HES trade-off studies

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CIMSS

UW-Madison

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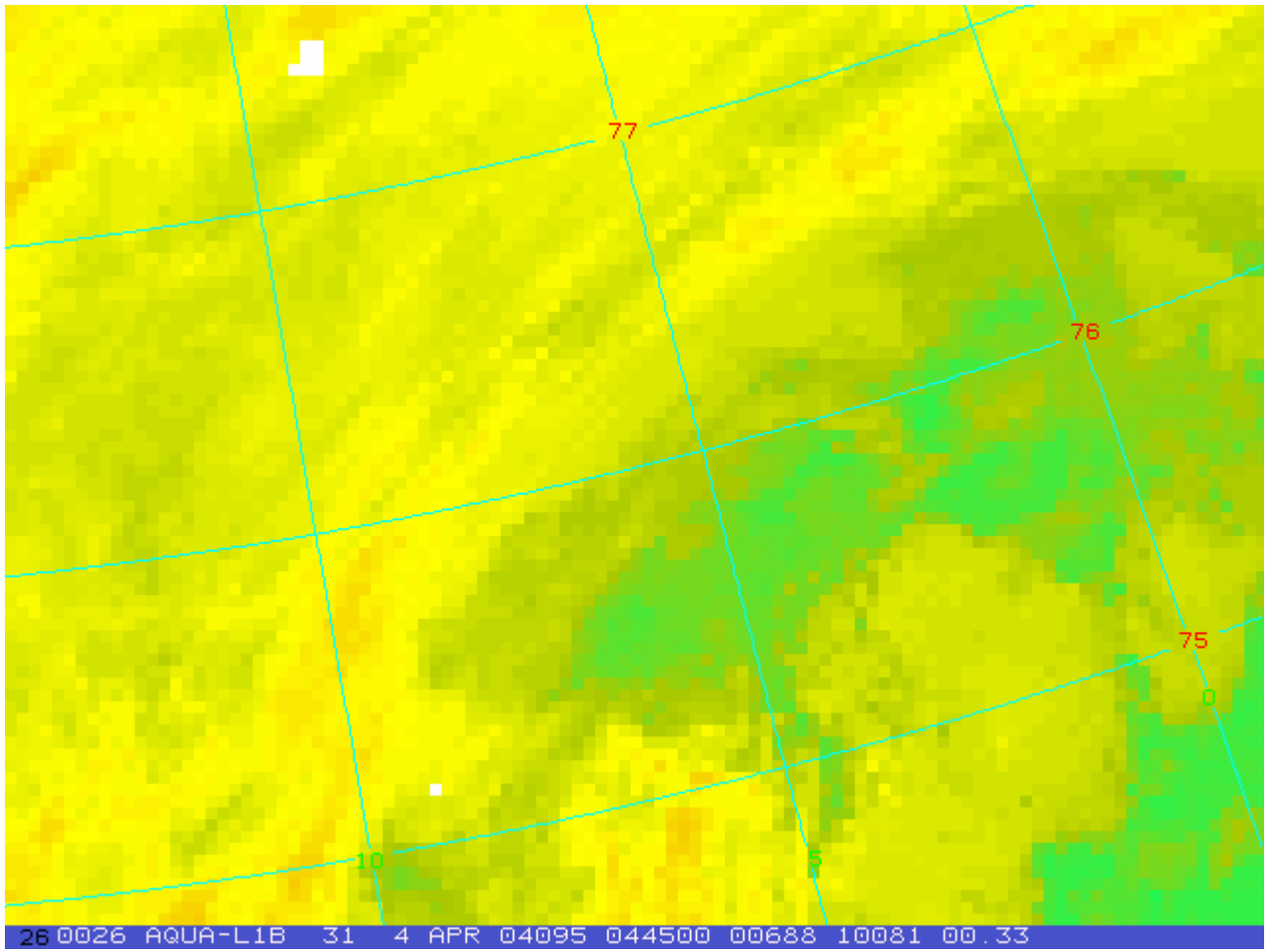
HES trade-off studies for

- **Temporal resolution** – how often does feature of interest need to be observed;
- **Spatial resolution** – what picture element size is required to identify feature of interest and to capture its spatial variability ?
- **Radiometric resolution** – what signal to noise is required and how accurate does an observation need to be ?
- **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 ?
- **Ensquared Energy** – what ensquared energy is required so that the far field radiances will not impact the sounding accuracy ?
- **Band-to-band mis-registration** – what is the impact of band-to-band mis-registration on sounding accuracy ?
- **GOES-R position** – what is the impact of two-satellite system on science ?

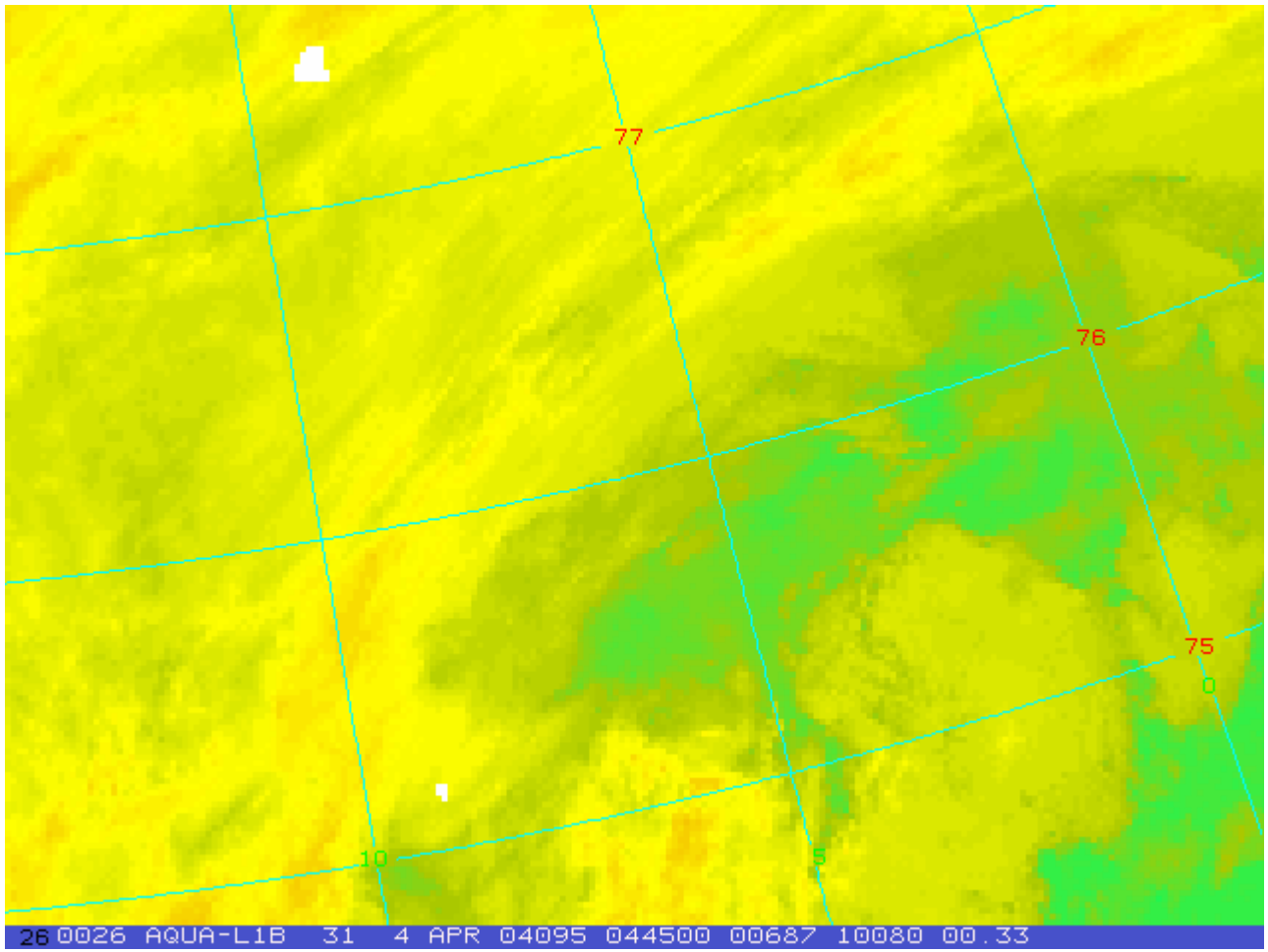
Temporal resolution

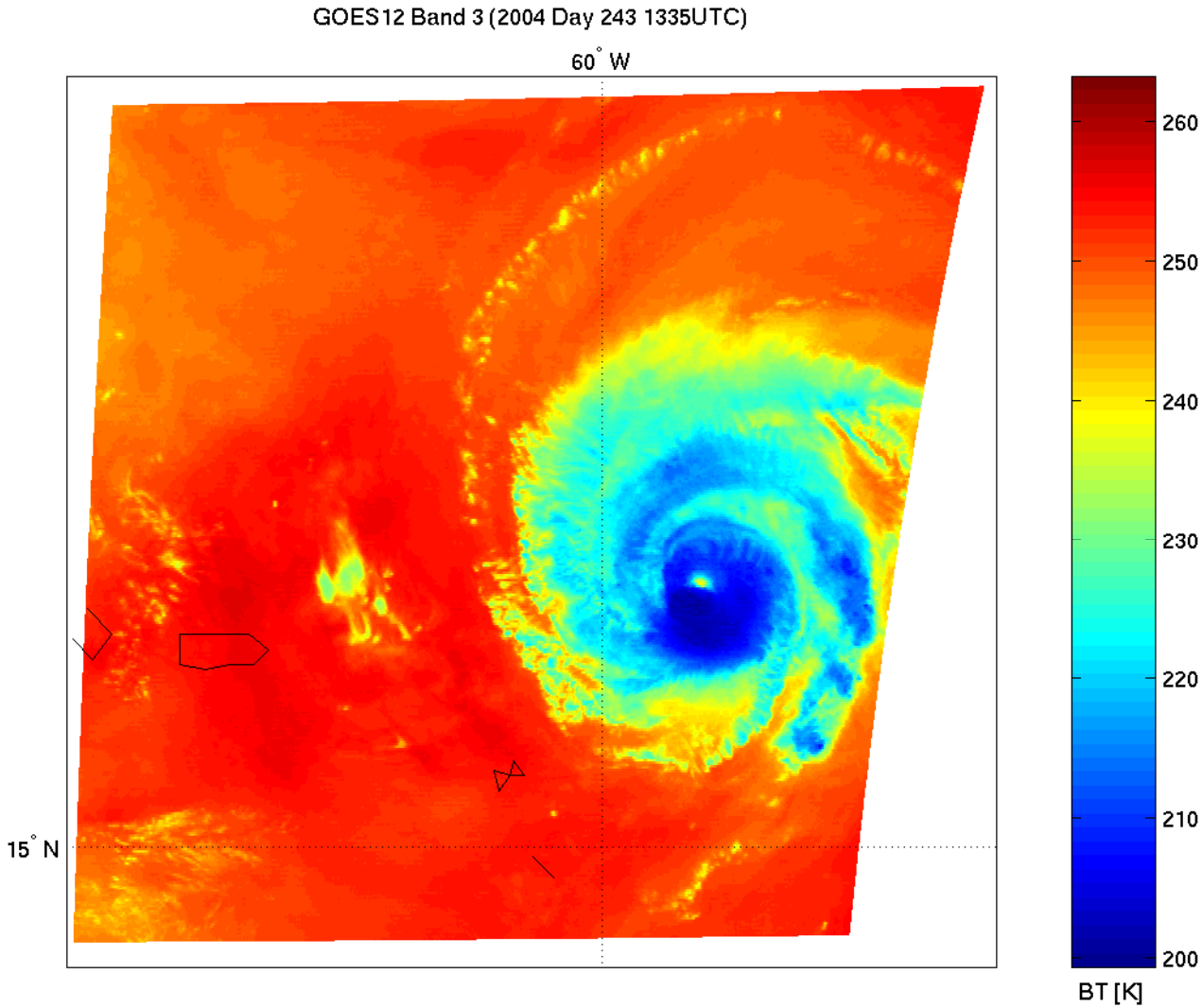
- For mesoscale application, 5 minutes is ideal for regional NWP applications
- For disk sounding, 1 hour or better is required

MODIS band 31 (11 μm) 30-minute morphing over the high latitude region.

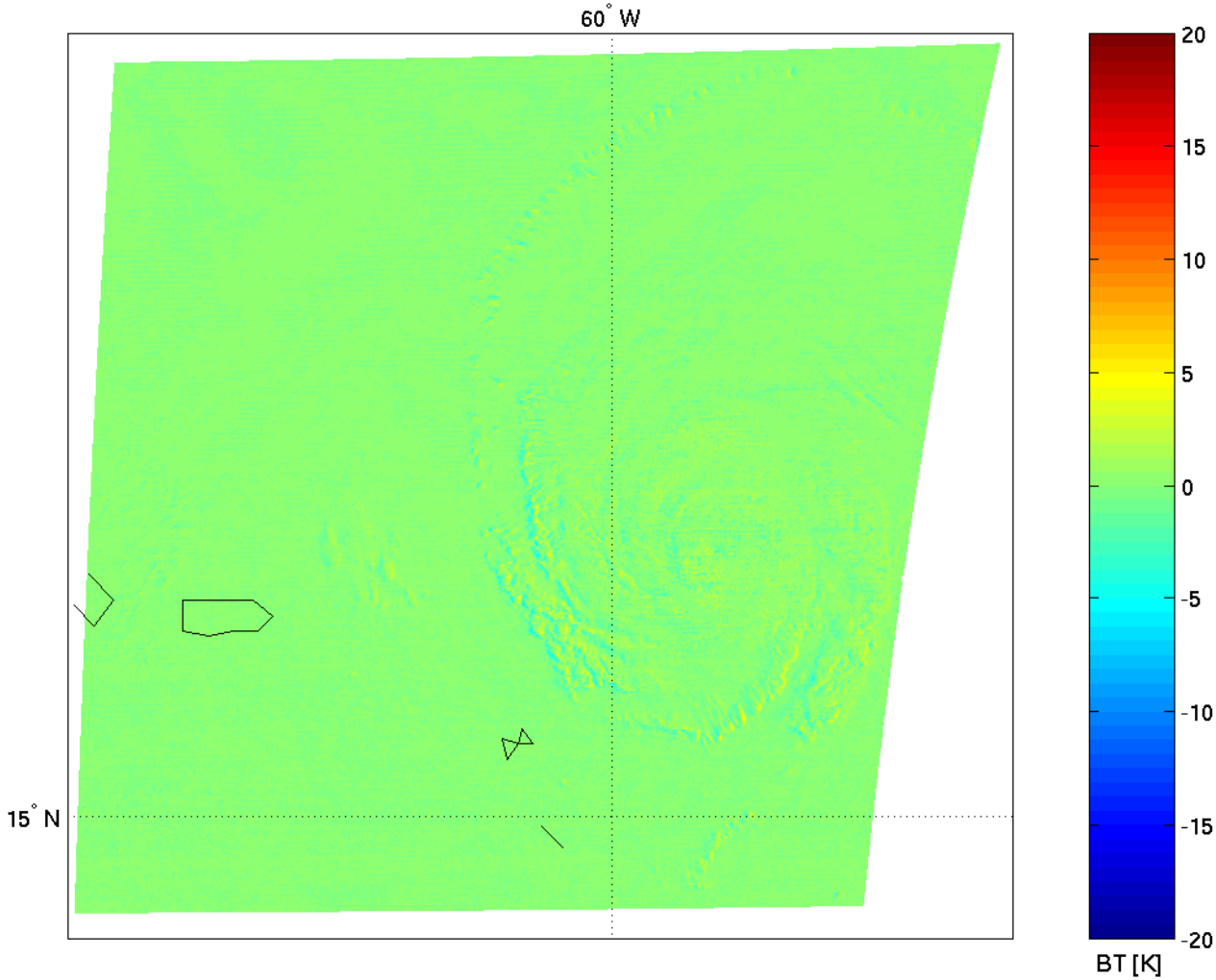


MODIS band 31 (11 μm) 5-minute morphing over the high latitude region.

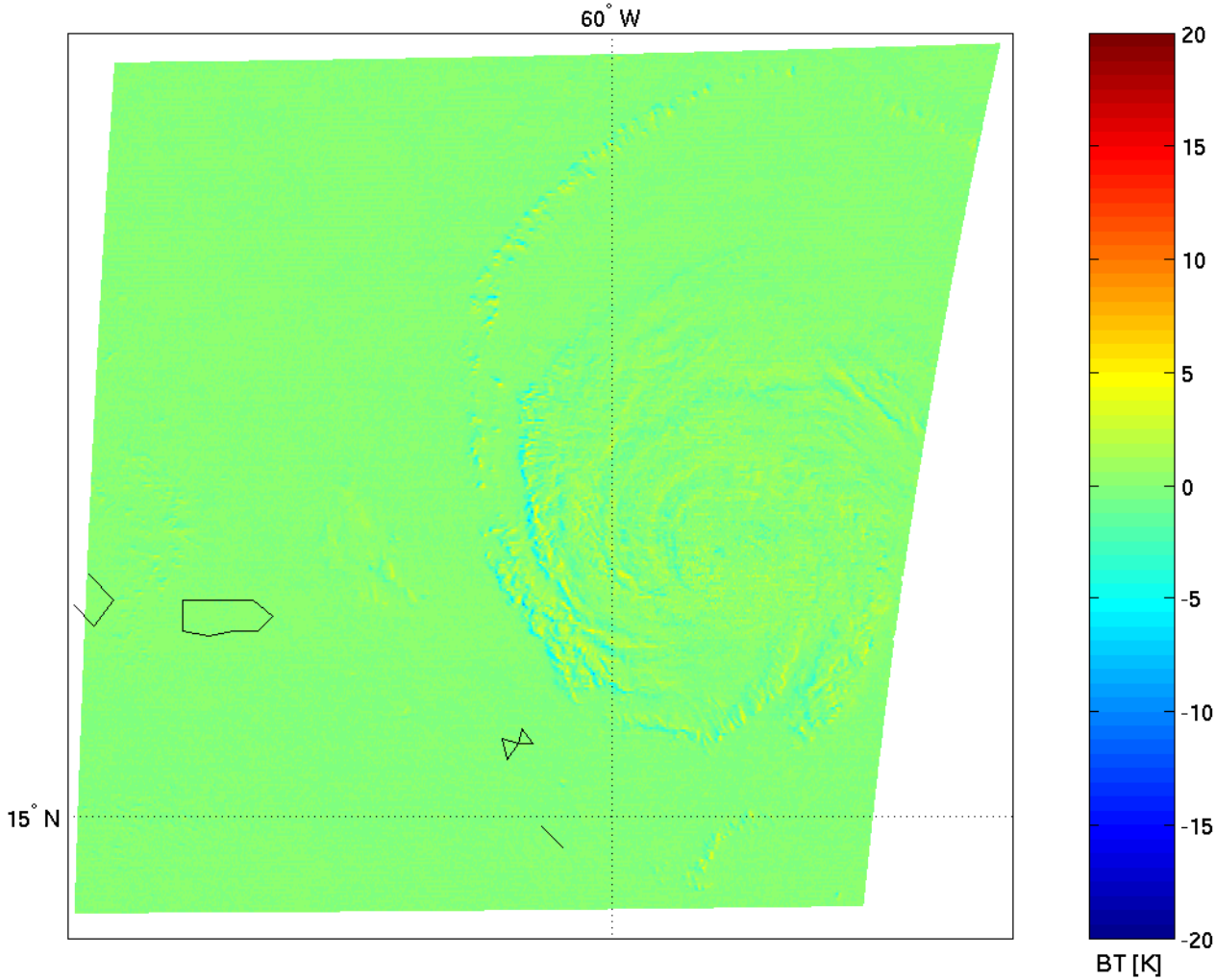




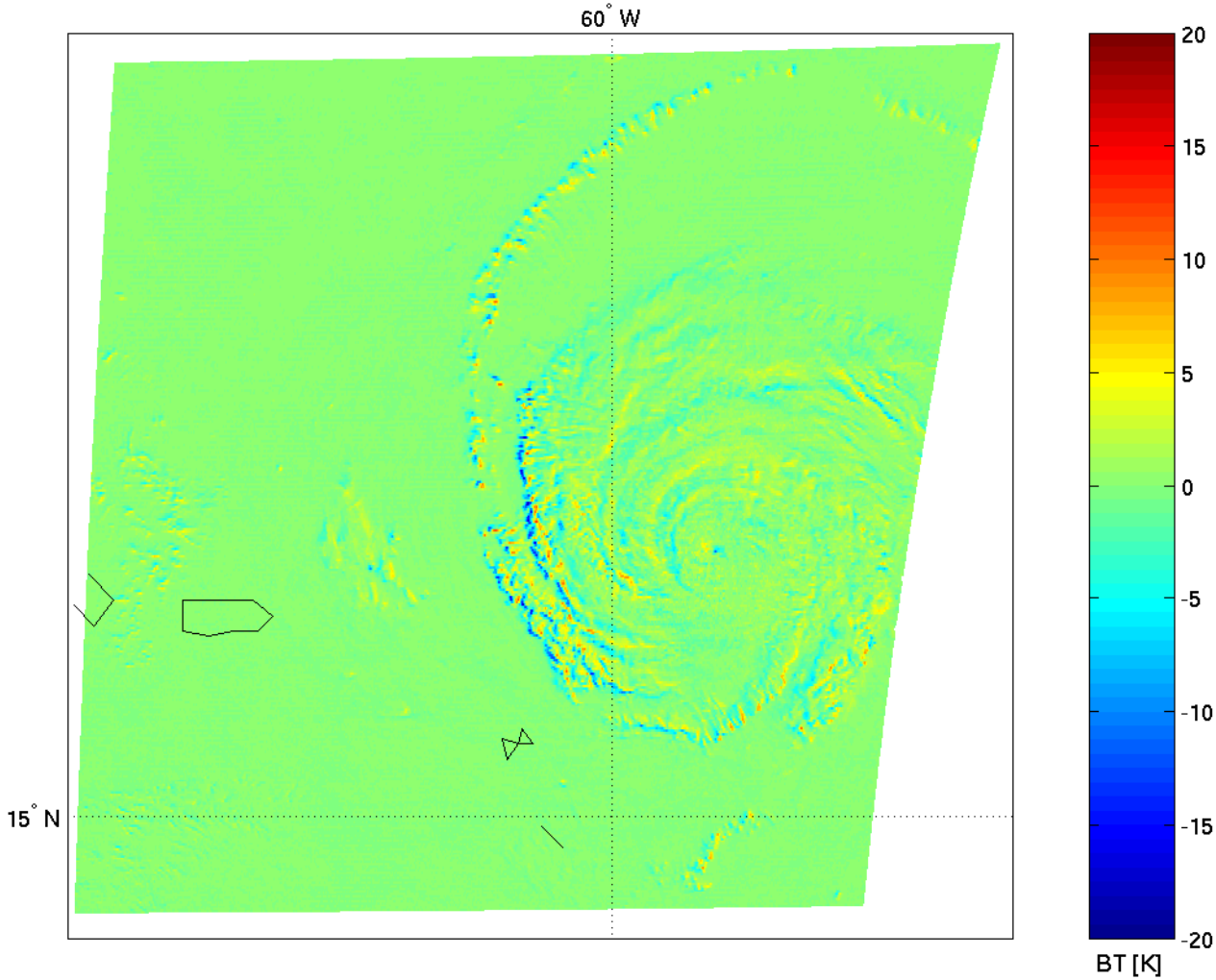
GOES-12 6.5 μm BT



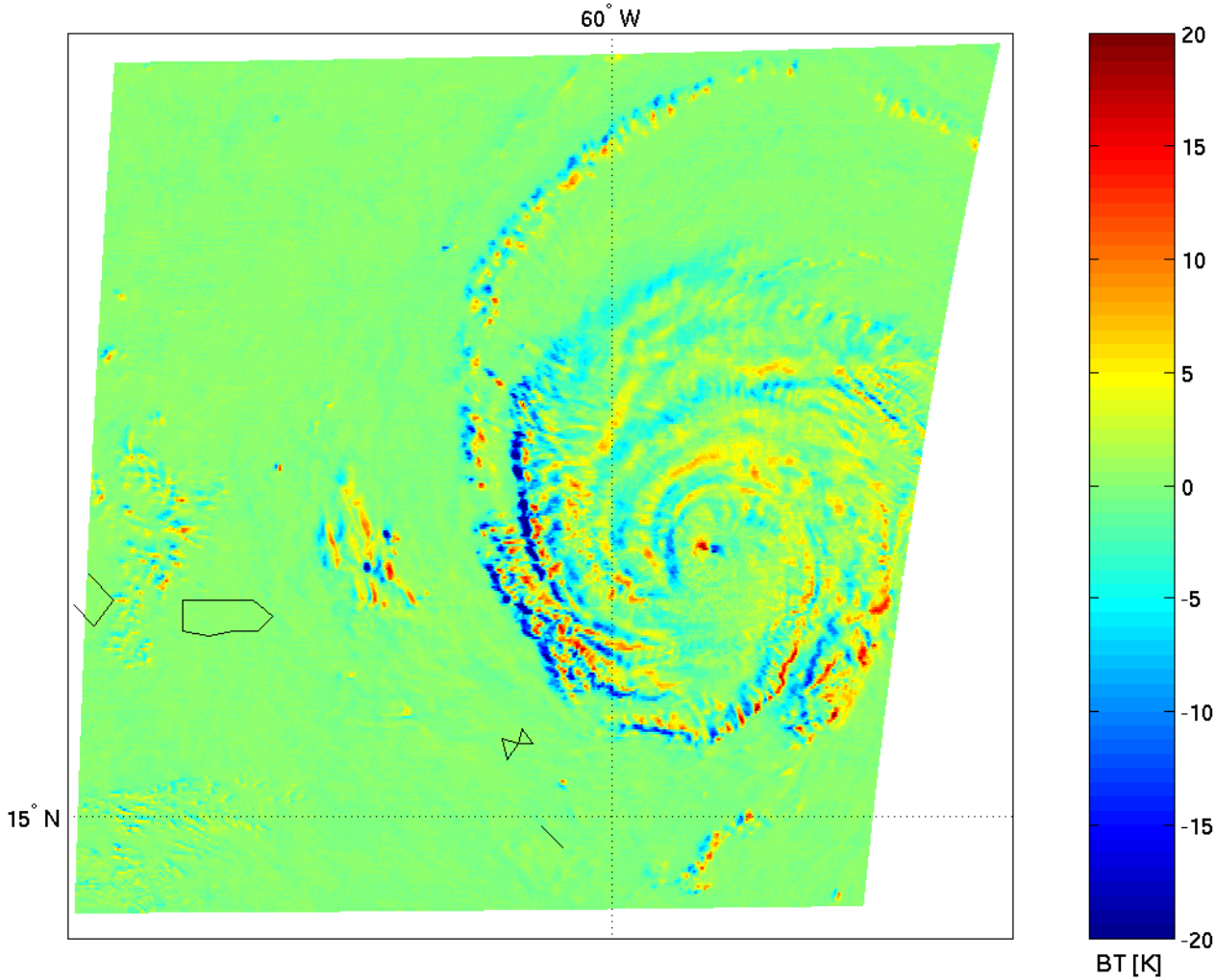
GOES-12 6.5 μm BT difference (change) 1 minute later



