Single footprint sounding, surface emissivity and cloud property retrievals from hyperspectral infrared radiances under all sky conditions

Jun Li[@], Elisabeth Weisz[@], Jinlong Li[@], Allen Huang[@], Chian-Yi Liu[@], Timothy J. Schmit[#], Mitchell D. Goldberg[#], D. K. Zhou[*], Larrabee Strow[&], W. L. Smith[%], Robert Knuteson[@], Hank Revercomb[@]

[@]CIMSS, University of Wisconsin-Madison
[#]NOAA/NESDIS/STAR
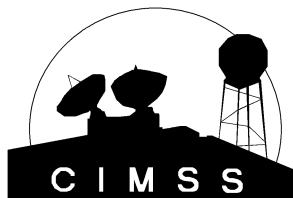**[&]University of Maryland Baltimore County**
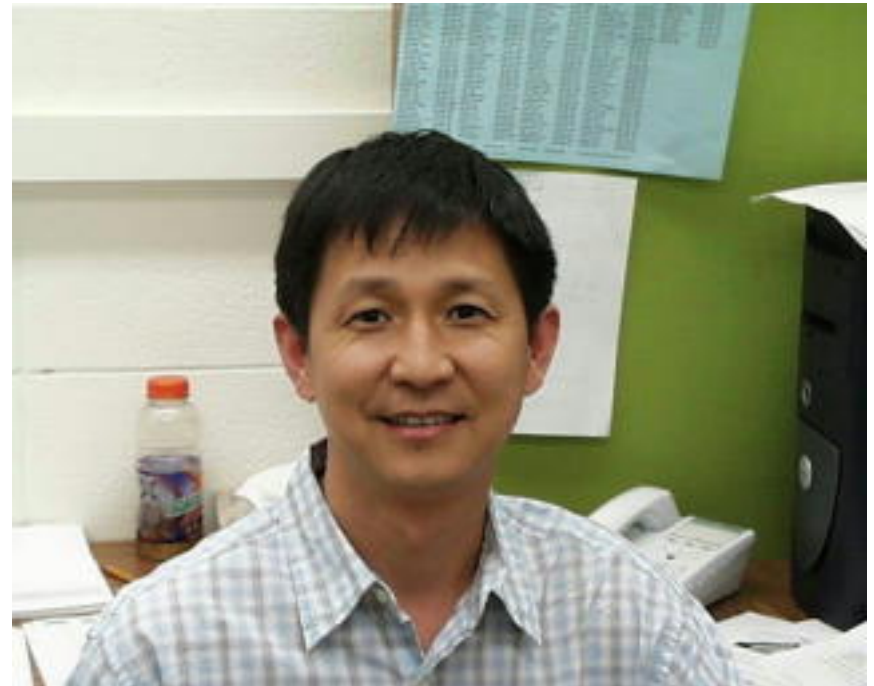**[%]Hampton University**
[*]LaRC/NASA

IASI Conference
13 – 16 November 2007
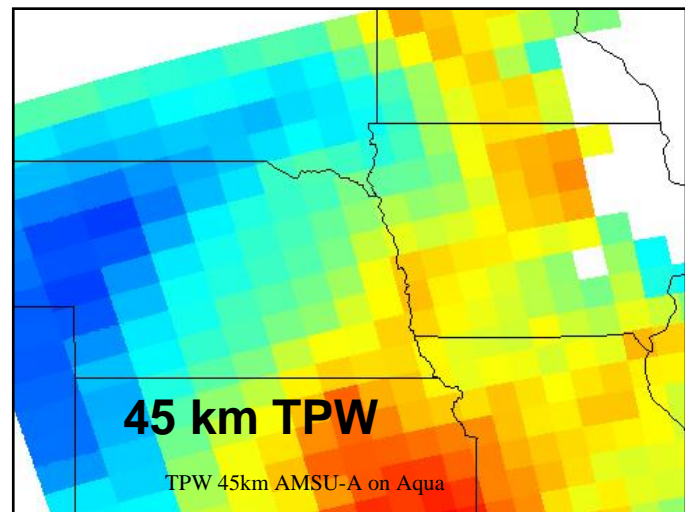**Atlanthal Hotel, Anglet, France**
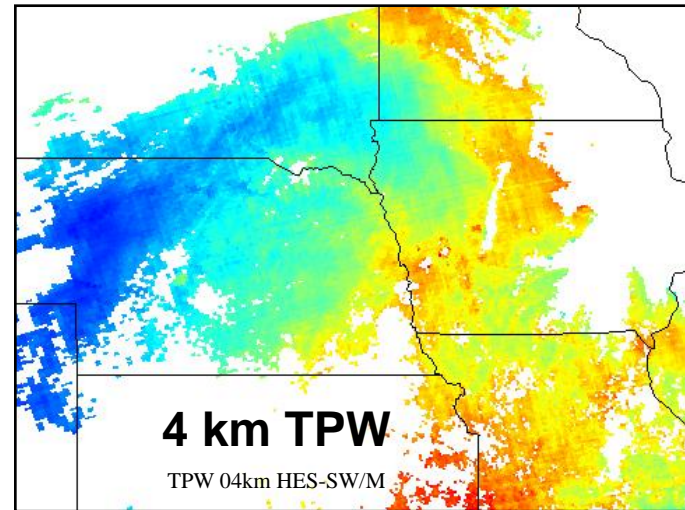
Acknowledgement

Dr. Elisabeth Weisz
Cloudy sounding

Dr. Jinlong Li
Emissivity spectrum and sounding

Motivation for IR SFOV soundings

2 km TPW — TPW 02km ABI on GOES-R

4 km TPW — TPW 04km HES-SW/M

14 km TPW — TPW ~14km AIRS on Aqua

45 km TPW — TPW 45km AMSU-A on Aqua
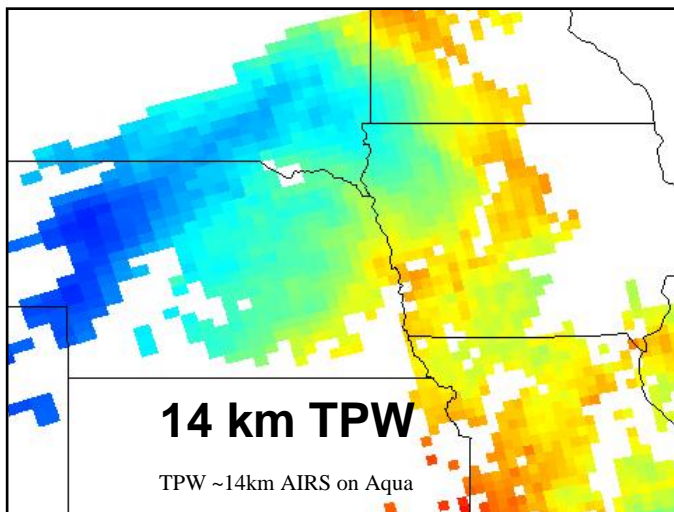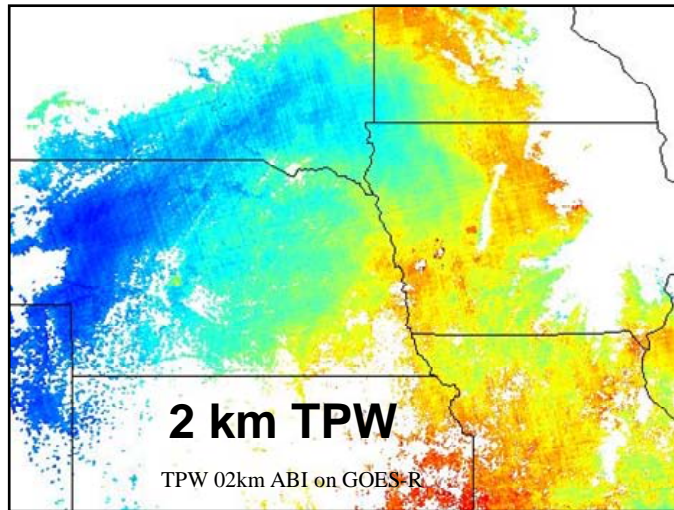
Moisture has large spatial variation, IR SFOV moisture soundings preserve spatial gradients that are important for monitoring/predicting mesoscale features, severe weather, and other weather events

Outline

- Handling surface IR emissivities in hyperspectral IR sounding retrieval

- Handling clouds – With hyperspectral IR radiances, cloudy soundings can be derived along with cloud properties

- Algorithm demonstration and validation with AIRS

- Apply to IASI data – preliminary results

Physical retrieval of surface emissivity spectrum from hyperspectral infrared radiances

Jun Li,[1] Jinlong Li,[1] Elisabeth Weisz,[1] and Daniel K. Zhou[2]

[1]   Retrieval of temperature, moisture profiles and surface skin temperature from hyperspectral infrared (IR) radiances requires spectral information about the surface emissivity. Using constant or inaccurate surface emissivities typically results in large temperature and moisture profile errors, particularly over semi-arid or arid areas where the variation in emissivity is large both spectrally and spatially. A physically based algorithm has been developed to retrieve a hyperspectral IR emissivity spectrum simultaneously with the temperature and moisture profiles, as well as the surface skin temperature. To make the solution stable and efficient, the hyperspectral emissivity spectrum is represented by eigenvectors, derived from the laboratory measured hyperspectral emissivity database, in the retrieval process. Experience with Atmospheric InfraRed Sounder (AIRS) radiances shows that simultaneous retrieval of the emissivity spectrum and the sounding improves the surface skin temperature and temperature and moisture profiles, particularly in the near surface layer. **Citation:** Li, J., J. Li, E. Weisz, and D. K. Zhou (2007), Physical retrieval of surface emissivity spectrum from hyperspectral infrared radiances, *Geophys. Res. Lett.*, *34*, L16812, doi:10.1029/2007GL030543.

Sounder [*Plokhenko and Menzel*, 2000] and Moderate Resolution Imaging Spectroradiometer (MODIS) [*Wan and Li*, 1997; *Ma et al.*, 2002; *Seemann et al.*, 2003; *Wan et al.*, 2004]. Handling IR surface emissivities in the retrieval process is essential for deriving accurate boundary layer temperature and moisture profiles, and surface skin temperature, especially over land. This is equally true for IR radiance assimilation in Numerical Weather Prediction (NWP).

[4]   Surface emissivity for a given channel is often not updated simultaneously with profiles in the physical iterative process, for example, using emissivities from a regression approach [*Li et al.*, 2000; *Zhou et al.*, 2006]. Some physical algorithms also retrieve emissivities together with the sounding, but only at selected channels and spectral bands. *Hayden* [1988] retrieved emissivities at two spectral bands (longwave and shortwave IR bands) in GOES sounding processing. *Zhou et al.* [2007] and *Susskind et al.* [2003] used approximately 40 and 4 channels, respectively, for emissivity retrieval in AIRS retrieval processing. It is difficult to retrieve emissivities of all channels directly in the sounding step, due to a large number of unknowns in the

Retrieval Algorithm

$$\boxed{y = F(x)} + e$$

$$y = (R_1, R_2, ..., R_n)^T ;$$

$$x = (t(p); w(p); o(p); t_s; \boxed{\varepsilon_1, ..., \varepsilon_n};)^T$$

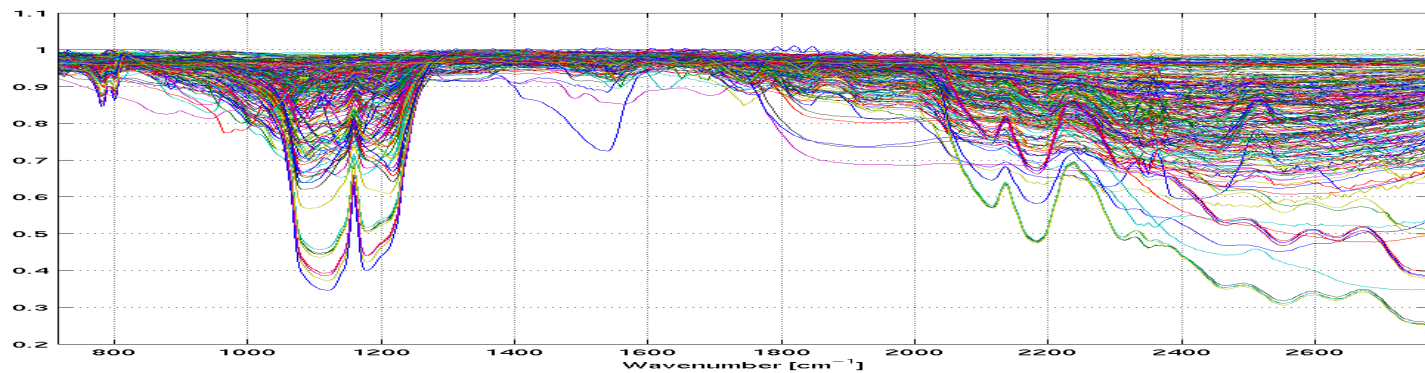Regularization and discrepancy principle (Li and Huang 1999)

(Cost function)

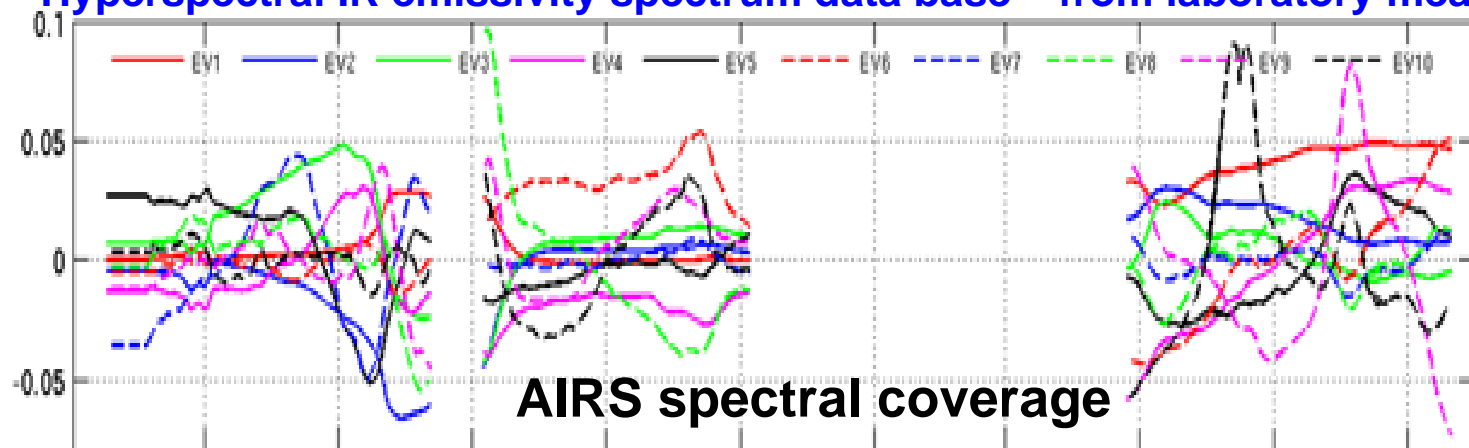$$J(x) = (y_m - y_c(x))^T E^{-1}(y_m - y_c(x)) + (x - x_0)^T \gamma S_0^{-1}(x - x_0)$$

