Hyperspectral Environmental Suite (HES) Evolution and Current Requirement Studies

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and

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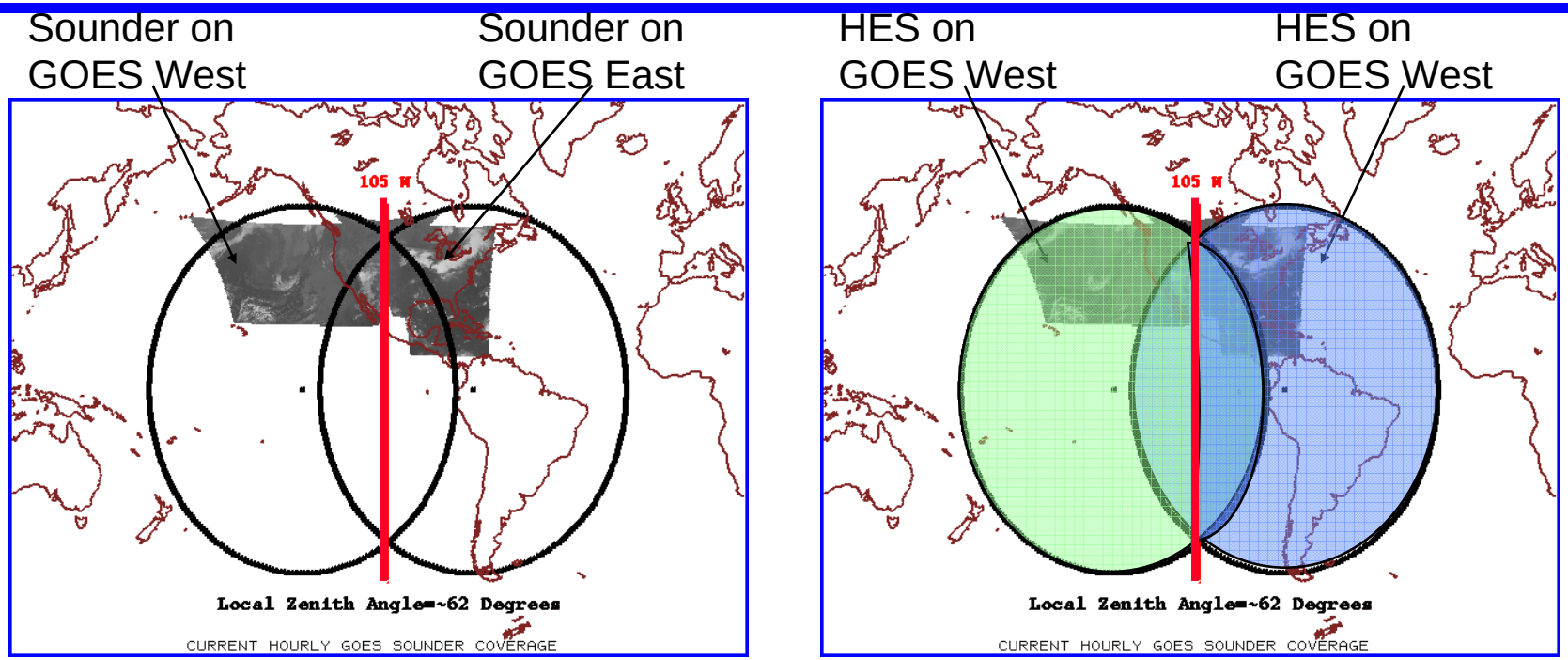
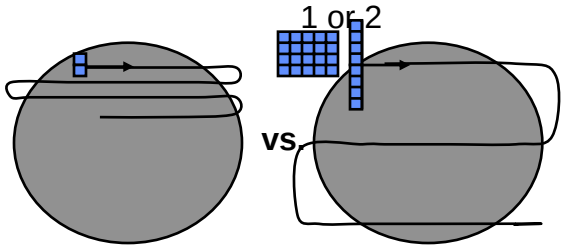
Outline

- Background
- HES Coverage Flexibility for User Needs
- Operational Considerations
- HES Spectral and Radiometric Requirement Revisions/Studies
- Summary

Sounding coverage rate from HES outperforms current sounder

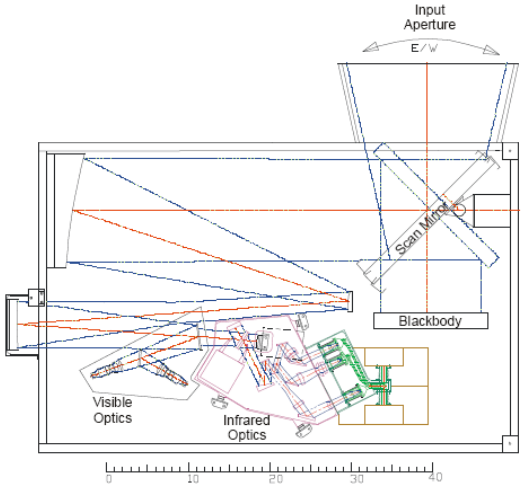


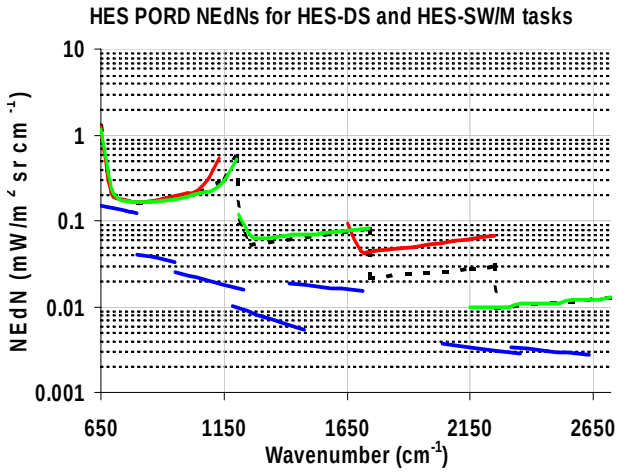
- **Current Sounders provides coverage (superimposed satellite images) from the GOES-East and GOES-West satellite positions in about 45 minutes.**
- **Two HES can provide a sounding coverage rate of each 62 degree local zenith angle (LZA) disk in one hour, shown by the area outlined in black (DS task)**
  - **> 5x improvement benefit from increased number of detectors observing simultaneously**