GOES-12 6.5 μm BT difference (change) 2 minute later



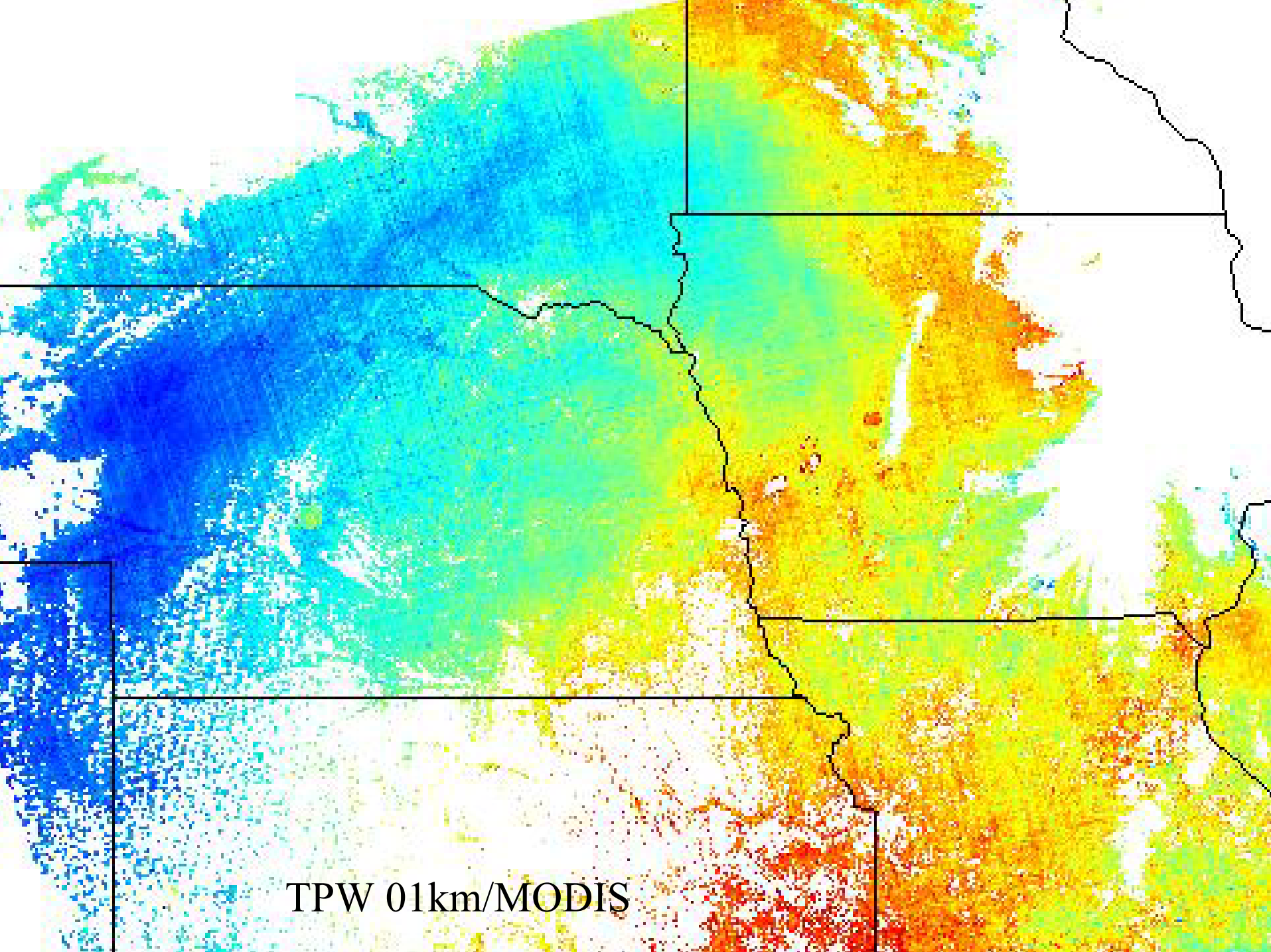
GOES-12 6.5 μm BT difference (change) 5 minute later

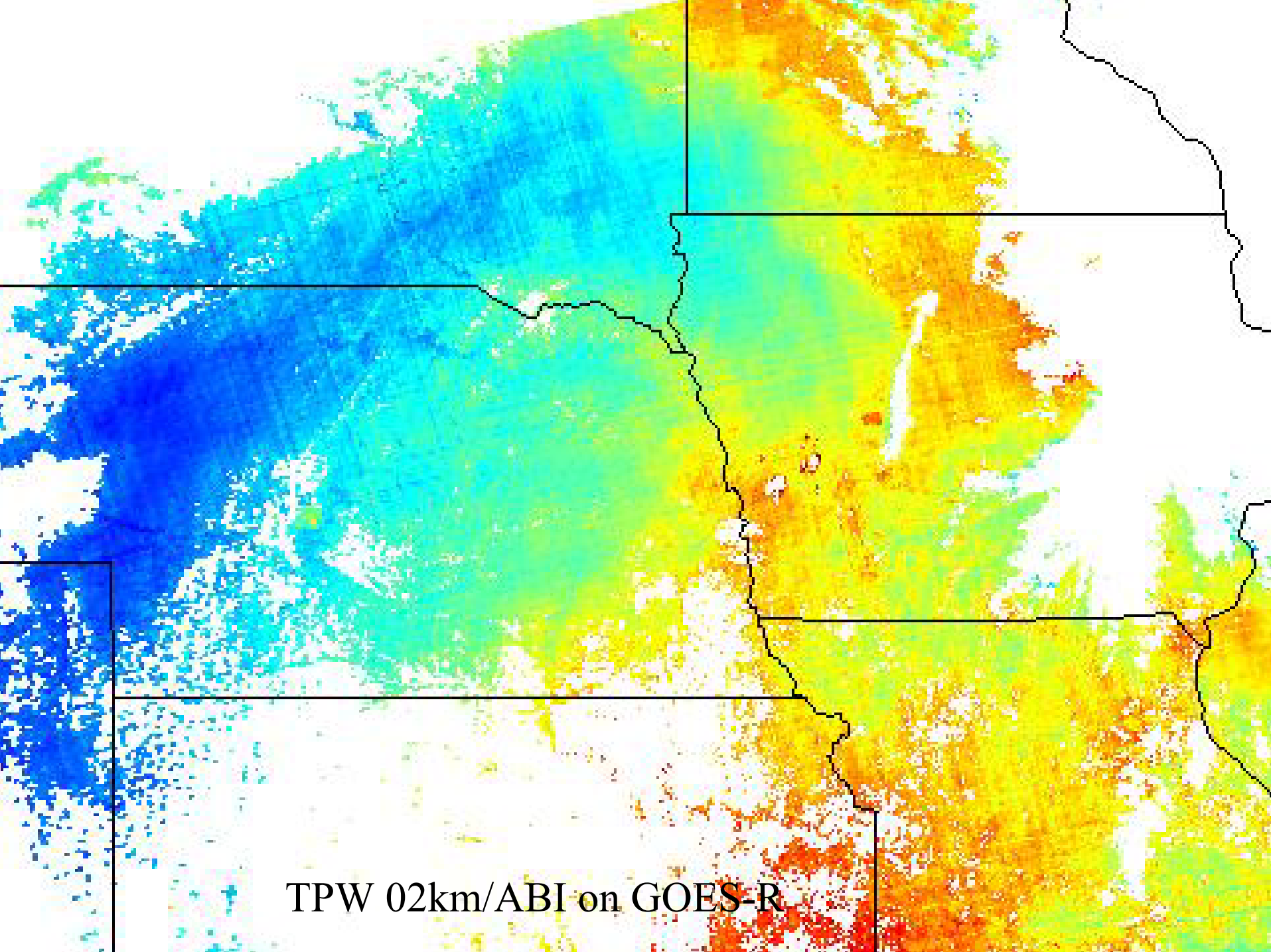


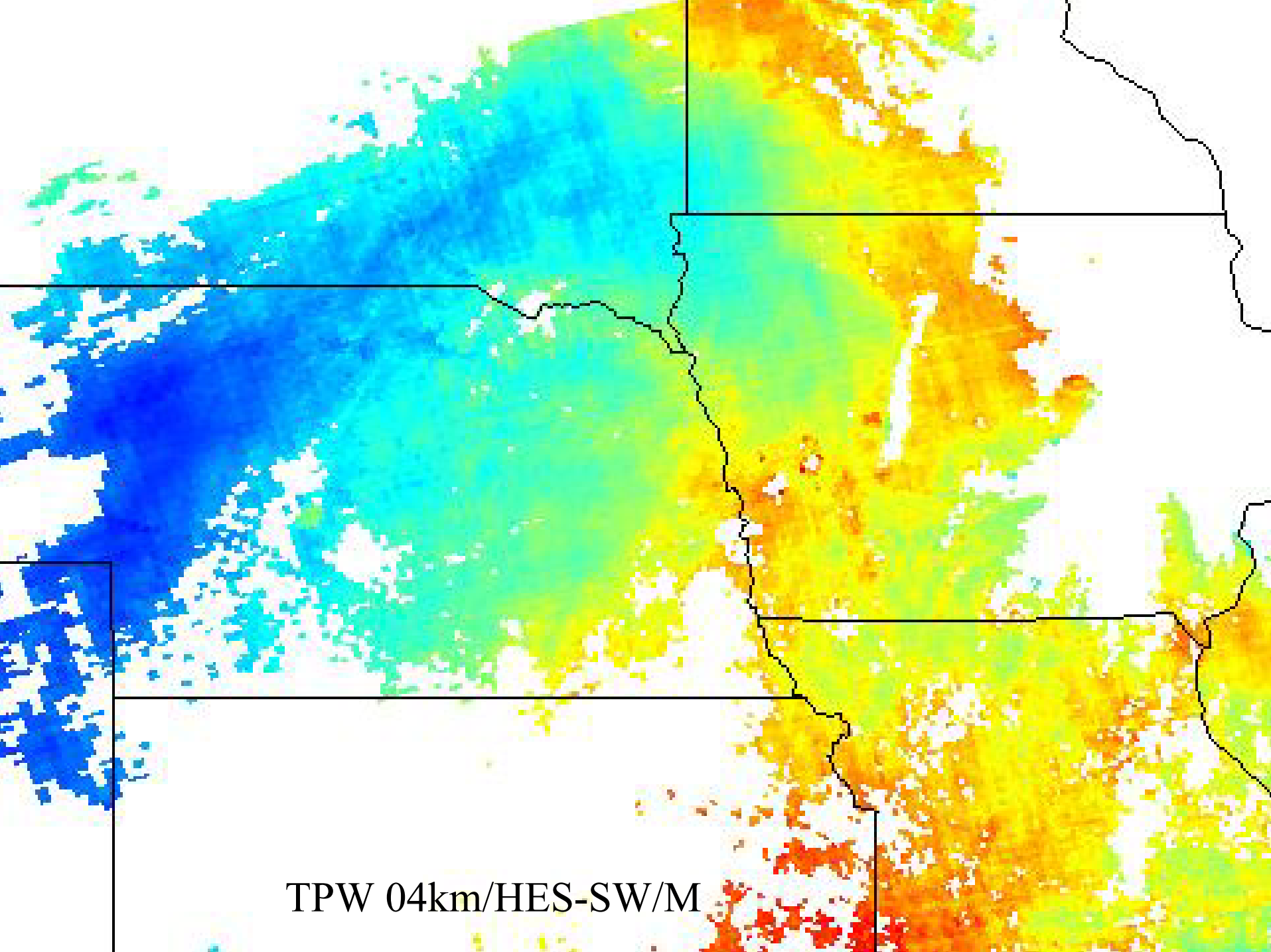
GOES-12 6.5 μm BT difference (change) 10 minute later

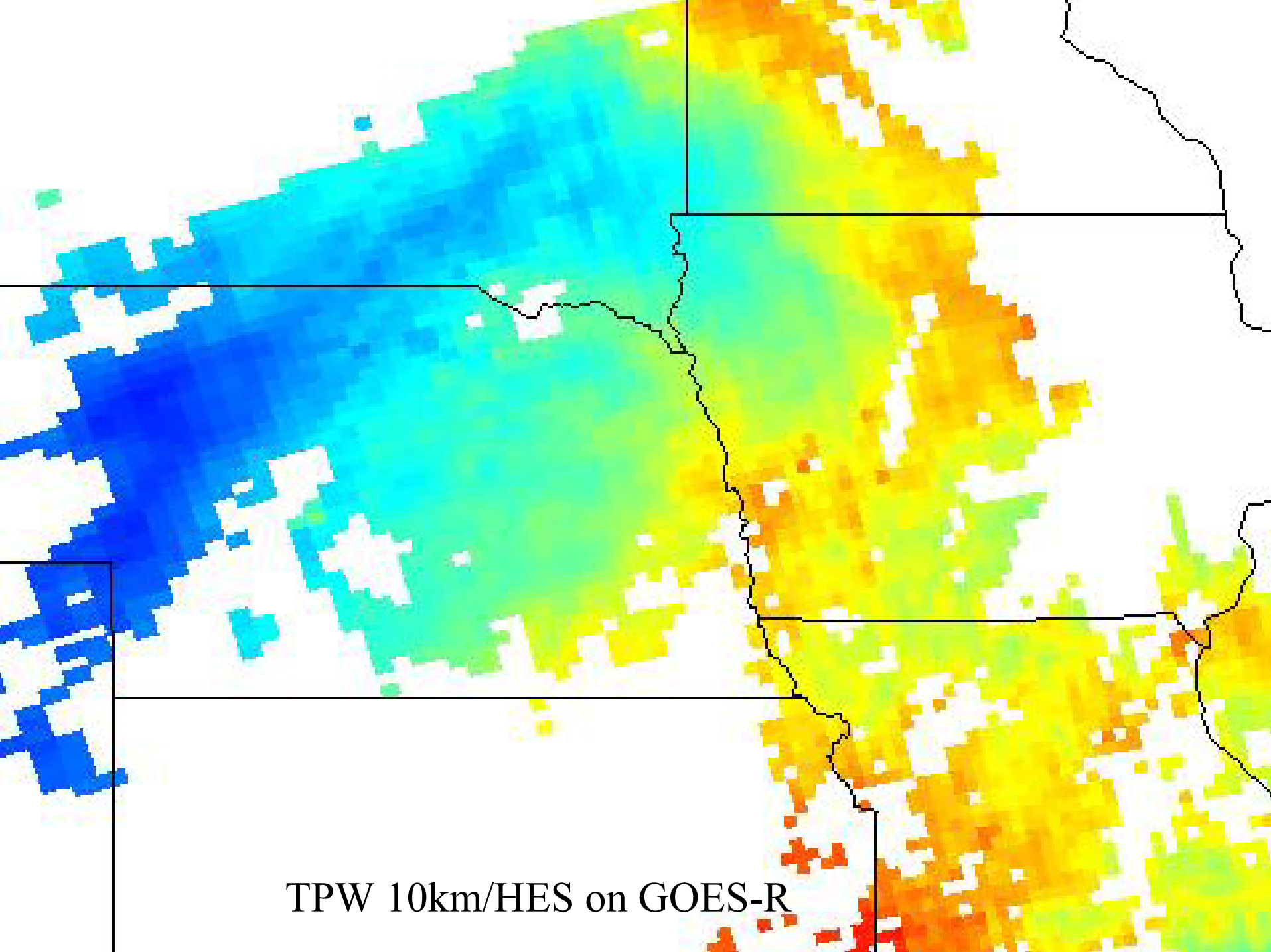
Spatial resolution

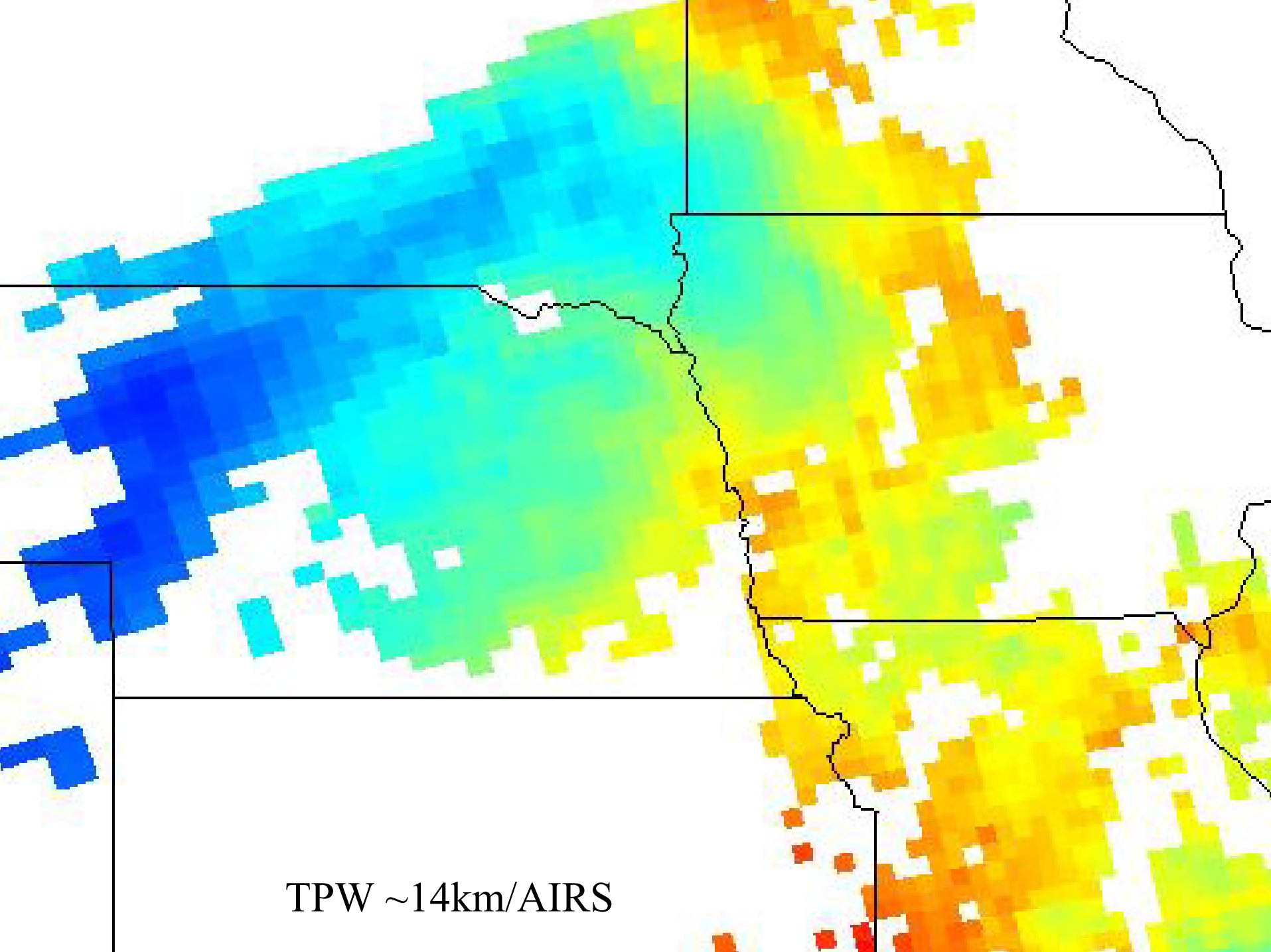
- 4 km or better for regional applications
- High spatial resolution allows more “clear holes” for sounding
- High spatial resolution depicts better water vapor gradients than temperature gradients