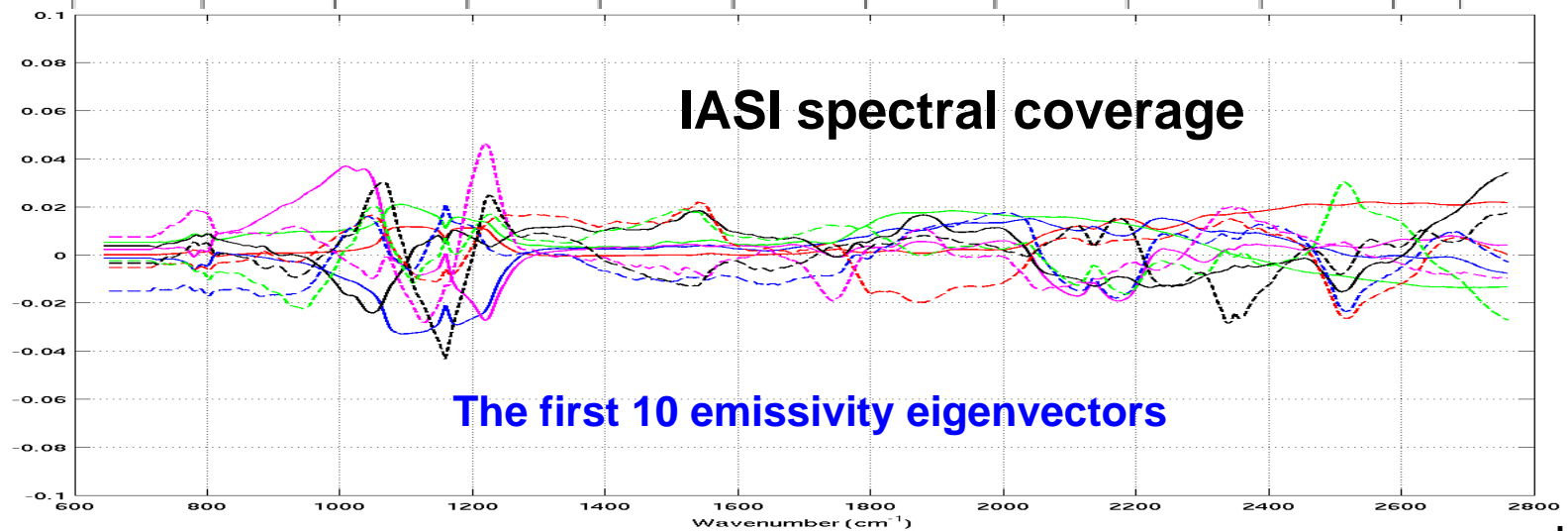**Too many parameters to retrieve if including all channels' emissivities !!!**

EOF expansion

$$x = \sum_i^l a_i \varphi_i = a\phi;$$

$\begin{cases} \phi\text{: eigenvector matrix;} \\ a\text{: eigenvector coefficients} \quad \textbf{to be retrieved} \end{cases}$

Hyperspectral IR emissivity spectrum data base – from laboratory measurements

AIRS spectral coverage

IASI spectral coverage

The first 10 emissivity eigenvectors

UW/CIMSS

Weighting Function for Surface Emissivity

Brightness Temperature

Jacobian for Emissivity
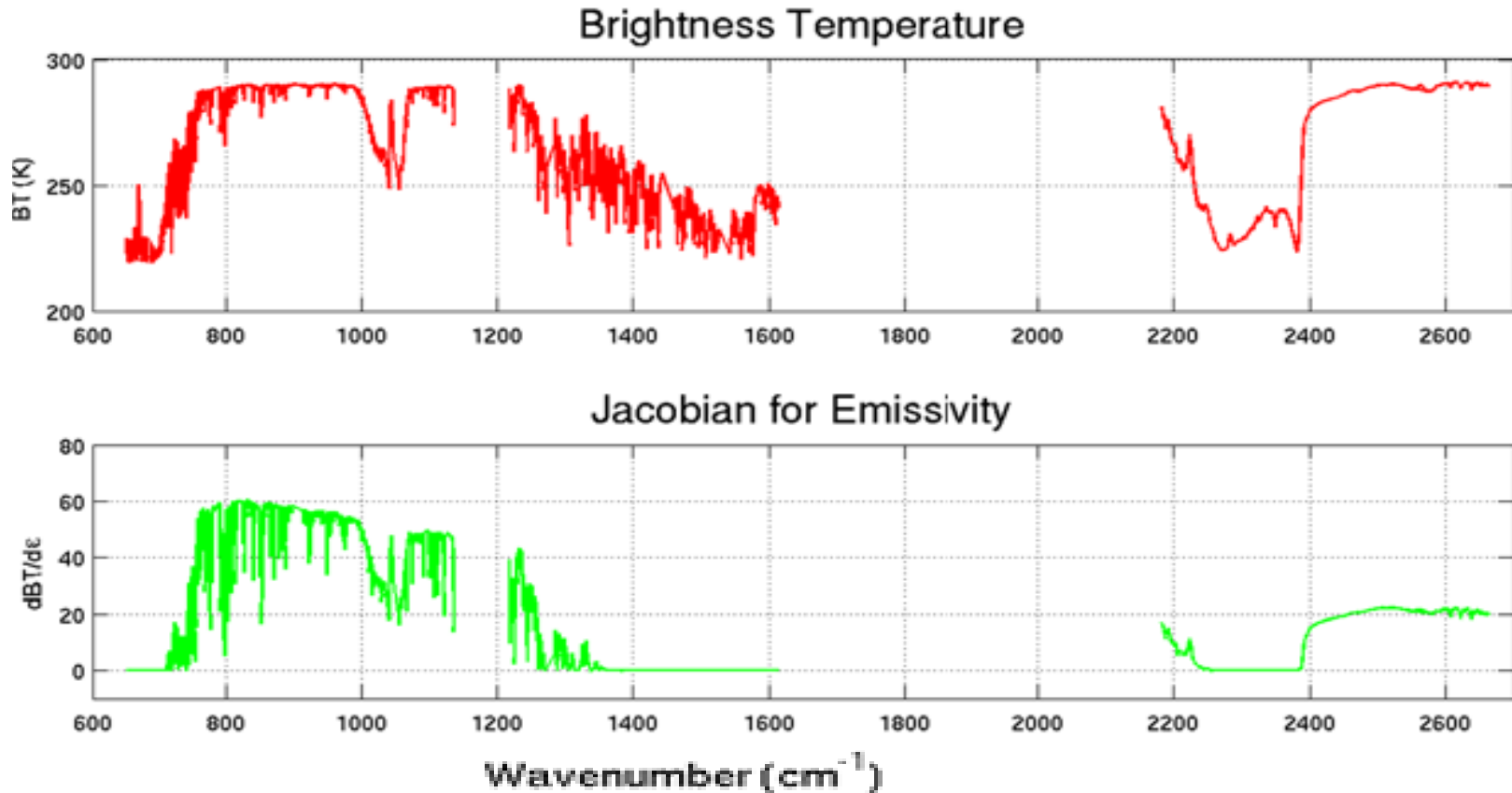
Emissivity signal in IR is small (e.g., 0.01 emissivity results in ~0.5 K change in window region), but its impact on boundary sounding is significant. Weaker signals in short wave region make it hard to retrieve.

Retrieval Experiments – Simulation over desert

32 Desert samples

Regression retrieval:

    T, W, O_3 profiles,
    Ts, Emisssivity
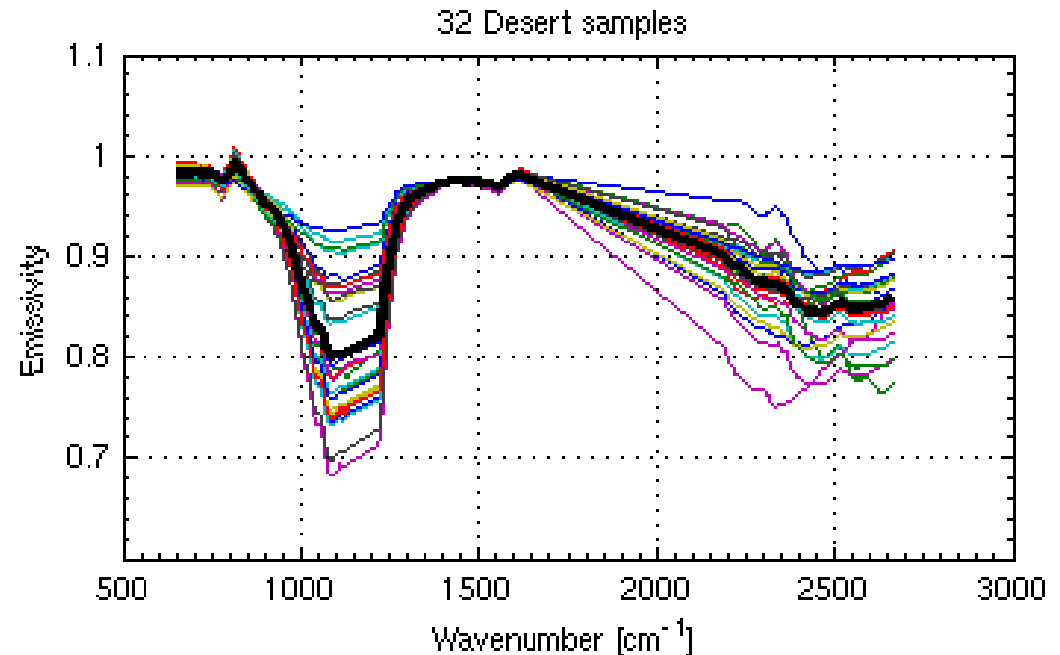
Three types of physical retrieval

1. Using constant emissivities of 0.98 and fixed in iterations.
2. Using regression emissivities and fixed in iterations.
3. Using regression emissivities and updated in iterations.

Simulated Retrieval for Desert (32 profiles)
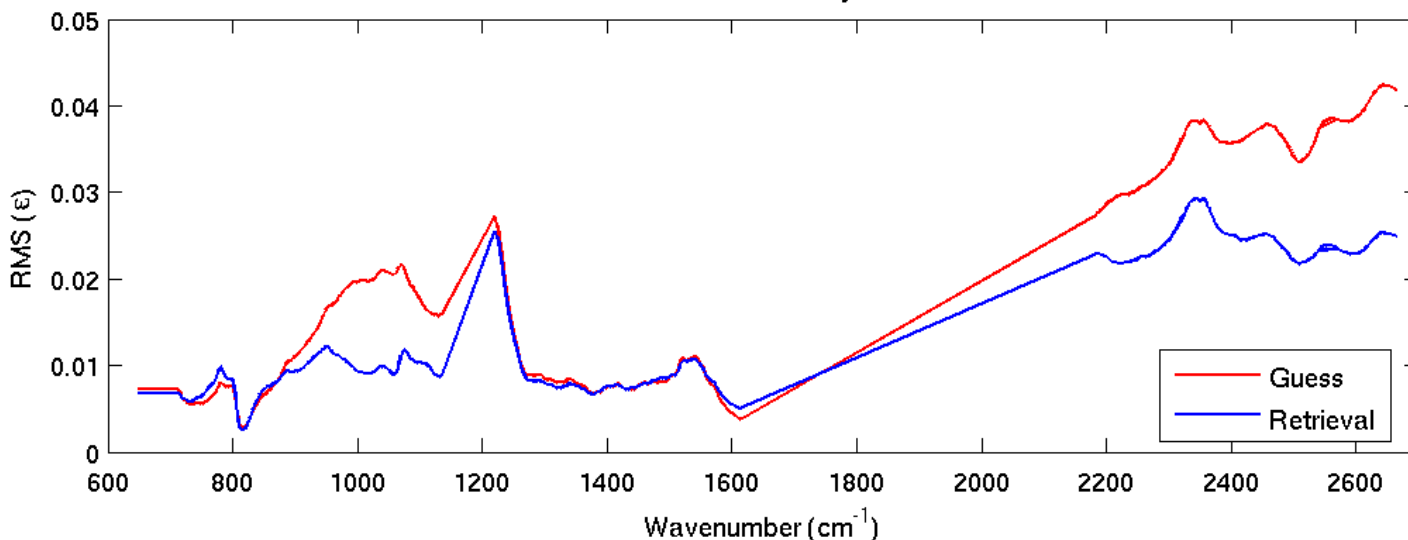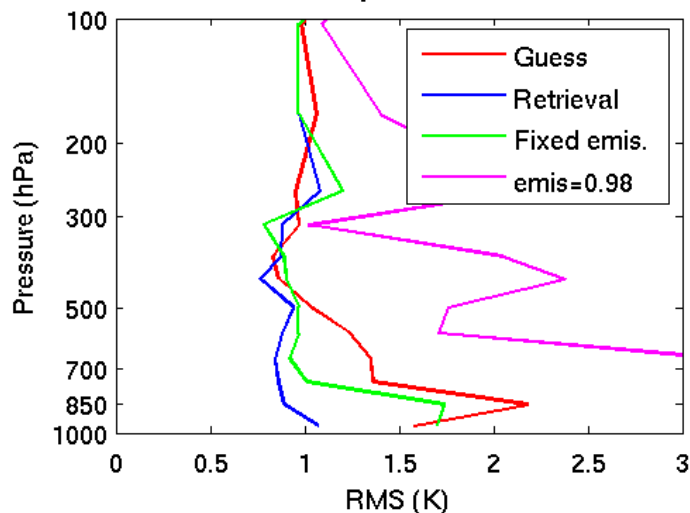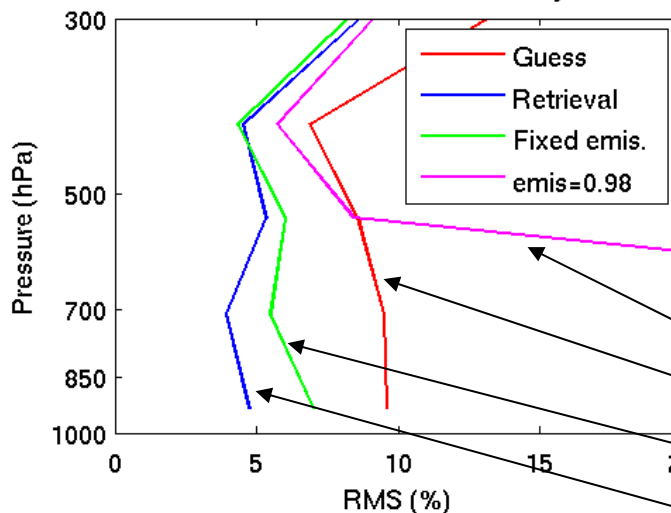
8-day composite of global hyperspectral IR emissivity spectrum from AIRS SFOV clear sky radiances between Jan. 1 and Jan. 8 of 2004 – CIMSS research product
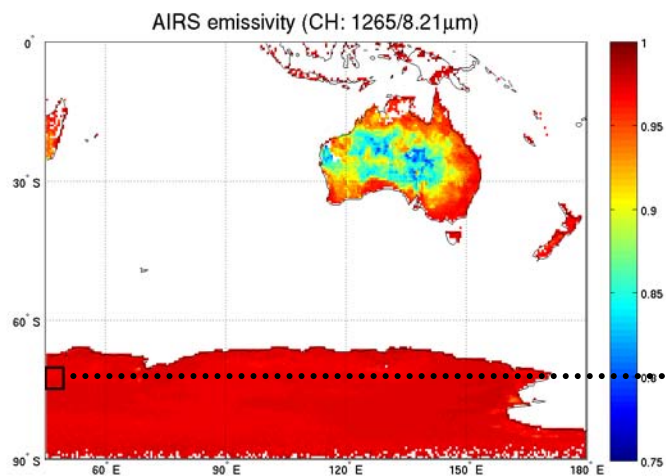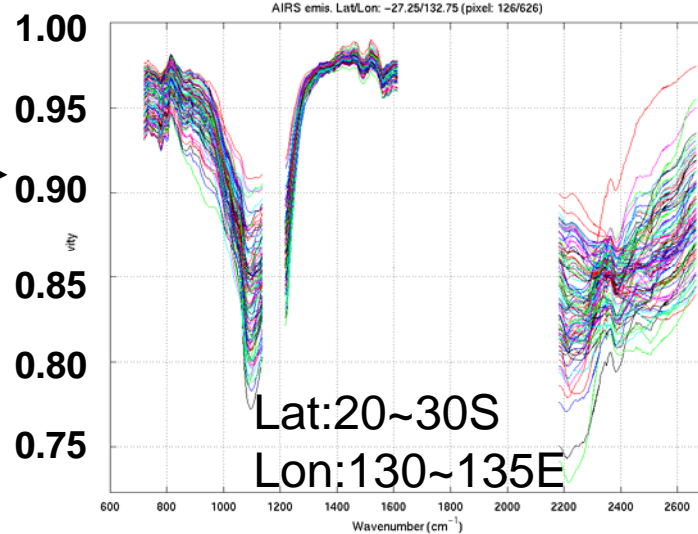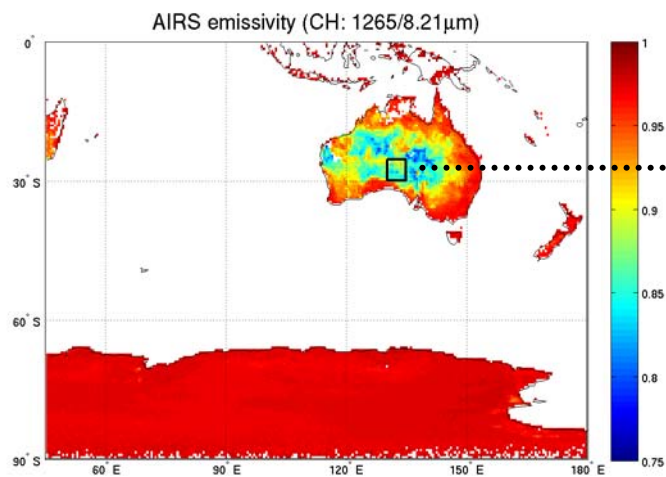
Global AIRS emissivity map – CIMSS research product

