Retrieval with IASI

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and

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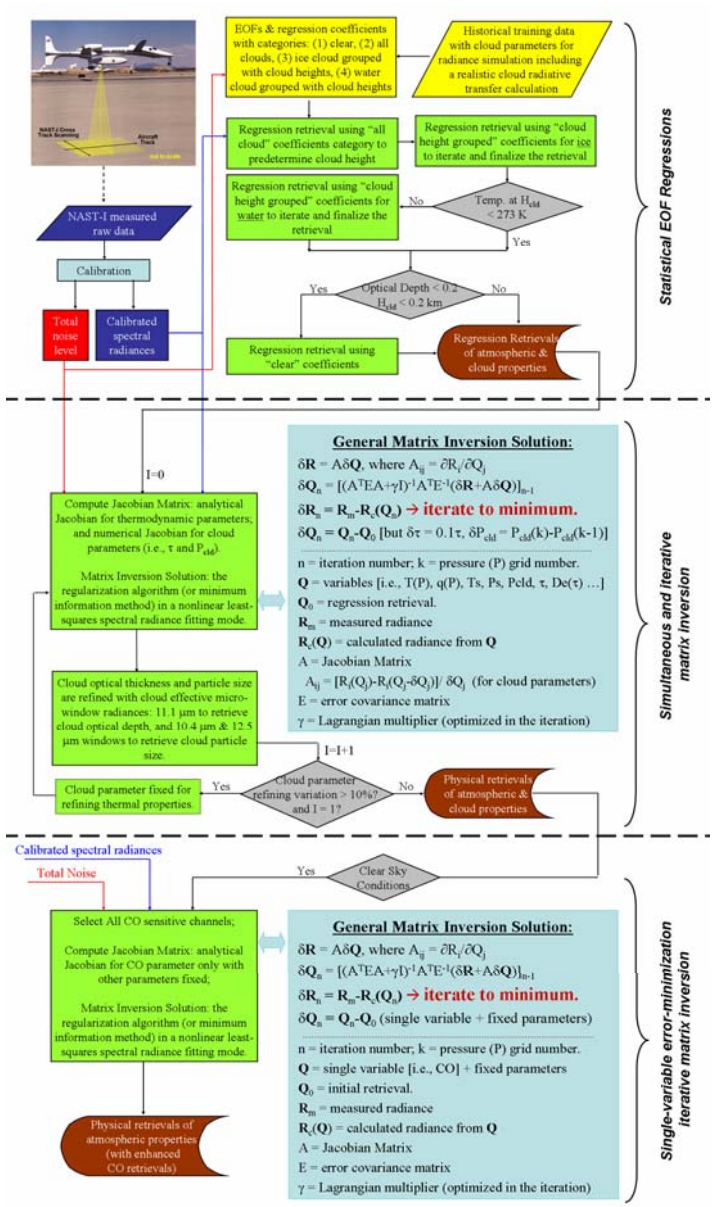
Outline:

- Retrieval methodology and NAST-I Demonstration
- Application to IASI data
- *Initial* retrievals and intercomparison from JAIVEx
- Conclusion…

Hybrid Retrieval Algorithm (HRA)



Related Publications:

2001: Surface temperature and emissivity from airborne measurements of IR radiance spectra, *Eos Trans.* AGU, **82**(47), Fall Meeting Suppl., Abstract A31A-09.

2002: Thermodynamic product retrieval methodology for NAST-I and validation, *Applied Optics*, **41**, 6957–6967.

2003: Validation of aircraft-measured land surface emissivity, *Proc. SPIE* **4891**, 384–391.

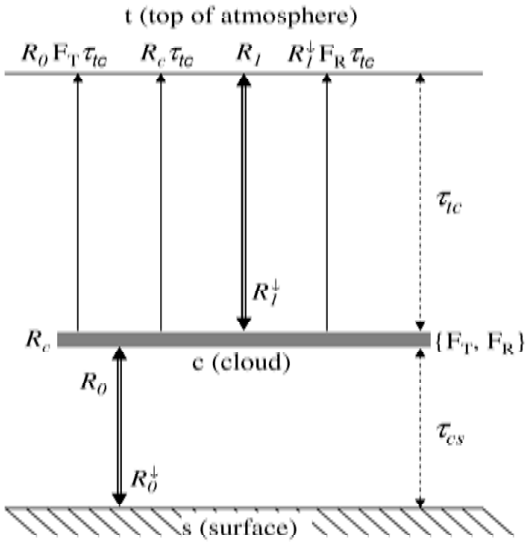
2005: Thermodynamic and cloud parameters retrieval using infrared spectral data, *Geophys. Res. Lett.*, **32**, L15805, doi:10.1029/2005GL023211.

2005: Tropospheric CO observed with the NAST-I: retrieval methodology, analyses, and first results, *Applied Optics*, **44**, 3032–3044.

2006: Surface emissivity effects on thermodynamic retrieval of IR spectral radiance, *Proc. SPIE* **6405**, 64051H.

2007: Physically retrieving cloud and thermodynamic parameters from ultraspectral IR measurements, *J. Atmos. Sci.*, **64**, 969–982.

Radiative Transfer Model (include clouds)



$$R = R_0 \, F_T \, \tau_{tc} + R_c \tau_{tc} + R_1 + R_1^{\downarrow} \, F_R \, \tau_{tc}$$

$$R_0 = \varepsilon \, B_s \, \tau_{cs} + \int_{\tau_{cs}}^{1} B \, d\tau + (1-\varepsilon) R_0^{\downarrow} \tau_{cs}$$

$$R_0^{\downarrow} = \tau_{cs} \left(R_1^{\downarrow} \, F_T + R_c \right) + \int_{\tau_{cs}}^{1} B d\tau'$$

$$R_c = (1 - F_R - F_T) B(T_c)$$

$$R_1 = \int_{\tau_{tc}}^{1} B d\tau$$

$$R_1^{\downarrow} = \int_{\tau_{tc}}^{1} B d\tau'$$

R = upwelling spectral radiance at the top of atmosphere

F_T = cloud transmissive function

F_R = cloud reflective function

R_0 = upwelling emission below the cloud

$R_0^{\downarrow}$ = downwelling emission below the cloud

R_c = emission from the cloud

R_1 = upwelling emission above the cloud

$R_1^{\downarrow}$ = downwelling emission above the cloud

ε = surface emissivity

B = Planck function

τ = total transmittance from any given level to an upper boundary such as cloud level or the top of the atmosphere

τ' = the total transmittance from any given level to a lower boundary such as cloud level or the Earth's surface

τ_{cs} = transmittance between the cloud level and the Earth's surface

τ_{tc} = transmittance between the top of the atmosphere and cloud level

Regression Inversion

Statistics are formulated for one class of data which contains all cloud height conditions

and

seven other classes for which the cloud height has been stratified to within approximately 1.5 km of the mean for that class.

$$R = R_0 \, \mathrm{F_T} \, \tau_{tc} + R_c \tau_{tc} + R_1 + R_1^{\downarrow} \, \mathrm{F_R} \, \tau_{tc} ,$$

$$\mathrm{M}_{ij} = \frac{1}{S} \sum_{k=1}^{S} \Re_{ki} \Re_{kj}$$

$$\psi_{\mathrm{i}} = \sum_{\mathrm{j}=1}^{5} \varepsilon_{\mathrm{j}} \mathrm{e}_{\mathrm{ji}}$$

$$\mathrm{C}_{\mathrm{i}} = \sum_{\mathrm{j}=1}^{\mathrm{nc}} \mathrm{R}_{\mathrm{j}} \mathrm{E}_{\mathrm{ji}}$$

$$\mathrm{A}_m = \sum_{i=1}^{n-1} \mathrm{K}_{mi} \, \mathrm{C}_i + \mathrm{K}_{mn} \mathrm{P}_s = \sum_{i=1}^{n-1} \mathrm{K}_{mi} \left(\sum_{j=1}^{nc} \mathrm{R}_j \mathrm{E}_{ji} \right) + \mathrm{K}_{mn} \mathrm{P}_s$$

R = radiance

P_s = surface pressure

S = number of sample profiles

$\Re$ = radiance deviation from the mean

M = covariance matrix of $\Re$

E = eigenvectors of M – EOFs

C = radiance EOF amplitudes

A = {T_s, ψ, T, q, ... Hcld, τcld, De, Pha} parameters

K = regression coefficients

ψ = emissivity EOF amplitudes

ε = emissivity

e = emissivity eigenvectors

F_T = cloud transmissive function {Hcld, τcld, De, Pha}

F_R = cloud reflective function {Hcld, τcld, De, Pha}

Hcld = cloud hight

τcld = cloud optical depth

De = cloud particle diameter

Pha = cloud phase (ice or water cloud)

Physical Inversion

$$Y = R_0\, \mathrm{F_T}\, \tau_{tc} + R_c \tau_{tc} + R_\mathrm{I} + R_\mathrm{I}^{\downarrow}\, \mathrm{F_R}\, \tau_{tc},$$

$$\delta Y = Y' \, \delta X$$

$$J(X) = [Y^m - Y(X)]^{\mathrm{T}} E^{-1} [Y^m - Y(X)] + [X - X_0]^{\mathrm{T}} (\gamma I) [X - X_0]$$

$$X_{\mathrm{n+1}} = X_\mathrm{n} + J''(X_\mathrm{n})^{-1} J'(X_\mathrm{n})$$

$$\delta X_{\mathrm{n+1}} = (Y_\mathrm{n}'^{\mathrm{T}} E^{-1} Y_\mathrm{n}' + \gamma\, I)^{-1}\, Y_\mathrm{n}'^{\mathrm{T}}\, E^{-1}\, (\delta Y_\mathrm{n} + Y_\mathrm{n}'\, \delta X_\mathrm{n})$$

$$\delta X_\mathrm{n} = X_\mathrm{n} - X_0$$

$$\delta Y_\mathrm{n} = Y^\mathrm{m} - Y(X_\mathrm{n})$$

$$\left\| Y[X(\gamma)] - Y^m \right\|^2 = \sigma^2$$

$$\gamma_{\mathrm{n+1}} = q_\mathrm{n}\, \gamma_\mathrm{n}$$

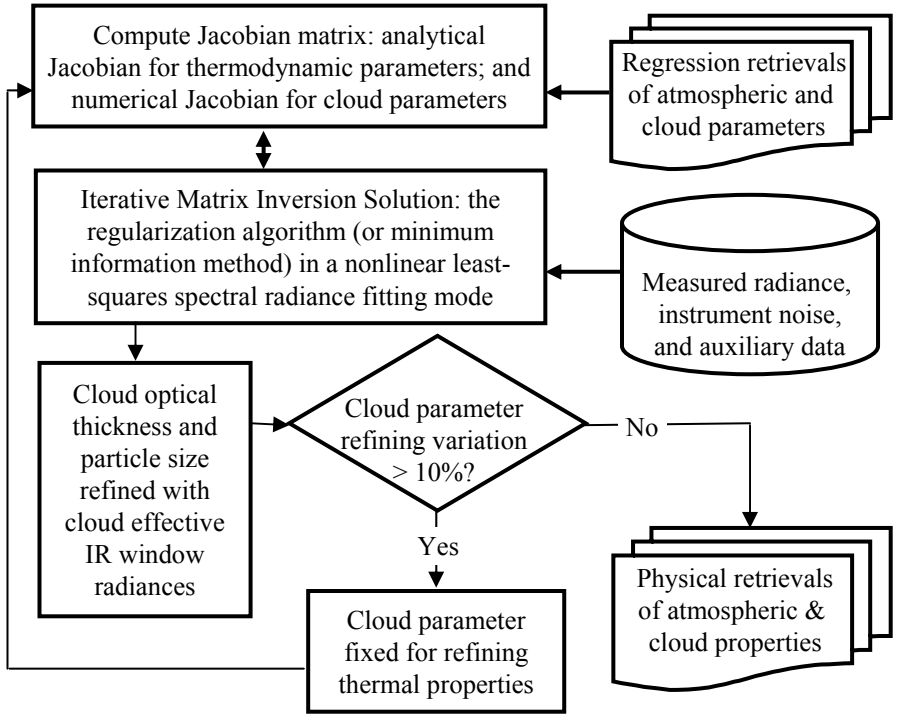
each iteration by satisfying the following conditions:

$$\mathrm{q_l} = 1.0;$$

$$\textit{if } \left\| Y(X_\mathrm{n}) - Y^\mathrm{m} \right\| < \sigma^2, \text{ then } \mathrm{q_n} = 1.5;$$

$$\textit{if } \left\| Y(X_\mathrm{n}) - Y^\mathrm{m} \right\| > \sigma^2, \text{ then } \mathrm{q_n} = 0.5;$$

$$\textit{if } \left\| Y(X_\mathrm{n}) - Y^\mathrm{m} \right\| = \sigma^2, \text{ then stop the iteration;}$$



Y = calculated Radiance

X = {T_s, T, q, o3, co, …, Hcld, τcld, De, Pha}

Y^m = observed Radiance

J = "Penalty function"

