ hyperspectral remote sensing** [6405-53]
P. V. Nagamani, M. Raman, P. Chauhan, R. M. Dwivedi, ISRO Space Applications Ctr. (India)
- 64051Y **Remote sensing of sea state through a Polaroid** [6405-55]
P. V. Sathe, A. K. Saran, National Institute of Oceanography (India)
- 640520 **Mapping imperviousness using TM data in water resources reservation area of Shanghai** [6405-79]
H. Zhang, Y. Qiu, X. Tong, Y. Zhang, J. Zhao, Tongji Univ. (China)
- 640521 **In-flight experimentation and preliminary marine application of AISA+ in Chinese coastal zone** [6405-82]
D. Wang, State Oceanic Administration (China), Shanghai Institute of Technical Physics (China), and Chinese Academy of Sciences (China); D. Pan, F. Gong, Z. Mao, State Oceanic Administration (China)

IMAGE PROCESSING, CORRECTIONS, AND CLASSIFICATION APPROACHES I

- 640525 **Geostationary satellite full disk image data-based automatic navigation** [6405-58]
B. S. Gohil, A. K. Mathur, A. Sarkar, V. K. Agarwal, ISRO Space Applications Ctr. (India)
- 640526 **Lossless compression studies for real-time rebroadcast of data from NOAA's future advanced GOES sounders** [6405-60]
B. Huang, A. Ahuja, Y. Sriraja, H.-L. Huang, Univ. of Wisconsin, Madison (USA)
- 640527 **Onboard multispectral data compression using JPEG-like algorithm: a case study** [6405-61]
A. S. Kumar, T. Radhika, P. V. N. Rao, A. S. Manjunath, K. M. M. Rao, National Remote Sensing Agency (India)

IMAGE PROCESSING, CORRECTIONS, AND CLASSIFICATION APPROACHES II

- 64052C **Remote sensing image classification based on geostatistics and ANN** [6405-62]
F. Yang, Shandong Univ. of Science and Technology (China); X. Li, China Institute of Water Resources and Hydropower (China); G. Zhou, C. Song, Shandong Univ. of Science and Technology (China); X. Song, Chinese Academy of Sciences (China)
- 64052D **DCT-based algorithm to remove vertical stripings from Ocean Colour Monitor (OCM) data in Indian Remote Sensing Satellite (IRS-P4)** [6405-63]
S. K. Tripathi, N. Dube, R. Ramakrishnan, ISRO Space Applications Ctr. (India)
- 64052E **Modeling and visualizing uncertainty in digital thematic maps** [6405-64]
M. S. G. Prasad, M. K. Arora, V. K. Sajith, Indian Institute of Technology, Roorkee (India)
- 64052I **Deriving classification uncertainty map in evidential reasoning classifier** [6405-95]
V. K. Sajith, M. K. Arora, Indian Institute of Technology, Roorkee (India)
- 64052J **Applicability and performance of some similarity metrics for automated image registration** [6405-101]
S. Suri, Indian Institute of Technology, Roorkee (India) and Technical Univ. of Dresden (Germany); M. K. Arora, Indian Institute of Technology, Roorkee (India); R. Seiler, E. Csaplovics, Technical Univ. of Dresden (Germany)

Author Index

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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

^aUniversity of Wisconsin-Madison, Space Science and Engineering Center
1225 West Dayton Street, Madison Wisconsin, 53706

^bHarvard 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).

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 INFRARED 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 (CO₂, N₂O, 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.

