6.2 THE GEOSYNCHRONOUS IMAGING FOURIER TRANSFORM SPECTROMETER (GIFTS)

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The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) combines a number of advanced technologies to observe atmospheric weather and chemistry variables in four dimensions. Large area format Focal Plane detector Arrays (LFPAs) provide near instantaneous large area coverage with high horizontal resolution. A Fourier Transform Spectrometer (FTS) in front of the LFPAs enables atmospheric radiance spectra to be observed simultaneously for all detector elements thereby providing high vertical resolution temperature and moisture sounding information. The fourth dimension, time, is provided by the geosynchronous satellite platform, which enables near continuous imaging of the atmosphere's three-dimensional structure. The key advance that GIFTS achieves beyond current geosyncronous capabilities is that the water-vapor winds will be altitude-resolved throughout the troposphere. GIFTS, will be launched in 2005, as NASA's third New Millennium Program (NMP) Earth Observing (EO-3) satellite mission, and will serve as the prototype of sounding systems to fly on future operational geosynchronous satellites. After a one year validation period in view of North America, the GIFTS will be repositioned to become the Navy's Indian Ocean METOC Imager (IOMI).

1. Introduction

A new era is about to begin in hyper-spectral remote sensing, namely the implementation of hyper-spectral remote sounding systems. The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS), selected for flight demonstration as NASA's New Millennium Program (NMP) Earth Observing-3 (EO-3) mission, combines new and emerging sensor and data processing technologies to acquire geophysical measurements that lead to revolutionary improvements in meteorological observations and forecasting. The NOAA, Navy, and Air Force are partners with NASA in the GIFTS program; the NOAA will provide the ground processing system to demonstrate the operational utility of the data, the Navy will provide the spacecraft and support the operation of GIFTS after the NMP phase of the program as its Indian Ocean METOC Instrument (IOMI), and the Air Force will provide the launch of the GIFTS-IOMI satellite to geosynchronous orbit using a new Delta IV rocket multiple payload launch capability developed under their Space Test Program (STP).

The GIFTS uses large area format focal plane (LFPA) infrared (IR) detector arrays (128 x 128) in a Fourier Transform Spectrometer (FTS) mounted on a geosyncronous satellite to gather high spectral resolution (0.6 cm $^{-1}$) and high spatial resolution (4-km footprint) Earth infrared radiance spectra over a large geographical 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 footprint 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 4-km 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, providing a measure of the wind velocity distribution as a function of altitude. The net result is a dense grid of temperature, moisture, and wind profiles which can be used for atmospheric analyses and operational weather prediction. O_3 and CO features observed in their spectral radiance signatures, provide a measure of the transport of these pollutant and greenhouse gases. It is the unique combination of the Fourier transform spectrometer and the large area format detector array (i.e., an imaging interferometer), and the geosyncronous satellite platform, that enables the revolutionary wind profile and trace gas transport remote sensing measurements.

2. The GIFTS Instrument

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 cooled by the first stage of the cryocooler to <150 K. The high data rates generated by the focal plane arrays (FPAs) are reduced by loss-less compression techniques and then passed to the telemetry system by low-power, low-volume, next-generation electronic components.