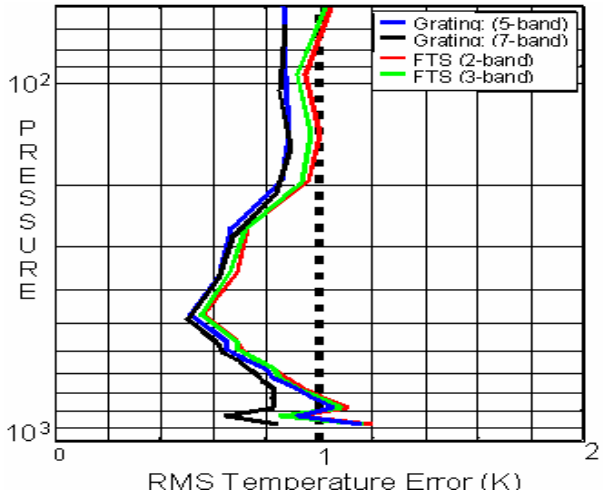


MIT- Lincoln Laboratory studies supported Phase A efforts

- MIT – Lincoln Laboratory has been providing technical support to the GOES program office since 1994.
- In the late 1990's, MIT – Lincoln Laboratory investigated longwave FPA technology to understand FPA limitations, particularly near the 15 um CO_2 feature
  - Noise and retrieval performance were examined based on real measurements from FPAs
- Over the next several years, four major instrument studies investigating the feasibility of development of the Advanced Baseline Sounder (ABS) were completed by Lincoln Laboratory
  - Interferometric point designs
  - Dispersive point design

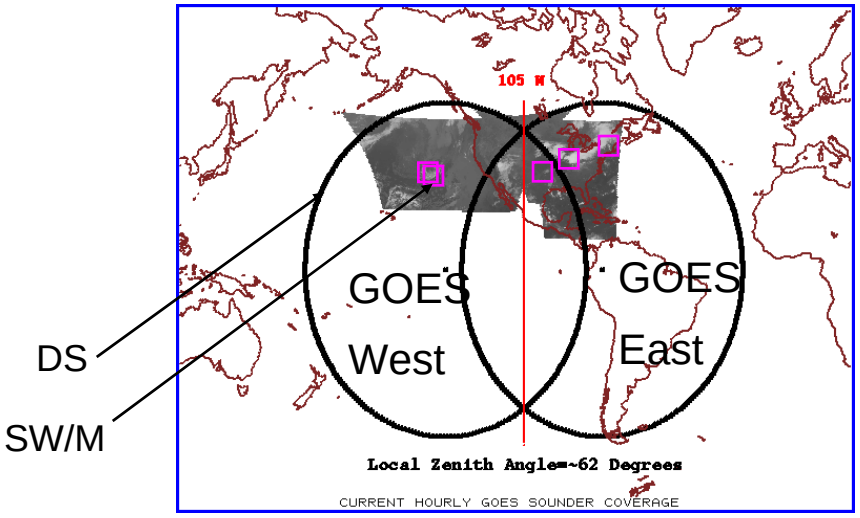


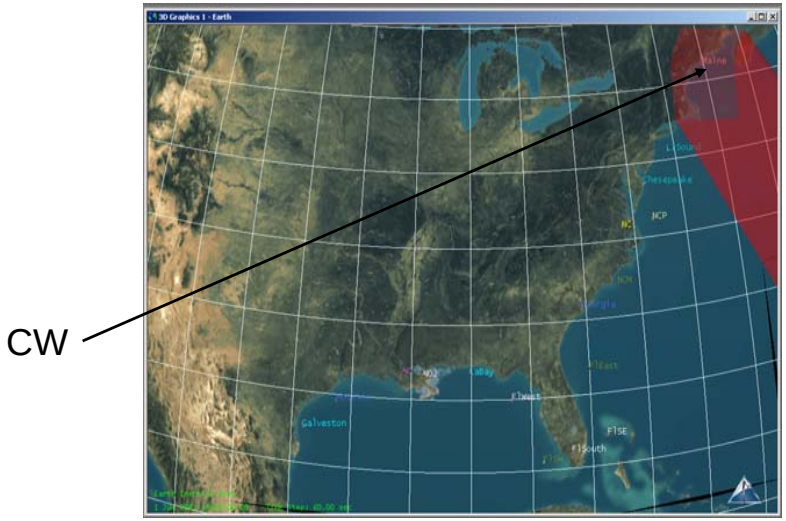




MRD requires three HES tasks to meet user needs

- With the collection of the user requirements in the GOES Program Requirements Document PRD (later the GPRD), and the development of the program office Mission Requirements Document (MRD) that responds to these, ABS evolved into the HES with two sounding tasks and a coastal waters task
  - During the HES Performance and Design Risk Reduction (formerly Formulation) Phase, three contactors have been studying HES requirements
  - Risk reductions have been examined
- Current HES parameters/capabilities for 3 Threshold Tasks
  - 62 degree LZA in 60 minutes at 10 km
  - Severe Weather / Mesoscale task in 4.0 minutes at 5 km
  - 0.75 x Coastal waters (400 km wide x ~ 6000 km) in 180 min at 0.375 km