σ = total noise

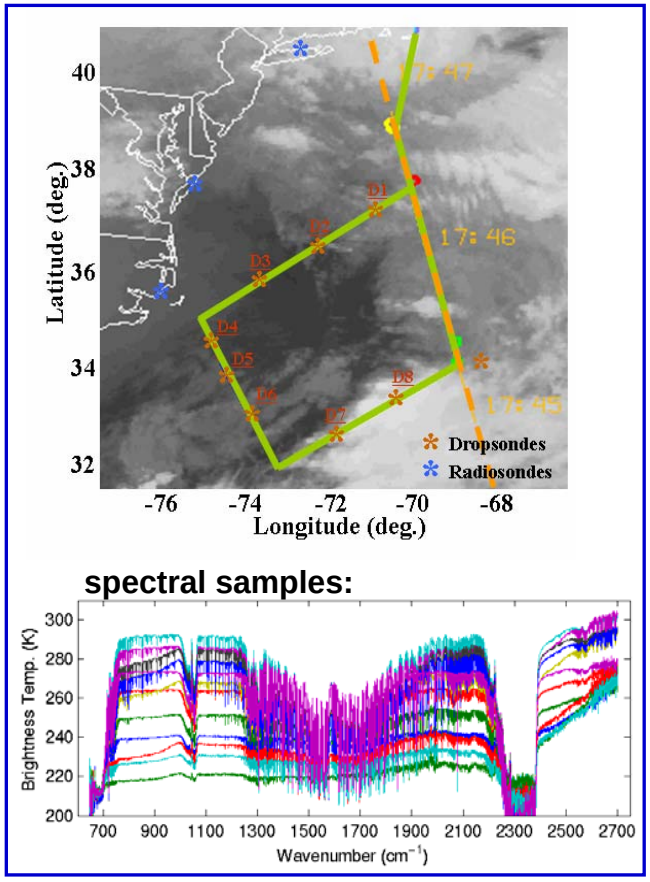
E = error covariance matrix

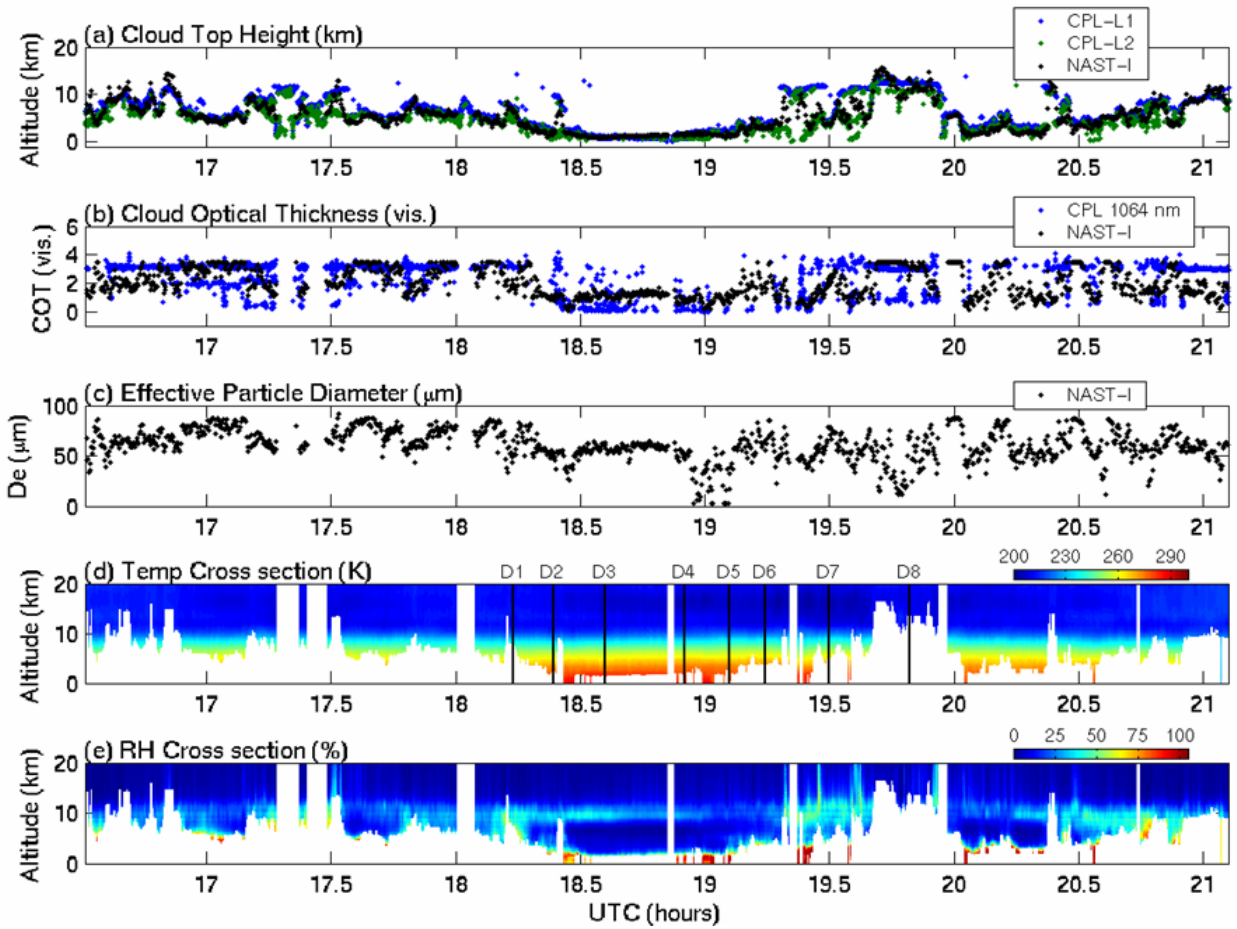
γ = a smoothing factor

n = iteration number

NAST-I Cloudy Retrieval Demo.

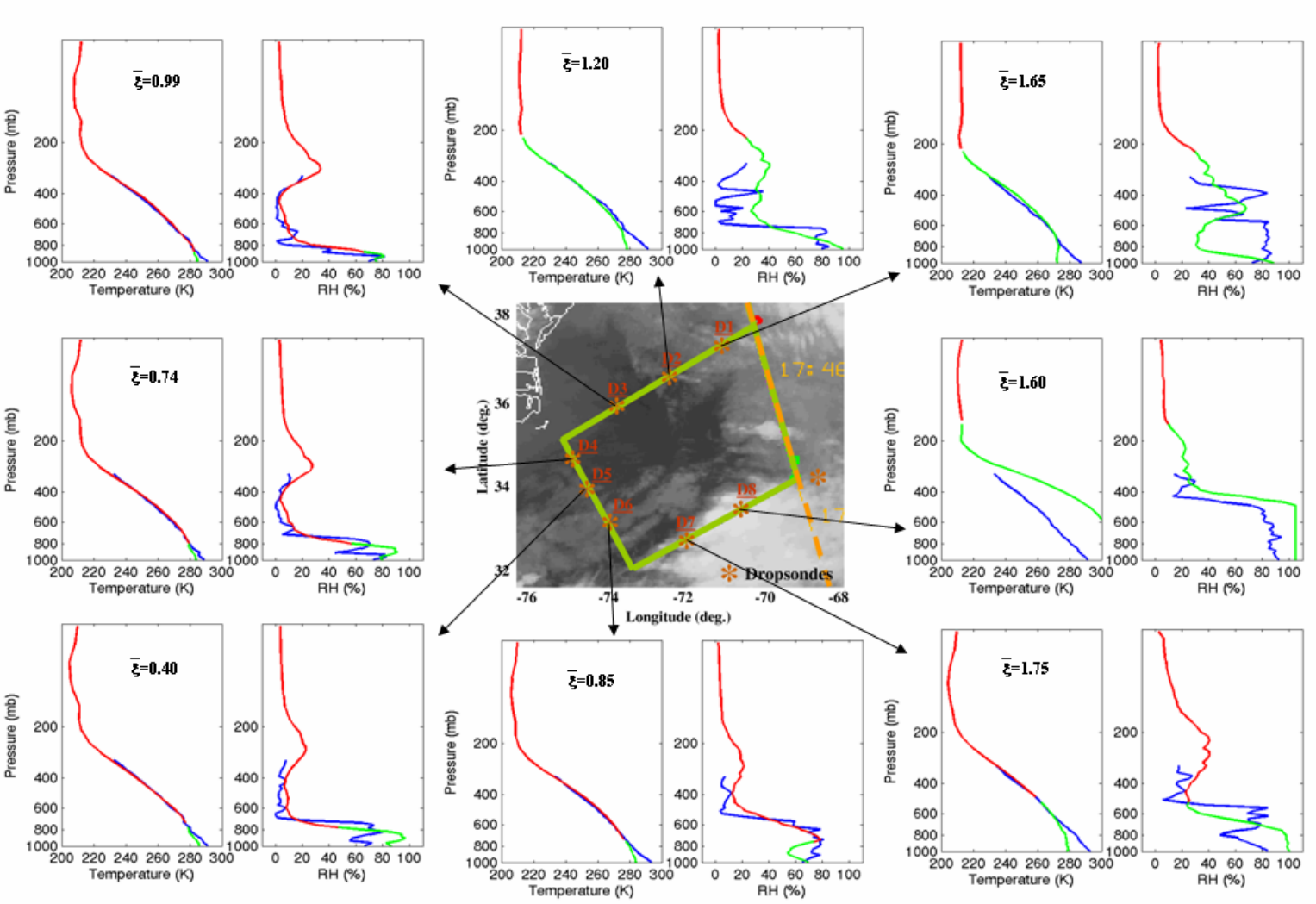
Cloud properties captured by NAST-I hyperspectral measurements. Sounding accuracies close to those achieved in totally cloud-free conditions are achieved down to cloud top level.





NAST-I Cloudy Retrieval Demo.

Soundings to the cloud top are captured and comparable to clear sounding retrievals.



Red curves: retrievals above the cloud.

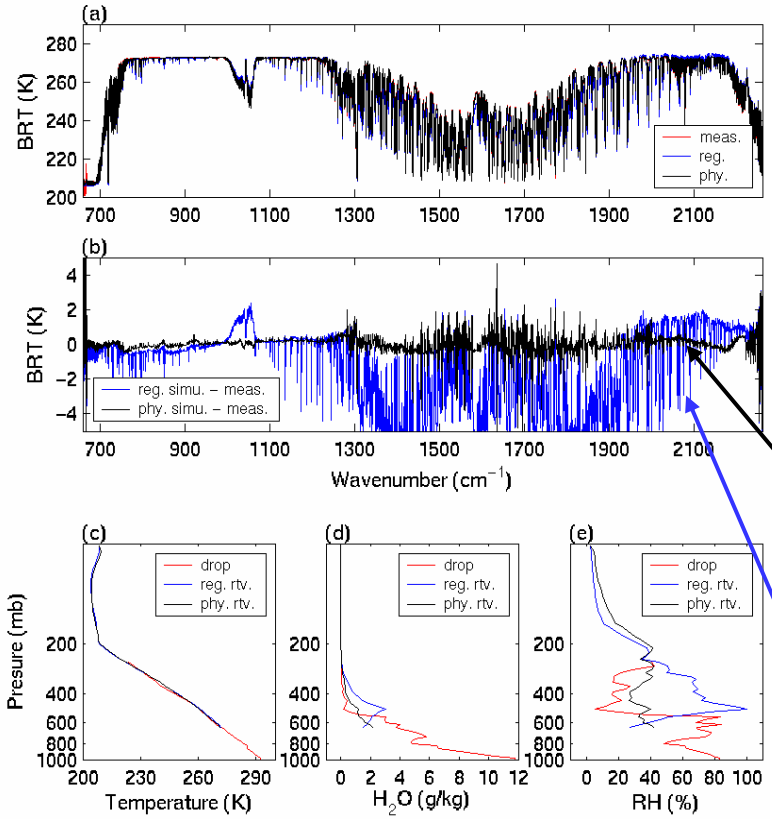
Green curves: retrievals below the cloud.

Blue curves: dropsondes.

Clouds can be presented before RH reaches 100%!

NAST-I Cloudy Retrieval Demo.

Radiance converged through physical iteration
Cloudy sounding validated with dropsondes

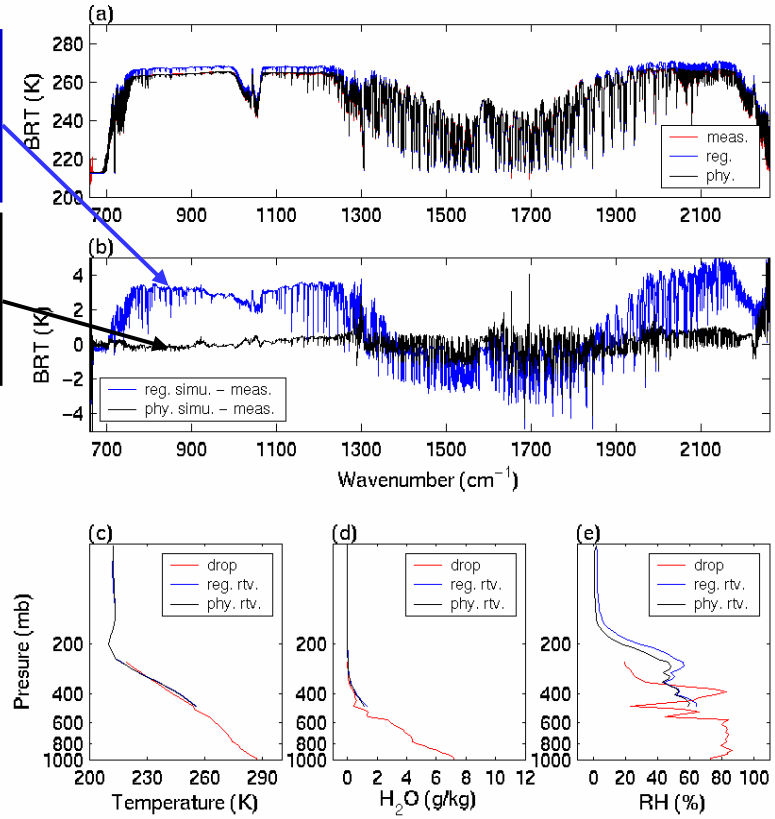


Reg. Retrieval:
CTH = 5.9 km
τ-vis = 1.37
D_e = 42.8 μm

Phy. Retrieval:
CTH = 6.8 km
τ = 0.96
De = 51.4 μm

Phy. Retrieval:
CTH = 3.7 km
τ = 1.81
De = 63.4 μm

Reg. Retrieval:
CTH = 5.4 km
τ-vis = 0.41
D_e = 44.7 μm



Clouds can be presented before RH reaches 100%!

JAIVEx – Joint Airborne IASI Validation Exp.

International collaboration to validate radiance and geophysical products obtained by the IASI aboard the MetOp satellite

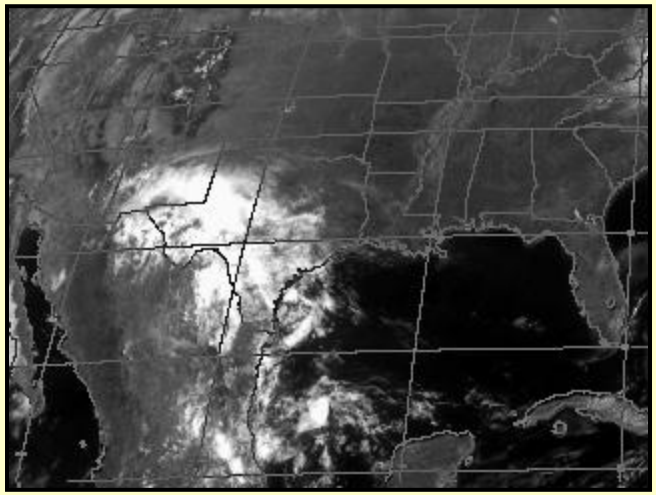
April 29, 2007:

1545 UTC MetOp (IASI)

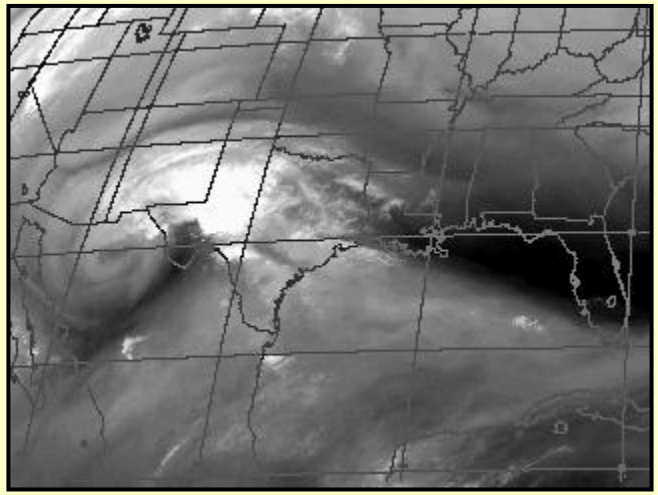
1930 UTC Aqua (AIRS)

1530–1930 UTC BW57 (NAST-I) & Bea-146 (*in situ*).

