

Infrared sounders on the geostationary Hyper-spectral Environmental Suite (HES)

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in collaboration with

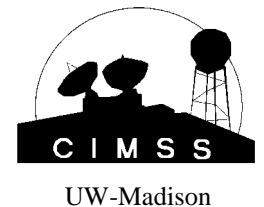
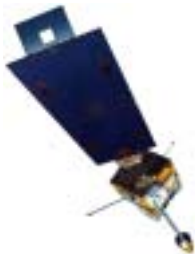
Jun Li, etc from the

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

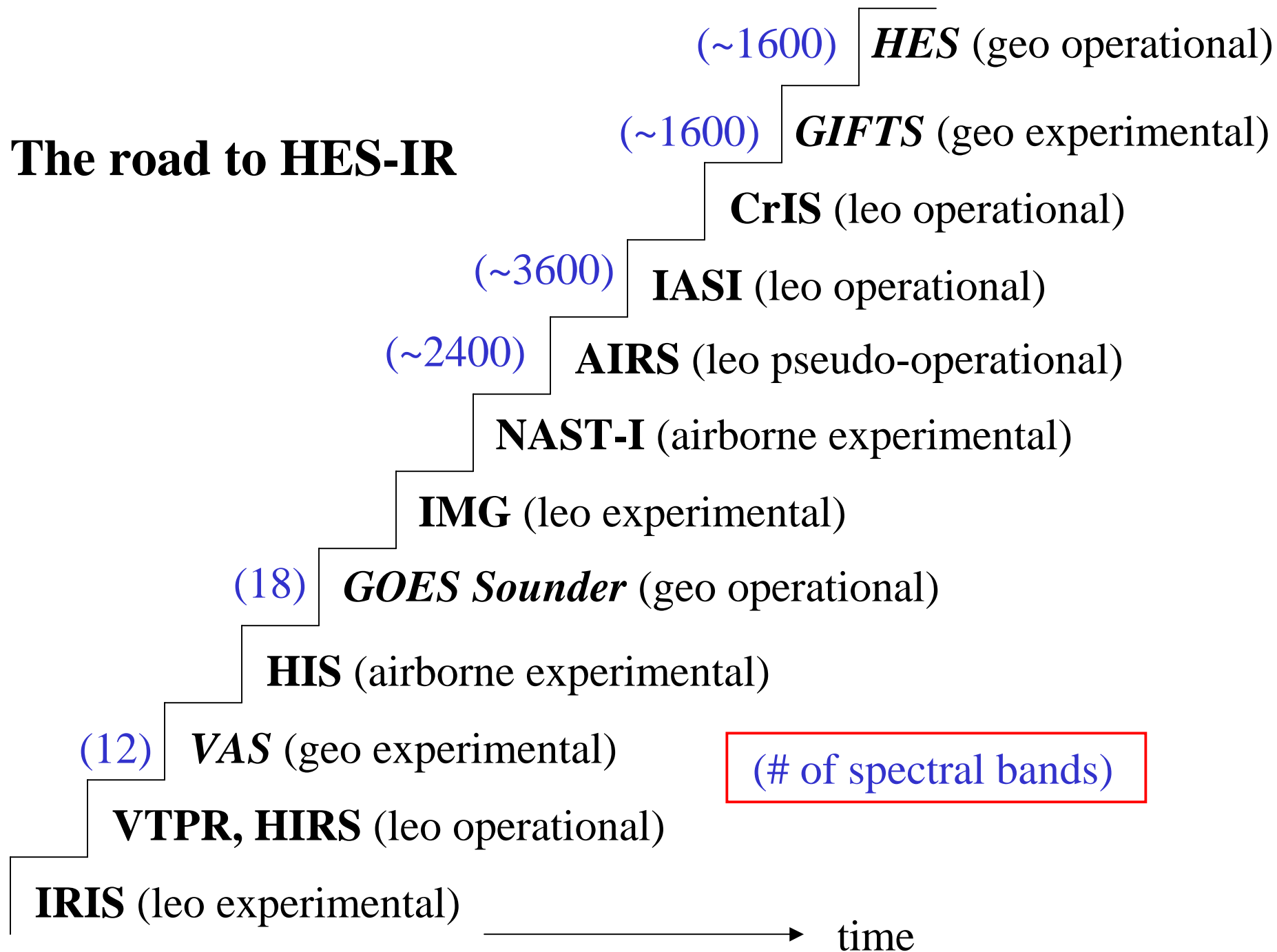
Madison, WI

And the HES PORD Team

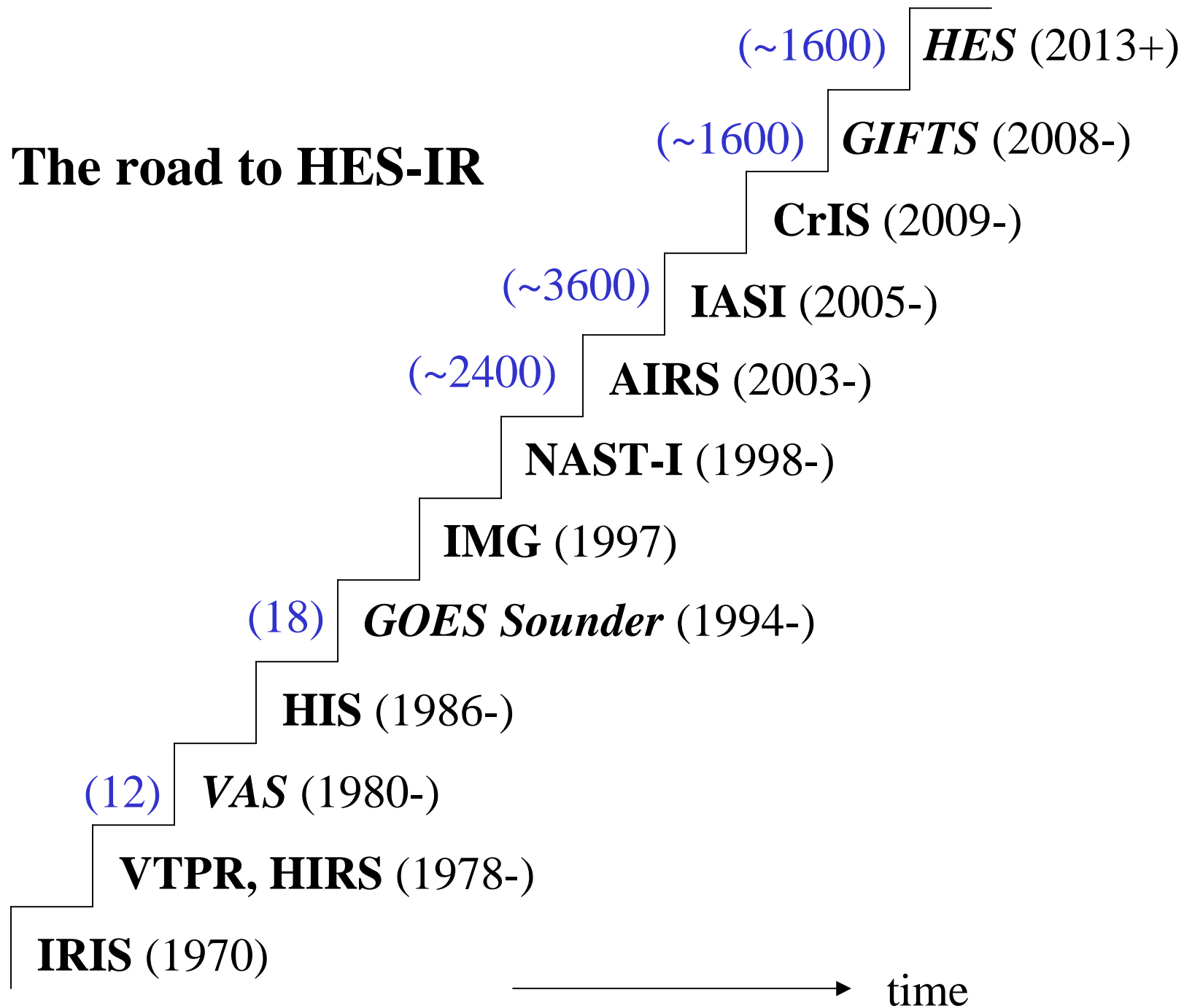
May 8, 2003



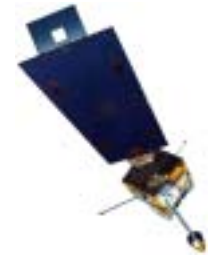
The road to HES-IR



The road to HES-IR



Future GOES



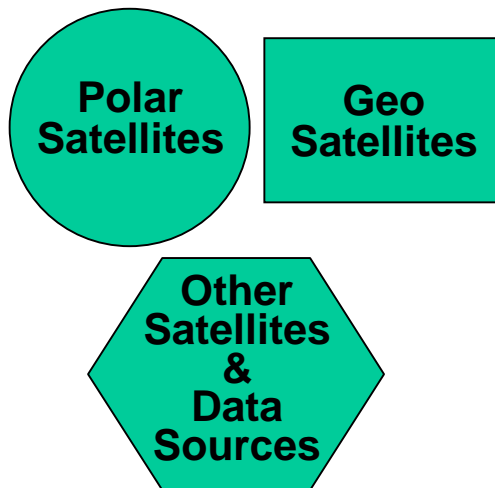
Future GOES will address all four key remote sensing areas

- * **spatial resolution** – what picture element size is required to identify feature of interest and to capture its spatial variability;
- * **spectral coverage and resolution** – what part of EM spectrum at each spatial element should be measured, and with what spectral resolution, to analyze an atmospheric or surface parameter;
- * **temporal resolution** – how often does feature of interest need to be observed; and
- * **radiometric resolution** – what signal to noise is required and how accurate does an observation need to be.



