Introduction of the Hyperspectral Environmental Suite (HES) on GOES-R and beyond

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SaTellite Applications and Research (STAR)
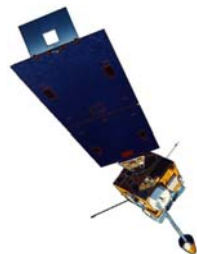
Advanced Satellite Products Team (ASPT)

Presented by *Jun Li* from the CIMSS
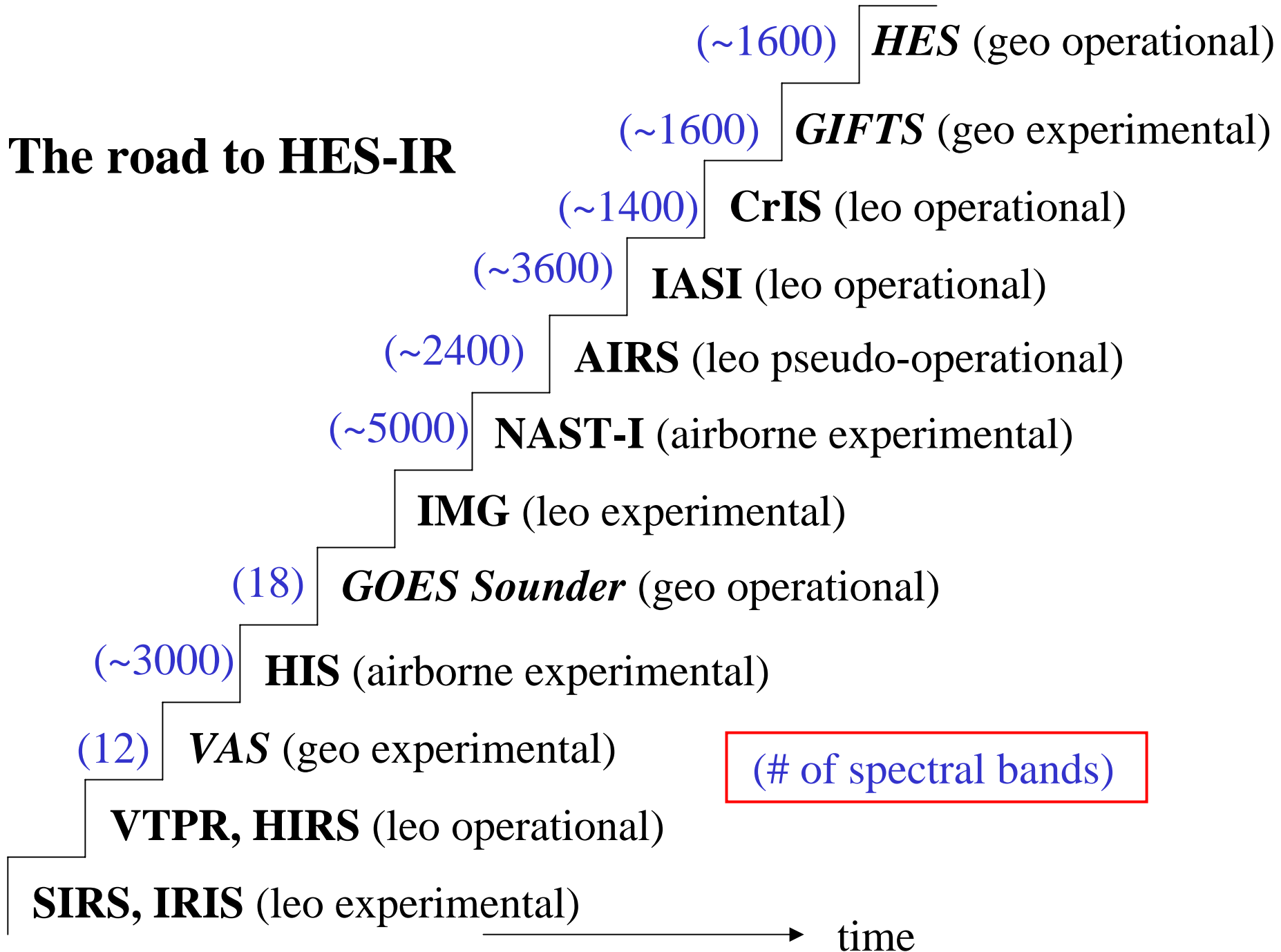
Madison, WI

James Gurka

NOAA/NESDIS/OSD

UW-Madison

The road to HES-IR

(~1600) | ***HES*** (geo operational)

(~1600) | ***GIFTS*** (geo experimental)

(~1400) | **CrIS** (leo operational)

(~3600) | **IASI** (leo operational)

(~2400) | **AIRS** (leo pseudo-operational)

(~5000) | **NAST-I** (airborne experimental)

IMG (leo experimental)

(18) | ***GOES Sounder*** (geo operational)

(~3000) | **HIS** (airborne experimental)

(12) | ***VAS*** (geo experimental)

VTPR, HIRS (leo operational)

SIRS, IRIS (leo experimental)

(# of spectral bands)

time

The road to HES-IR

(~1600) | *HES* (2013-)

(~1600) | *GIFTS* (2008-)

(~1400) | **CrIS** (2006-)

(~3600) | **IASI** (2005-)

(~2400) | **AIRS** (2002-)

(~5000) | **NAST-I** (1998-)

IMG (1997)

(18) | *GOES Sounder* (1994-)

(~3000) | **HIS** (1985-)
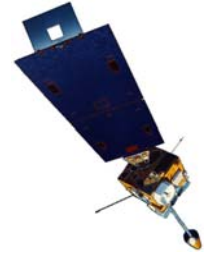
(12) | *VAS* (1980-)

VTPR, HIRS (1973, 1975-)