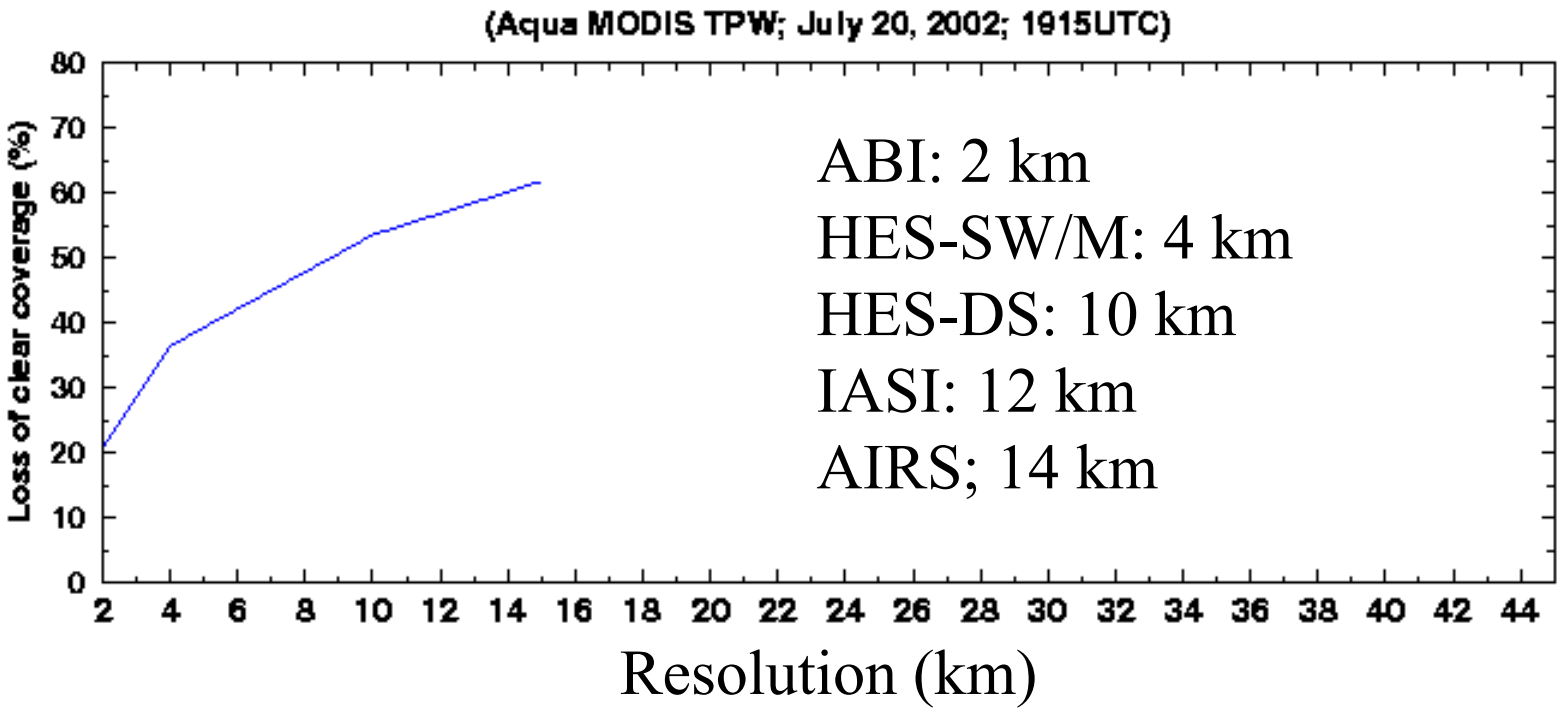

TPW 01km/MODIS


TPW 02km/ABI on GOES-R

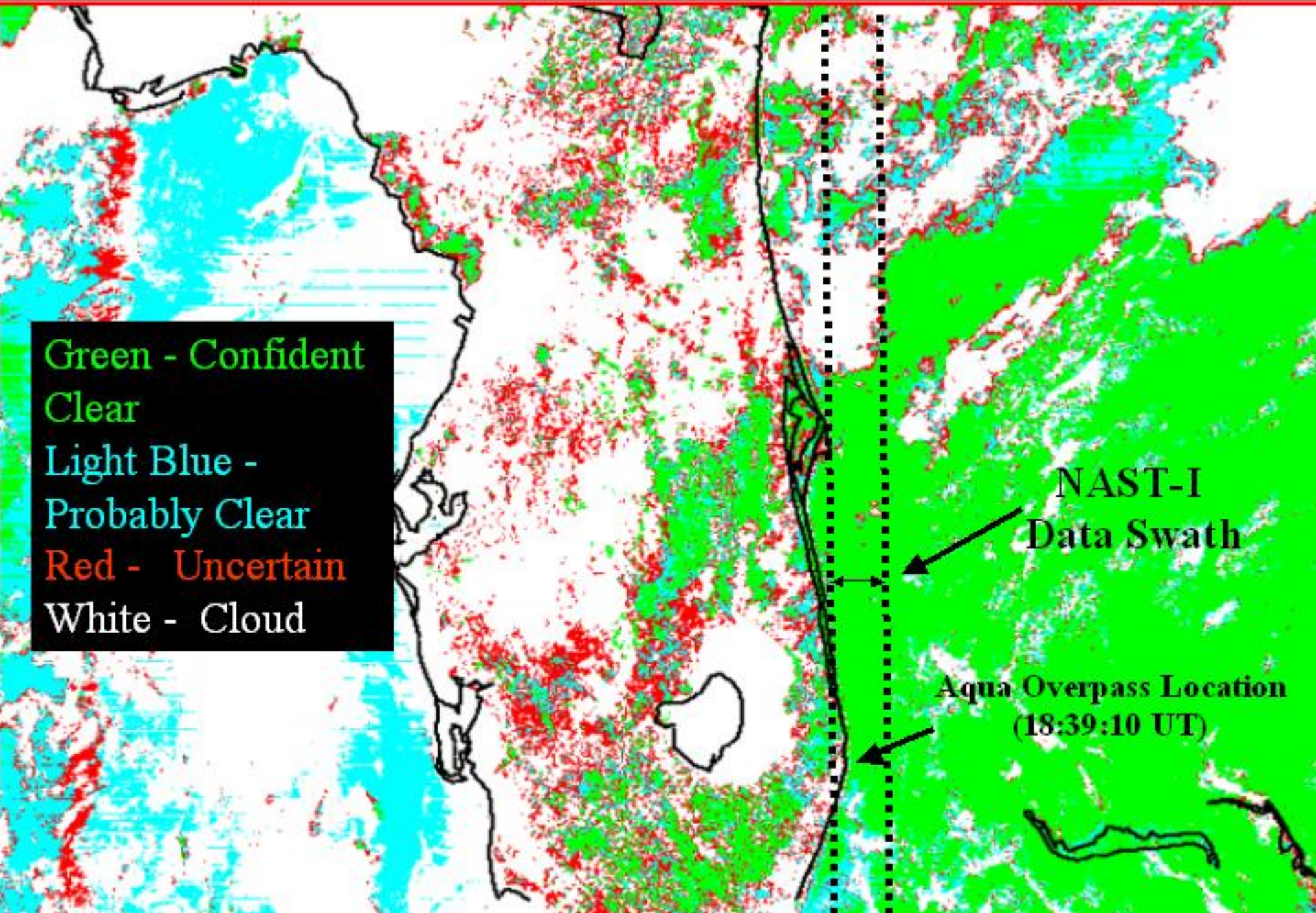

TPW 04km/HES-SW/M

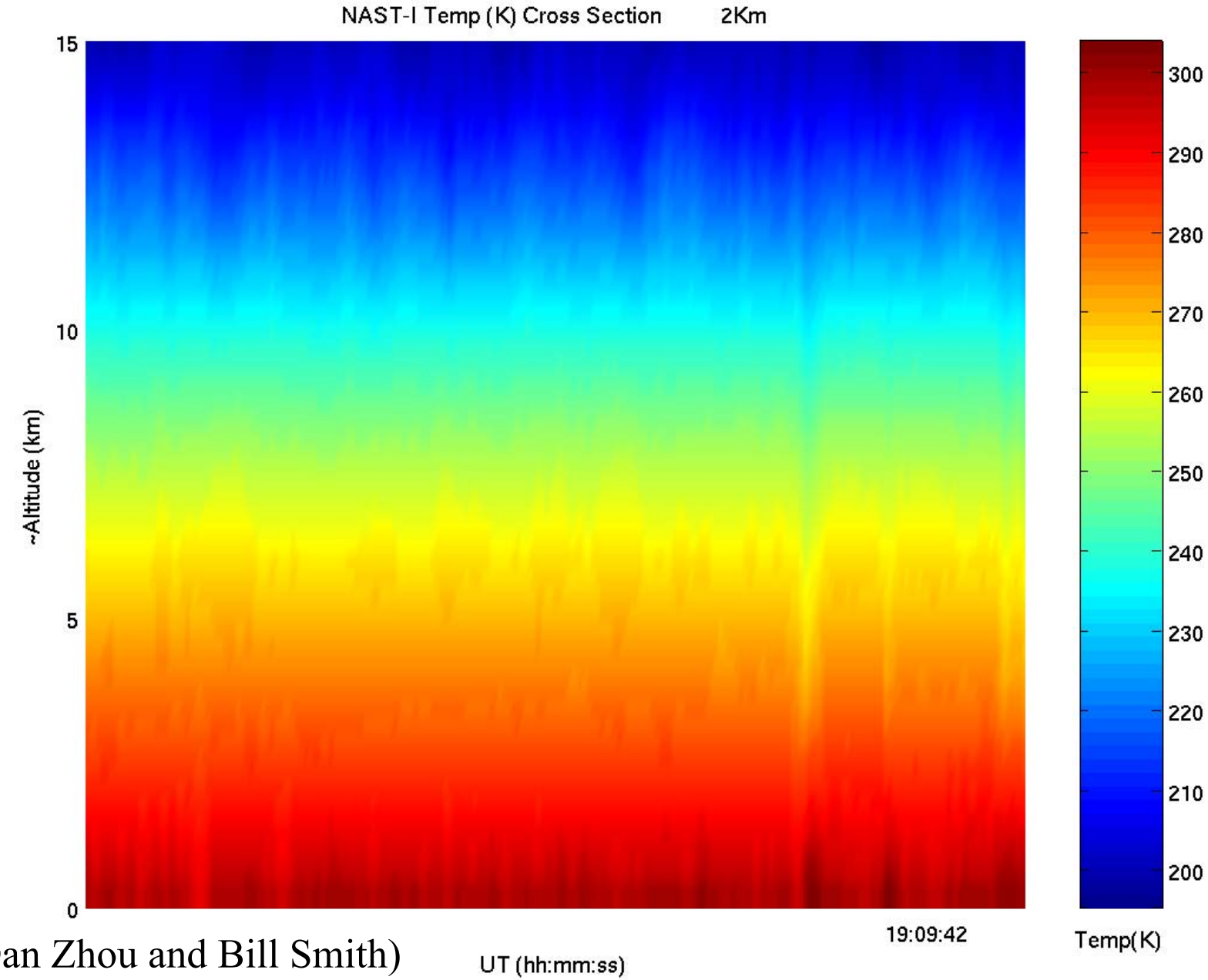

TPW 10km/HES on GOES-R


TPW ~14km/AIRS

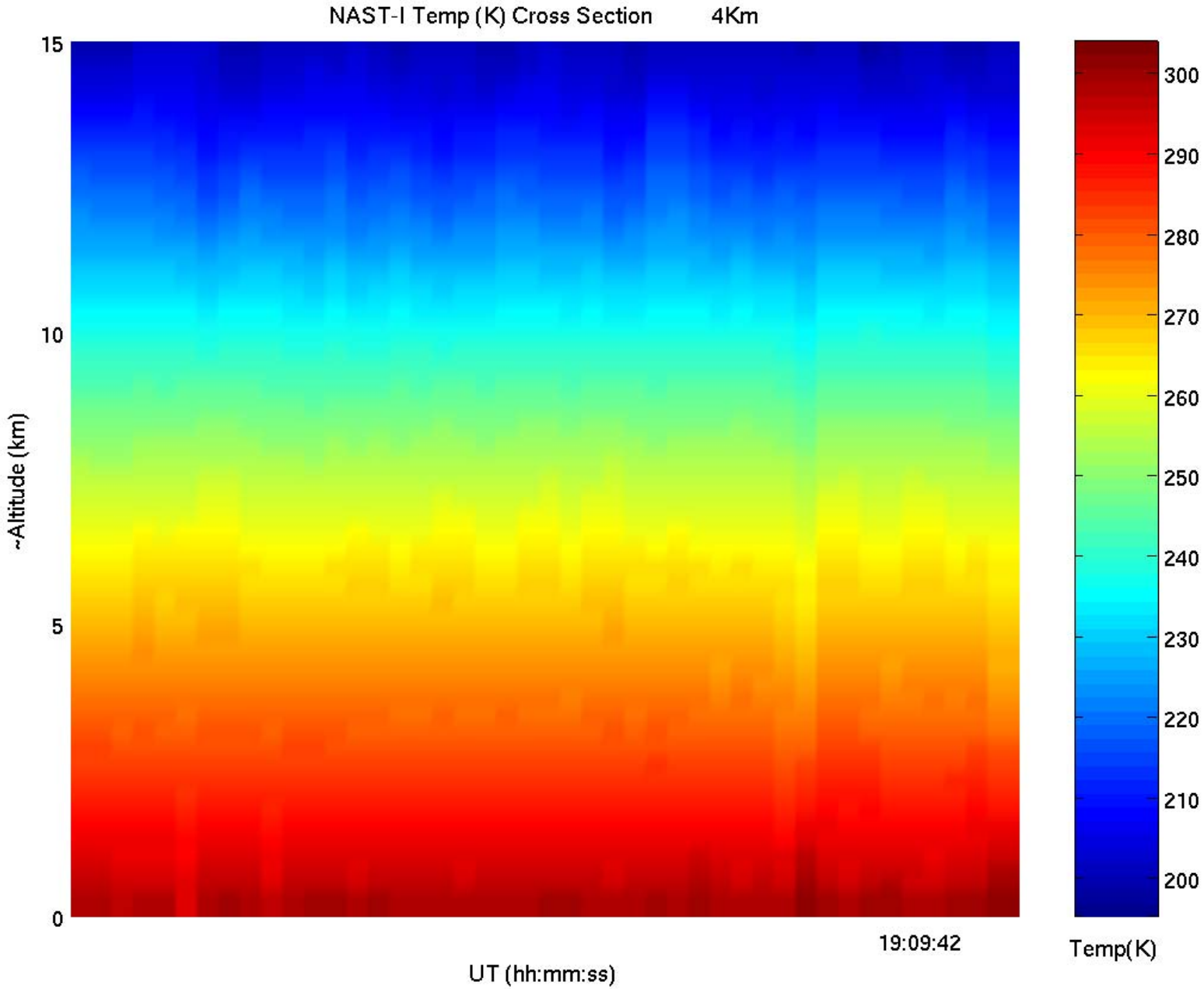

(Aqua MODIS TPW; July 20, 2002; 1915UTC)
Loss of clear coverage (%)
0
10
20
30
40
50
60
70
80
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
Resolution (km)
ABI: 2 km
HES-SW/M: 4 km
HES-DS: 10 km
IASI: 12 km
AIRS; 14 km

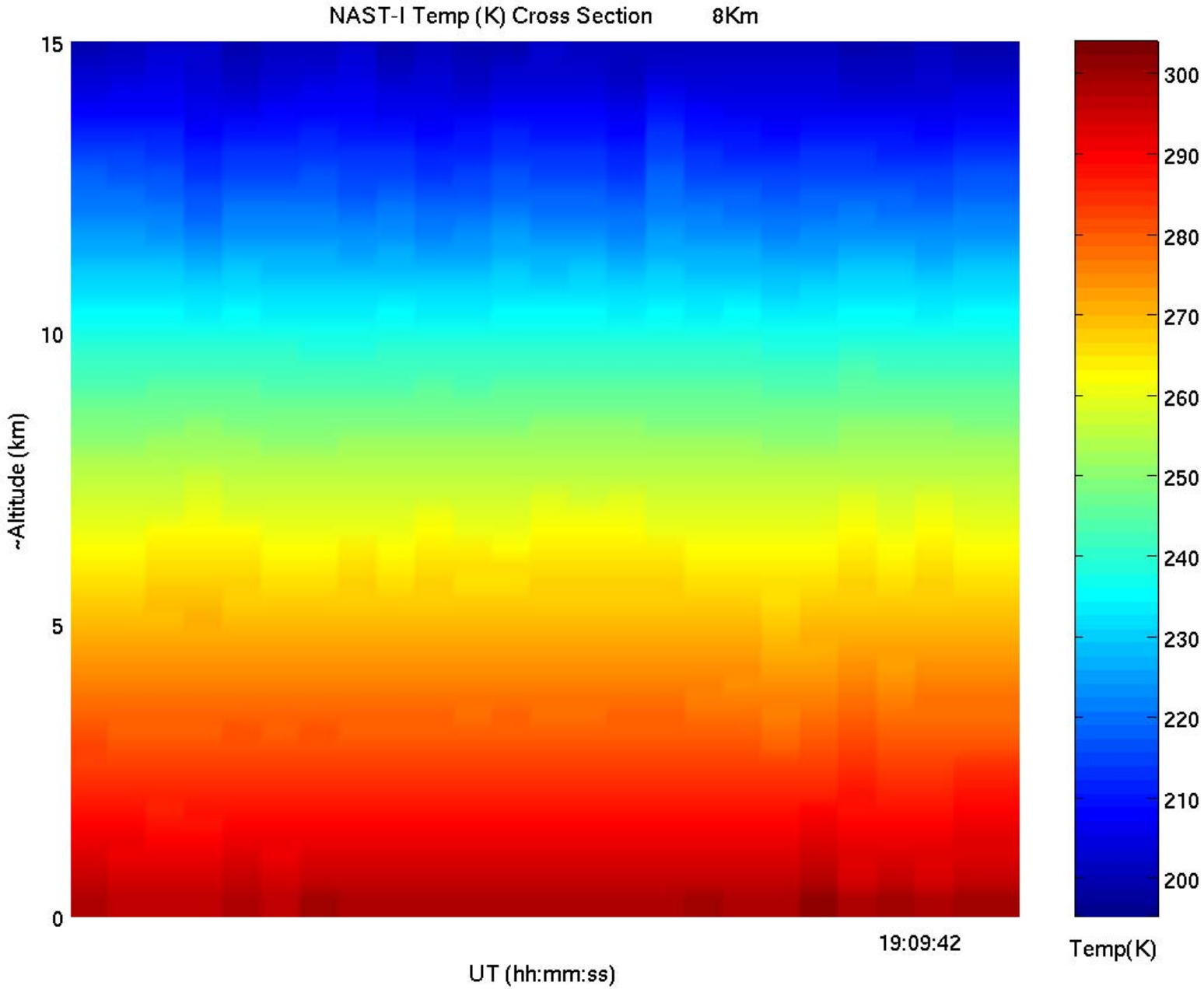
MODIS Cloud Mask - 26 July 2002, 18:40 UTC

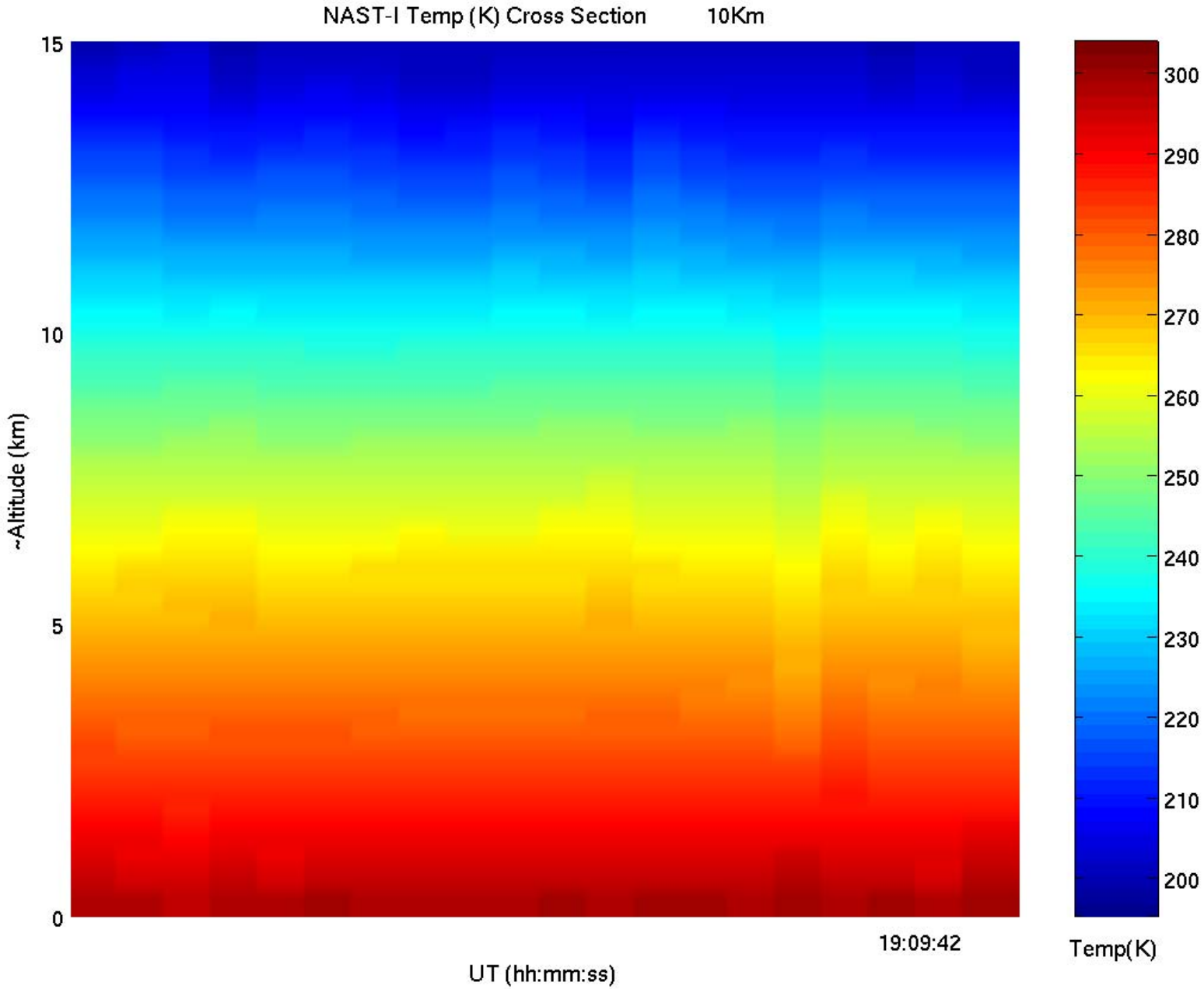


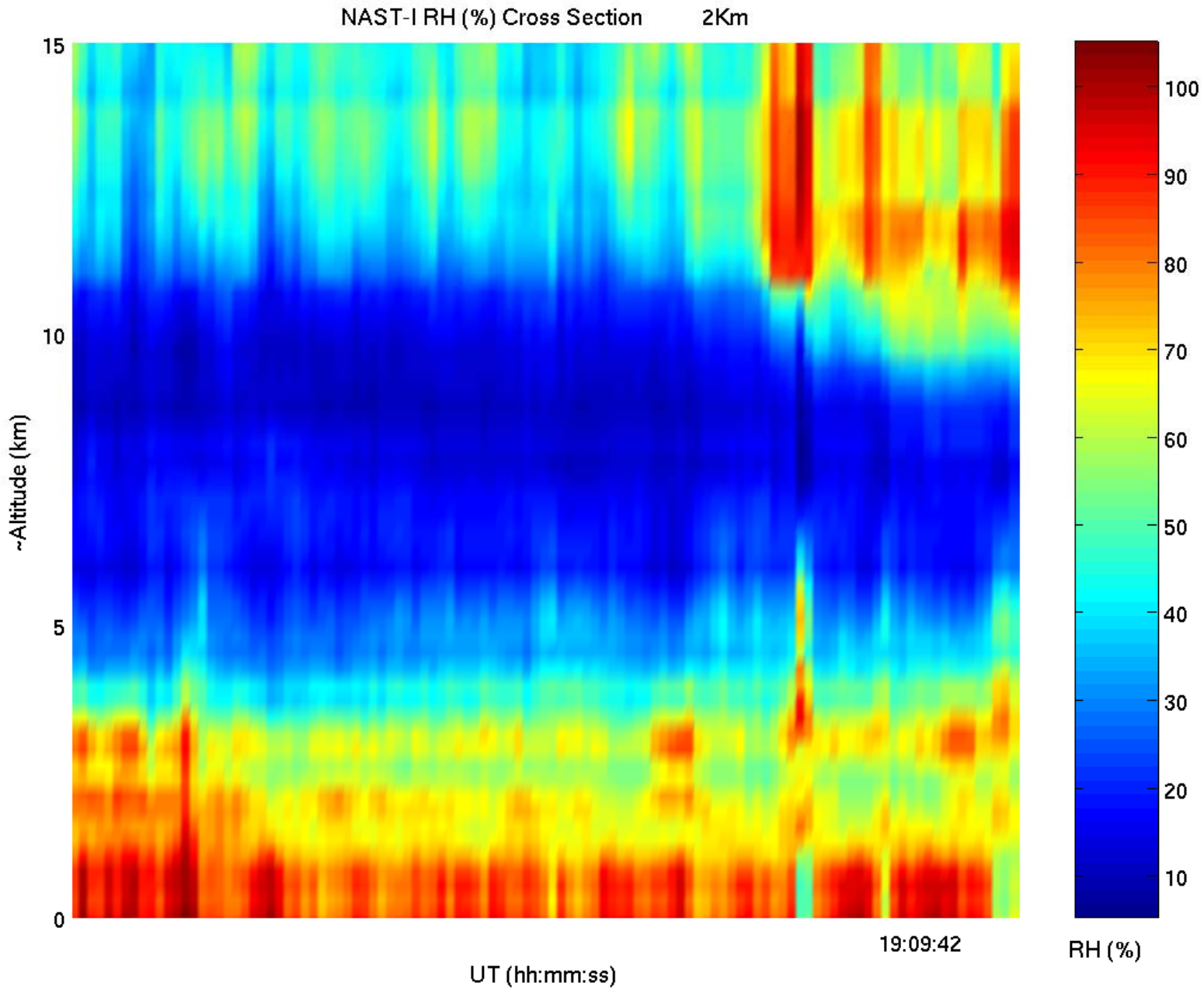


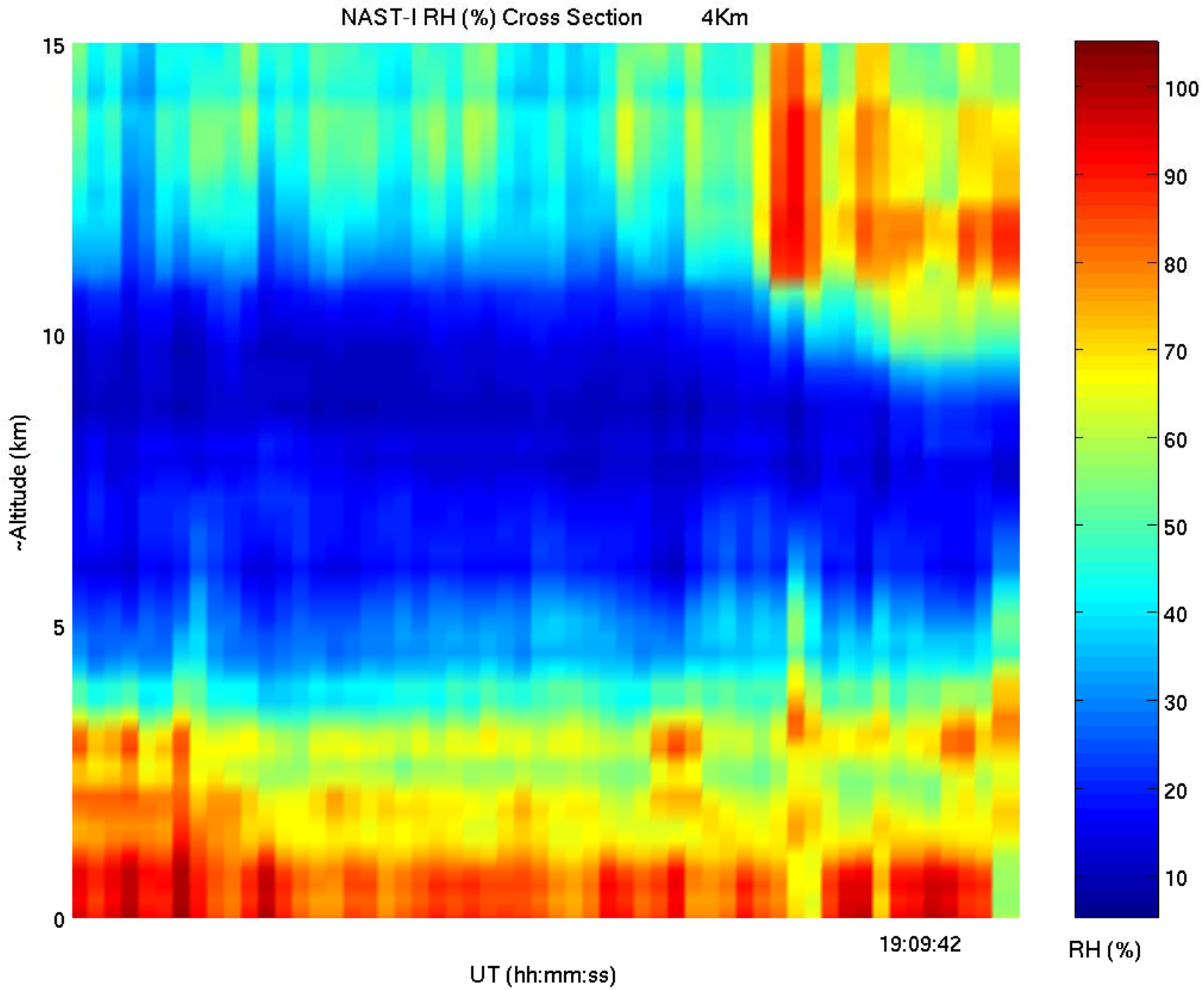
(Dan Zhou and Bill Smith)

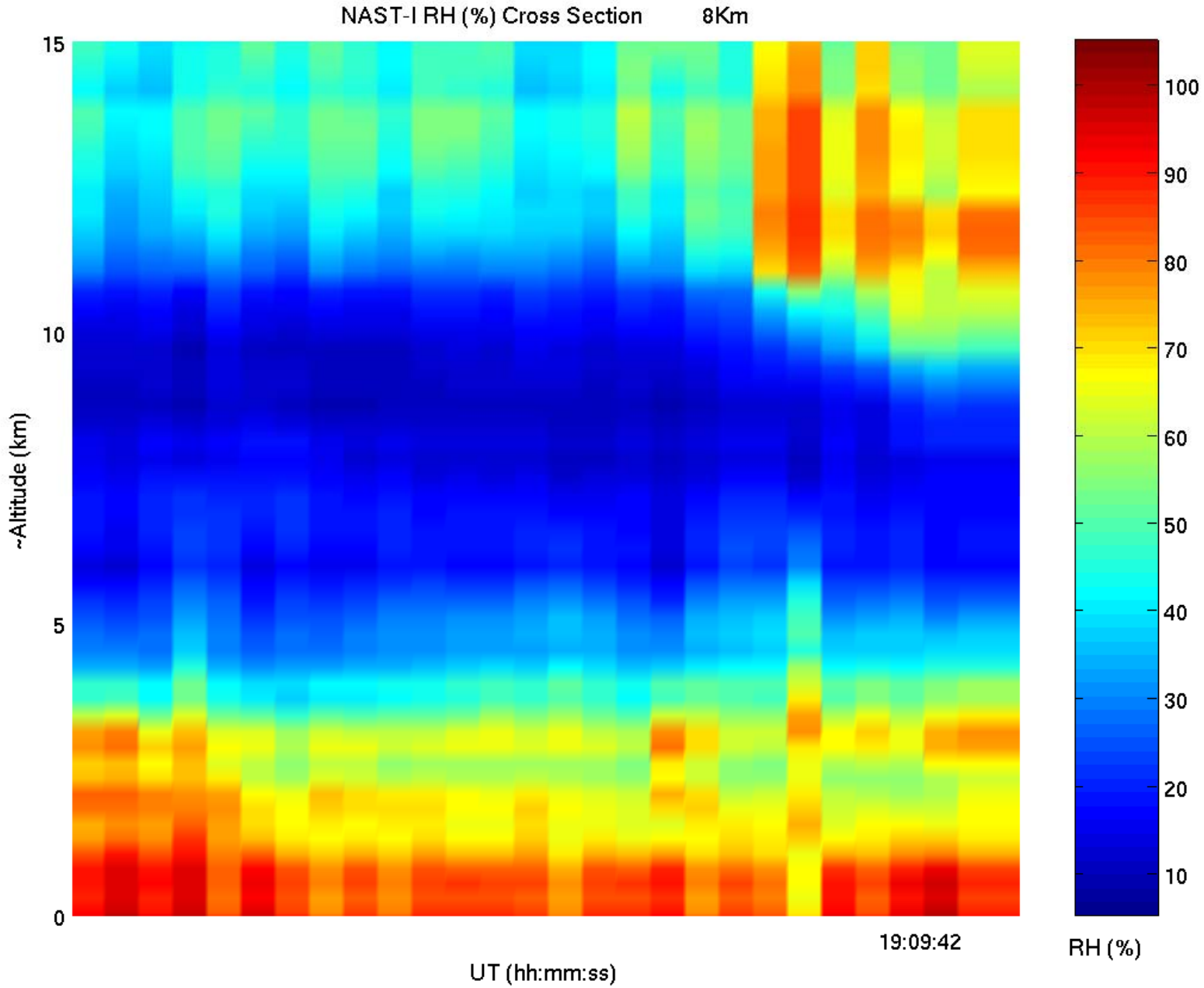

NAST-I Temp (K) Cross Section 4Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
300
290
280
270
260
250
240
230
220
210
200
Temp(K)

