Retrieval with Infrared Atmospheric Sounding Interferometer and validation during JAIVEx

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Outline

1. LaRC IR-only Retrieval Algorithm Introduction
2. Retrieval Demonstration: Global and Regional Cases
3. Validation with Radiosondes and Dropsondes
4. IASI, AIRS, and NAST-I Inter-comparison
5. Summary and Future Work

LaRC IR Retrieval Algorithm

PART A: REGRESSION RETRIEVAL (Zhou et al., GRL 2005)

Using an all-seasonal-global training database to diagnose 0-2 cloud layers from training relative humidity profile:

A single cloud layer is inserted into the input training profile. Approximate lower level cloud using opaque cloud representation.

Use parameterization of balloon and aircraft cloud microphysical data base to specify cloud effective particle diameter and cloud optical depth:

Different cloud microphysical properties are simulated for same training profile using random number generator to specify visible cloud optical depth within a reasonable range. Different habitats can be specified (Hexagonal columns assumed here).

Use LBLRTM/DISORT "lookup table" to specify cloud radiative properties:

Spectral transmittance and reflectance for ice and liquid clouds interpolated from multi-dimensional look-up table based on DISORT multiple scattering calculations.

Compute EOFs and Regressions from clear, cloudy, and mixed radiance data base:

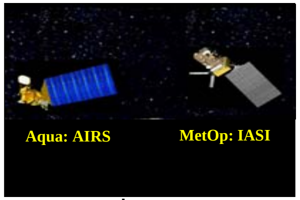
Regress cloud, surface properties & atmospheric profile parameters against radiance EOFs.

PART B: 1-D VAR. PHYSICAL RETRIEVAL (Zhou et al., JAS 2007)

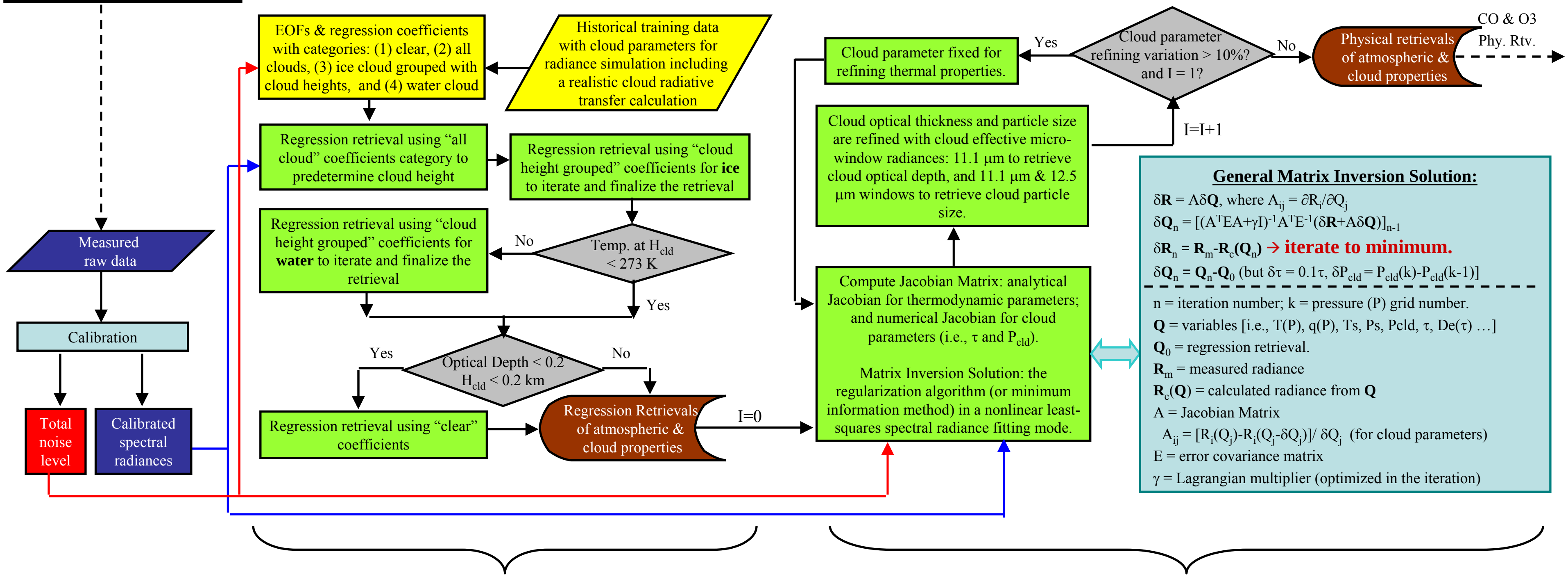
A one-dimensional (1-d) variational solution with the regularization algorithm (i.e., the minimum information method) is chosen for physical retrieval methodology which uses the regression solution as the initial guess.

Cloud optical/microphysical parameters, namely effective particle diameter and visible optical thickness, are further refined with the radiances observed within the 10.4 μm to 12.5 μm window region.

LaRC Algorithm Flowchart



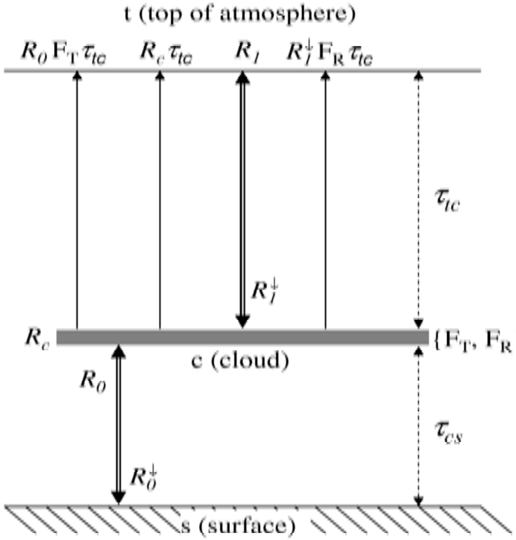
Hybrid Retrieval Algorithm Flowchart



Statistical EOF Physical Regressions

Simultaneous 1-D Var. Iterative Matrix Inversion

Radiative Transfer Model (include clouds)



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

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

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

$$R_c = \left(1 - \mathrm{F_R} - \mathrm{F_T}\right)\mathrm{B}(T_c)$$

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

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

- 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

EOF Physical Regression Inversion

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

and

2 other classes for which the cloud phase has been stratified to liquid and ice.

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

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

$$\mathrm{C_i} = \sum_{\mathrm{j=1}}^{\mathrm{nc}} \mathrm{R_j E_{ji}}$$

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

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

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)

1-D Var. Physical Iterative Retrieval

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

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

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

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

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

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

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

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

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

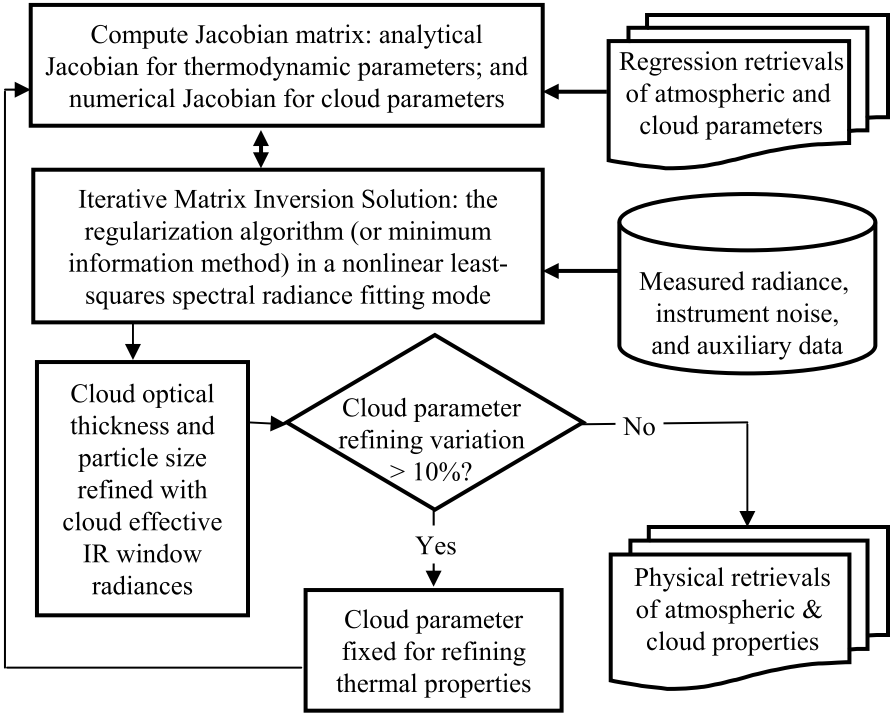
each iteration by satisfying the following conditions:

$$\mathrm{q}_1 = 1.0;$$

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

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

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



Y = calculated Radiance

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

Y^m = observed Radiance

J = "Penalty function"

