GIFTS-
A SYSTEM FOR WIND PROFILING FROM GEOSTATIONARY SATELLITES

William Smith, Wallace Harrison, Dwayne Hinton, Vickie Parsons and Allen Larar
NASA LaRC, Hampton Virginia (USA)

Henry Revercomb[1], Allen Huang[2], Christopher Velden[2], Paul Menzel[3], and Ralph Petersen[3]
[1]SSEC,[2] CIMSS, and [3]NOAA
University of Wisconsin, Madison WI (USA)

Gail Bingham and Ronald Huppi
Utah State University, Logan Utah (USA)

ABSTRACT

The Geostationary Imaging Fourier Transform Spectrometer (GIFTS) is a NASA New Millennium Program mission to validate a revolutionary new instrument capable of providing high density temperature and moisture profiles with very high vertical and temporal resolution from geostationary satellites. The GIFTS will fly on NASA's Earth Observing-3 geostationary satellite to be launched in 2004. The technology uses is a combination of large area format focal plane detector arrays, which enable frequent high spatial resolution coverage over large areas, with the Fourier Transform Spectrometer, which enables simultaneous high vertical resolution soundings for all detector elements of the array. It has been demonstrated, both theoretically through numerical model simulation and experimentally using an aircraft prototype instrument, that the vertical profile of wind velocity can be achieved by tracking the movement of small-scale moisture features observed as a function of altitude. The instrument concept, results from aircraft measurements and model simulations, and plans for the satellite implementation of the GIFTS are presented.

1. Introduction

The Geostationary Imaging Fourier Transform Spectrometer (GIFTS) combines new and immerging sensor and data processing technologies to acquire geophysical measurements that lead to revolutionary improvements in meteorological observations and forecasting. The GIFTS measurement concept uses a large area format focal plane detector array (128 x 128) in a Fourier Transform Spectrometer (FTS) (Smith et. al., 1979, Smith et. al., 1990) mounted on a geostationary satellite to enable the simultaneous gathering of high spectral resolution (as great as 0.3 cm^{-1}) and high spatial resolution (4-km x 4-km pixel) Earth infrared radiance spectra over a large area (512-km x 512-km) of the Earth within a 10 second time interval. A low visible light level camera provides quasi-continuous imaging of clouds at 1-km spatial resolution. Extended Earth coverage is achieved by step scanning the instrument field of view in a contiguous fashion across any desired portion of the visible Earth. The radiance spectra observed at each time step are transformed to high vertical resolution (1-2 km) temperature and water vapor mixing ratio profiles using rapid profile retrieval algorithms. These profiles are obtained on a 4km grid and then converted to relative humidity profiles. Images of the horizontal distribution of relative humidity for atmospheric levels, vertically separated by approximately 2 km, are constructed for each spatial scan. The sampling period will range from minutes to an hour, depending upon the spectral resolution and the area coverage selected for the measurement. Successive images of clouds and the relative humidity for each atmospheric level are then animated to reveal the motion of small scale thermodynamic features of the atmosphere. Automated auto-correlation feature tracking programs are then used to compute the speed and direction of movement of these small scale features, providing a measure of the wind velocity distribution at each atmospheric level. The net result is a dense grid of temperature, moisture, and wind profiles which can also be used for atmospheric analyses and operational weather prediction. Feature tracking can be performed for mixing ratio profiles of O_3 and

CO, derived from their spectral radiance features observed by the instrument, providing a direct measure of the transport of these pollutant and greenhouse gases. It is the unique combination of the FTS and the large area format detector array (i.e., an imaging interferometer) and the geostationary satellite observation platform that enables the revolutionary tracer wind profile and trace gas transport remote sensing measurements. The optical layout of the GIFTS instrument is shown in Figure 1. The imaging FTS produces the interferometric patterns for spectral separation of scene radiation reaching the detector arrays. To limit the background signal, the FTS is thermally controlled at a low temperature. The high data rates generated by the focal plane arrays (FPAs) are reduced by loss-less compression techniques then passed to the telemetry system by low-power and -volume next-generation electronic components.