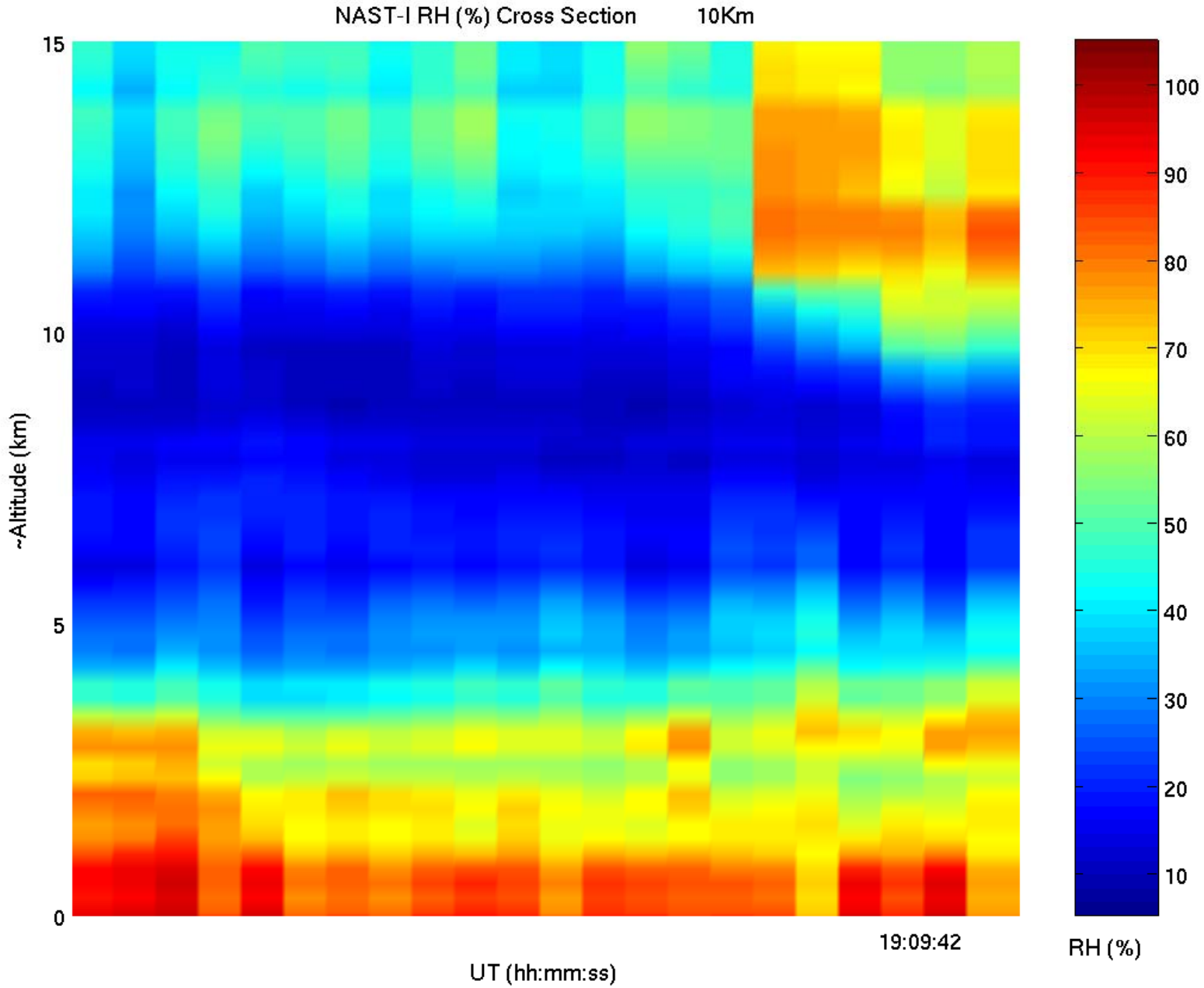

NAST-I Temp (K) Cross Section 8Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
300
290
280
270
260
250
240
230
220
210
200
Temp(K)


NAST-I Temp (K) Cross Section 10Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
300
290
280
270
260
250
240
230
220
210
200
Temp(K)


NAST-I RH (%) Cross Section 2Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
100
90
80
70
60
50
40
30
20
10
RH (%)

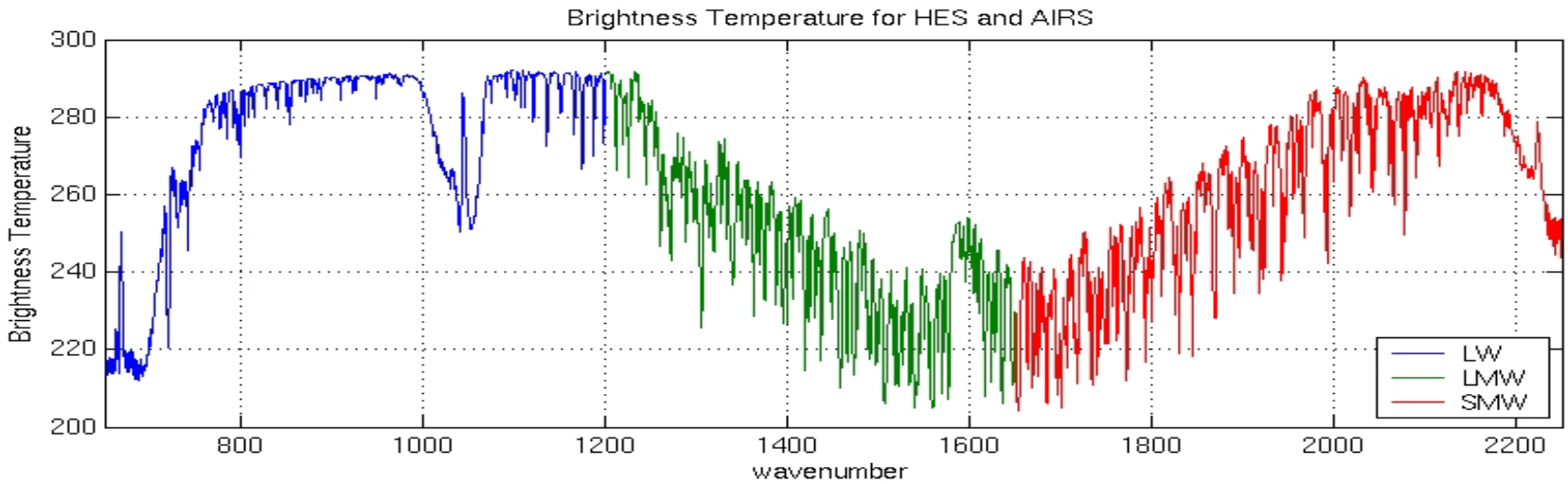

NAST-I RH (%) Cross Section 4Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
100
90
80
70
60
50
40
30
20
10
RH (%)

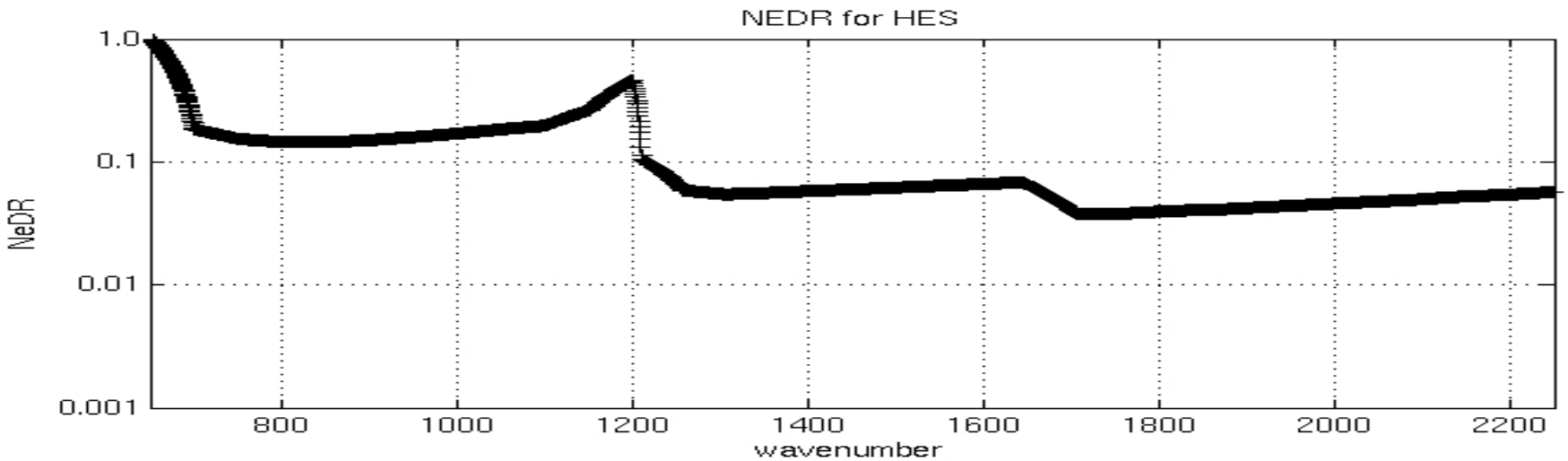

NAST-I RH (%) Cross Section 8Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
100
90
80
70
60
50
40
30
20
10
RH (%)

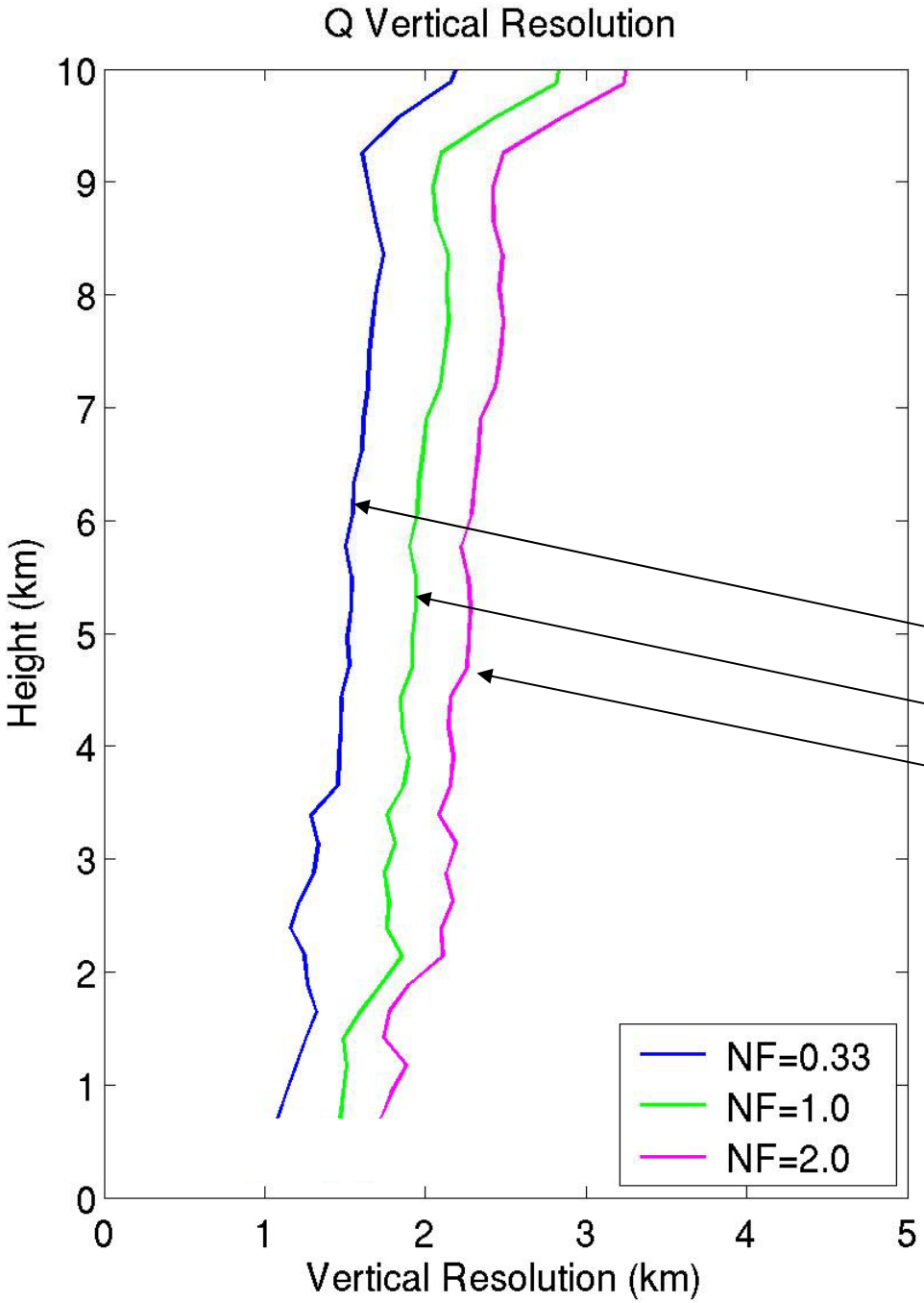

NAST-I RH (%) Cross Section
10Km
15
10
5
0
~Altitude (km)
19:09:42
UT (hh:mm:ss)
100
90
80
70
60
50
40
30
20
10
RH (%)

Signal-to-noise ratio

- Impact on sounding is significant, SNR is key element for sounding
- With given spatial resolution, spectral coverage, spectral resolution and signal-to-noise ratio need to be balanced


Brightness Temperature for HES and AIRS
Brightness Temperature
300
280
260
240
220
200
800
1000
1200
1400
1600
1800
2000
2200
wavenumber
LW
LMW
SMW

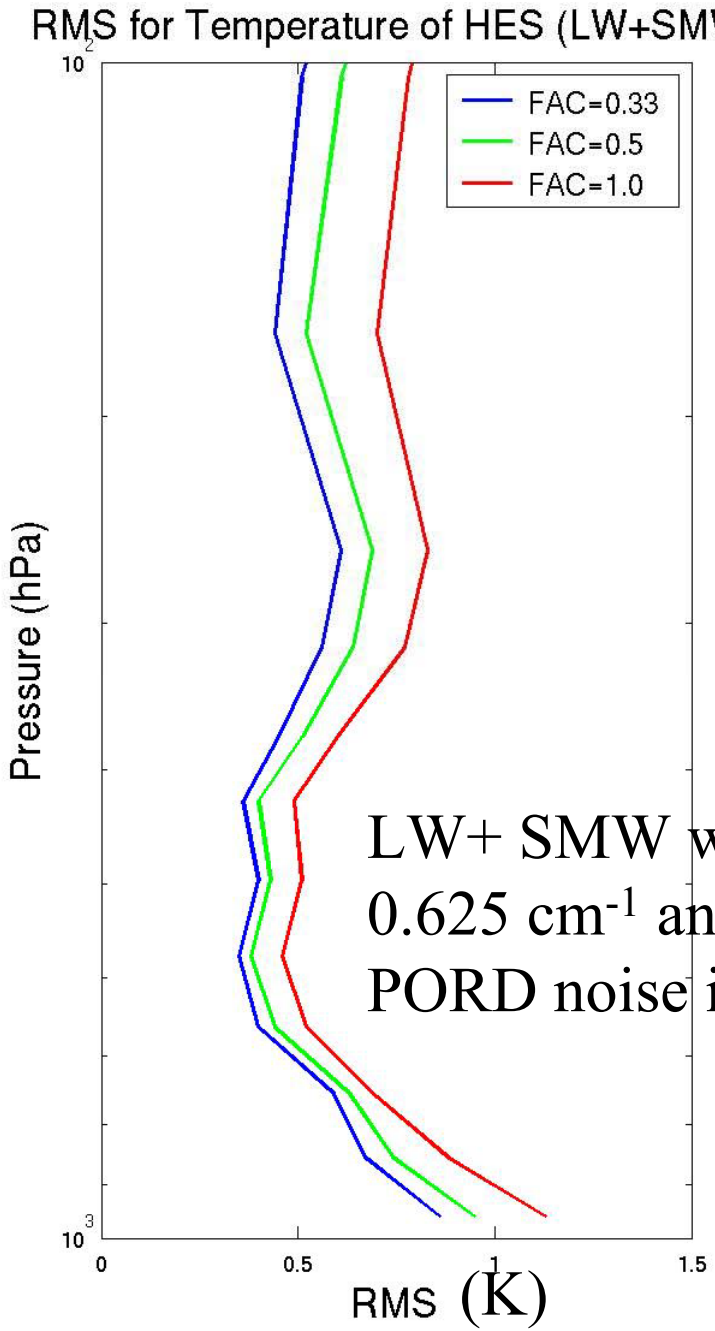

NEDR for HES
NeDR
1.0
0.1
0.01
0.001
800
1000
1200
1400
1600
1800
2000
2200
wavenumber

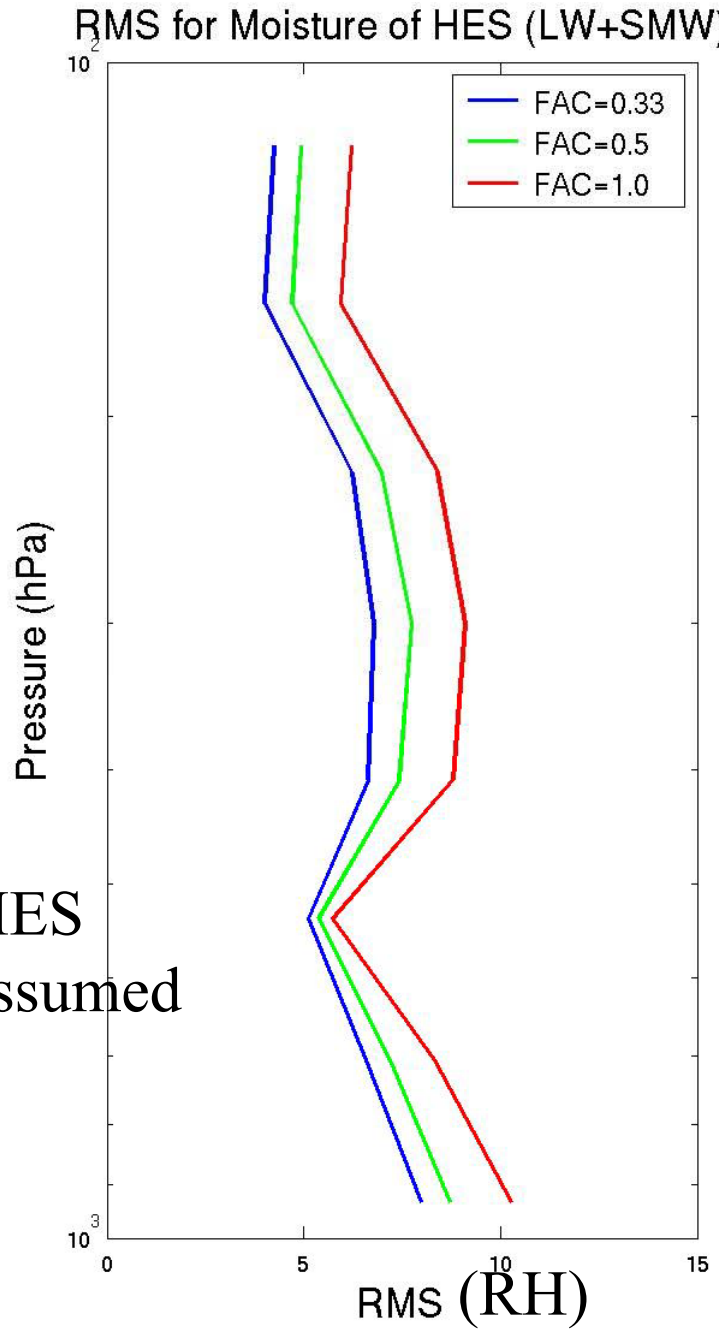


Water vapor mixing ratio vertical resolution:
LW + SMW with 0.625 cm^{-1} and HES PORD noise is assumed

NF=0.33
NF=1.00
NF=2.00

Shortage: like other information content analysis, it is linear analysis based in single profile.

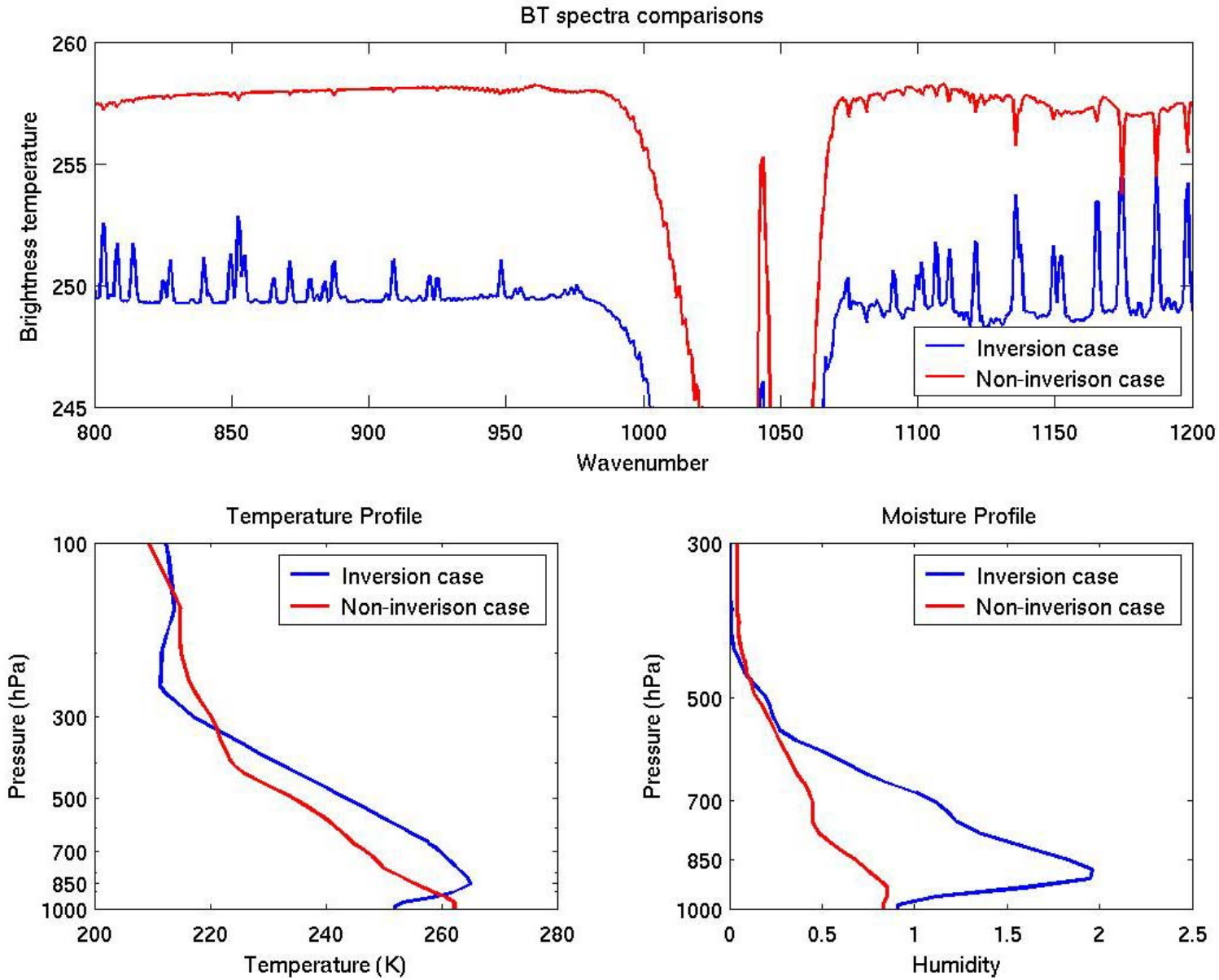


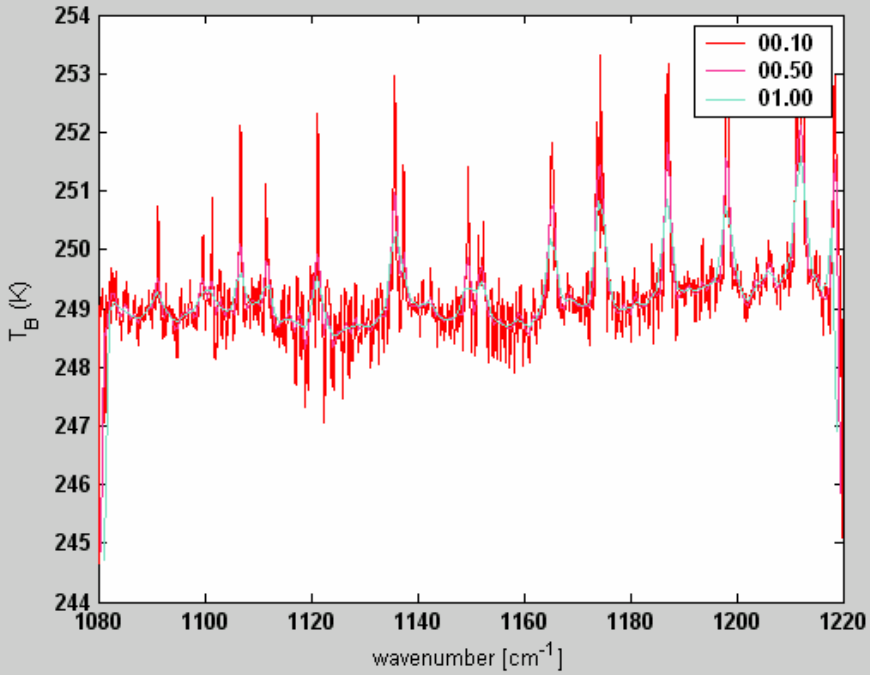


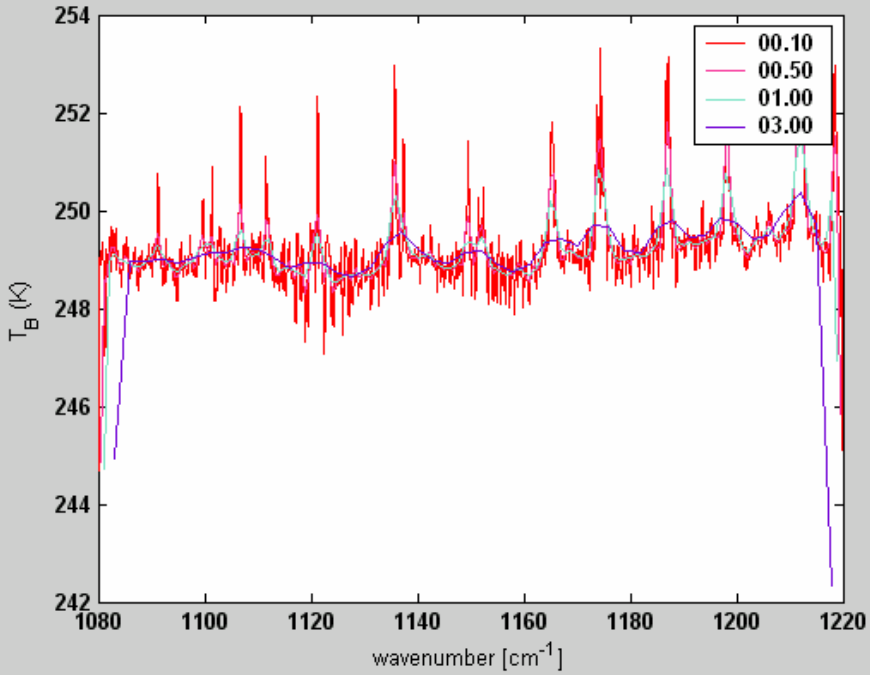
LW+ SMW with
0.625 cm^{-1} and HES
PORD noise is assumed