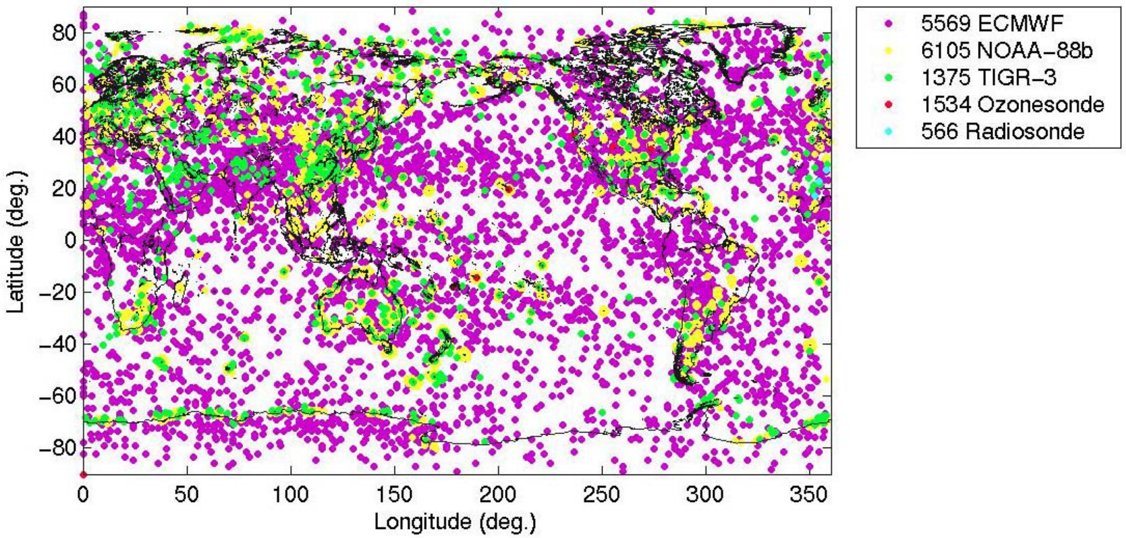
σ = total noise

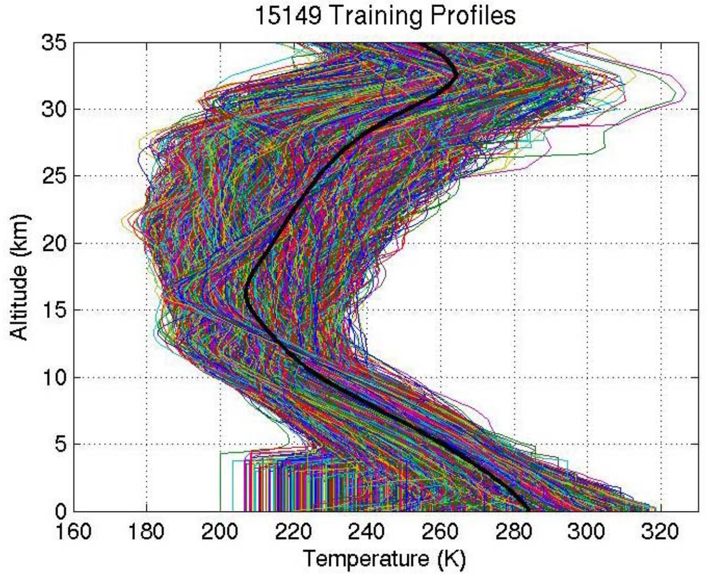
E = error covariance matrix

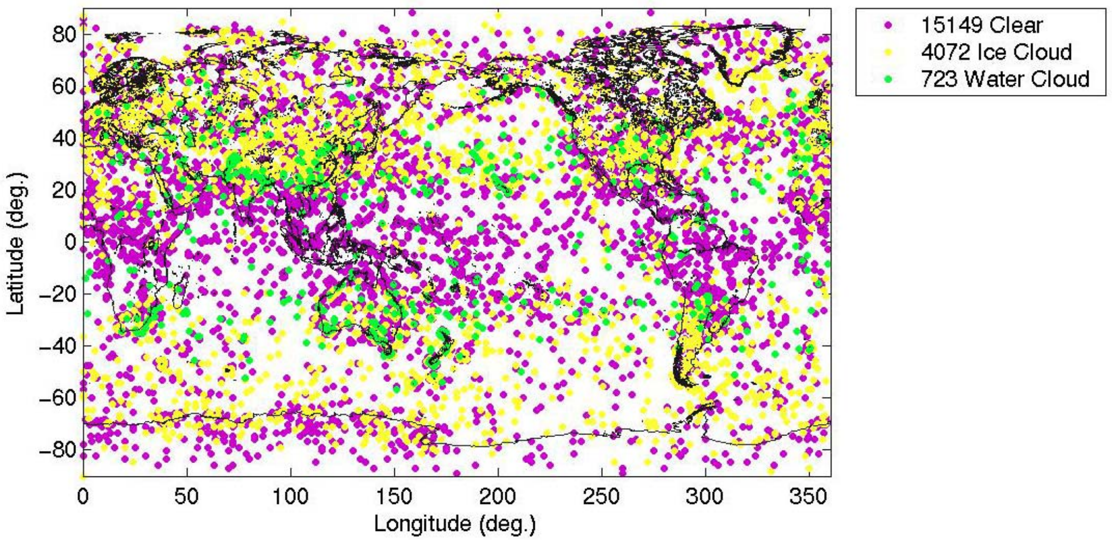
γ = a smoothing factor

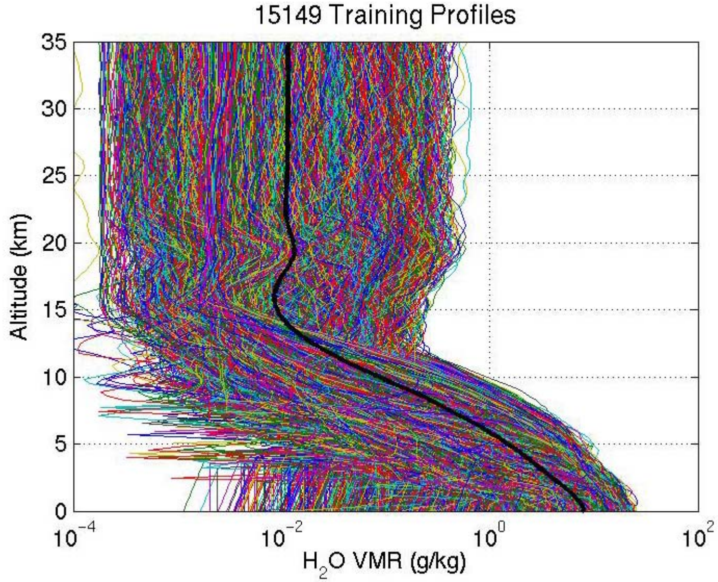
n = iteration number

Global Training for LaRC Algorithm



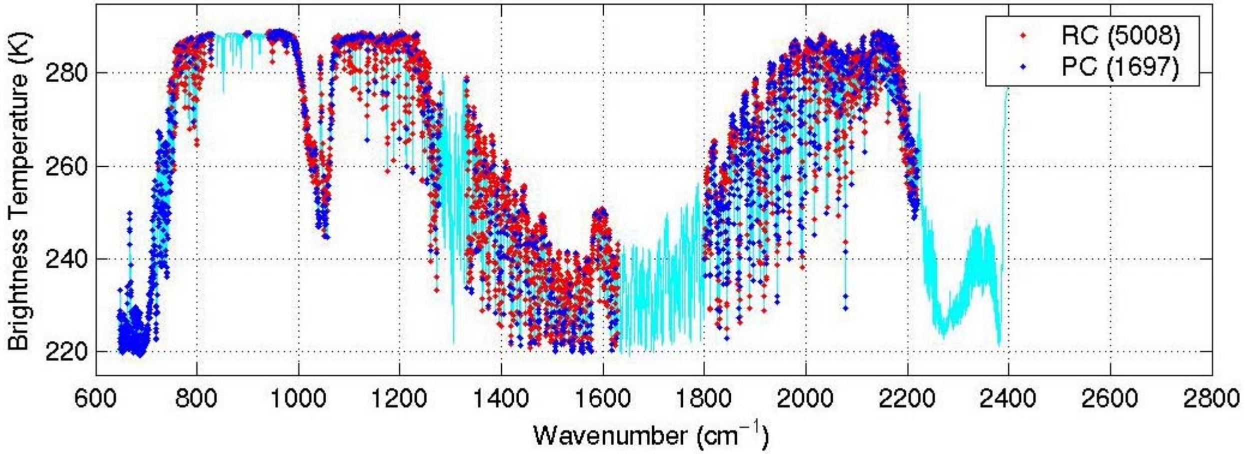




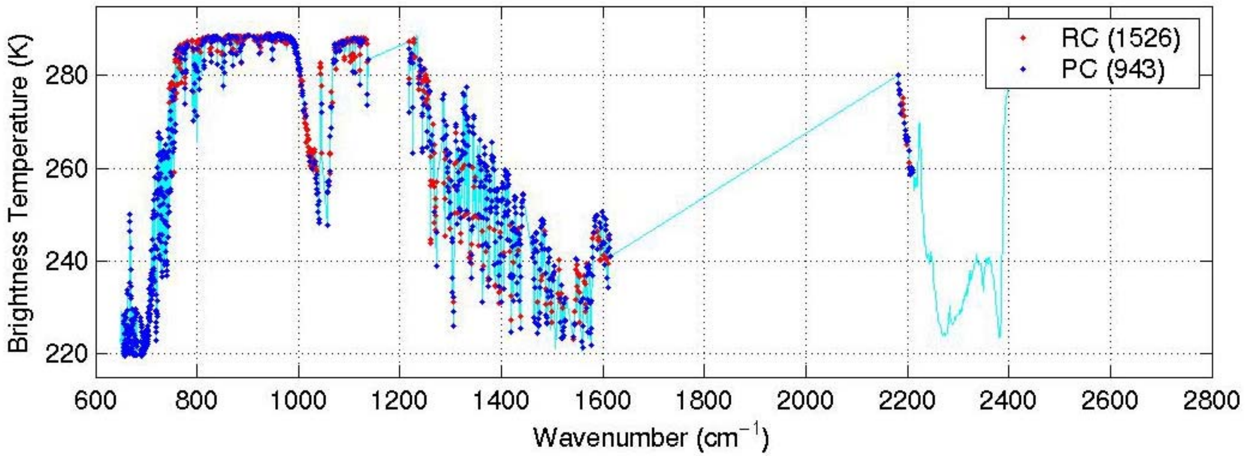


Channel Used in LaRC Retrieval Algorithm

IASI: 5008 channels for regression, 1697 channels for physical retrieval

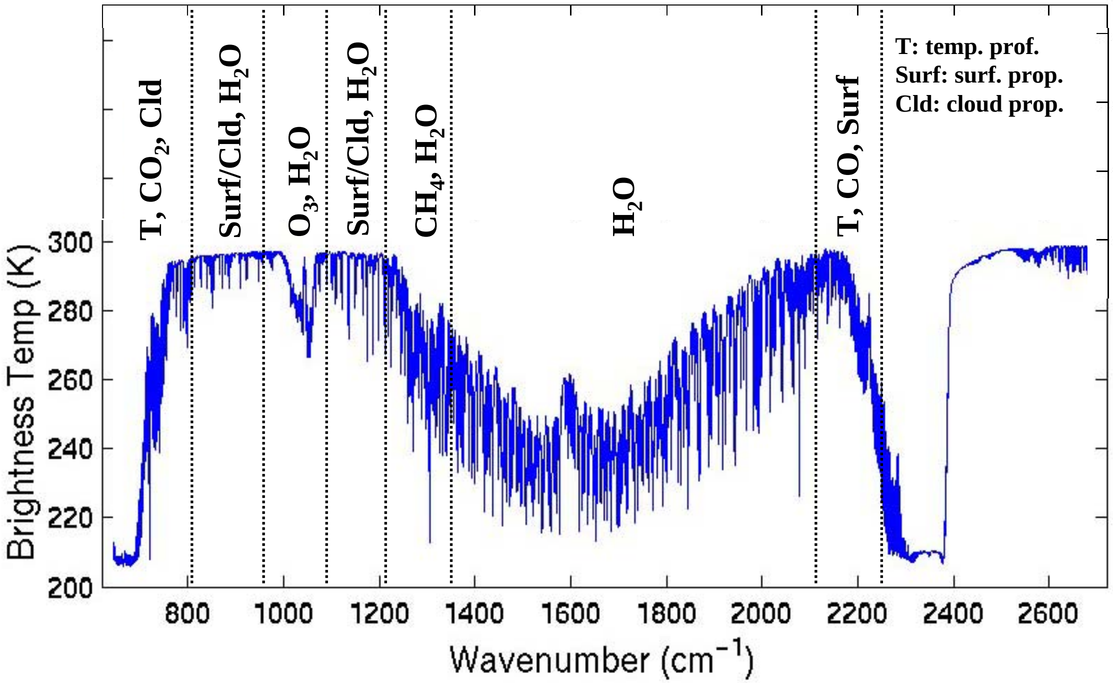


AIRS: 1526 channels for regression, 943 channels for physical retrieval