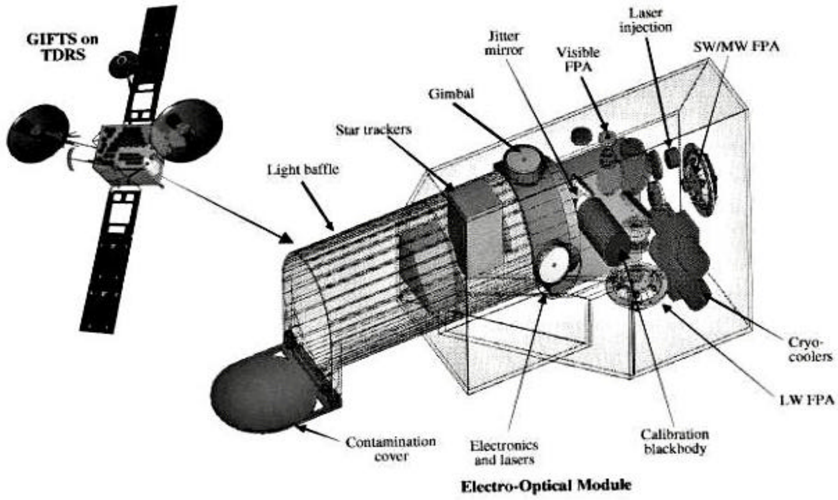

Figure 1. GIFTS Optical System.

2. GIFTS data products

2.1 Temperature, Moisture, and Wind Profiles

GIFTS measurements will be used to determine temperature and moisture profiles with unprecedented high spatial and temporal resolution. These measurements will produce wind profiles and record thermodynamic and dynamic features of the turbulent atmosphere and the evolution of severe storm systems, including tornadoes and hurricanes. Wind profile estimates can be diagnosed through the direct real-time assimilation of GIFTS retrieved temperature and water vapor profile data, in a mesoscale numerical model. Alternatively, vertical profiles of wind velocity can be estimated by tracking the horizontal displacement of features in the retrieved water vapor profiles. A similar feature-tracking approach is now used operationally and has been shown to provide improved weather forecasts on both regional and global scales. However, the current Geostationary Operational Environmental Satellite (GOES) application only provides upper tropospheric winds from images of radiance for a single water vapor channel (Stewart et. al., 1985, Velden et. al., 1997). More complete vertical profiles of wind velocity are needed to realize the full potential of satellite measurements to greatly improve both regional scale intense weather forecasts and global scale synoptic weather predictions. The capability of GIFTS to observe small scale atmospheric water vapor features for inferring the wind field has been investigated through (1) the analysis of National Polar-Orbiting Environmental Satellite System (NPOESS) Aircraft Sounder Test-bed Interferometer (NAST-I) data and (2) the simulation of GIFTS measurements for the hurricane Bonnie landfall in 1998. NAST-I has similar spectral and spatial measurement properties to the GIFTS, and the hurricane simulation used a very sophisticated Nonhydrostatic Mesoscale numerical Model (NMM) (Tripoli, 1992). The results of these supporting studies are shown in detail on the GIFTS web pages at http://its.ssec.wisc.edu/~bormin/GIFTS/.

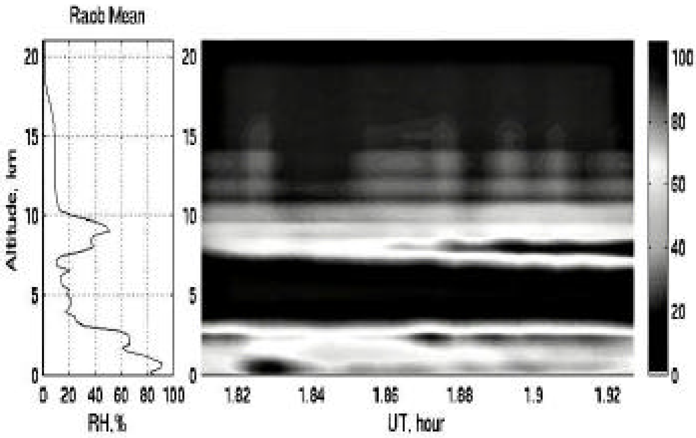

Figure 2. Horizontal cross-section (75 km) of relative humidity derived from NAST-I radiances observed from the NASA ER-2 flying over Andros Island Bahamas on September 14, 1998. The average of several radiosondes released during the aircraft overpass is shown.