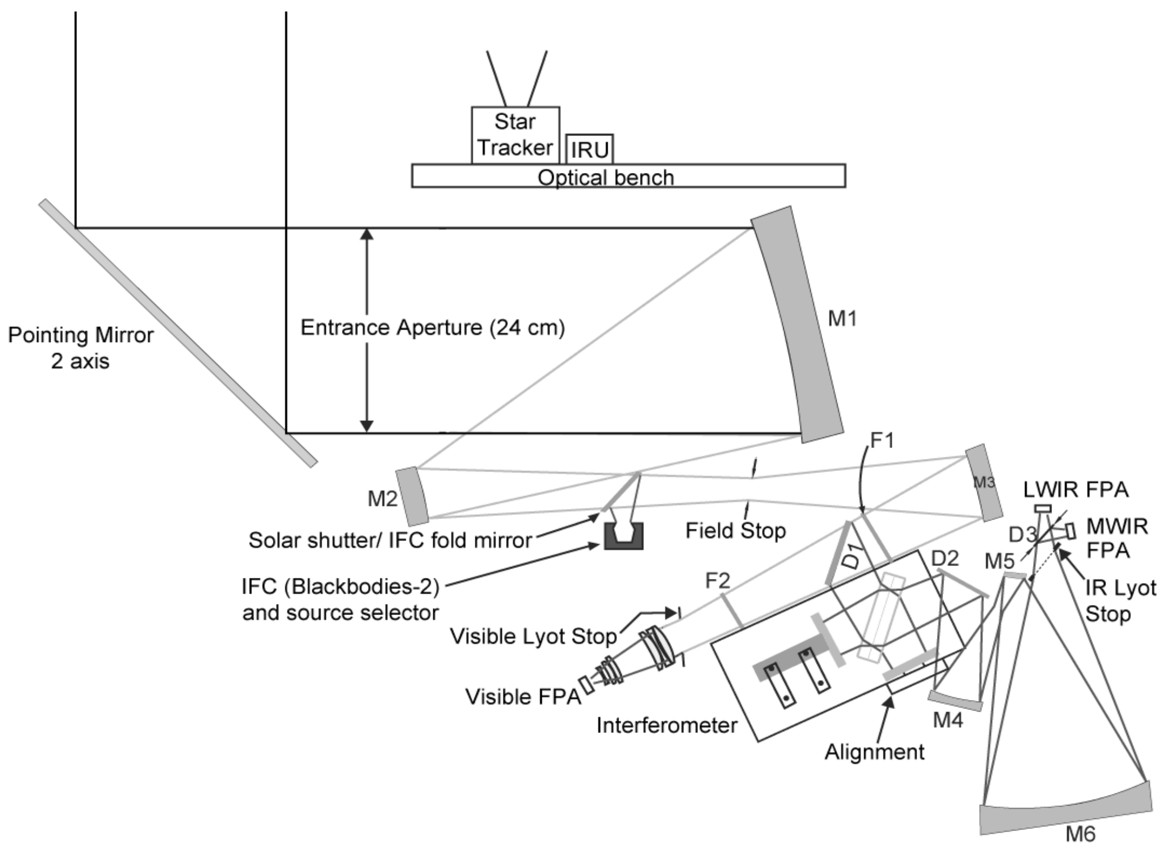

Figure 1. Schematic of GIFTS Sensor Module

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 10.0 sec, depending on the data application (i.e., imaging or sounding). GIFTS uses two detector arrays within a

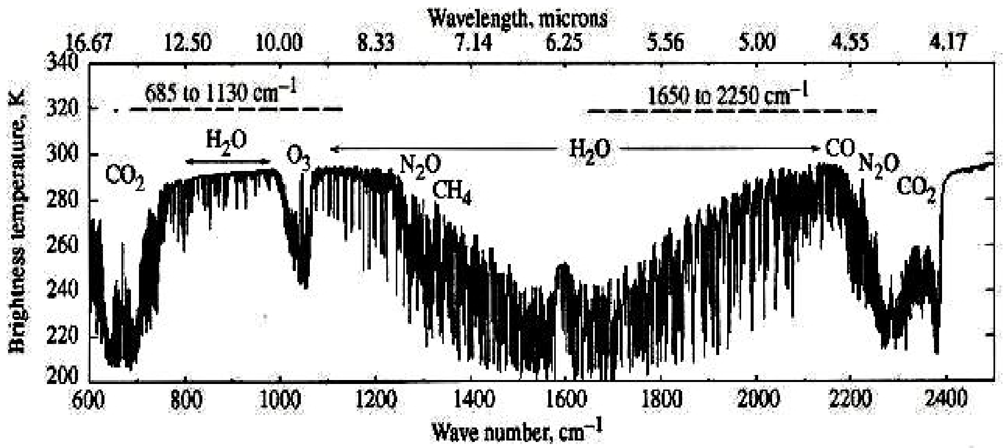

Figure 2: GIFTS spectral coverage with 2 detector arrays with the spectral regions of key radiatively active atmospheric trace gases.