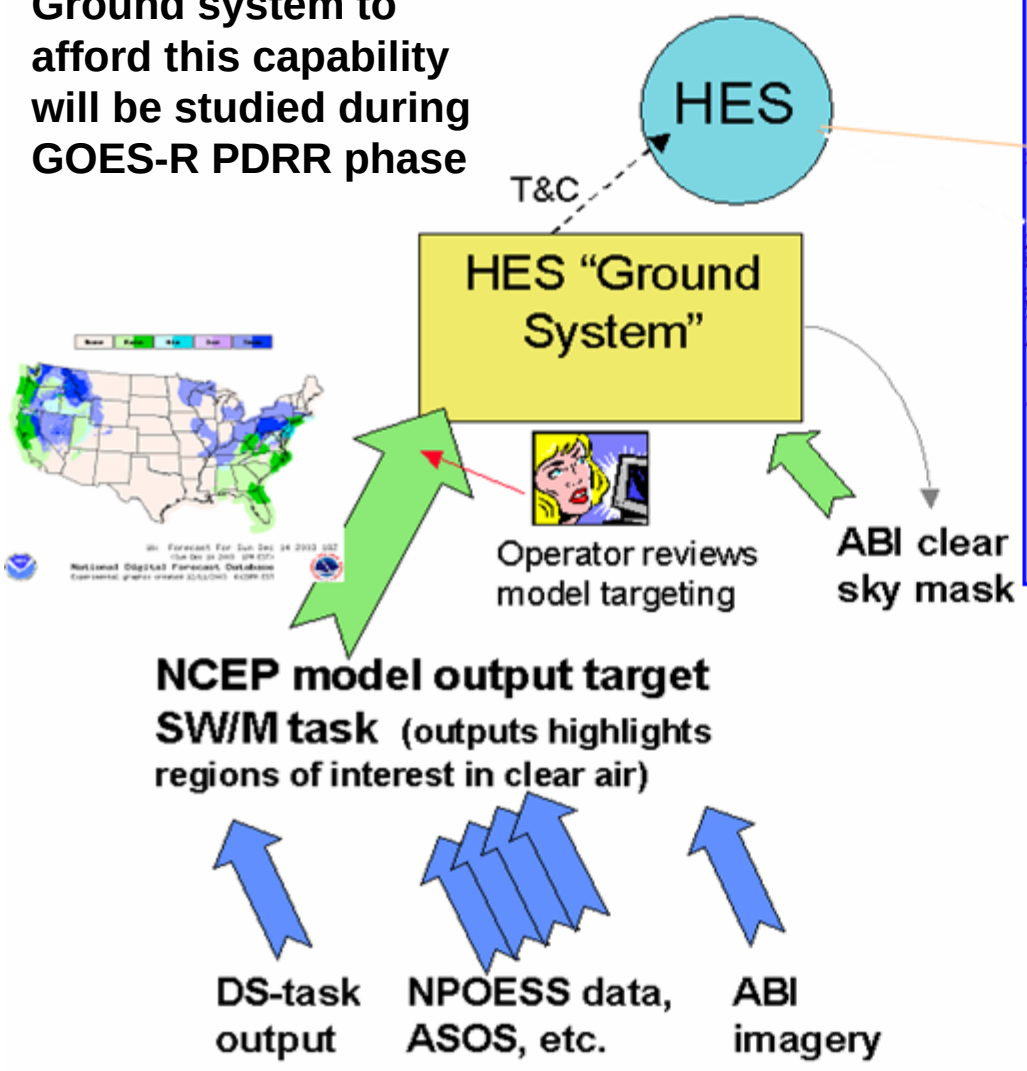


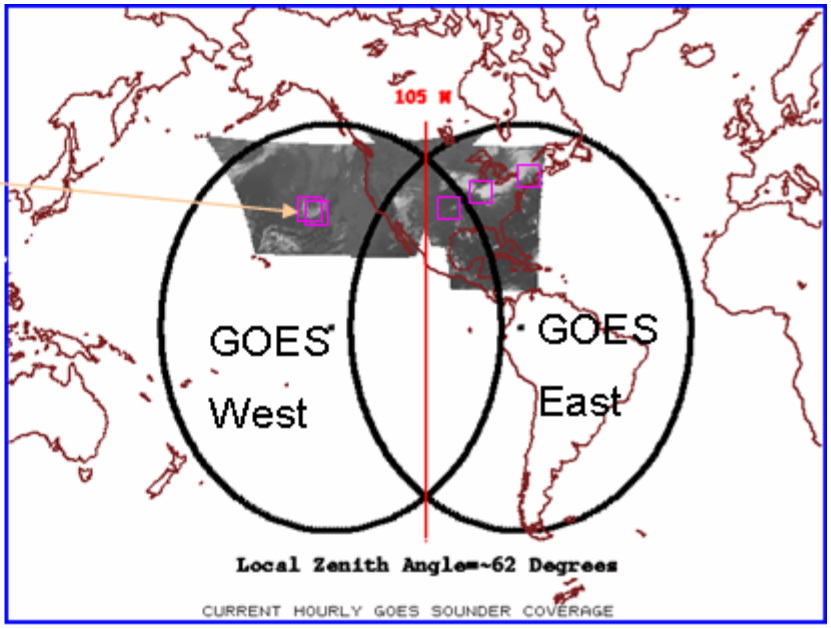
Operational consideration: HES can address users varying needs

- **Operational topics for consideration (briefly highlighted in MRD)**
  - **HES provides slower coverage rate than ABI**
  - **CW and SW/M HES tasks should be targeted to regions of interest**
    - **Slower HES coverage but finer spatial and spectral, respectively**
    - **CW task is time shared with sounding tasks, so clear air identification which can be afforded by ABI is critical**
  - **ABI cloud cover masks should direct HES to clear air in advance of storm for SW/M task**
    - **Multiple sequential observations in SW/M are likely for a single potential storm region, and multiple regions may be of interest.**
    - **SW/M task should be performed first over the CW until coverage of modeled SW/M region is afforded.**
  - **When SW/M task is employed, DS coverage area may be reduced from 62° LZA disk due to time sharing.**

Automated Targeting for HES from Ground System will be studied

Ground system to afford this capability will be studied during GOES-R PDRR phase



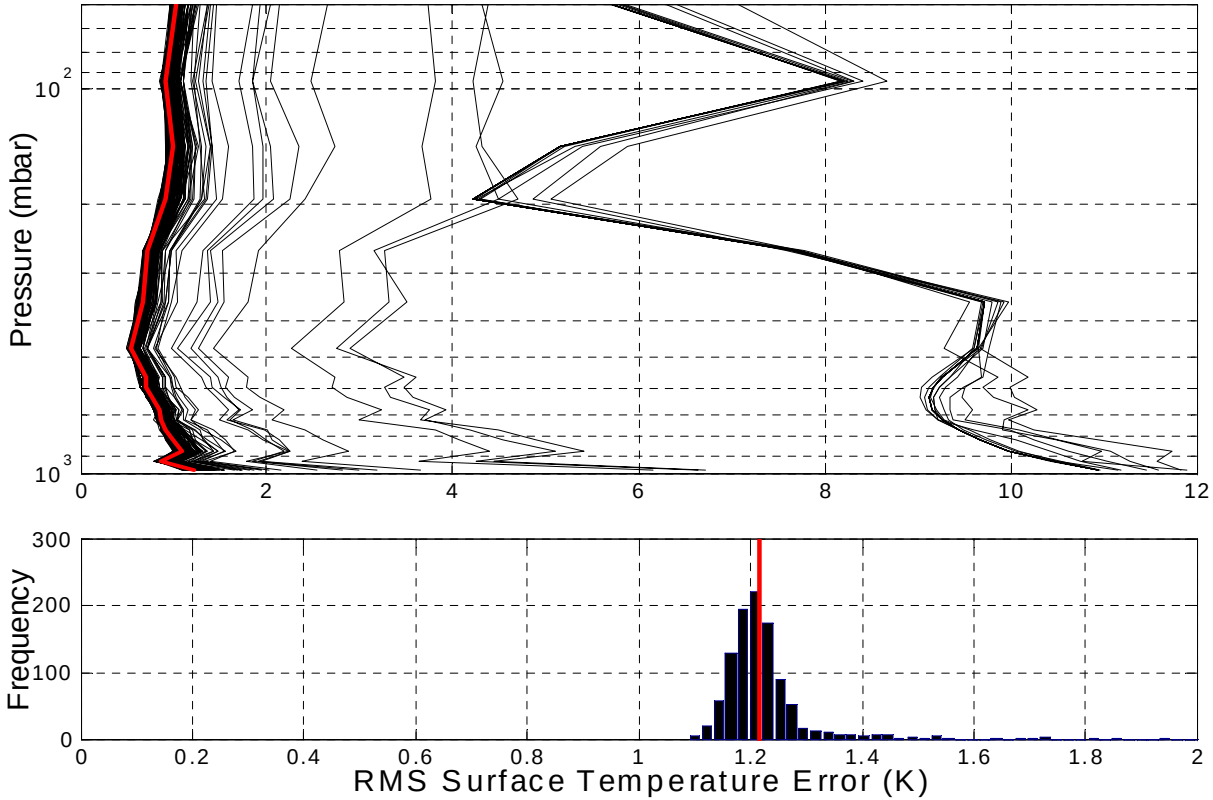


- **Model outputs should be used to trigger HES-SW/M**
  - **When not specifically targeted, a routine schedule may be used**

