Advanced Geostationary Sounders

Imaging Spectrometer:

**Horizontal:** Large area format Focal Plane detector Arrays

**Vertical:** Fourier Transform Spectrometer

**Time:** Geostationary Satellite
Geostationary Atmospheric Sounder Evolution

Nimbus 3 & 4
IRIS/SIRS
(1969-1972)

Nimbus 5/ITPR
ITOS/VTPR
Nimbus 6/NOAA HIRS
GOES/VAS & HIRS
(1972-2010)

High Resolution
Interferometer Sounder (HIS)
(1985-)

GOES-HIS (GHIS)
Replaced Filter Wheel with FTS
(1996)

First Satellite
Sounder Spectrometers
High Horizontal
Resolution
Adv. Geo-Sounder
A/C Demonstrator
Lab. Demonstration of Concept

NAST-I / SHIS
(1998 -)

GIFTS-EDU (2006)

METOP-IASI
(2006) [LEO]

GIFTS?
MTG-IRS, others

Aircraft 3-d
FTS Sounding Demonstration
1st Groundbased
4-d Imaging FTS Demonstration
1st Operational Satellite 3-d FTS Sounder
Geostationary 4-d Imaging FTS Sounder
Satellite Ultra-spectral Sounders

Water vapor weighting function

Temperature weighting function

Water vapor weighting function
Importance of Geo-Imaging FTS

**Improved Weather Forecasting**
- Convective Storms/Tornadoes
- Hurricane Landfall Location and Time
- Global Numerical Weather Prediction (Temperature, Water Vapor & Wind Profiles)

**Atmospheric Gas Transport**
- Pollutant Gases (CO & O₃)
- Greenhouse Gases (H₂O, CO₂, O₃, CH₄)

**Monitor Climate Dynamics**
- Cloud Properties (Height, Particle Size, Optical Depth)
- El Nino / La Nina (Ocean Temp & Winds)

Geostationary Imaging FTS measurement capability is key to improving the quality and timeliness of forecasts for severe weather, pollution, global weather, and climate.
Observation of Atmospheric Dynamics

Three Dimensional Moisture Flux & Wind Observations

4-d Water Vapor Imaging Geo-FTS

3-d Wind Vector Distribution

Atmospheric Thermodynamic Stability Change

X Sounding

Thermodynamic Stability (LI)

Atmospheric Sounding Dynamics (LI)
High Vertical Resolution Sounding Concept

High spectral resolution and broad spectral coverage enables high system S/N for providing accurate de-convolution of vertically smeared thermal radiance signals.

High Vertical Resolution Provided by Ultraspectral Resolution Radiance Spectra

• Spectrum
  Several thousand spectral channels are observed to profile the atmosphere with high vertical resolution.
PC Statistical Retrieval

Initial Profile PC Regression Retrieval:

\( a(T, Rh) = G(A, R) \, r(T, Rh, T_s, \varepsilon_s, \text{gases},,) \)
- \( a \) is a vector of atmospheric state pc scores
- \( G(A, R) \) is a regression matrix relating atmospheric profiles (A) to LBLRTM calculated IASI radiance spectra (R) for a statistically representative set of surface and atmospheric profile conditions
- \( r \) is a vector of radiance pc scores

\( R = R^* T r_v \)
- \( R^* \) is a matrix of radiance spectra PCs, \( R^{*T} \) being the transpose of \( R^* \)
- \( r_v \) is a vector of radiances (i.e., an individual radiance spectrum)

\( T/Rh = a(T, Rh) \, A^* \)
- \( T/Rh \) is a vector of the temperature (T) and humidity (Rh) profile values, plus sfc T, sfc emissivity PC scores, etc.
- \( A^* \) is a matrix of atmospheric state PCs

LBLRTM IASI simulated radiance and atmospheric statistics defined from statistical sample of radiosondes *10 randomly selected surface temperature/emissivity conditions per radiosonde sounding
Given: $R = R^* r_v$

The Physical Solution is:

$$a_{n+1} = a_0 + (K_n^{T} S_{\epsilon(R)}^{-1} K_n + \lambda S_a^{-1})^{-1} K_n^{T} S_{\epsilon(R)}^{-1} [R_m - R(a_n) + K_n(a_n - a_0)]$$

Where:

- $S_{\epsilon(R)} = R^* T E(r_v)$
- $S_a = A^* T S(R, Rh)$ (with T/Rh covariances set = 0)
- $K_n = [\delta R(a)/\delta a]_n$
- $\lambda =$ Lagrangian multiplier

**Two step physical retrieval:**

1. solve for an improved relative humidity profile, assuming all the temperature profile PC score Jacobians are zero (i.e. temperature fixed to initial regression solution)
2. simultaneous solution for the final T and Rh PC scores.