SIRS, IRIS (1969)

time

Future GOES
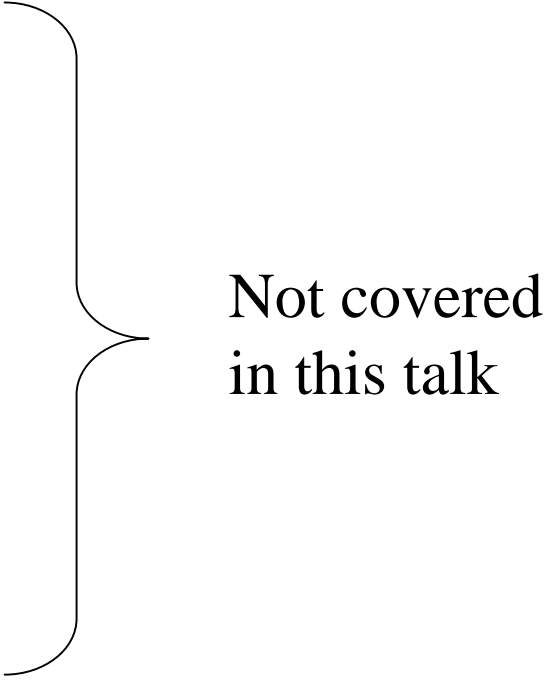
Future GOES will address all four key remote sensing areas

* **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.

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 – Open Ocean (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.

105 W

Local Zenith Angle=~62 Degrees

CURRENT HOURLY GOES SOUNDER COVERAGE
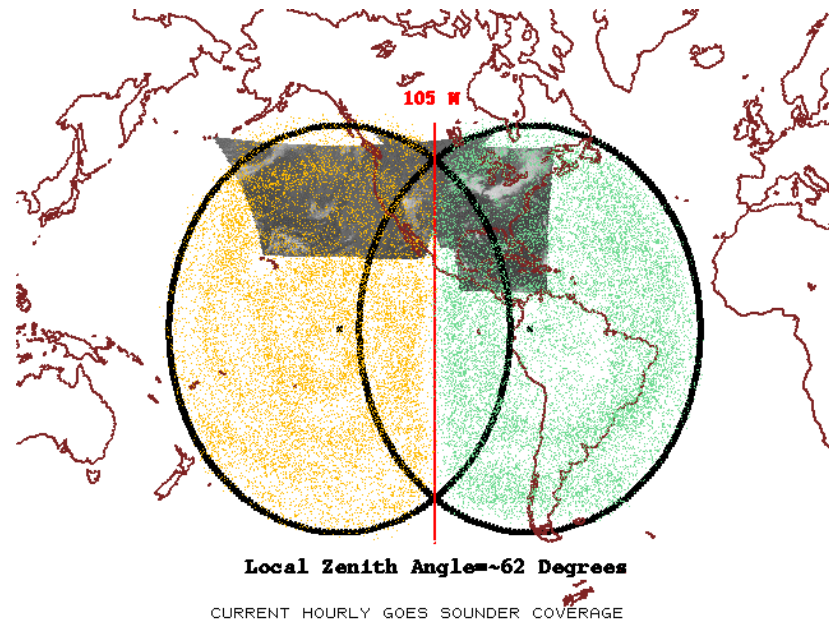
HES-Disk Sounding (HES-DS) task

- ## Spectral Coverage
  - Three specific examples of coverage have been defined
  - Essentially: 15 um CO_2 band for temperature, clear windows from 13 um and extending past the ozone band at 9.6 um to 8.3 um, and either side of the 6 um H_2O band. More temperature: Coverage of 4.7 um to 4.4 um and goal coverage of 4.7 um to 3.7 um. Visible: 0.52-0.7 um

- ## Spectral resolution:
  - 15 um 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 um: 2.5 cm-1, Visible: 0.18 um

IR Spectral Coverage (DS or SW/M)
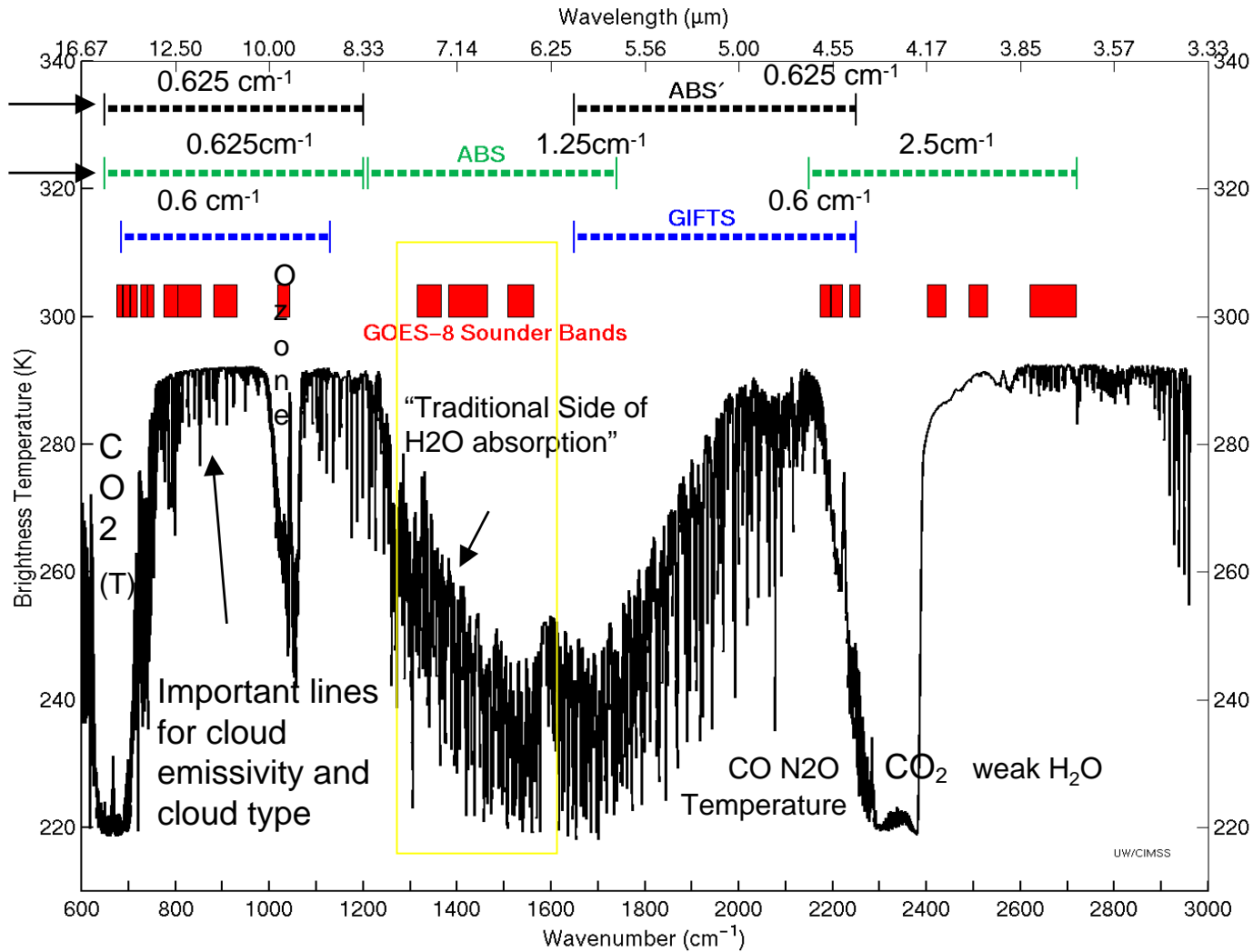
Some uses of the **current GOES Sounder**

