GEOSTATIONARY SOUN丁ING:

Current and Future GOES Sounders

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  - The authors thank Jeanine Murphy/NASA GSFC for granting us permission to use her paper presented in 1996 as a starting point for this paper.
  - The CrIS EDR Algorithm developed by AER, Inc. was used to compare the current sounder product to the predicted ABS product.
  - Further information can be found on the Internet. Go to the home page of the GOES Project Scientist, Dr. Dennis Chesters, [http://rsd.gsfc.nasa.gov/goes/](http://rsd.gsfc.nasa.gov/goes/) and information from the University of Wisconsin at [http://cimss.ssec.wisc.edu/goes/](http://cimss.ssec.wisc.edu/goes/).

• **REFERENCES**
  - Preliminary Design Review for GHIS Engineering Model, August 1997
“Long & Winding Road” topics for today:

• **Current:** GOES-NOPQ Sounder

• **Shelved design:** GOES High-resolution Interferometric Sounder (GHIS)

• **Future:** Advanced Baseline Sounder (ABS)

• ABS Modeled Performance
GOES-NOPQ Sounder Overview
GOES-NOPQ Sounder
Instrument Modules

Electronics Module
(E-box)

Sensor Module

Power Supply Module

Modules Not Shown To Scale
GOES-NOPQ Spacecraft

+Z (EARTH)

+SOUNDER OPTICAL PORT

+X (EAST)

+Y (SOUTH)
GOES-NOPQ Sounder
Sensor Module

- RADIANT COOLER
- SUN SHIELDS
- PATCH
- FILTER WHEEL COOLER
- FILTER WHEEL ASSY
- TELESCOPE ASSY
- SCAN MIRROR

ITSC - 12 Conference
## GOES-NOPQ Sounder Spectral Characteristics

<table>
<thead>
<tr>
<th>Channel</th>
<th>Central Wavelength (cm(^{-1}))</th>
<th>Central Wavelength (µm)</th>
<th>Half-Power Bandwidth (cm(^{-1}))</th>
<th>Specified NE(_{\text{DN}}) (mW/(m(^2)sr/cm(^{-1})))</th>
<th>Meteorological Parameter Determined</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>680</td>
<td>14.71</td>
<td>13</td>
<td>1.43</td>
<td>Stratosphere temperature</td>
</tr>
<tr>
<td>2</td>
<td>696</td>
<td>14.37</td>
<td>13</td>
<td>1.43</td>
<td>Tropopause temperature</td>
</tr>
<tr>
<td>3</td>
<td>711</td>
<td>14.06</td>
<td>13</td>
<td>0.69</td>
<td>Upper-level temperature</td>
</tr>
<tr>
<td>4</td>
<td>733</td>
<td>13.64</td>
<td>16</td>
<td>0.69</td>
<td>Mid-level temperature</td>
</tr>
<tr>
<td>5</td>
<td>748</td>
<td>13.37</td>
<td>16</td>
<td>0.57</td>
<td>Low-level temperature</td>
</tr>
<tr>
<td>6</td>
<td>790</td>
<td>12.66</td>
<td>30</td>
<td>0.28</td>
<td>Total precipitable water</td>
</tr>
<tr>
<td>7</td>
<td>832</td>
<td>12.02</td>
<td>50</td>
<td>0.23</td>
<td>Surface temp, moisture</td>
</tr>
<tr>
<td>8</td>
<td>907</td>
<td>11.03</td>
<td>50</td>
<td>0.16</td>
<td>Surface temperature</td>
</tr>
<tr>
<td>9</td>
<td>1030</td>
<td>9.709</td>
<td>25</td>
<td>0.33</td>
<td>Total ozone</td>
</tr>
<tr>
<td>10</td>
<td>1345</td>
<td>7.435</td>
<td>55</td>
<td>0.16</td>
<td>Low-level moisture</td>
</tr>
<tr>
<td>11</td>
<td>1425</td>
<td>7.018</td>
<td>80</td>
<td>0.12</td>
<td>Mid-level moisture</td>
</tr>
<tr>
<td>12</td>
<td>1535</td>
<td>6.515</td>
<td>60</td>
<td>0.15</td>
<td>Upper-level moisture</td>
</tr>
<tr>
<td>13</td>
<td>2188</td>
<td>4.570</td>
<td>23</td>
<td>0.013</td>
<td>Low-level temperature</td>
</tr>
<tr>
<td>14</td>
<td>2210</td>
<td>4.525</td>
<td>23</td>
<td>0.013</td>
<td>Mid-level temperature</td>
</tr>
<tr>
<td>15</td>
<td>2245</td>
<td>4.454</td>
<td>23</td>
<td>0.013</td>
<td>Upper-level temperature</td>
</tr>
<tr>
<td>16</td>
<td>2420</td>
<td>4.132</td>
<td>40</td>
<td>0.0080</td>
<td>Boundary layer temperature</td>
</tr>
<tr>
<td>17</td>
<td>2513</td>
<td>3.979</td>
<td>40</td>
<td>0.0082</td>
<td>Surface temperature</td>
</tr>
<tr>
<td>18</td>
<td>2671</td>
<td>3.744</td>
<td>100</td>
<td>0.0036</td>
<td>Surface temperature, moisture</td>
</tr>
<tr>
<td>19</td>
<td>14367</td>
<td>0.696</td>
<td>1000</td>
<td>0.05%Albedo</td>
<td>Cloud cover</td>
</tr>
</tbody>
</table>
GOES-NOPQ Sounder
Optical Elements