Current requirements and possible usage scenarios

- To permit CW task coverage in addition to sounding, HES is shall be capable of performing the following tasks in a period of 3 hours:
  - 2.5 (TBR) 62-degree LZA regions or 37.5 mesoscale regions sounded
  - 0.75 (TBR) CW regions observed
- Possible usage scenarios can be envisioned to address the HES sounding user needs while employing the sounding tasks
  - ***Possible*** usage scenarios (not final scenarios) provide frequent CONUS coverage with regular coverage of Southern Hemisphere within 60 min
    - The first 4.0 minutes on SW/M task alternating with 3.3 minutes of CW task coverage, repeated for 22 minutes; a 3000 km x 5000 km areas of interest in South America, the tropics, or elsewhere could be observed and calibrated in 15 minutes from 0:22 to 0:37; and a 5000 km x 5000 km region including CONUS could be observed and calibrated in 23 minutes from 0:37 through 0:60.
    - For spring storm season or hurricanes season: The first 4.0 minutes on SW/M task alternating with 3.3 minutes of CW task coverage, repeated for 44 minutes, with 15 minutes for the 3000 km x 5000 km CONUS coverage from 0:44 through 0:59.
    - Estimates based on the required coverage rates, calibration, and scan overheads

Operational consideration: Pixel variability and operability impact on NEdNs and retrievals



- **HES sounding will afford measurements from many more pixels than CrIS and AIRS.**
  - **Multiple pixels carry calibration challenges; however pixel with 2x median noise are considered inoperable for HES**
  - **ABI will experience similar challenges**
- **Measurements of 1057 FPA detectors were used in Monte Carlo simulation**
- **Median curve shown in red for reference**

Operational consideration: Spectral channel center variations

- Inherent properties of both interferometric and dispersive instruments can lead to spectral shifting that can vary with pixel position on the FPA
  - Type of effects and their spectral dependence are known
  - Can be thermally dependent though
- Numerical Weather Prediction model tuning for variation with pixel considered undesirable, as noted by NWP modeler / JSCDA director input
- Requirement was added for spectral channel center stability of less than 1% (TBR) channel width
  - Channel width is ~ 1 /1000 of channel center

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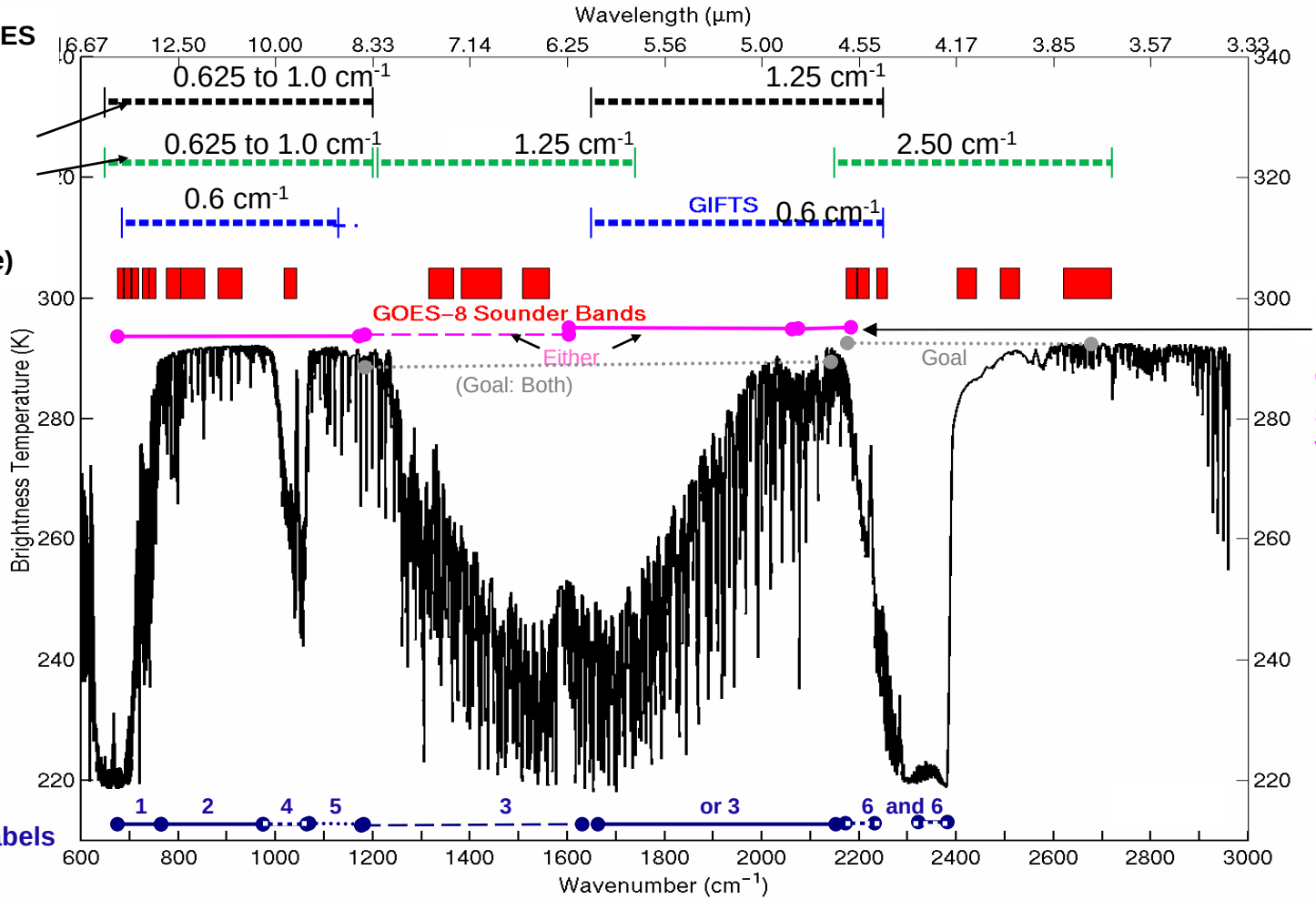
IR Spectral Coverage for HES sounding

Original HES spectral coverage options (CrIS- like and AIRS-like, then GIFTS-like)