NWP (Numerical Weather Prediction):
      Clear-sky radiances (Global, Eta)
      Precipitable water layers (CRAS, RUC, Eta)
      Cloud-top information (CRAS, RUC)
      Winds (NOGAPS)

Nowcasting/short-term forecasting:

TPW	Skin Temperature
Lifted Index	CAPE
Total Ozone	Images
Cloud Height	Effective Cloud Amount

The range of uses will dramatically increase with the improved spatial, spectral and temporal coverage of the HES-IR.

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

Coverage Region	Coverage Area (km^2)	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 (km^2)	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

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

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

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 ≤ 0.061or < 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
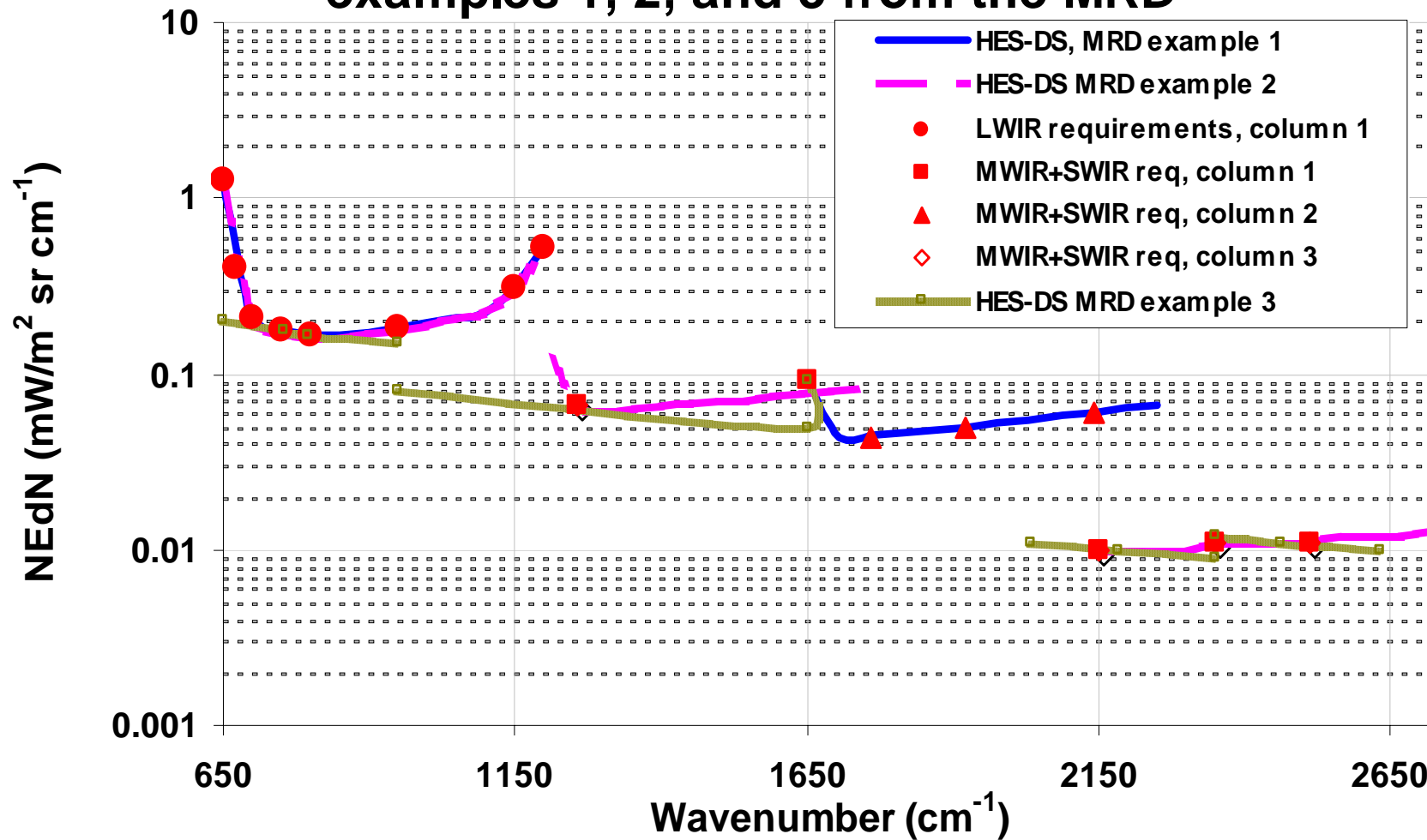
HES-Severe Weather/Mesoscale task