Michelson interferometer to cover the spectral bands, 685 to 1130 cm $^{-1}$ and 1650 to 2250 cm $^{-1}$ (Figure 2), to achieve a wide range of spectral resolutions (figure 3). These spectral characteristics are optimized to achieve all technology/scientific validation objectives of GIFTS, as well as the sounding accuracy desired for a future operational sounding system. The Michelson interferometer, or FTS, approach for geosyncronous satellite applications allows spectral resolution to be easily traded for greater area coverage or higher temporal resolution. The 4-km footprint size of the IR LFPAs enable sounding to the ground under most broken-to-scattered cloud situations and resolving small scale atmospheric water vapor and cloud features required for wind profiling.

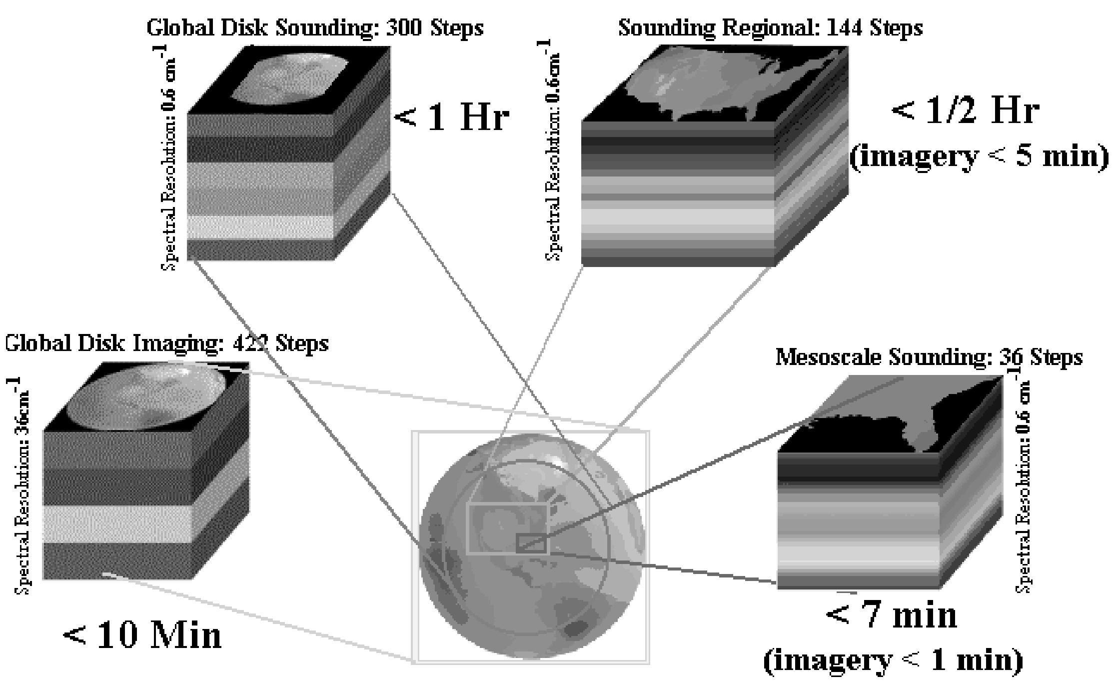

Figure 3. Example operating modes for GIFTS

Figure 3 shows the area 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. Relatively high spectral resolution (36 cm $^{-1}$) full disk imagery will be obtained in less than 10 min. 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 will cover a major portion of the visible disk with high vertical resolution soundings in less than one hour; and regions the size of CONUS and surrounding oceans will be observed with a half hourly frequency. This feature is important for obtaining wind profiles from geosyncronous temperature and moisture sounding data.

The sounding performance of GIFTS (figure 4) has been determined by radiance simulation.

