

GIFTS –The Precursor Geostationary Satellite Component of the Future Earth Observing System

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Abstract: The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) combines advanced technologies to observe surface thermal properties and 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) enables atmospheric radiance spectra to be observed simultaneously for all LFPA 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 advances that GIFTS achieves beyond current geosynchronous capabilities are: (1) the water-vapor winds will be altitude-resolved throughout the troposphere, (2) surface temperature and atmospheric soundings will be achieved with high spatial and temporal resolution, and (3) the transport of tropospheric pollutant gases (i.e., CO and O₃) will be observed. 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). In this presentation we describe the GIFTS technology and provide examples of the GIFTS remote sensing

capabilities using aircraft interferometer data. The GIFTS is an important step in implementing the NASA Earth Science Enterprise vision of a sensor web for future Earth observations.

I. 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 revolutionary geophysical measurements that should lead to dramatic improvements in weather forecasting. The GIFTS is an important development for realizing a sensor web around the globe for future Earth observations. This sensor web would enable the "2020 vision" of the global meteorological community to become reality; *"By the year 2020, mankind will have the technology (observations and models) to digitize the earth's surface and its atmosphere with a resolution of 1 km and 1 minute And every individual on earth will have personal and timely access to weather observations and accurate weather forecasts through a "palm" computer/display unit."* The NOAA, Navy, and Air Force are partners with NASA in moving forward to realize this vision in the execution of 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 (LFFA) infrared (IR) detector arrays (128 x 128) in a Fourier Transform Spectrometer (FTS) mounted on a geosynchronous satellite to gather high spectral resolution (0.6 cm^{-1}) and high spatial resolution (4-km footprint on the Earth) infrared radiance spectra over a large geographical area (512-km x 512-km) 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 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 geosynchronous satellite platform, that enables the revolutionary wind profile and trace gas transport remote sensing measurements.

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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 Michelson interferometer to cover the spectral bands, 685 to 1130 cm^{-1} and 1650 to 2250 cm^{-1} (Figure 1), to achieve a wide range of spectral resolutions (figure 2). 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.

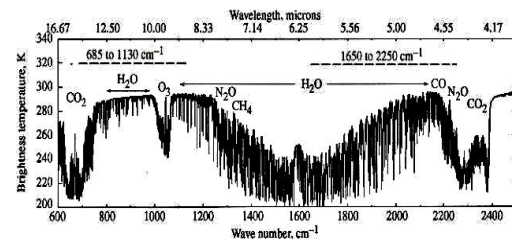


Fig. 1. GIFTS spectral coverage with 2 detector arrays with the spectral regions of key radiatively active atmospheric trace gases.

The Michelson interferometer, or FTS, approach for geosynchronous 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 LFFAs enables 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.

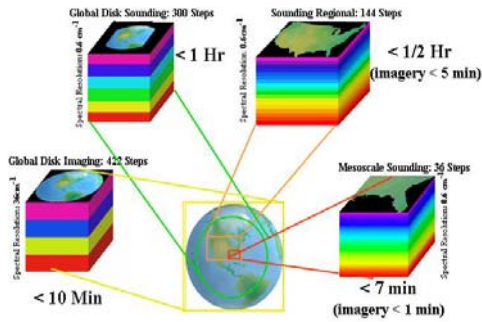


Fig. 2. Example operating modes for GIFTS

Figure 2 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 with 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 geosynchronous temperature and moisture sounding data.

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 ($685\text{--}1130 \text{ cm}^{-1}$) $< 0.2 \text{ mW/m}^2 \text{ sr cm}^{-1}$, (2) NEN in the SW/MW spectral band ($1650\text{--}2250 \text{ cm}^{-1}$) $< 0.06 \text{ mW/m}^2 \text{ sr cm}^{-1}$, and (3) Absolute calibration accuracy better than 1 K brightness temperature for Earth scene brightness temperatures $> 190 \text{ K}$ for the LW and $> 240 \text{ K}$ 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.

The expected sounding performance of GIFTS has been determined by radiance simulation and the results are shown in figure 3 below. As shown, for the GIFTS maximum spectral resolution of 0.6 cm^{-1} , a vertical profiling accuracy of $1 \text{ K} / 1 \text{ km}$ layer and $15\% / 2 \text{ km}$ layer temperature and moisture, respectively, profiling accuracy should be achieved. These accuracies are similar to those to be achieved by the advanced sounding instruments to fly aboard future polar orbiting operational satellites (i.e., the European METOP and the US NPOESS). The added features of GIFTS are its high spatial and high temporal resolution being provided from geostationary altitude. It is this added feature which enables GIFTS to achieve its primary measurement objective of measuring atmospheric wind profiles.

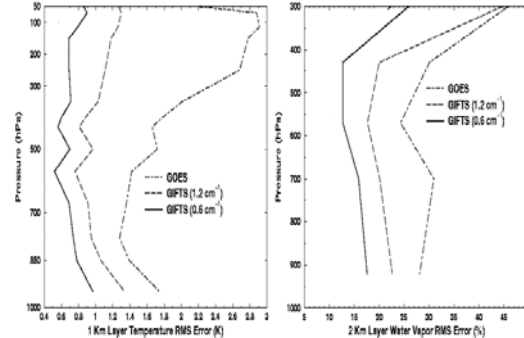


Fig. 3. RMS temperature and mixing ratio profile errors for 2 different GIFTS spectral resolutions compared to those associated with the current GOES sounder

II. Primary Measurement Objective and Forecast Applications

The primary measurement objective of GIFTS is to profile atmospheric wind velocity. This is accomplished by the ability of GIFTS to measure the geographical distribution of temperature and water vapor as a function of time and altitude. The temperature and water vapor profiles are transformed into profiles of relative humidity; patches of high humidity have the appearance of clouds and move with the

wind in the manner that ice and water clouds move with the wind. Since water vapor motion is a good tracer of the wind velocity, GIFTS is able to observe the three dimensional wind velocity structure of the atmosphere.