- 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 um 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 um: 2.5 cm^{-1}, Visible: 0.18 um
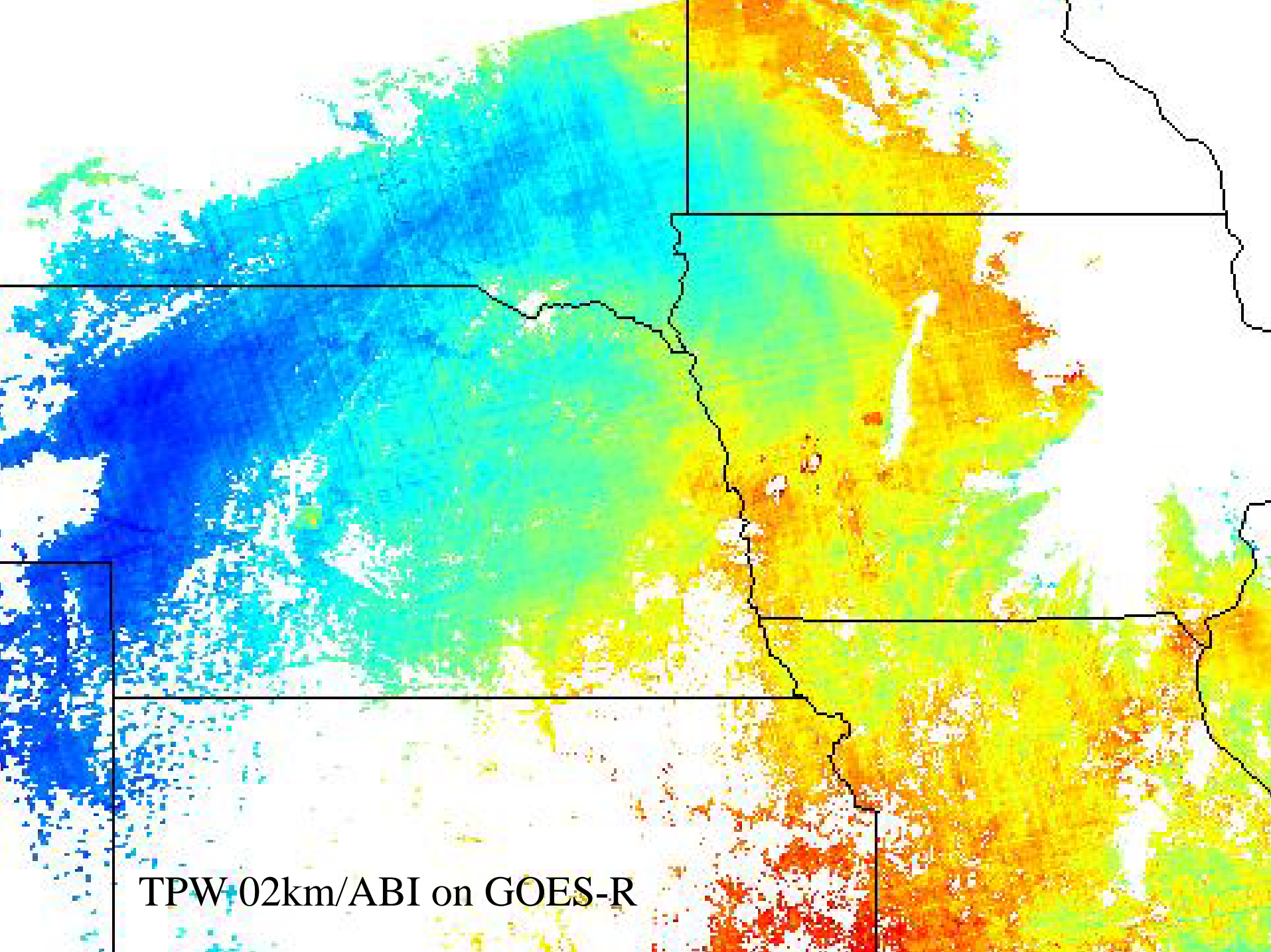
TPW 02km/ABI on GOES-R
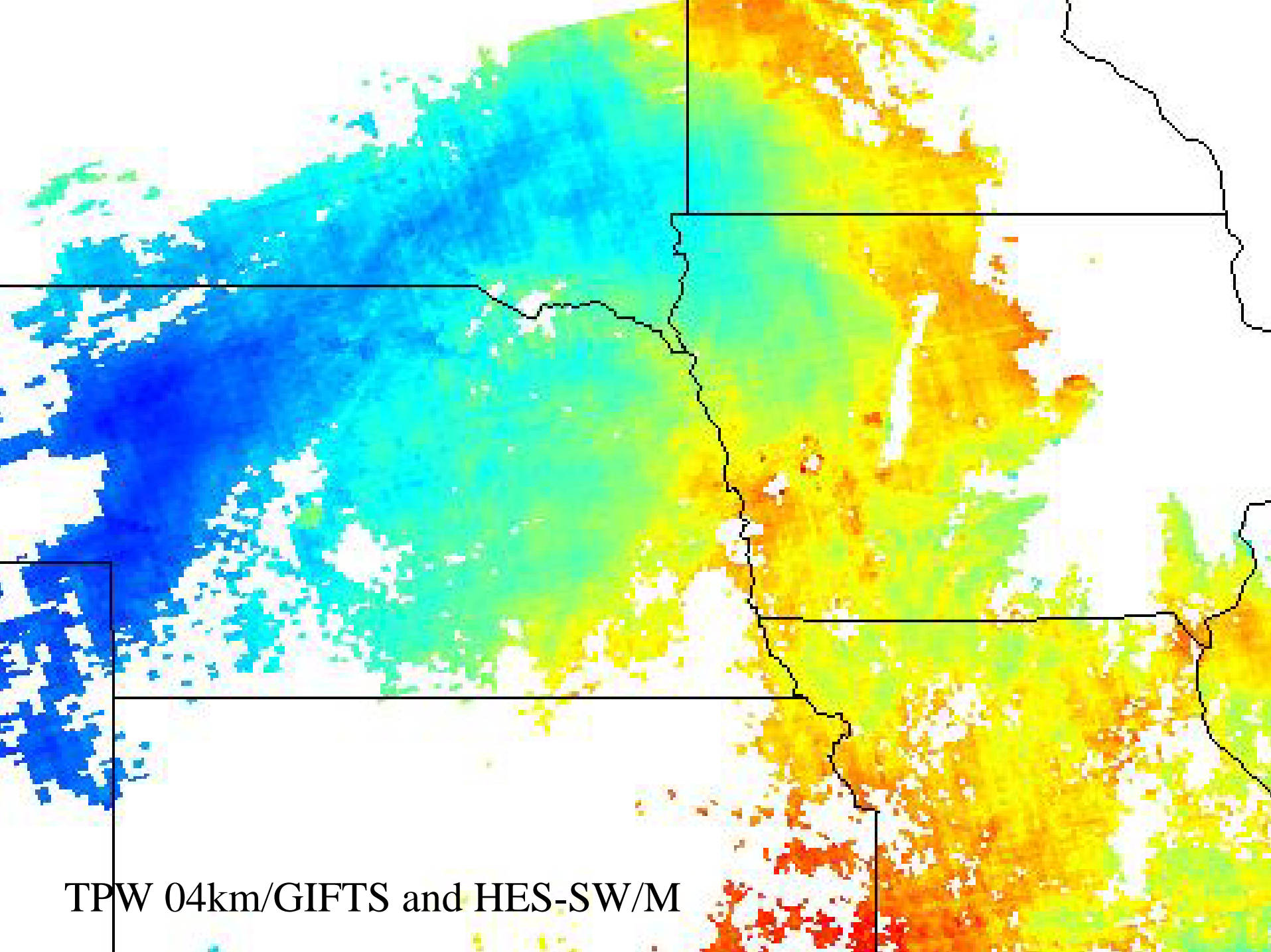
TPW 04km/GIFTS and HES-SW/M
