

# INTERNATIONAL GEOSTATIONARY LABORATORY (IGEOLAB)

Liu Jian

Space Programme, World Meteorological Organization

## Abstract

This paper mainly introduces the concept and status of International Geostationary Laboratory (IGEOLab) and the Geostationary Imaging Fourier Transform Spectrometer (GIFTS). GIFTS is one of two test IGEOLab systems. The ability of GIFTS to observe water vapour dynamics is a key to gaining a better understanding of the global water cycle and improving our understanding of climate, as well as short-term weather processes. The GIFTS high temporal resolution temperature, water vapour, and wind profile data is expected to improve severe convective weather forecasts and tropical storm motion and landfall predictions.

## 1 International Geostationary laboratory (IGEOLab)

To date, the missing component of the Global Observing System is the observation of the time continuity of surface and atmospheric processes as needed to gain a more complete understanding of the dynamics and the life cycle of environmental phenomena. Time continuity enables applications such as monitoring air quality and pollution transport processes, understanding El Niño onset and other climate anomalies, and studying the development of intense storm activity, such as hurricanes and tornadoes, to improve severe weather prediction and response strategies. Such observations cannot be achieved from low earth orbit satellites because of their relatively long revisit period of hours to days, depending on the inclination and altitude of the satellite and the scan geometry of the sensor. It was recognized that there was considerable value in coordinated geostationary research missions; this included the opportunity for evolution of sensor technologies, the unique perspective from geostationary orbit for monitoring rapidly evolving phenomena, and most importantly the early involvement of the user community.

The IGeoLab concept is focused on sharing the benefit of a geostationary demonstration mission across several space development agencies, operators of operational meteorological satellites, and satellite data users. It would be a joint undertaking to provide a platform for demonstrations from geostationary orbit of new sensors and capabilities. The full IGeoLab concept would include several stages:

- Stage 1: early presentation of a mission concept and its possible applications and benefits to the international user community; with early involvement of a group of international experts in the definition and assessment of the mission and the conduct of related scientific studies, and publications of the results of such studies;
- Stage 2: international cooperation in the definition and development of a mission, in particular with regard to the instrument(s) and the ground segment, with a view towards (a) sharing costs and facilitating accommodation of the demonstrated capabilities across a ring of satellites, and, (b) planning and establishing the real time and off line data and product services required for adequate pre-operational assessment of the new capabilities by committed users;
- Stage 3: implementation of a phased mission profile (declared to be a research element of the space component of the WMO World Weather Watch's Global Observing System, in the framework of the WMO Space Programme) enabling the new capabilities to be assessed across a representative sample of geostationary slots with the involvement of "local" user communities through free and unrestricted access to key data and products (real time and offline);
- Stage 4: selection of an international group of investigators who (1) calibrate/validate, analyze, evaluate the data, and demonstrate their value in research and applications; (2) who organize international workshops at key mission milestones, starting with commissioning results, and addressing

demonstration results for each key application and/or each regional phase of the mission; and (3) who present results to CGMS and appropriate WMO constituent body sessions; and who formulate with the WMO Space Programme the relevant recommendations for transition to operational status and accommodation across the ring of geostationary satellites.

The IGeoLab concept would enable:

- cooperation between several space development agencies;
- cooperation with and involvement of operational agencies (e.g., in the ground segment and real time services);
- international commitment to the scientific aspects of the mission;
- involvement of the worldwide user community in the evaluation of the new capability in various geographical locations, based on the phased mission approach;

The IGeoLab concept was approved by the 5<sup>th</sup> Consultative Meeting on High-level Policy on Satellite Matters (CM-5), held in Geneva in January 2005.

## **2 The Geostationary Imaging Fourier Transform Spectrometer(GIFTS)**

In order to meet existing user requirements in NWP, nowcasting, hydrology and other applications areas, two test proposals that would be high priority and necessary enhancements to the GOS are considered for IGeoLab. The Geostationary Imaging Fourier Transform Spectrometer (GIFTS) is one of two systems. GIFTS offers the opportunity to establish a facility for investigating the dynamic processes of various surface and atmospheric phenomena associated with weather, climate, and chemistry processes affecting our environment. The societal benefits of IGeoLab will be realized through the international operational implementation of a GIFTS-like observational capability.