15:32 UTC GOES IR

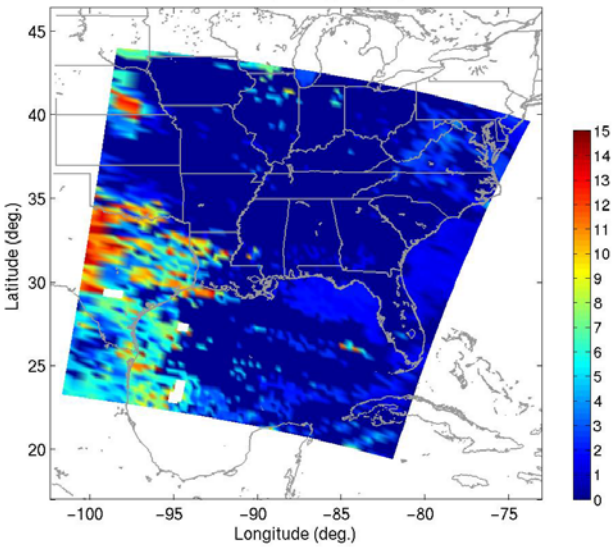


15:32 UTC GOES WV

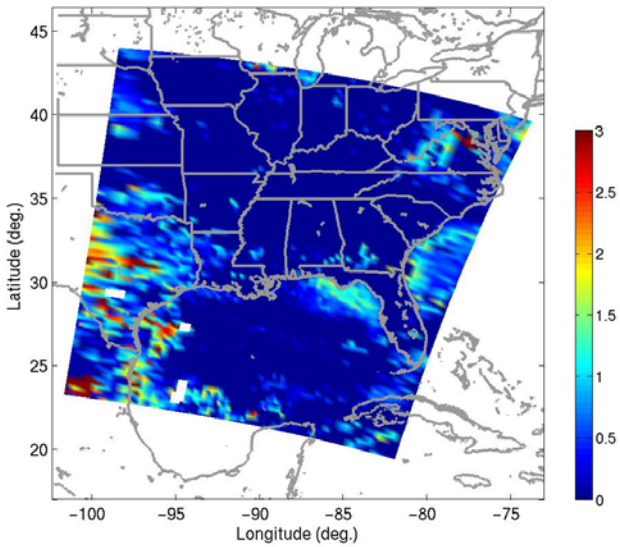


Cloud Properties Retrieved with IASI (4.29.2007)

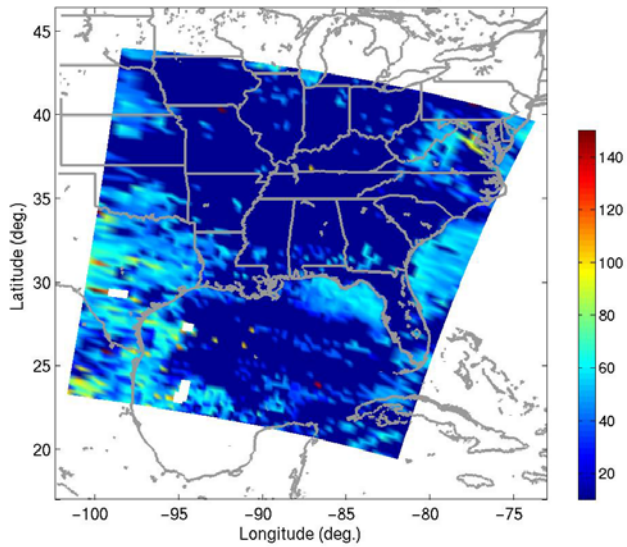
Cloud Top Height (km)



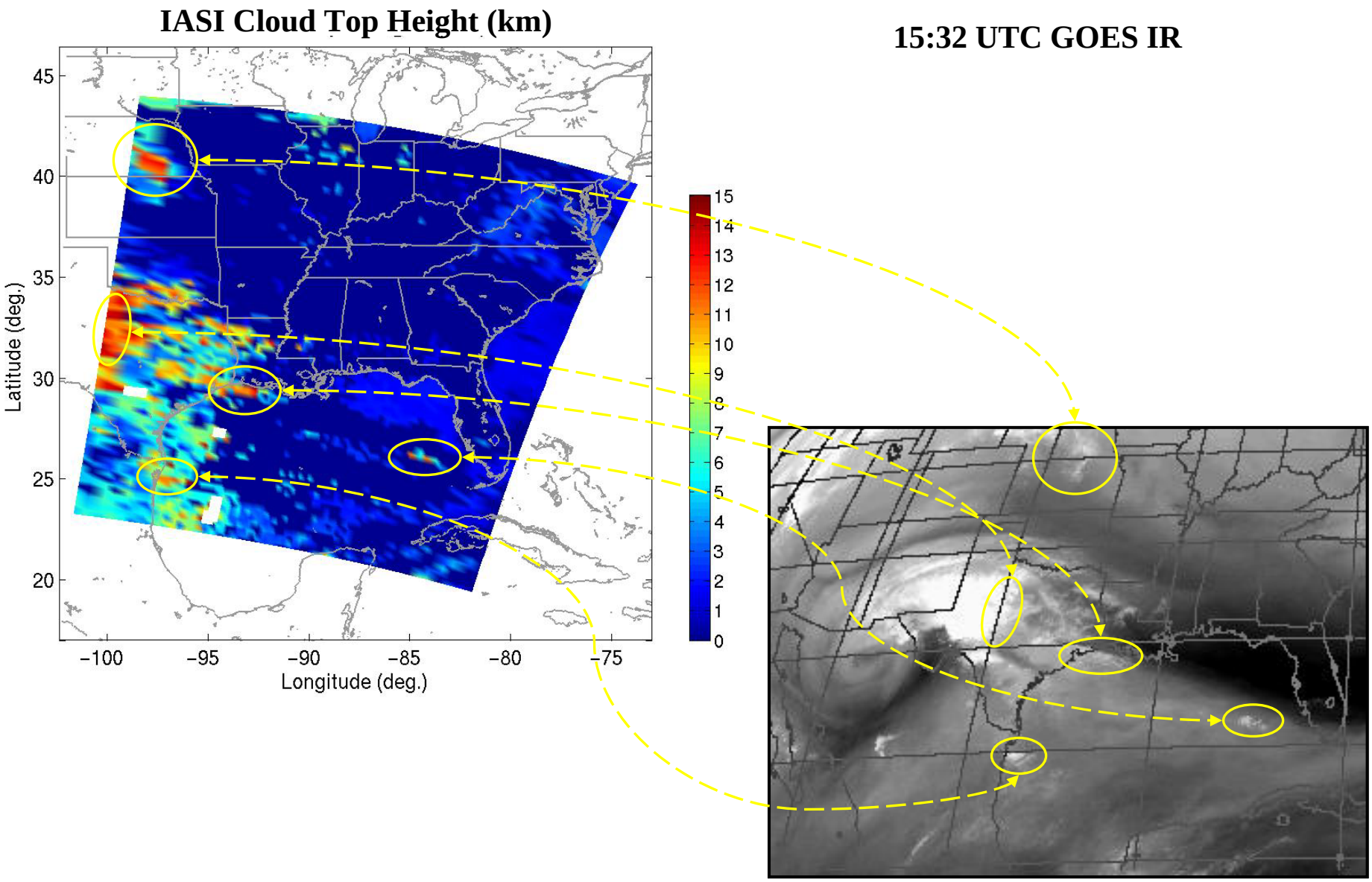
Cloud Optical Depth



Cloud Particle Diameter (μm)



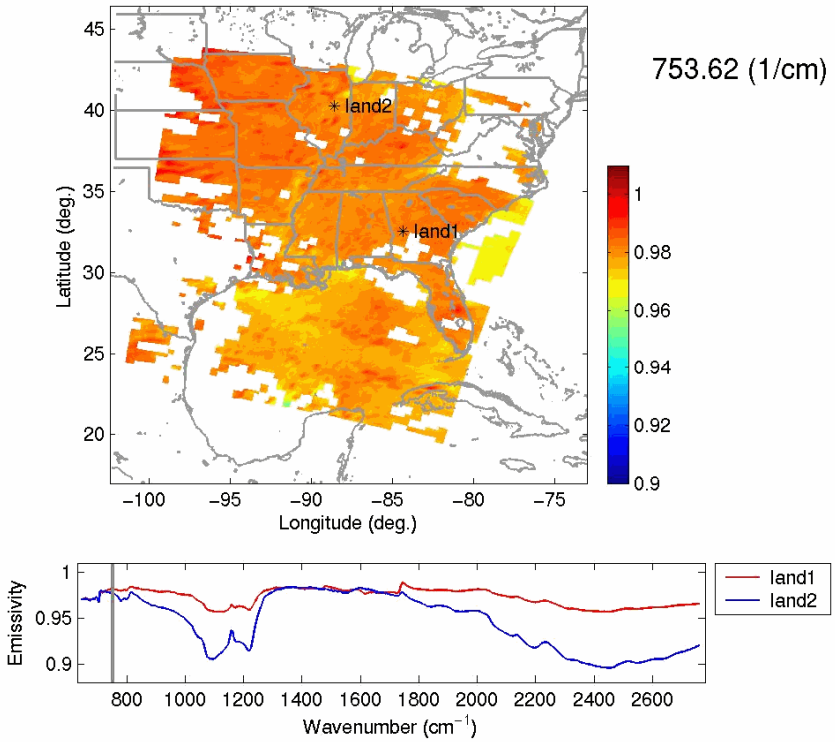
IASI Cloud vs. GOES Image (4.29.2007)

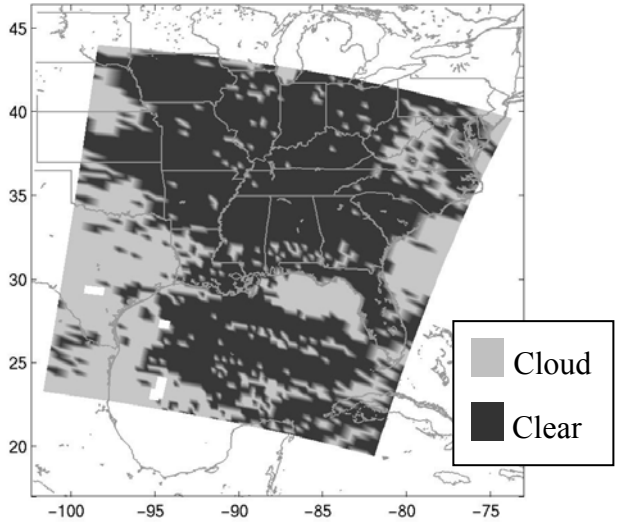


Surf. Emis. Retrieved with IASI (4.29.2007)

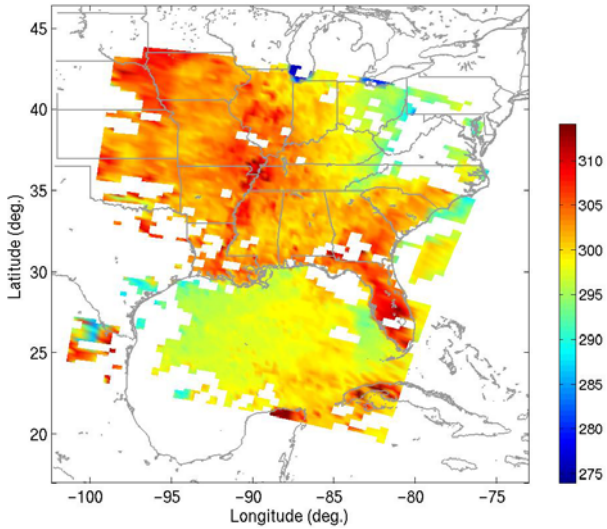
The surface emissivity is one of the key elements for accurately retrieving other thermodynamics parameters.

Surface emissivity as a function of wavenumber.

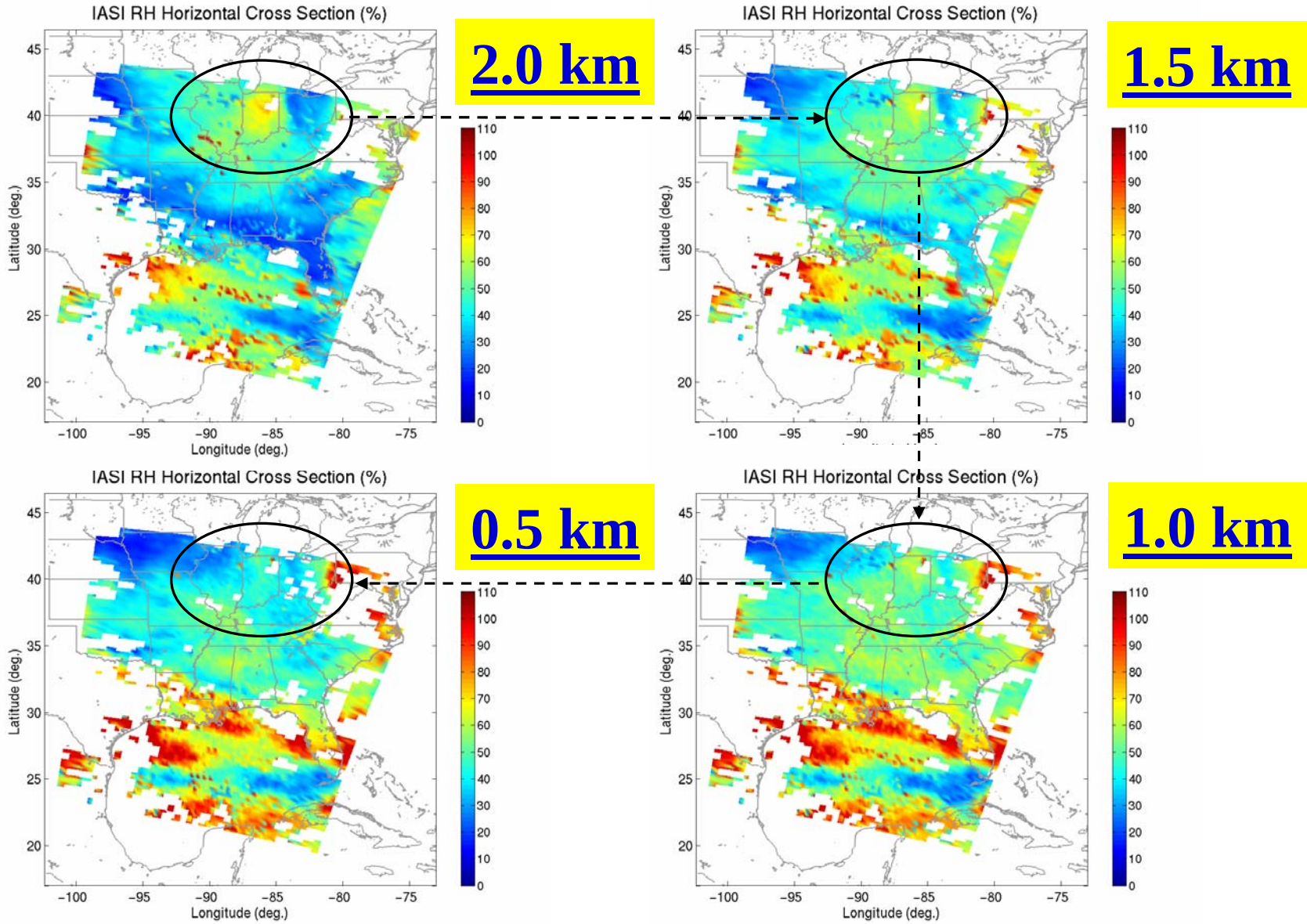




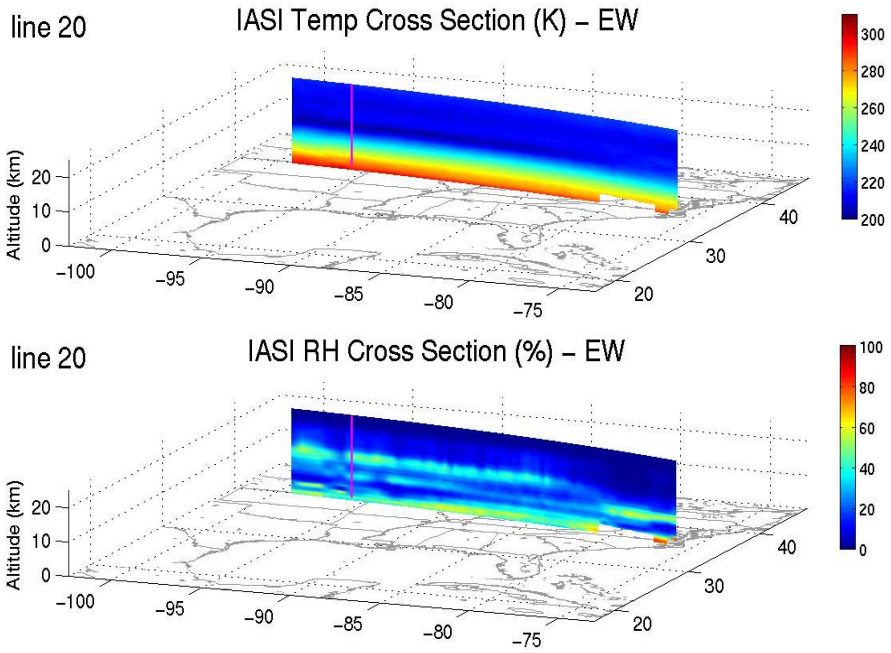
Retrieved Surf. Skin Temp. (K)