AIRS emissivity (CH: 1265/8.21μm)
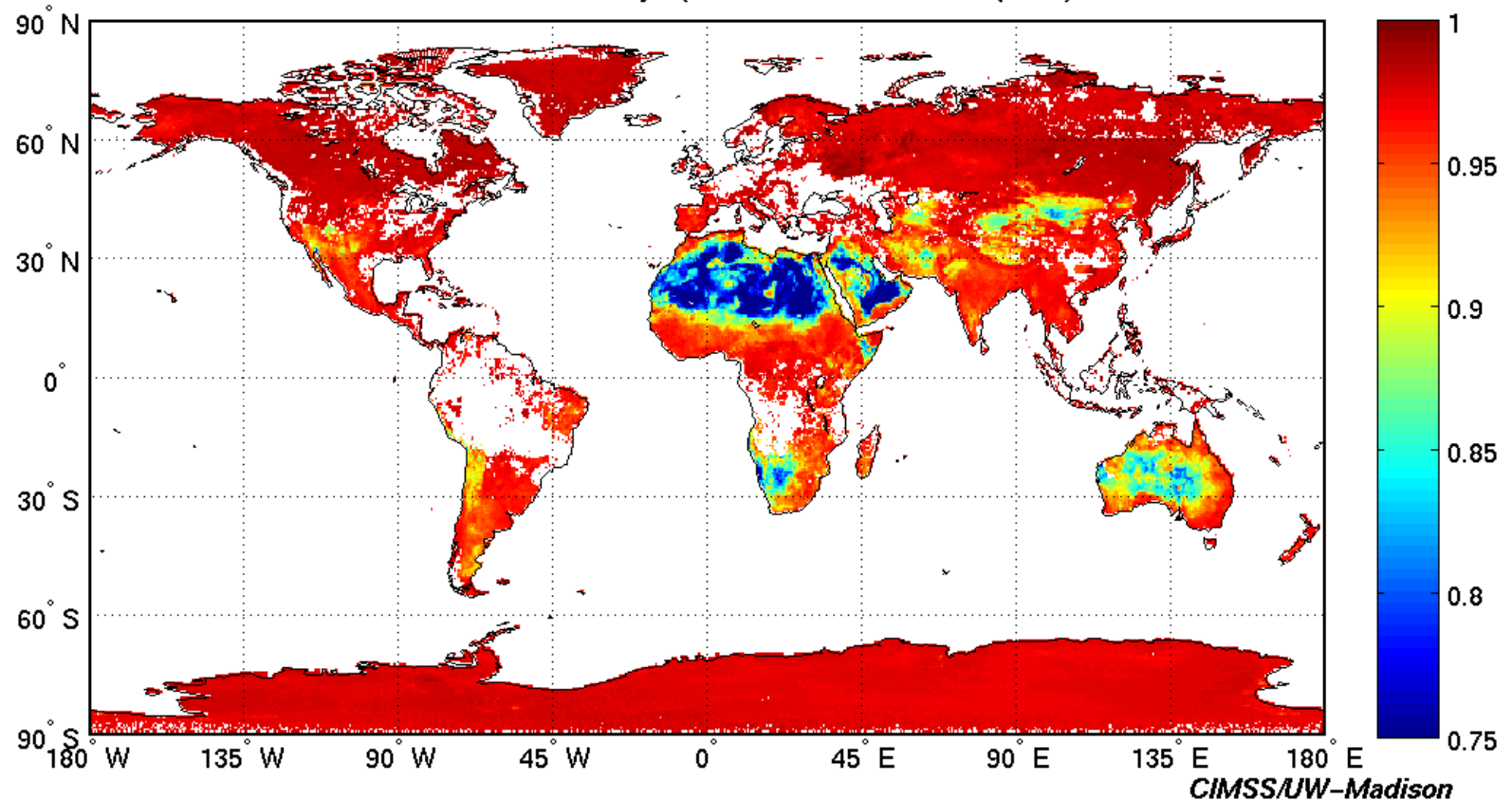
Algorithm will also be applied to IASI for global emissivity product

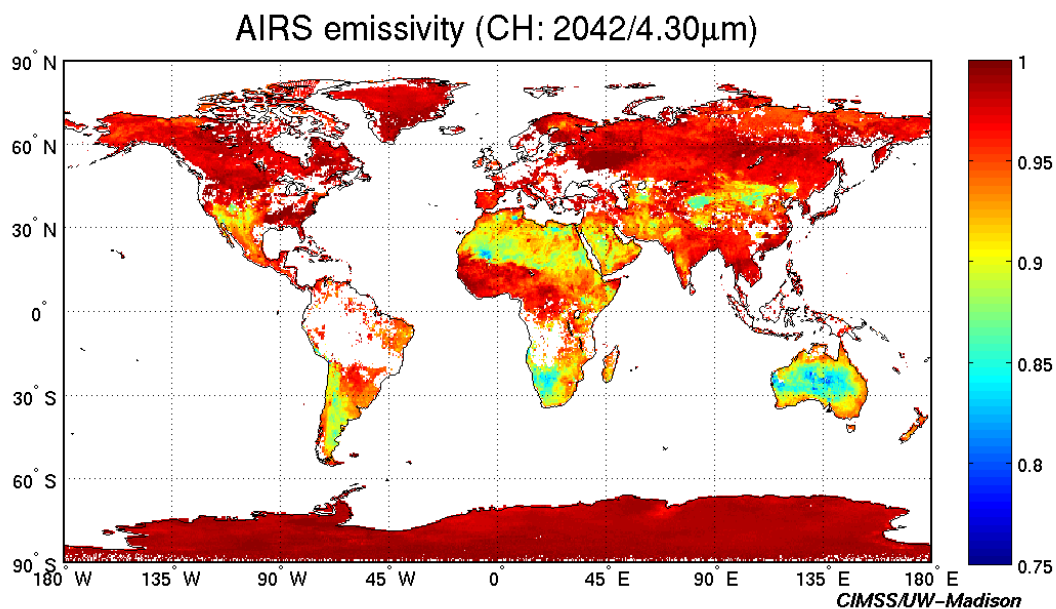AIRS emissivity (CH: 1265/8.21µm)

AIRS emis. Lat/Lon: 37.75/−112.25 (pixel: 256/136)

Lat:35~40N
Lon:110~115W

AIRS emissivity (CH: 1265/8.21µm)

AIRS emis. Lat/Lon: 62.75/−132.25 (pixel: 306/96)

Lat:60~65N
Lon:130~135W

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AIRS emissivity (CH: 1265/8.21μm)

AIRS emis. Lat/Lon: −27.25/132.75 (pixel: 126/626)

Lat:20~30S
Lon:130~135E

Wavenumber (cm⁻¹)

AIRS emissivity (CH: 1265/8.21μm)

AIRS emis. Lat/Lon: −72.25/47.75 (pixel: 36/456)

Lat:70~75S
Lon:45~50W

Wavenumber (cm⁻¹)

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Comparison with operational MODIS emissivity product

- 4.30 μm
- 9.30 μm
- 12.10 μm

AIRS emissivity (CH: 2042/4.30μm)

MODIS emissivity (MYD11C3: 4.3μm)

4.30 μm
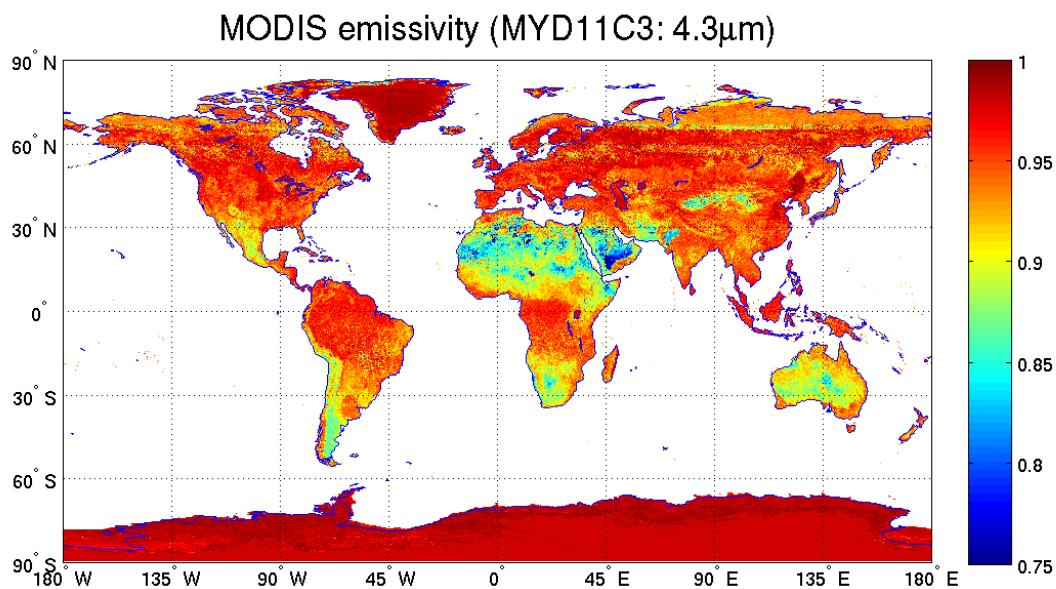
AIRS SFOV - CIMSS
AIRS is narrow ch.

MODIS - operational
**MODIS is broad band**

CIMSS/UW–Madison

CIMSS/UW

AIRS emissivity (CH: 1144/9.30μm)

9.30 μm

AIRS SFOV - CIMSS
AIRS is narrow ch.

CIMSS/UW–Madison

MODIS emissivity (MYD11C3: 9.3μm)

MODIS - operational
MODIS is broad band

CIMSS/UW

12.10 μm

AIRS emissivity (CH: 543/12.10μm)

CIMSS/UW–Madison

**AIRS SFOV - CIMSS
AIRS is narrow ch.**

MODIS emissivity (MYD11C3: 12.1μm)
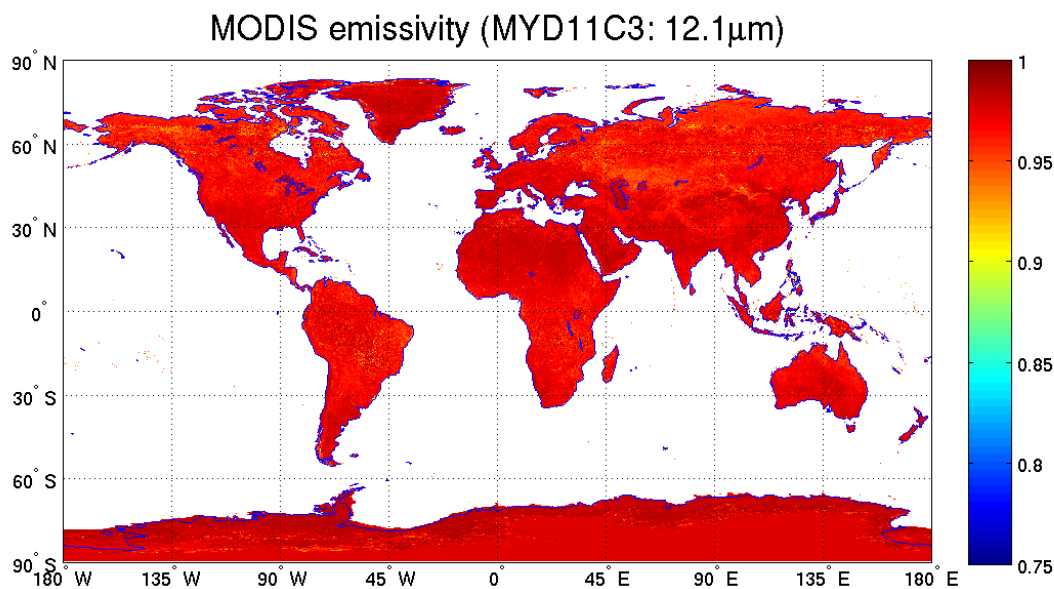
**MODIS - operational
MODIS is broad band**

