IR Imaging Sounders for Geosynchronous Orbit:
A key capability for future multi-national observing systems

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AMS Annual Meeting
Meteorological and Environmental Satellite Observing Systems:
From 50 Years Ago to 15 Years Ahead
Atlanta, Georgia, 19 January 2010
Operational Weather Satellites

**ROLE**

- Global NWP
- Mesoscale
- Severe Wx

**APPROACH**

- POES
- GOES
- GPS
- Imager
- Sounder
- Limb
- Lidar
- Radar
- GPS

GOES

- Sounder
  - = ¼ Wx Sat. role
- Imager
  - = ½ Severe Wx Sat. role

Not just one in a long list!
IR Imaging Sounder

Topics

1. Chronology: 50 years ago to 15 years ahead

2. Observing System Simulation Experiment (OSSE) shows hours of improved lead time for developing severe storms

3. Advanced GOES IR Sounder capabilities, status, and Technological Readiness
GEO Sounder

- GOES-Sounder
  - 3-Axis SC /Filter Rad
- VAS
  - Spinning SC /Filter Rad / NASA-NOAA Demonstration
- GOES-MOD
  - Spectrometer to replace filters
- GIFTS/HES Spectrometer
- US Advanced Sounder ???
- Started by Verner Suomi

Timeline:
- '60: GOES-Sounder
- '70: VAS
- '80: GOES-MOD
- '90: GIFTS/HES Spectrometer
- '00: US Advanced Sounder
- '10: GOES-R Launch
- '20: HIS Adv Sounder demo
- '30: Plus 15 yrs

Note: The timeline is not to scale and serves as a visual representation of events.
GEO Sounder

- GOES-R Launch
- NOAA S/C, NASA Instrument
- Sounder Demo
- GOES-MOD
- Spectrometer to replace filters
- GOES Sounder
- 3-Axis SC/Filter Rad
- VAS
- Spinning SC/Filter Rad/ NASA-NOAA Demonstration
- HIS Adv Sounder demo
- Plus 15 yrs
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GEO Sounder

- GOES-R Launch
- NOAA S/C, NASA Instrument
- Sounder Demo
- GOES-MOD
- GOES Sounder
- 3-Axis SC /Filter Rad
- VAS
- ATS Imagers
- Spinning SC /Filter Rad/ NASA-NOAA Demonstration
- HIS Adv Sounder demo
- Plus 15 yrs

Started by Verner Suomi

There is still time! but immediate action is required
NRC Decadal Survey: Sounder is needed
The Forgotten Recommendation

“Recommendation: NOAA should restore several key climate, environmental, and weather observation capabilities to its planned NPOESS and GOES-R missions; namely:”
(followed by 4 bullets)

4th bullet: “Develop a strategy to restore the previously planned capability to make high-temporal- and high-vertical-resolution measurements of temperature and water vapor from geosynchronous orbit.”

“the committee recommends consideration of the following approaches:

- Working with NASA, complete the GIFTS instrument, deliver it to orbit via a cost-effective launch and spacecraft opportunity, and evaluate its potential to be a prototype for the HES instrument, and/or

- Extend the HES study contracts focusing on cost-effective approaches to achieving essential sounding capabilities to be flown in the GOES-R time frame.”

from Executive Summary, p 5-6, 4 October 2007
Advanced GOES Sounder Development fits with Congressional view of NOAA & NASA Roles

2008 NASA Authorization Act

◆ SEC. 204. TRANSITIONING EXPERIMENTAL RESEARCH INTO OPERATIONAL SERVICES.
  – It is the sense of the Congress that experimental NASA sensors and missions that have the potential to benefit society if transitioned into operational monitoring systems be transitioned into operational status whenever possible.

◆ SEC. 203. DECADAL SURVEY MISSIONS.
  [Advanced GEO Sounder is the forgotten Recommendation!]

◆ SEC. 208. TORNADOES AND OTHER SEvere STORMS.
  – The Administrator shall ensure that NASA gives high priority to … cooperative activities with NOAA …, with the goal of improving the Nation's ability to predict tornados and other severe storms.

(H.R.6063 became law on 15 October 2008)
Summary of Support

- **Best of the past:** Father of Satellite Meteorology, Verner E. Suomi
- **Best of the present:** National Research Council, Decadal Survey
- **Congress:** 2008 NASA Authorization Act
- **NWS Forecast Offices***:
  - Jeff Craven, SOO, Milwaukee; looks to sounder for “Warn on Forecast”
  - Jack Beven, Nat. Hurricane Ctr, Lead Forecaster; NHC could significantly benefit from an advanced sounder on the GOES-R satellite series

* From GOES User Conference Townhall, 4 November 2009
2. Observing System Simulation Expt (OSSE) showing hours of improved lead time for developing severe storms