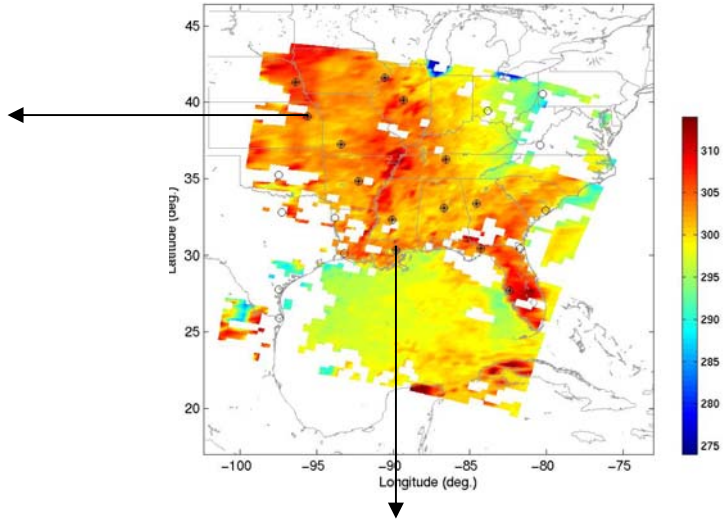


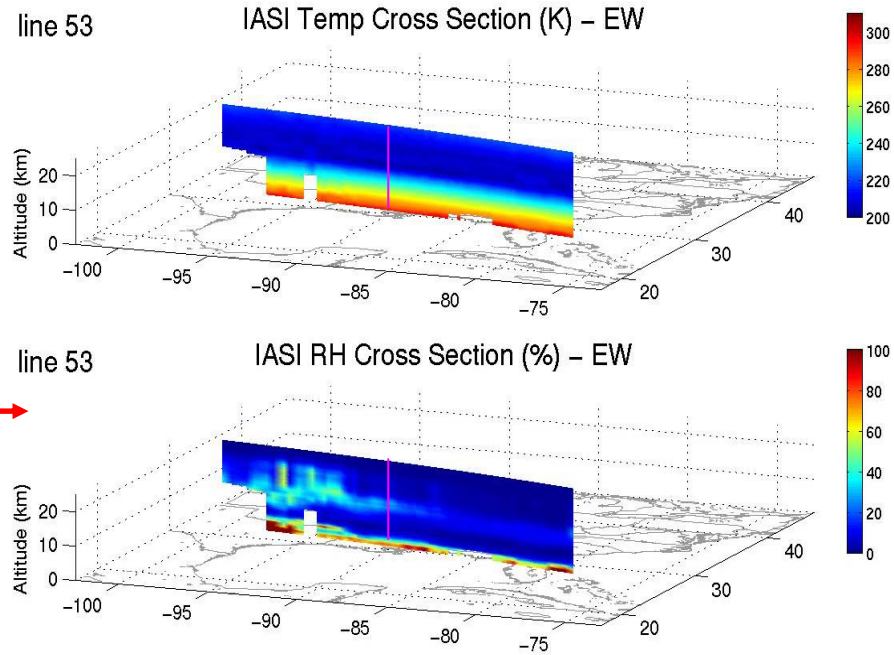
TBL Moisture Variation Captured by IASI



Atmospheric Variation Captured by IASI

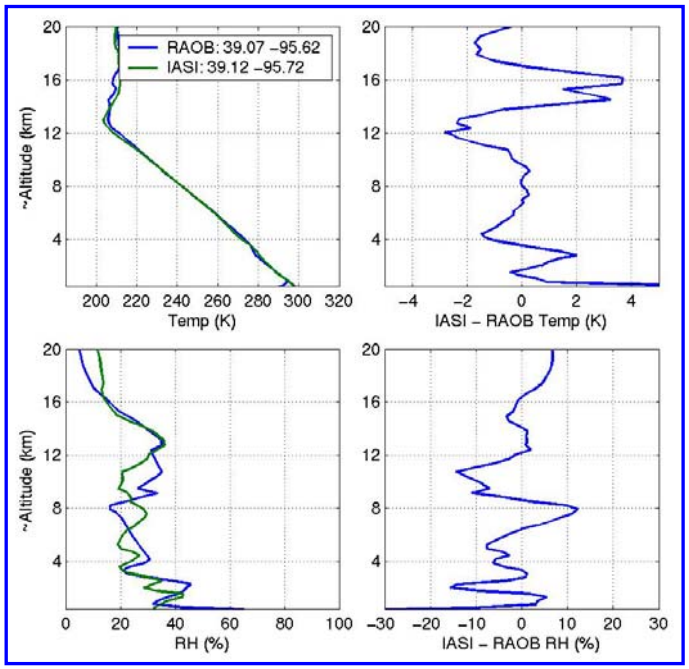


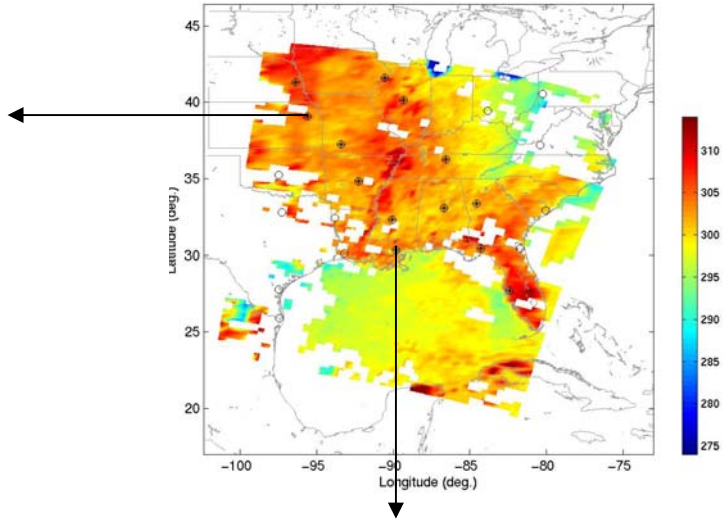


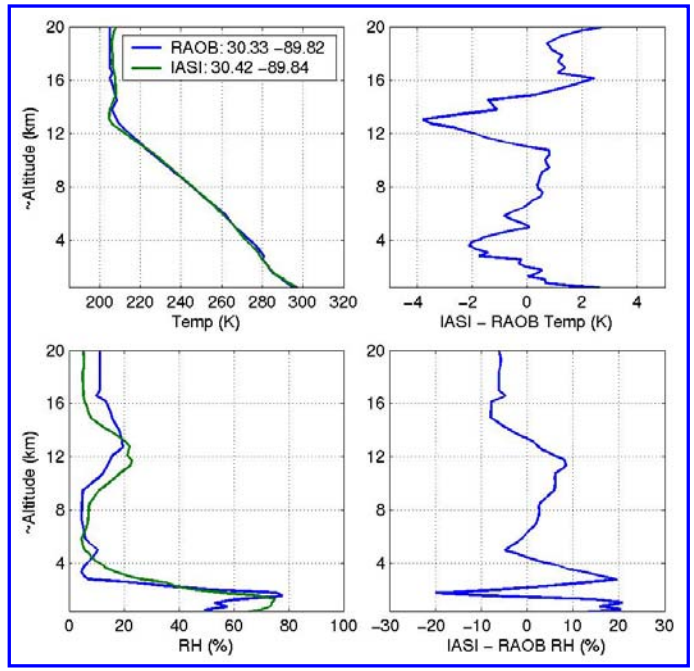


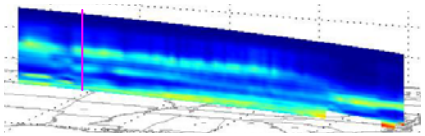
- **High vertically resolved water vapor structure is real.**
- **Location to location variation is captured by IASI retrievals.**

IASI (1545 UTC) vs. Raobs (1200 UTC)

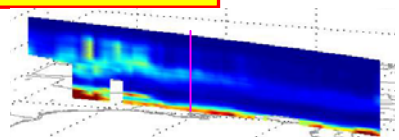




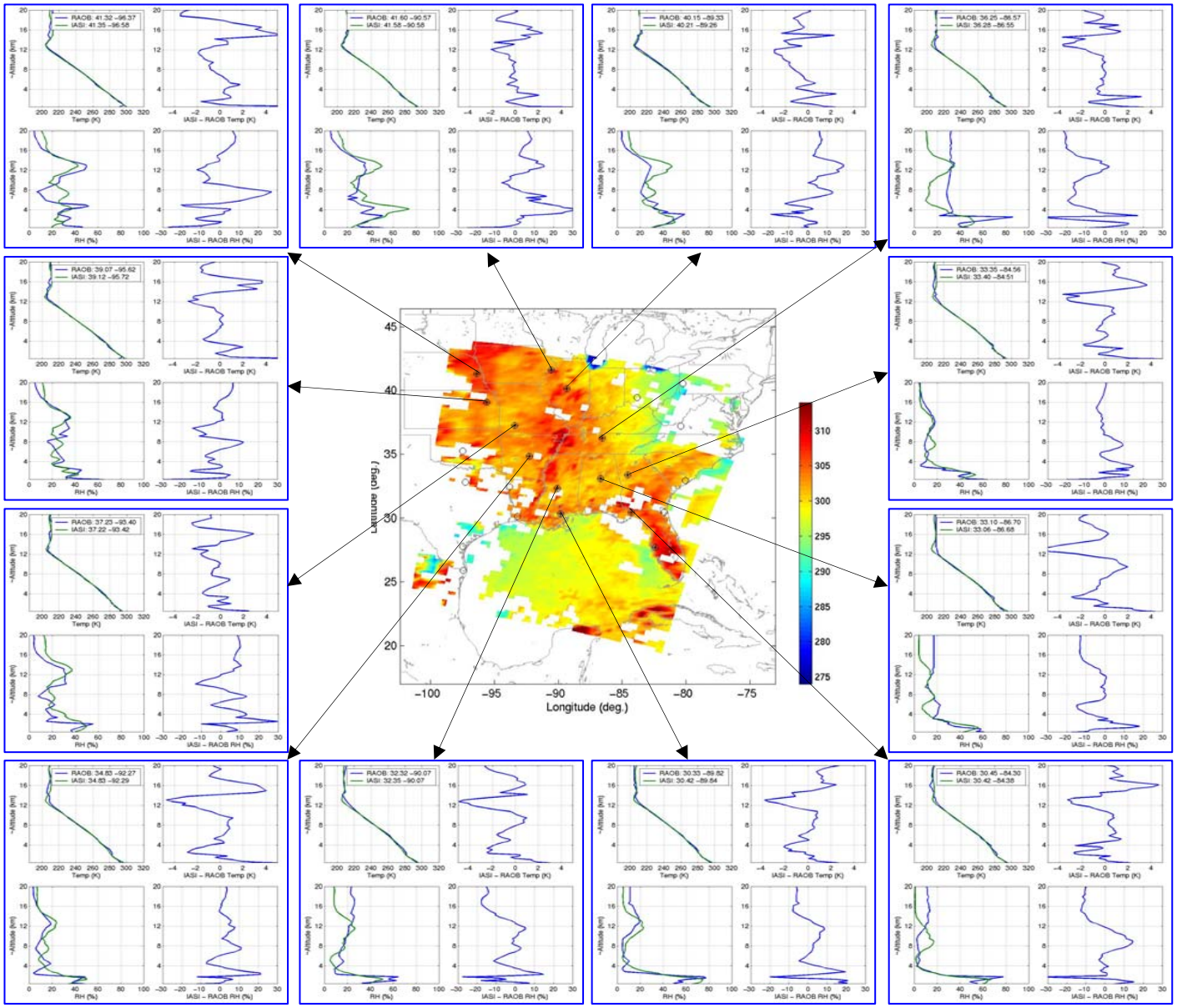




- **High vertically resolved water vapor structure is real.**
- **Location to location variation is captured by IASI retrievals.**

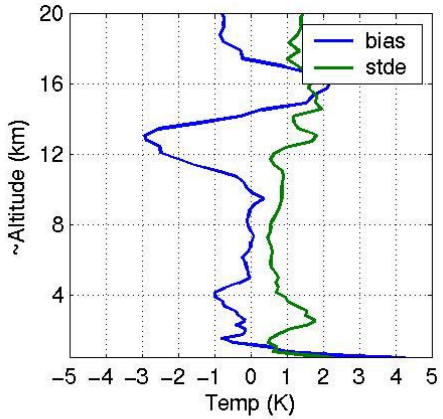


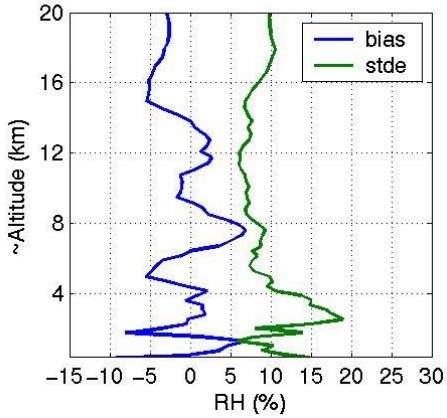
IASI (1545 UTC) vs. Raobs (1200 UTC)



Note:
1200 UTC = 0700 Local
1545 UTC = 1045 Local

Radiosonde and IASI retrieval comparison and statistical profiles over 13 radiosondes