Spectral resolution

- Has impact on temperature and moisture soundings, especially when there are vertical structures such as level inversions
- Has impact on surface emissivity retrieval using window band


BT spectra comparisons
Brightness temperature
260
255
250
245
800
850
900
950
1000
1050
1100
1150
1200
Wavenumber
Inversion case
Non-inverison case
Temperature Profile
Pressure (hPa)
100
300
500
700
850
1000
200
220
240
260
280
Temperature (K)
Inversion case
Non-inverison case
Moisture Profile
Pressure (hPa)
300
500
700
850
1000
0
0.5
1
1.5
2
2.5
Humidity
Inversion case
Non-inverison case

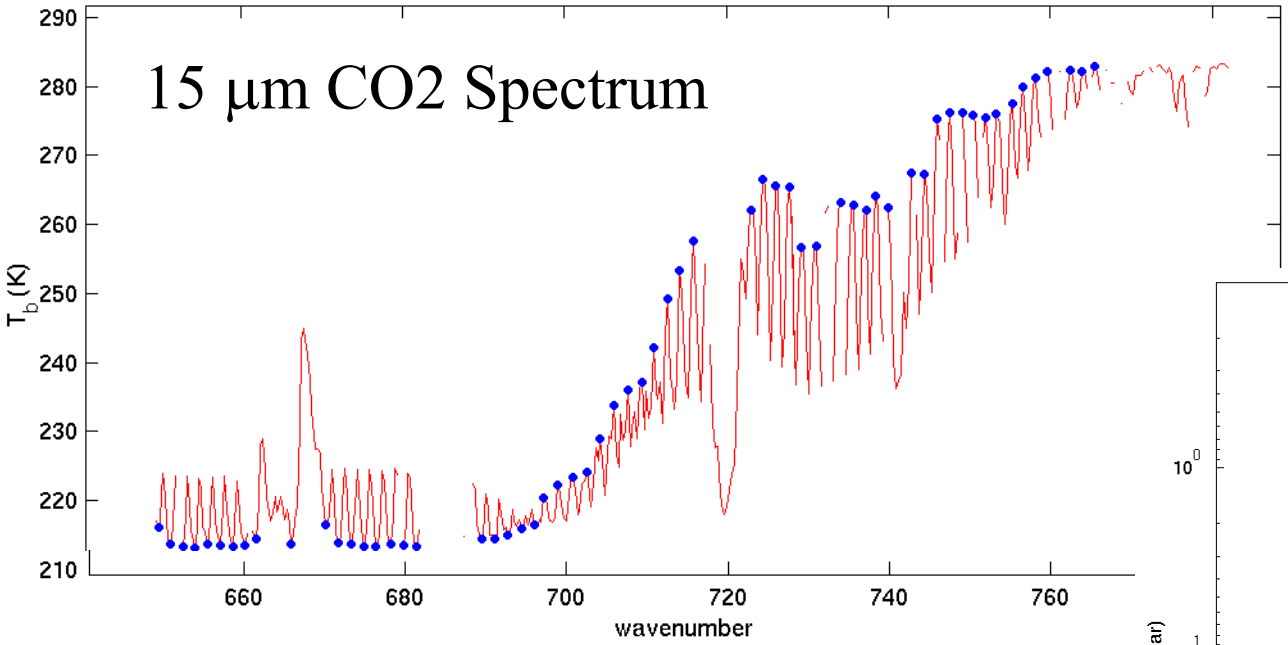




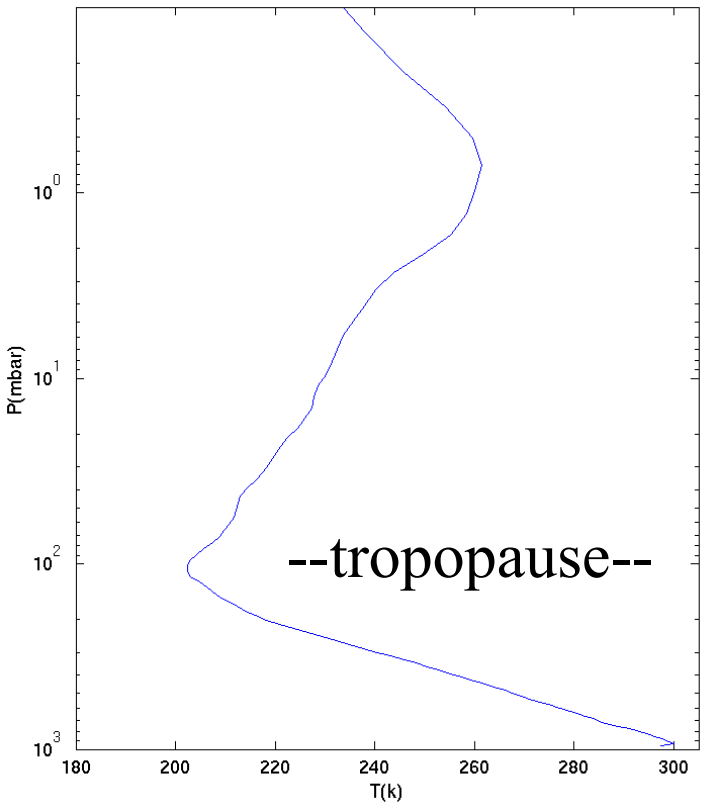
Ability to detect inversions disappears with broadband observations (> 3 cm-1)

Twisted Ribbon formed by CO_2 spectrum:

Tropopause inversion causes On-line & off-line patterns to cross



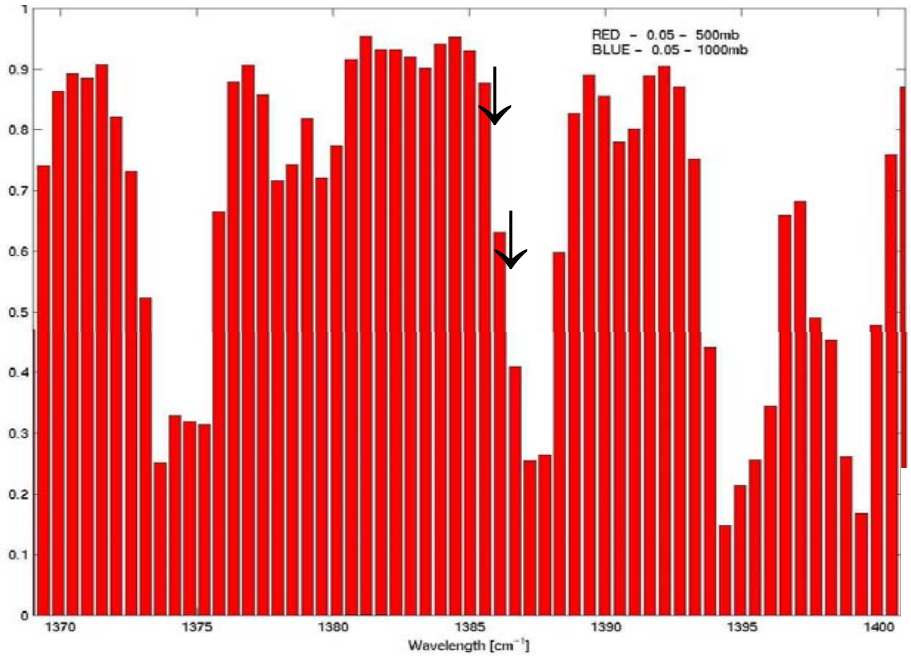
(Dave Tobin, CIMSS)



Blue between-line T_b
warmer for tropospheric channels,
colder for stratospheric channels

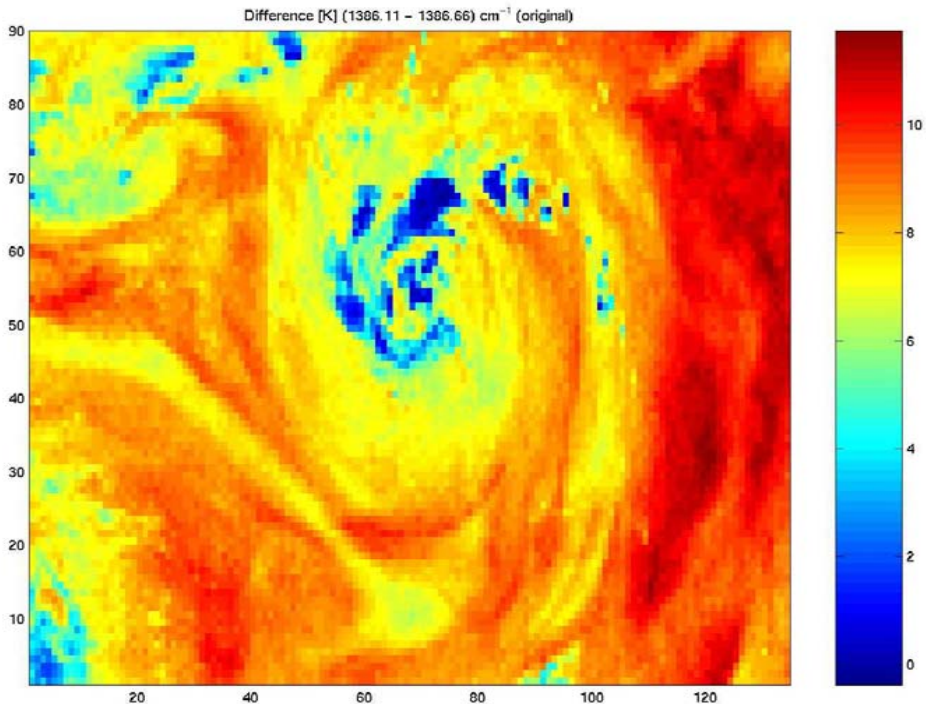
Signature not available at low resolution

Atmospheric transmittance in H2O sensitive region of spectrum



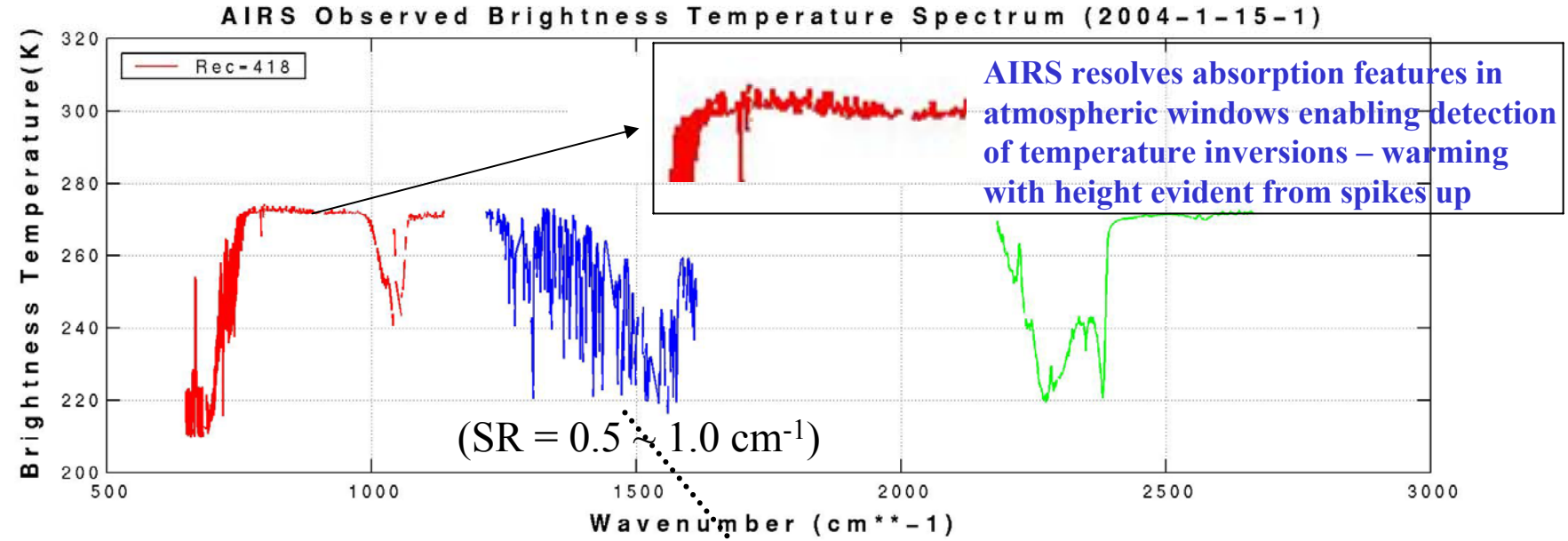
Studying spectral sensitivity with AIRS Data

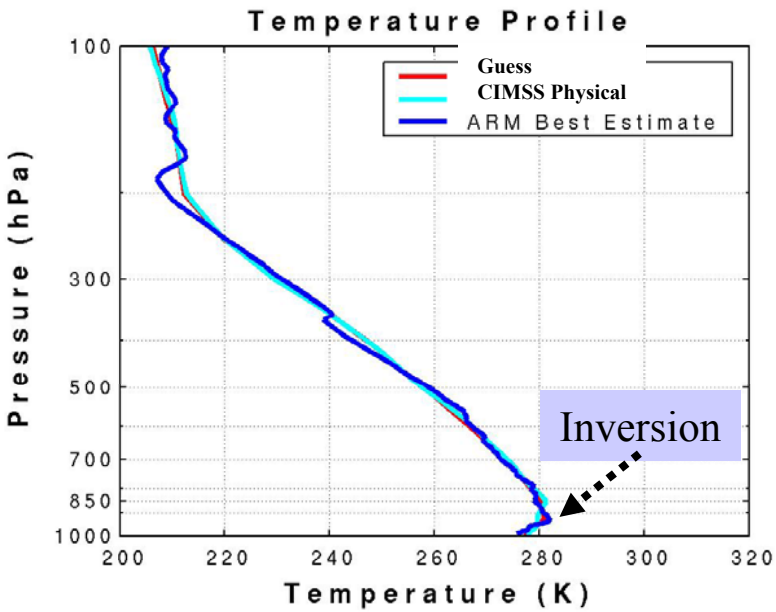
AIRS BT[1386.11] – BT[1386.66]

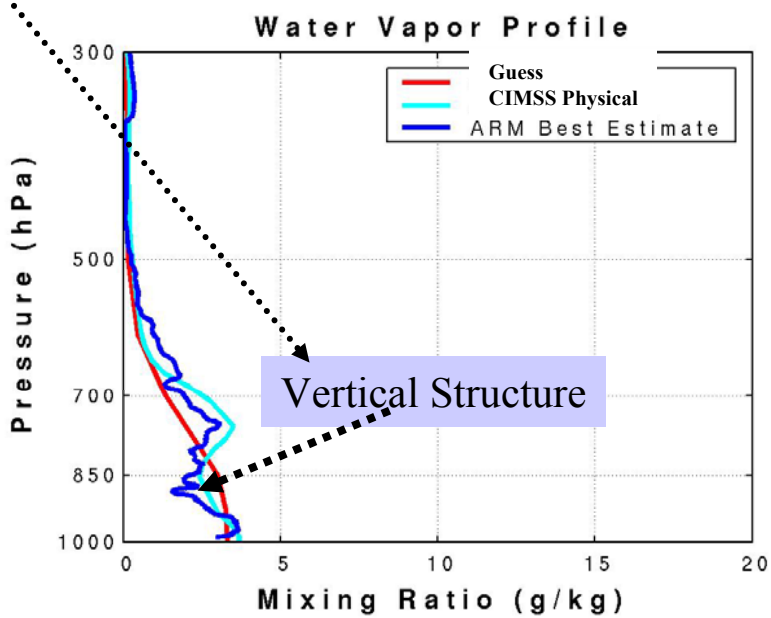


Spectral change of 0.5 cm-1 causes BT changes > 10 C

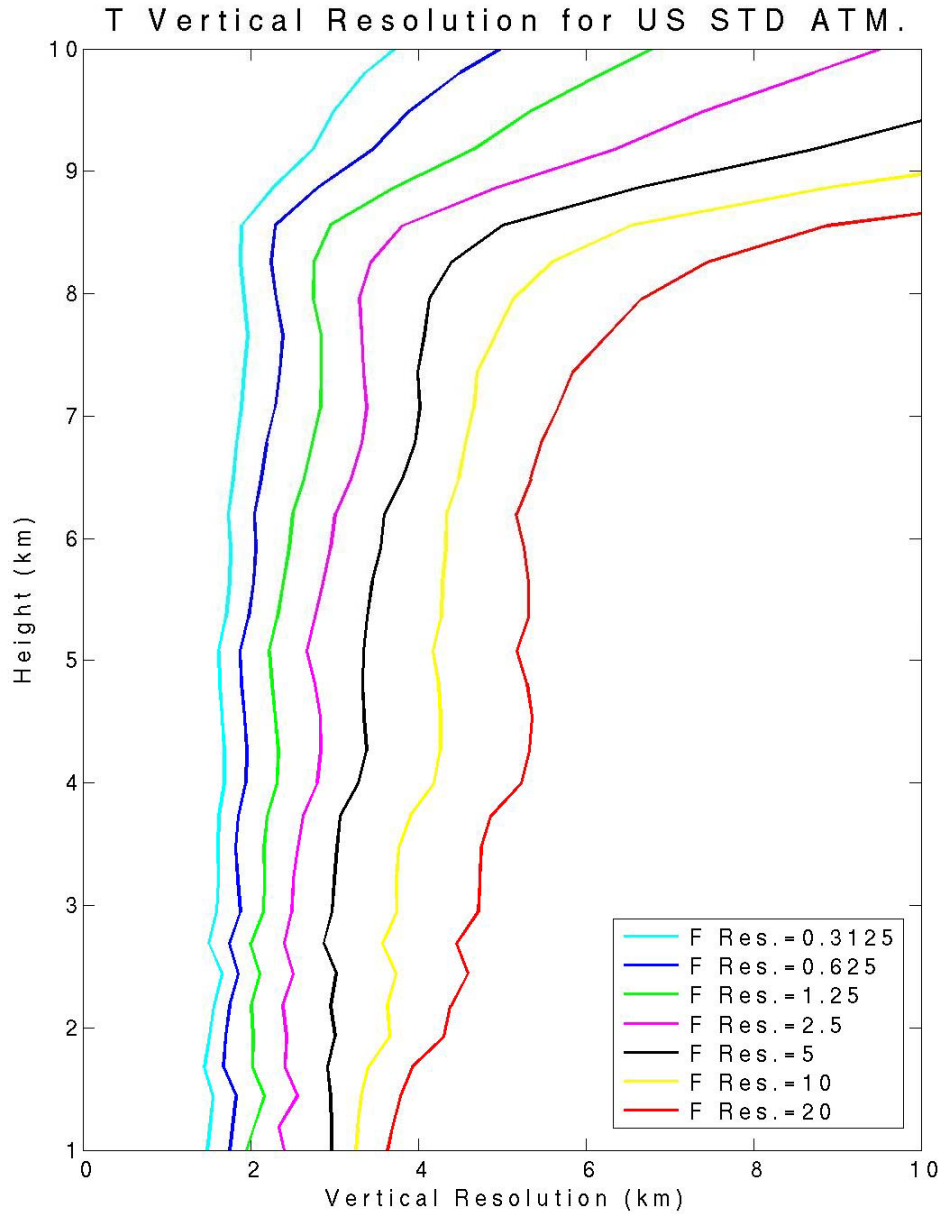
Validation of AIRS profile retrievals at CART site



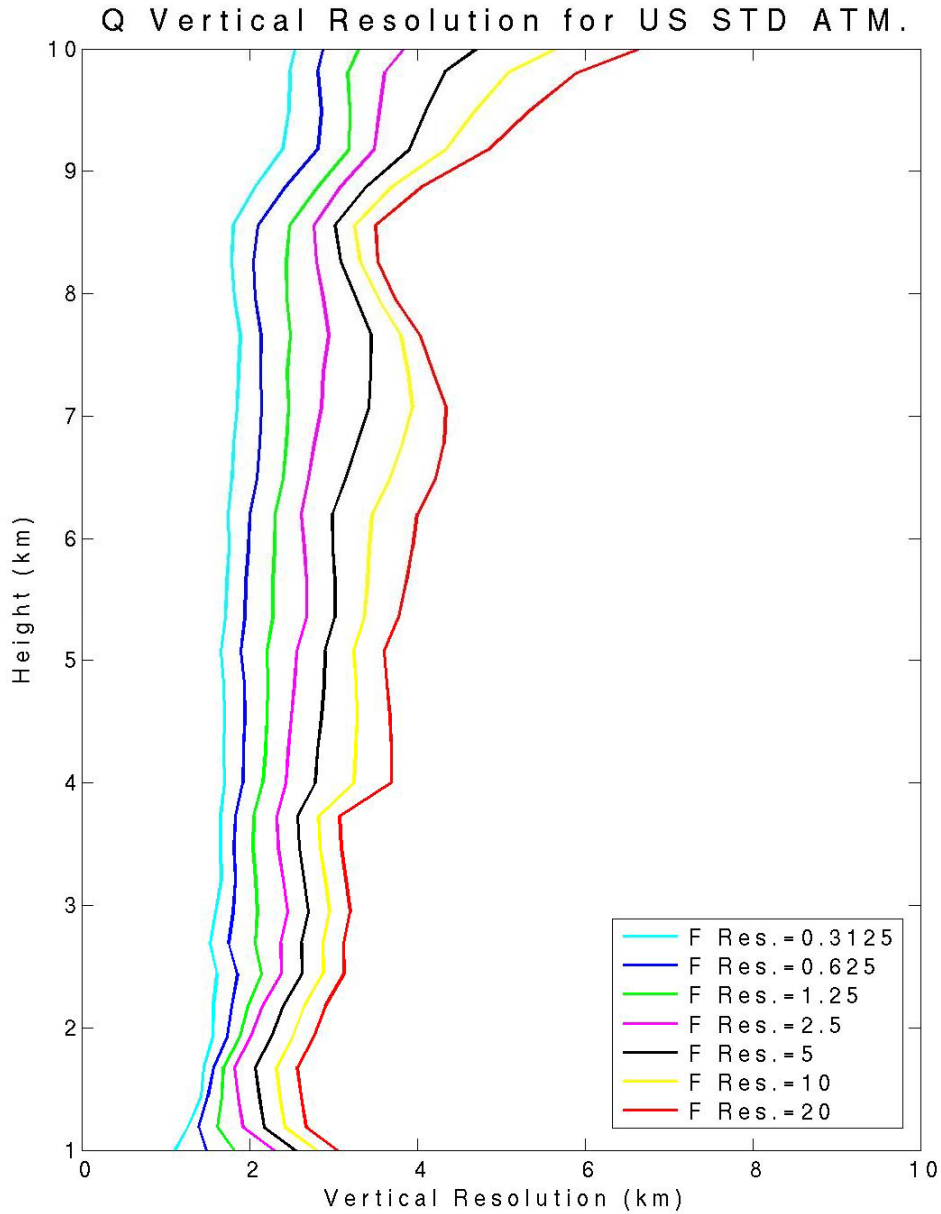




Li, CIMSS, 2006

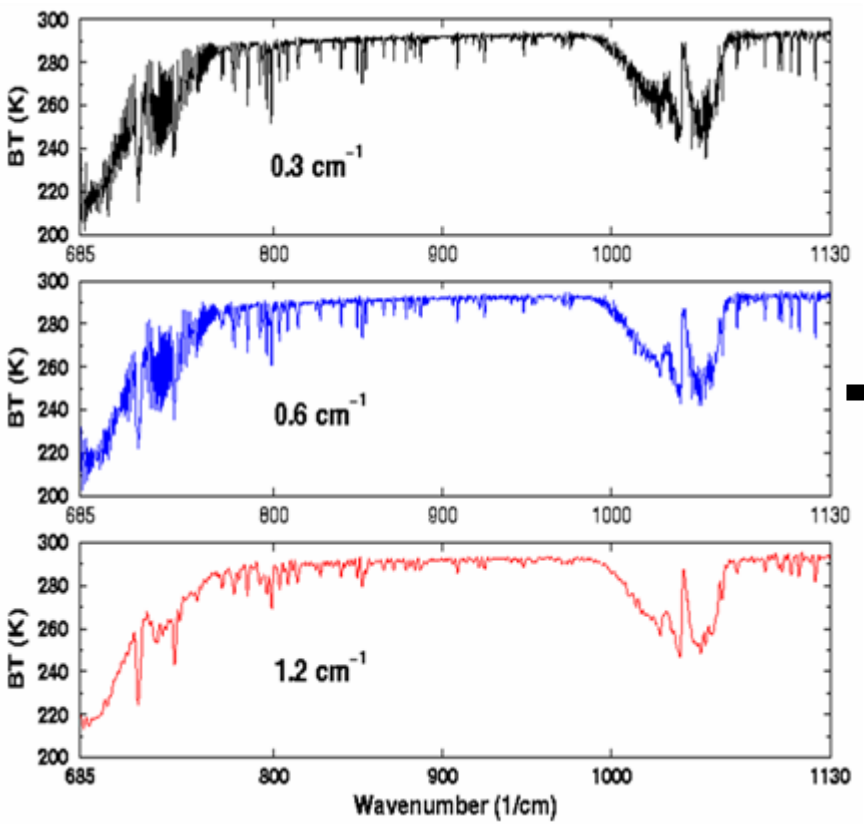


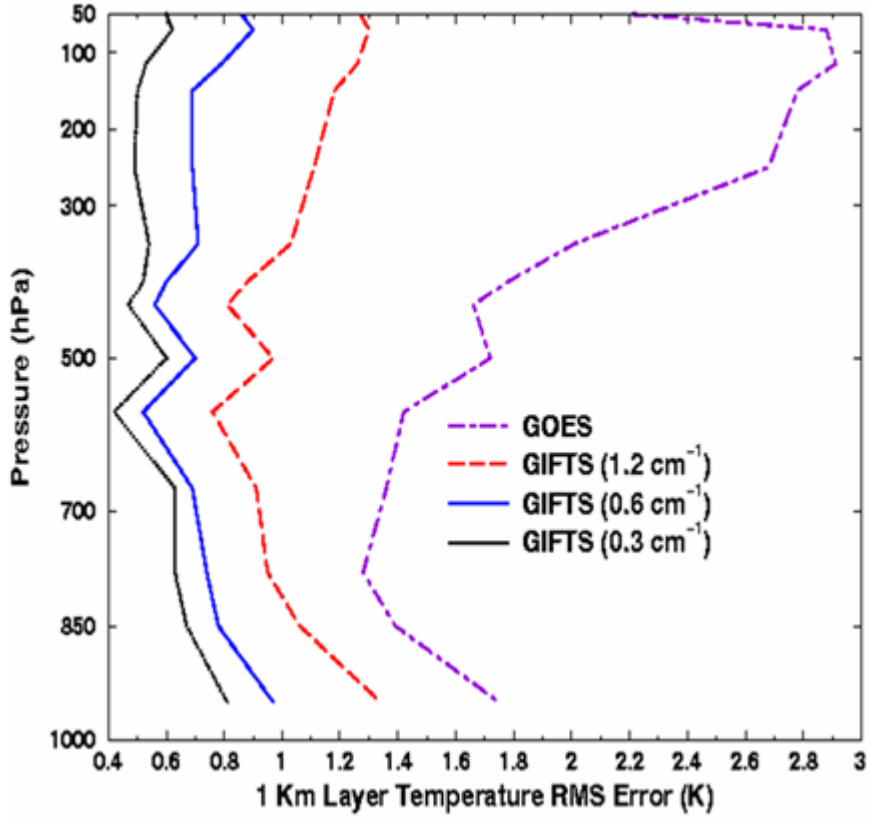
Temperature vertical resolution:
LW + SMW with PORD noise is assumed