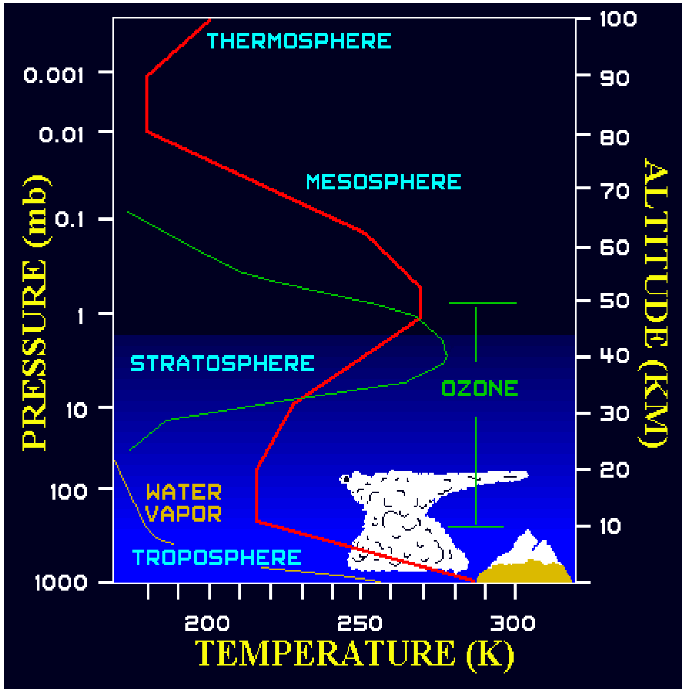


Retrieval Parameters from this System

Brightness Temperature or Radiance Spectrum



Geophysical Parameters



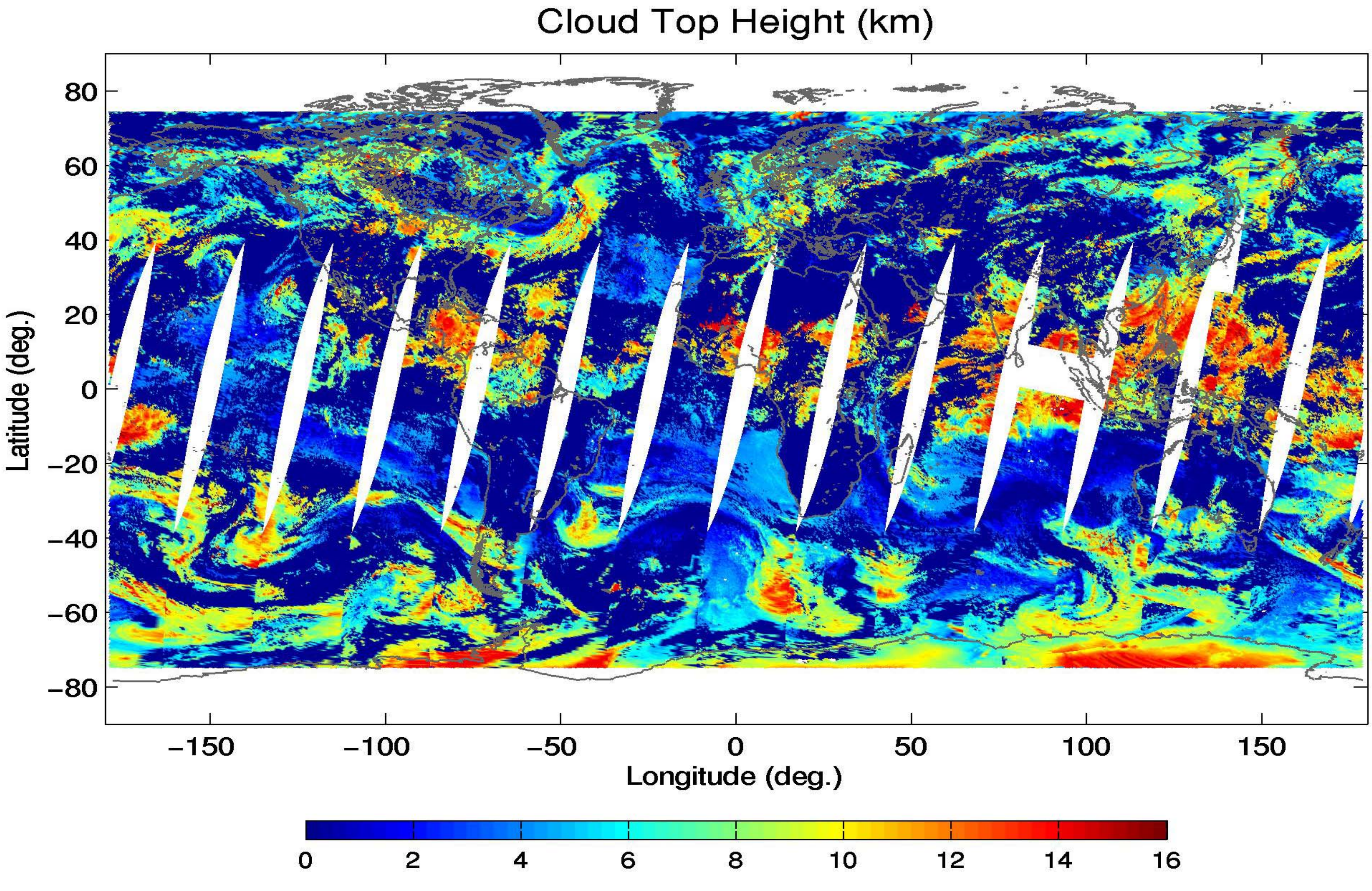
Retrievals under clear conditions:

- Surface properties (skin temp and emissivity).
- Atmospheric temperature and moisture profiles.
- Atmospheric CO and O_3 abundances.

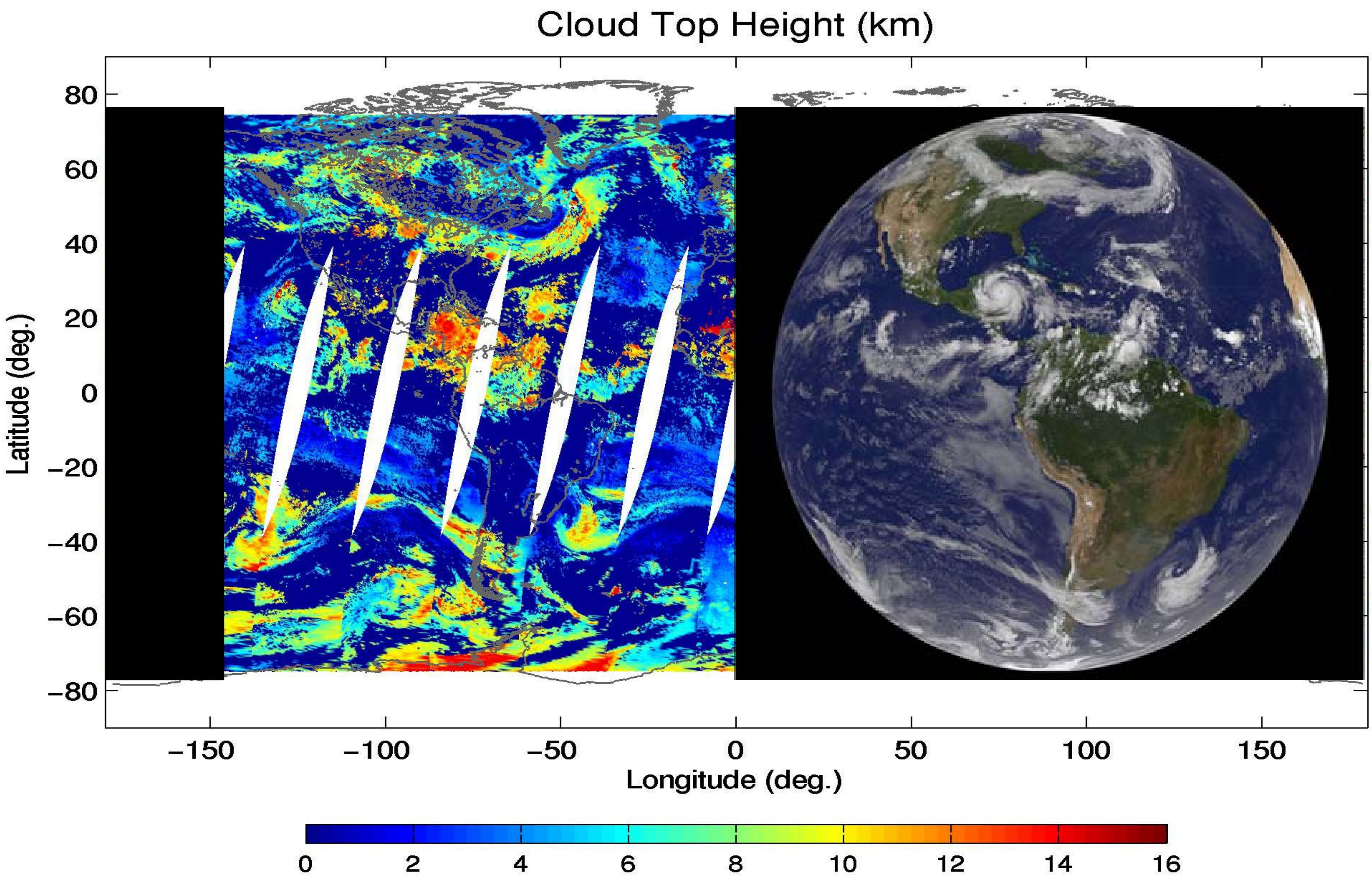
Retrievals under cloudy conditions:

- Atmospheric profile through optically thin cirrus clouds and above optically thick clouds.
- Effective cloud parameters (i.e., cloud top pressure, particle size, and optical depth).