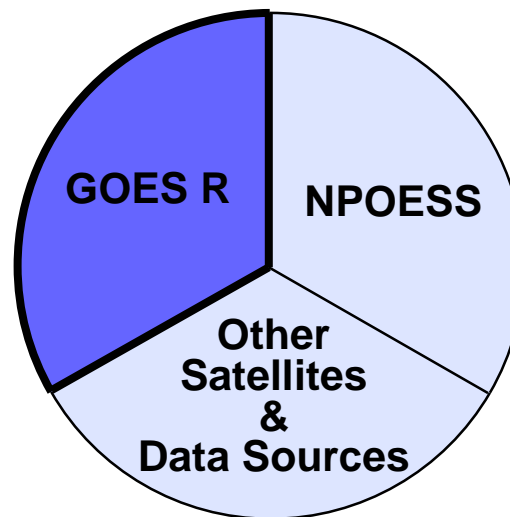
Goal - Transition from Individual Systems to “System of Systems” Architecture

Today



Programs formulated independent of one another

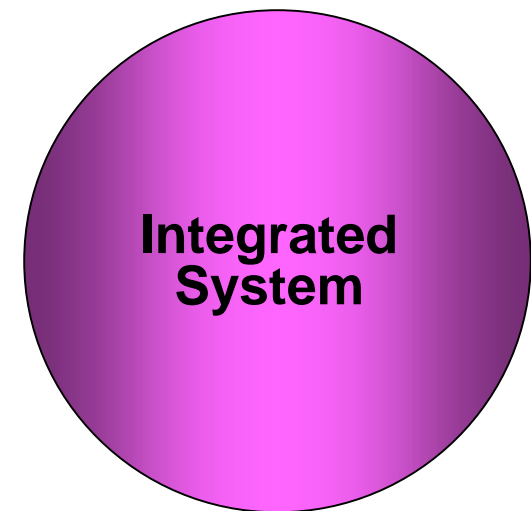
2012



Formulate integrated system – GOES R with

- **Defined NPOESS**
- **Structured approach to including Other Satellites**

2020+



Programs formulated as one integrated system

HES

- The Hyperspectral Environmental Suite (HES) will be located on a geostationary platform.
 - 2013
 - NOAA operational
 - Currently in formation phase
- HES is an outgrowth of earlier ABS efforts
 - HES includes the functionality of the old Advanced Baseline Sounder (ABS)
 - HES has been expanded to include other capabilities for environmental monitoring employing the improved temporal resolution from GEO.
 - Coastal Ocean
 - Open Ocean
 - Land

HES Tasks

- HES - Disk Sounding (HES-DS)
 - Formerly ABS -- Threshold Task
- HES - Severe Weather / Mesoscale (HES-SW/M)
 - Threshold Task

- HES - Coastal Waters (HES-CW)
 - Threshold Task

- HES - Ocean Waters (HES-OO)
 - Goal Task

- HES - Land (HES-L)
 - Goal Task



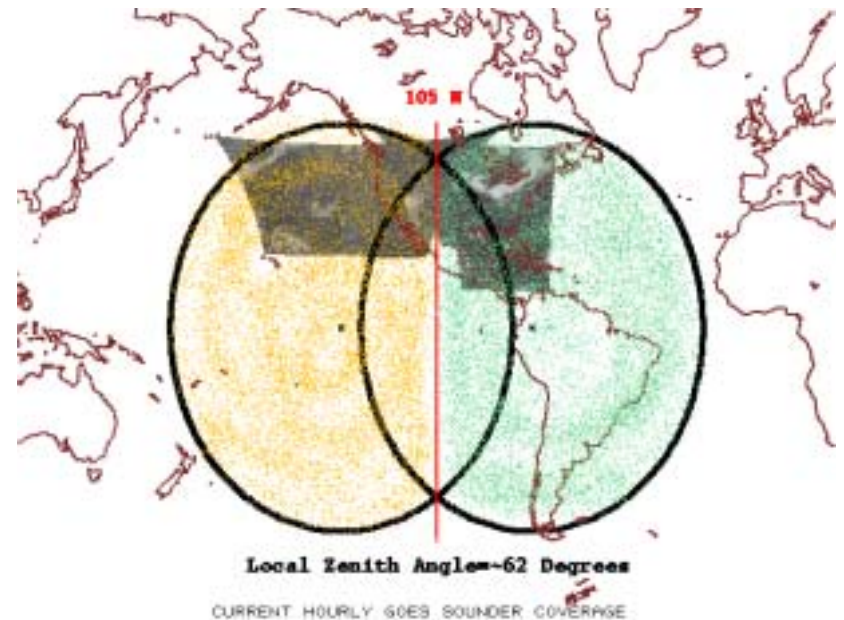
Not covered
in this talk

HES Tasks

- HES - Disk Sounding (HES-DS)
 - Provide **vertical moisture and temperature information**, and **other environmental data** that will be used by NOAA and other public and private agencies to produce routine meteorological analyses and forecasts
 - Provide data that may be used to extend knowledge and understanding of the atmosphere and its processes in order to **improve short/long-term weather forecasts**.
- HES - Severe Weather / Mesoscale (HES-SW/M)
 - Provide **environmental data** that can be used to expand knowledge of **mesoscale** and synoptic scale storm development and provide data that may be used to help in forecasting severe weather events.
 - Backup mode in the event of a GOES-R ABI failure (both).

HES-Disk Sounding (HES-DS) task

- Spatial Resolution
 - IR: Threshold=10 km, Goal=2 km,
 - Vis: Threshold=1.0 km, Goal= 0.5 km
- Coverage rate (Threshold)
 - 62 degree LZA / hour at 10 km resolution
 - Coverage area must be flexible and selectable.



HES-Disk Sounding (HES-DS) task

- Spectral Coverage
 - Three specific examples of coverage have been defined
 - Essentially: 15 μm CO_2 band for temperature, clear windows from 13 μm and extending past the ozone band at 9.6 μm to 8.3 μm , and either side of the 6 μm H_2O band. More temperature: Coverage of 4.7 μm to 4.4 μm and goal coverage of 4.7 μm to 3.7 μm . Visible: 0.52-0.7 μm
- Spectral resolution:
 - 15 μm CO_2 band: 0.6 cm^{-1} , Windows: 0.6-1.0 cm^{-1} , Ozone: 1 cm^{-1} , H_2O : 1-2 cm^{-1} , near 4 μm : 2.5 cm^{-1} , Visible: 0.18 μm

IR Spectral Coverage (DS or SW/M)

Example 1

Example 2

(Example 3 not shown)

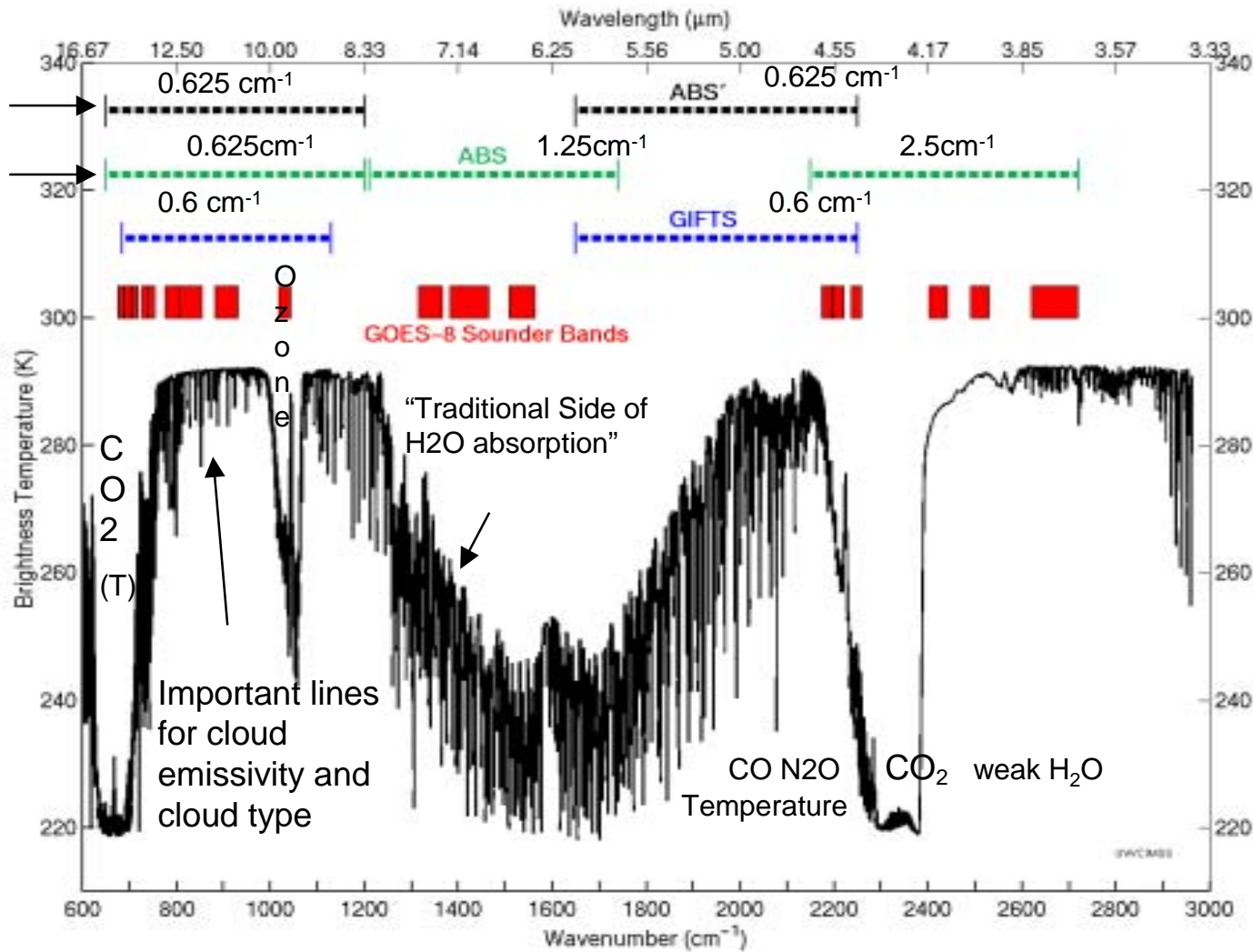


Table 3.2.1 Sounding sensor(s) THRESHOLD bands.