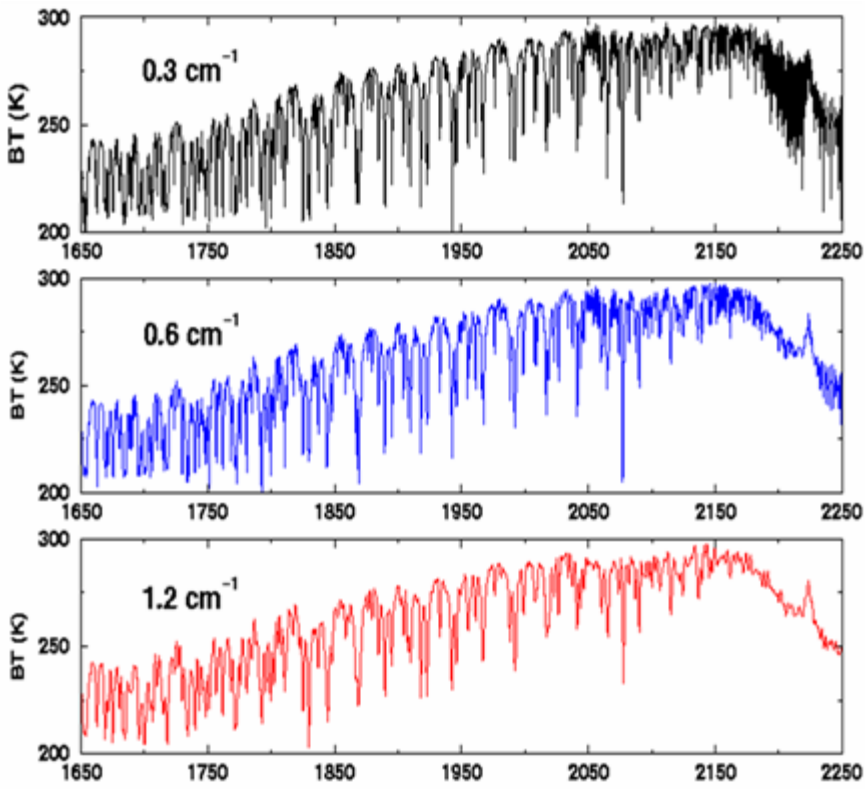
Water vapor mixing ratio vertical resolution:
LW + SMW with PORD noise is assumed

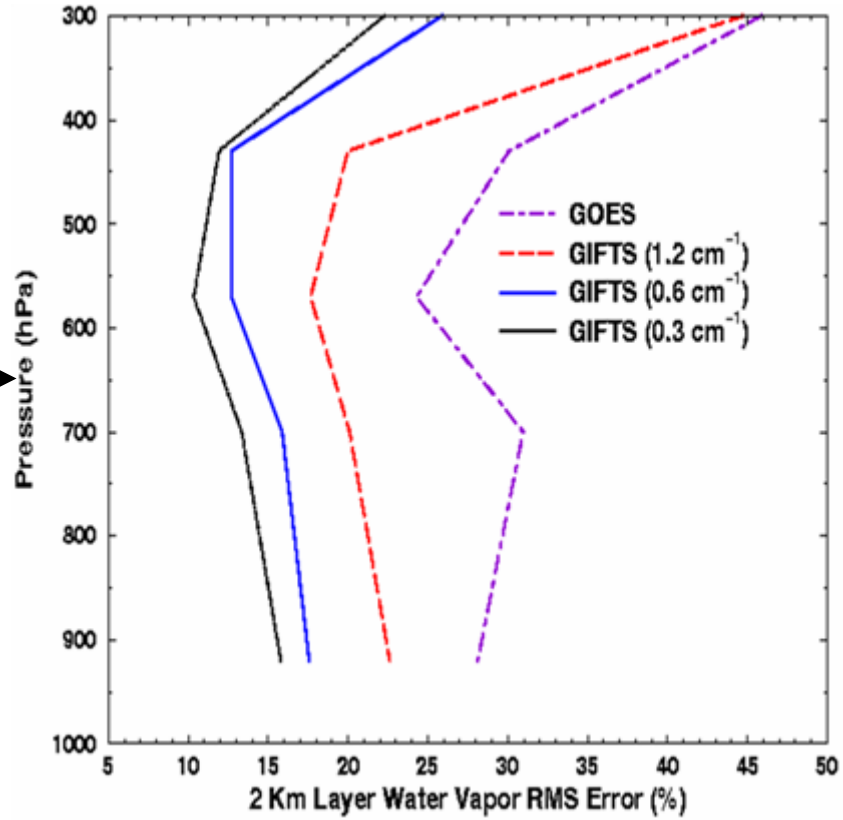
LW channels


BT (K)
0.3 cm^{-1}
0.6 cm^{-1}
1.2 cm^{-1}
Wavenumber (1/cm)


Pressure (hPa)
GOES
GIFTS (1.2 cm^{-1})
GIFTS (0.6 cm^{-1})
GIFTS (0.3 cm^{-1})
1 Km Layer Temperature RMS Error (K)

Shorter side MW channels

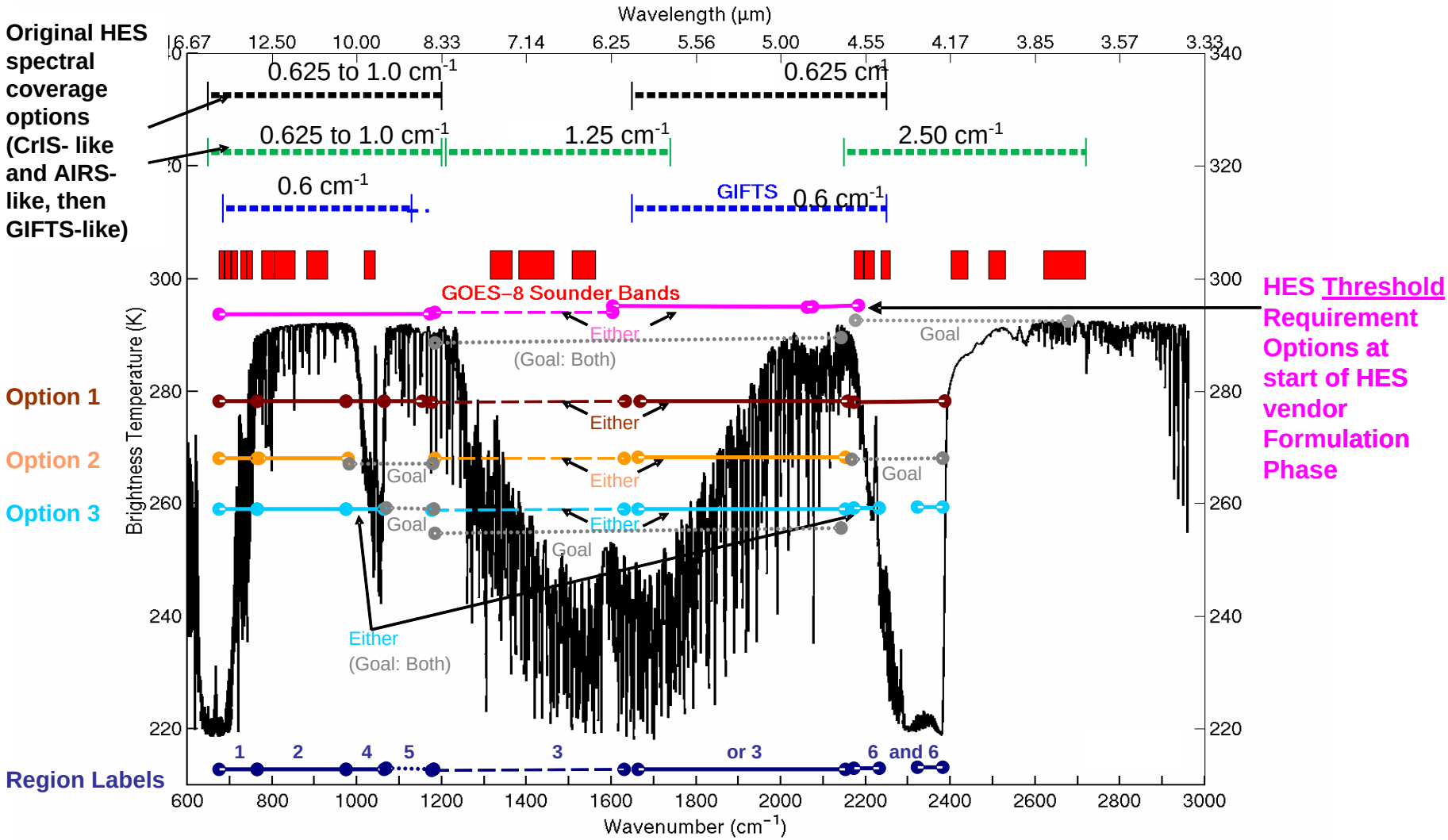




Spectral coverage

- Highly related to cost/budget and requirement in some designs
- Need to optimize the spectral coverage for a cost effective instrument
- Products and applications dependent
- Should consider other available data source for synergistic applications (LEO, GPS)
- Some trade-off studies for HES

IR Spectral Considerations for HES

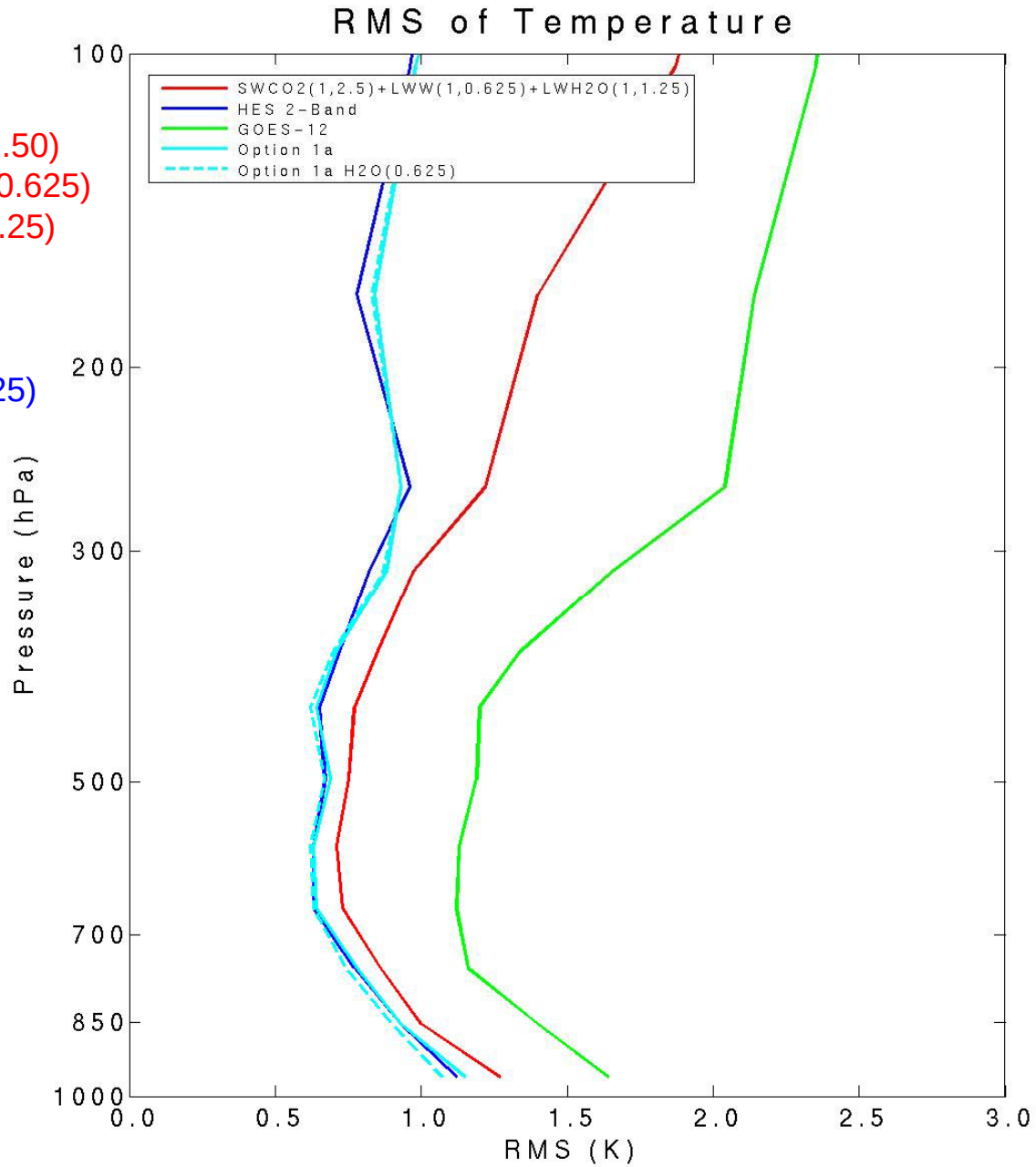


1 = 675 – 800 cm-1 (14.8 – 12.5 um), 2 = 800 – 1000 cm-1 (12.5 - 10.0 um), 3 = 1210 – 1645 or 1689 – 2150 cm-1 (8.26 – 6.08 um or 5.92- 4.65 um), 4 = 1080 – 1000 cm-1 (10.0 - 9.26 um), 5 = 1080 – 1200 cm (9.26 – 8.33 um), 6 = 2150 – 2400 (4.65 – 4.167) but considering 2150 – 2250 and 2350 – 2400 cm-1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

Minimum Mission:
SWCO2 (2150 – 2400) (2.50)
LLW (800 – 990 (0.625) (0.625)
LWH2O (1210 – 1666) (1.25)

HES 2-band
LW (650 – 1200) (0.625)
SMW (1650 – 2250) (0.625)

Option 1a
(675 - 1200) (0.625)
(1689 - 2150) (1.250)
(2150 - 2400) (2.500)



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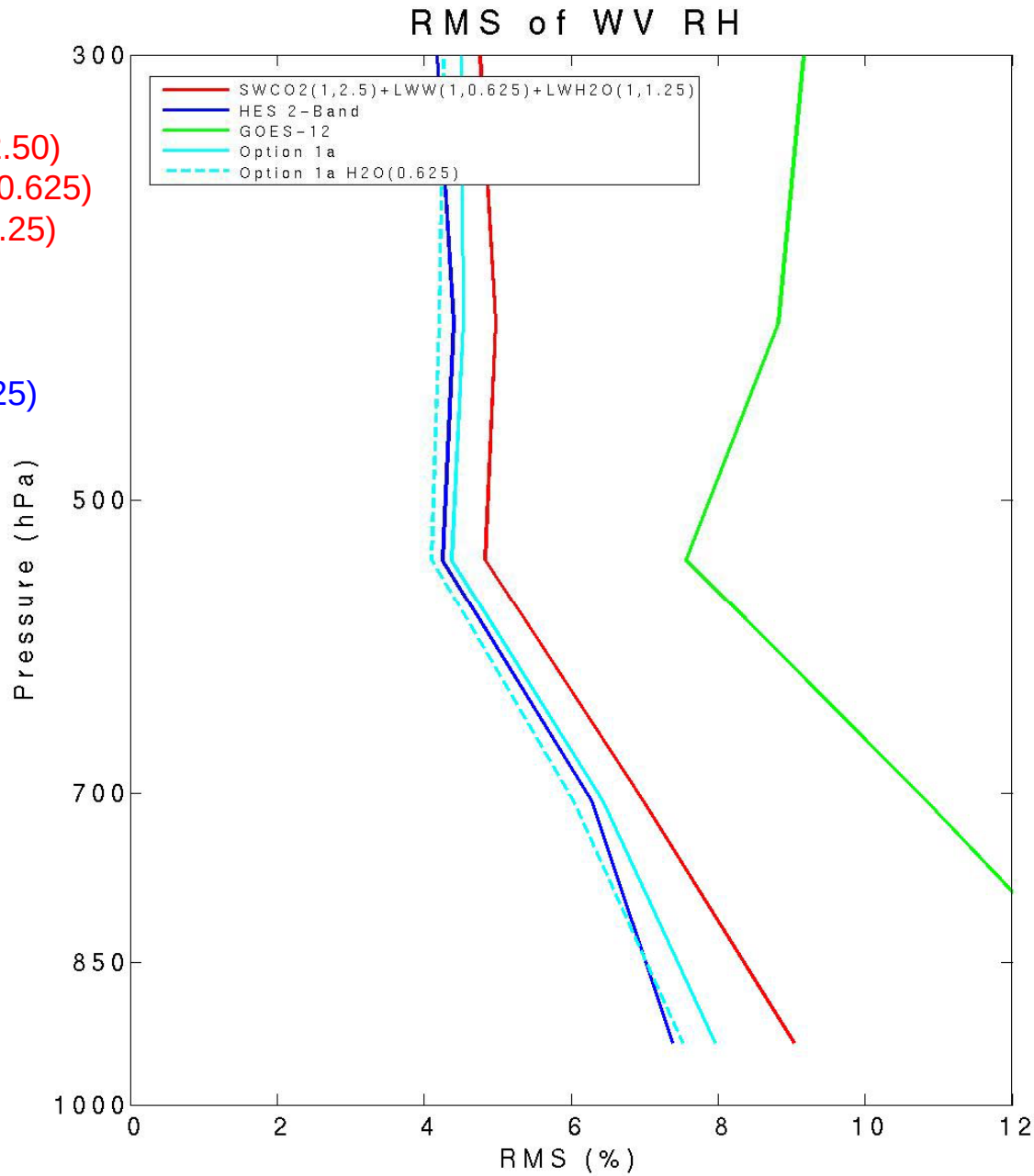
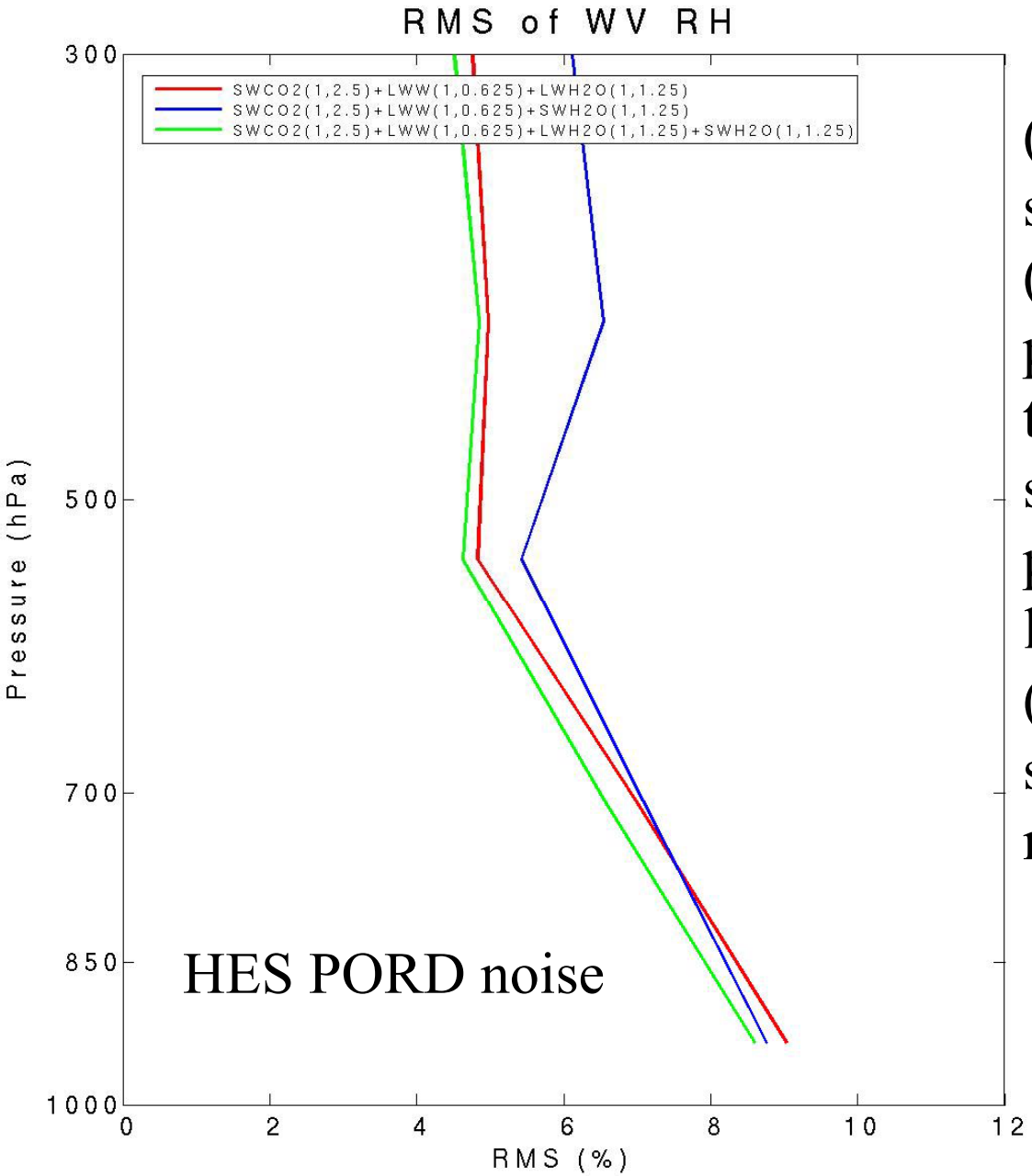




(1) Both sides have the similar spectral information;
(2) Longer side H2O region provides better mid-tropospheric moisture, shorter side H2O region provides better boundary layer moisture;
(3) Combination of both sides provides the best moisture information.