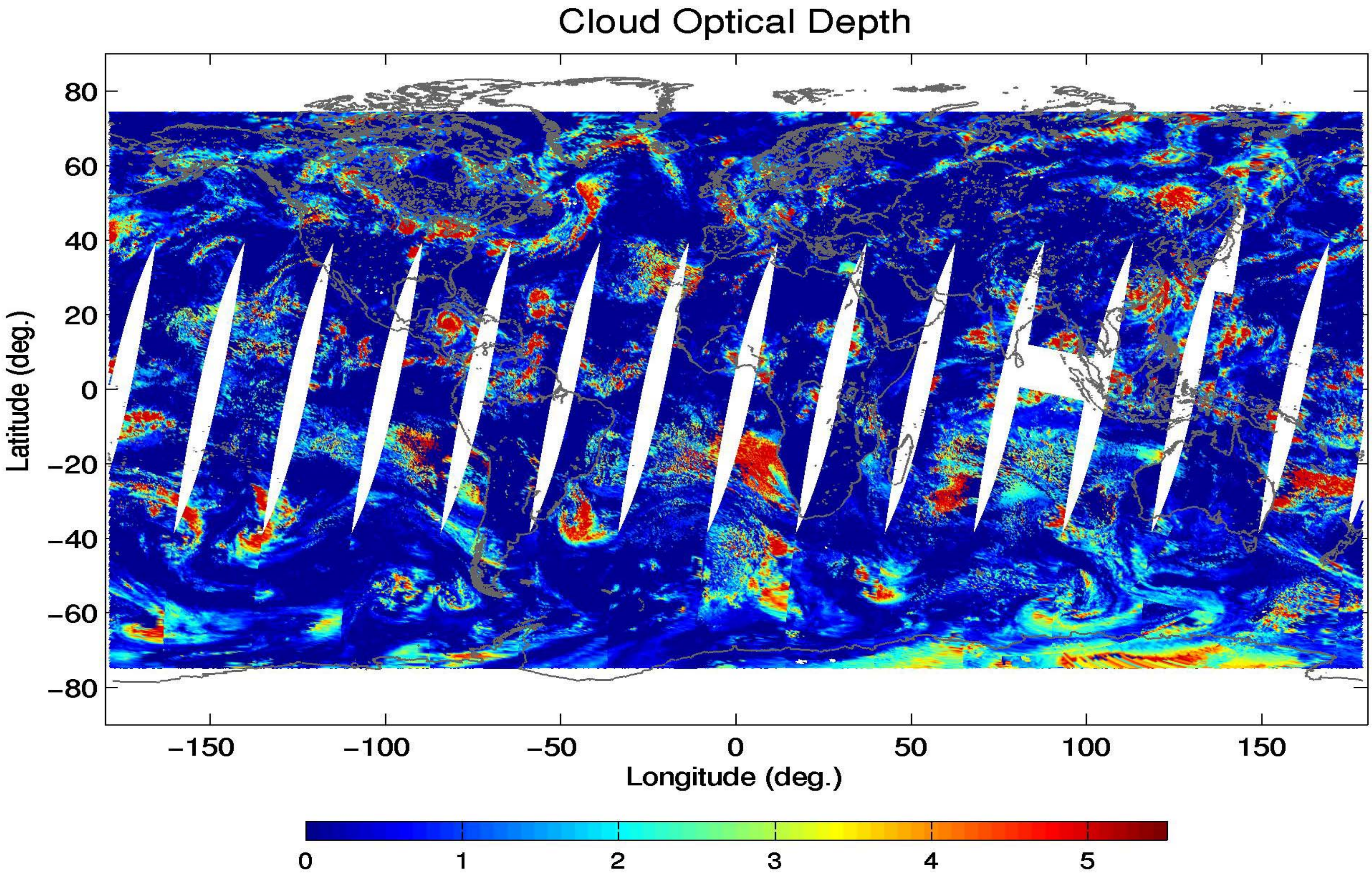
IASI Retrieval Demo: Cloud Top Height



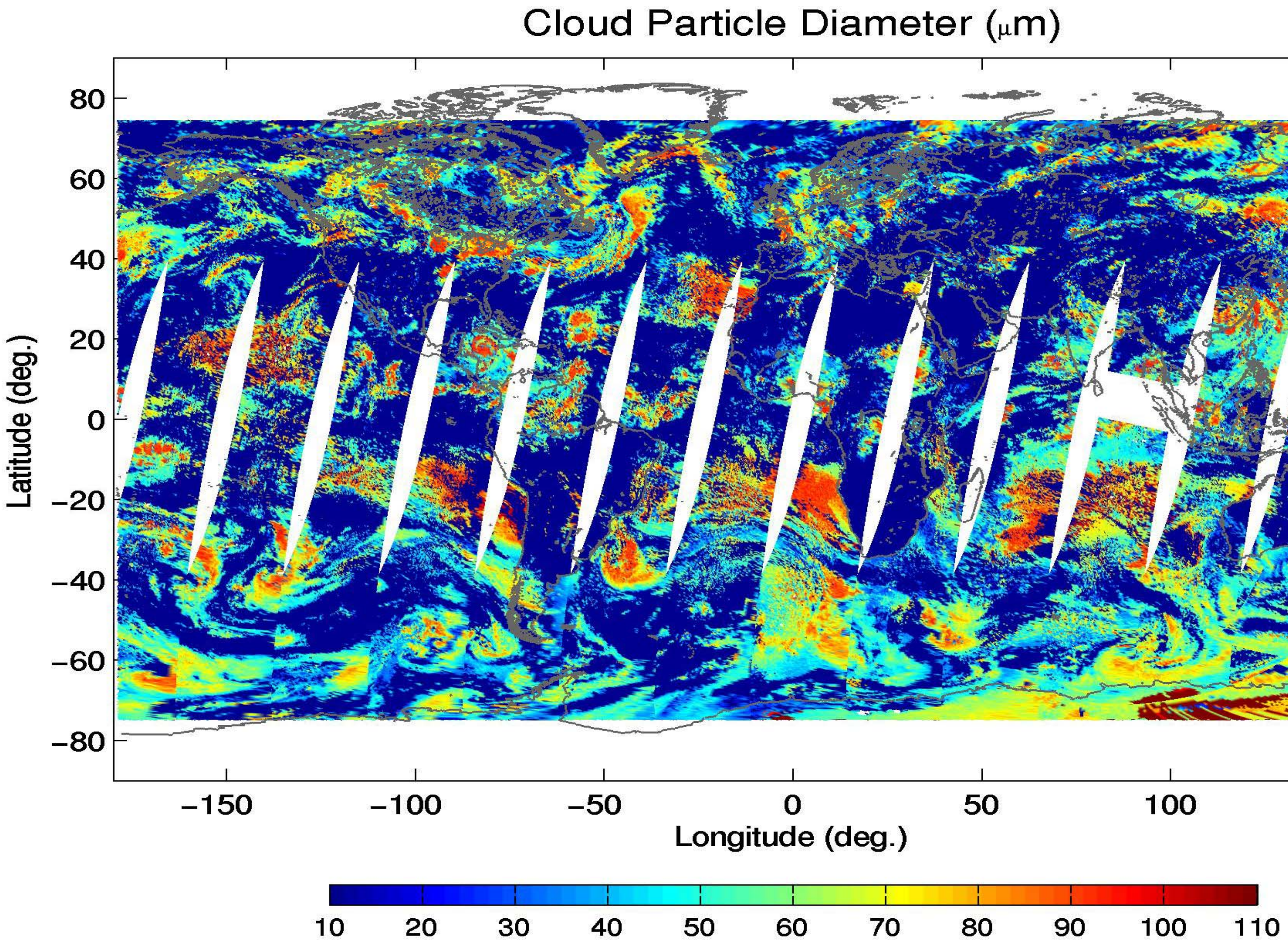
IASI vs. GOES-12: Cloud



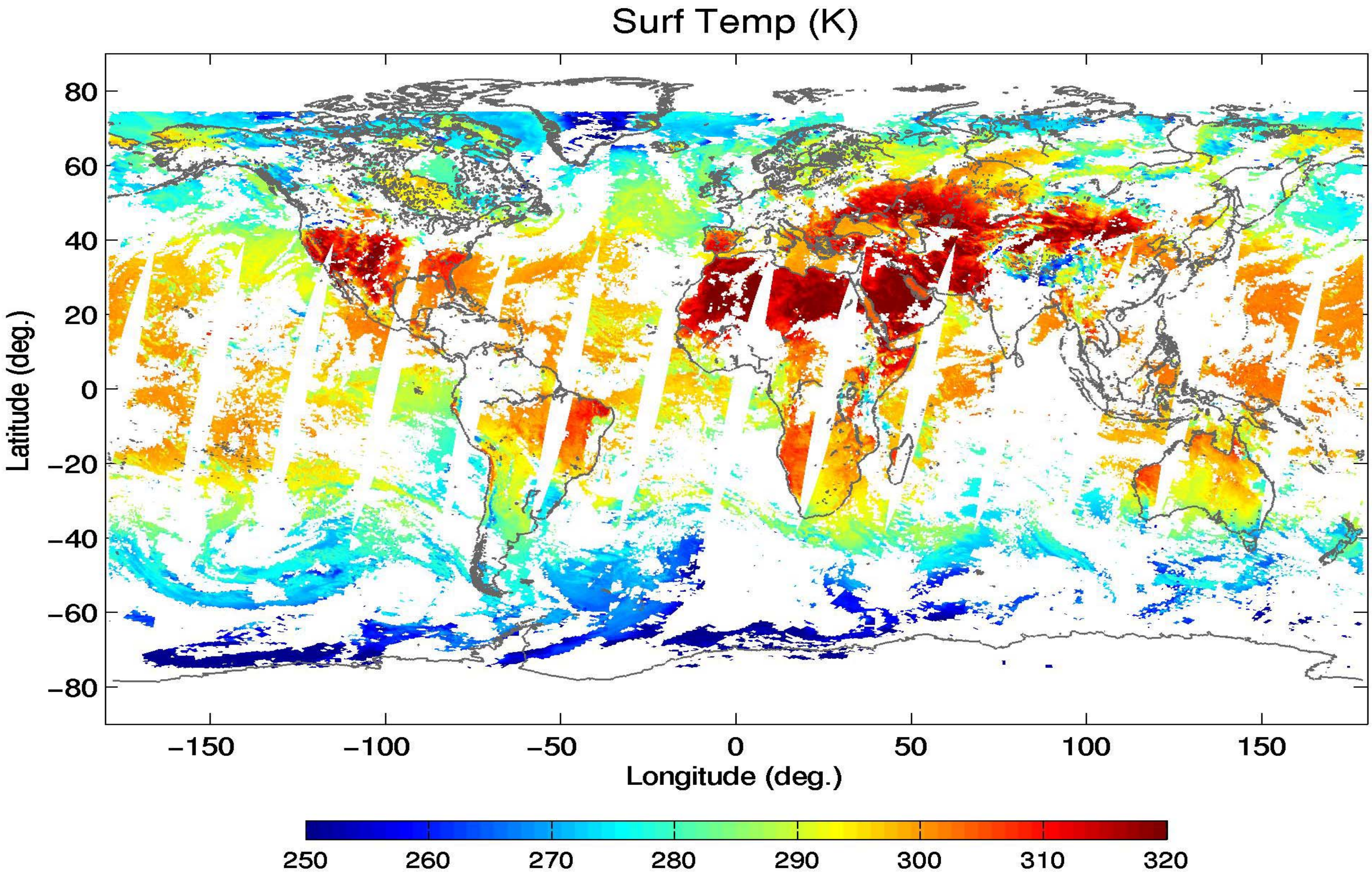
IASI Retrieval Demo: Cloud Optical Depth