CIMSS/UW

Some applications of global hyperspectral IR emissivity data

- Data assimilation of hyperspectral IR radiances

- Surface property and ecosystem change study

- Data base for other products (dust, aerosol) from LEO and products from GEO

- Climate model

- Climate emissivity data record (AIRS, IASI, CrIS ….)
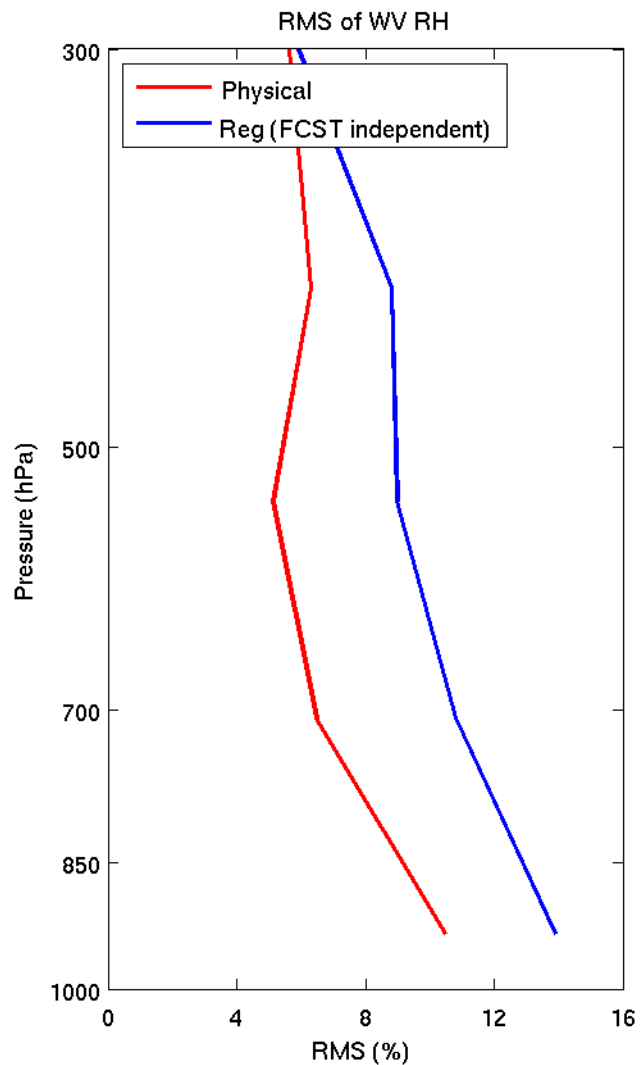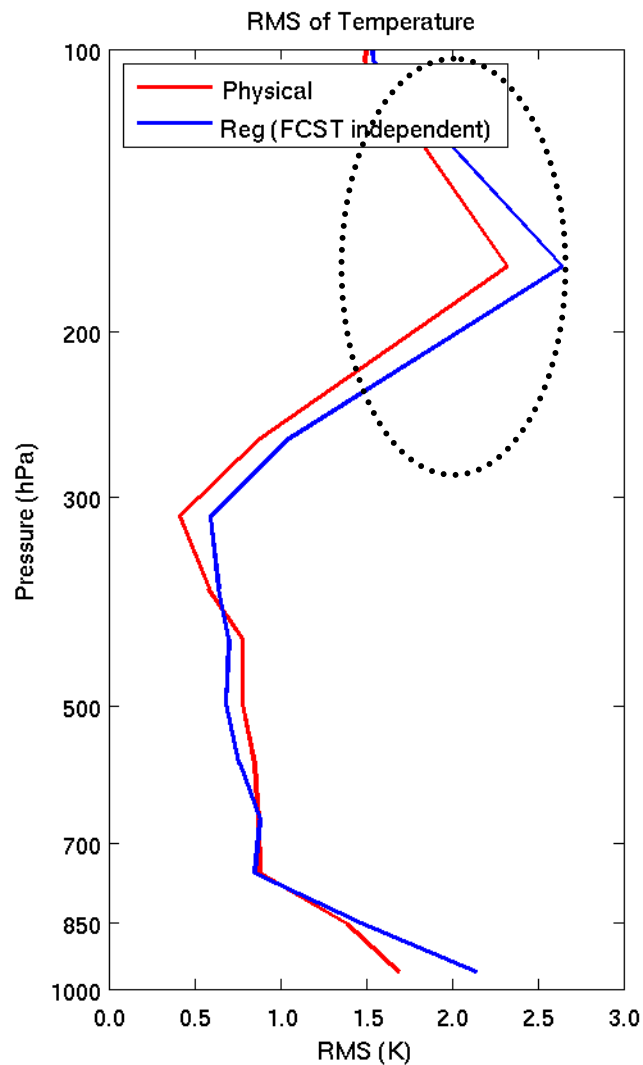
Comparisons between AIRS SFOV retrievals and dropsondes
(18 dropsondes processed by Jim Kossin)

UW/CIMSS
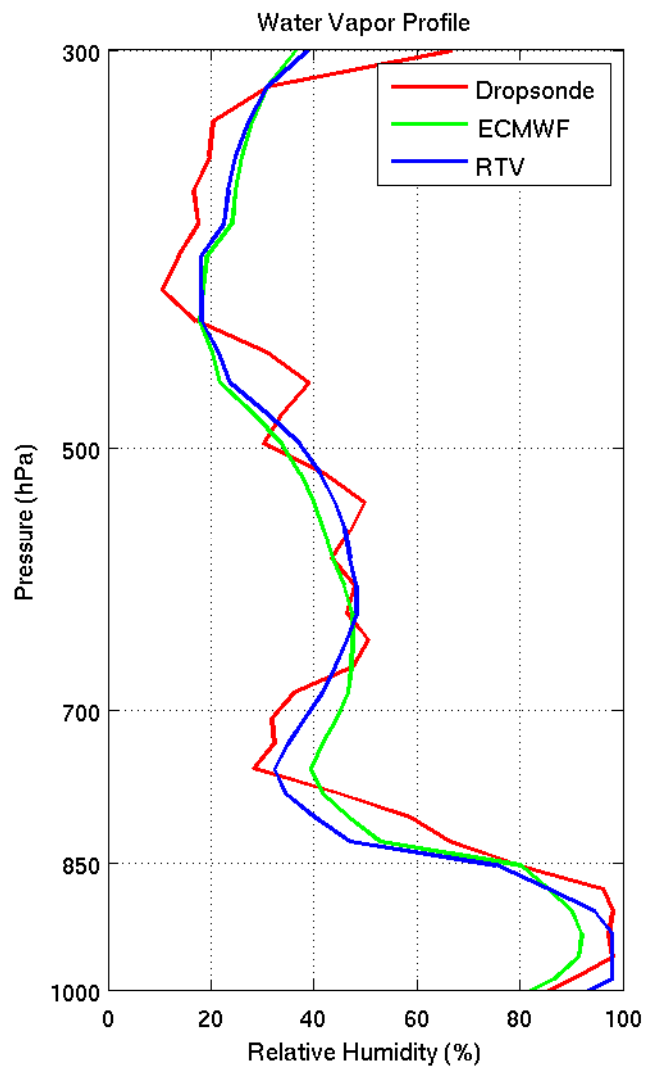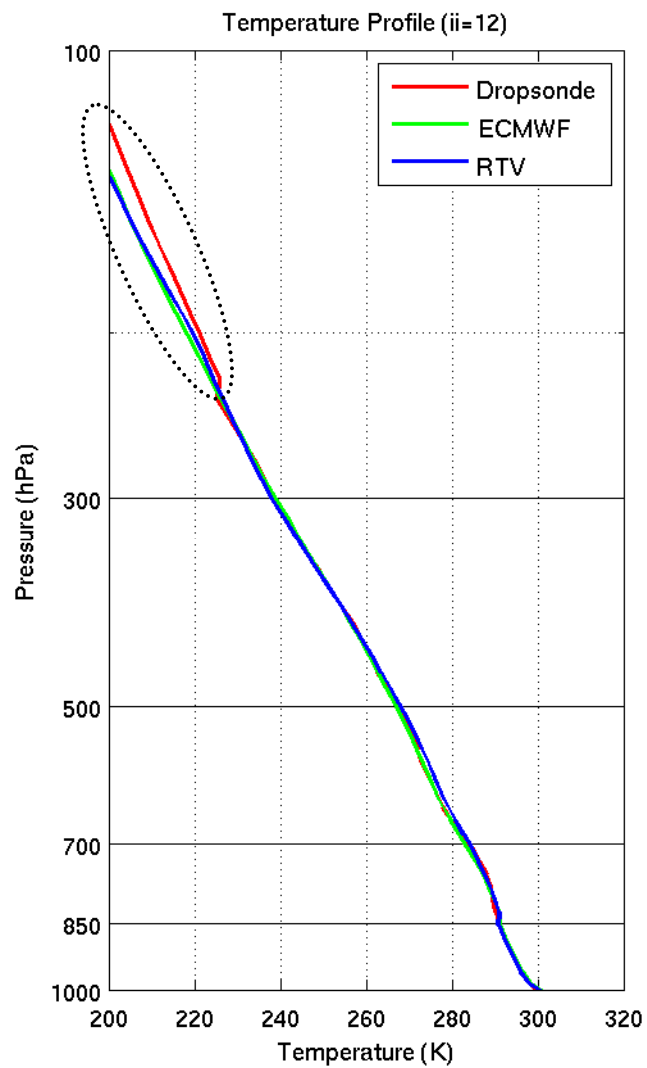
Cloudy soundings and cloud properties

- Two approaches
  - Retrieval of cloud properties when sounding is available, for example, using forecast profile (Wei et al. 2004; Li et al. 2004; 2005)
  - Simultaneous retrieval of sounding and cloud properties (Zhou et al. 2007, Weisz et al. 2007)

AIRS cloudy BT spectrum with various cloud optical thickness
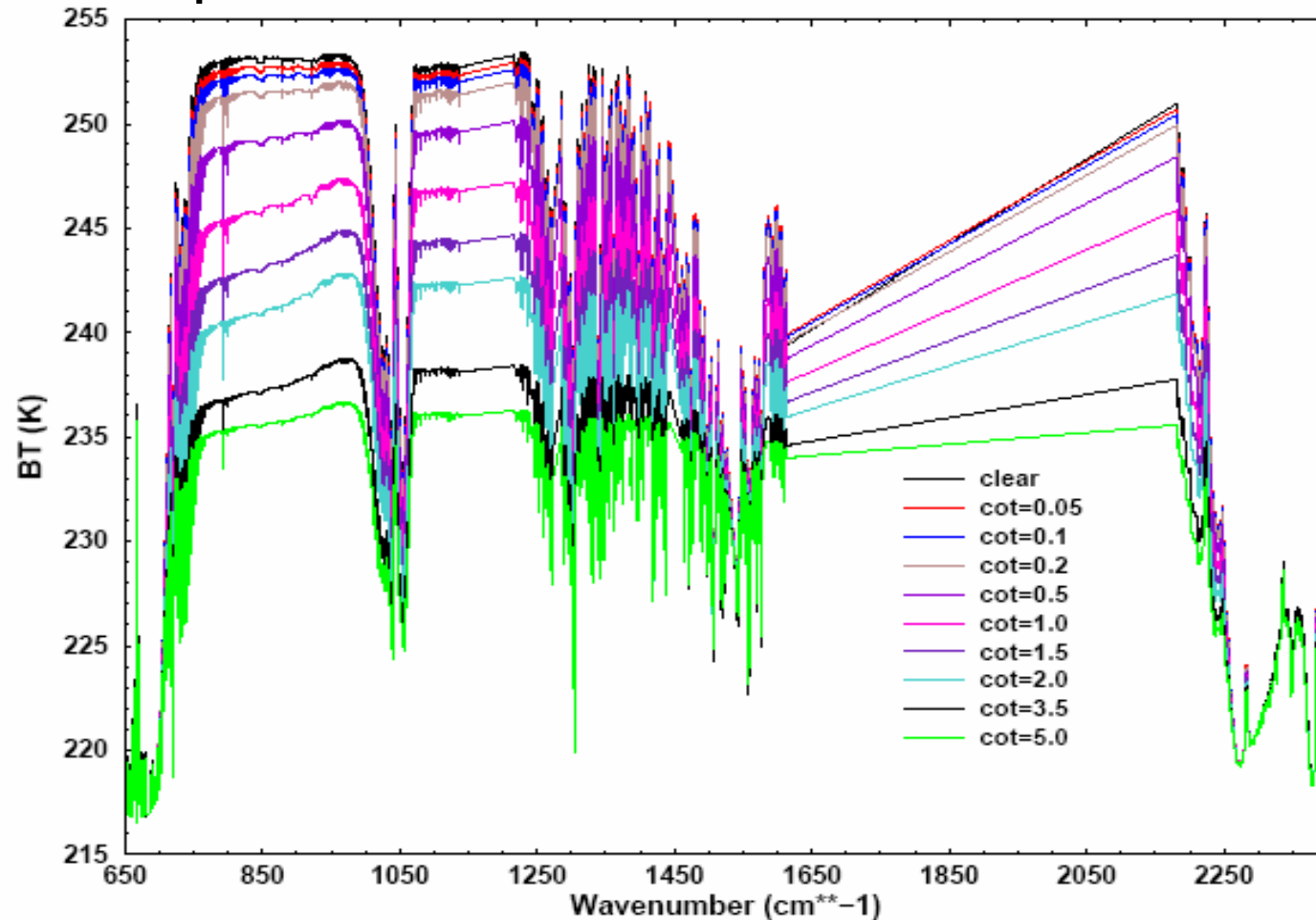
A fast cloudy radiative transfer model accounting for atmospheric absorption, cloud particle scattering and absorption has been developed.

$$R = R_o F_T \, \tau_c + (1 - F_T - F_R) \, B_c \tau_c - \int_0^{pc} B \, d\tau \; + F_R \, \tau_c \int_0^{pc} B_c d\tau^*$$

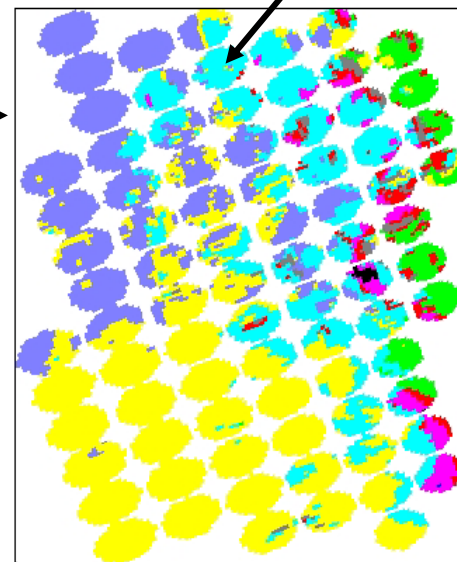R_0…radiance below cloud (=R_s+$R\!\uparrow$+$R\!\downarrow$), B…Planck function, pc …cloud top pressure,

τ_c…transmittance of cloud top, $\tau^* = \tau_c^2/\tau$ … downwelling transmittance,