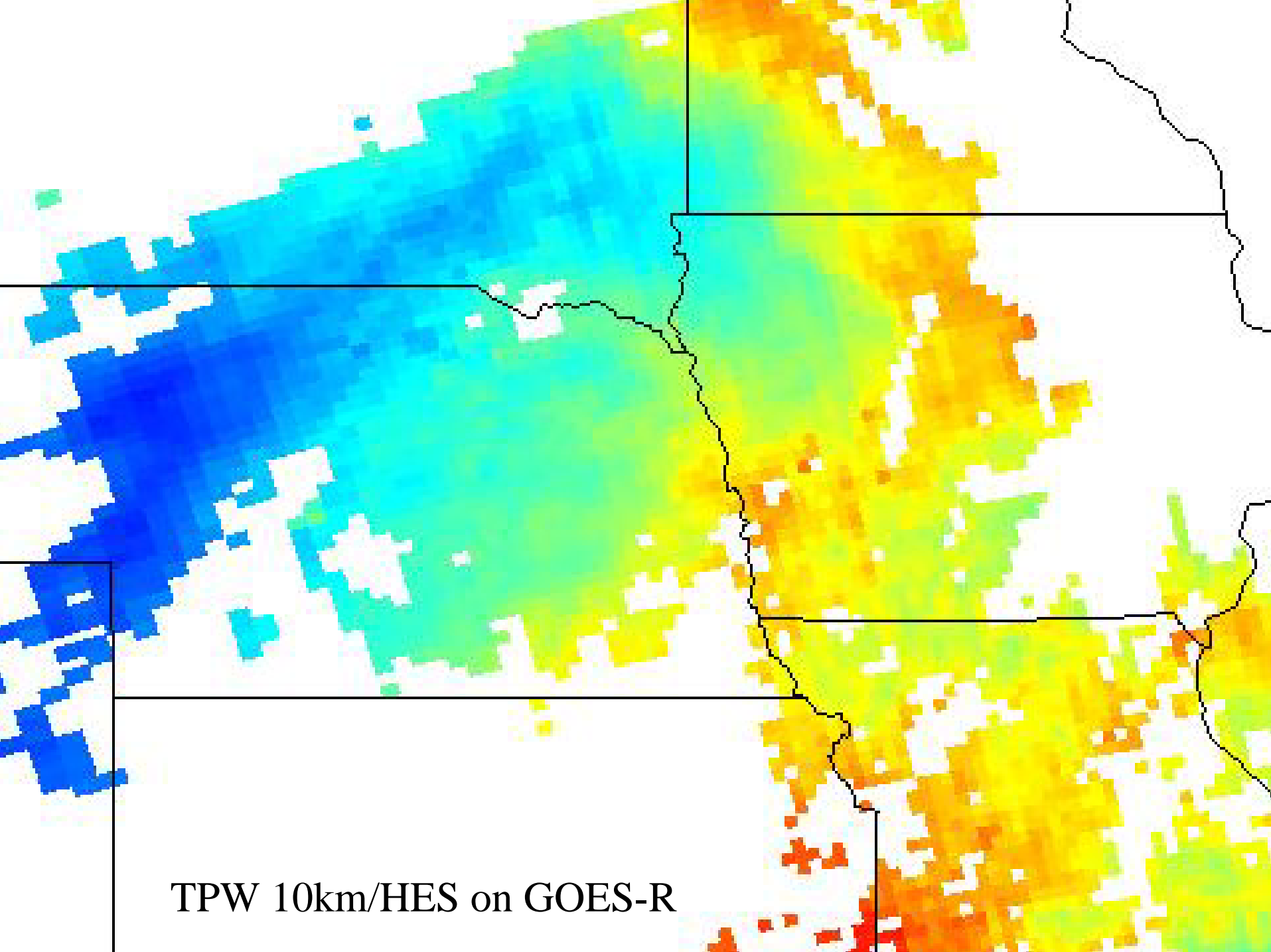
TPW 10km/HES on GOES-R
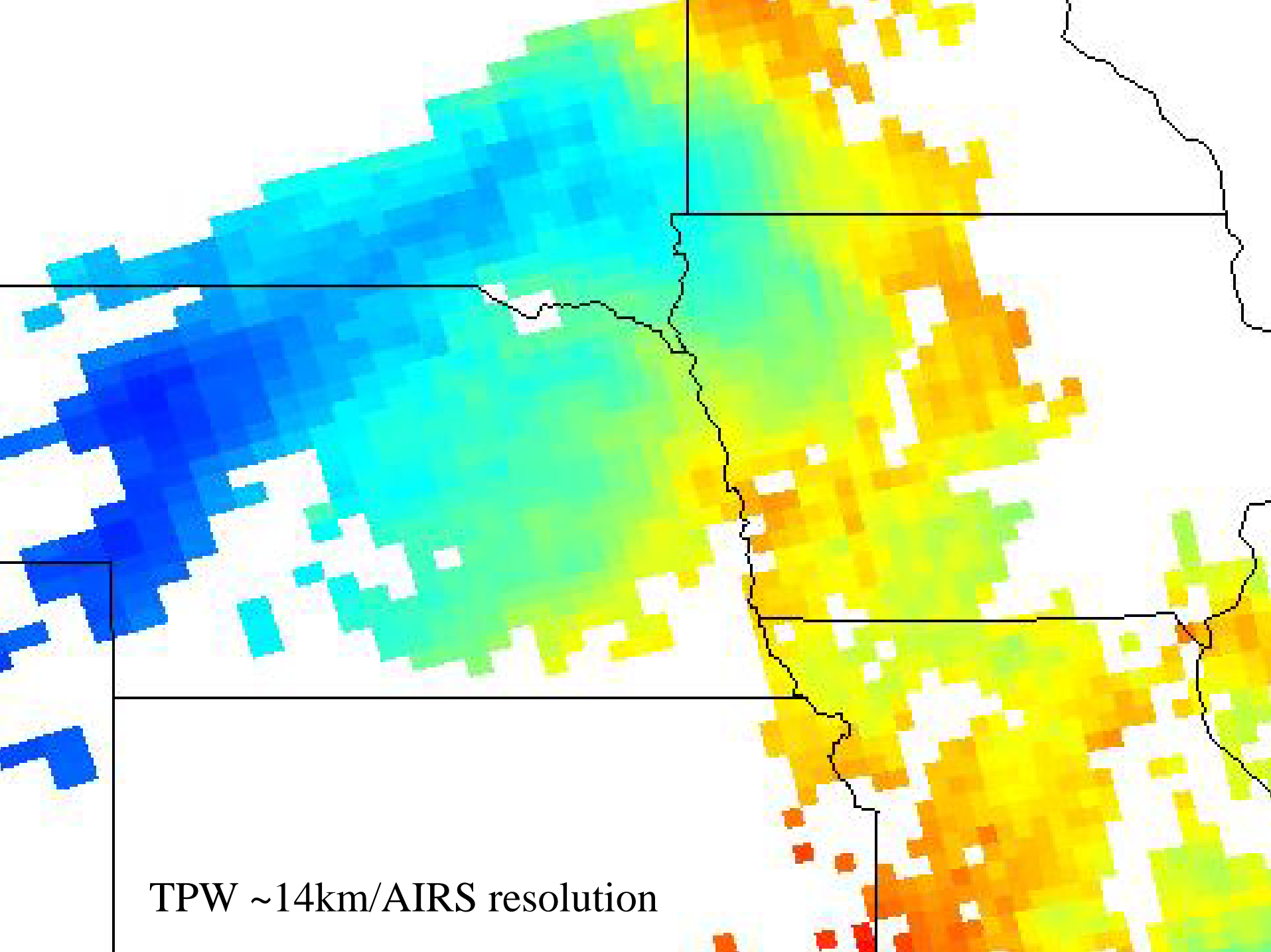
TPW ~14km/AIRS resolution