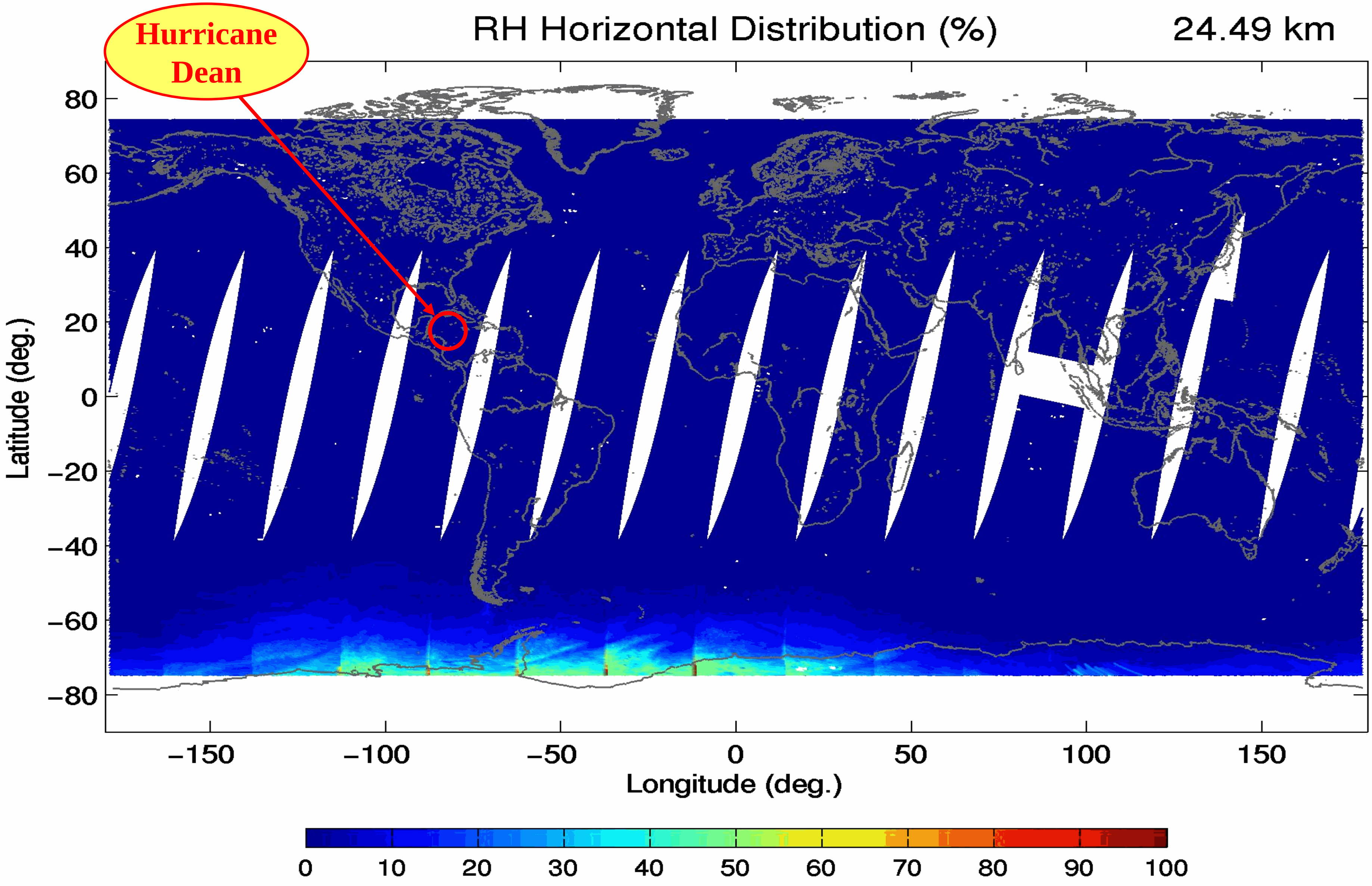
IASI Retrieval Demo: Cloud Particle Size



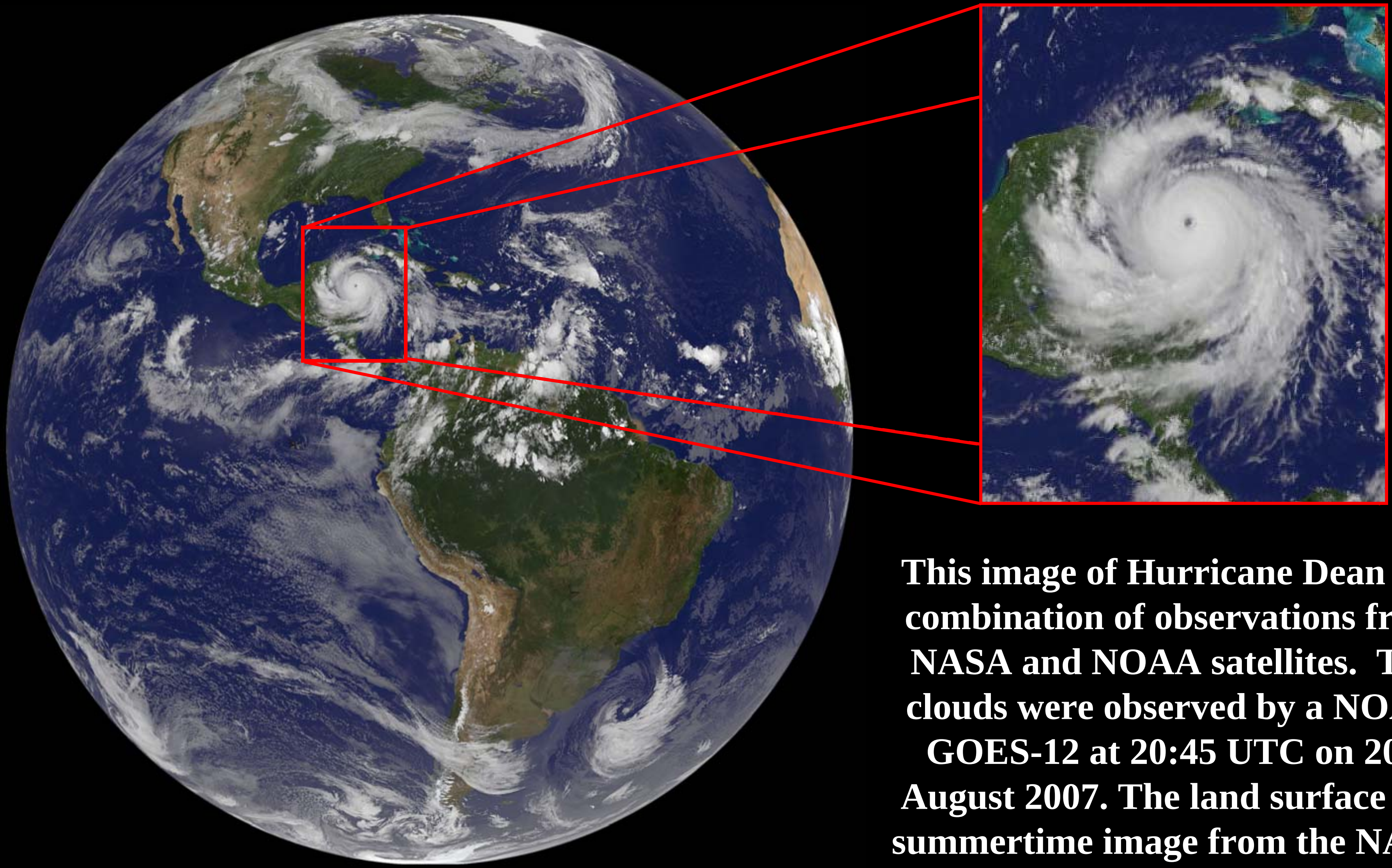
IASI Retrieval Demo: Surface Skin Temp



IASI Retrieval Demo: Moisture Distribution

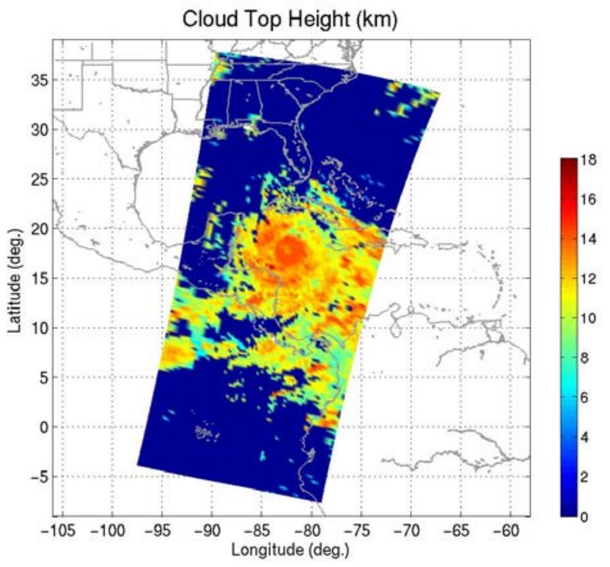


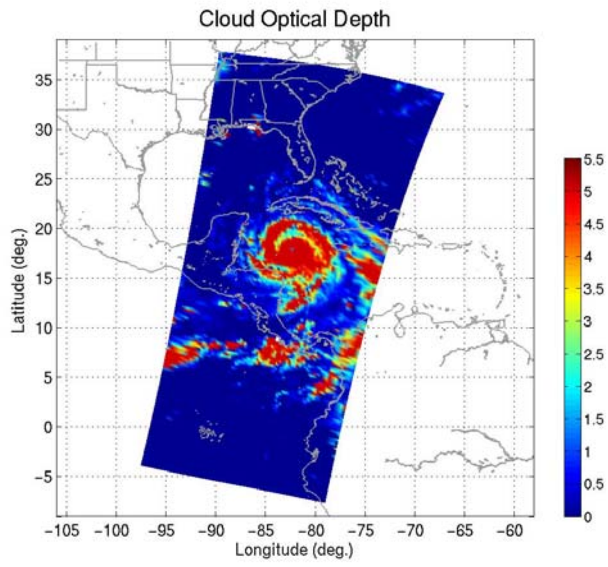
Hurricane Dean (2007.8.20)