HES Threshold Requirement Options at start of HES vendor Formulation Phase

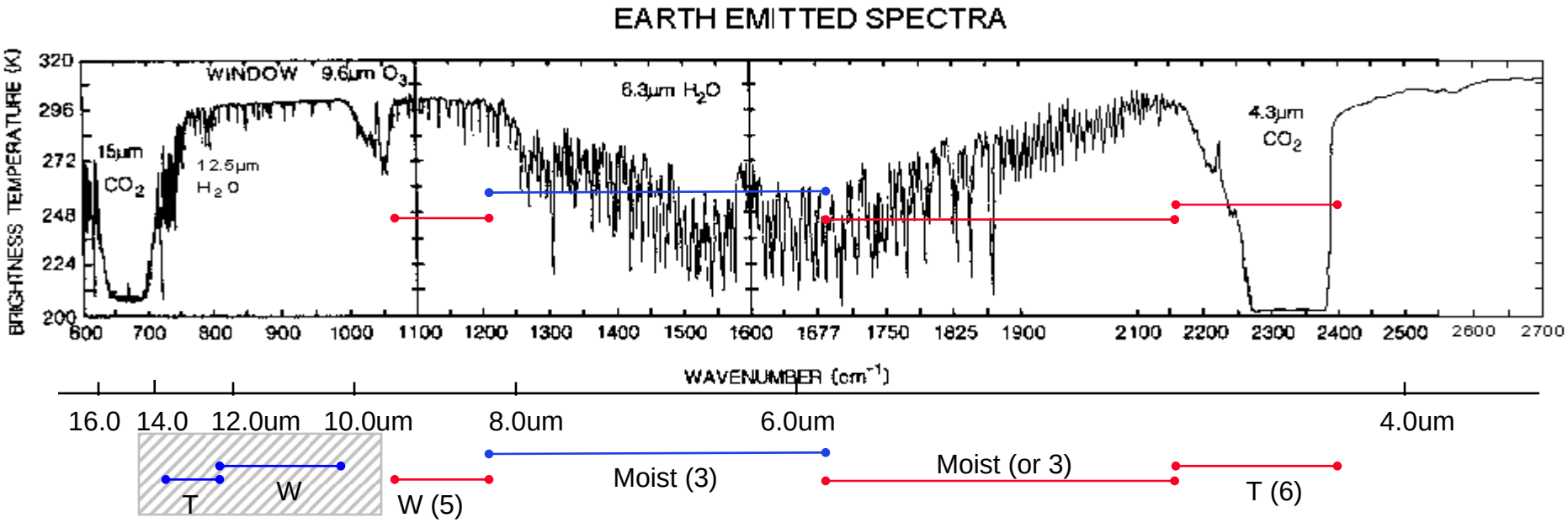
Region Labels

1 = 675 – 800 cm-1 (14.8 – 12.5 um), 2 = 800 – 1000 cm-1 (12.5 - 10.0 um), 3 = 1210 – 1645 or 1689 – 2150 cm-1 (8.26 – 6.08 um or 5.92- 4.65 um), 4 = 1080 – 1000 cm-1 (10.0 - 9.26 um), 5 = 1080 – 1200 cm (9.26 – 8.33 um), 6 = 2150 – 2400 (4.65 – 4.167) but considering 2150 – 2250 and 2350 – 2400 cm-1 (4.65 – 4.44 and 4.255 – 4.167 um)

HES Minimum Mission

- In April 2005, HES Minimum Mission definition requested by GOES Program office
  - Requirements reductions were examined
- Driven by resource limitations
- Reductions were requested to be provided for vendor study
  - Impacts on instrument changes on retrieval performance were assessed on the government side
  - Metric was to maintain comparable grating and interferometric retrieval performance
- AOL TAP provided input GOES Program Office
- Program Office
  - Approved requirement reduction for study phase only
  - Began soliciting input on baseline option

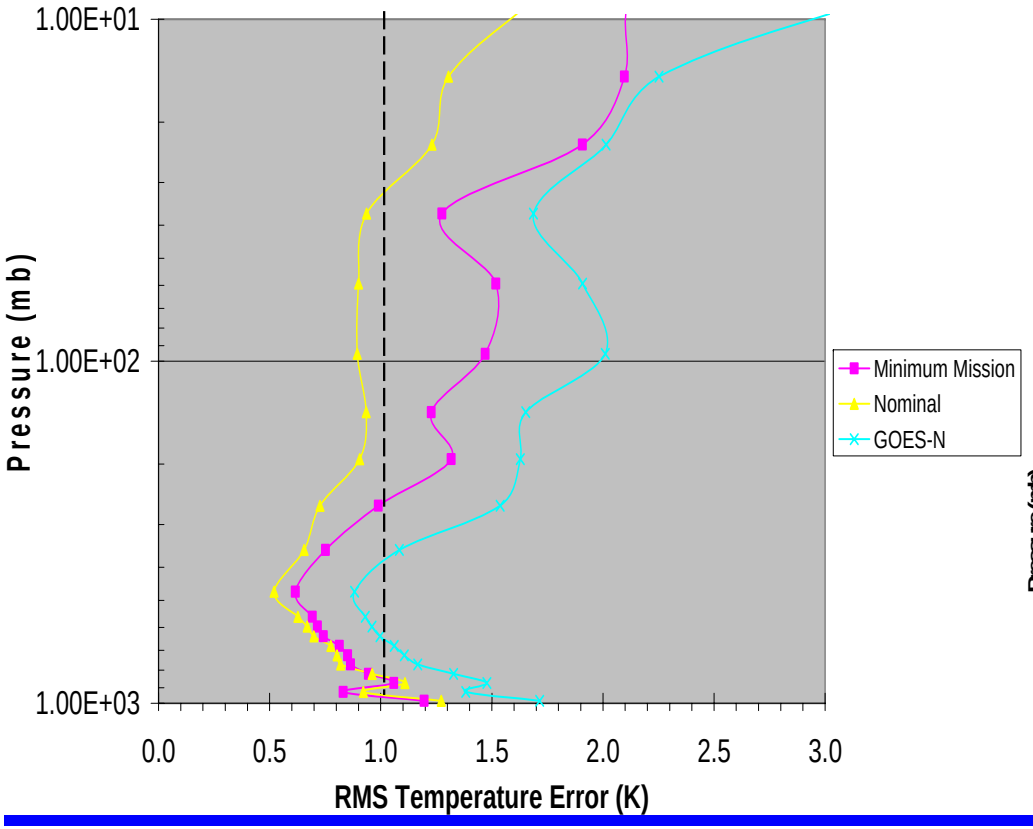
HES Minimum Mission study finally baselined coverage < 9.3 um for review

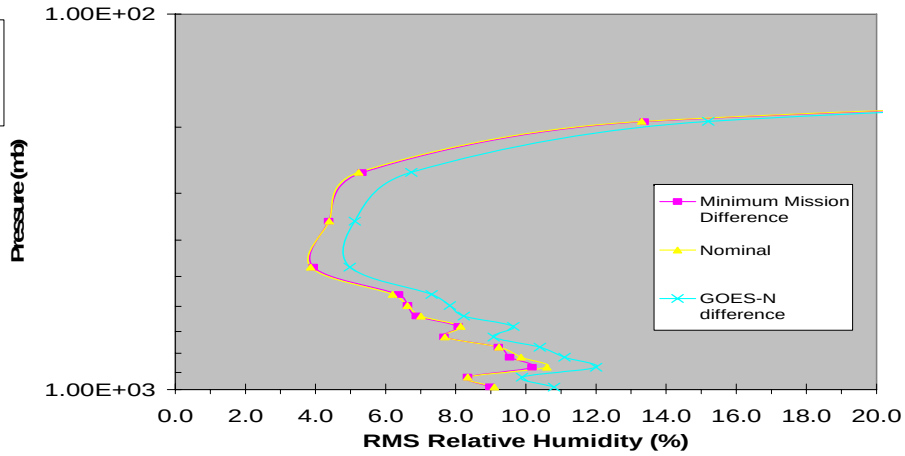


Band	Wavenumber (cm-1)	Wavelength (um)
Temperature	2150-2400	4.167-4.65
Moisture	1210-1689 or 1647-2150	6.08-8.26 or 4.65-5.92
Window	1075-1200	8.33-9.3
Visible		0.52-0.70