Sounder Comparison
(GOES-Current to HES-Req)

	Current	**Requirement**
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%

GOES water vapor mixing ratio weighting functions

GOES
(18)

Advanced Sounder
(3074)
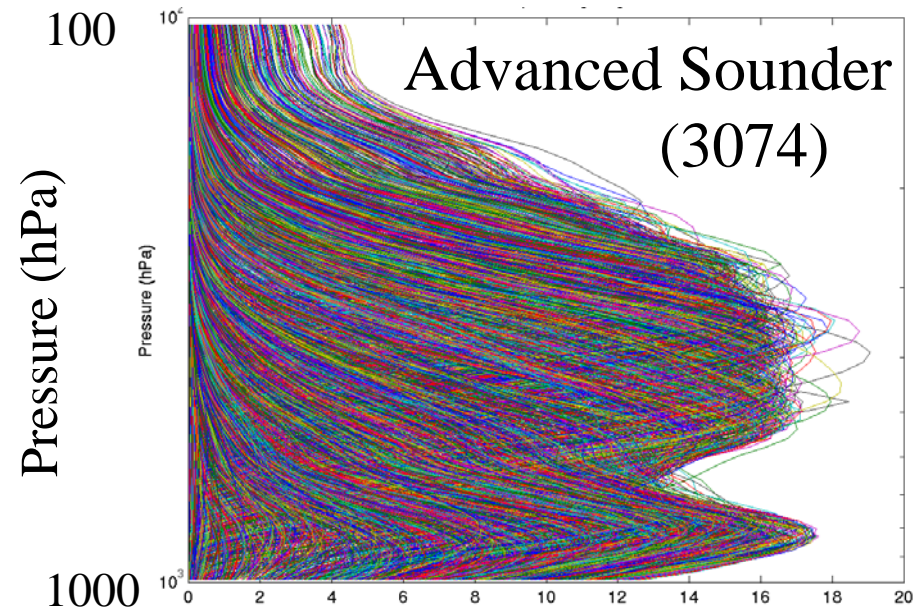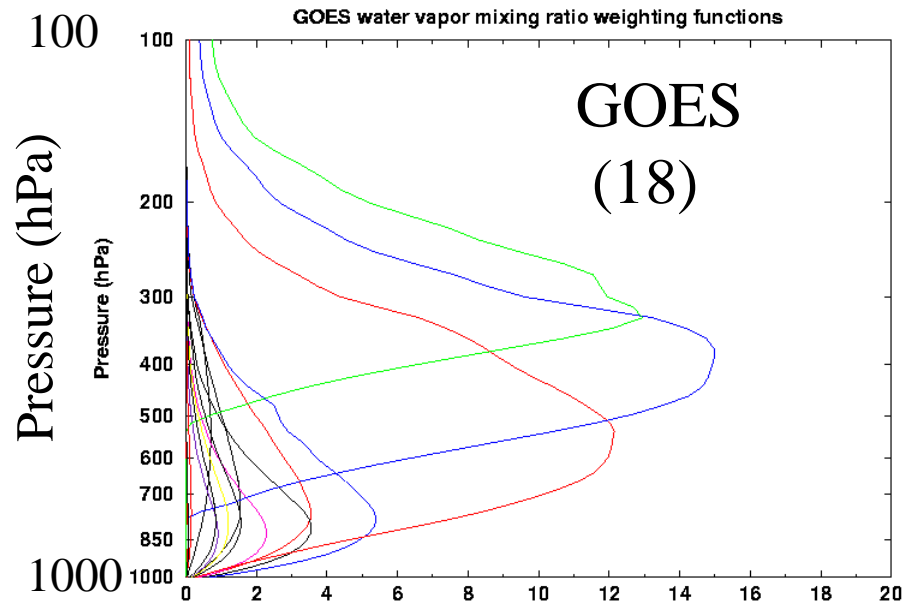
Moisture Weighting Functions

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/dlnq scaled by dlnp).
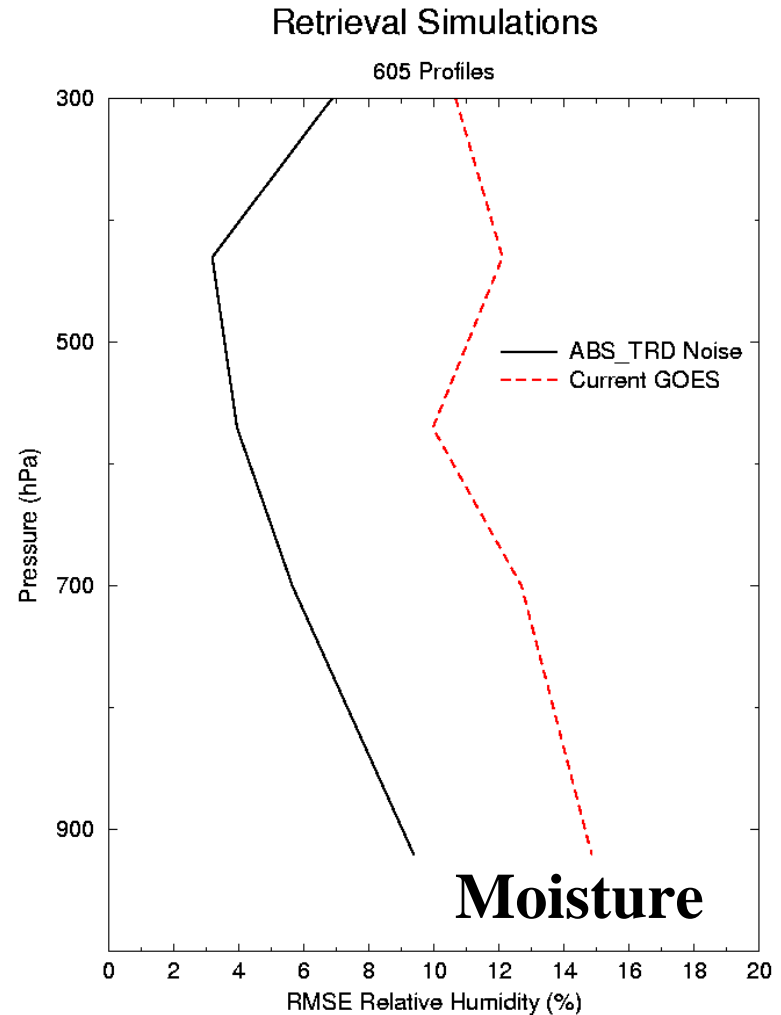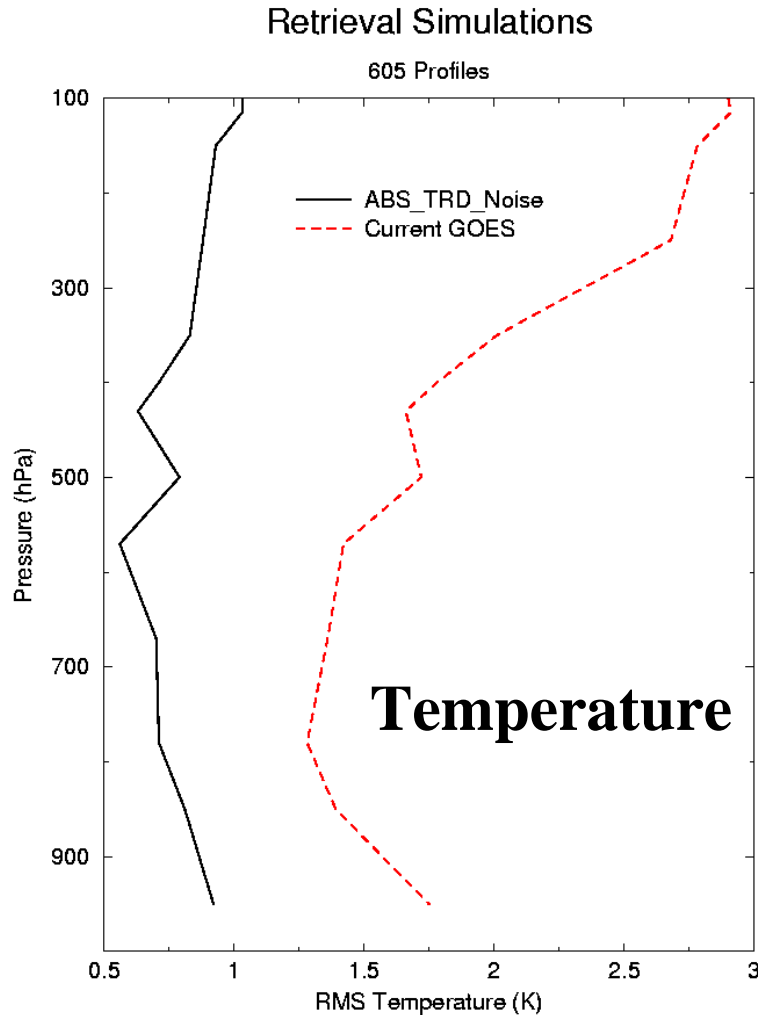