Band	HES Band Number	Spectral Range (cm⁻¹)	Spectral Range (microns)	Band Continuity
LWIR	1	650 – 1200	15.38 - 8.33	Contiguous
MWIR (option 1)	2	1650 – 2150	6.06 - 4.65	Contiguous
MWIR (option 2)	2	1210 – 1740	8.26 - 5.74	Contiguous
SWIR	3	2150 – 2250	4.65 - 4.44	Contiguous
VIS	4	NA	0.52 - 0.70	Contiguous

As a GOAL, the sounding task sensor(s) SWIR contiguous spectral range (HES band 3) should be 2150 – 2720 cm⁻¹ (4.65 – 3.68 microns).

The following is under review by the HES PORD Team

Table 3.2.4 Sounding sensor(s) THRESHOLD spectral resolution.

Band	HES Band Number	Spectral Resolution (cm⁻¹)	Spectral Resolution (microns)
LWIR	1	0.625	TBS
MWIR (option 1)	2	1.25	TBS
MWIR (option 2)	2	1.25	TBS
SWIR	3	2.5	TBS
VIS	4	NA	0.18

Table 3.2.5 Sounding sensor(s) GOAL spectral resolution

Band	HES Band Number	Spectral Resolution (cm⁻¹)	Spectral Resolution (microns)
LWIR	1	0.625	TBS
MWIR (option 1)	2	0.625	TBS
MWIR (option 2)	2	0.625	TBS
SWIR	3	0.625	TBS

Abstracted list of NEDN points

Wavenumber (cm ⁻¹)	Resolution element	NEDN (mW/m ² sr cm ⁻¹)	NEdT at 250 K(K)
650	0.625	< / = 1.265	< / = 1.036
670	0.625	< / = 0.40	< / = 0.31
700	0.625	< / = 0.212	< / = 0.175
750	0.625	< / = 0.176	< / = 0.147
800	0.625	< / = 0.166	< / = 0.146
950	0.625 or <0.75	< / = 0.182 or <0.17	< / = 0.191 or <0.18
1150	0.625 or <0.90	< / = 0.310 or <0.26	< / = 0.483 or <0.40
1200	0.625 or <0.94	< / = 0.529 or <0.43	< / = 0.918 (goal) or <0.75
1258 or 1923 or 1258	1.25 or 0.625 or 1.25	≤ 0.066 or ≤ 0.050 or ≤ 0.066	≤ 0.135 or ≤ 0.853 or < 0.135
1650 or 1644 or 1650	1.25 or 0.625 or 1.25	≤ 0.092 or ≤ 0.077 or < 0.092 (using 0.05 for the third column meets all point across the band, as shown in Fig. 4)	≤ 0.605 or ≤ 0.504 or < 0.605 (using 0.33 for the third column meets all points across the band, shown Fig.4)
2150 or 2141 or 2150	2.50 or 0.625 or 2.50	≤ 0.01 or ≤ 0.061 or < 0.01	≤ 0.416 or ≤ 2.383 or < 0.416
2350 or xx or 2350	2.50 or xx or < 2.50	≤ 0.011 or xx or < 0.01	≤ 0.966 or xx or < 0.966
2513 or xx or 2513	2.50 or xx or < 2.50	≤ 0.011 or xx or < 0.011	≤ 1.981 or xx or < 1.981

HES-DS Noise (Abstracted NEDN)

NEdNs for HES-DS when using examples 1, 2, and 3 from the MRD

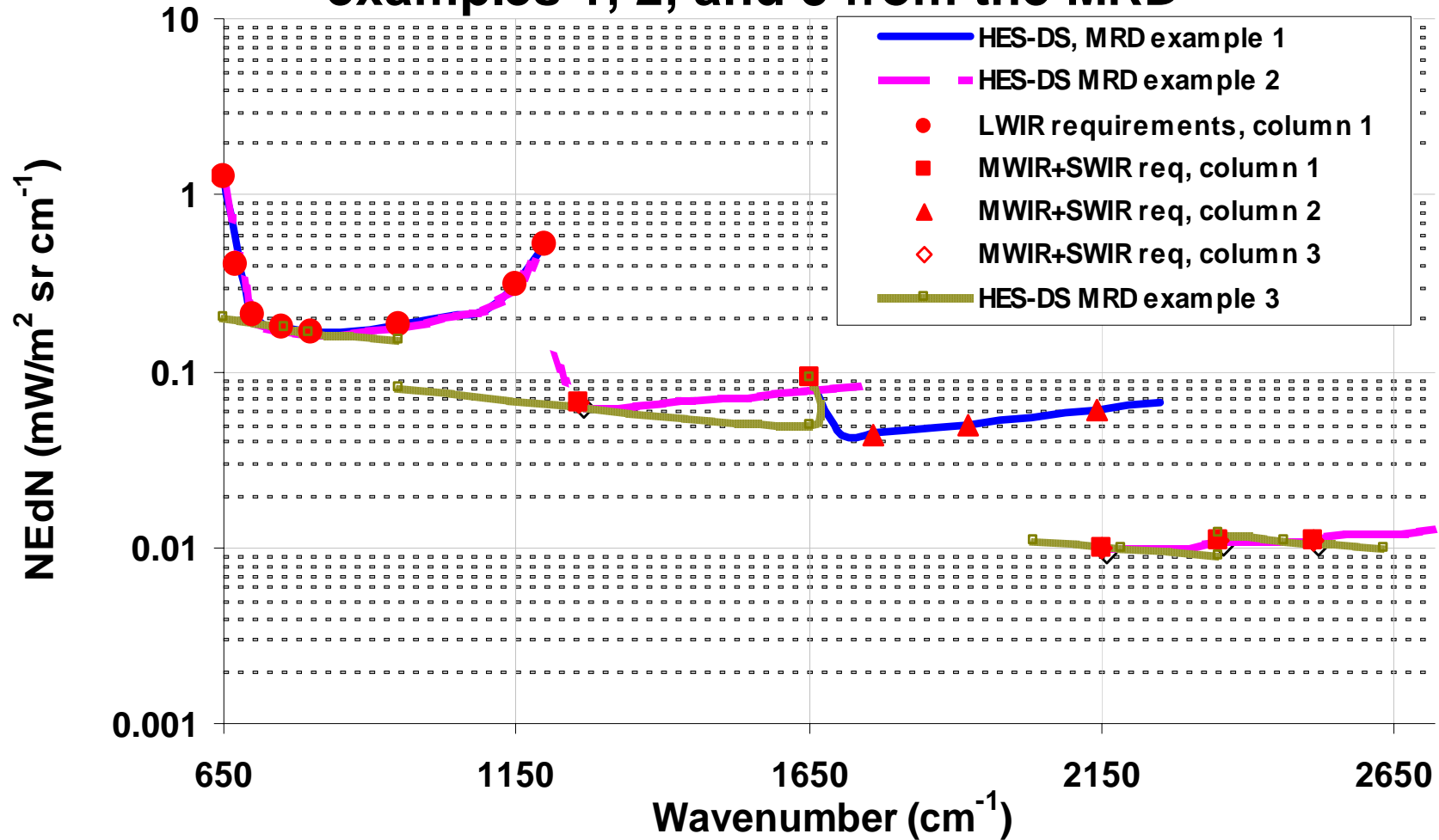


Table 3.1.1 THRESHOLD and GOAL Operational Zones

Channel	Outer Limit (THRESHOLD)	Outer Limit (GOAL)
Emitted IR bands (650-2720 cm ⁻¹)	10° (TBR)	5° (TBR)
Reflected Solar (0.4-3.0 um)	10° (TBR)	5° (TBR)
Low light	10° (TBR)	5° (TBR)