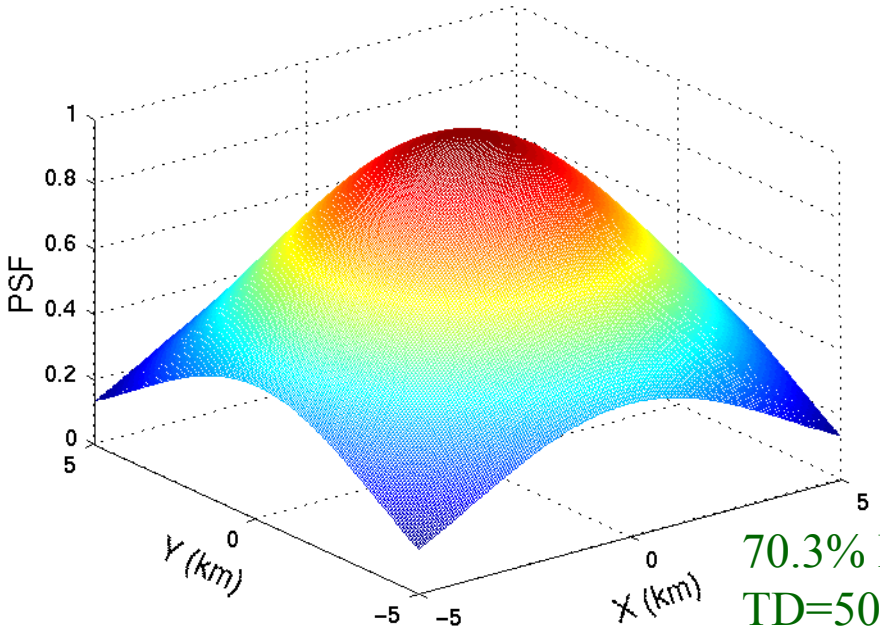
LWCO2: 12.5 um to 13.92 um (800 cm-1 to 718 cm-1) or
SWCO2: 4.167um to 4.65um (2400cm-1 to 2150cm-1) at goal NEdN

SWH2O: 4.65um to 6.0um (2150cm-1 to 1666cm-1) or
LWH2O: 6.0um to 8.26um (1666cm-1 to 1210cm-1)

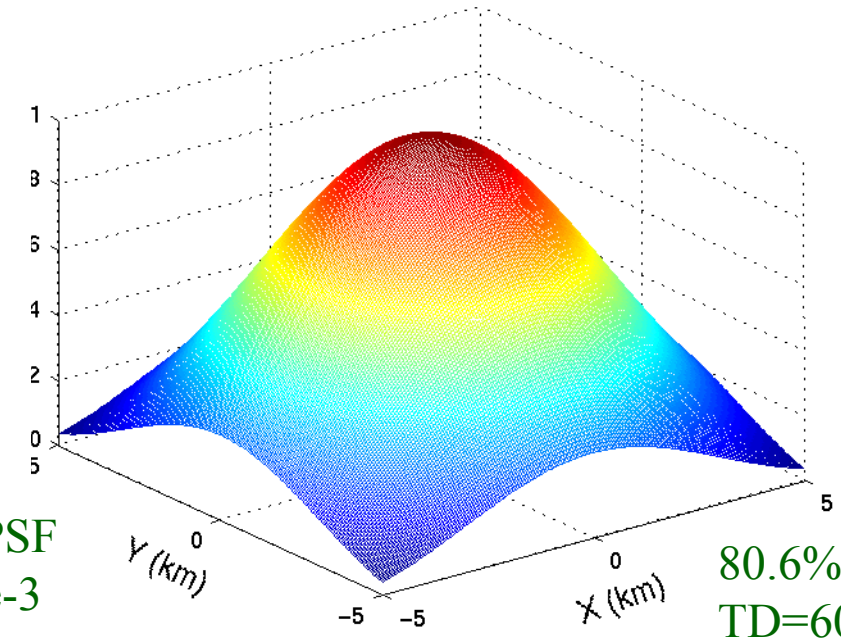
LWWindow: 10.1um to 12.5um (990cm-1 to 800cm-1) or
SWWindow: 8.33um to 9.3um (1200cm-1 to 1075cm-1)

HES Detector Optical Ensquared Energy (DOEE) study

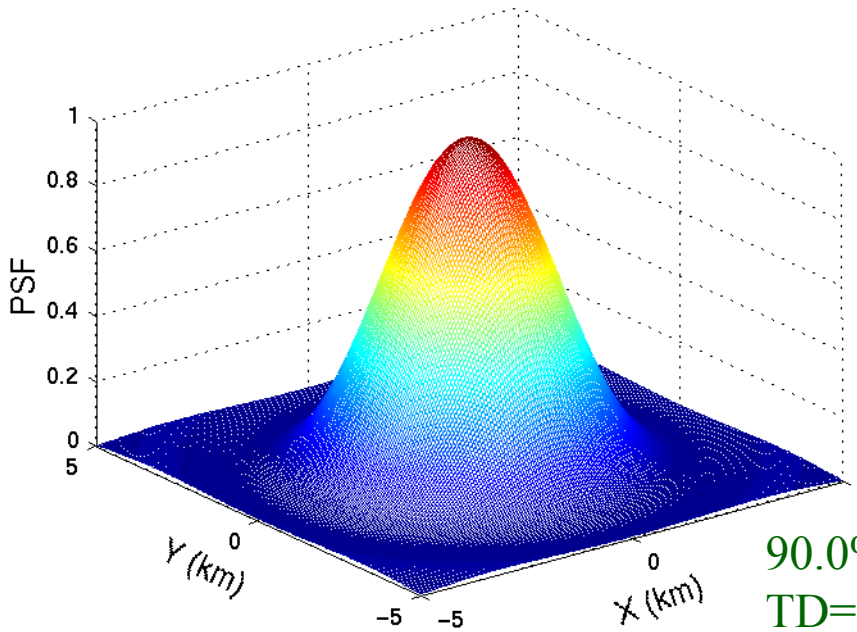
- MAS IR data with 50 meter resolution is used
- Point Spread Function (PSF) from GIFTS
- MODIS 1 km IR data are used to study the impact of PSF on retrieval



70.3% PSF
TD=50e-3



80.6% PSF
TD=60e-3



90.0% PSF
TD=120e-3

70%, 80%, 90%PSF
(λ=12 μm)
was prepared for testing
with MAS data

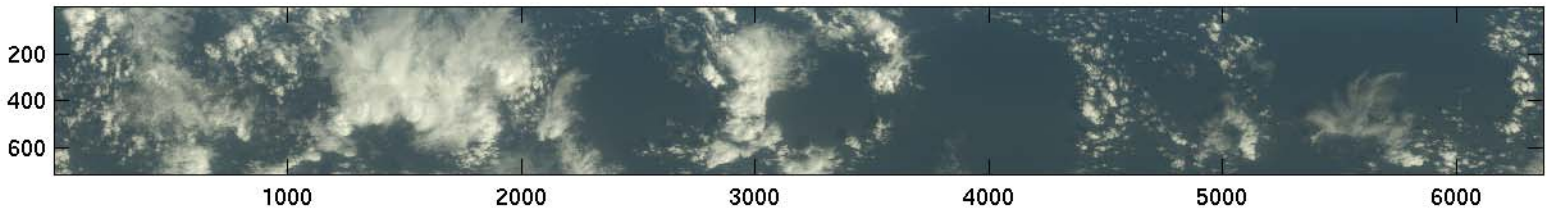
MAS data: Clear/Cloudy

MAS Data Flight Date: MASL1B_03915_09_20021123_1918_1937_V01.hdf

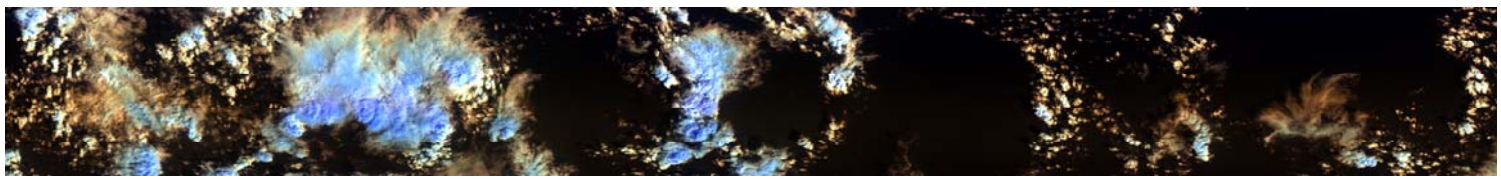
R (3:0.66)G(2:0.55)B(1:0.47)

R (20:2.15)G(10:1.64)B(2:0.55)

MAS Data Flight Date: MASL1B_03613_12_20030220_0019_0036_V01.hdf



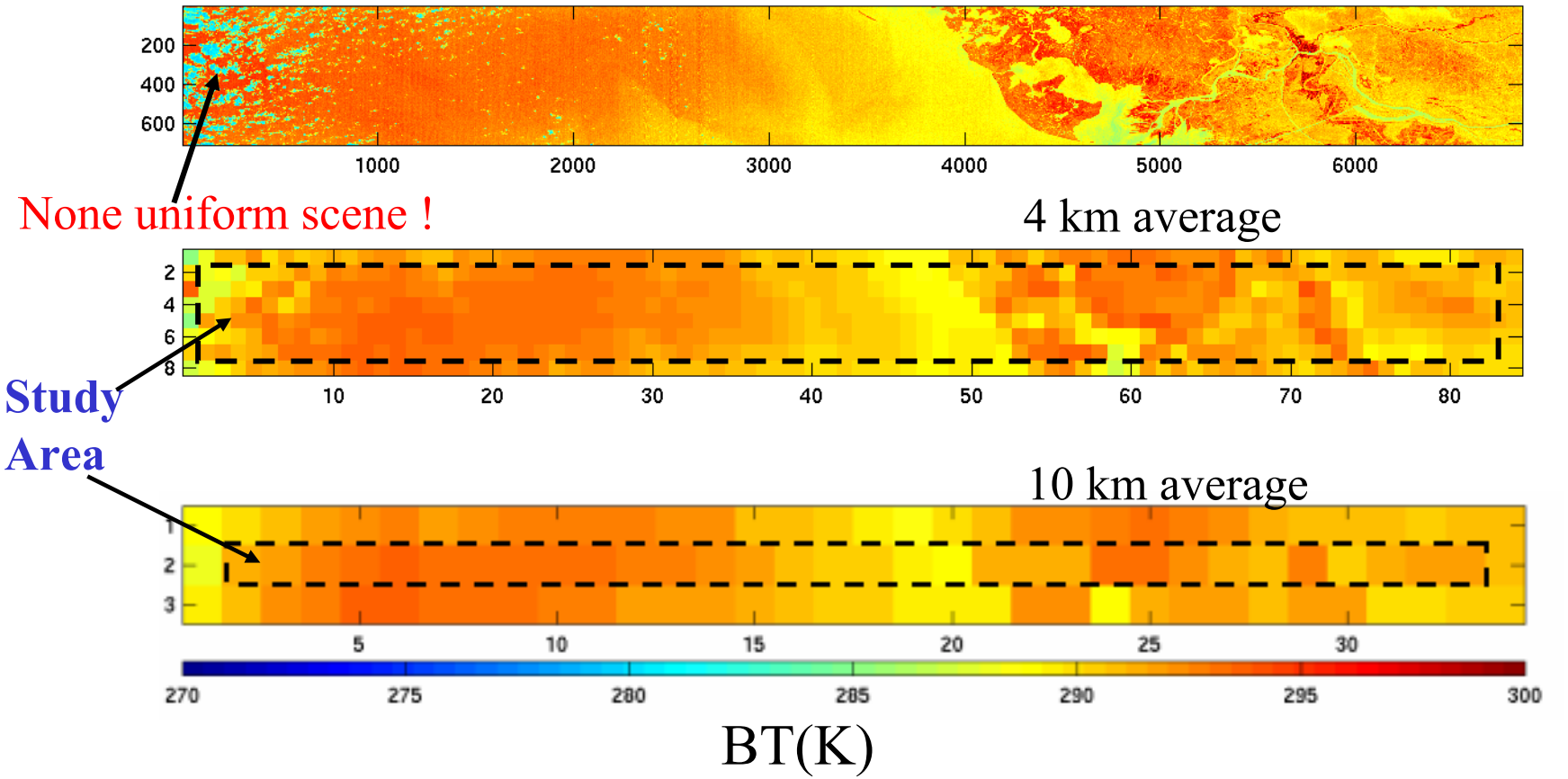
R (3:0.66)G(2:0.55)B(1:0.47)



R (20:2.15)G(10:1.64)B(2:0.55)

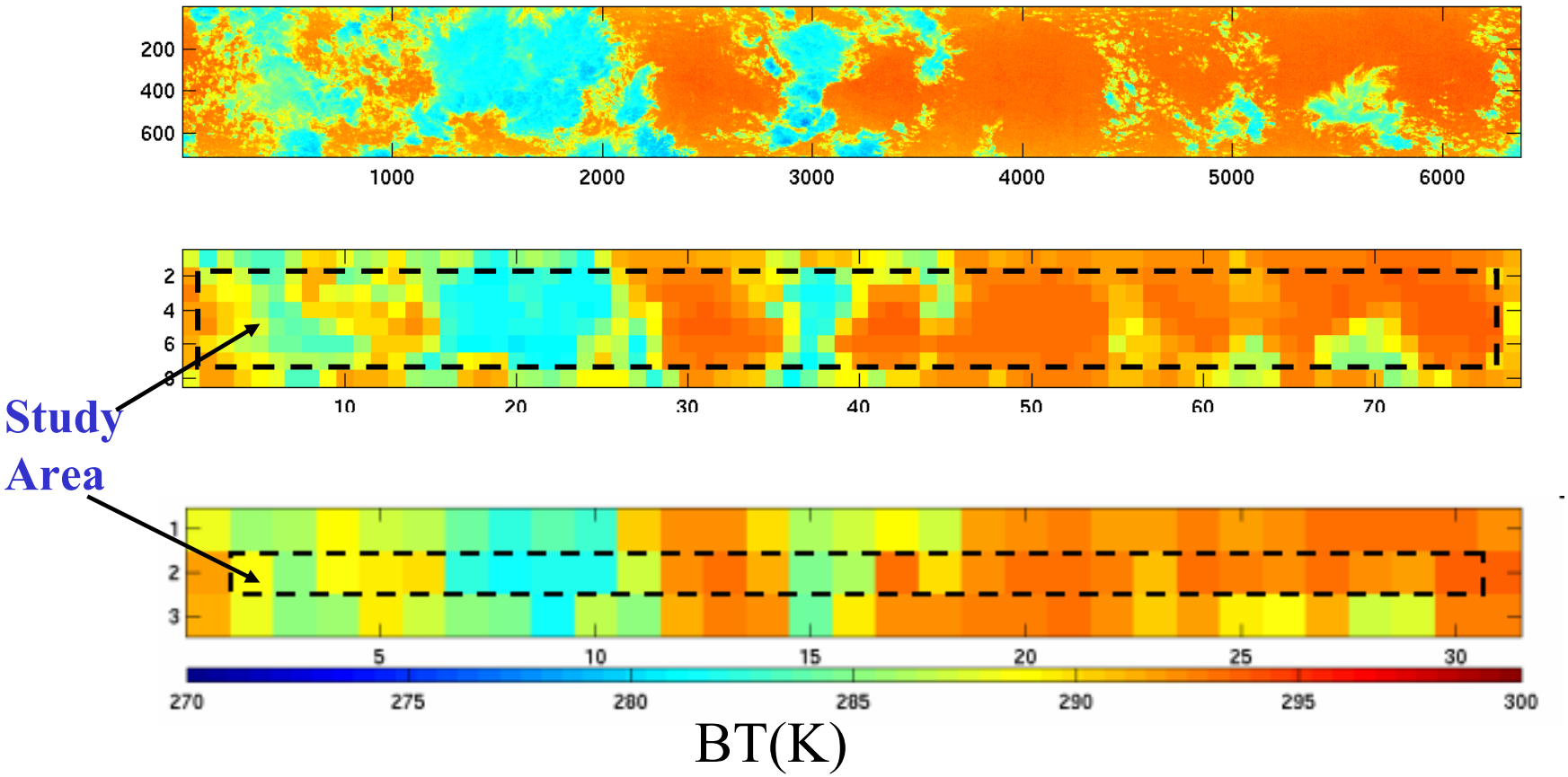
4 km and 10 km BT average (Clear, 12.00 μm)

BT image: MAS VS 4 km average VS 10 km average



4 km and 10 km BT average (Cloudy, 12.00 μm)

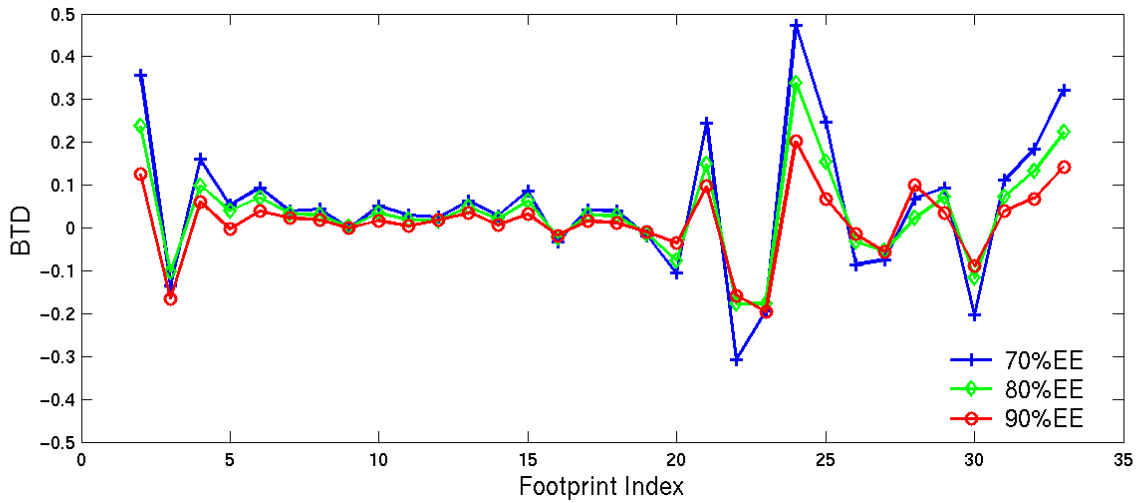
BT image: MAS VS 4 km average VS 10 km average



BTD by EE (10 km, 12.00 µm)

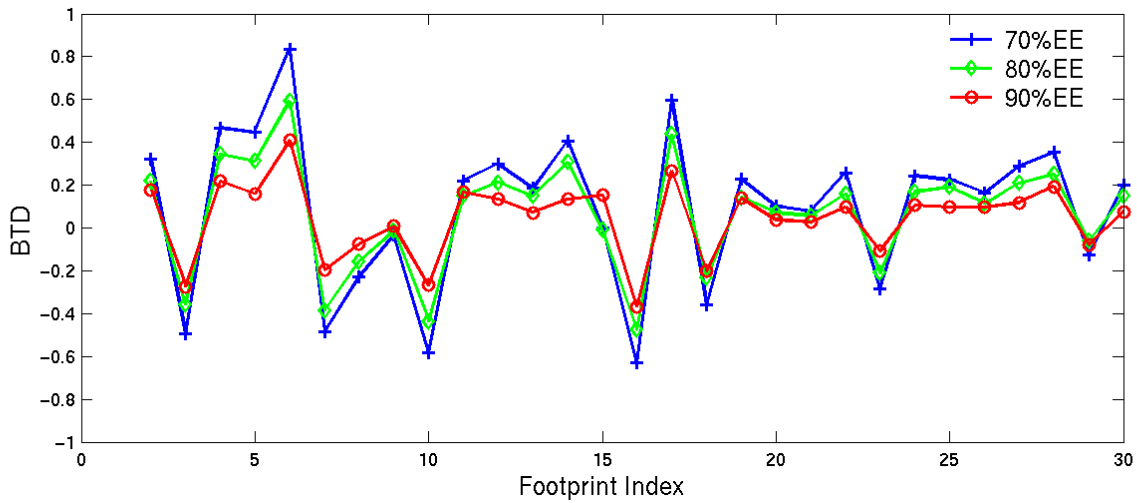
BTD alone center line (nadir)

Clear



70%rmsd=0.17
maxd=0.47
80%rmsd=0.11
maxd=0.34
90%rmsd=0.08
maxd=0.20

Cloudy

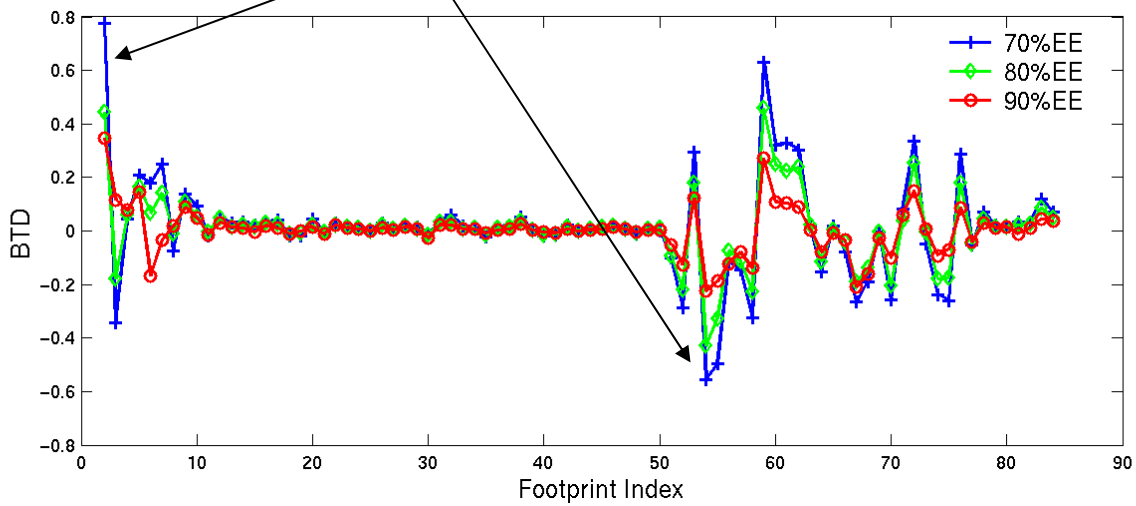


70%rmsd=0.37
maxd=0.84
80%rmsd=0.27
maxd=0.59
90%rmsd=0.18
maxd=0.41

BTD by EE (4 km, 12.00 μm)

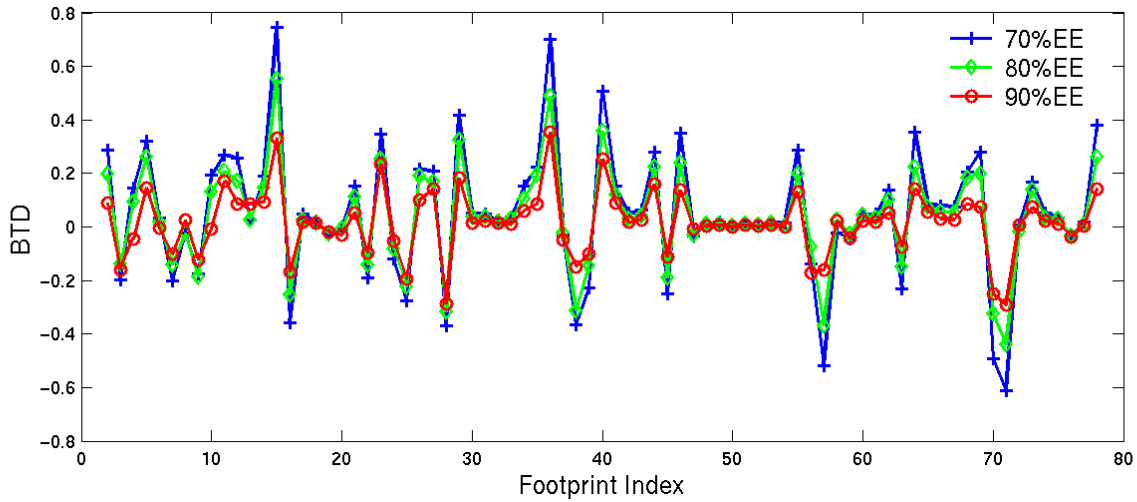
Extreme situation

Clear

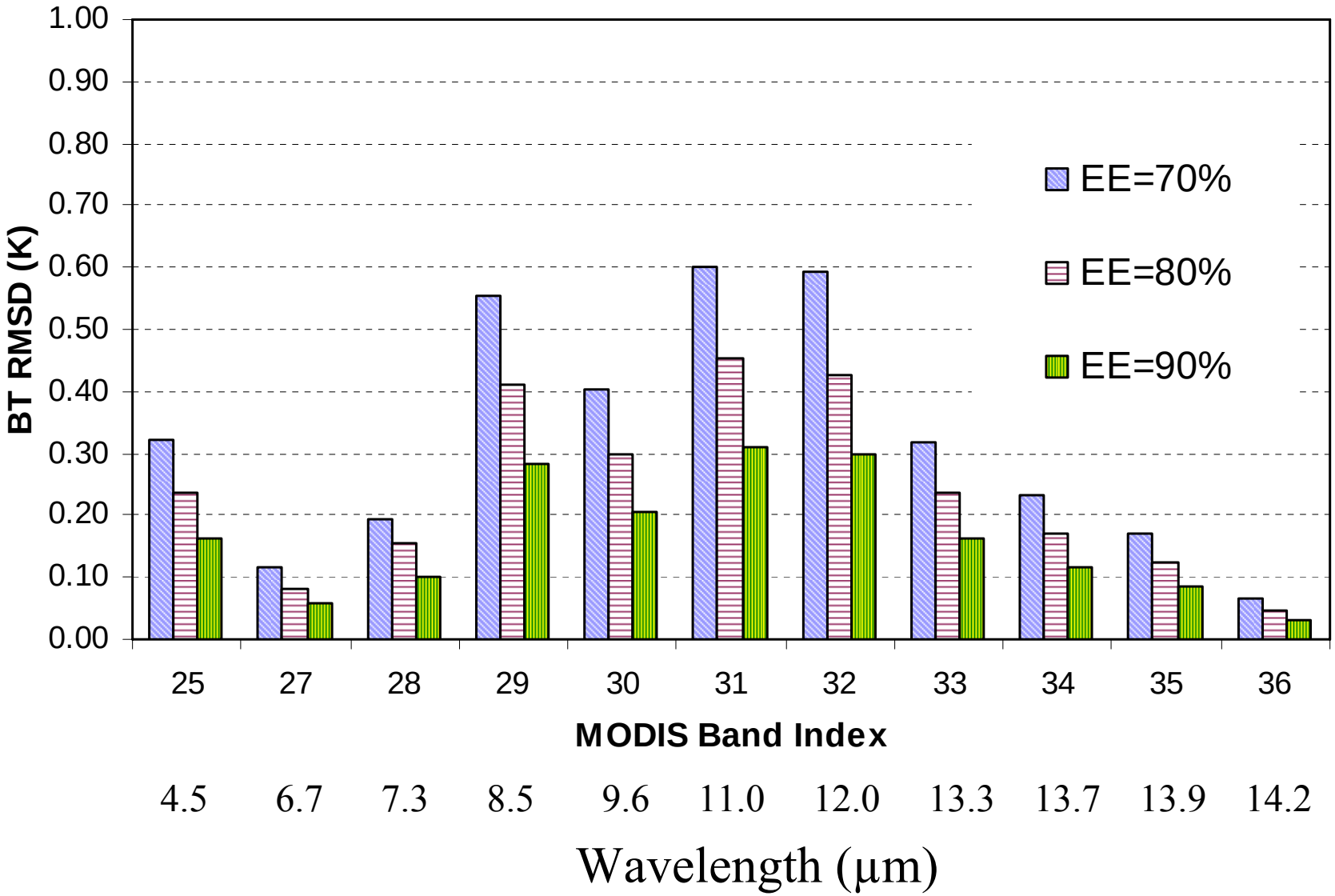


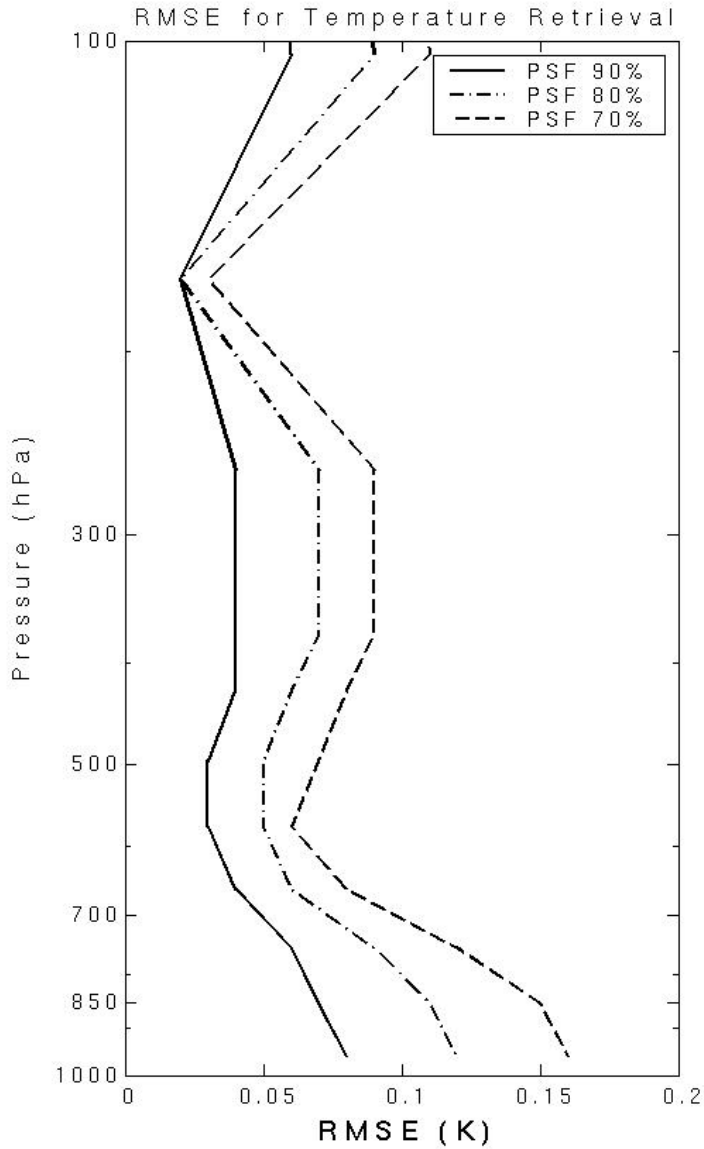
70%rmsd=0.19
maxd=0.78
80%rmsd=0.13
maxd=0.46
90%rmsd=0.09
maxd=0.35