Figure 2 displays the high vertical resolution sounding capability of a high spectral resolution passive remote sounder. Moist and dry layers of 1- to 2-km atmospheric depth are clearly resolved with the NAST-I system. This same vertical resolving power will be achieved with GIFTS. Using the NMM, fields of atmospheric temperature, water vapor, and wind velocity were output at 6-km spatial resolution and a 10-min time interval. The vertical distribution of cloud water content and microphysical properties were also output for each model grid point. These fields were used with a radiative transfer model to simulate GIFTS spectral radiance observations. Expected instrument noise was added to the simulated radiances. Temperature and moisture profiles were then produced for each model grid point and time step to simulate GIFTS. Figure 3 is the derived horizontal wind vectors derived from GIFTS NMM simulated radiance observations for hurricane Bonnie. The ability of GIFTS to observe the vertical structure of the hurricane circulation is clearly shown. The wind velocity errors to be derived from GIFTS will be much smaller than those associated with current geostationary satellite water vapor radiance tracer results as a result of the much higher vertical resolution of the GIFTS. The revolutionary aspect of GIFTS is that it provides access to the vertical dimension of the wind field, with accurate altitude assignment.

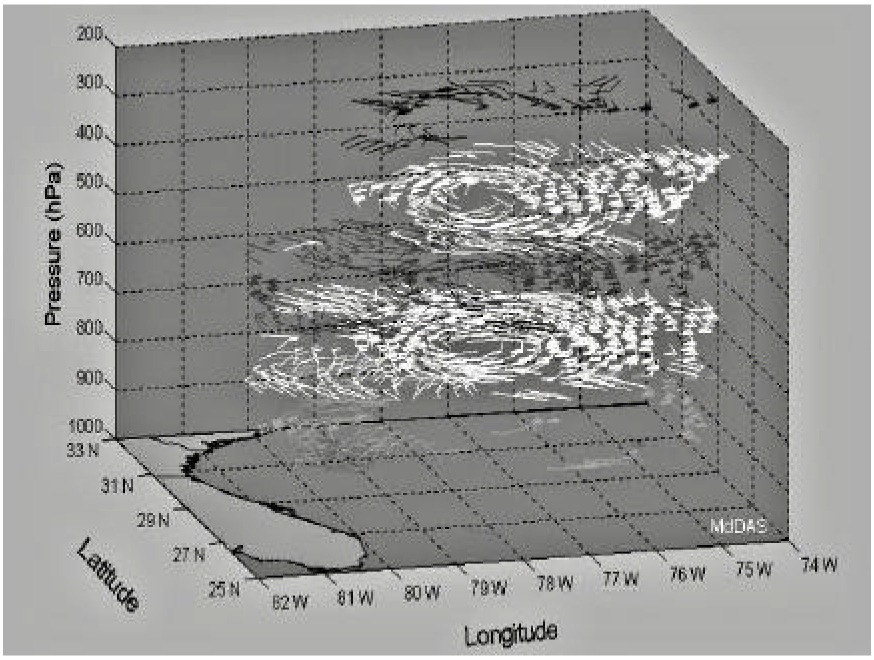

Figure 3. Wind vectors derived from NMM simulated GIFTS radiances for Hurricane Bonnie on Aug.26 1998.

2.2 Trace Gas Concentrations

GIFTS measurements will also be used to determine the time varying spatial distribution of CO and O_3 with a 3- to 11-km vertical resolution, decreasing with increasing altitude. The vertical resolving power is illustrated in Figure 4: Vertical resolution functions for GIFTS retrieved carbon monoxide and ozone profiles at 0.6- and 0.3 cm^{-1} spectral resolutions, dashed and solid curves, respectively (courtesy of Nikita Pougatchev, CNU).

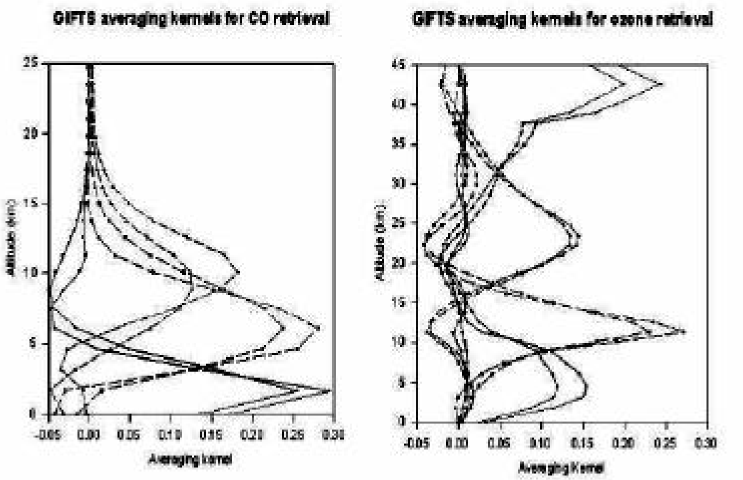

Figure 4. obtained using the EOS-CHEM platform Thermal Emission Spectrometer (TES) level-2 algorithm software.