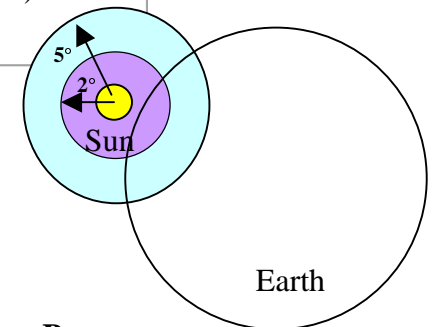
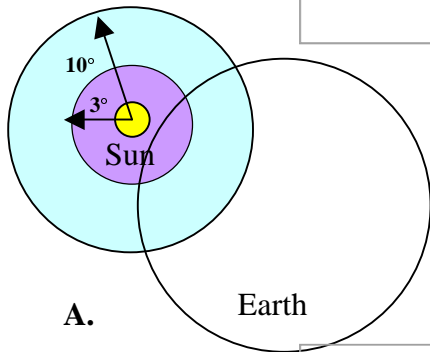
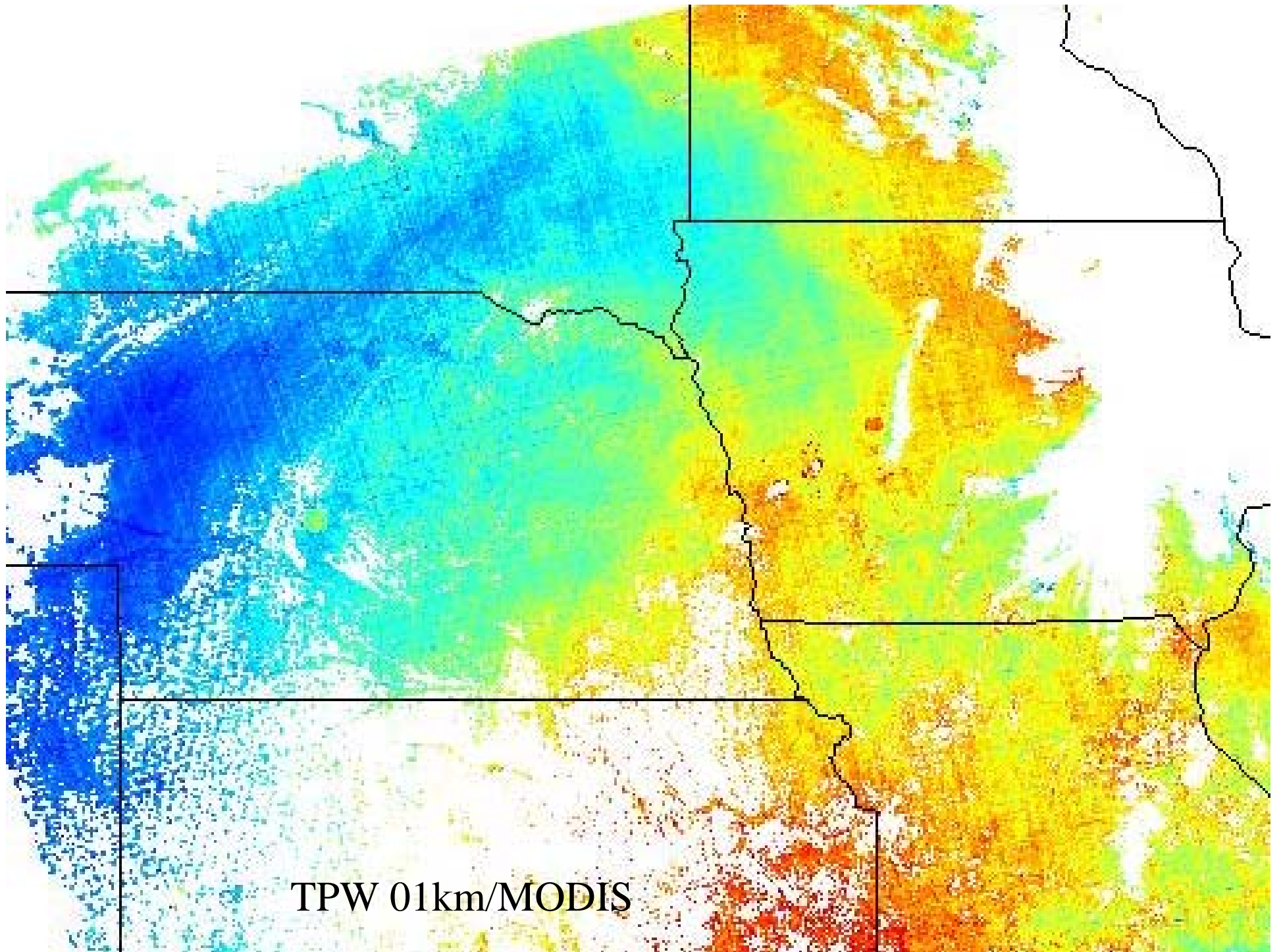


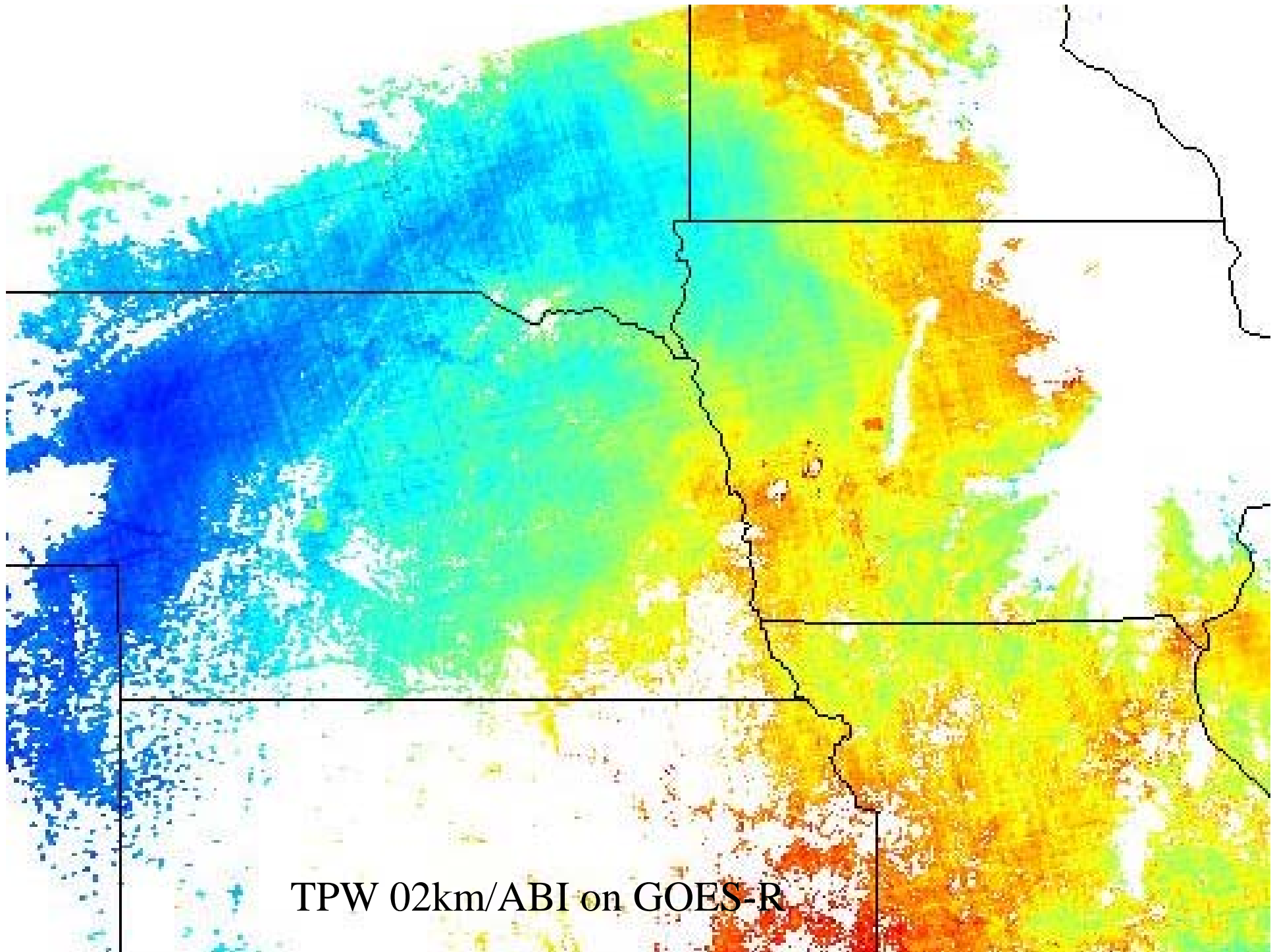
Table 3.1.2 THRESHOLD and GOAL Restricted Zones

Channel	Outer Limit (THRESHOLD)	Outer Limit (GOAL)
Emitted IR bands (650-2720 cm ⁻¹)	3° (TBR)	2° (TBR)
Reflected Solar (0.4-3.0 um)	3° (TBR)	2° (TBR)
Low light (visible)	3° (TBR)	2° (TBR)