GIFTS could also become the first Global Observing System inter-calibration standard, functioning as a spectrally accurate transfer standard for all IR spacecraft flying in lower orbits. GIFTS was designed from its inception for calibration accuracy and stability. From its position in geostationary orbit, all the lower orbit satellites will underfly GIFTS at least twice per day; this allows GIFTS high spatial and spectral resolution measurements, taken at the same look angles, to be integrated to match the lower sensor's FOV and bandpass. GIFTS incorporates a thermally stabilized optical system which includes a system of three high emissivity blackbody calibration sources that is referenced to both US NIST and Russian VNIIOFI calibration standards. Using demonstrated techniques, GIFTS spectral radiometric accuracy could be verified and tracked to within the 0.1 K and  $10^{-6} \text{ cm}^{-1}$  standard required for climate data record certification throughout the GIFTS mission lifetime, pioneering a capability desired for the future GOS.

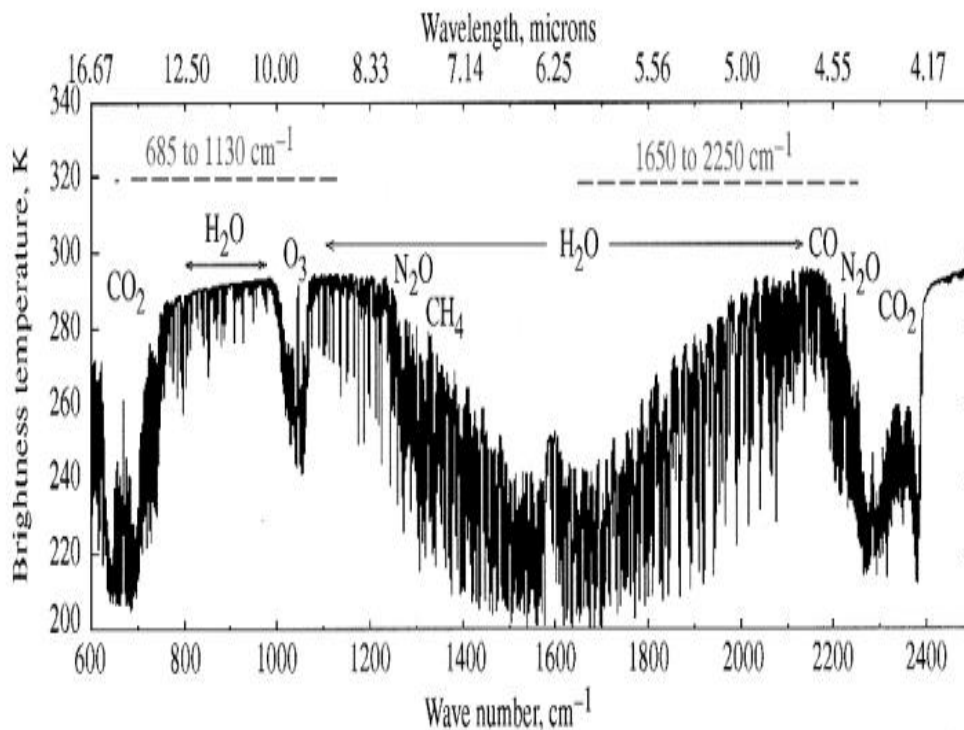
### **2.1 GIFTS instrument**

GIFTS combines a number of advanced technologies to observe atmospheric weather and chemistry variables in four dimensions. The GIFTS uses large area format focal plane area (LFPA) infrared (IR) detector arrays (128 x 128) in a Fourier Transform Spectrometer (FTS) mounted on a geosynchronous satellite to gather high spectral resolution ( $0.6 \text{ cm}^{-1}$ ) 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 visible light camera provides continuous imaging of clouds and the Earth's surface at 1-km spatial resolution over the 512 km field of regard of the GIFTS sensor. 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<sub>3</sub> and CO features observed in their spectral radiance signatures provide a measure of the transport of these pollutant and 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.

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.

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<sup>-1</sup> and 1650 to 2250 cm<sup>-1</sup>, to achieve a wide range of spectral resolutions (Figure 1).



**Figure 1.** Electromagnetic spectrum of the Earth's radiance to space showing the GIFTS 685-1130 cm<sup>-1</sup> and 1650 – 2250 cm<sup>-1</sup> infrared measurement bands.

For the geostationary satellite application, co-registration of the various spectral radiance measurements is critical for the observation of atmospheric dynamics, since one must achieve profile retrievals for every sensor footprint, regardless of the scene condition, in order to get time coherent imagery of atmospheric structure. The FTS (such as employed by the GIFTS) has a major advantage, over other instrumental

approaches to atmospheric sounding, since it uses the same detector element for observing most, if not all, of the radiances forming a spectrum, thereby optimizing the spectral continuity of the radiance measurements. As a consequence, the FTS is the preferred instrumental approach for obtaining the high spectral precision of radiance spectrum measurement needed for remotely sensing small-scale vertical features of the atmosphere.