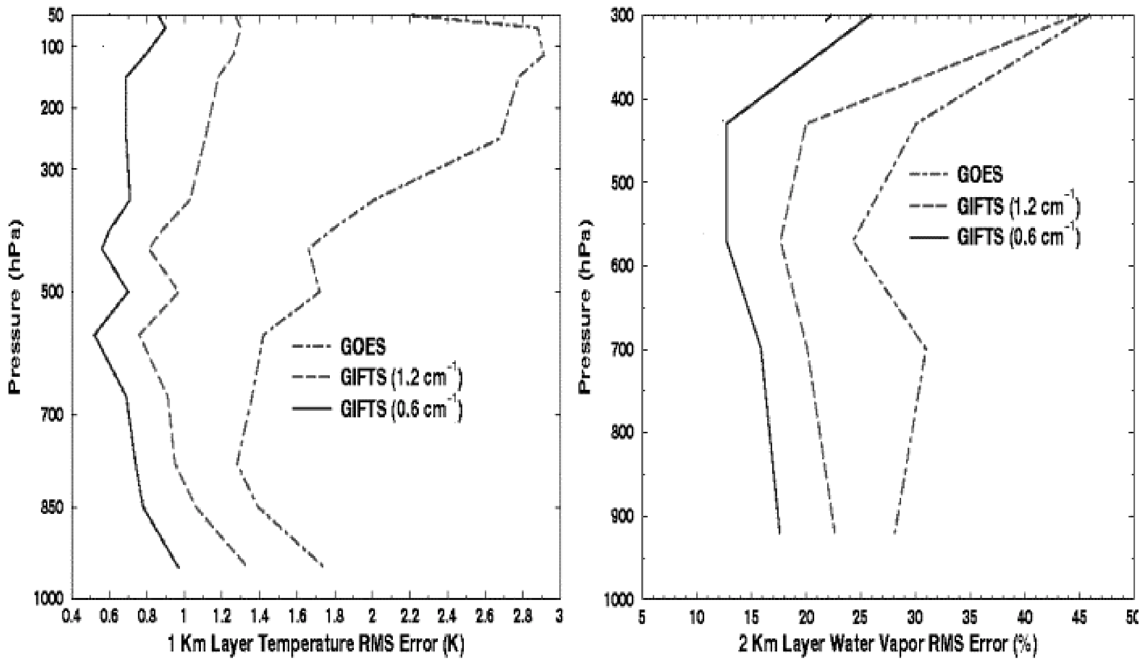

Figure 4: RMS temperature and mixing ratio profile errors for 2 different GIFTS spectral resolutions compared to those associated with the current GOES sounder

The significance of the lower spectral resolution (i.e., 1.2 cm^{-1}) sounding mode is that twice the area coverage, or a doubling of the refresh rate, can be achieved by sacrificing the vertical resolution and, consequently, the accuracy of the sounding products. The radiometric noise and accuracy requirements for the retrieval of temperature and water vapor in the highest spectral resolution (0.6 cm^{-1}) mode with a 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 lower vertical resolution 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.

3. Aircraft Demonstrations of Measurement Capability

A high spectral resolution (0.25cm-1) and high spatial resolution scanning interferometer sounding system, called the NPOESS Aircraft Sounding Testbed-Interferometer (NAST-I) has been built and flown to provide experimental observations needed to finalize the specifications and to test proposed designs and data processing algorithms for the Cross-track scanning Infrared Sounder (CrIS) to fly on the National Polar-orbiting Operational Satellite System (NPOESS). Because of the selection of the GIFTS to fly on the Earth Observing Three (EO-3) satellite, the data collected by the NAST-I has become an important source of information to test the design characteristics and data processing algorithms for GIFTS as well. NAST-I is a passive infrared (IR) Michelson interferometer that scans the Earth and atmosphere from an aircraft, such as the high-altitude NASA ER-2 research airplane and the Scaled Composites, Incorporated, (SCI) Proteus aircraft. The NAST-I, measures thermal radiation contiguously across the spectral region 3.5-16 microns with a spectral resolution of 0.25 cm^{-1}, which is sufficient for simulating the full spectral measurement capabilities of both the CrIS and the GIFTS. NAST also spatially scans the earth beneath the aircraft with 1-3 km spatial resolution, depending on aircraft altitude, thereby providing three-dimensional images of spectral radiance, and derived products, similar to that to be obtained by the GIFTS. Unlike the GIFTS, however, the NAST-I does not use large focal plane arrays to achieve its imaging capability; instead, it uses a cross-track scanning mirror and the motion of the aircraft to produce a similar result. The NAST retrieval results to be shown were obtained using the eigenvector regression retrieval method as applied to high spectral resolution interferometer data. In this technique, a training sample of historical radiosonde data is used to simulate radiance spectra for the NAST instrument. Eigenvectors are computed; and regression equations, which relate the eigenvector amplitudes to the radiosonde temperature and water vapor values, are derived, assuming a variable number of eigenvectors for the representation of the spectral radiance information. Appropriate random instrumental noise is added to the simulated radiance data set, and retrievals are performed for all cases as a function of the number of eigenvectors. The optimal number of eigenvectors is selected as that number which minimizes the RMS retrieval error for the historical radiosonde data set. This number ranges between 20 and 200, depending upon the variance associated with the historical data set used (such as regional or global, seasonal or annual). The regression equations for the optimal set are then applied to real NAST-I radiance measurements. Since all the radiative transfer calculations and eigenvector decomposition analysis is done “off-line” to the actual data processing, the algorithm is extremely fast when applied to real data. Because of both it’s speed and accuracy, the eigenvector retrieval method will be used for the real-time processing of GIFTS data. Figure 5 shows a derived temperature profile and a cross-section for atmospheric relative humidity in the vicinity of Andros Island Bahamas. The spatial detail of the retrieved humidity distribution is particularly noteworthy. Most of the fine scale vertical details shown in the radiosonde validation data are displayed by the NAST soundings.