Moisture Weighting Functions
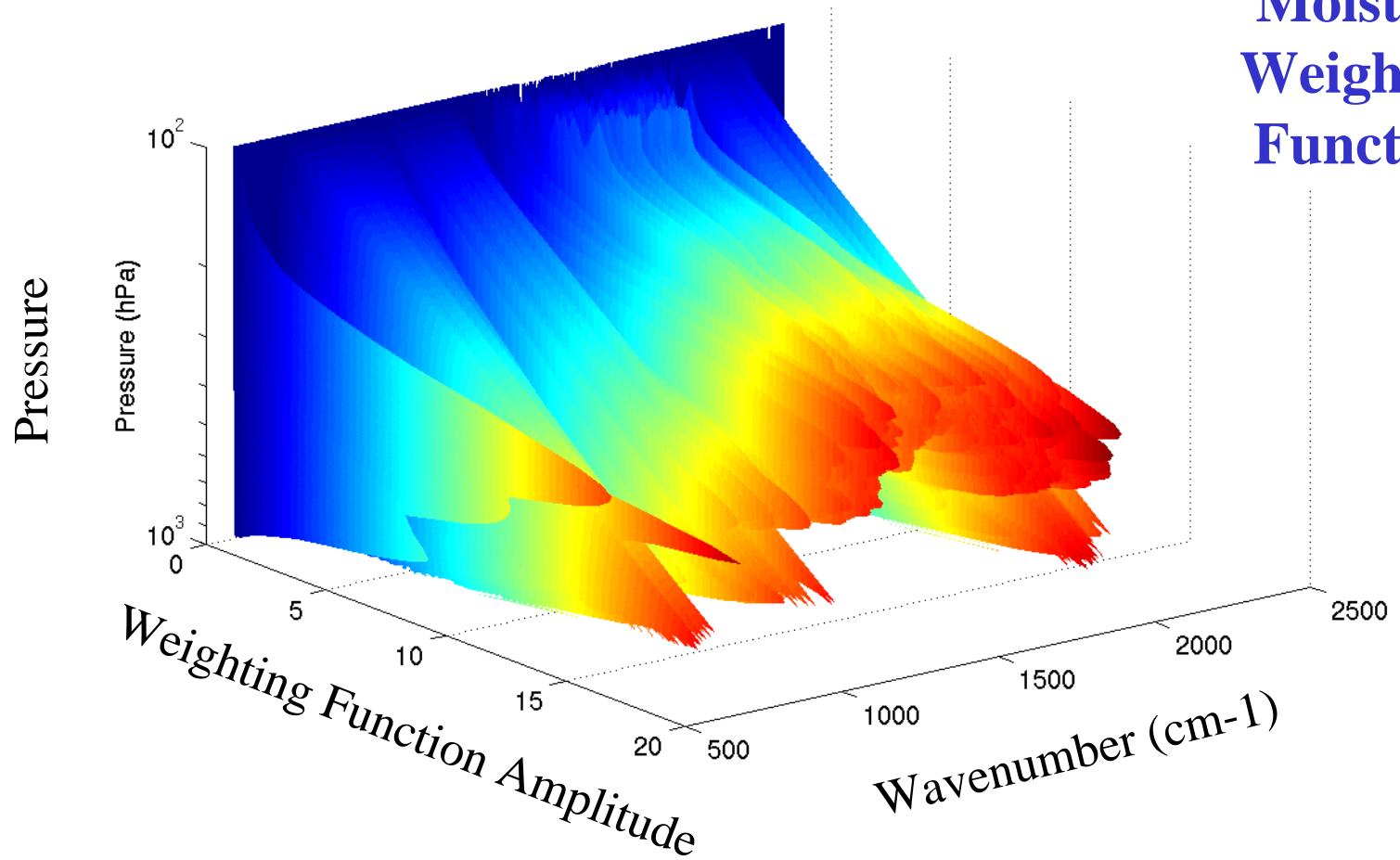
UW/CIMSS

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**

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/HES/

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