Aircraft measurements obtained from the NASA ER-2 aircraft from a 20 km flight altitude by the NPOESS Aircraft Sounder Testbed – Interferometer show that the intended temperature, moisture, and wind profiling capability should be achievable with GIFTS. The NAST-I measurements cover the spectral range of the GIFTS and, like GIFTS, possess a high spatial resolution (~4 km dependent upon scan angle and altitude). Figure 4 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.

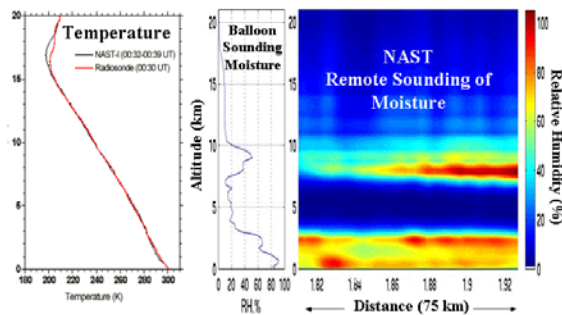


Fig. 4. Retrieved and radiosonde Temperature profiles and a 75 km. vertical cross-section of atmospheric relative humidity near Andros Island Bahamas, on September 11, 1998.

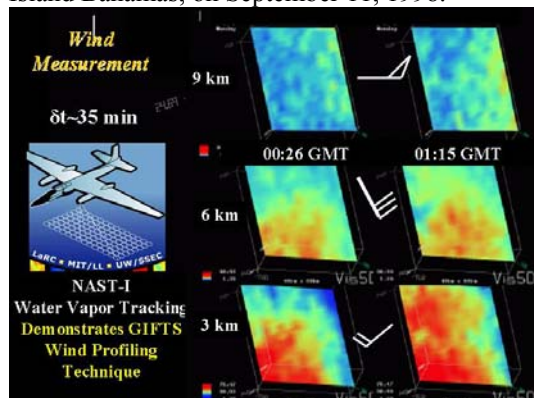


Fig. 5. NAST-I measurements of the water vapor humidity at three different levels observed with the NAST-I aboard the NASA ER-2 aircraft

flying over Andros Island, Bahamas, on September 12, 1998.

The images shown in figure 5 are obtained from two successive passes of the ER-2, over a 60 km x 40 km cloud free area, with a 49 minute time separation. It can be seen from the apparent motion of the water molecules that the winds change with altitude being west to south westerly at low altitudes and backing to easterlies at high altitudes. These data illustrate the ability to measure atmospheric wind velocity as a function of altitude.

Wind measurements, together with the temperature and humidity measurements, as a function of pressure altitude will be provided by GIFTS with high spatial and temporal resolution and broad geographical coverage. It is this revolutionary advance in meteorological observation capability which is expected to have dramatic impacts on weather forecasting capability. For example, the ability to observe water vapor flux and convergence and divergence patterns should enable meteorologists to view the formation of storm systems before clouds and rainfall are produced. The GIFTS three dimensional water vapor imaging capability, which will reveal the upward spiral of water vapor associated with a convective storm, will alert meteorologists to where and when severe storms will occur before they are visible in satellite cloud imagery or from ground based RADAR systems. This new observation capability will enable advanced warnings to the public residing in the areas of storm formation.

The winds observed in the environment of an already developed storm will also enable meteorologists and numerical prediction models to predict where the storm will move. This capability is important for providing advanced warnings to population centers downstream of a developed storm. The GIFTS capability to provide these environmental winds as a function of altitude over oceanic areas is particular value for warning those who reside in coastal areas where a hurricane will landfall.

Most important for realizing the “2020 Vision” mentioned above, the GIFTS high density temperature and moisture profile data can be continuously assimilated into advanced numerical weather prediction models of the atmosphere to enable complete diagnoses of the atmospheric state at any instant of time. The numerical model is important for filling in the space and time gaps in the global observing system through spatial interpolations and time

extrapolations of the observations provided through the numerical integration of the dynamical equations governing the changing state of the atmosphere. Given a quasi-continuous and spatially dense coverage of the atmospheric temperature and moisture is expected to force the data assimilation system to accurately simulate the dynamics of the atmosphere leading to initial conditions which should enable more precise and longer range numerical weather predictions.

III. Conclusions

GIFTS will usher in a new era of rapid advances in remote sensing from geostationary meteorological satellites. The three state parameters, temperature, humidity, and wind velocity, will all be measured in a near real time fashion. Once the wind profiling measurement concept is validated using a one year data set acquired during the first year in view of CONUS, the GIFTS-IOMI satellite will be moved to an Indian Ocean position near 75 E in order to support the Navy fleet operating in this part of the world.

The technology to be demonstrated with GIFTS will be the basis for the development of remote sounding and imaging systems for future operational satellites. Once this technology is implemented aboard the international system of geostationary satellites, they will become an important element of the sensor web envisioned to provide a quasi-complete set of global observations as required for precise and extended range numerical weather predictions. Thus, the GIFTS technology, together with other observation systems being implemented on low altitude satellites, aircraft, and on the ground, will enable the "2020 Vision" to be realized; *"By the year 2020, mankind will have the technology (observations and models) to digitize the earth's surface and its atmosphere with a resolution of 1 km and 1 minute And every individual on earth will have personal and timely access to weather observations and accurate weather forecasts through a "palm" computer/display unit."*