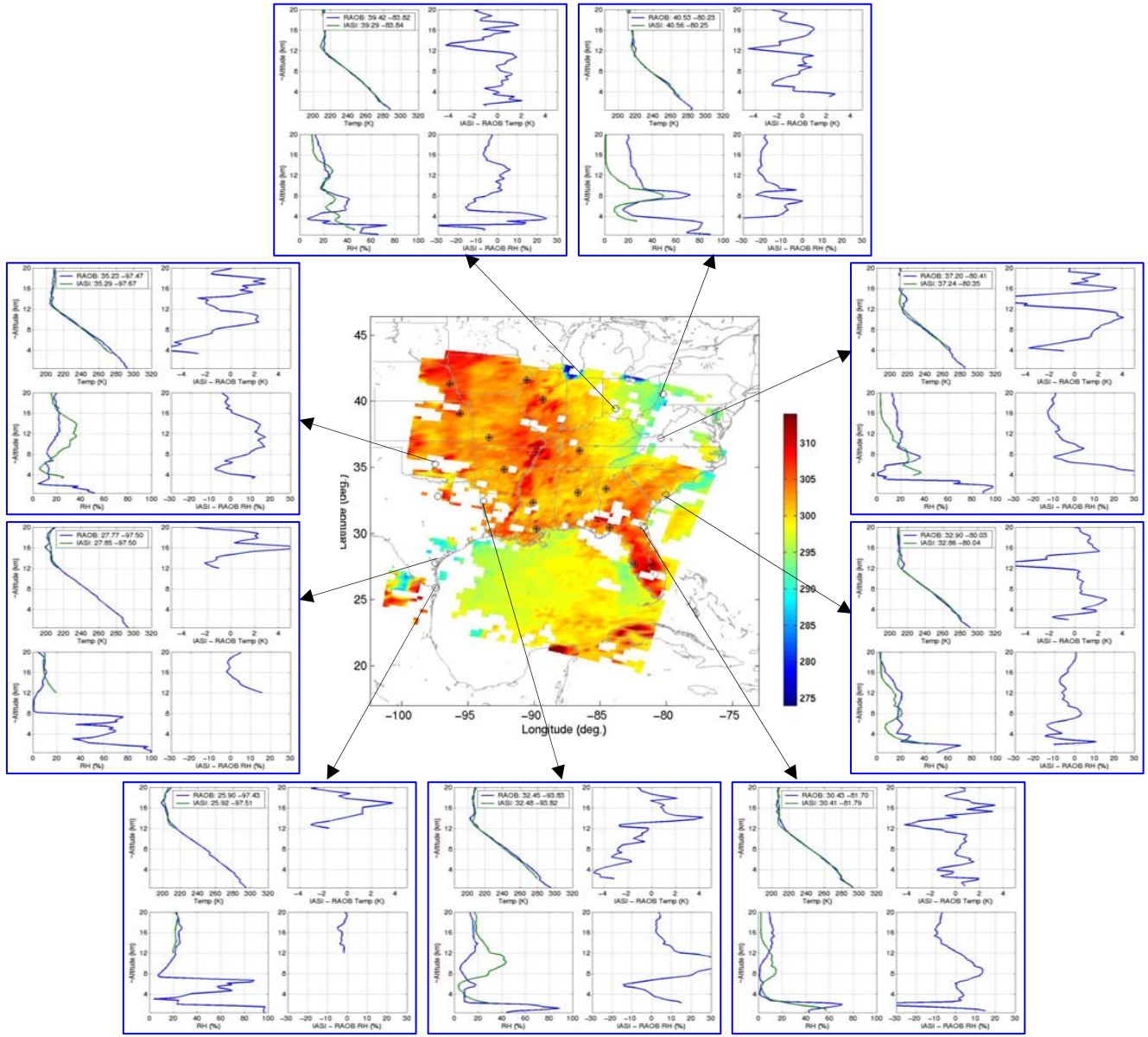


IASI (1545 UTC) vs. Raobs (1200 UTC)

Note:
1200 UTC = 0700 Local
1545 UTC = 1045 Local

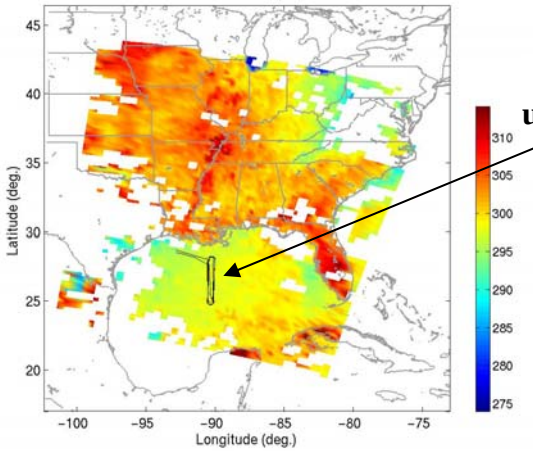
Radiosonde and IASI retrieval comparison over relatively opaque clouds.

Large discrepancy is mainly due to time miss-matching between IASI and radiosonde (cloud is moving).

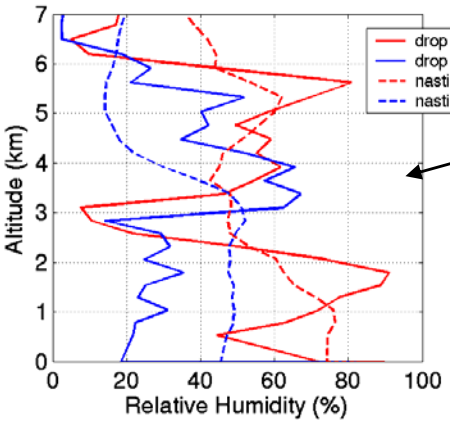


NAST-I Retrievals (4.29.2007; 1530-1930 UTC)

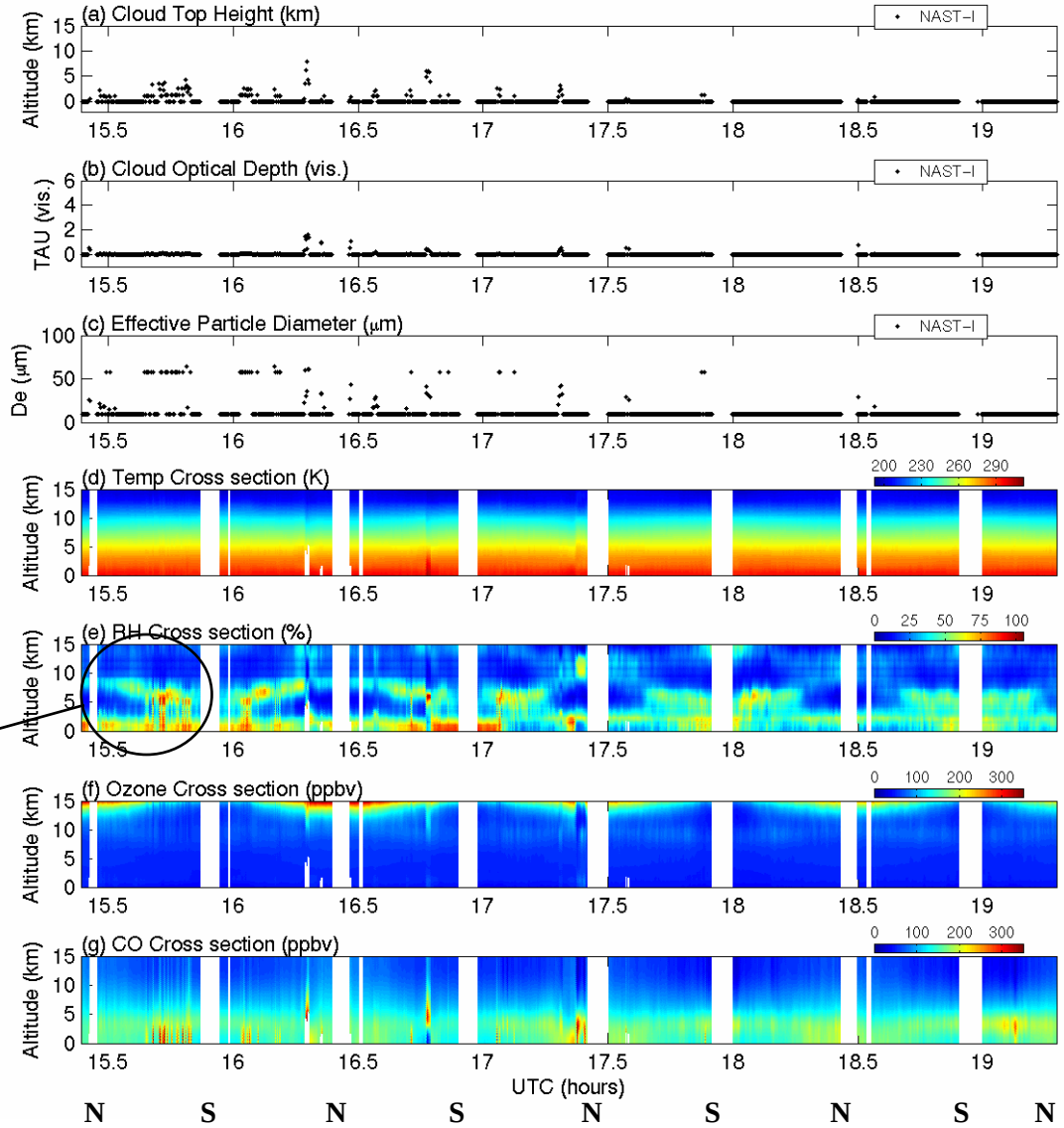
IASI Surf. Temp. (K) at 1545 UTC



BW57/NAST-I under flight Track (15-19 UTC)

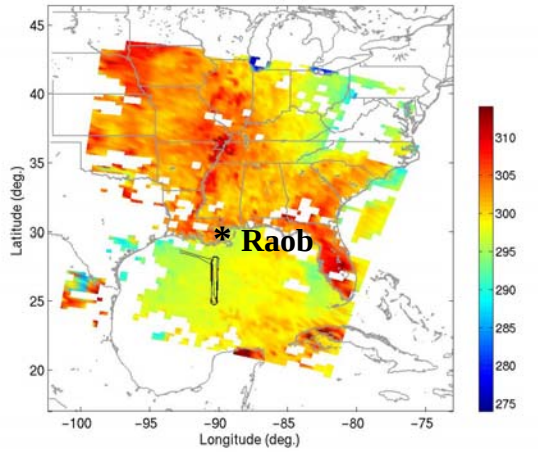


Validation with BAe-146 Dropsondes with higher spatial resolution.

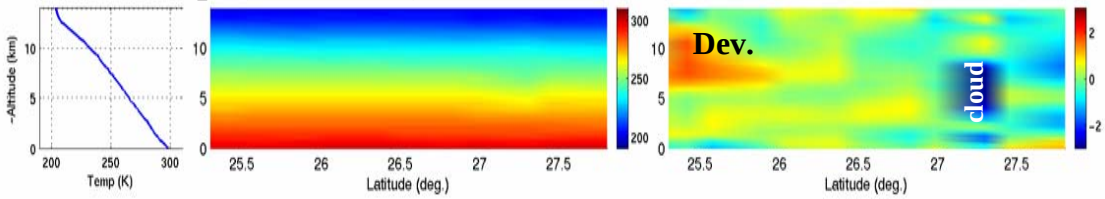


NAST-I vs. IASI (4.29.2007)

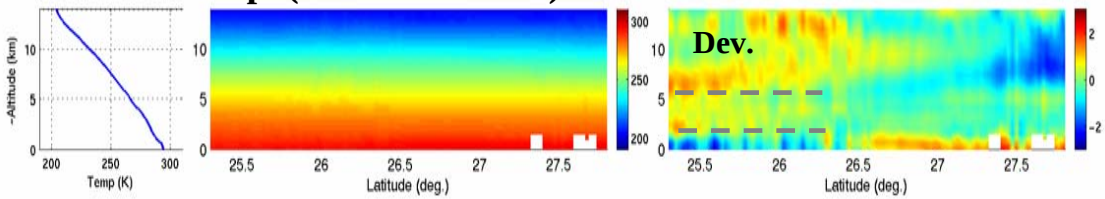
IASI Surf. Temp. (K) at 1545 UTC

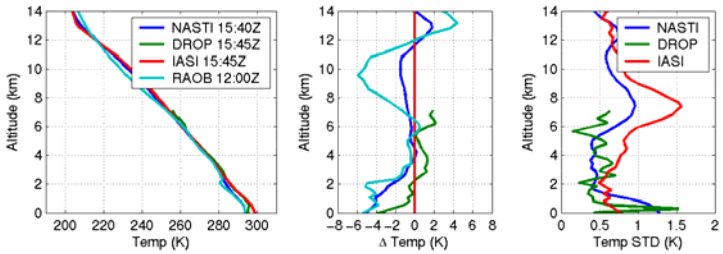


IASI Temp. (1545 UTC)

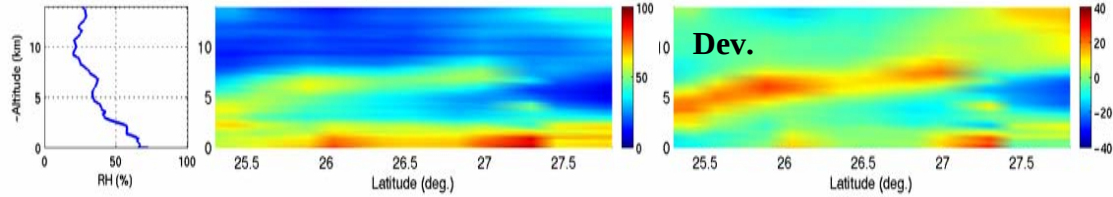


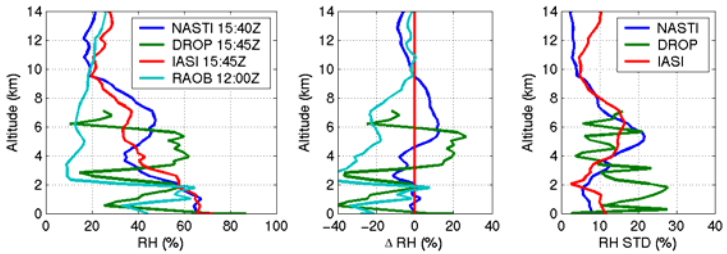
NAST-I Temp. (1530-1600 UTC)



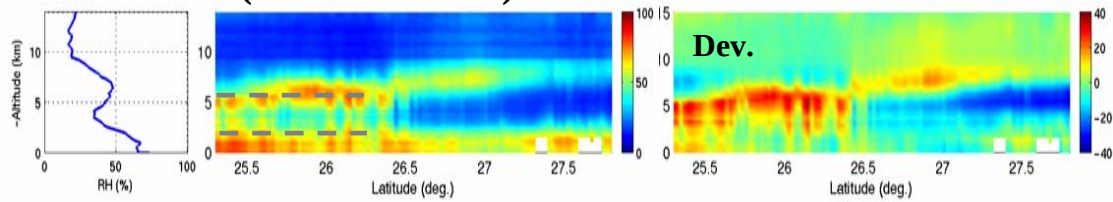


IASI RH (1545 UTC)