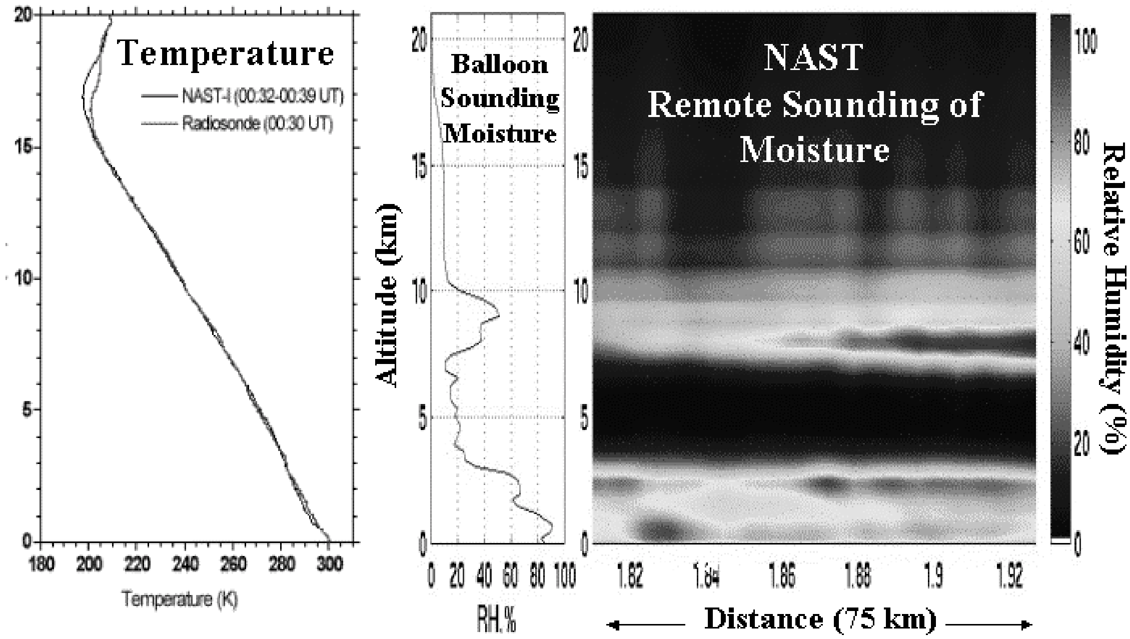

Figure 5: Retrieved and radiosonde Temperature profiles and a 75 km. vertical cross-section of atmospheric relative humidity near Andros Island Bahamas, on September 11, 1998.

More recent results obtained with NAST-I aboard the Proteus flying over a scattered Cirrus deck demonstrate that GIFTS should be able to sound below most scattered-to-broken cloud decks. Figure 6 shows the GOES IR image with the flight track superimposed for the case being presented.