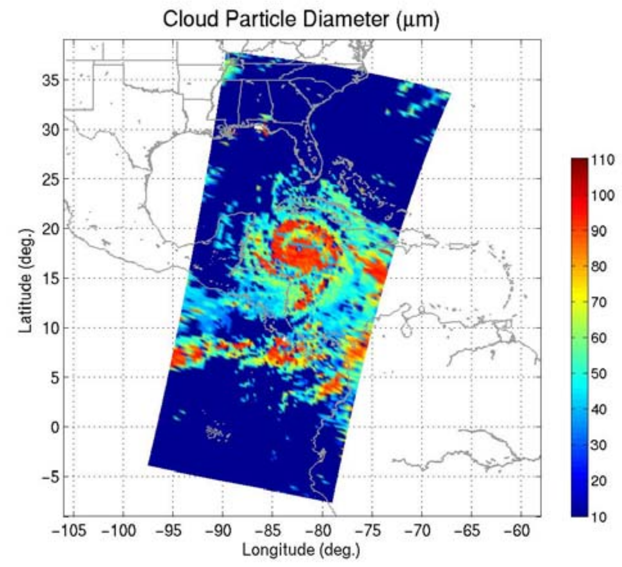


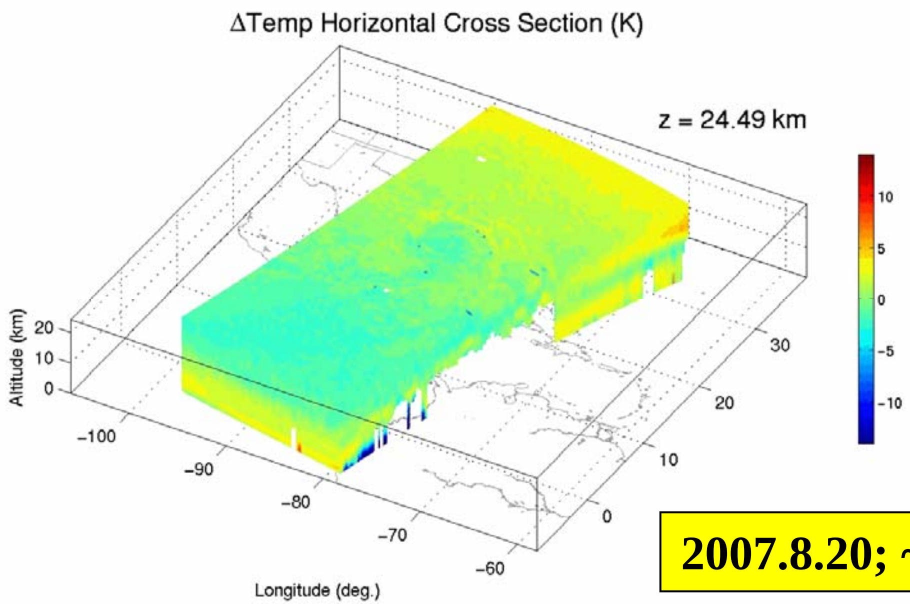
This image of Hurricane Dean is a combination of observations from NASA and NOAA satellites. The clouds were observed by a NOAA GOES-12 at 20:45 UTC on 20th August 2007. The land surface is a summertime image from the NASA Blue Marble image collection.