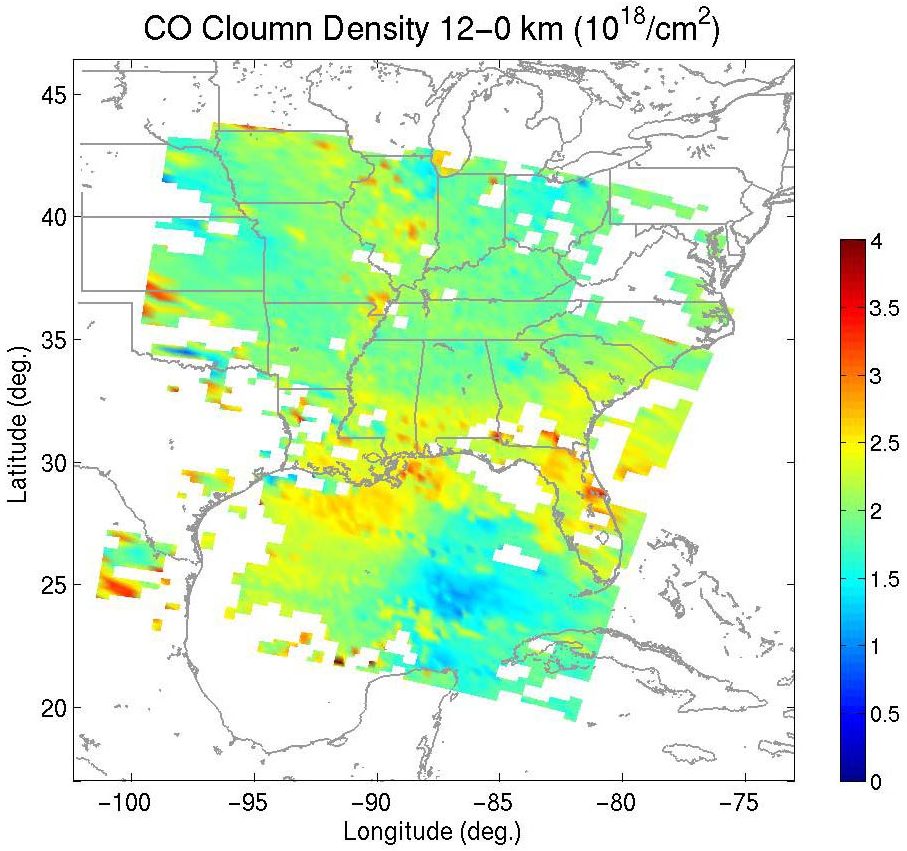


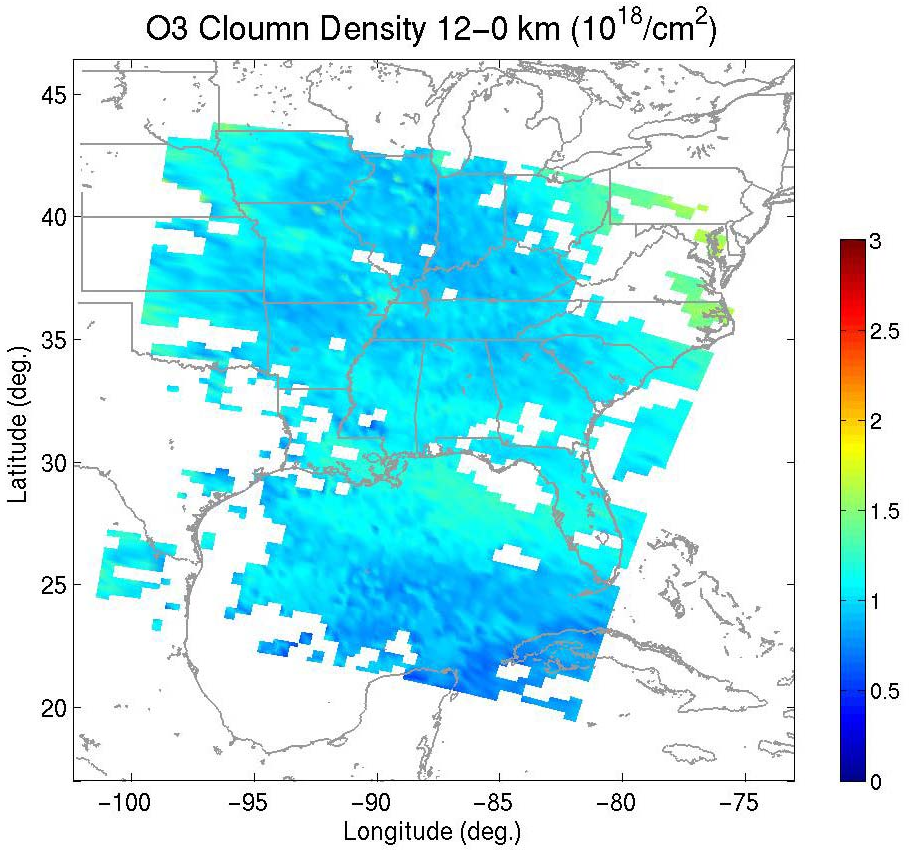


NAST-I RH (1530-1600 UTC)



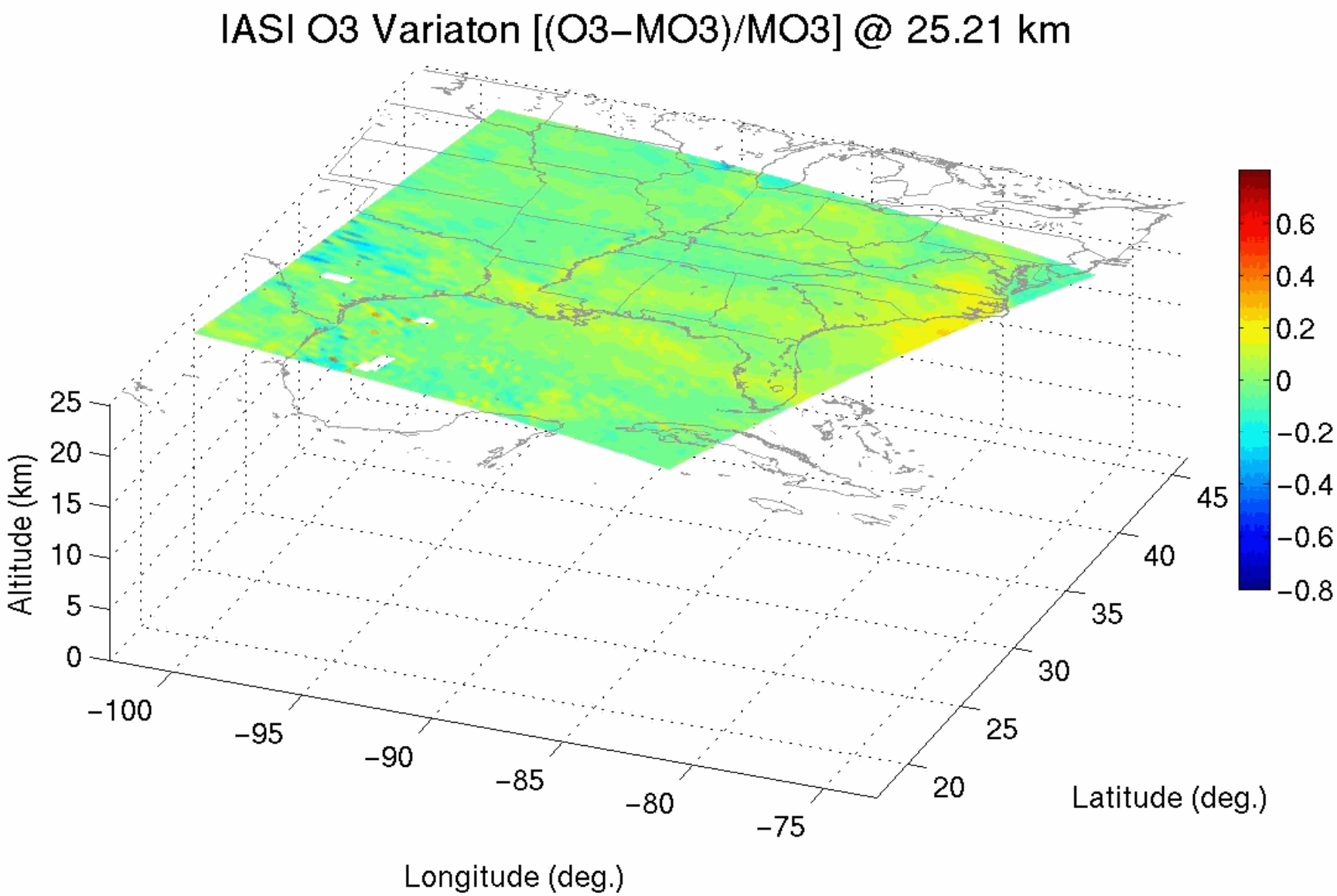
IASI O_3 and CO (4.29.2007)





Atmospheric O_3 and CO column densities are simultaneously retrieved.

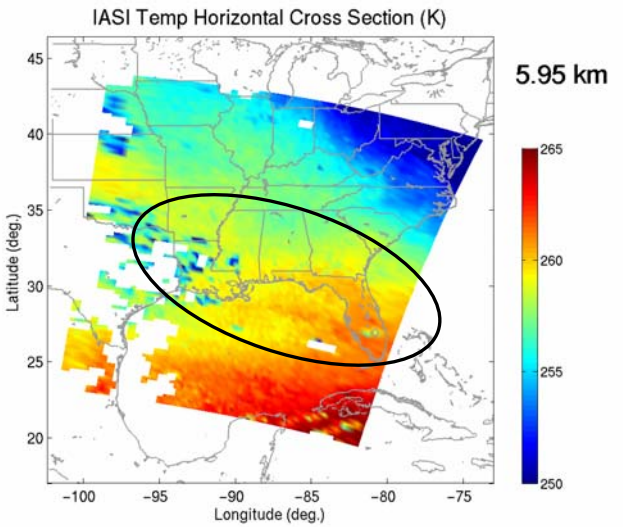
Tropospheric O_3 Variation (4.29.2007)



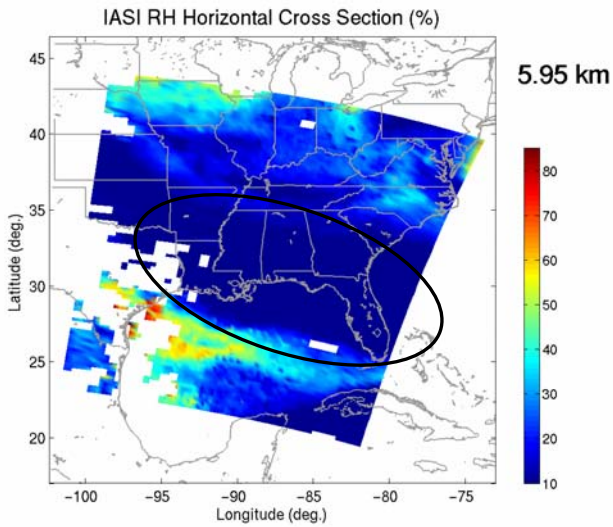
Tropospheric T, RH, and O_3 (4.29.2007)

5.95 km

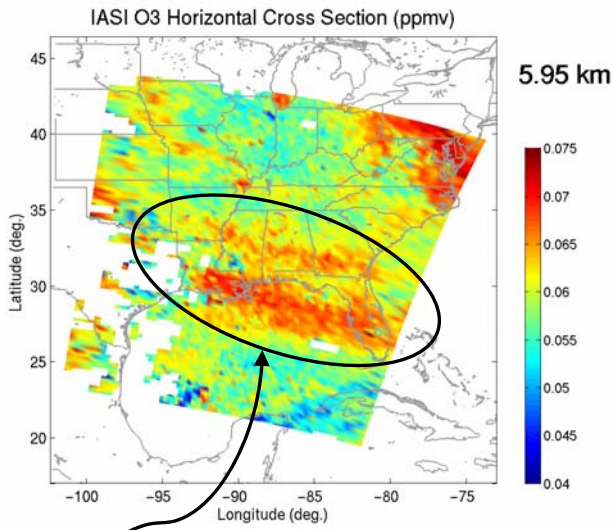
Temp Distribution



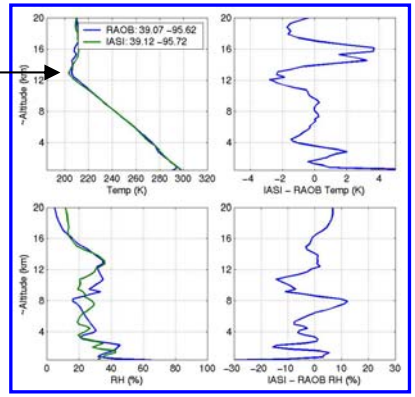
RH Distribution



Ozone Distribution



~12 km →



Tropospheric ozone enhancement

JAIVEx – Joint Airborne IASI Validation Exp.

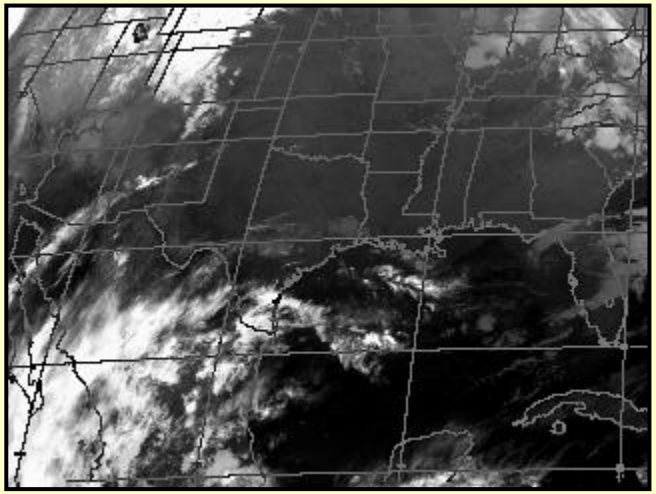
International collaboration to validate radiance and geophysical products obtained by the IASI aboard the MetOp satellite

April 19, 2007:

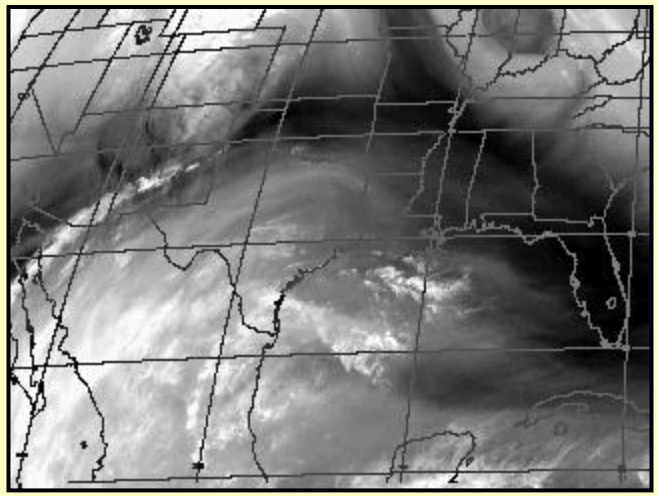
0333 UTC MetOp (IASI)

0310–0510 UTC BW57 (NAST-I) & Bea-146 (*in situ*).