The GIFTS capability to track vertically resolved trace gas concentrations together with the Water vapor winds is important for monitoring the global transport of pollutant gases resulting from biomass burning and industrial sources. Global Tropospheric Experiment (GTE) data have shown that this transport takes place at middle tropospheric levels (Pougatchev, 1999). Thus, GIFTS water vapor and trace gas motion sensing ability will provide a unique measure of chemical pollutant episode evolution and transport

3. Measurement characteristics

GIFTS will view areas of the Earth with a linear dimension of about 500-km, anywhere on the visible disk for a period between 0.125 and 25.0 sec, depending on the data application (i.e., imaging, sounding, or chemistry). GIFTS uses two detector arrays to cover the spectral bands 685 to 1130 cm^{-1} and 1650 to 2250 cm^{-1} (Figure 5) and a Michelson interferometer to achieve a wide range of spectral resolutions (Table I).

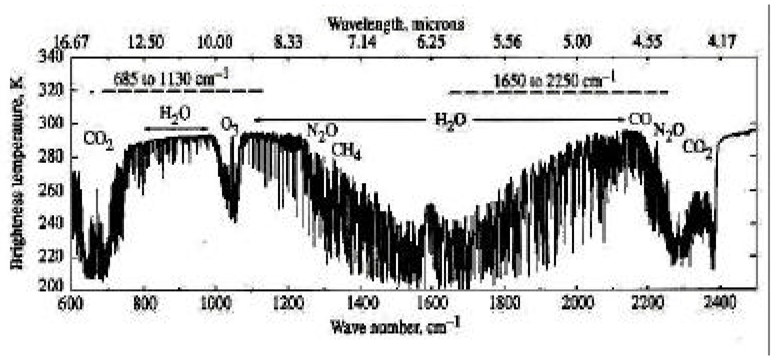

Figure 5. GIFTS spectral coverage with 2 detector arrays with spectral features of key radiatively active atmospheric trace gases.

These spectral characteristics achieve all scientific objectives of GIFTS, as well as the sounding accuracy desired for a future operational sounding system. The Michelson interferometer, or FTS, approach for geostationary satellite applications allows spectral resolution to be easily traded for greater area coverage or higher temporal resolution.

Table I: Five example GIFTS operating modes

Visible Resolution= 1 km; IR Resolution = 4 km

Mode	Resolution		Coverage	
	Spectral	OPD	Area	Time*
Stare Mode	0.3-36 cm-1	0.014-1.744 cm	512 km	<1-20 sec
Regional Imaging	36 cm-1	0.014 cm	6,000 km	3 min
Global Sounding	18 cm-1	0.027 cm	10,000 km	7 min
Regional Sounding and Chemistry	0.6 cm-1	0.872 cm	6000 km	25 min
Self Validation**	0.3 cm-1	1.744 cm	1000 km	60 min

Assumes a constant data rate associated with a Michelson mirror scan velocity of 0.17cm/sec and 1 sec telescope pointing step time.
** Provides radiometric precision better than 0.1 K over all wavelengths

Table I shows the areal coverage, measurement frequency, spectral resolution, and geophysical measurement for example modes of operation for GIFTS. Quasi-continuous imagery of localized areas and minute-interval imagery of large scale areas can be achieved. Full disk sounding coverage can be obtained every 7 min at contemporary sounder spectral resolutions (e.g., 18 cm^{-1}). High vertical resolution soundings and atmospheric chemistry measurements of GIFTS require 0.6 cm^{-1} spectral resolution and a longer stare time, thereby reducing the area coverage and/or frequency of observation relative to the imagery mode of operation. Nevertheless, GIFTS can cover a major portion of the visible disk with high vertical resolution soundings in less than 0.5 hour. This feature is important for obtaining wind profiles from geostationary temperature and moisture sounding data. A relatively long dwell time and a more limited area coverage "self validation mode" of operation will enable 0.3-cm^{-1} spectral resolution radiances to be achieved with very high radiometric precision. The self validation mode will be for radiance, sounding, and chemistry product validation of the routine larger area, higher frequency, spectra and geophysical products provided by the global and regional sounding and chemistry modes of operation. GIFTS can achieve good simultaneity with Earth orbiting satellite observations to enhance overall ESE science mission objectives.