F_R…cloud reflectance function, F_T…cloud transmissive function
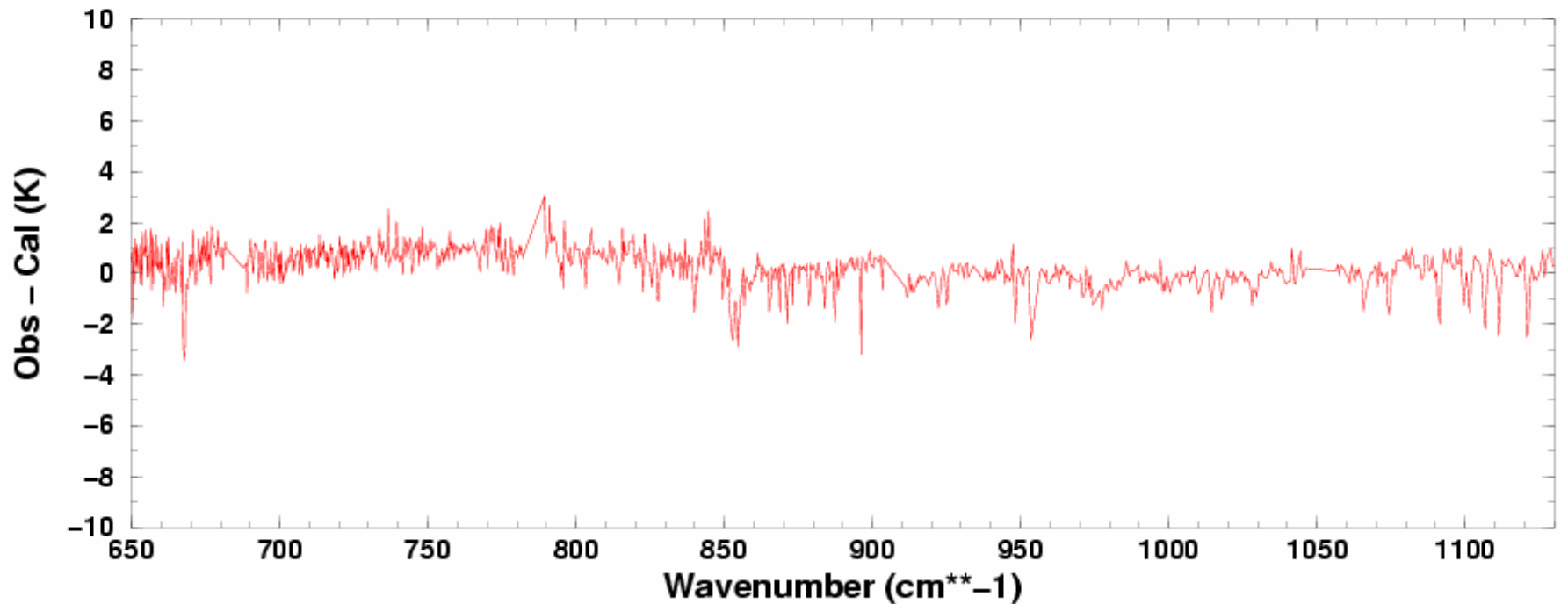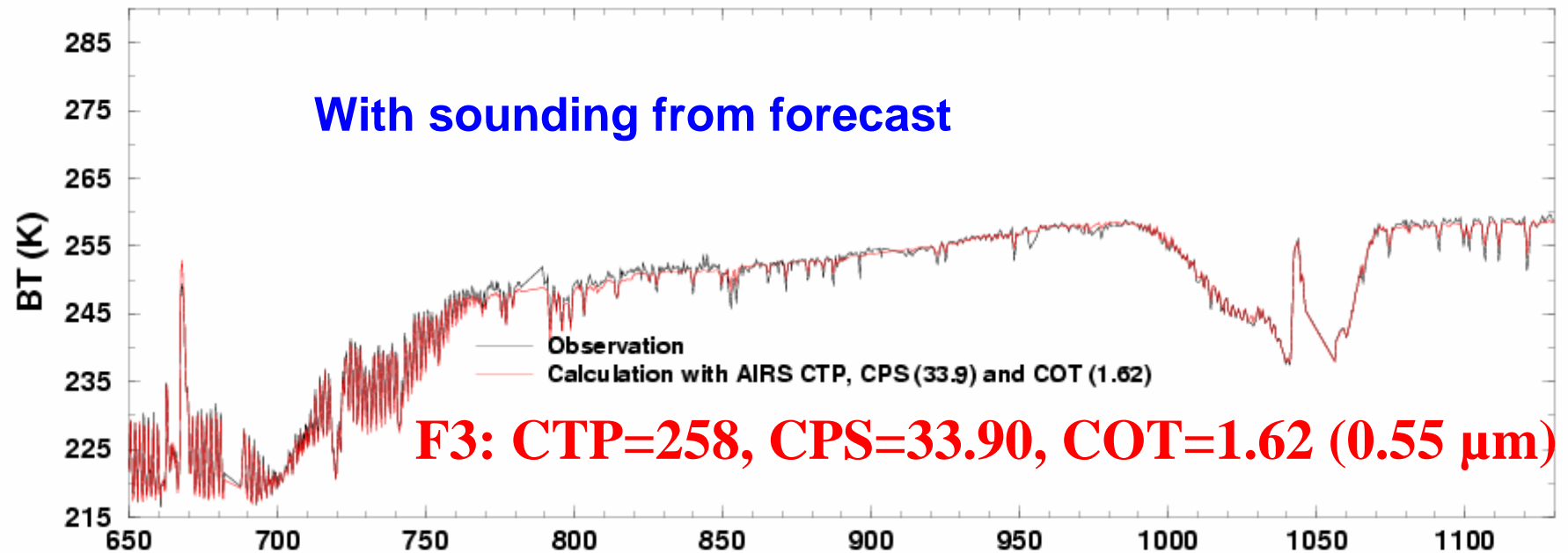
F3: Thick ice clouds
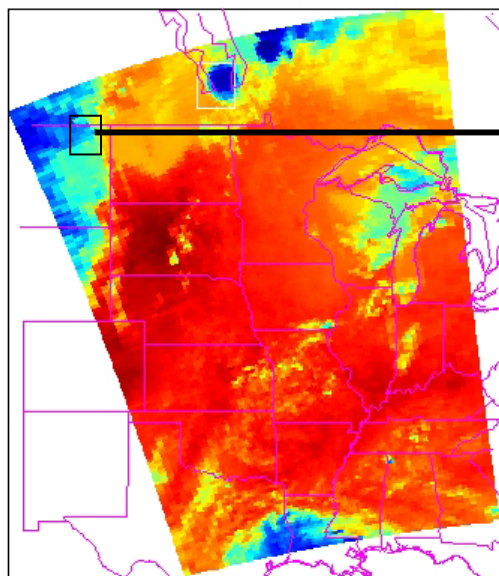
MODIS Classification Mask

AIRS BT(K) @ 901.69 cm^{-1}

| 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 290 | 300 | 310 |

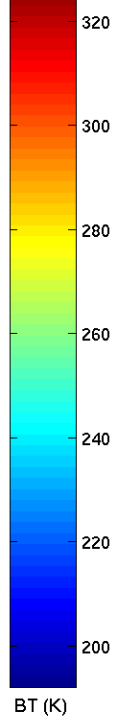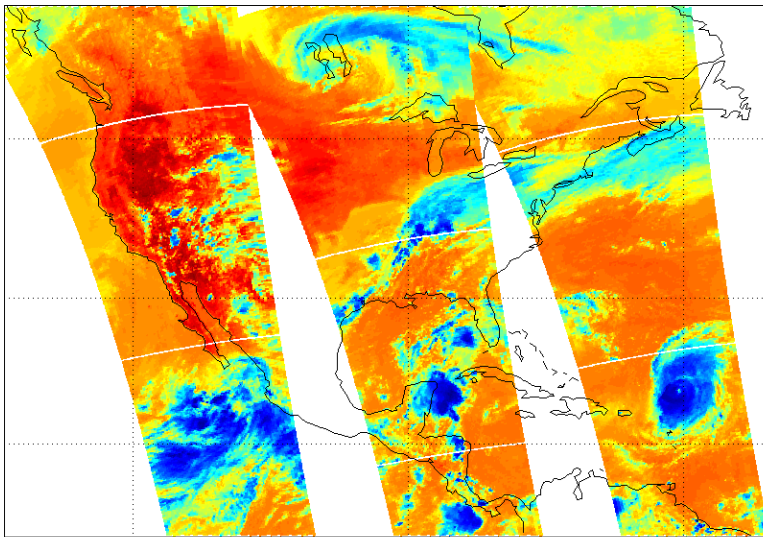| Water | Land | Mixed cld | Mixed clr | Low cld | Mid cld | High cld | Mid cld | Low cld |

1 km MODIS classification mask superimposed to AIRS footprints

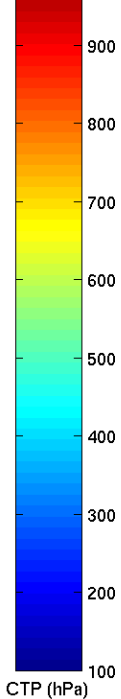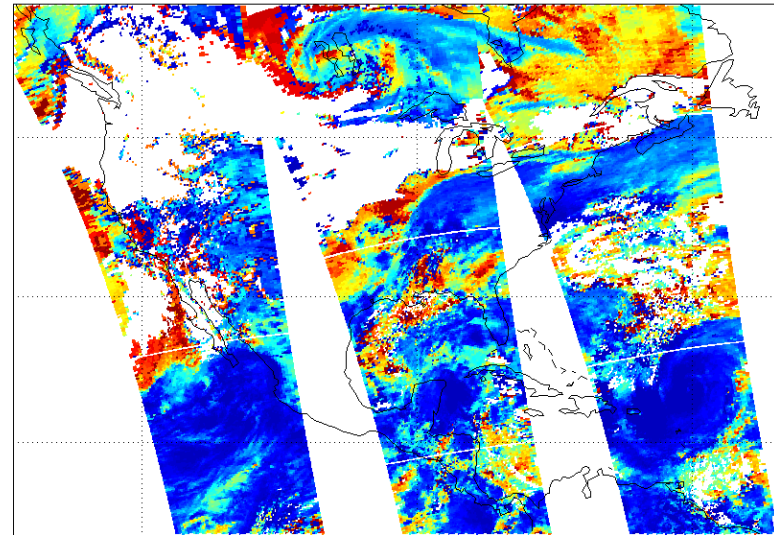**IASI sub-pixel cloud mask and classification mask can be derived from AVHRR !**

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With sounding from forecast

Observation
Calculation with AIRS CTP, CPS (33.9) and COT (1.62)

F3: CTP=258, CPS=33.90, COT=1.62 (0.55 μm)

(Li et al. 2005 – JAM)

AIRS BT @ 901.7 cm⁻¹ Sept. 02 2003

BT (K)

AIRS alone

CTP (hPa)

MODIS + AIRS

COT

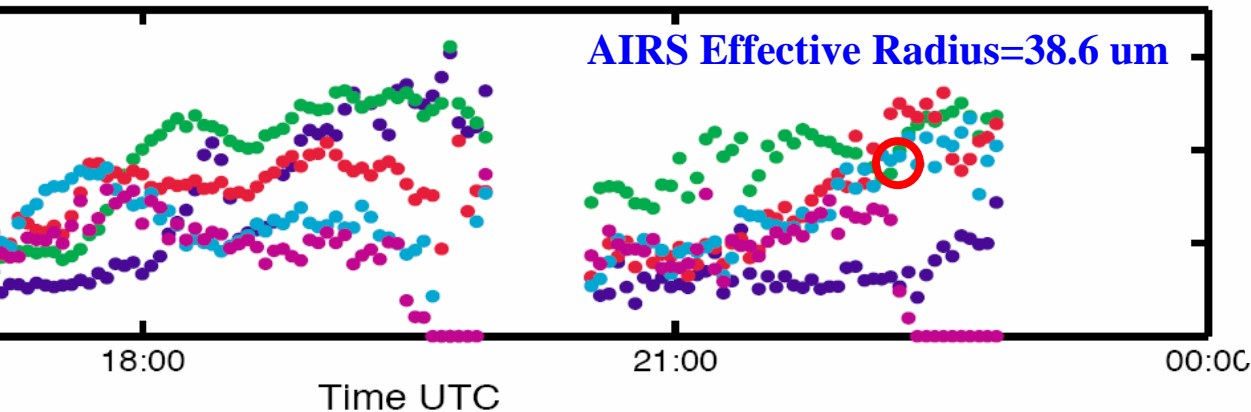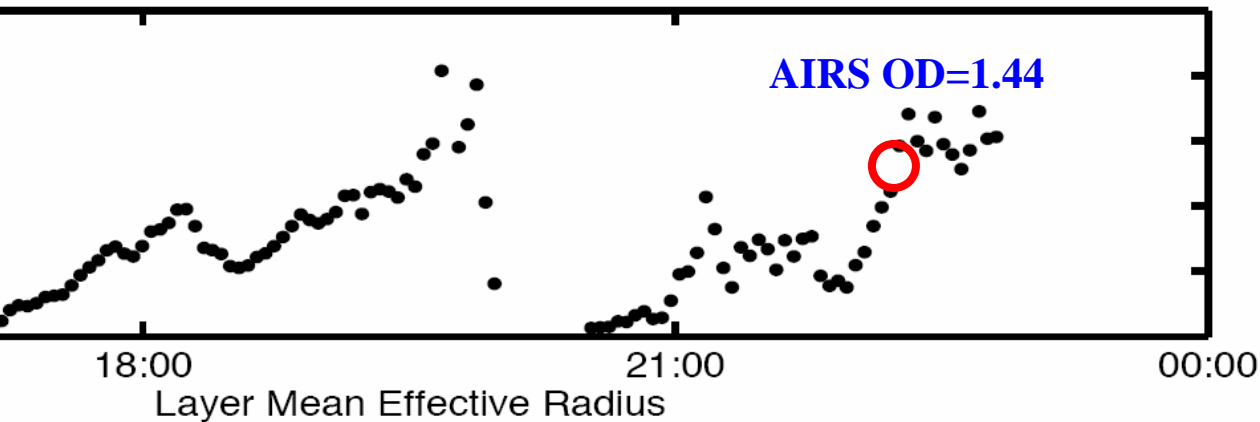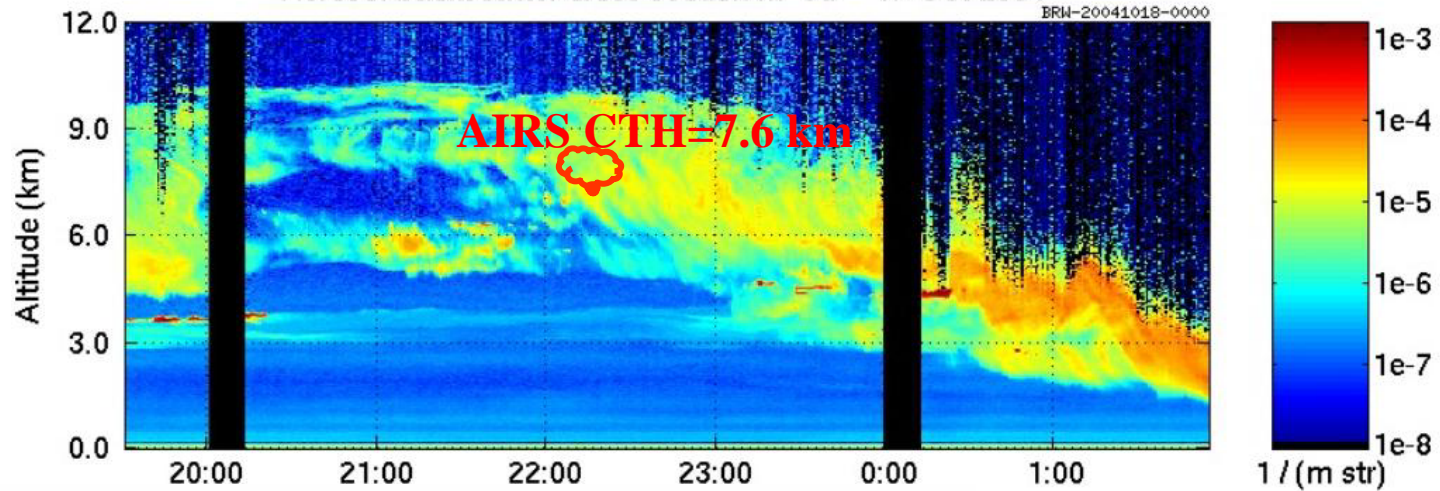**AIRS
Window BT**