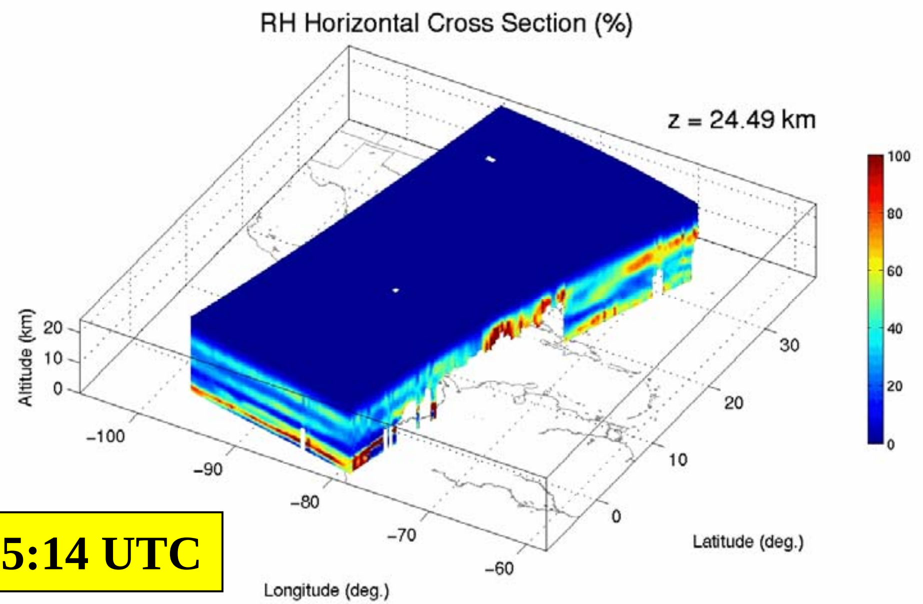
Hurricane Dean Observed with IASI





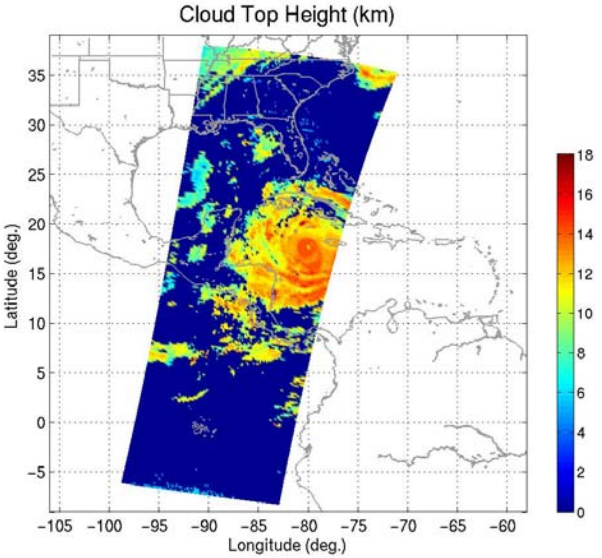


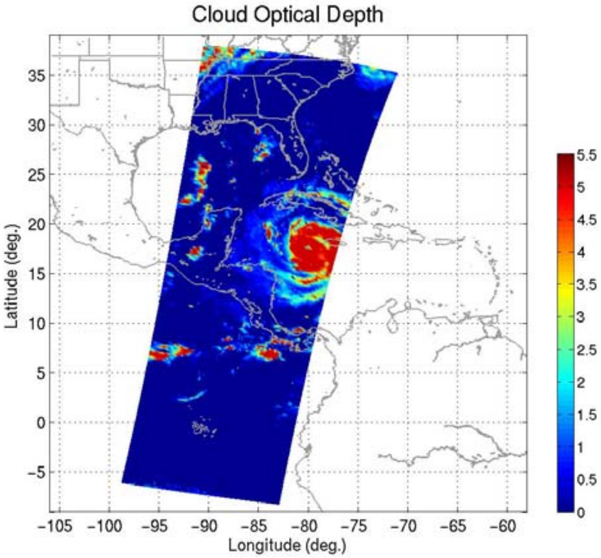


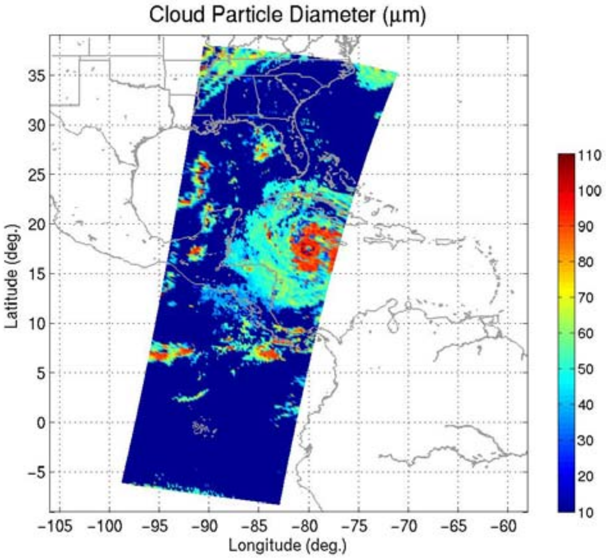


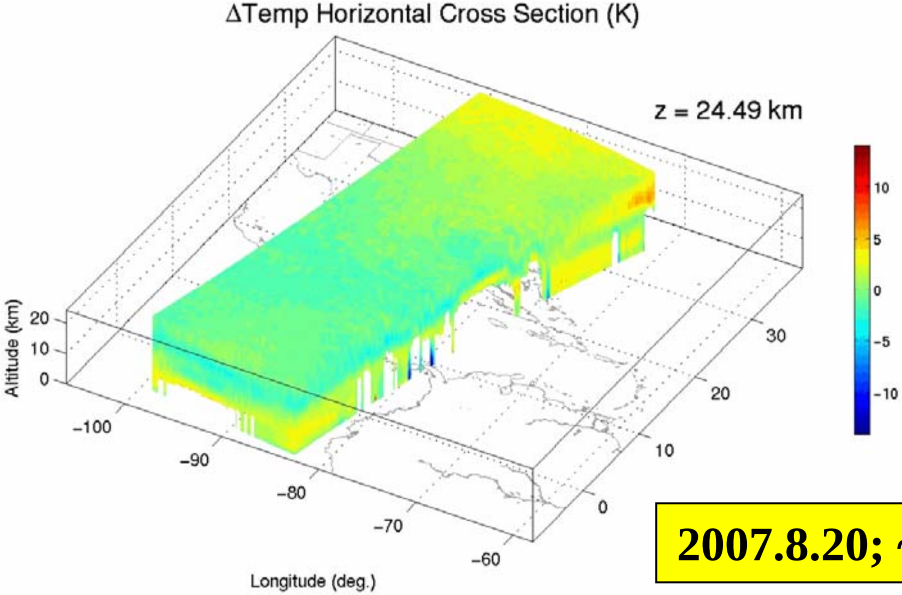
2007.8.20; ~15:14 UTC

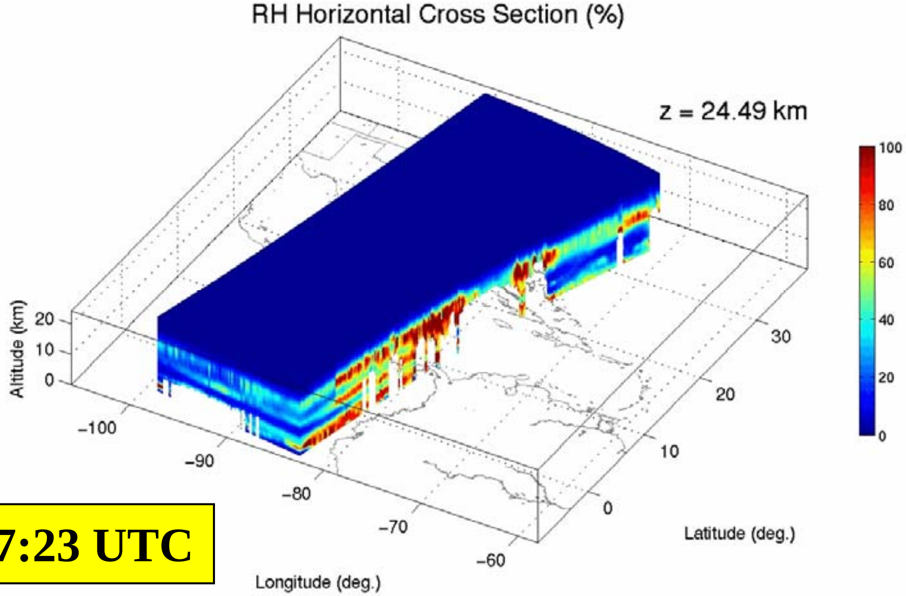
Hurricane Dean Observed with AIRS









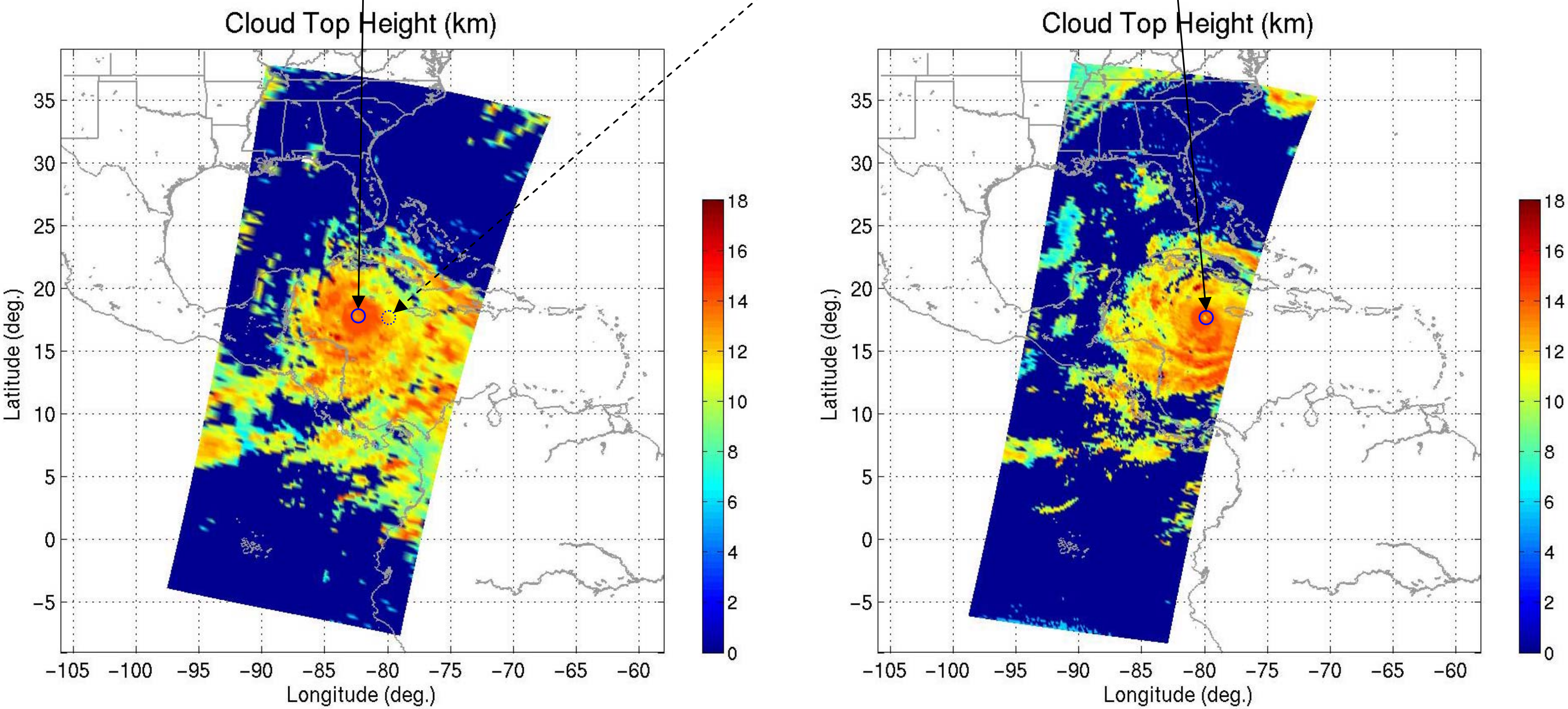


2007.8.20; ~07:23 UTC

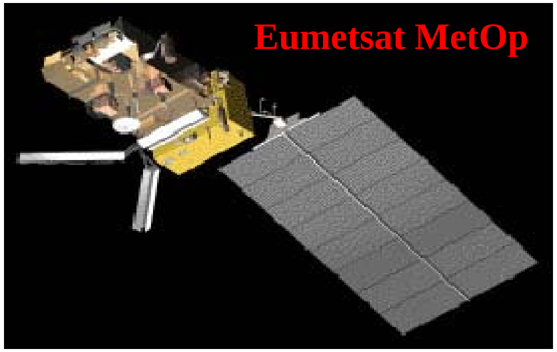
IASI vs. AIRS: Cloud Top Height

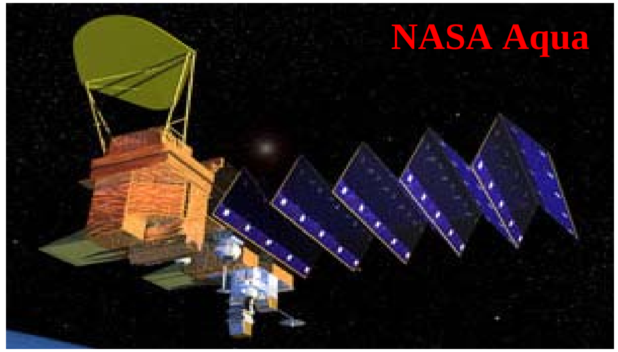
Metop Satellite / IASI
Time: ~15:14 UTC
Eye Location: 17.8 N, 82.5 W

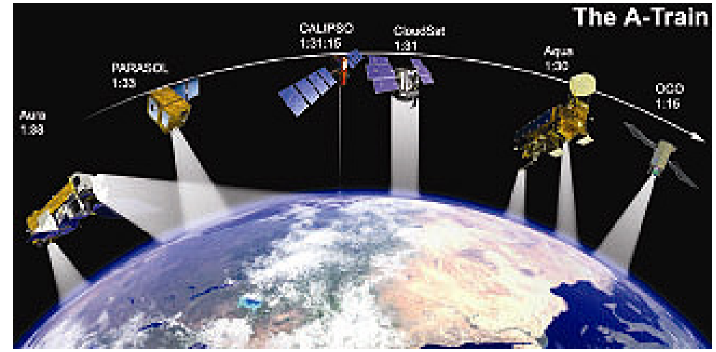
Aqua Satellite / AIRS
Time: ~07:23 UTC
Eye Location: 17.7 N, 80.0 W



Joint Airborne IASI Validation Exp.







Location/dates:

Ellington Field (EFD), Houston, TX, 14 Apr – 4 May, 2007.

Aircraft:

NASA WB-57 (NAST-I, NAST-M, S-HIS);

UK FAAM BAe146-301 (ARIES, MARSS, SWS; dropsondes; in-situ cloud phys. & trace species; etc.).

Satellites:

Metop (IASI, AMSU, MHS, AVHRR, HIRS).

A-train (Aqua AIRS, AMSU, HSB, MODIS; Aura TES; CloudSat; and Calipso).

Ground-sites:

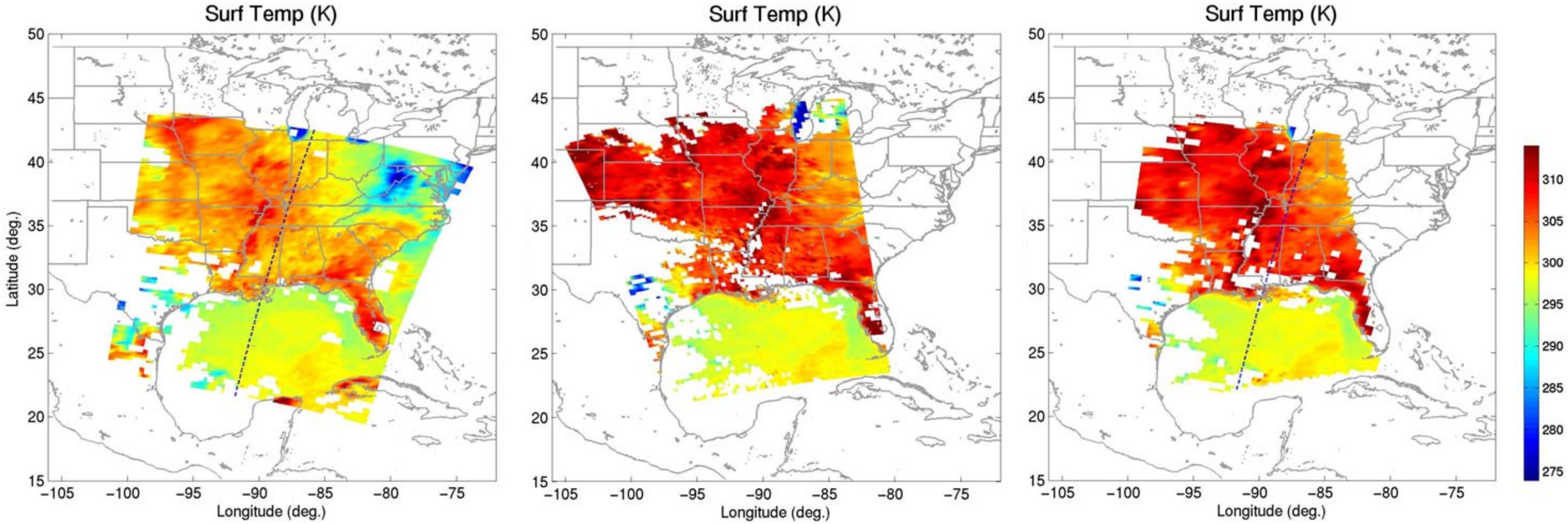
DOE ARM CART ground site (radiosondes, lidar, etc.)