## 2.2. GIFTS Data Products

GIFTS measurements will be used to determine temperature and moisture profiles from a geostationary satellite 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 vapour 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 vapour profiles. A similar feature-tracking approach is now used operationally with the international system of geostationary satellites by tracing water vapour features displayed in radiance imagery. These winds provide improved weather forecasts on both regional and global scales. However, the current geostationary satellite application only provides upper tropospheric winds from images of radiance for one or two water vapour channels. Furthermore, the utility of these water vapour radiance tracer winds is limited by the uncertainty of the height of the feature being tracked. More complete vertical profiles of wind velocity and correct height assignment of the wind vectors are needed to realize the full potential of satellite wind measurements to greatly improve both regional scale intense weather forecasts and global scale synoptic weather predictions. Figure 2 shows a comparison of the vertical resolution of retrieved GIFTS water vapour profile values compared to those of the GOES sounder, which possesses three broadband water vapour radiance channels. As can be seen, whereas the current GOES sounding instrument possesses a water vapour resolution of 3-5 km, the GIFTS possesses a water vapour profile vertical resolution of 1-2 km, depending upon level. The GIFTS will provide many more levels of horizontal wind velocity, with much improved height assignment accuracy, than can be provided by the current geostationary satellite systems.

The resulting difference in wind vector coverage expected for the GIFTS relative to that achievable from current geostationary satellites is shown in figure 3. The GIFTS wind vectors were achieved through the simulation of GIFTS radiances from atmospheric temperature and moisture fields produced by a

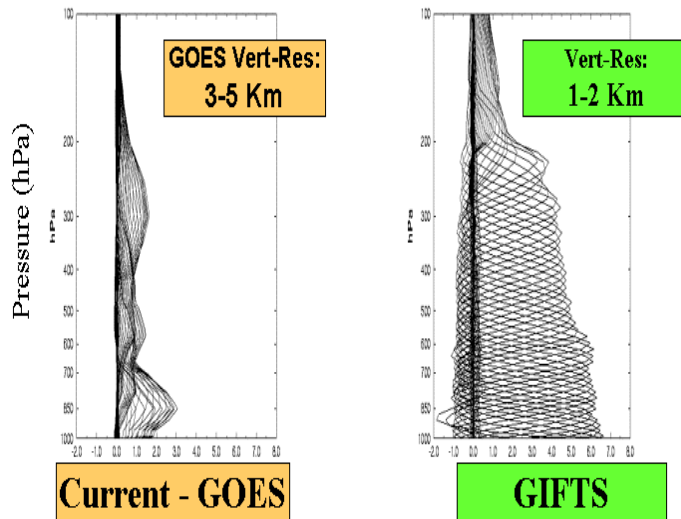
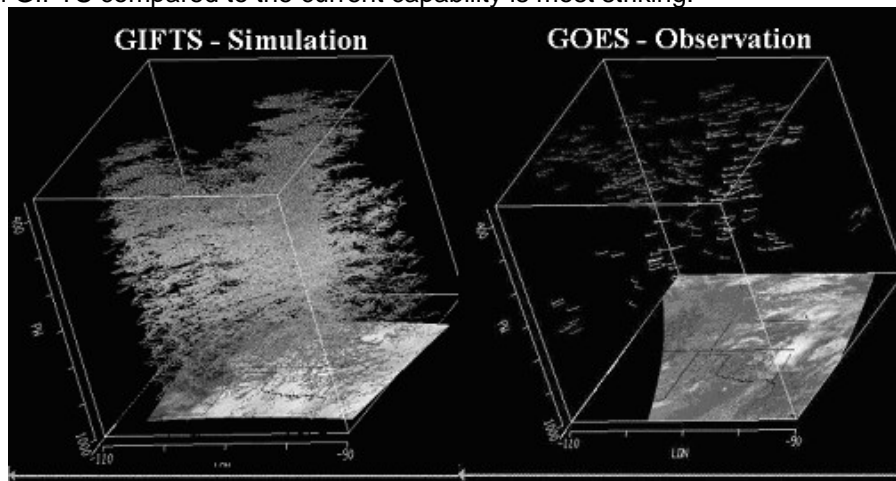


Figure 2. Water vapour vertical resolution functions for the GOES sounder and the GIFTS

mesoscale numerical model. For comparison, high-density winds produced from GOES cloud and water vapour radiance imagery are shown for this case. The difference in the detail of the circulation features resolvable with GIFTS compared to the current capability is most striking.