**AIRS CTP
retrievals**

**AIRS COT
(0.55 μm)
retrievals**
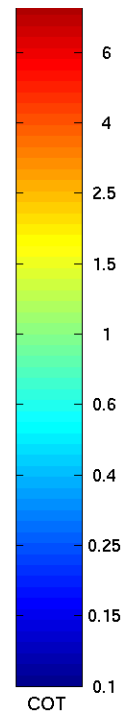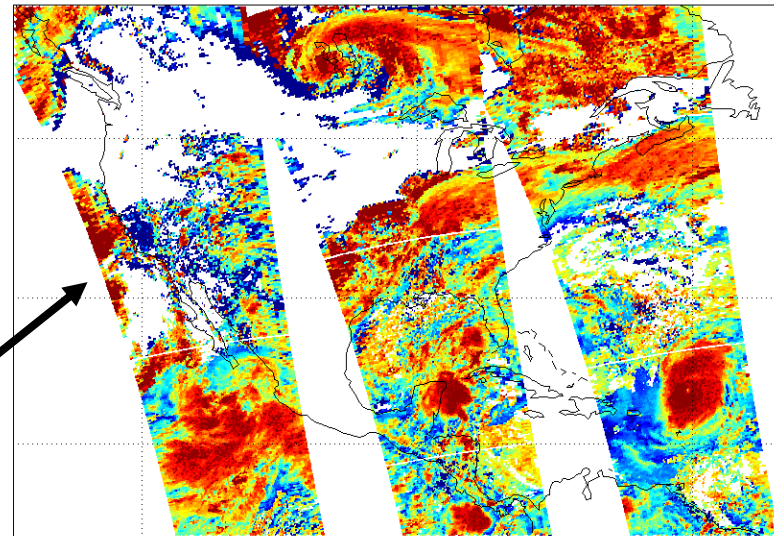
MODIS cloud mask is used for AIRS cloud detection !

CIMSS/UW

Aerosol backscatter cross section m⁻¹str⁻¹ 17-Oct-2004

AIRS CTH=7.6 km

HSRL Total Optical Depth

AIRS OD=1.44

Layer Mean Effective Radius
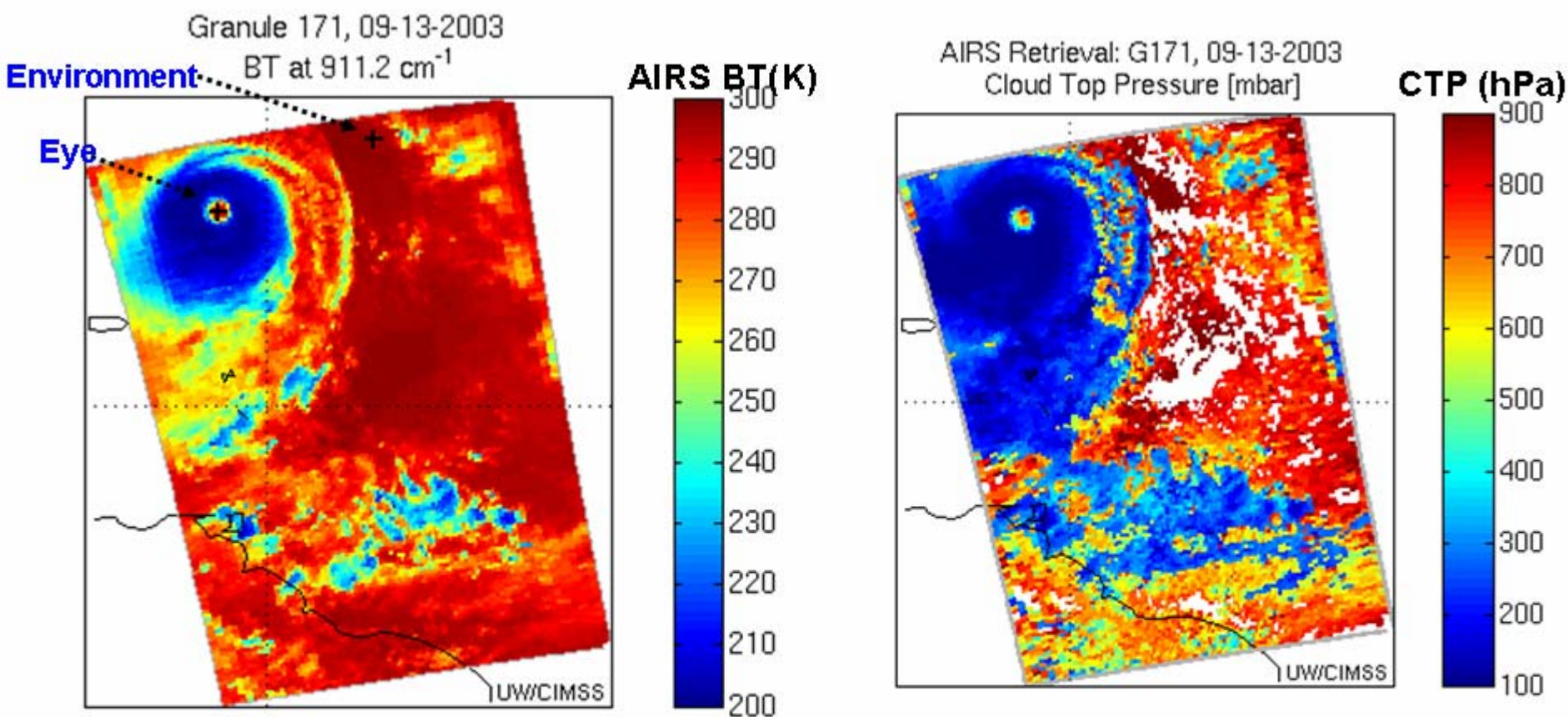
AIRS Effective Radius=38.6 um

Time UTC

AIRS (time is 22:17:32) cloud properties (cloud-top pressure, optical depth, particle radius) comparison with UW lidar measurements during MPACE (Mixed Phase Arctic Cloud Experiment)

Vertical Layers

- 4.5   5.0 km
- 5   7 km
- 7   8 km
- 8   9 km
- 9   10 km

CIMSS/UW

Cloudy sounding approach

- Using the cloudy RTM, soundings are derived down to the surface in clear and thin cloudy skies, while above-cloud soundings are derived in thick cloud conditions, details see (Weisz et al. 2007 - GRL; Zhou et al. 2007 – JAS).

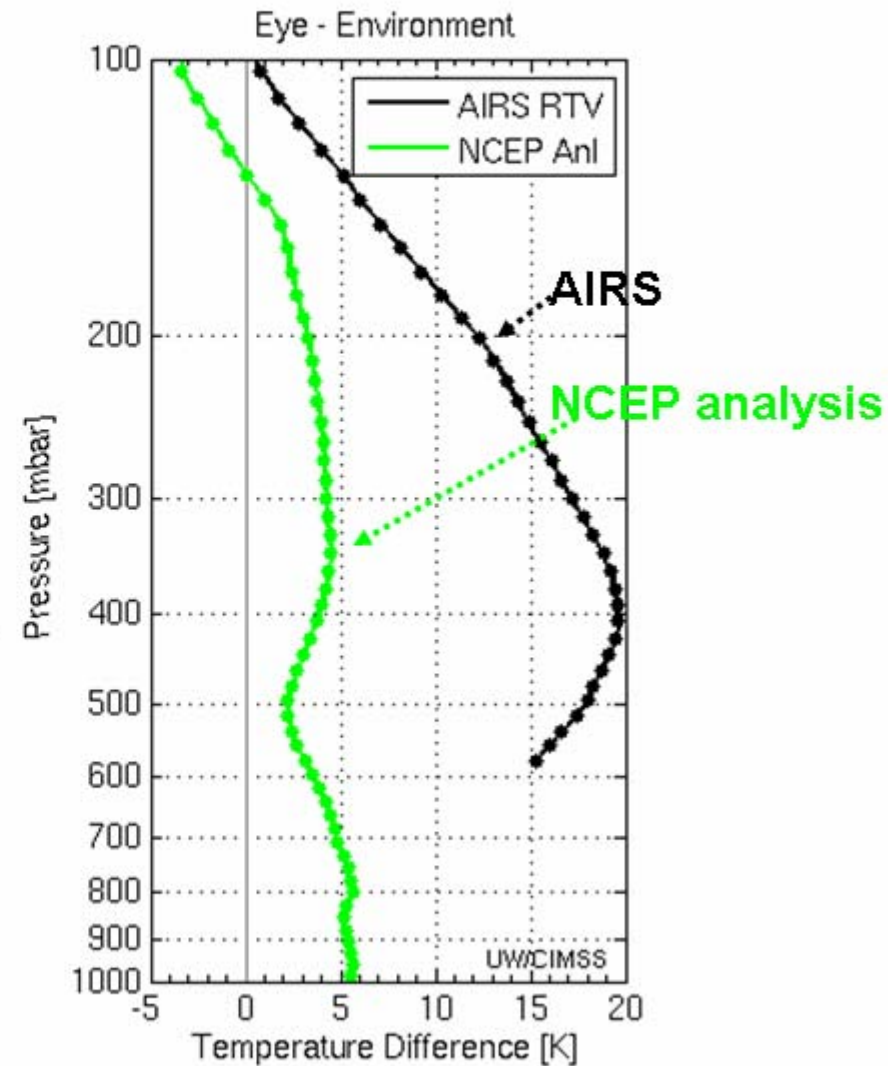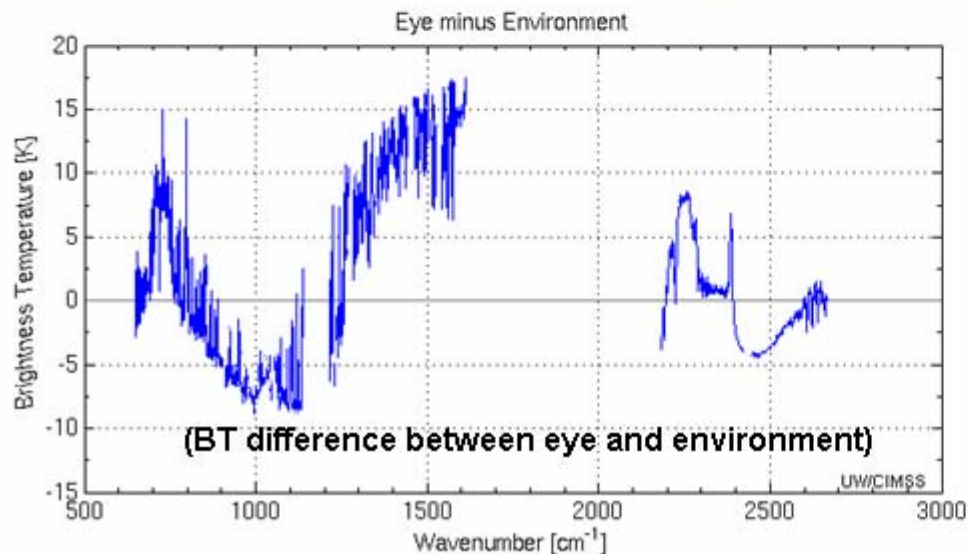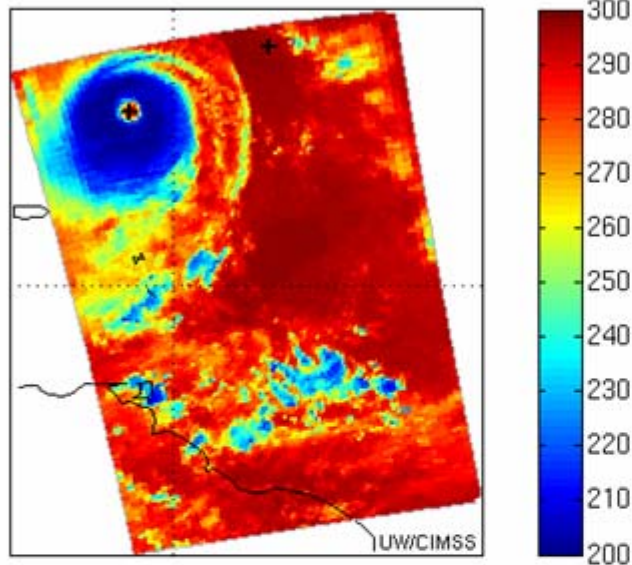# Hurricane Cloud-top pressures in eye and environment regions

Granule 171, 09-13-2003
BT at 911.2 cm^{-1}

AIRS BT(K)

Environment

Eye

UW/CIMSS

AIRS Retrieval: G171, 09-13-2003
Cloud Top Pressure [mbar]

CTP (hPa)

UW/CIMSS

	Eye	Environment
AIRS Index (line/footprint)	19 / 118	66 / 129
Lat / Lon [°]	22.4 / -61.9	25.3 / -55.7
Cloud Fraction	0.88	0.51
Cloud-top pressure (hPa	732.0	568.3

Temperature difference between hurricane eye and outside pixel


Granule 171, 09-13-2003
BT at 911.2 cm⁻¹

Eye - Environment

AIRS RTV
NCEP Anl

AIRS

NCEP analysis

Eye minus Environment

(BT difference between eye and environment)

CIMSS/UW-Madison

AIRS Index	65 / 121
Lat / Lon [°]	23.9 / -55.6
Cloud fraction	0.1
AIRS alone cloud-top pressure (hPa)	883.2

Dropsonde 3 (20030913n 023555081)