D1 = DICHLROIC BEAMSPILLTER, VIS/IR
D2 = DICHLROIC BEAMSPILLTER, LW/(SW + MW)
D3 = DICHLROIC BEAMSPILLTER, SW/MW
L1-L6 = INTERMEDIATE LENSES
M = FOLDING MIRROR (MIDWAVE)
D4 = STAR/VIS TRICHLROIC BEAMSPILLTER
W1, W2, W3 = FILTER WHEEL WINDOWS
F1 = VISIBLE FILTER
F2 = STAR SENSING FILTER
P = DEPOLARIZING WINDOW
LS = LYOT STOP
GOES-NOPQ Sounder
Filter Wheel and Channel Separation

Detectors:
- Four Detectors per channel (IR & Visible)
- Each detector has 8.7 km (242.6 µrad) IGFOV (max)
- Neighboring detectors on 10 km (280 µrad) centers

Filter Wheel
- Rotating wheel inserts selected filters into the optical path
- Wheel rotation is synchronized with stepping motion of the scan mirror (10 steps/sec)
- Rotation speed is 600 rpm
GOES-NOPQ Sounder
On-orbit Calibration

• IR Channels
  – Internal Calibration Target
    – 4 second view of the internal blackbody every 20 minutes establishes a high temperature baseline for calibration in orbit
  – Space Looks
    – 4 second view of space every 2 minutes for reference
  – Electronic Calibration
    – Amplifiers and data stream are checked by an electronic staircase signal during each blackbody cycle.
GOES High-resolution Interferometric Sounder (GHIS)

-- Engineering Model PDR in 1997 --
GHIS -- in 1997

Key Mission Requirement:

Achieve < 1.0°K temperature retrieval accuracy with < 1 km vertical resolution

Completed Objectives:

• Develop preliminary design for Flight Model EDU
• Detailed design for Engineering Model
• Address key technical risks through technology demonstrations and simulations

In May, 1997, notice was received to terminate the GHIS program due to insufficient out-year funding to support Flight Model development
The ITT GHIS Program Demonstrated the Feasibility of ABS by Adding an Interferometer to the GOES Sounder

GHIS Study Was Funded By the GOES Program Office in 1995-1997

GHIS Reached PDR and Demonstrated a Prototype (w/1,336 channel capability) in the GOES SN02 Sounder
GHIS Activities / Milestones

**Requirements Definition**
- Reqs. Defin.
- SRR
- Concept Design
- SDR
- FM Preliminary Design
- PDR
- SDR
- EM Preliminary Design
- PDR

**Tech Demos for Risk Reduction**
- Detector Tests
- EMI Tests
- Porch Swing Tests
- Laser Diode Procurement and Characterization
- DAPS Upgrades (Porch Swing, Diodes, Neon)
- Interferometer Simulations
- Wavelength Calibration
- DAPS Upgrade Hardware
- Key Component Accelerated Life Tests
- Vibration Tests
- Electronics Breadboards