A unique capability of the advanced GOES sounder
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1200 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1200 UTC
Lifted index [°C]

Red = extreme instability

Simulated Radar

06-12-2002, 1200 UTC
Radar reflectivity [dBZ]

ABI/GOES Sounder like

Jun Li, Jinlong Li, Jason Otkin, and Tim Schmit
Based on detailed WRF model run produced as proxy data for GOES-R imager (ABI)

12-13 June 2002 IHOP experiment, Oklahoma

2 km model grid

Realistic clouds verified with measurement comparisons

Jun Li, Jinlong Li, Jason Otkin, and Tim Schmit
OSSE of GEO advanced IR sounder for storm Nearcasting

Extreme instability indicated

1300 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1400 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1400 UTC
Lifted index [°C]

Simulated Radar

1400 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1500 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1500 UTC
Lifted index [°C]

Simulated Radar
06-12-2002, 1500 UTC
Radar reflectivity [dBZ]

ABI/GOES Sounder like
06-12-2002, 1500 UTC
Lifted index [°C]

1500 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

**True**
06-12-2002, 1600 UTC
Lifted index [°C]

**GIFTS/HES/IRS**
06-12-2002, 1600 UTC
Lifted index [°C]

**Simulated Radar**
06-12-2002, 1600 UTC
Radar reflectivity [dBZ]

**ABI/GOES Sounder like**
06-12-2002, 1600 UTC
Lifted index [°C]

1600 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1700 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1700 UTC
Lifted index [°C]

Simulated Radar

ABI/GOES Sounder like

Start to see extreme instability 1700 UTC 4 hours later
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1800 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1800 UTC
Lifted index [°C]

06-12-2002, 1800 UTC
Radar reflectivity [dBZ]

Simulated Radar

ABI/GOES Sounder like

Extreme instability clearly shown 1800 UTC 5 hours later, but note false alarms
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 1900 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 1900 UTC
Lifted index [°C]

Simulated Radar

ABI/GOES Sounder like

1900 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 2000 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 2000 UTC
Lifted index [°C]

Simulated Radar

ABI/GOES Sounder like

2000 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

True
06-12-2002, 2100 UTC
Lifted index [°C]

GIFTS/HES/IRS
06-12-2002, 2100 UTC
Lifted index [°C]

Simulated Radar
06-12-2002, 2100 UTC
Radar reflectivity [dBZ]

ABI/GOES Sounder like
06-12-2002, 2100 UTC
Lifted index [°C]

Rain line shows in radar 8 hours later 2100 UTC
OSSE of GEO advanced IR sounder for storm Nearcasting

GIFTS/HES/IRS provides needed instability and warning information hours earlier than current GOES Sounder (+4-5 hrs) and Radar (+8 hrs)
New Nearcasting Approach Demonstrates Power of Sounder

5-hour Nearcast for 2000 UTC using Equivalent Potential Temperature (Theta-E)

Strong, localized low-level Theta-E gradients seen by HES, not ABI
(enhanced vertical resolution gives HES much higher sensitivity to low level moisture)

Vertical Theta-E Differences (500-800 mb) indicate where instability
(large negative) supports severe deep convection
Using the GOES-12 Sounder to Nearcast Severe Weather

Robert Aune (NESDIS) and Ralph Petersen (CIMSS)

The CIMSS Near-casting Model uses hourly GOES Sounder retrievals of layered precipitable water (PW) and equivalent potential temperature (Theta-E) to predict severe weather outbreaks up to 6 hours in advance!

Hourly, multi-layered observations from the GOES Sounder are projected forward in time along Lagrangian trajectories forced by gradient winds. “Trajectory observations” from the previous six hours are retained in the analysis. Destabilization is indicated when theta-E decreases with height.

Limitations:
- Sounder channels support only two layers for near-casting
- Only useful for elevated convection – Sounder can’t detect low-level moisture
- Frequent false alarms – Sounder can’t detect inversions

One Example of a Successful Near-cast

Low-level Theta-E NearCast shows warm moist air band moving into far NW Iowa by 2100 UTC.

Vertical Theta-E Differences predict strong convective instability by 2100 UTC.

Severe thunderstorms occurs as predicted!