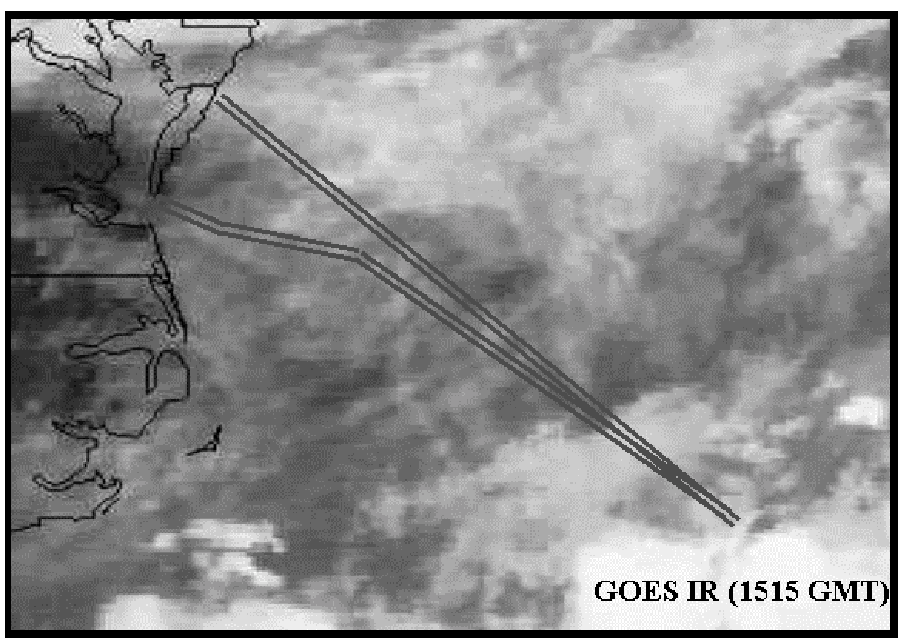

Figure 6: GOES IR image of Cirrus cloud cover associated with Proteus flight track for 07/12/01.

Figure 7 shows the vertical cross-sections of temperature and moisture retrieved along the flight tracks over the Cirrus cloud cover. The vertical streaks in this plot are due to the attenuation by the Cirrus cloud, which can be seen in the cloud image shown at the bottom of this chart. The moisture cross-section indicates that the top of the Cirrus cloud is at about the 9 km level and extends downward to about the 6 km level. Below 6 km, there is a layer of dry air extending down to a marine boundary layer of moisture whose top is at 2 km at the northern end of the track and extends upward to the Cirrus level at the southern end of the track (the middle of figure 7) where deep convection is occurring. As can be seen from figure 7, the GIFTS should be able to resolve and track the movement of important moisture features below a scattered and semi-transparent Cirrus cloud deck. The result is analogous to viewing an object through a window with partially open Venetian blinds. Further validation of this conclusion is shown by the comparison of the retrievals at the northern end of the cross-section with the nearby Wallops Island radiosonde observation, as shown in figure 8 below. It is further noted that since the lower tropospheric water vapor feature signal is inherent in the spectral radiance data for partially cloudy and semi-transparent Cirrus cloud situations, "cloud-clearing" techniques can be used to filter out any cloud artifacts (i.e., the Venetian blinds) from the water vapor imagery prior to the specification of wind profiles from the GIFTS data. This result is a very important finding in support of the use of the GIFTS passive wind sounding technique for achieving high density wind profiles extending into the lower troposphere under the Cirrus shield that exists in the vicinity of active storm systems (e.g., the hurricane environment).