- LBLRTM used for background radiance and Jacobian calculation
- ~ 4000 spectral channels (0.5 cm$^{-1}$ spacing)
- No Bias Correction
Radiance Residual Mean and Standard Deviation (96 Retrievals)

IASI Mean Radiance

Residual, Bias

Residual, SE
**IASI Retrievals at CART site (19 April, 2007, 03:30 UTC)**

Variational Solution (EOF regression guess) using LBLRTM w/o Bias Correction.

The diagram shows the comparison of temperature (T) and relative humidity (RH) profiles over different times (2:35 UT and 3:35 UT) with IASI retrievals at 03:30 UT. The graphs indicate that the variational solution resolves inversions in the data, as marked by the text "Resolves Inversions."
Imaging Ultra-spectral FTS Vs Multi-spectral IR

Simulate ABI/MSG via Spectral Convolution of IASI
Geostationary Imaging Fourier Transform Spectrometer

Ultraspectral Instrument for Atmospheric Temperature, Moisture, Chemistry, & Winds

Provides ~ 80,000 Atmospheric Soundings every minute

The opportunity for greatly improved environmental forecasts

“GIFTS”

4-d Digital Camera:

Horizontal: Large area format Focal Plane detector Arrays

Vertical: Fourier Transform Spectrometer

Time: Geostationary Satellite
IASI Demonstrates Ultraspectral Capability to Observe 3-D H₂O Structure
(US on April 29, 2007)
• 1999: GIFTS was selected from a competitive process for the NASA New Millennium Program (NMP) Earth Observing 3 (EO-3) mission.
  - GIFTS had significant programmatic risk related to technology development and to securing a geosynchronous spacecraft with limited funding. NASA partnered with the U.S. Navy to secure spacecraft.

• 2004: The GIFTS flight project was terminated as a result of a Navy budget shortfall and changing priorities.

• 2006: The GIFTS was completed as an EDU and successfully tested by upward viewing of the sky and the moon.
GIFTS T-V Tests Show That HES LW Band Measurements With Required S/N & High Operability Are Achievable

GIFTS Single Sample Spectrally Random Noise

EDU Threshold

Cold Test 2

EDU Goal

Cold Test 3

Significance:
- Can achieve IASI-like radiometric performance for 4 km spatial footprints covering 500x500 km field every 12 seconds.
- Coverage about 40 x faster than GOES, 5-6 times faster at full spectral resolution, all with spatial footprints that are 4 times smaller in area and contiguous.

<table>
<thead>
<tr>
<th>Pixels with responsivity in range 80%-120% of mean</th>
<th>98.2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels with noise less than 3X mean noise</td>
<td>96.3%</td>
</tr>
<tr>
<td>Active pixels (those that meet both responsivity &amp; noise criteria)</td>
<td>95.9%</td>
</tr>
</tbody>
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GIFTS and AERI Viewing Sky

GIFTS

AERI

45° External Scene Mirror
Interferogram Scan Movie

DC output of the LW detector array during one $>10^9$ sample (66,276 point/pixel) interferogram scan (11 sec)

Movie made from a sequence of every 50th Frame (1325 frames)

← 135 meters @ 10 km altitude →
Moon viewing/tracking demonstrates the GIFTS imaging spectrometer capability. Lunar and sky measurements are obtained with the GIFTS visible and two infrared spectral bands. Data recorded at 05:50 MST on 11 September 2006 in Logan, Utah.
GIFTS Vs AERI
(Logan UT, Sept. 13, 2006)
GIFTS Vs Radiosonde (Logan UT, Sept. 13, 2006)
Temperature & Humidity Images
September 13, 2006 (10 min. interval: 5 AM – 2 PM)
GIFTS—A Technical Success

• All technologies successfully integrated to create a revolutionary Geostationary Satellite Imaging Spectrometer, fully tested and characterized in a space (T/V) chamber

• Accurate radiometric data demonstrated through direct comparisons with AERI

• High resolution temperature and moisture sounding capability demonstrated through ground-based sky viewing measurements
• IR Imaging FTS Technology is now proven

• The ability to achieve the Geo science measurement objectives have been demonstrated with IASI

• Advanced geostationary sounding capability will greatly improve severe weather forecasts, thereby saving lives and property, as well as provide data useful for improving extended range, air quality, and climate predictions.

• It's time to get this proven technology and revolutionary measurement capability into orbit ASAP!