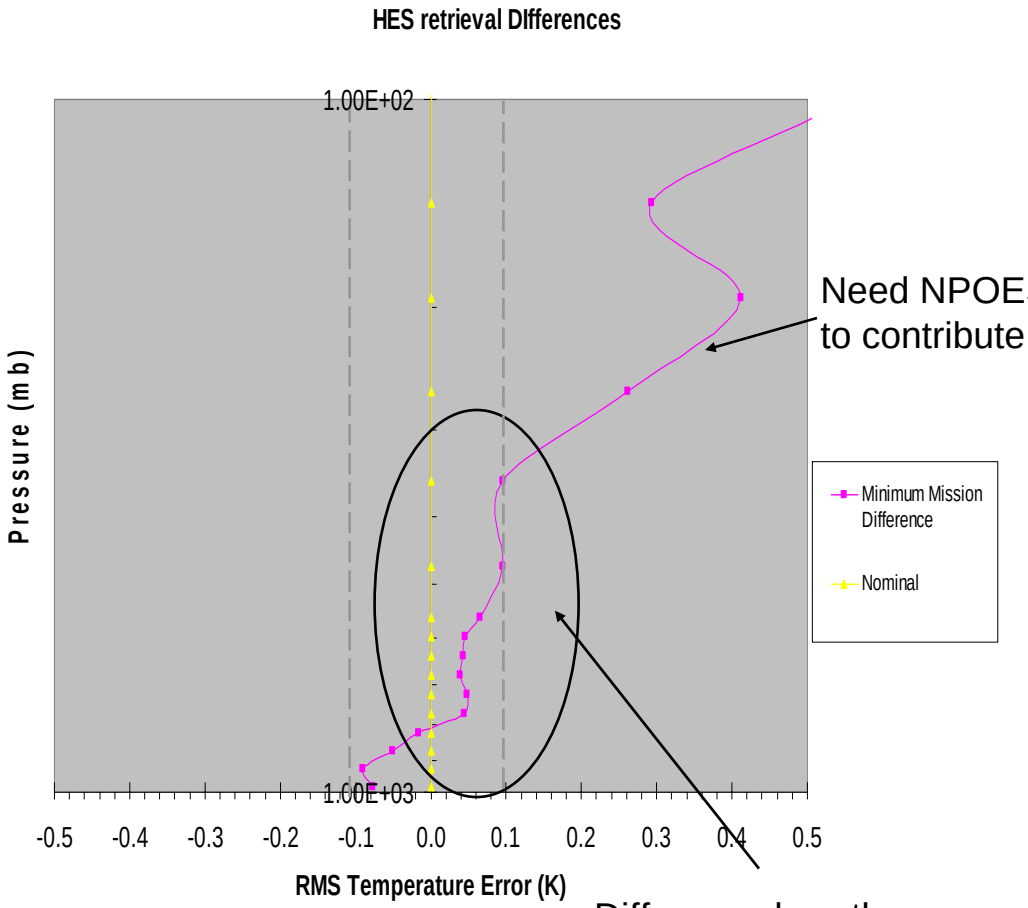
Retrieval impacts and comparisons

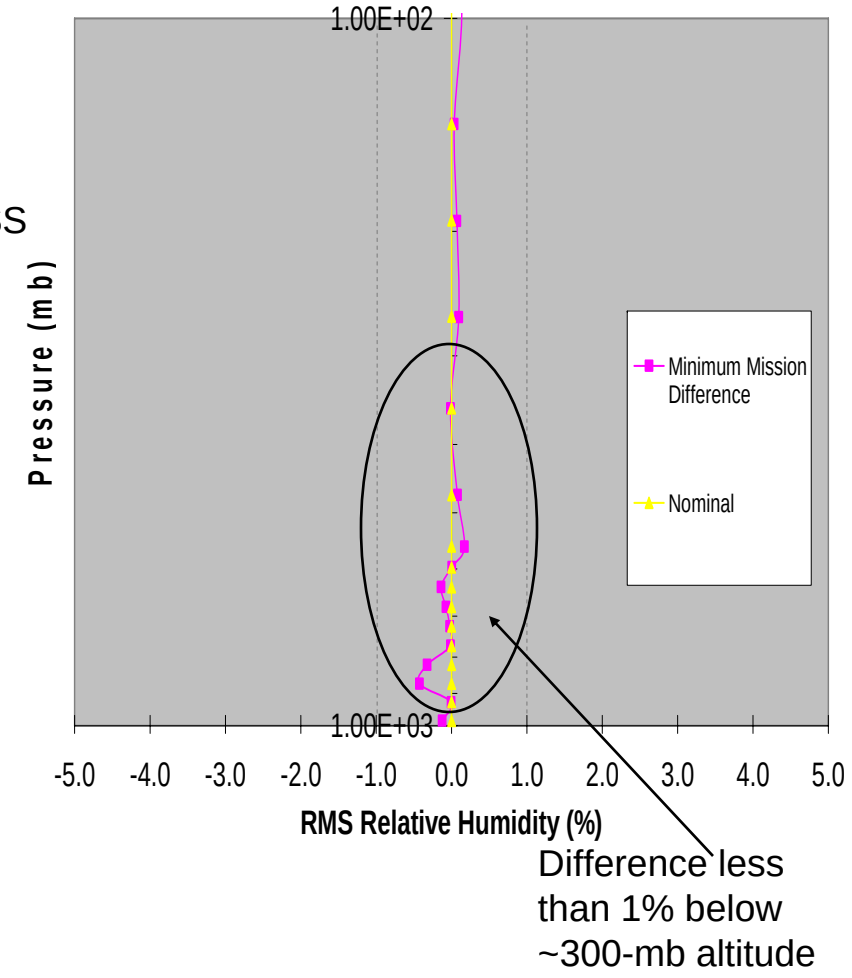
- **Retrieval performance (and underlying radiances) are impacted if no coverage shortward of 9.3 um is afforded**
  - **Impact is difference between Minimal Mission and Nominal curves below**
  - **Pink squares are neural net results for wavelengths shortward of 9.3 um**
  - **GOES – N performance from measured NEdNs shown for reference.**