Dropsonde 3 (20030913n 023555081)
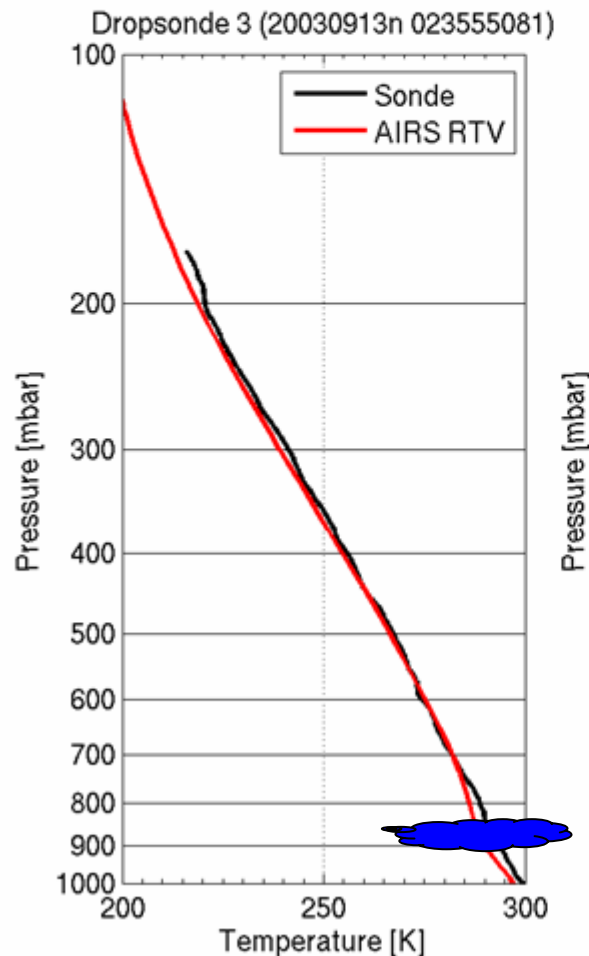
AIRS Time:
17:15 UTC
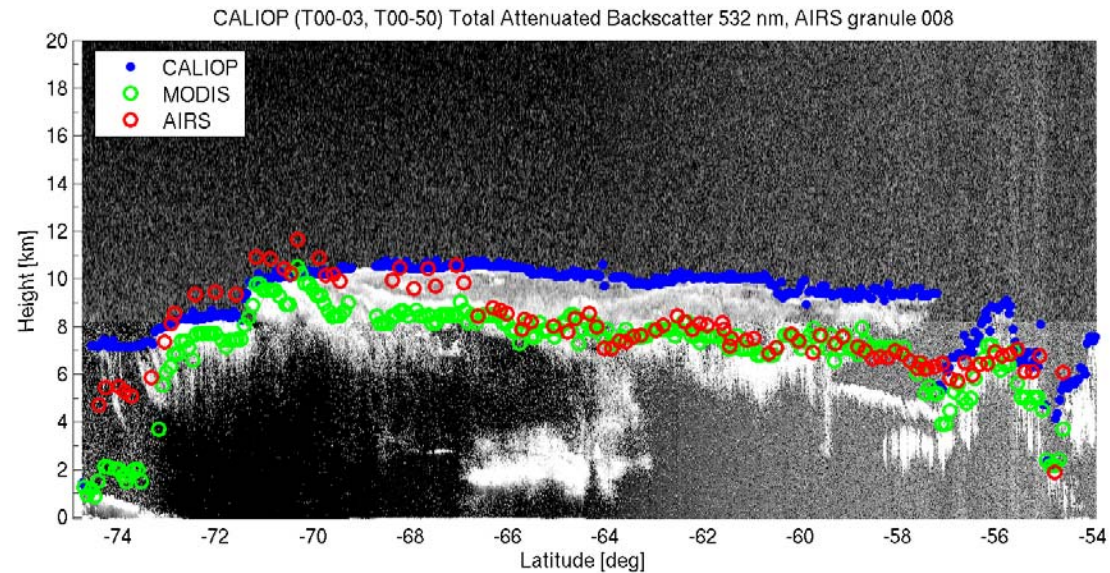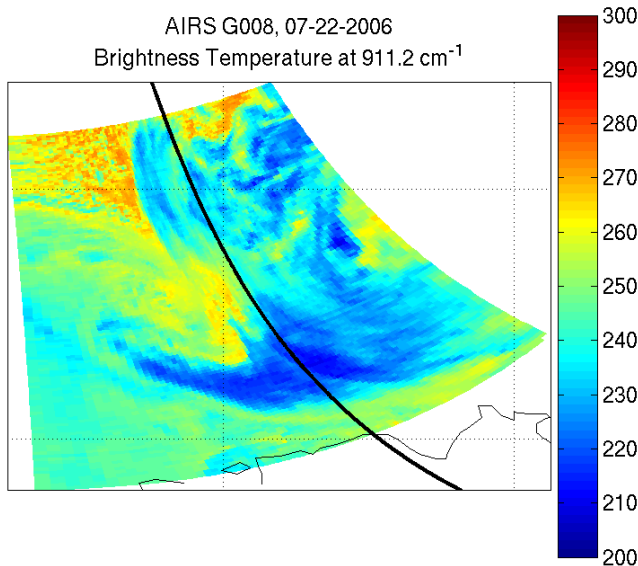
Dropesonde time:
22:55 UTC

CIMSS/UW-Madison
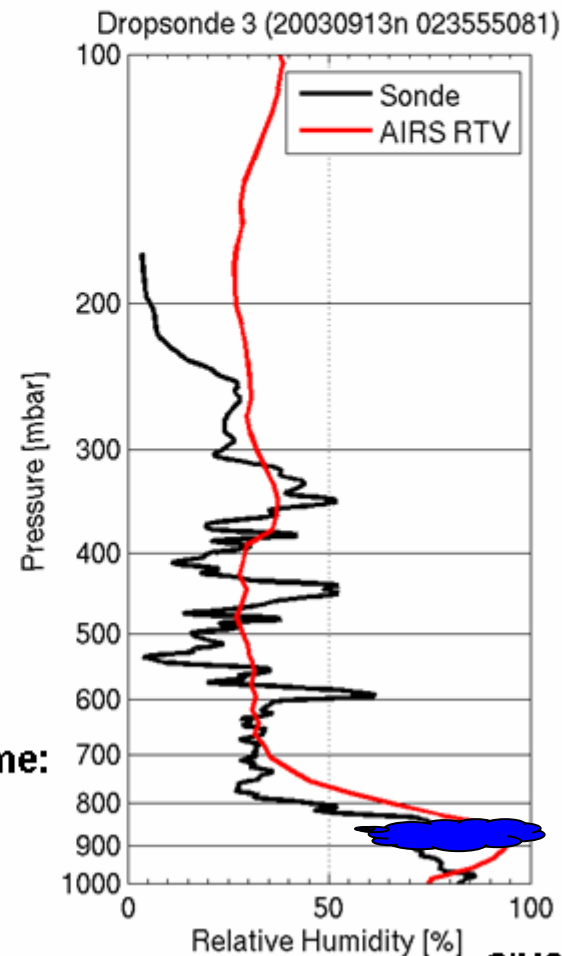
Case Study 1: 07-22-2006, AIRS granule 8 (asc)
"Interesting SH 2-layer cloud structure" (Weisz et al. 2007 – GRL)

AIRS.2006.07.22.008
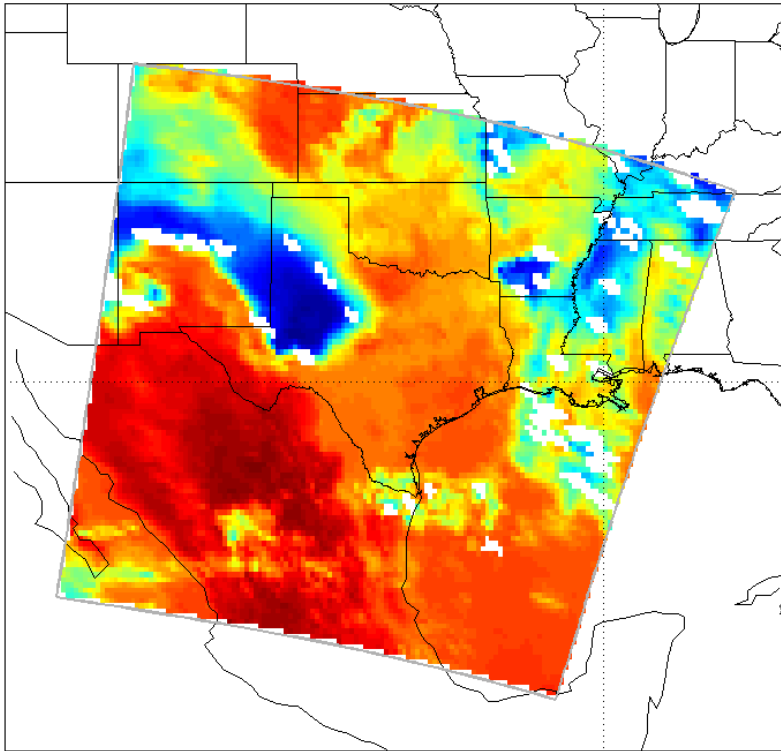MYD06_L2.A2006203.0045 /0050
2006203001959_01233_CS

CPR Cloudmask orbit 01233, AIRS granule 008
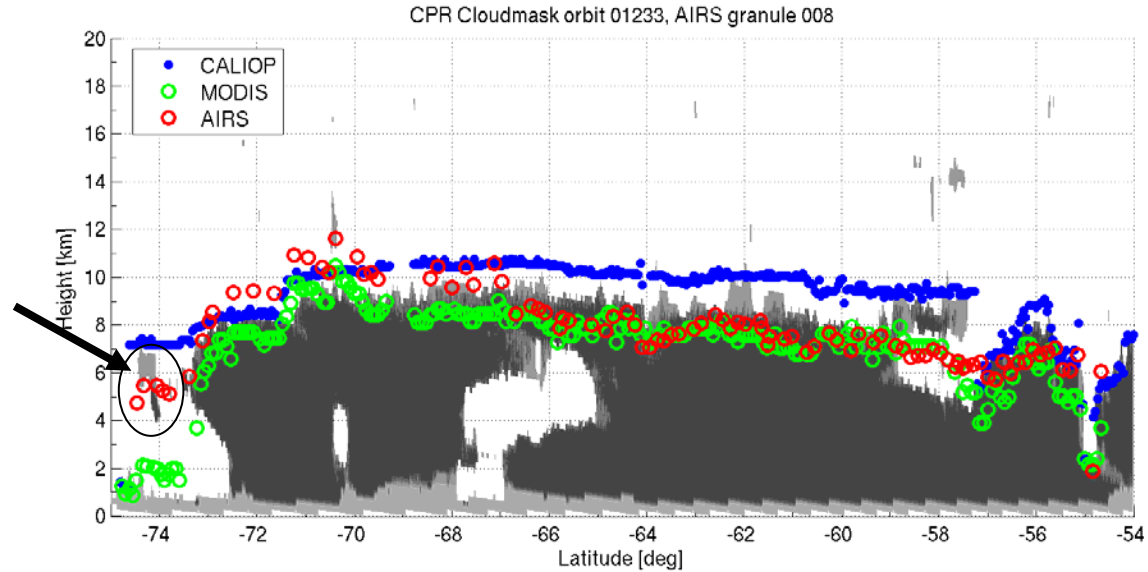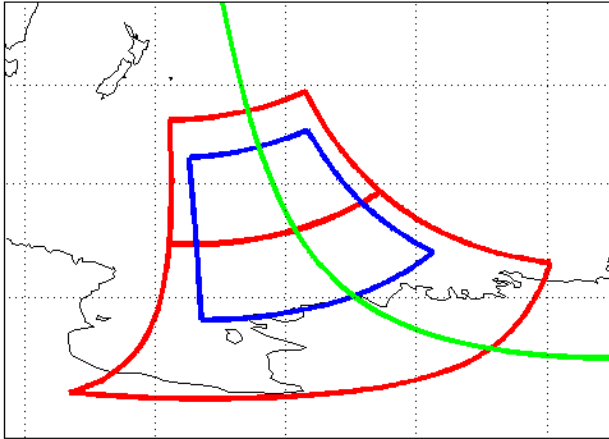
AIRS G008, 07-22-2006
Brightness Temperature at 911.2 cm^{-1}

CALIOP (T00-03, T00-50) Total Attenuated Backscatter 532 nm, AIRS granule 008

Initial IASI Retrieval (JAIVEx case on 05-02-2007)

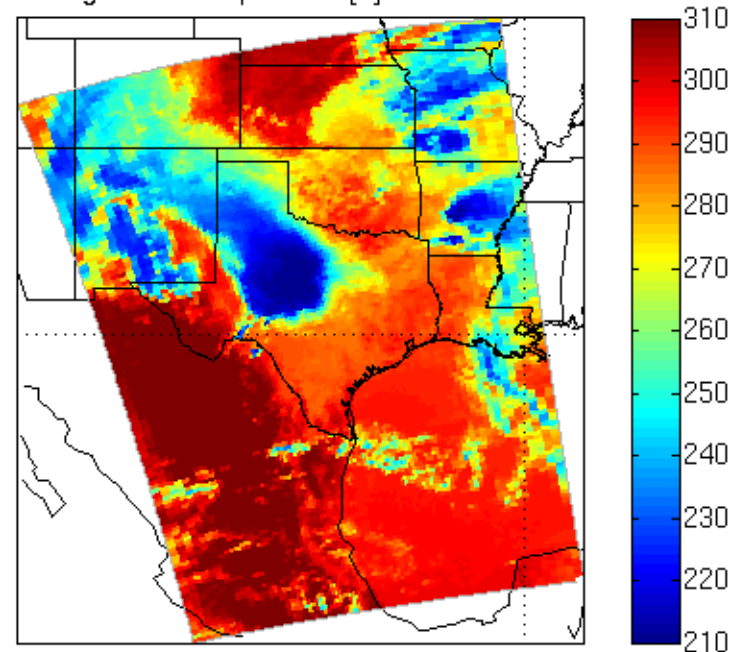IASI START: 20070502161453Z
BT at 902.50 cm^{-1} (11.08 μm)

IASI Start Time: 16:14 UTC (desc)

AIRS and IASI has ~3.5 hours time difference in this case

AIRS Start Time: 19:47 UTC (asc)

AIRS.2007.05.02.198.L1B.AIRS_Rad.v4.0.9.0.G07123182226.hdf
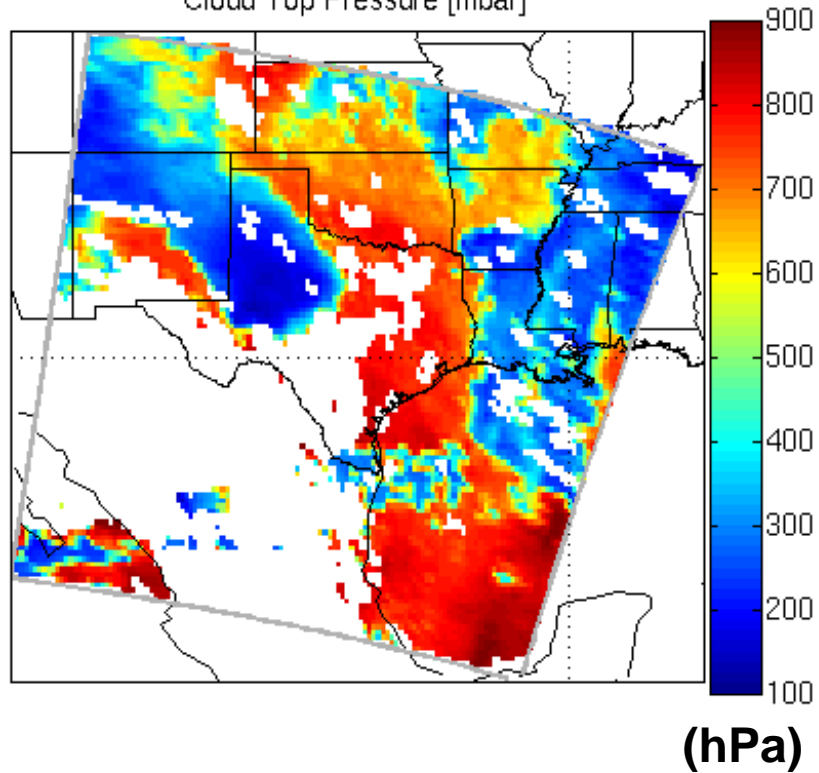Brightness Temperature [K] at 902.0 cm^{-1}