**ITT IR&D**
- Laser Diode Procurement and Characterization
- DAPS Upgrades (Porch Swing, Diodes, Neon)

**MIT/LL Tests**
- Test Planning
- Test Preps
- TRR
- Test Operations
- Data Analysis

**ITSC - 12 Conference**
ITT Successfully Installed an MIT/LL-Built Prototype of the GHIS Interferometer in the SN02 Sounder

MIT/LL Interferometer in Subsystem Test Fixture

Interferometer Installed and Operating in GOES SN02 Sounder
MIT/LL Interferometer Tests in SN02 Were Successfully Completed

SN02 Interferometer Test Results:

- Operation of an interferometer in the GOES Sounder was clearly demonstrated
- Alignment process went smoothly, with the help of an interface matching plate
- Control and signal processing system worked well
- Integrated test objectives were satisfied
Benefits & Status of GHIS

• Advanced IR Sounder developments have benefited from Synergy between GHIS technologies and NPOESS CrIS instrument requirements

• GHIS Program Restart is a Viable Option at ITT A/CD
  – Personnel remain available for possible program restart
  – Interferometer skills base has been retained and applied to NPOESS / CrIS
  – Synergy with CrIS development and operational applications of new technologies could significantly reduce GHIS non-recurring costs
  – a GEO hyperspectral sounder is still possible within the next 5 years rather than after another 10 years
Advanced Baseline Sounder (ABS)
# ABS Sounding Performance
(Accuracies and Vertical Resolution in Clear Air)

<table>
<thead>
<tr>
<th>Altitude Range</th>
<th>Observational Accuracy</th>
<th>Vertical Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>THRESHOLD</td>
<td>GOAL</td>
</tr>
<tr>
<td>Surface – 300 hPa</td>
<td>± 1.0 K</td>
<td>± 5%</td>
</tr>
<tr>
<td></td>
<td>± 0.5 K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>± 10%</td>
<td>Surface – 500 hPa</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3 – 0.5 km layers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 – 300 hPa;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 – 2 km layers</td>
</tr>
<tr>
<td>300 hPa – 100 hPa</td>
<td>± 1.0 K</td>
<td>± 10%</td>
</tr>
<tr>
<td></td>
<td>± 0.5 K</td>
<td>1 – 2 km layers</td>
</tr>
<tr>
<td></td>
<td>± 20%</td>
<td>&lt; 1 – 2 km layers</td>
</tr>
<tr>
<td>100 hPa and above</td>
<td>± 1.0 K</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>± 0.5 K</td>
<td>2 – 3 km layers</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>&lt; 2 – 3 km layers</td>
</tr>
</tbody>
</table>
# ABS Instrument Requirements
(Critical Parameters)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ABS Threshold Requirement</th>
<th>ABS Goal Requirement</th>
<th>GOES N/Q Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground Sample Distance</strong>_{\text{max}}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible</td>
<td>1 km</td>
<td>1 km</td>
<td>10 km</td>
</tr>
<tr>
<td>650 - 1200 cm(\text{c}m)</td>
<td>10 km</td>
<td>8 km</td>
<td>10 km</td>
</tr>
<tr>
<td>1210 - 1740 cm(\text{c}m)</td>
<td>10 km</td>
<td>4 km</td>
<td>10 km</td>
</tr>
<tr>
<td>2150 - 2720 cm(\text{c}m)</td>
<td>10 km</td>
<td>4 km</td>
<td>10 km</td>
</tr>
<tr>
<td><strong>Ensquared energy</strong>_{\text{min}} (The detector signal produced by radiance from the square grid defined by the ground sample distance divided by the total detector signal produced by scene radiance.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>650 - 1200 cm(\text{c}m)</td>
<td>90%</td>
<td>90%*</td>
<td>73% or 78%**</td>
</tr>
<tr>
<td>1210 - 1740 cm(\text{c}m)</td>
<td>90%</td>
<td>67%*</td>
<td>78%**</td>
</tr>
<tr>
<td>2150 - 2720 cm(\text{c}m)</td>
<td>90%</td>
<td>67%*</td>
<td>85%**</td>
</tr>
</tbody>
</table>

*The threshold ensquared energy values are for a ground sample distance (GSD) >8 km. The goal ensquared energy values are for a GSD of 4 km. For other values of GSD, the ensquared energy requirement shall be scaled linearly between the requirements for 8 km and 4 km.