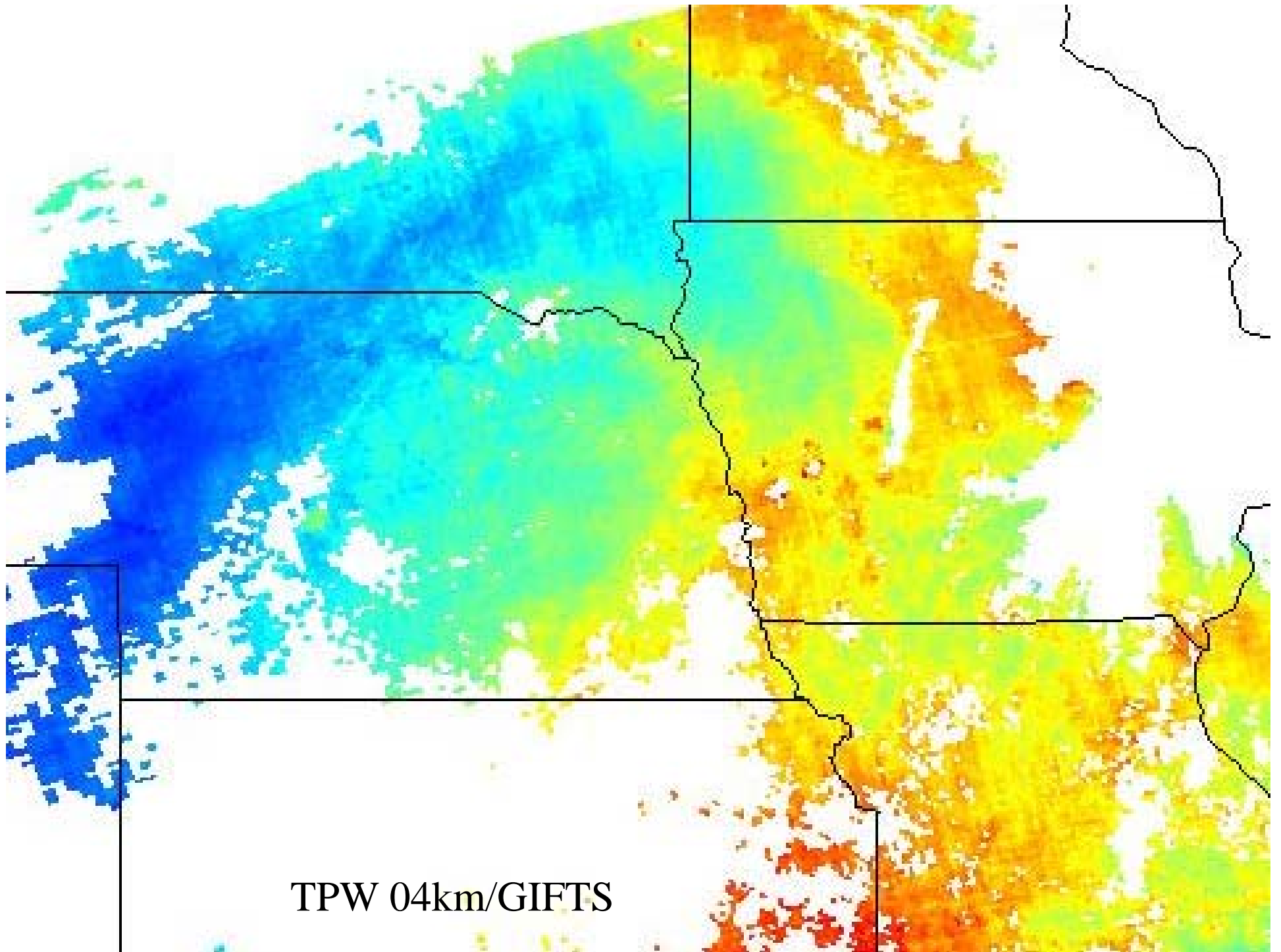
HES-Severe Weather/Mesoscale task

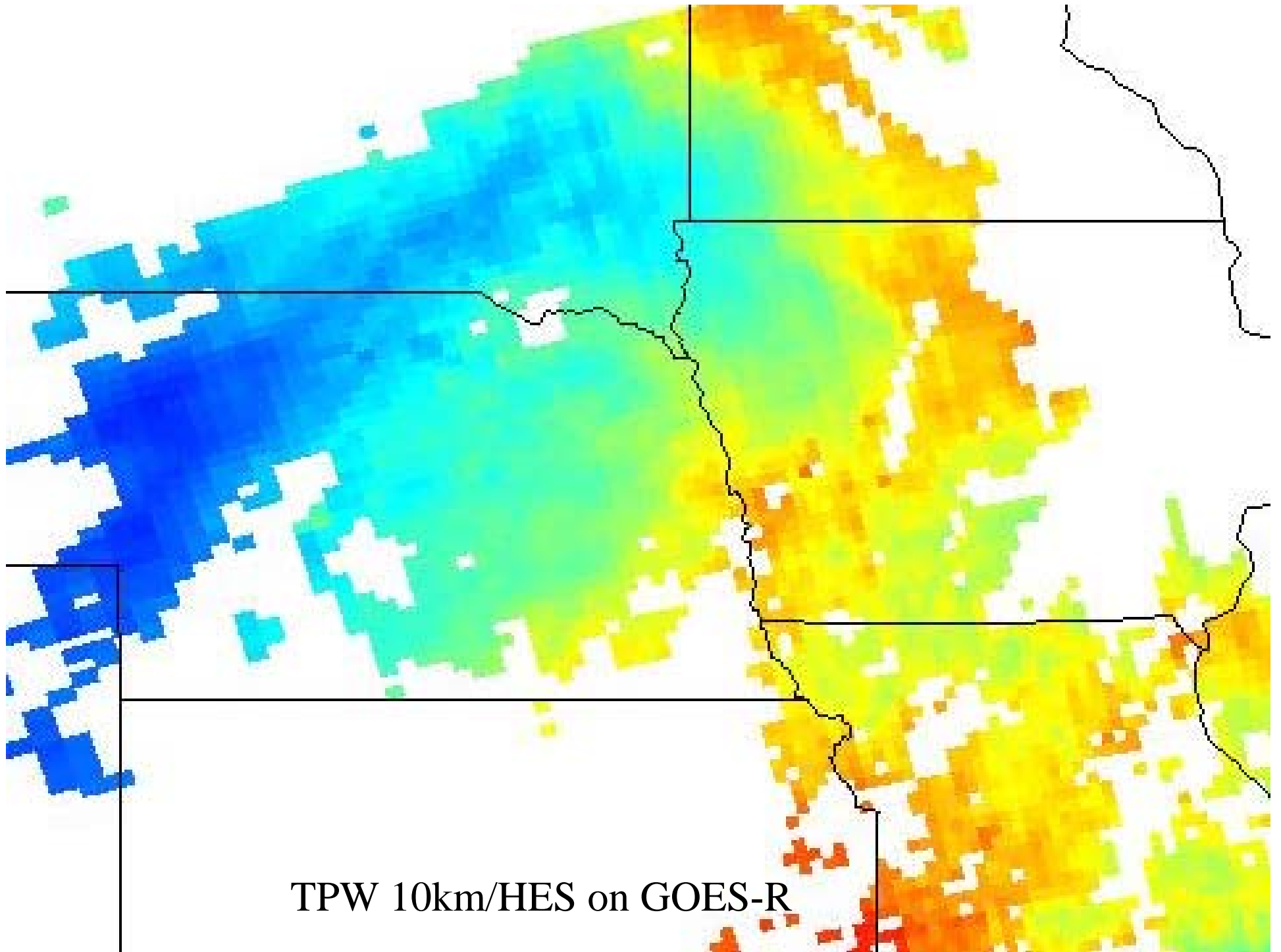
- Spatial Resolution
 - IR: Threshold=4 km, Goal=2 km,
 - Vis: Threshold=1.0 km, Goal= 0.5 km
- Coverage rate
 - 1000 km x 1000 km (locations vary) in 4.4 minutes
 - Coverage area must be flexible and selectable.
- Spectral coverage:
 - Specific examples are cited in the MRD, same as HES-DS
- Spectral resolution:
 - 15 μm CO₂ band: 0.6 cm⁻¹, Windows: 0.6-1.0 cm⁻¹,
Ozone: 1 cm⁻¹, H₂O: 1-2 cm⁻¹, near 4 μm : 2.5 cm⁻¹,
Visible: 0.18 μm