03:32 UTC GOES IR

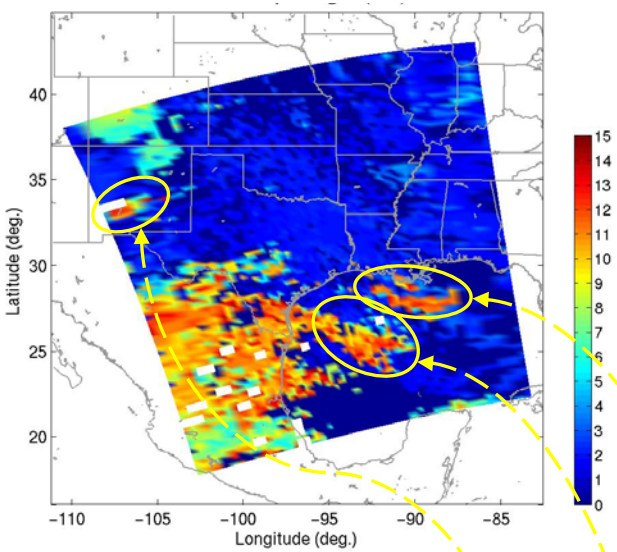


03:32 UTC GOES WV

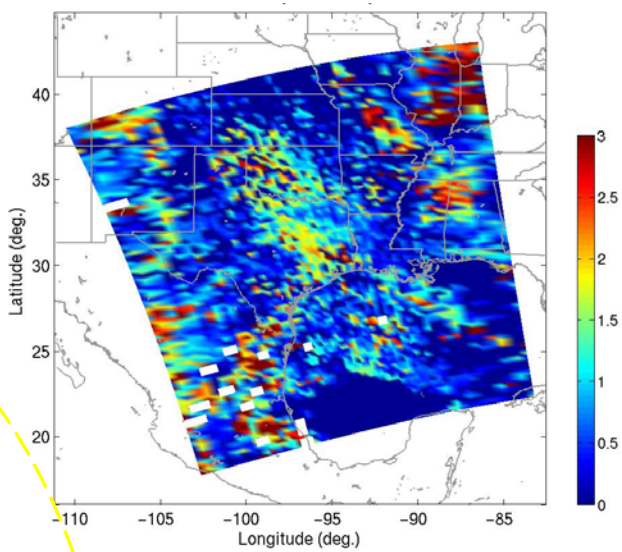


Cloud Properties Retrieved with IASI (4.19.2007)

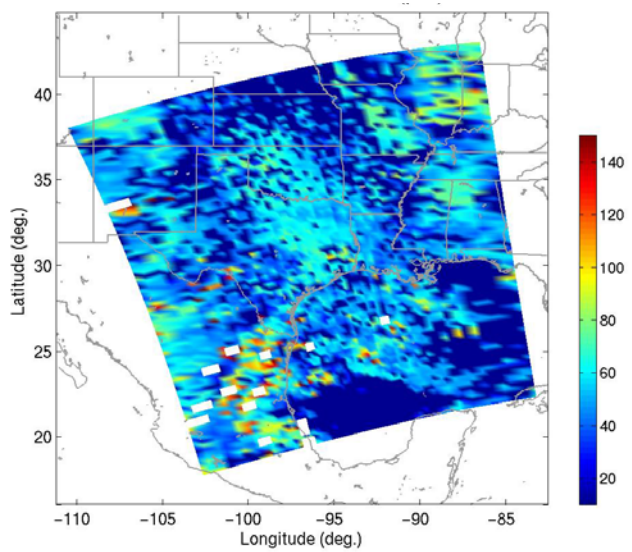
Cloud Top Height (km)

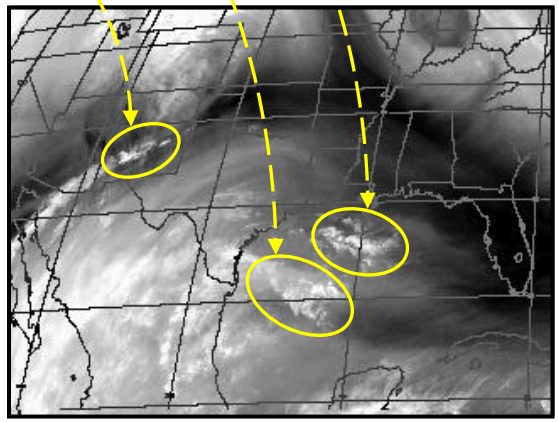


Cloud Optical Depth



Cloud Particle Diameter (μm)

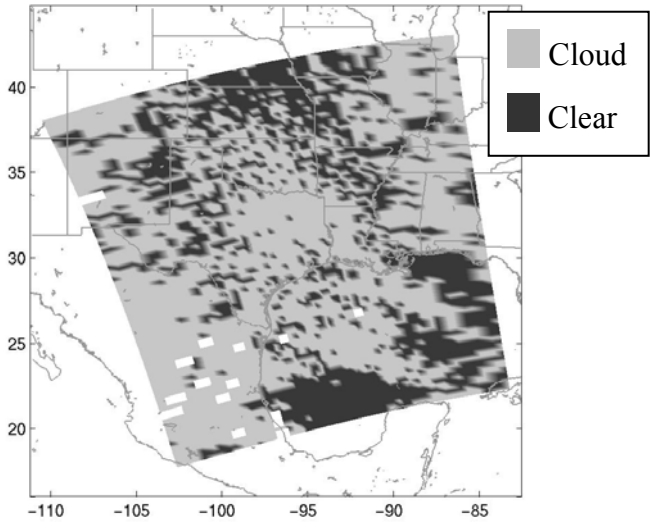




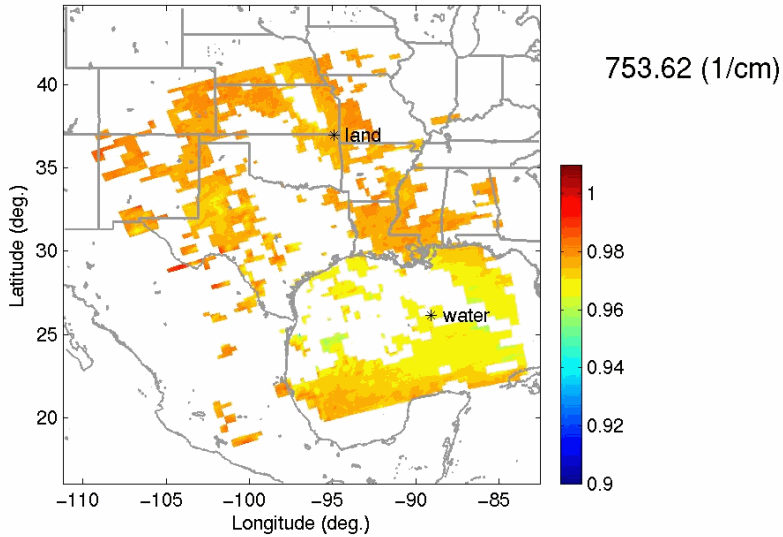
Surf. Emis. Retrieved with IASI (4.19.2007)

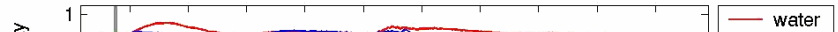
The surface emissivity is one of the key elements for accurately retrieving other thermodynamics parameters.

Surface emissivity as a function of wavenumber.



Retrieved Surf. Skin Temp. (K)



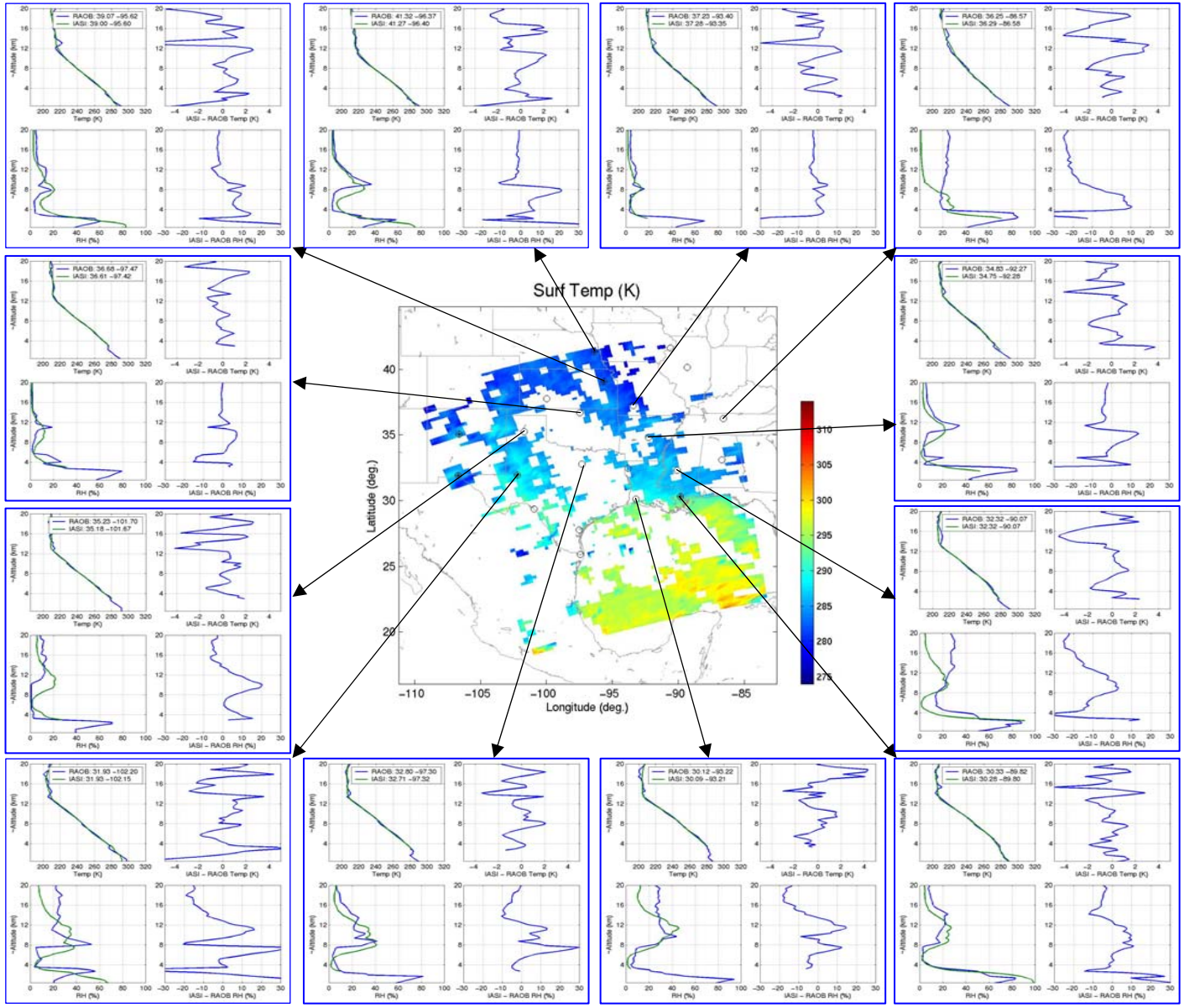


IASI (0333 UTC) vs. Raobs (0000 UTC)

Note:
0000 UTC = 1900 Local
0333 UTC = 2233 Local

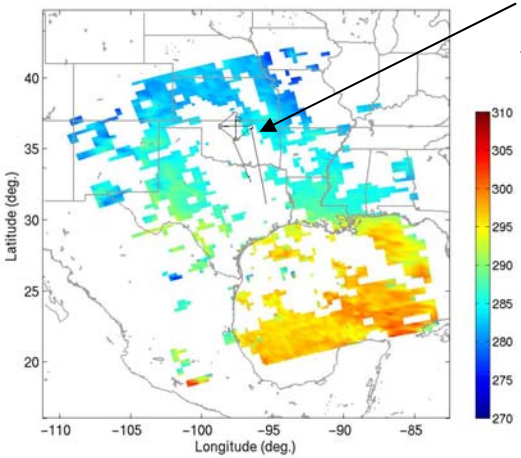
Radiosonde and IASI retrieval comparison over relatively opaque clouds.

Large discrepancy is mainly due to time miss-matching between IASI and radiosonde (cloud is moving).



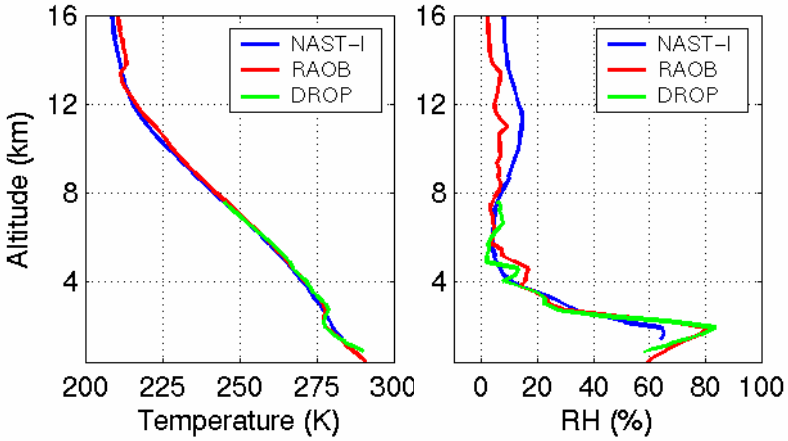
NAST-I Retrievals (4.19.2007; 0310-0510 UTC)

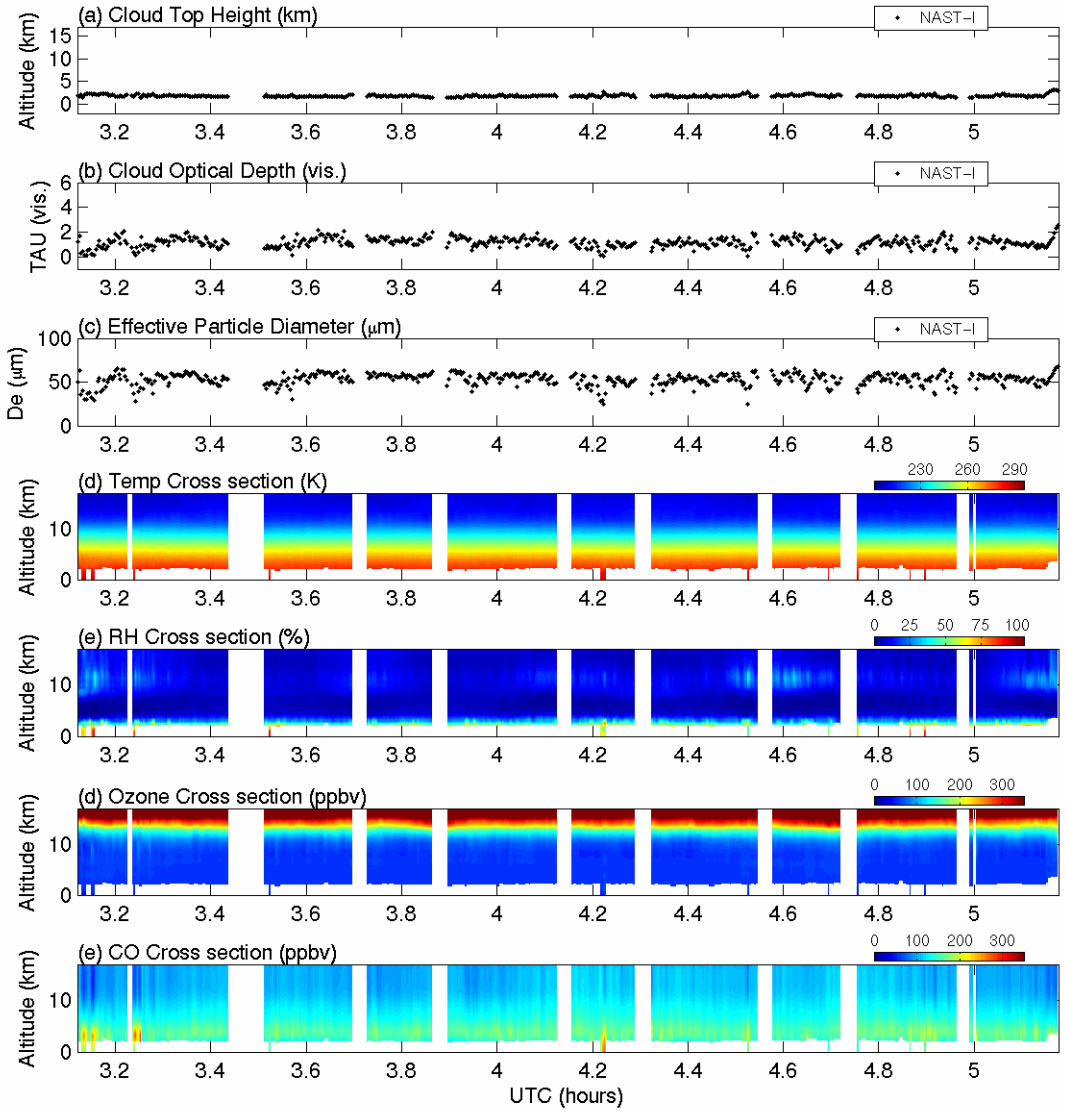
IASI Surf. Temp. (K) at 0333 UTC



BW57/NAST-I under flight Track (15-19 UTC)