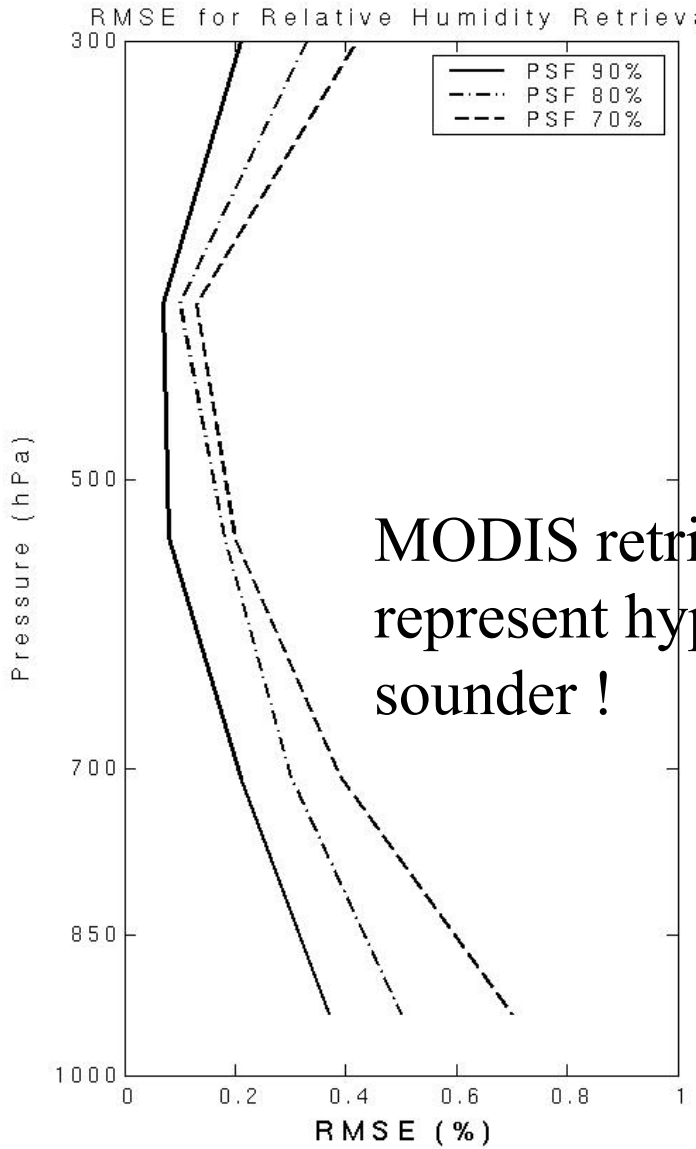
Cloudy



70%rmsd=0.25
maxd=0.75
80%rmsd=0.18
maxd=0.55
90%rmsd=0.12
maxd=0.36


1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
BT RMSD (K)
EE=70%
EE=80%
EE=90%
25
27
28
29
30
31
32
33
34
35
36
MODIS Band Index
4.5
6.7
7.3
8.5
9.6
11.0
12.0
13.3
13.7
13.9
14.2
Wavelength (μm)

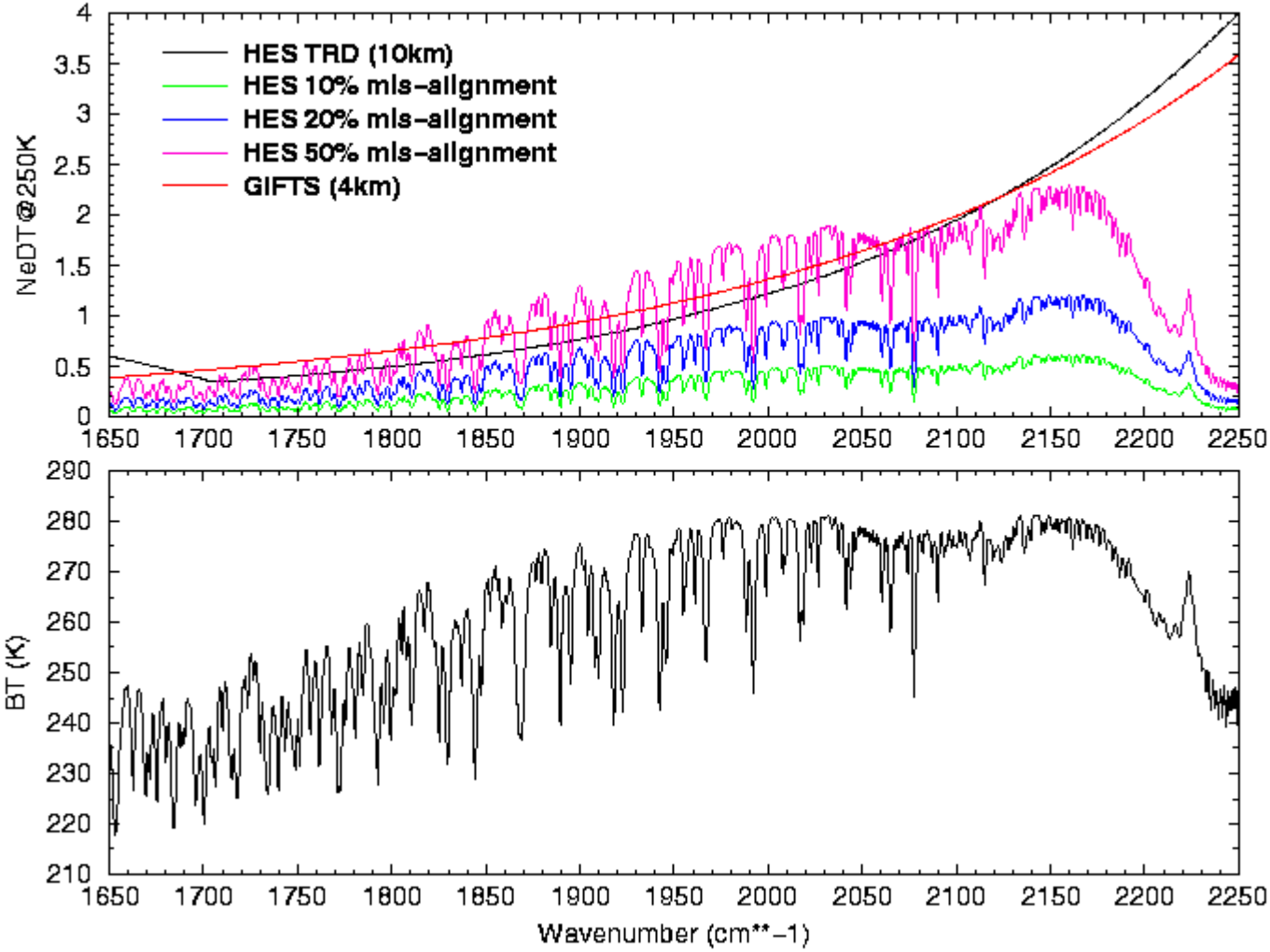




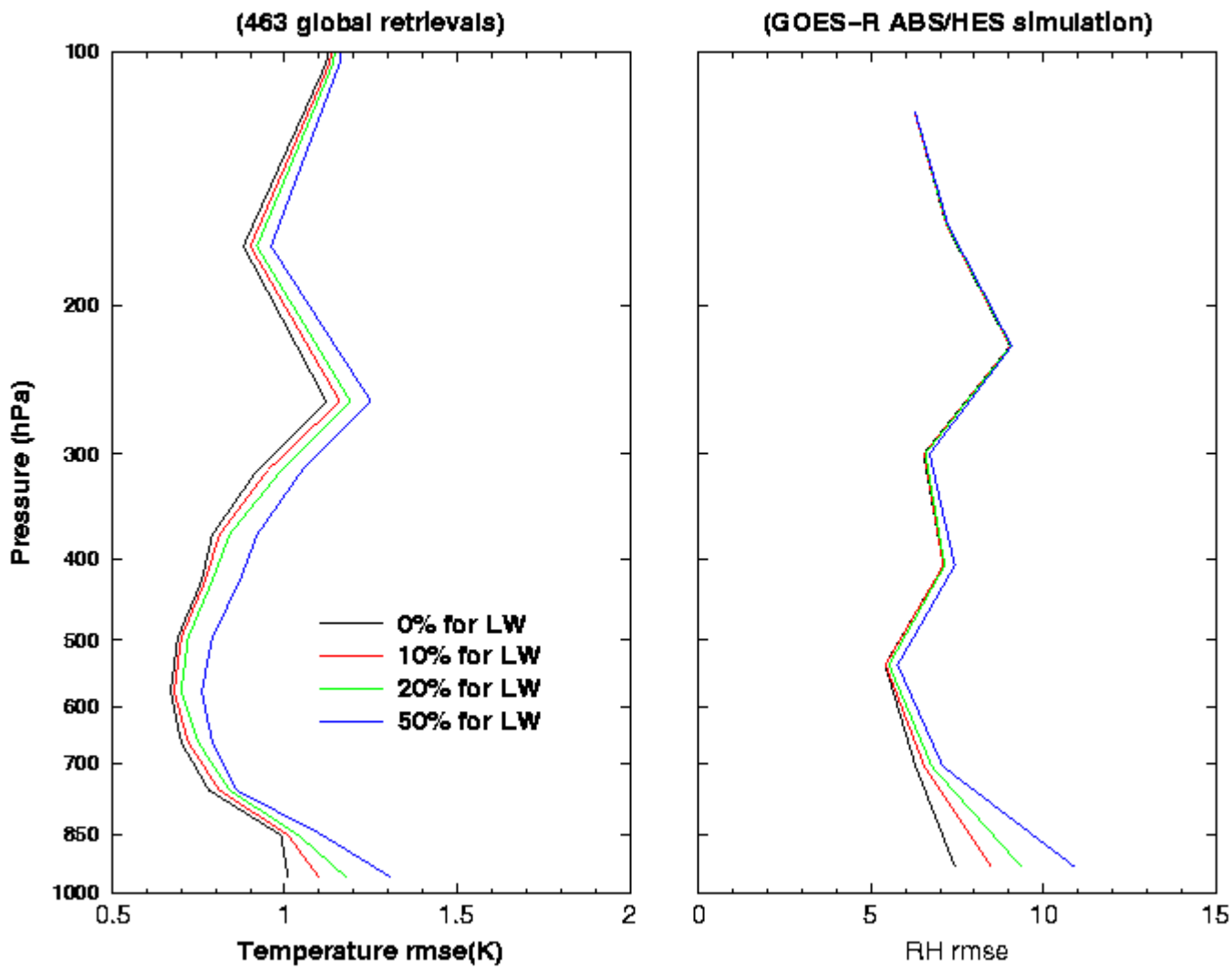
MODIS retrieval, may not represent hyperspectral IR sounder !

Band-to-band mis-registration

- What is the BT error due to band-to-band mis-registration ?
- What is the impact on sounding accuracy ?


HES TRD (10km)
HES 10% mis-allgnment
HES 20% mis-allgnment
HES 50% mis-allgnment
GIFTS (4km)
NeDT@250K
BT (K)
Wavenumber (cm**-1)

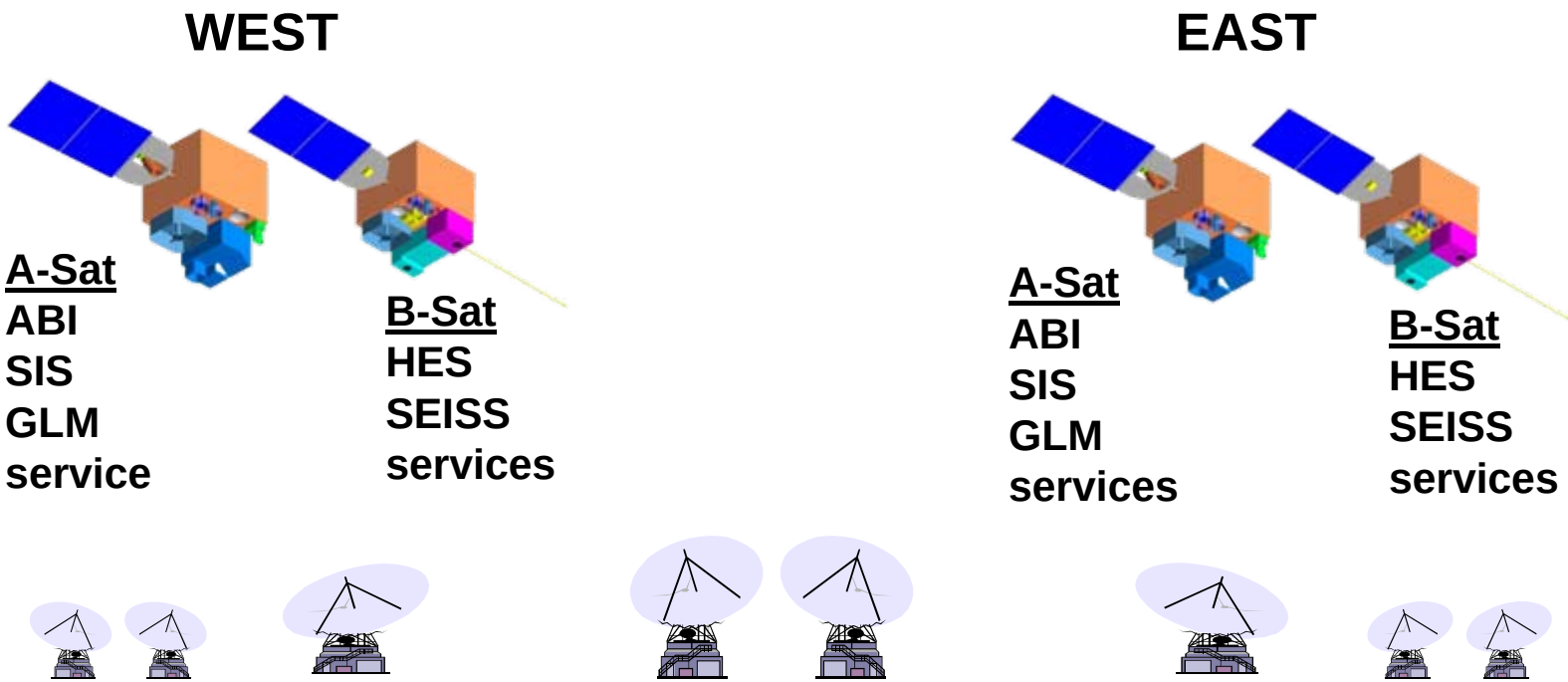
(UW/CIMSS)


(463 global retrievals)
(GOES-R ABS/HES simulation)
Pressure (hPa)
100
200
300
400
500
600
700
850
1000
0.5
1
1.5
2
Temperature rmse(K)
0% for LW
10% for LW
20% for LW
50% for LW
0
5
10
15
RH rmse

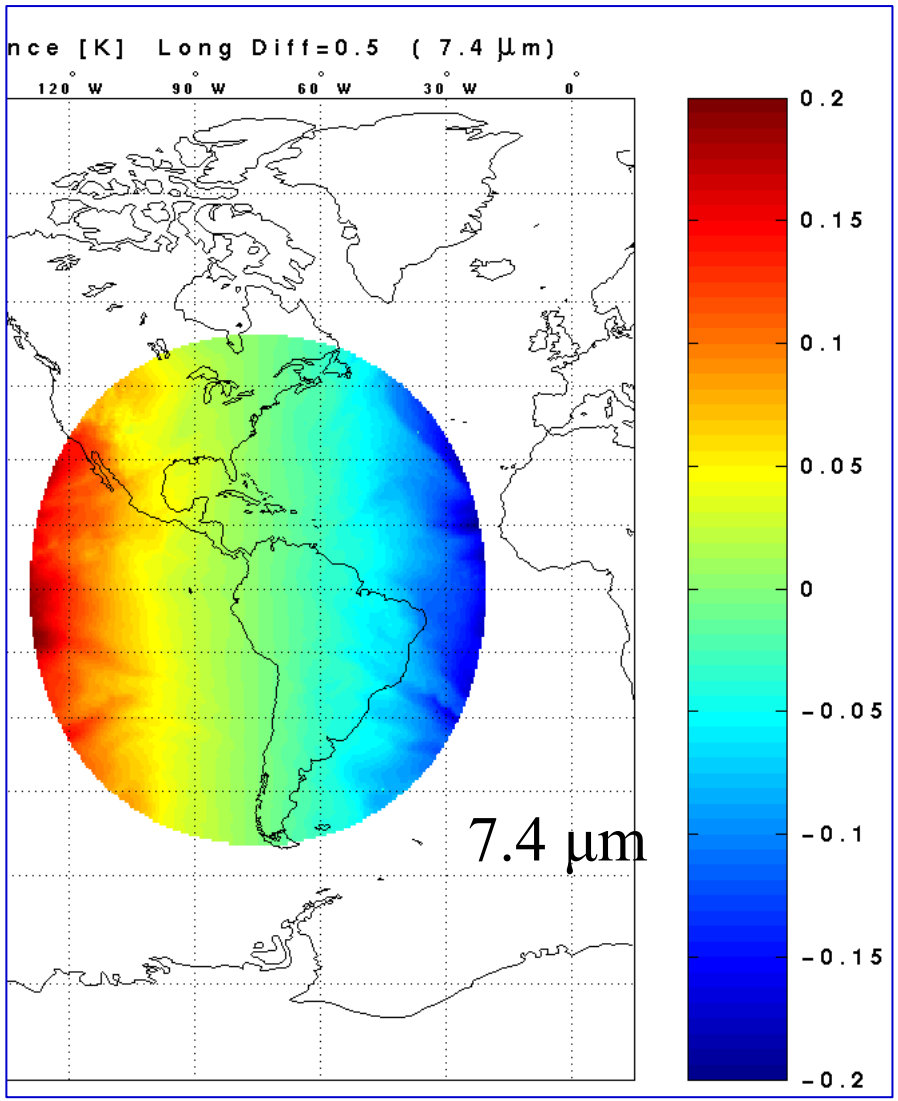
GOES-R satellite positions and their impact on science

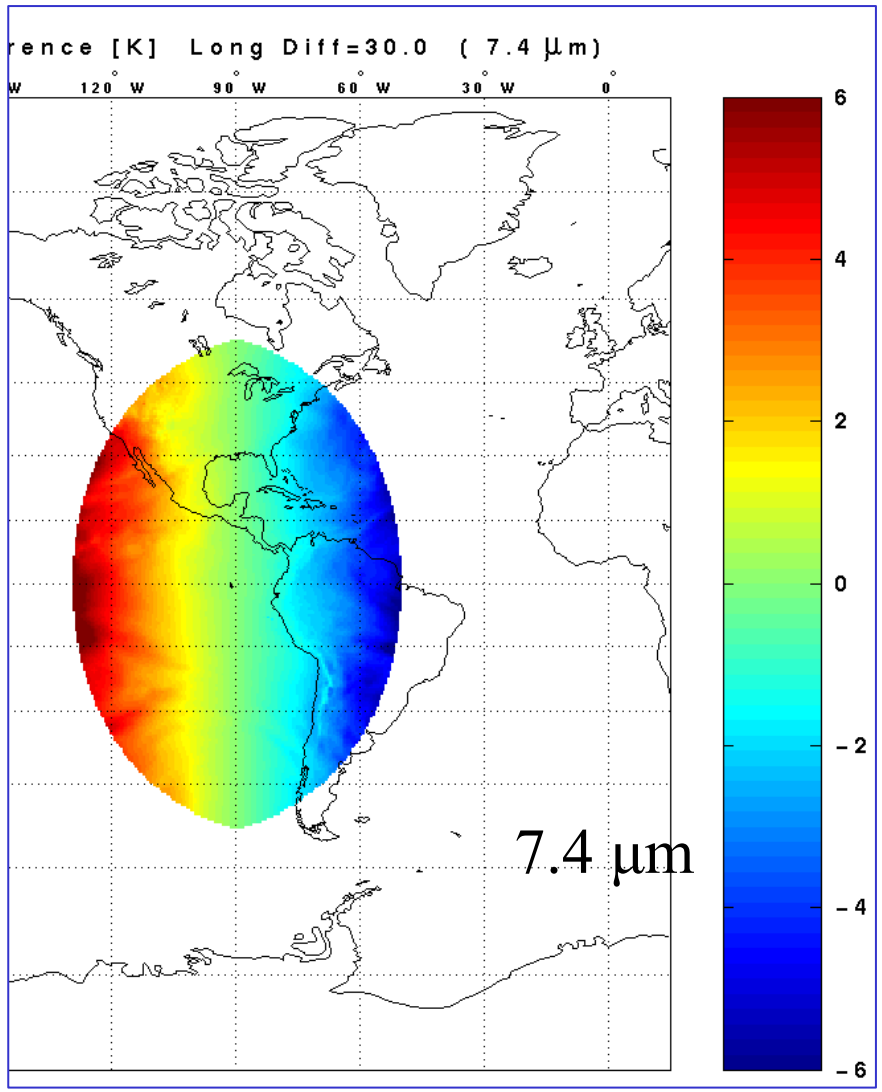
- Impact on ABI/HES synergy (the ABI brightness temperature difference between one satellite system and two-satellite system)
- Clear skies with ECMWF data in calculation
- Surface emissivity effects are not considered

Distributed Architecture Concept Notional Baseline



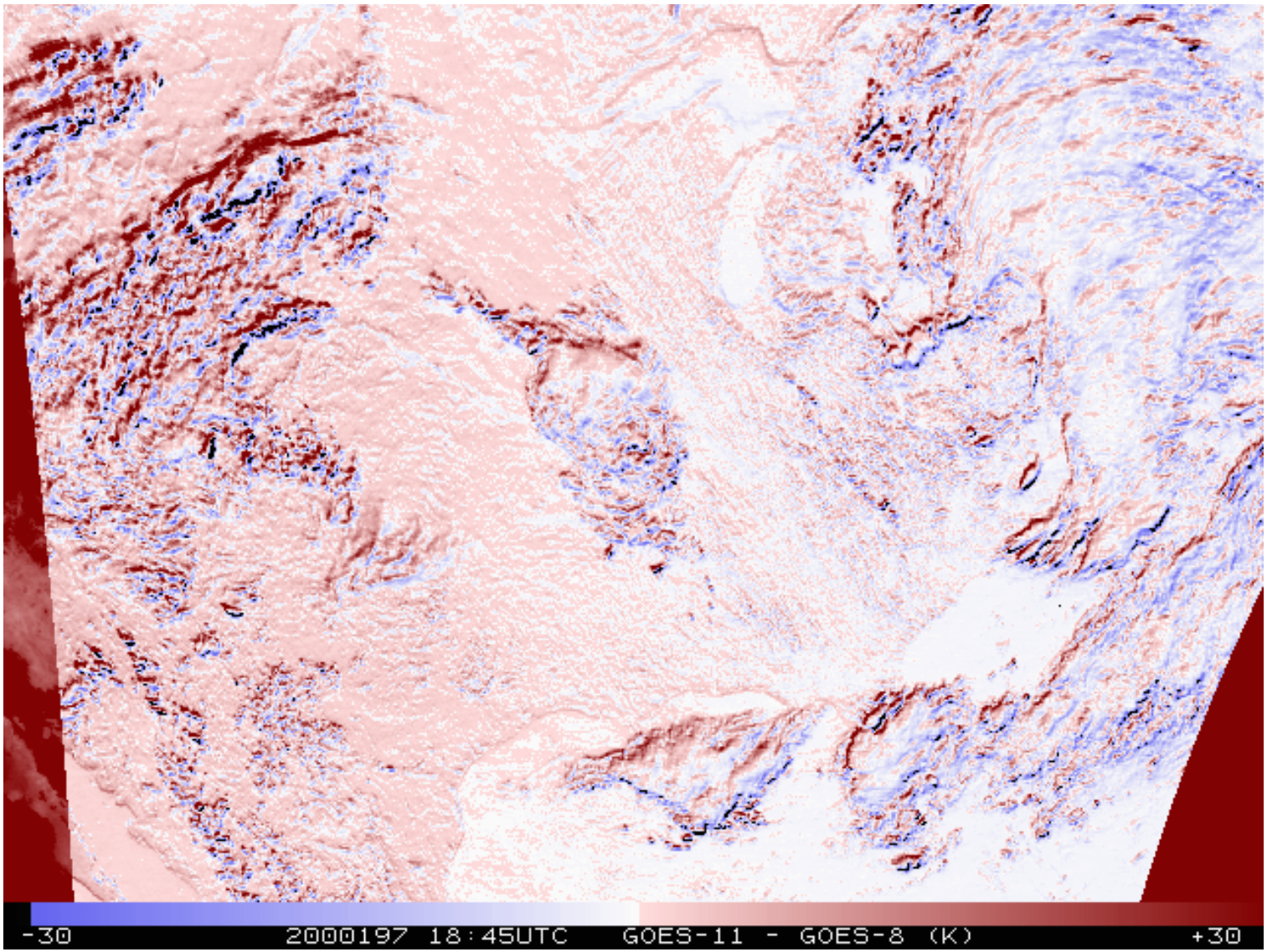
- Advanced Baseline Imager (ABI)
- Hyperspectral Environmental Suite (HES)
- Solar Imaging Suite (SIS)
- Space Environmental In-Site Suite
- Geostationary Lightning Mapper (GLM)





Distance=0.5 **BTD (K)** **Distance=30** **BTD(K)**

Parallax between 75 and 105 degrees (infrared window)



Summary

- Need to balance spectral resolution and coverage, spatial resolution, signal-to-noise, etc. for a cost effective Geo advanced IR sounder that meets the science requirements.
- Impact of point spread functions, band-to-band mis-registration on science need to be considered
- Impact of satellite position and scan strategy on science need to be considered
- Simulation need to be realistic for Geo IR sounder trade-off study, ideal real data (e.g., NASTI and IASI) should also be used.