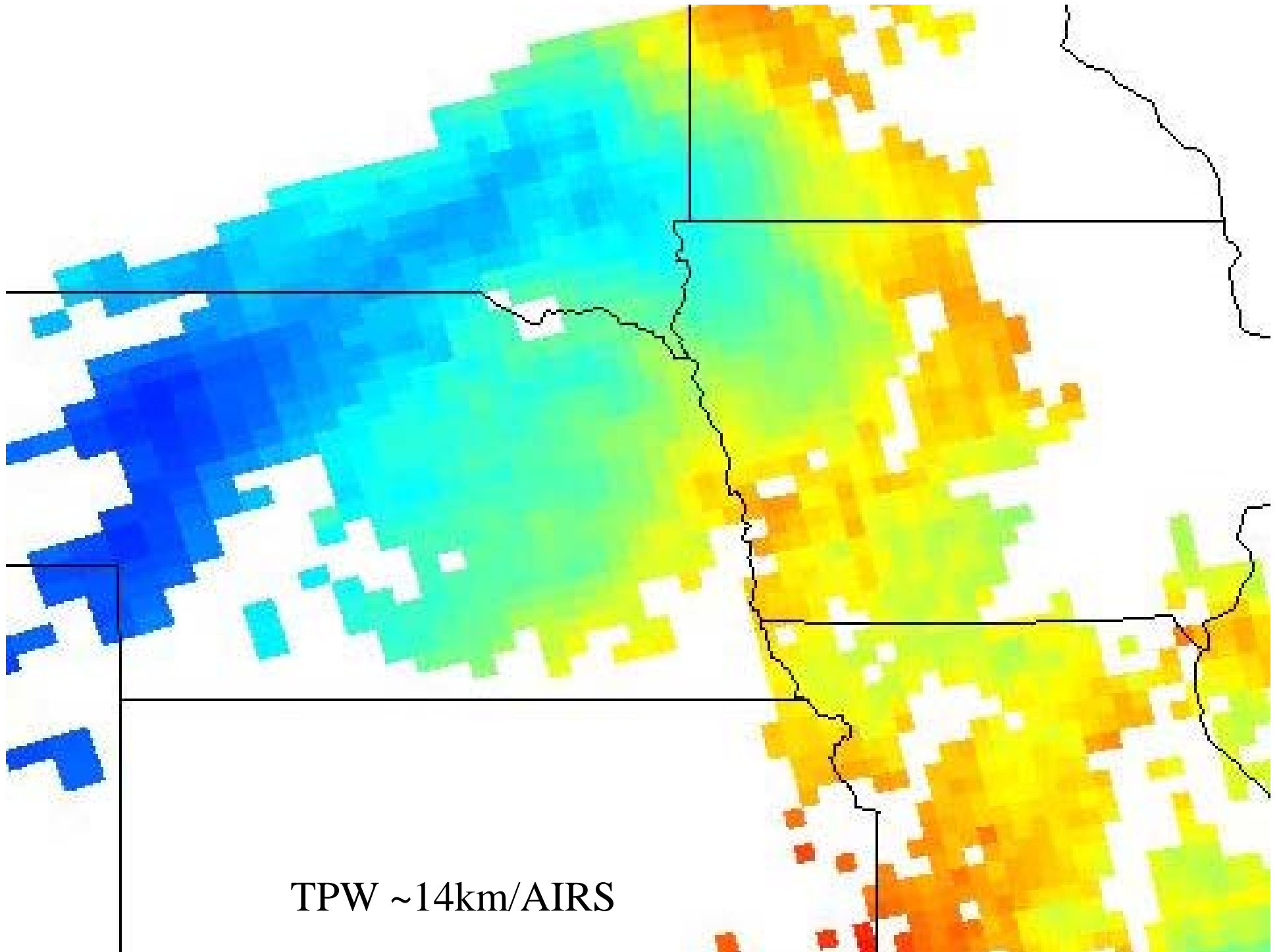


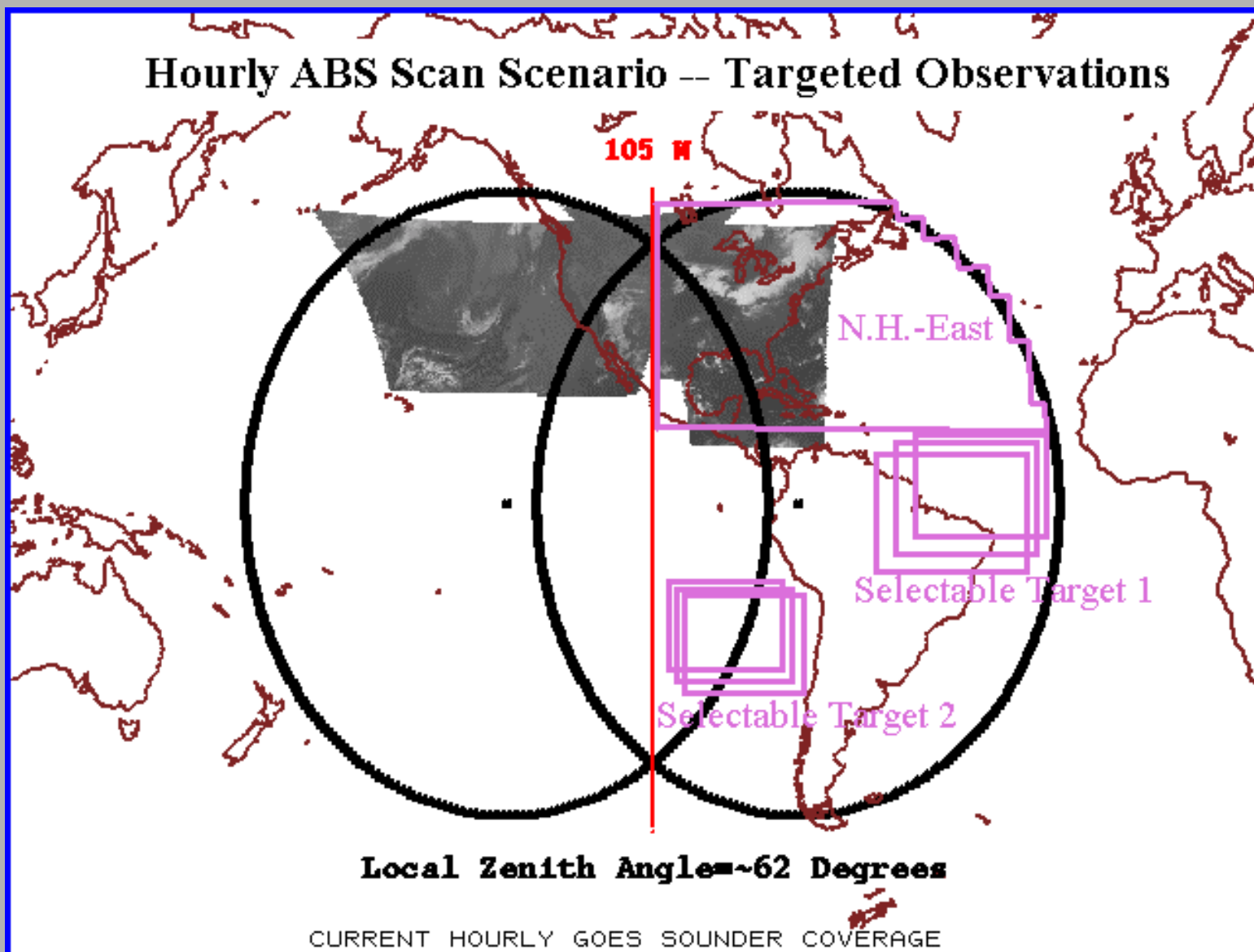
TPW 02km/ABI on GOES-R





TPW 10km/HES on GOES-R





Targeted observations -- look where we need the information

Table 3.2.33 Expected scan times for the DS task sensor emissive bands (HES bands 1-3).

Coverage Region	Coverage Area (km²)	GSR (Hz)	GSD (km)	Within Frame Scan Efficiency	Coverage Time
Full Disk	1.00E+08	300	10	0.6	1 hr 32.6 min
62-degree LZA	7.00E+07	300	10	0.65	0 hr 59.8 min
CONUS	1.50E+07	300	10	0.9	0 hr 9.3 min
Mesoscale	1.00E+06	300	10	0.8	0 hr 0.7 min
Coastal Waters	2.40E+06	300	10	0.95	0 hr 1.4 min

Table 3.2.34 Expected scan times for the SW/M task sensor emissive bands (HES bands 1-3).

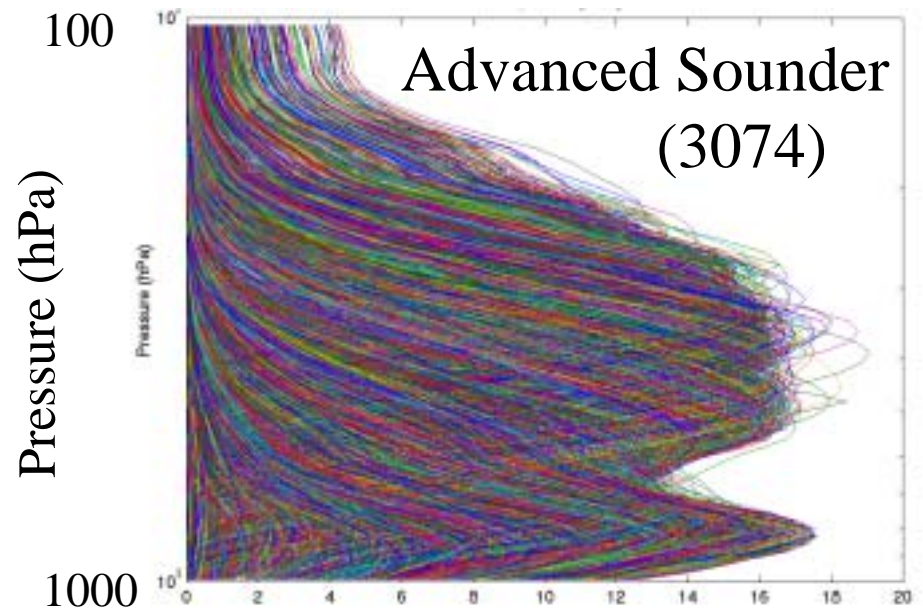
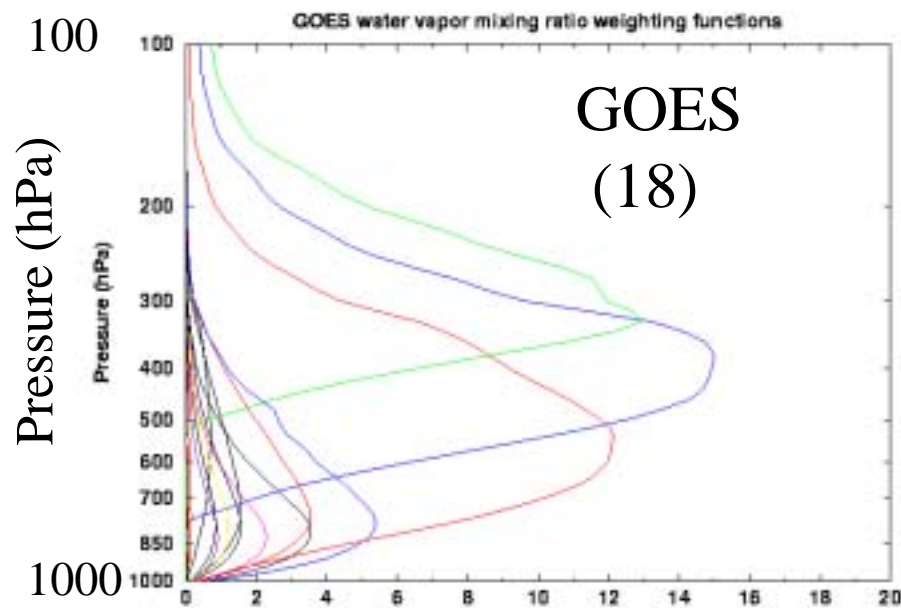
Coverage Region	Coverage Area (km²)	GSR (Hz)	GSD (km)	Within Frame Scan Efficiency	Coverage Time
Full Disk	1.00E+08	300	4	0.6	9 hr 38.7 min
62-degree LZA	7.60E+07	300	4	0.65	6 hr 46.0 min
CONUS	1.50E+07	300	4	0.9	0 hr 57.9 min
Mesoscale	1.00E+06	300	4	0.8	0 hr 4.3 min
Coastal Waters	2.40E+06	300	4	0.95	0 hr 8.8 min

Notional HES

- Features:
 - HES-IR Full Disk, SW/M (Severe Weather/Mesoscale) tasks
 - HES-Vis/nIR CW (Costal Waters) task
- Mass: 280 kg (combined)
- Power: 550 W (combined); 100% duty cycle
- Volume:
 - 1.80m (EW) x 1.50m (NS) x 1.60m (Nadir)
- Data Rate: 65 Mbps

Sounder Comparison (GOES-Current to HES-Req)

	<u>Current</u>	<u>Requirement</u>
Coverage Rate	CONUS/hr	Sounding Disk/hr
Horizontal Resolution		
- Sampling Distance	10 km	10 km
- Individual Sounding	30-50 km	10 km
Vertical resolution	~3 km	1 km
Accuracy		
Temperature	2 deg. K	1 deg. K
Relative Humidity	20%	10%