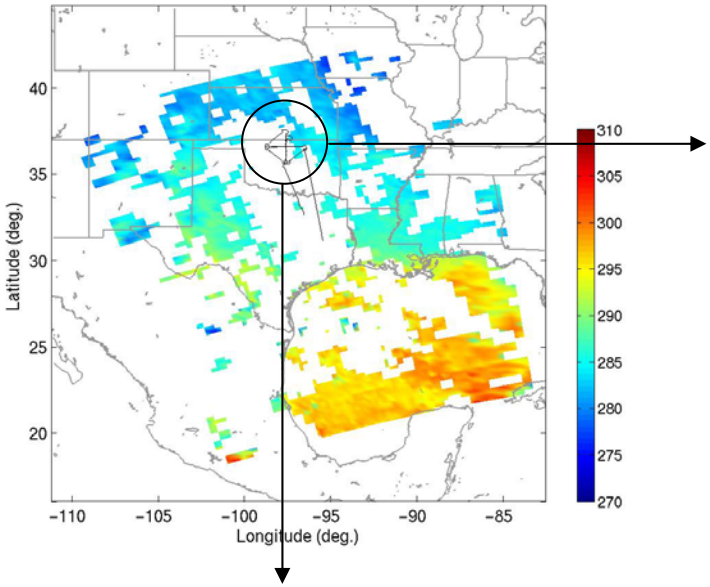
Validation with BAe-146 Dropsondes with higher spatial resolution.

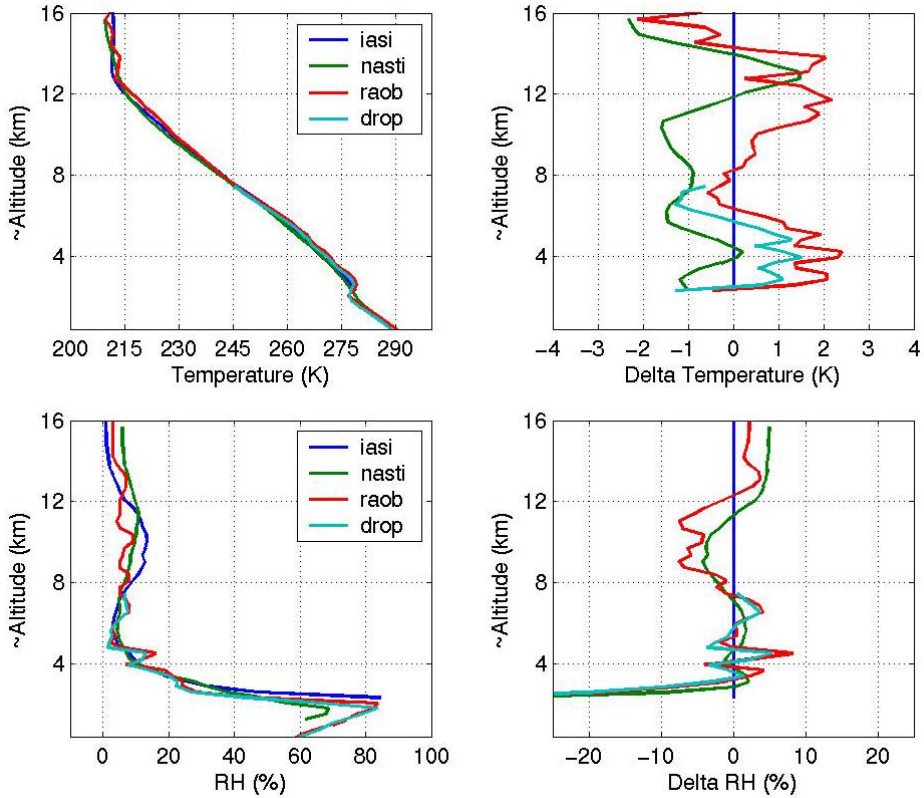




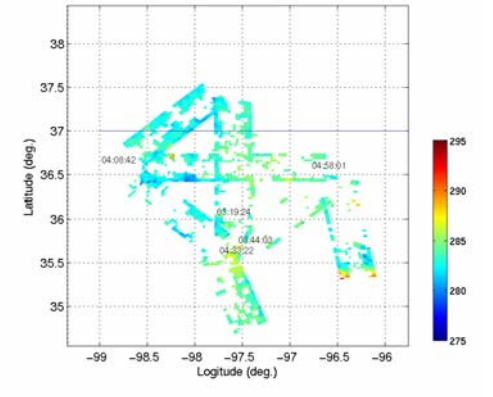
IASI, NAST-I, Radiosonde, and Dropsondes

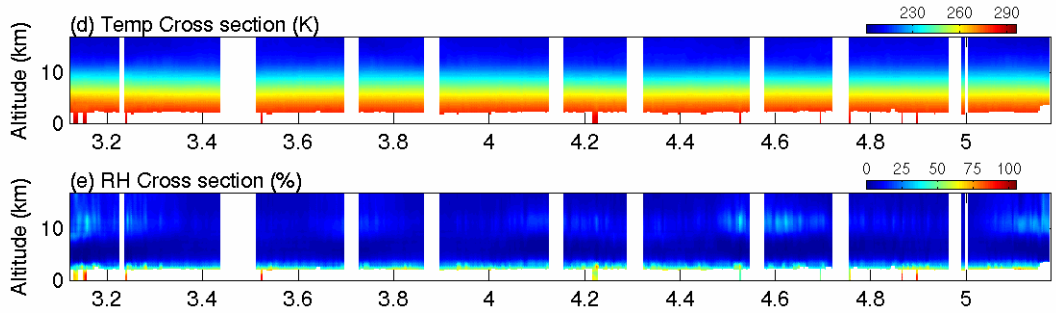
IASI Surf. Temp. (K) at 0333 UTC





NAST-I Surf. Temp. (K) at 0310-0510 UTC

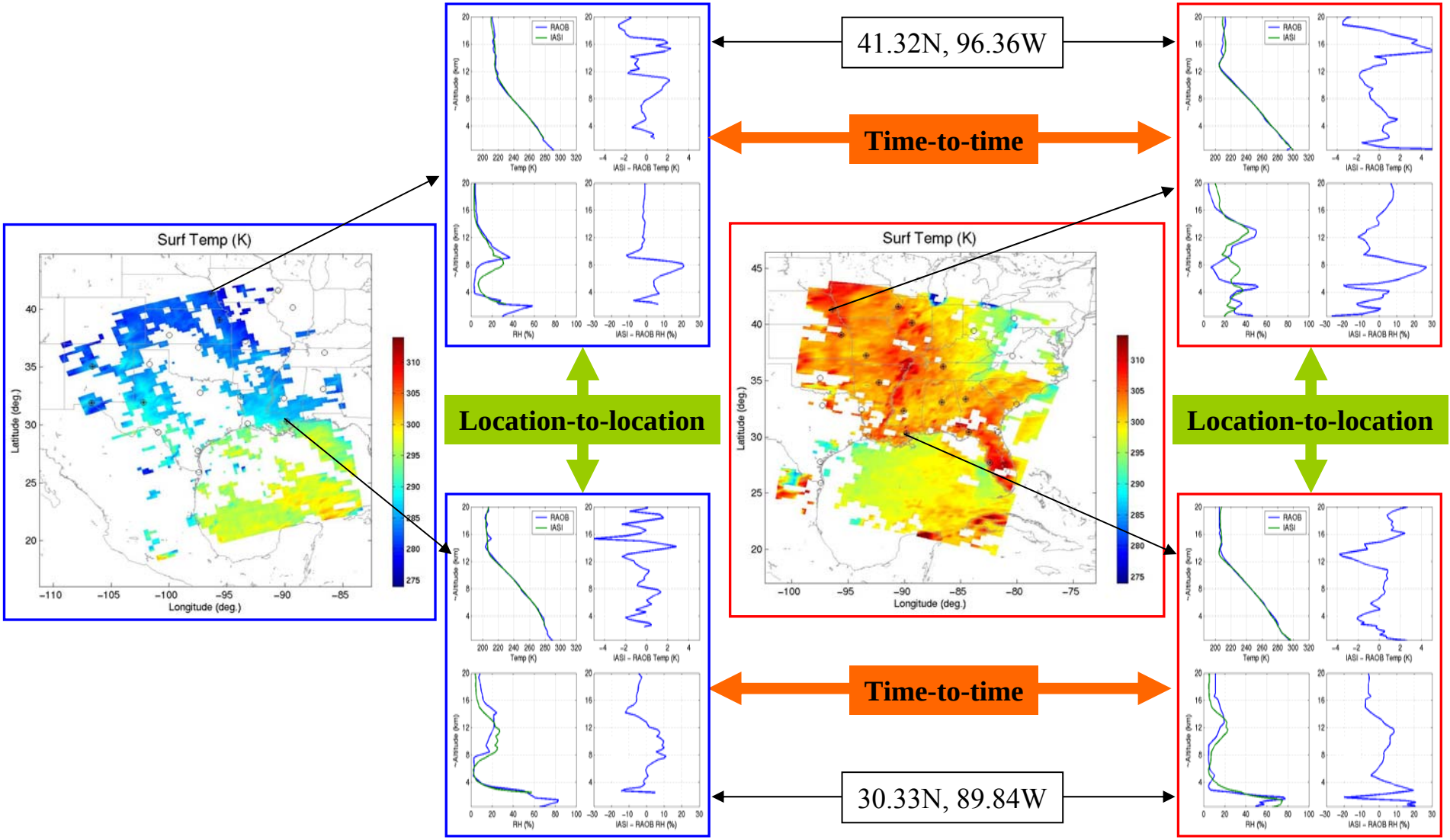




Time-to-Time & Location-to-Location

4.19.2007 (0333Z, 2233 Local)

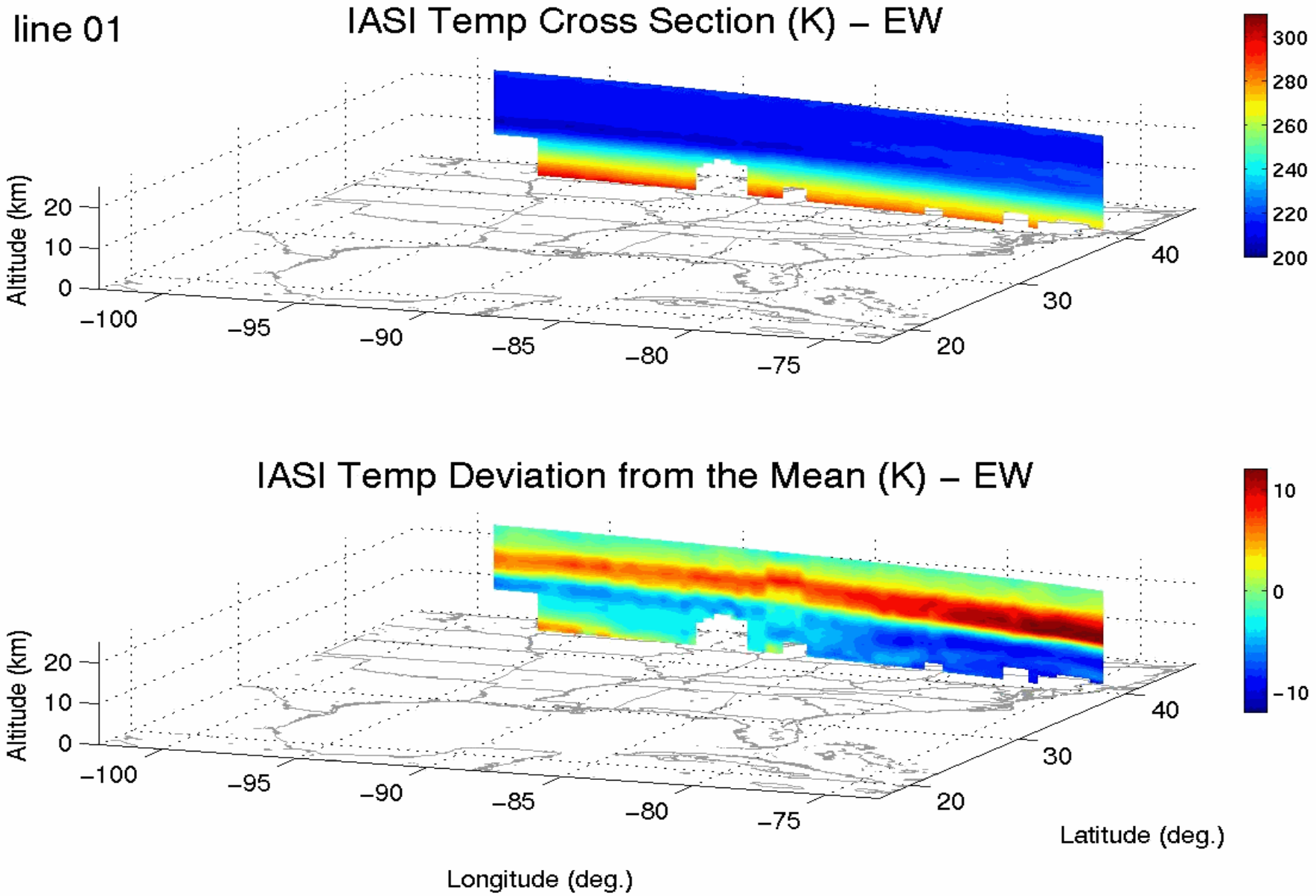
4.29.2007 (1545 Z; 1045 Local)



Conclusion…

1. A state-of-the-art Hybrid Retrieval Algorithm (HRA) has been developed based on NAST-I ultra-spectral measurements. HRA deals with clouds in ultra-spectral observations, and retrieves cloud/surface, and geophysical parameters simultaneously.
2. JAIVEx have served and continue to serve as useful validation data for IASI evaluation and validation.
3. Retrievals have also been achieved from algorithm application to space-based IASI single FOV observations. Surface, cloud, and atmospheric structure and variation are well captured by IASI measurements and/or retrievals.
4. High vertically resolved atmospheric structure is revealed with IASI retrievals. IASI temperature and moisture profile accuracy is within 1 K (per 1 km) and 10% (per 2 km), respectively (*preliminary*). Additional validation analyses are needed to provide more-definitive conclusions.
5. Research with cloud radiative transfer model and retrieval algorithm will continue to provide more accurate and efficient algorithms for ultra-spectral instrument.

Thanks to IASI!



Thank you for your time!