6-hour NearCast for 2100 UTC
Low level Theta-E

6-hour NearCast for 2100 UTC
Low to Mid level Theta-E Differences

Rapid Development of Convection over NW Iowa between 2000 and 2100 UTC 9 July 2009
GEO IR Imaging Sounder capability is unique

- **Polar Sounders:**
  Inadequate temporal coverage

- **GPS:** Inadequate spatial resolution and temporal coverage

- **Current GEO Sounder:**
  Vertical resolution 2-3 times lower

- **ABI Imager:**
  Inadequate vertical resolution

- **GEO Microwave:**
  Vertical resolution 2-3 times lower
3. Advanced GOES IR Sounder Capabilities, Status & Technological Readiness
Spectral Coverage of GIFTS/IRS/HES*
Compared to IASI, CrIS, AIRS, S-HIS & NAST-I

Advanced GEO Sounders

*HES option
Advanced Sounder Capabilities
(GIFTS example)

- **Spectral Coverage & resolution:**
  broad contiguous coverage,
  resolving power >1000

- **Vertical Resolution:** increased by x 3

- **Horizontal Image Sampling:**
  increased from 10 km to 4-5 km

- **Temporal Sampling Rate:**
  increased by x 5.5 at full spectral resolution

*Factor of 100 improvement in spatial/temporal detail*
Current Sounder Information Volume

Current GOES Sounder

Temporal

Vertical

Horizontal

Current GOES Sounder
Advanced Sounder (GIFTS example)

This is where the extra 4-5 hours come from
It is going to happen in Europe!

EUMETSAT/ESA plan for advanced IR Sounder (IRS) to fly on Meteosat 3rd Generation (MTG) in 2017

Artist Impression, Phase A

Joe Schmetz, Goes Users Conference, 4 Nov 2009
China has an Advanced Sounder Plan too!

Next Generation of GEO satellite FY-4

4 main instruments

Interferometric Infrared Sounder

Multiple Channel Scanning Imager

Lightning Mapper

Solar X-EUV imaging telescope (not available on 1st satellite)

Prototype structure of FY-4A

Jun Yang, GOES Users Conference, 4 Nov 2009
Other GEO IR Sounders: Status

- Japan is considering implementation following GOSAT Success
- India is flying the 1st non-US filter-based sounder on INSAT-3D early 2010
- In the US, GOES-R is proceeding without a sounder, in spite of strong endorsements, and technological demonstrations of low risk approaches
  - GIFTS: NASA Engineering Demonstration Unit was successfully tested in 2006, showing readiness to proceed with a demonstration mission
  - HES: NOAA funded efforts by BAE, Ball, and ITT yielded other mature designs for the Sounder that have been assessed as low risk
GIFTS Proof of Concept was successfully demonstrated in 2006 with the Engineering Development Unit Thermal/Vacuum & Sky Viewing Tests (expected long-poles are working well: LW detector with good sensitivity and operability, Long-lived stable laser, mechanical cooler and cryogenic thermal design, imaging FTS radiometric integrity, plus many others)

Results Demonstrate that NOAA Requirements for a Successful GOES Imaging Spectrometer are achievable with a GIFTS Flight Model (spatial coverage and resolution, spectral coverage, spectral calibration and Instrument line shape knowledge, and spectral scale standardization)
Cold Test 3, LW Random (spectrally uncorrelated) Noise

Meets goal for total NESR at all but the longest wavelength end of the band

- Count Noise computed from STDDEV of real part of complex spectra in out-of-band region (4000-4500 cm\(^{-1}\)) (~279 counts) and then divided by the magnitude responsivity to get random (spectrally uncorrelated) NESR:
LWIR Cold Test 3 Active Pixel Inventory Radiometer Mode

LWIR FPA Statistics

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vignetted pixels excluded from statistics</td>
<td>768</td>
</tr>
<tr>
<td>Pixels with responsivity in range 30%-120% of mean</td>
<td>98.2%</td>
</tr>
<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>
</table>

Pixel (70,72) shown on later slides for responsivity and NESR

Very Good (96%) Operability
Cold Test 3, Interferometer Modulation Efficiency

- Modulation Efficiency = \( \frac{c-d}{a-b} \) = 72.6% LW, 78.9% SW

Approach gives lower bound: wavenumber-dependent phase variations are not accounted for.

Demonstrates proper functioning of interferometer
**GIFTS EDU Measured Instrument Line Shapes are Essentially an Ideal Sinc Function**

**CO\textsubscript{2} Laser Input Line Source**

Spectral file lwp_ILS00010_00.h5
Factor of 32 interpolation

**Excellent Line Shape Confirmation**
Gas Cell: CO$_2$ Transmission
(Preliminary comparison of GIFTS and Model)

Very good agreement
708-792 cm\(^{-1}\), 15 micron CO\(_2\) band
Lunar Views Demonstrate GIFTS Imaging Capability

Results from a single interferometer scan of the moon, viewed in the visible, mid-wave IR, and long-wave IR. Also, the spectral intensities of two selected pixels from the IR images, one viewing the moon, the other the clear sky background.
Summary

- The advanced GEO sounder concept represents a dramatic new capability to provide longer lead times for severe weather.

- Implementation is proceeding in Europe and Asia (and International agreements call for sounders on all GEOs).

- US has proven technological capability.


- **GEO Research Platform Strongly Recommended** for Sounder Demonstration & other pioneering Decadal Survey missions—NASA/NOAA Partnership.