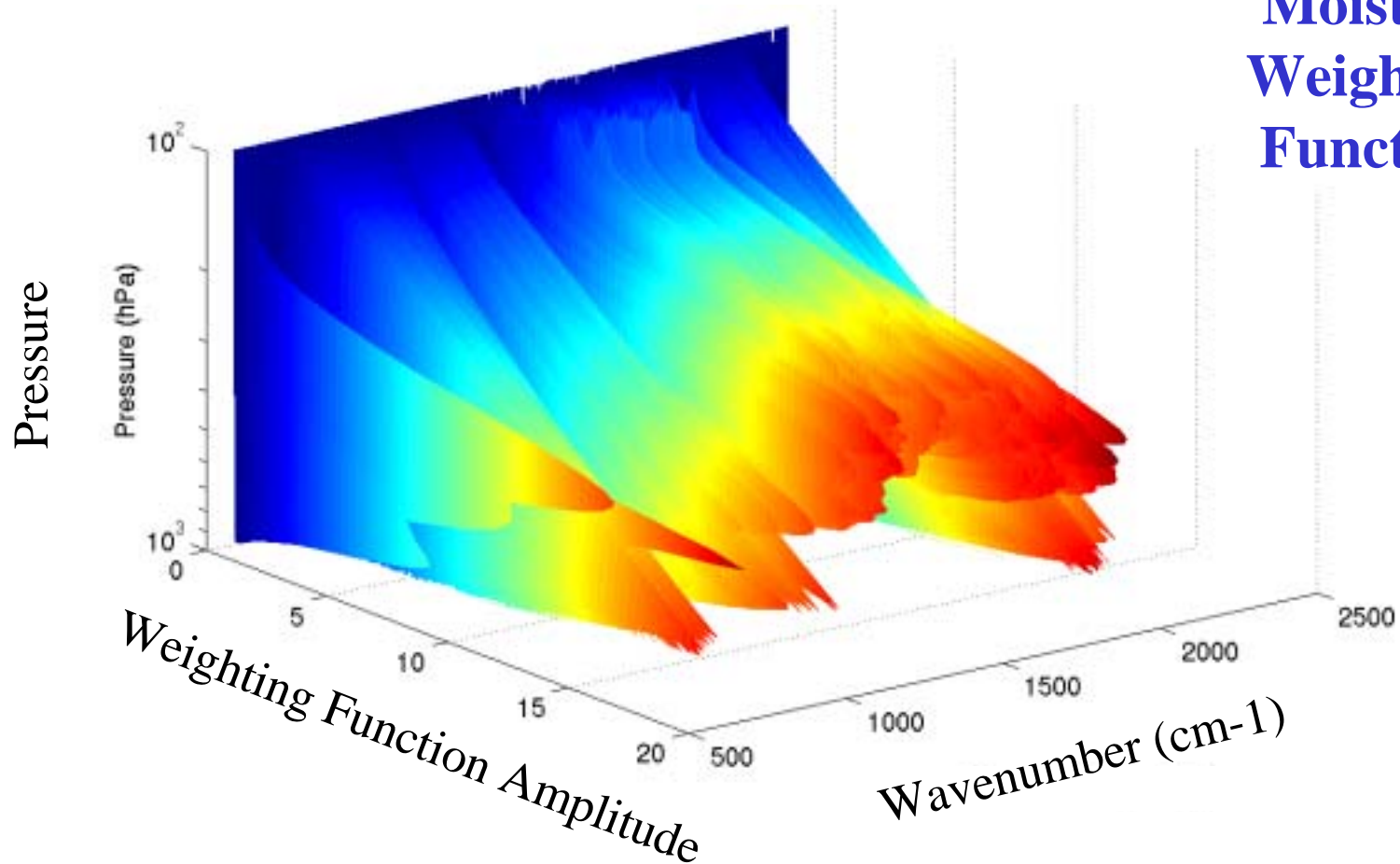


Moisture Weighting Functions

High spectral resolution advanced sounder will have *more and sharper weighting functions* compared to current GOES sounder. Retrievals will have better vertical resolution.

These water vapor weighting functions reflect the radiance sensitivity of the specific channels to a water vapor % change at a specific level (equivalent to $dR/d\ln q$ scaled by $d\ln p$).

Moisture Weighting Functions

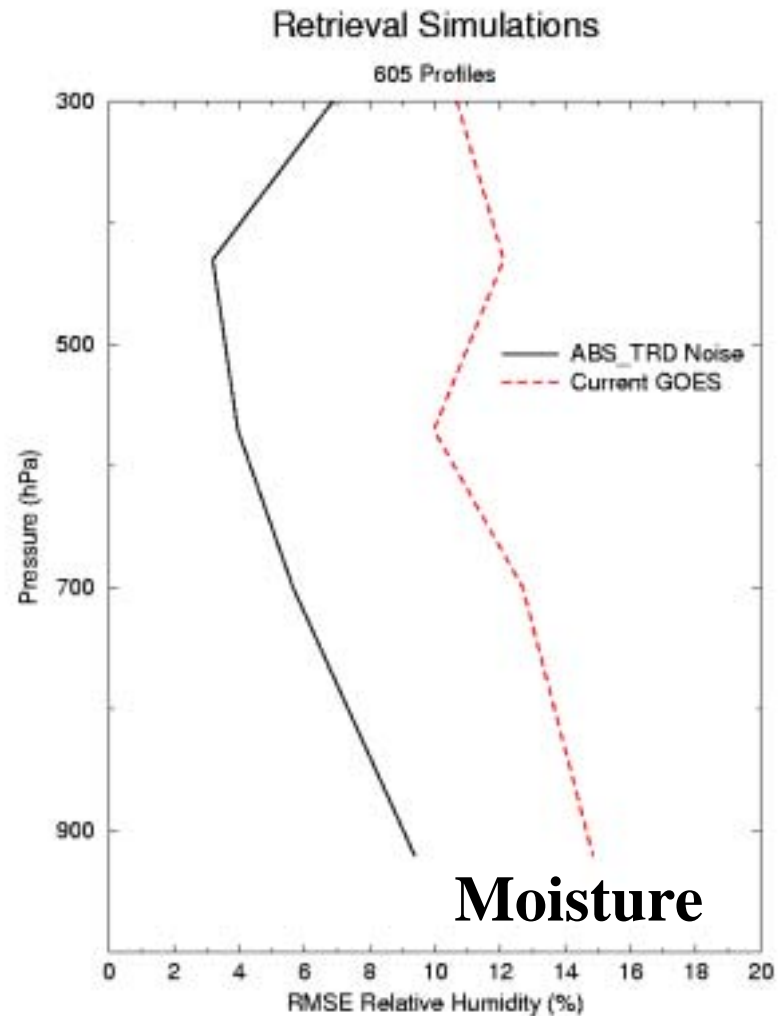
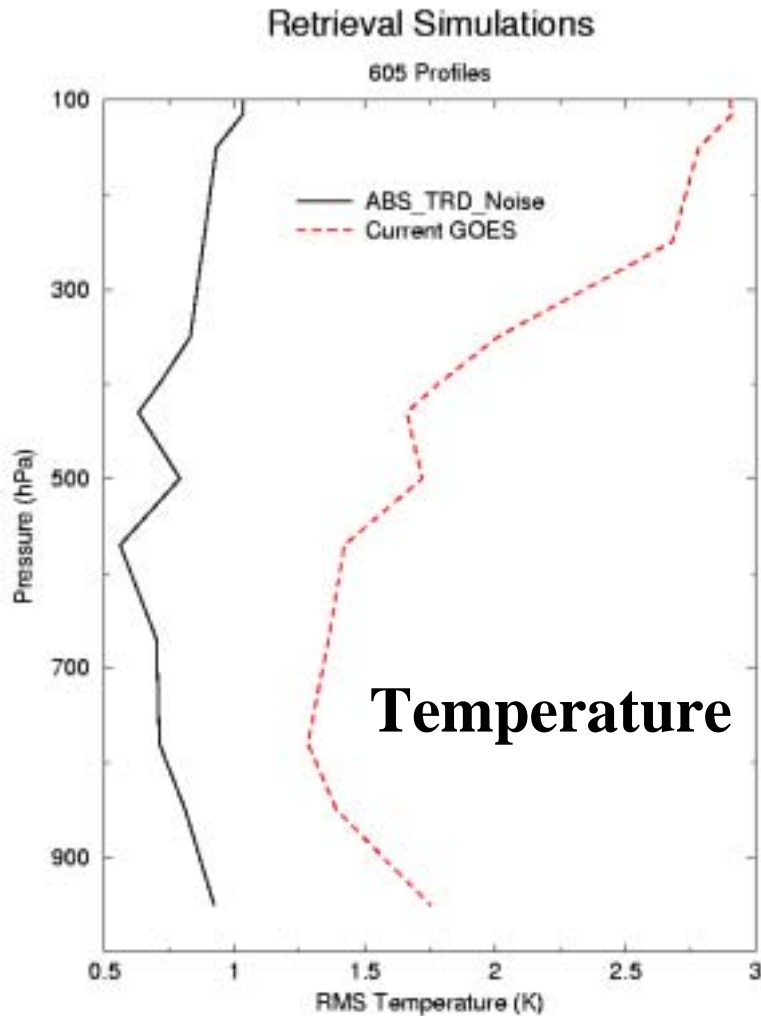