Minimum Mission Degradations (expanded scale) for T and RH



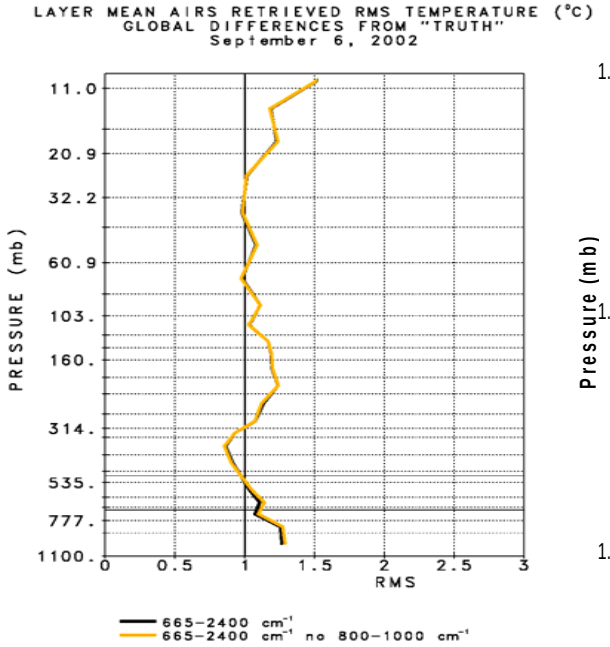


Retrievals

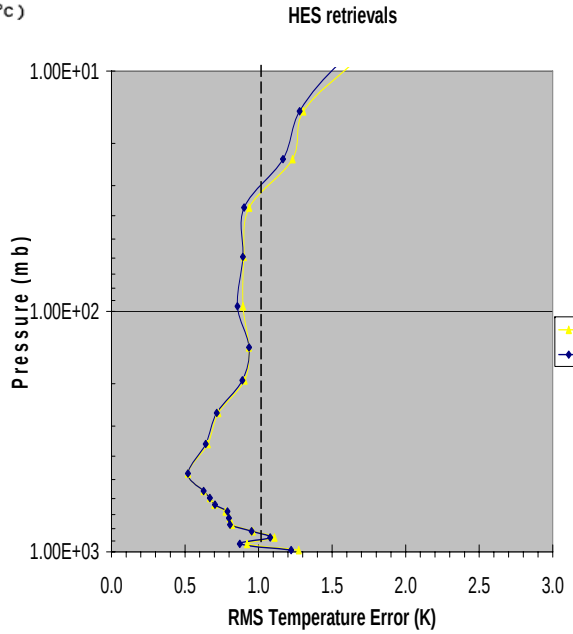
- Retrieval simulations performed by Bill Blackwell of MIT – Lincoln Laboratory
- Retrieval simulation characteristics
  - Neural Network retrievals
    - Combines the Projected Principal Components transform and a neural network was developed and tested
    - About 50 times faster than physical/iterative retrieval
  - Using NOAA88b data set
    - 4756 profiles for training, 576 for testing.
    - CH_4 and N_2O that are assumed to be uniformly mixed in known quantities
  - Surface emissivities are randomly generated
    - Statistics of the hinge points were calculated using the UCSB MODIS emissivity library of measured emissivities for a variety of surface types
  - SWIR solar effects are included
  - Land and oceans surfaces are included
  - Clouds can be turned on in the simulations
    - However, they have not been used in order to address threshold performance which is specified for clear air

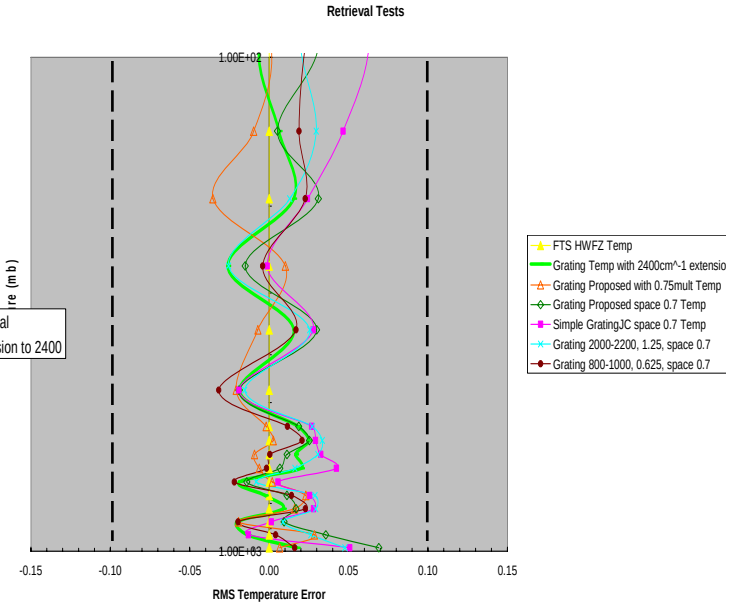
HES Formulation Phase Retrievals

- **Retrievals typically performed at multiple locations for AOL TAP discussion and subsequent GOES Program Office review**
  - **Goddard, CIMSS, and MIT-LL**
  - **"General" agreement found despite different retrieval techniques**
    Physical retrieval, Neural network retrieval, Physical retrieval with AIRS data



Susskind

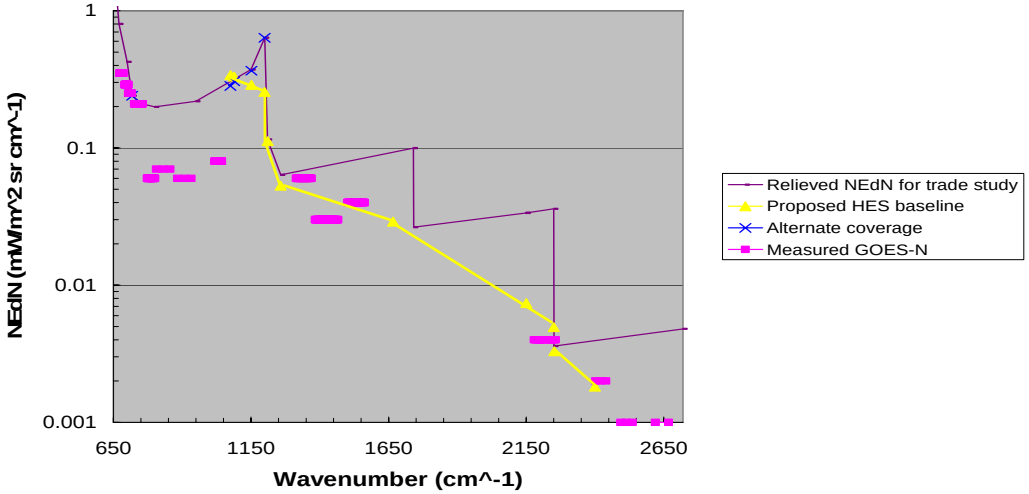




Blackwell

Additional study of LWIR coverage

- NOAA sounding scientists met on December 22, 2005 to review minimum mission
- Impact was considered significant
  - Loss of heritage on data and algorithms
  - Risk of SWIR only temperature retrievals
  - Impact to NWP model forecast capability with SWIR only
- Spectral trade study for LWIR coverage re-inclusion was envisioned
  - LWIR coverage from 675 cm^{-1} (14.8 um) to 1000 cm^{-1} (10 um)
  - Goal spectral coverage being investigated (next slide)
  - Noise performance already relaxed for minimum mission