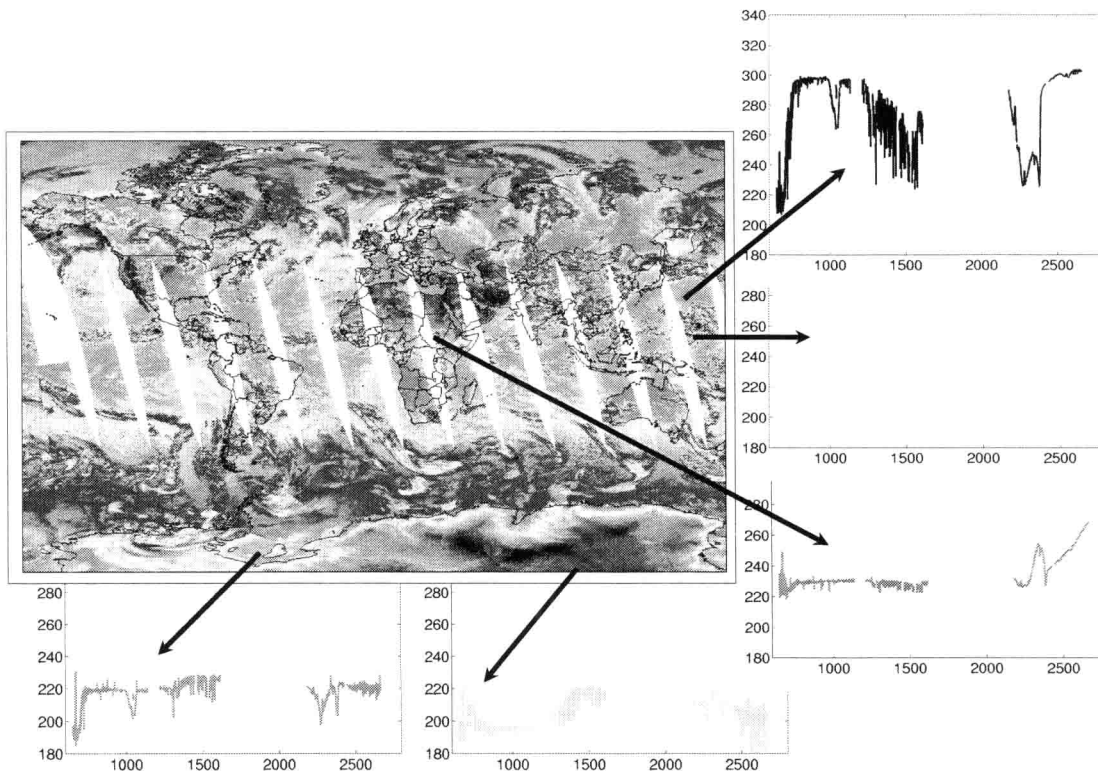


Figure 1. Sample brightness temperature spectra as a function of wavenumber from AIRS (20 July 2002), illustrating the complexity captured by high resolution IR emission spectra.

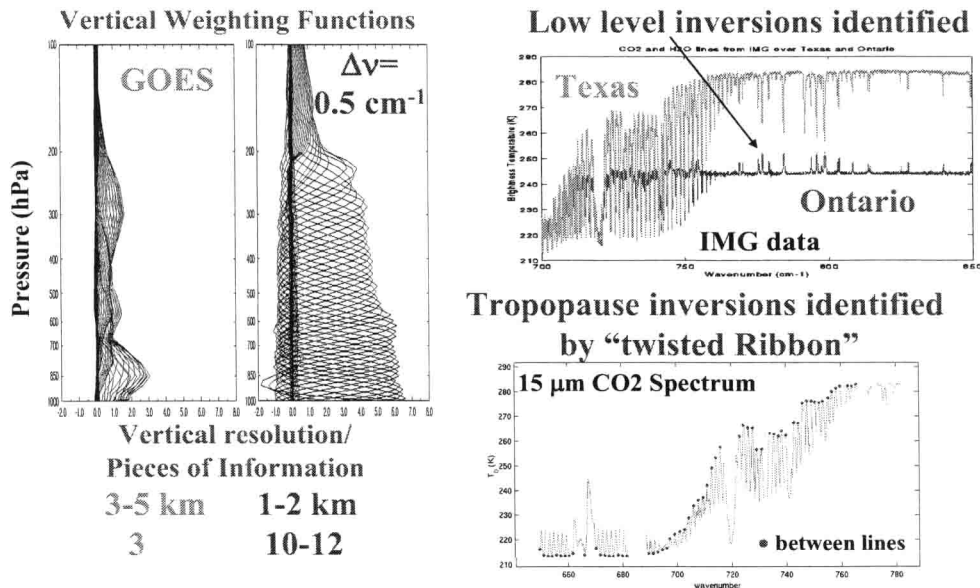


Figure 2. Examples illustrating the sensitivity to vertical structure of IR spectra with resolution capable of resolving individual spectral lines. This sensitivity is important to the characterization of climate change.