UW/CIMSS

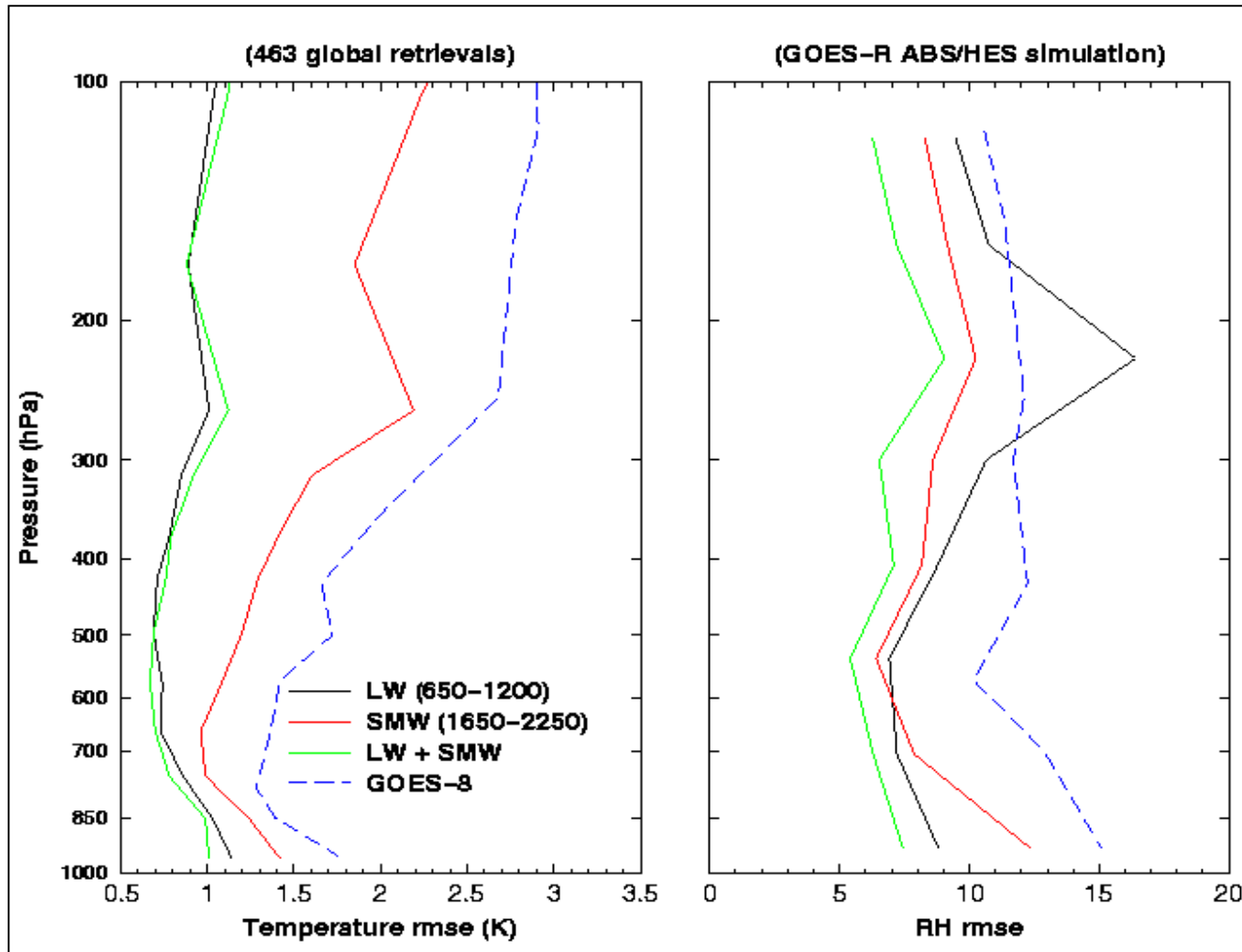
The advanced sounder has more and sharper weighting functions

Simulations of Low vs High Spectral Resolution Retrievals

Geo-I gets <1 K rms for 1 km T(p) and <10% rms for 2 km RH(p)

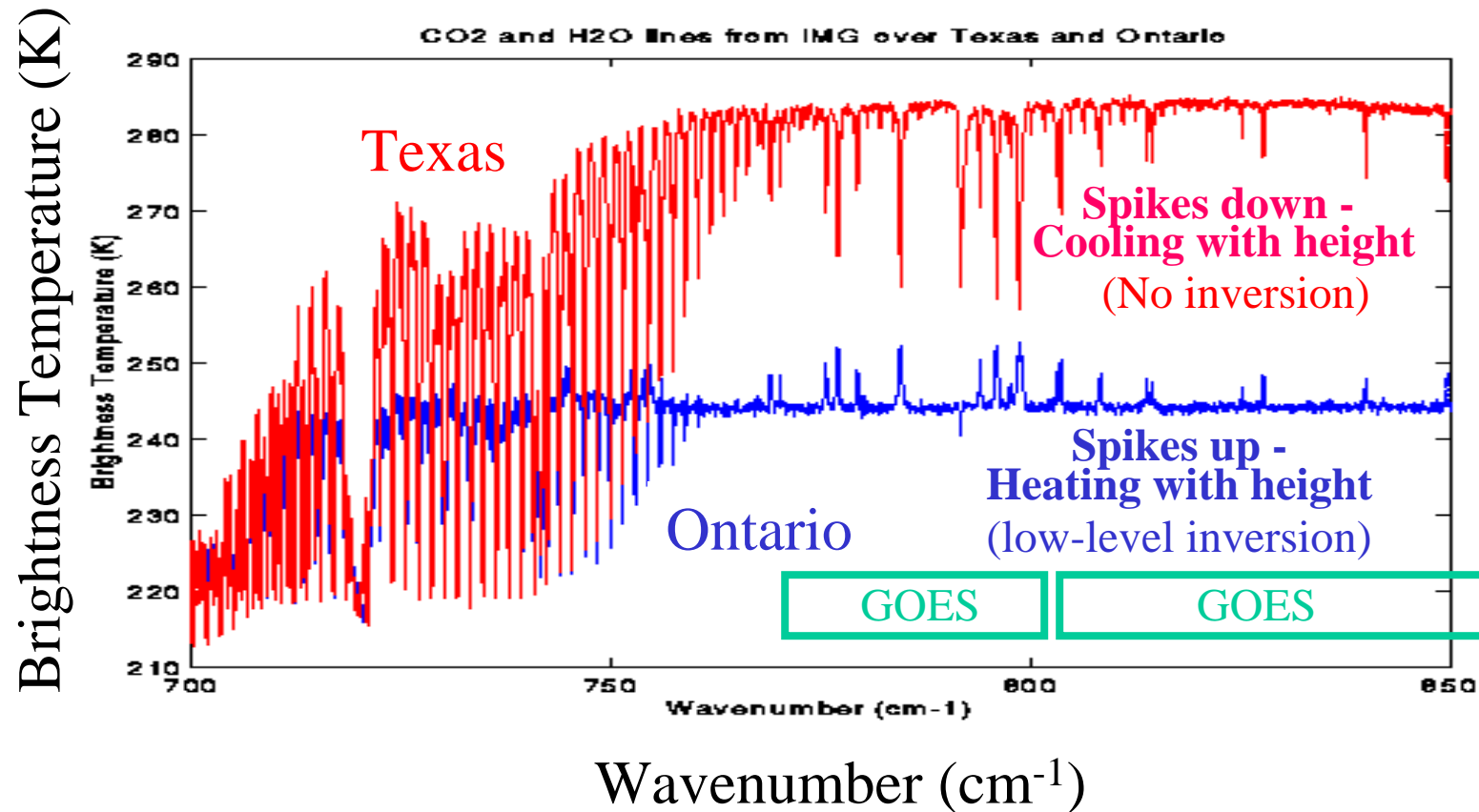


**Strategy is (1) use all channels in a regression first guess
and then (2) use sub-set of channels for physical retrieval**



The 1km vertical temperature retrieval RMSE (left panel) and 2km vertical water vapor (RH) retrieval RMSE (right panel) from HES LW only, SMW only, LW + SMW, and current GOES sounder. 463 independent profiles distributed globally are included in the retrieval statistics; TRD noise is used in the simulation.

Detection of Temperature Inversions Possible with Interferometer



Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.

The following is under review by the HES PORD Team

Table 3.2.8 THRESHOLD and GOAL spectral operability requirements

HES Band Number	Band/Task	Spectral Operability THRESHOLD	Spectral Operability GOAL
1	LWIR-Sounding	50%	100%
2	MWIR-Sounding	50%	100%
3	SWIR-Sounding	50%	100%
4	VIS-Sounding	100%	NA

Table 3.2.32 HES THRESHOLD and GOAL pixel operability and outage requirements

HES Band Number	Band/Task	Operability THRESHOLD	Outages THRESHOLD
1	LWIR-Sounding	87 %	4%
2	MWIR-Sounding	97 %	1%
3	SWIR-Sounding	99% (TBR)	0% (TBR)
4*	VIS-DS	99.9%	0% (TBR)
4*	VIS-SW/M	99.9% (TBR)	0% (TBR)

Table 3.2.37 - HES Navigation Requirements

HES Task	Threshold	Eclipse Threshold	Goal
DS	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA
SW/M	0.5 IR GSA	0.75 IR GSA	0.25 IR GSA
CW	56 urad	84 urad	28 urad

HES balance of temporal (30 min), spectral (0.5 cm⁻¹), spatial (2-10 km), and radiometric (0.1 K) capabilities will

- * depict water vapor as never before by identifying small scale features of moisture vertically and horizontally in the atmosphere
- * track atmospheric motions much better by discriminating more levels of motion and assigning heights more accurately
- * characterize life cycle of clouds (cradle to grave) and distinguish between ice and water cloud
- * measure surface temperatures (land and sea) by accounting for emissivity effects
- * distinguish atmospheric constituents with improved certainty; these include volcanic ash, ozone, and possibly others trace gases.

More information...

NASA's (draft) HES PORD (PERFORMANCE AND OPERATION REQUIREMENTS DOCUMENT):

<http://goes2.gsfc.nasa.gov/HEShome.htm>

Industry Day briefings:

http://goes2.gsfc.nasa.gov/goesr_industry.htm

CIMSS page:

<http://cimss.ssec.wisc.edu/goes/abs/>

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