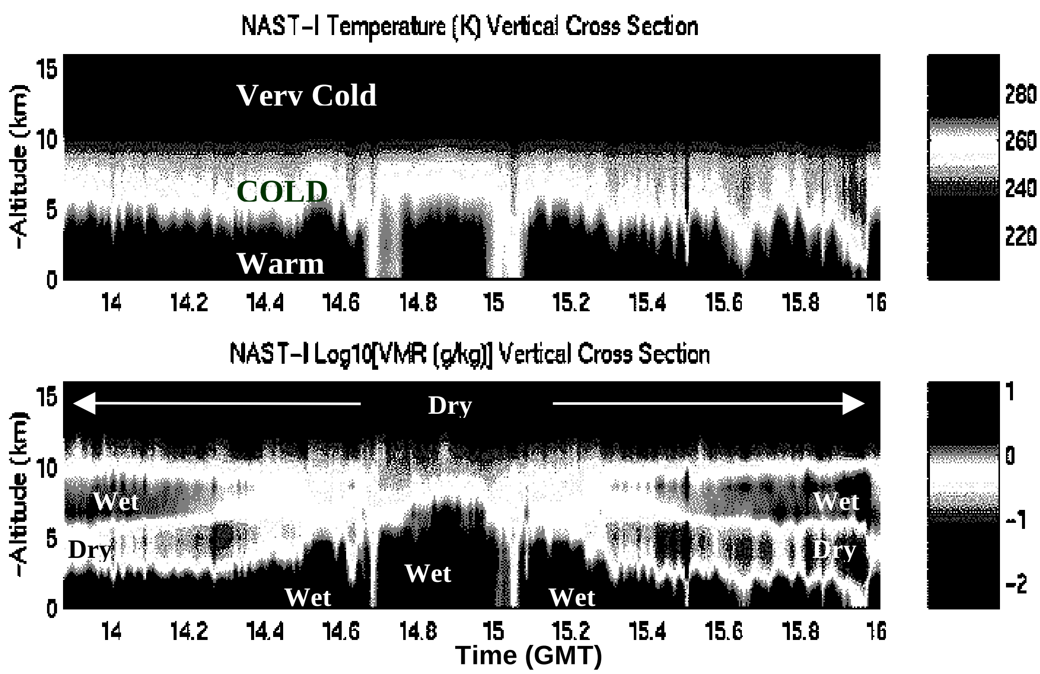

Figure 7: Vertical cross-sections of temperature and moisture observed by NAST-I along the flight track shown in Figure 6.

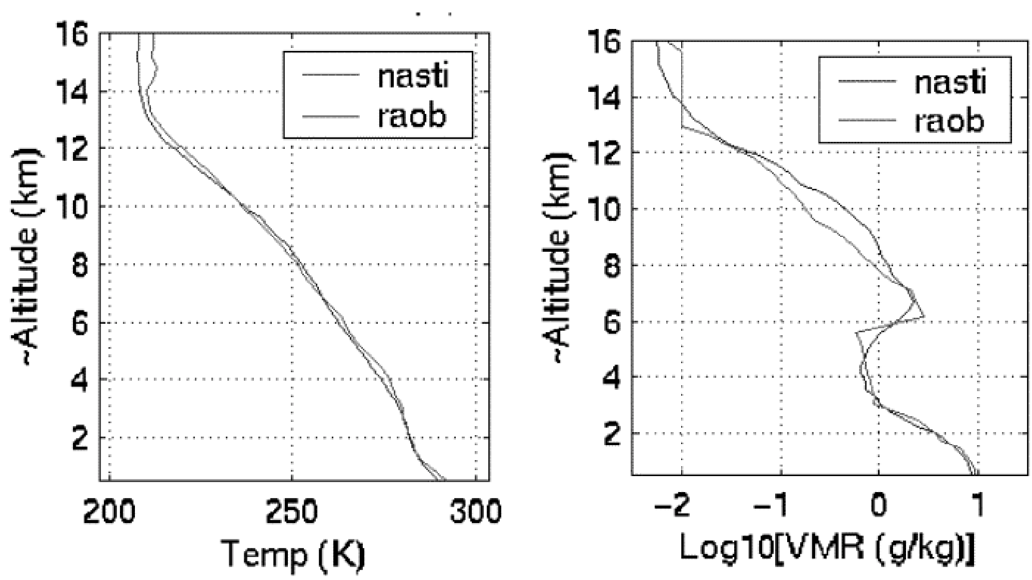

Figure 8: Comparison of Clear air NAST sounding with the Wallops radiosonde (7/12/01).

4. Summary

The first hyper-spectral imaging spectrometer designed for atmospheric sounding, GIFTS, will be orbited aboard a geosynchronous satellite to usher in a new era of high space and time resolution measurements of the atmosphere. Such measurements will lead to revolutionary improvements in our ability to forecast weather and climate. Observations with an airborne Michelson interferometer flying aboard the NASA ER-2 and the SCI Proteus aircraft validate the approach being used to achieve the scientific objectives of the GIFTS-IOMI mission.

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