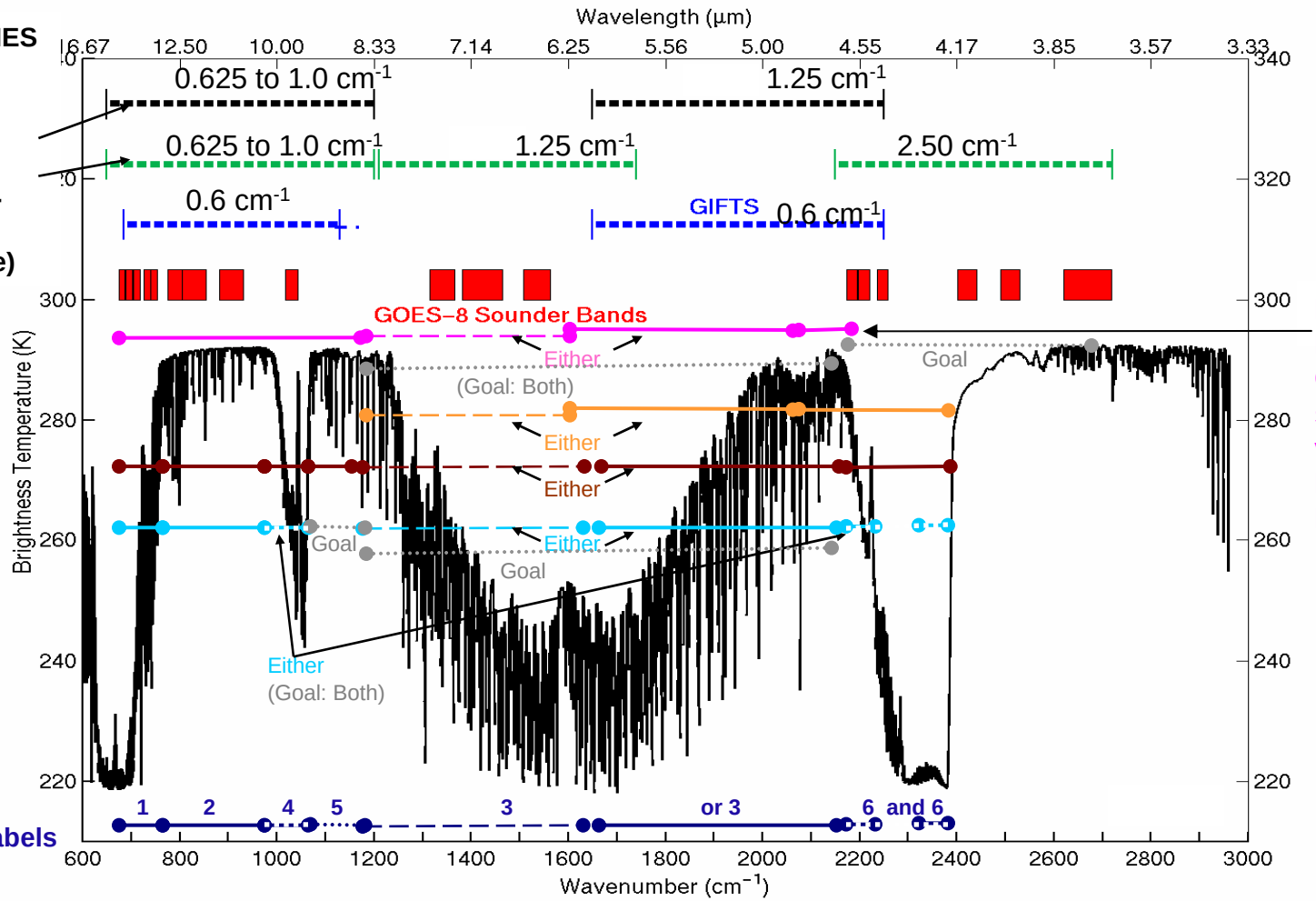
Noise performance relief by 2x between 718 and 800 cm^{-1} and 20% elsewhere

Noise performance tightened to goal level beyond 2150 cm^{-1}

Noise comparable to GOES-N < 9.3 um

Proposed noise requirements optimized by instrument type (nominally "flat" NEdN per band for interferometer; nominally "flat" NEdT per band for grating)

New options for HES sounding



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HES Spectral Resolution

Maximum Width for Sounding Channels (if present)

Spectral Range	Threshold Wavenumber (cm^{-1})	Threshold Wavelength (um)
650 to 950 cm^{-1} 10.53 to 15.38 um	0.875 (to 1st minimum); 0.625 to 1st zero)	0.01417
951 to 1075 cm^{-1} 8.7 to 10.52 um	1.050* (to 1st minimum); 0.75 to 1st zero)	0.00961*
1075 to 1150 cm^{-1} 8.7 to 10.52 um	1.050* (to 1st minimum); 0.75* to 1st zero)	0.00961*
1151 to 1200 cm^{-1} 8.33 to 8.69 um	1.260* (to 1st minimum); 0.9* to 1st zero)	0.00912*
1210 to 1740 cm^{-1} 5.75 to 8.26 um	1.751(to 1st minimum); 1.25 to 1st zero)	0.00832
1650 to 2150 cm^{-1} 4.65 to 6.06 um	1.750 (to 1st minimum); 1.25 to 1st zero)	0.00493
2150 to 2250 cm^{-1} 4.44 to 4.65 um	3.500 (to 1st minimum); 2.5 to 1st zero)	0.00724
2251 to 2400 cm^{-1} 3.68 to 4.43 um	3.500 (to 1st min.)	0.00572

(Asterisk notes under study)

CW band spectral coverage and resolution

Nominal Channel Center Wavelength (μm)	Nominal Resolution (μm)	Tolerance on center wavelength (μm)
0.412	0.02	+/- 0.002 (TBR)
0.443	0.02	+/- 0.0011 (TBR)
0.490	0.02	+/- 0.0012 (TBR)
0.510	0.02	+/- 0.0015 (TBR)
0.550	0.02	+/- 0.005 (TBR)
0.667	0.01	+0.001-0.002 (TBR)
0.678	0.01	+/- 0.001(TBR)
0.750	0.02	+/- 0.002 (TBR)
0.865	0.02	+/- 0.0022 (TBR)

- **Signal to Noise Threshold of 300:1**
- **Visible calibrations absolute accuracy requirement was reduced; vicarious calibration with lunar and MOBY-like system envisioned**

Summary

- Instrumentation for sounding from GOES-R studied extensively
- Original HES MRD requirements complied with GPRD requirements
- The three tasks of HES (DS, SW/M, and CW) can provide NOAA with improved capability
  - Tasking of HES can optimize its data collection
- HES Program Definition and Risk Reduction Phase studies are providing vendor feedback
  - Two significant studies for risk reduction were requested by the program office
    - Reductions had product impacts
    - Larger NOAA science community weighed in that LWIR coverage was still needed; user impact being quantified
    - Further study to address this while minimizing risk will occur
  - Being reviewed by NOAA
- Despite its requirements being in flux, HES outperforms GOES-N
  - Coverage rate: >5x
  - Spatial resolution: 2x finer mode
  - Spectral resolution and number of channel
  - Radiance and Retrieval performance: yes, although the level of performance is still varying