Note: to obtain cloudmask simple 10.5,11.5,12.5 tri-spect and on/off technique (cloudmask1f.m) is applied for now
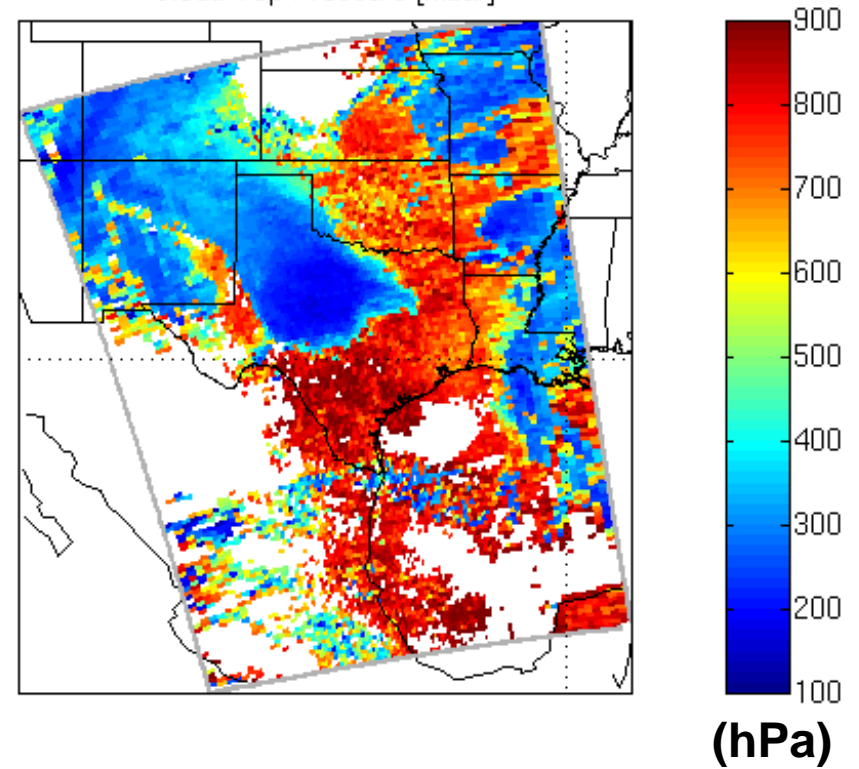
SFOV Cloud Top Pressure [hPa]

IASI

IASI Retrieval: 20070502161453Z
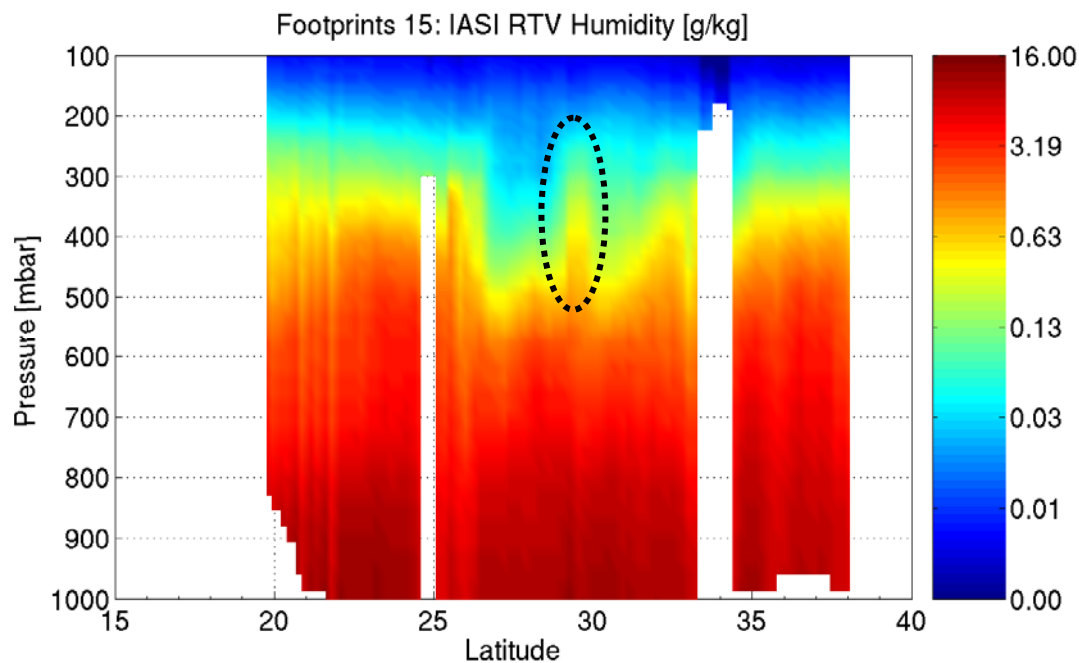Cloud Top Pressure [mbar]

(hPa)

AIRS

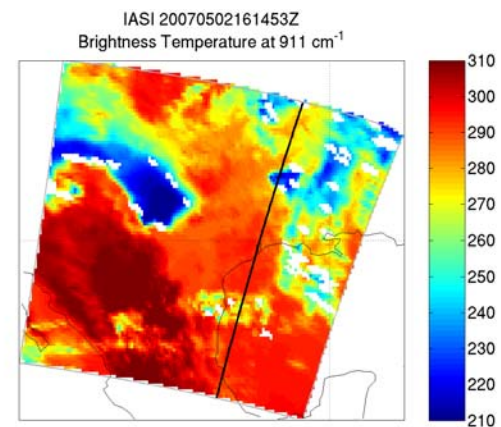AIRS Retrieval: G198, 05-02-2007
Cloud Top Pressure [mbar]

(hPa)

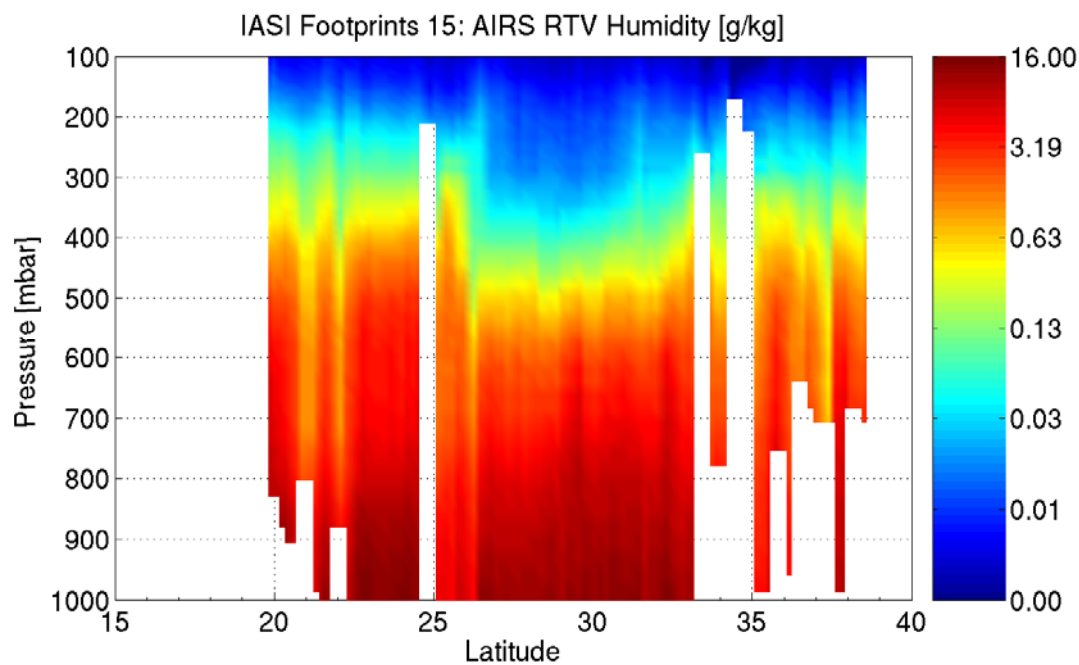# SFOV water vapor mixing ratio [g/kg] cross-section along IASI footprints 15
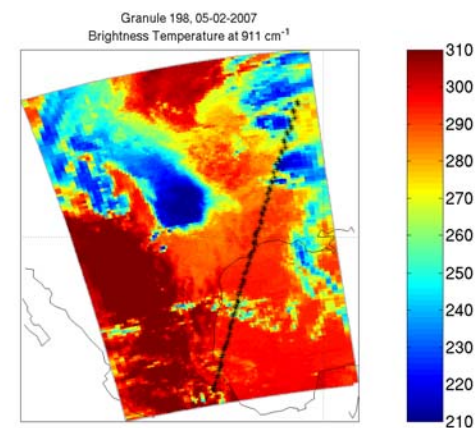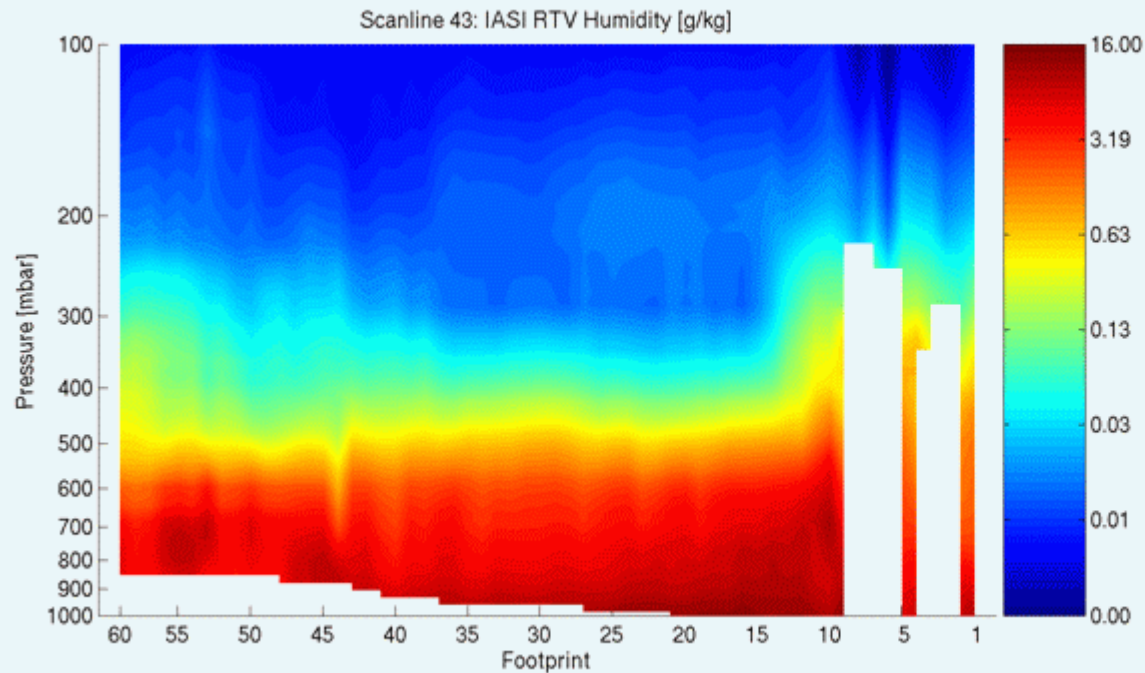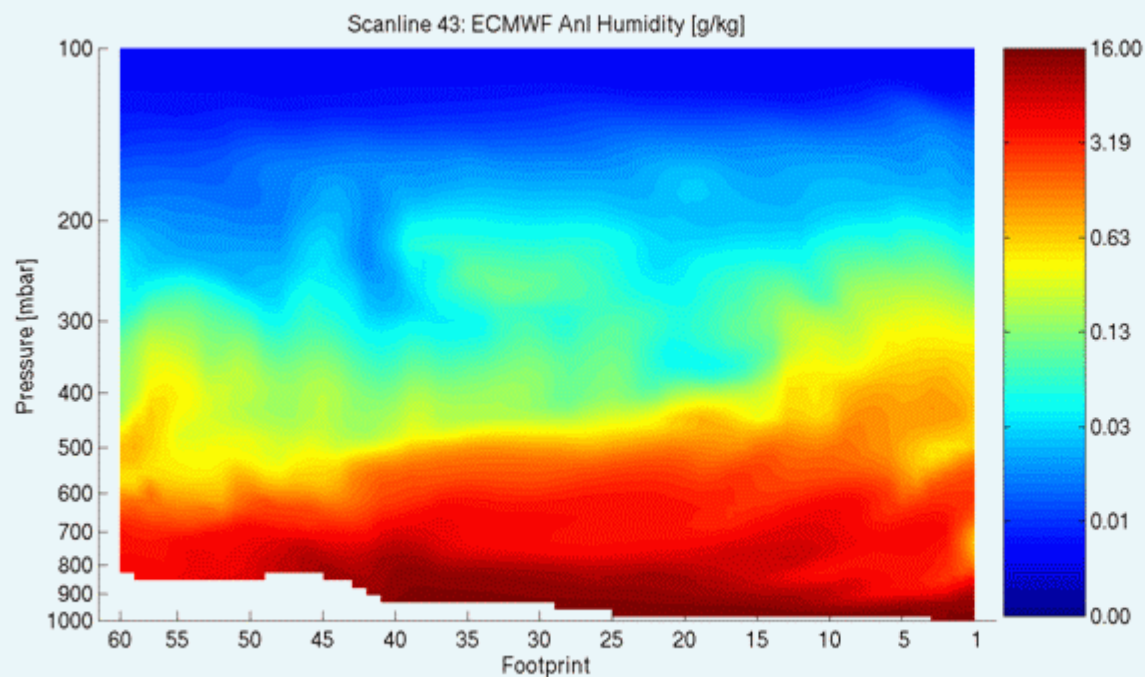
Scanline 43: IASI RTV Humidity [g/kg]

Scanline 43: ECMWF Anl Humidity [g/kg]

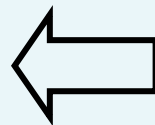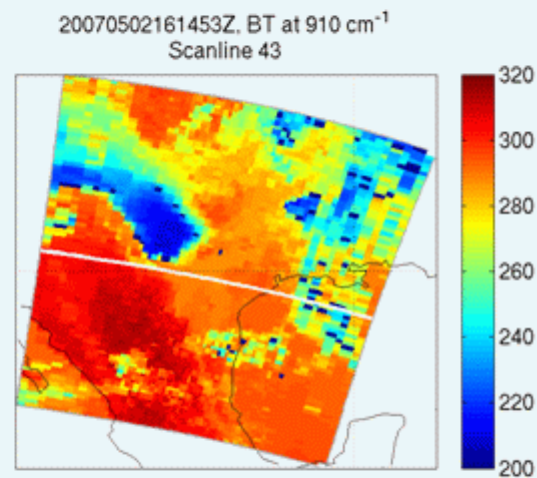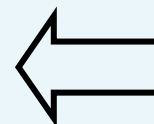20070502161453Z, BT at 910 cm⁻¹
Scanline 43

IASI SFOV mixing ratio (g/kg)

ECMWF mixing ratio analysis (g/kg)

UW/CIMSS

Summary

- Algorithms for hyperspectral IR SFOV approach is developed for retrieval of sounding, surface IR emissivity spectrum and cloud properties

- AIRS and IASI show promising on applying the algorithms to the hyperspectral infrared radiance measurements

- Focus will be on cloudy sounding improvement and impact on hurricane genesis, intensity and track forecast in our future work