**The GOES-N/Q requirement (encircled incident energy) is for detector signal produced by radiance from one circular IGFOV divided by the total detector signal produced by scene radiance.
### ABS Instrument Requirements, Cont’d
(Critical Parameters)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ABS Threshold Requirement</th>
<th>ABS Goal Requirement</th>
<th>GOES N/Q Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IR Spectral bands and spectral resolution</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>650 - 1200 cm(^{-1})</td>
<td>880 bins (0.625 cm(^{-1}) resolution)</td>
<td>Same as threshold</td>
<td>9 channels (13 - 50 cm(^{-1}) half-power bandwidth)</td>
</tr>
<tr>
<td>1210 - 1740 cm(^{-1})</td>
<td>424 bins (1.25 cm(^{-1}) resolution)</td>
<td></td>
<td>3 channels (55 - 80 cm(^{-1}) half-power bandwidth)</td>
</tr>
<tr>
<td>2150 - 2720 cm(^{-1})</td>
<td>228 bins (2.5 cm(^{-1}) resolution)</td>
<td></td>
<td>6 channels (23 - 100 cm(^{-1}) half-power bandwidth)</td>
</tr>
<tr>
<td><strong>NEdN(_{\text{max}})</strong> (mW/m(^2)/sr/cm(^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>650 – 670 cm(^{-1})</td>
<td>1.0</td>
<td>1.25*</td>
<td>NA**</td>
</tr>
<tr>
<td>670 – 685 cm(^{-1})</td>
<td>0.7</td>
<td>0.88*</td>
<td>1.43</td>
</tr>
<tr>
<td>685 – 700 cm(^{-1})</td>
<td>0.5</td>
<td>0.63*</td>
<td>1.43</td>
</tr>
<tr>
<td>700 – 1150 cm(^{-1})</td>
<td>0.15</td>
<td>0.19*</td>
<td>0.69 – 0.33</td>
</tr>
<tr>
<td>1150 – 1200 cm(^{-1})</td>
<td>0.3</td>
<td>0.38*</td>
<td>NA**</td>
</tr>
<tr>
<td>1210 – 1740 cm(^{-1})</td>
<td>0.06</td>
<td>0.15*</td>
<td>0.12 – 0.16</td>
</tr>
<tr>
<td>2150 - 2720 cm(^{-1})</td>
<td>0.008</td>
<td>0.02*</td>
<td>0.013 – 0.0036</td>
</tr>
</tbody>
</table>

*The threshold NEdN values are for a threshold ground sample distance (GSD). If the GSD is less than the threshold, the NEdN requirement can be increased in inverse proportion of the GSD.

**The GOES-N/Q Sounder does not have IR channels in this spectral range.
# ABS Instrument Requirements, Cont’d
**(Critical Parameters)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ABS Threshold Requirement</th>
<th>ABS Goal Requirement</th>
<th>GOES N/Q Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage rate</td>
<td>In 60 minutes, scan one region within 62 degrees local zenith angle*</td>
<td>In 60 minutes, scan one full disk</td>
<td>In 60 minutes, scan one CONUS and one Gulf of Mexico region**</td>
</tr>
<tr>
<td>Regional and Mesoscale (when required)</td>
<td>Must be supported and selectable</td>
<td>Must be supported and selectable</td>
<td>Must be supported and selectable</td>
</tr>
</tbody>
</table>

*Although only scan half of the region of overlap between the eastern and western satellites, nominally at 105W, as shown in Scan Scenario slide.*

**An image for one hour of the infrared window channel from the GOES East and West instruments are shown in Scan Scenario slide.*
ABS Scan Scenario

Hourly ABS Scan Scenario – Targeted Observations

Local Zenith Angle ~ 62 Degrees
IR Spectral Coverage
ABS (1,532) and GOES Sounder (18)
Moisture Weighting Functions
ABS (1,532) and GOES Sounder (18)
Modeled Performance of Advanced Baseline Sounder (ABS)
Vertical Structure of Retrieved Temperatures (ABS vs. GOES)
Vertical Structure of Retrieved Moistures (ABS vs. GOES)
Conclusions

• Advanced IR Sounders for GEO are climbing a “long and winding road”
• The required technologies are ready
• Eventual benefits will be tremendous with improved:
  – Resolutions:
    » temporal
    » spectral
    » spatial

    Resulting in
    Major data product improvements for:
    » nowcasting
    » short-range weather forecasts
    » longer-range NWP updates