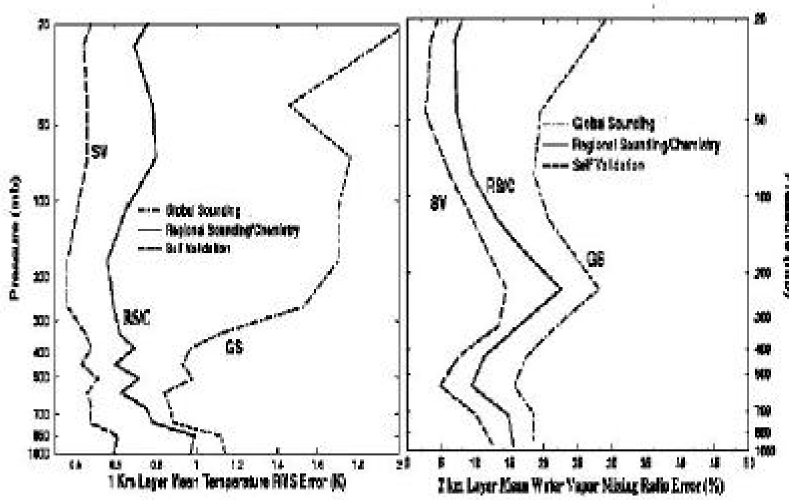

Figure 6. Profile RMS errors for 3 GIFTS sounding modes of operation shown in Table 1 using expected radiometric noise performance

The expected sounding performance of GIFTS has been determined by radiance simulation. The results for the three example sounding modes of operation (Table 1) are shown in Figure 6. The radiometric noise and accuracy requirements for this retrieval of temperature and water vapor in the Regional Sounding and Chemistry mode with 10 sec dwell time are: (1) Noise Equivalent Radiance (NEN) in the LW spectral band (685-1130 cm^{-1}) <0.2 mW/m 2 sr cm^{-1}, (2) NEN in the SW/MW spectral band (1650-2250 cm^{-1}) <0.06 mW/m 2 sr cm^{-1}, and (3) Absolute calibration accuracy better than 1 K brightness temperature for Earth scene brightness temperatures > 190 K for the LW and >240 K for the SW/MW band. Periodic views of onboard references and cold space will be used to realize this high calibration accuracy. Achieving these radiometric requirements for the primary high spectral resolution sounding mode is sufficient to insure the performance of other GIFTS imaging and sounding modes. The only other necessary constraints are that the time required to point the field-of-view to an adjacent region on Earth be less than 1 sec and that the pointing knowledge be better than 0.4 km for wind determination.

4. Summary

GIFTS will be put into geostationary orbit in 2004 to demonstrate the ability to obtain revolutionary improvements in weather and air quality forecasts using its high temporal and spatial resolution temperature and moisture products. GIFTS is the experimental forerunner of a global operational system of advanced sounders. A global system will enable these revolutionary improvements to be achieved on a world-wide basis as needed to realize the full potential of the GIFTS measurement approach.

REFERENCES

Smith, W. L., H. B. Howell, and H. M. Woolf, 1979: The use of interferometric radiance measurements for sounding the atmosphere. *J. Atmos. Sci.*, **36**, 566-575.

Smith, W. L., H. E. Revercomb, D. D. LaPorte, L. A. Sromovsky, S. Silverman, H. M. Woolf, H. B. Howell, R. O. Knuteson, and H.-L. Huang, 1990: GHIS - The GOES High resolution Interferometer Sounder. *J. Appl. Meteor.*, **29**, 1189-1204.

Stewart, T. R., C. M. Hayden, and W. L. Smith, 1985: A note on water vapor wind tracking using VAS data on McIDAS. *Bull. Amer. Meteor. Soc.*, **66**, 1111-1115. Sounder (HIS) observations. *J. Appl. Meteor.*, **29**, 658-662.

Tripoli,G.J., 1992: A Nonhydrostatic Mesoscale Model Designed to Simulate Scale Interaction. *Mon. Wea. Rev.*, **120**, 1342-1359.

Velden, C.S., C. M. Hayden, S.J. Nieman, W.P. Menzel, S. Wanzong and J. S. Goerss, 1997: Upper-tropospheric winds derived from geostationary satellite water vapor observations. *Bull. Amer. Meteor. Soc.*, **78**, 173-195.

Pougatchev,N.S., 1999: PEM Tropics Carbon Monoxide Measurements in Historical Context. *J. Geophysical Research* (in press).