**Figure 3.** Comparison of wind density achievable with GIFTS and those from the current GOES.

Orbiting aboard IGeoLab, the GIFTS could be positioned at several locations about the globe to provide unique research data sets for studying weather and climate processes as well as providing experimental data sets needed to enable international weather centers to possess day one utility of next generation operational satellite hyper-spectral resolution imaging and sounding radiance measurements. Table A1 below identifies the potential weather and climate applications of the GIFTS on IGeoLab.

### **3 Report of the 1<sup>st</sup> meeting of the IGeoLab GIFTS Focus Group**

Following CM-5, the WMO Space Programme, with the help of two consultants (the two Principal Investigators for GIFTS and GOMAS, respectively) organized the first meetings of the two Focus Groups that were facilitated by NOAA/NESDIS in Washington DC, sequentially on 6 June and 7 June 2005. The first meeting of the IGeoLab Focus Group on GIFTS was held on 6 June 2005 in Washington DC,.

At the meeting, both NOAA and EUMETSAT had identified strong support for the IGeoLab GIFTS mission as risk reduction for the GOES-R and Meteosat Third Generation (MTG) missions.

The GIFTS Engineering Demonstration Unit (EDU) is available for space qualification after May 2006, when NASA is finished with its use for GOES-R technology risk reduction. However, a considerable amount of funding (estimates vary from less than US\$30 million to US\$75 million, depending on the specific approach taken) is required for the space qualification of the GIFTS instrument, particularly for the development of the spacecraft/instrument Control Module Interface. Thus, innovative alternative internationally shared approaches to the space qualification need to be considered in order to lower the actual cost of the space qualification to any one nation. One approach suggested, although not evaluated further, involved the development of a space qualified control module by an international partner who would seek to advance its internal capabilities for producing space instruments.

The Russian Elektro-L satellite is the prime candidate as a space vehicle to conduct the IGeoLab GIFTS mission. It would be the second flight unit, Elektro-L N2, recently approved for launch in 2009, to be positioned at either 76 or 15 degrees East. A 2009 launch of GIFTS on Elektro-L would provide several years of experience with geostationary satellite hyperspectral sounding observations prior to the launch of the GOES-R and Meteosat Third Generation satellites. Additionally, if the launch of an IGeoLab GIFTS mission were to be delayed beyond 2009, it would still be valuable to put GIFTS in orbit since it would

most likely be placed in a geographical position that would complement the GOES-R and MTG for providing global wind profile data in support of the Global Earth Observation System of Systems (GEOSS).

IGeoLab GIFTS project achieved considerable progress at the 1<sup>st</sup> Focus Group meeting. Specifically, the importance of a GIFTS space mission for the development of the next generation satellite component of the WMO World Weather Watch Global Observing System, particularly in the context of the GEOSS, was reaffirmed by all space agency participants. Moreover, considerable progress has been made in the GIFTS instrument completion, with ground tests of the instrument soon to be underway to demonstrate the radiometric measurement capabilities of this revolutionary remote sensing technology.

#### **4 Summary**

GIFTS instrument utilizes advanced sensor, processor, and communications technologies to provide a revolutionary improvement in capability for observing the Earth's surface and atmosphere from geostationary orbit. GIFTS will provide 80,000 relatively high vertical resolution (1-2 km) atmospheric soundings of temperature and water vapour, with 4 km ground spacing, every minute. The time sequence of the three dimensional images of water vapour will enable derivation of altitude resolved wind velocities that are sorely needed for improved global weather prediction. The GIFTS high temporal resolution temperature, water vapour, and wind profile data is expected to improve severe convective weather forecasts and tropical storm motion and landfall predictions. The ability of GIFTS to observe water vapour dynamics is key to gaining a better understanding of the global water cycle and improving our understanding of climate, as well as short-term weather processes.

The first hyper-spectral imaging spectrometer designed for atmospheric sounding, GIFTS, could be orbited aboard an International Geostationary satellite Laboratory (IGeoLab) to usher in a new era of high space and time resolution measurements of the atmosphere. The technology and measurement concept to be demonstrated during the GIFTS will serve speed the development and reduce the time required to benefit from the next generation international system of operational geostationary satellites. Once implemented, the GIFTS-like measurements will lead to revolutionary improvements in our ability to understand and forecast weather, pollution, and climate.

#### **Reference**

- 1 International Geostationary Laboratory Task Force Meeting final report, 2004, Geneva
- 2 The sixth Consultative Meetings On High-Level Policy On Satellite Matters, final report, 2006, Buenos Aires, Argentina