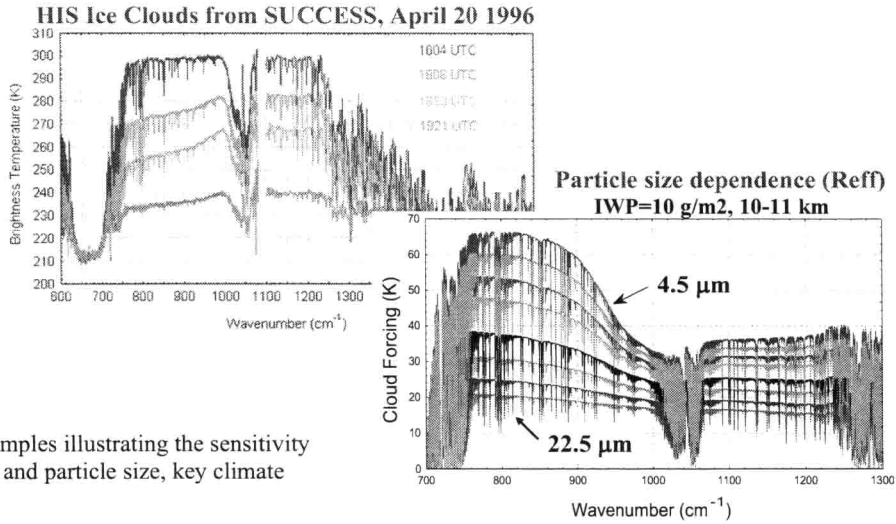


Figure 3. Examples illustrating the sensitivity to cloud phase and particle size, key climate parameters.

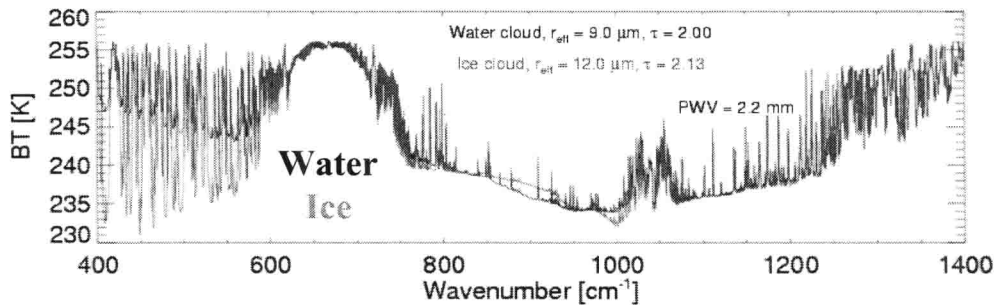


Figure 4. Calculated up-looking brightness temperature spectra illustrating the added information provided by extending the longwave limit of the IR spectrum beyond the normal 15 micron limit. The difference between these two cloud spectra, one for ice cloud and one for water, are hard to identify without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

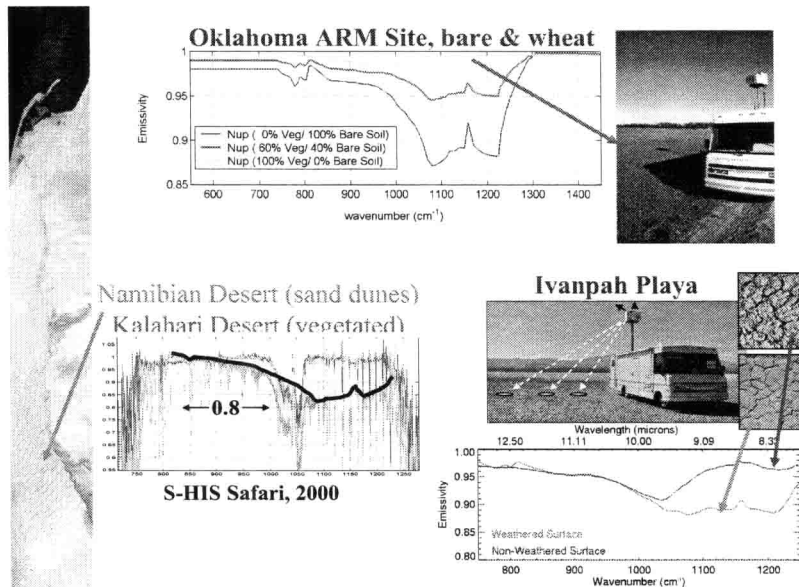


Figure 5. Illustration of land surface emissivity spectral properties that convey information about the effects of climate change on the land surface.