Participants:

include NASA, UW, MIT, IPO, NOAA, UKMO, EUMETSAT, ECMWF, …

Case Study and Validation (2007.04.29)

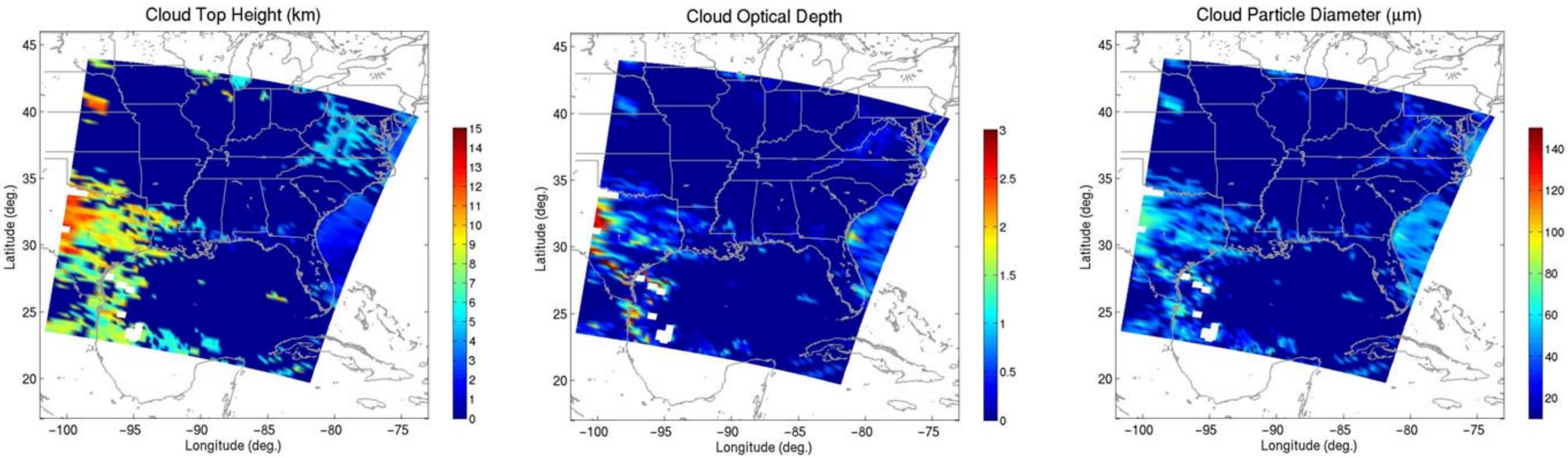
IASI @ ~15:48 UTC | **AIRS @ ~19:30 UTC** → **AIRS Interoperated to IASI FOV**



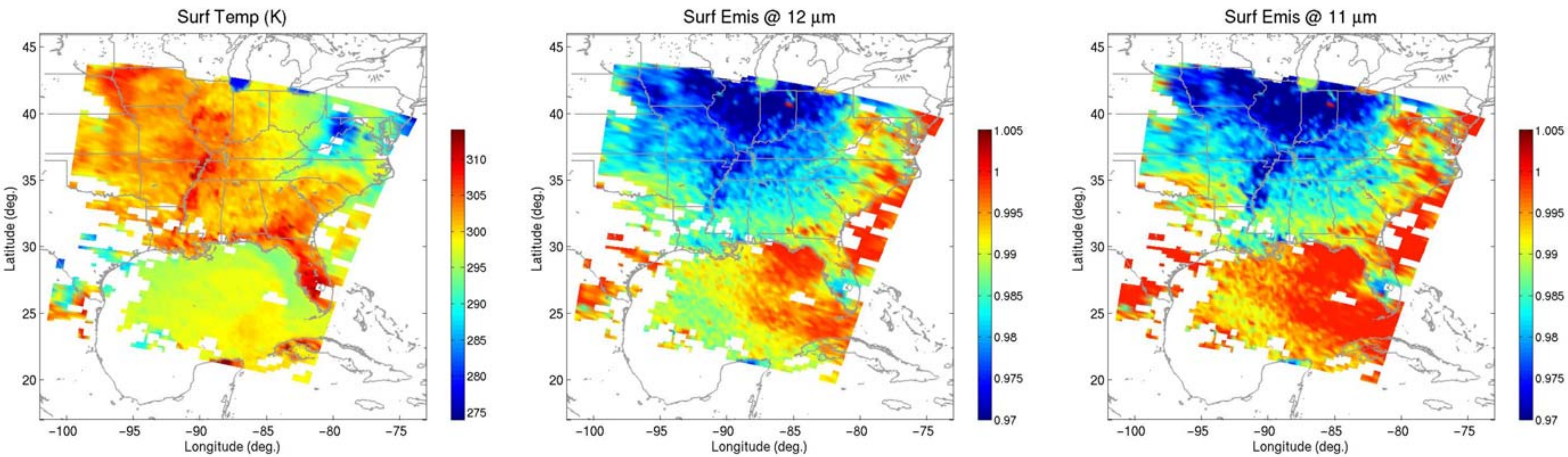
IASI and AIRS inter-comparison at the same geophysical location and same horizontal resolution

IASI Retrieval: Cloud & Surface

Cloud Parameters:

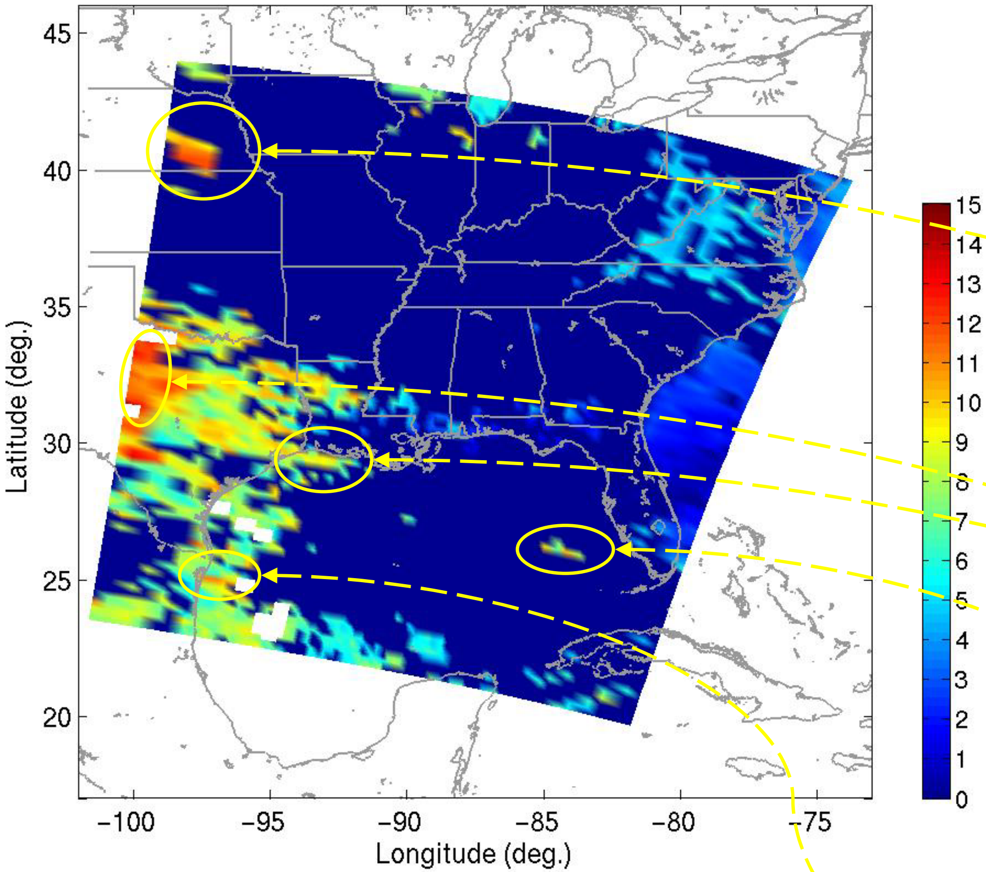


Surface Properties:

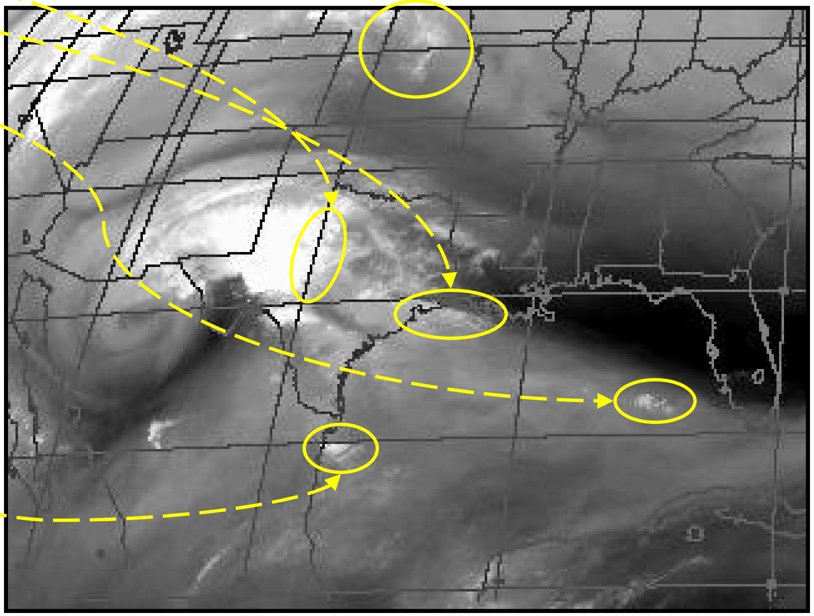


IASI Cloud vs. GOES Image (4.29.2007)

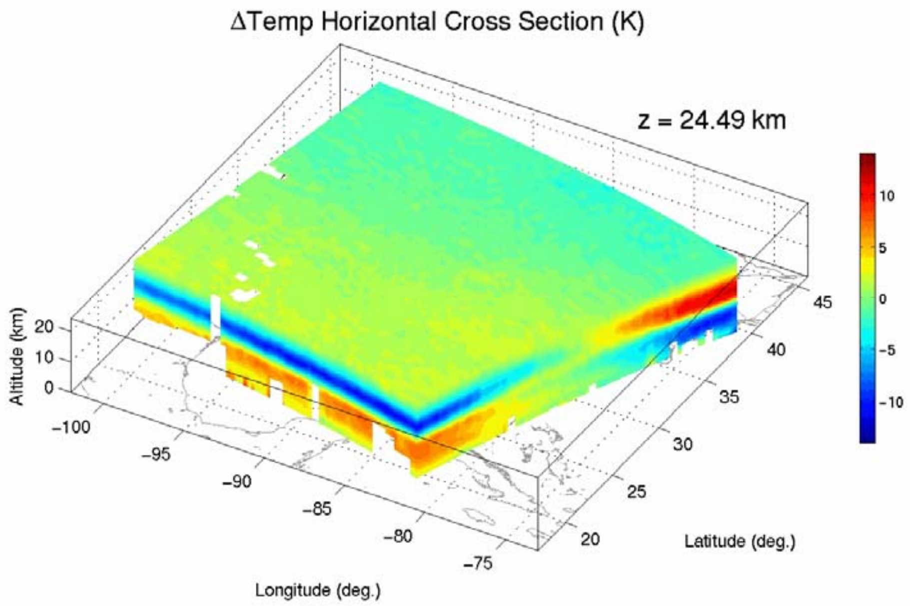
IASI Cloud Top Height (km)

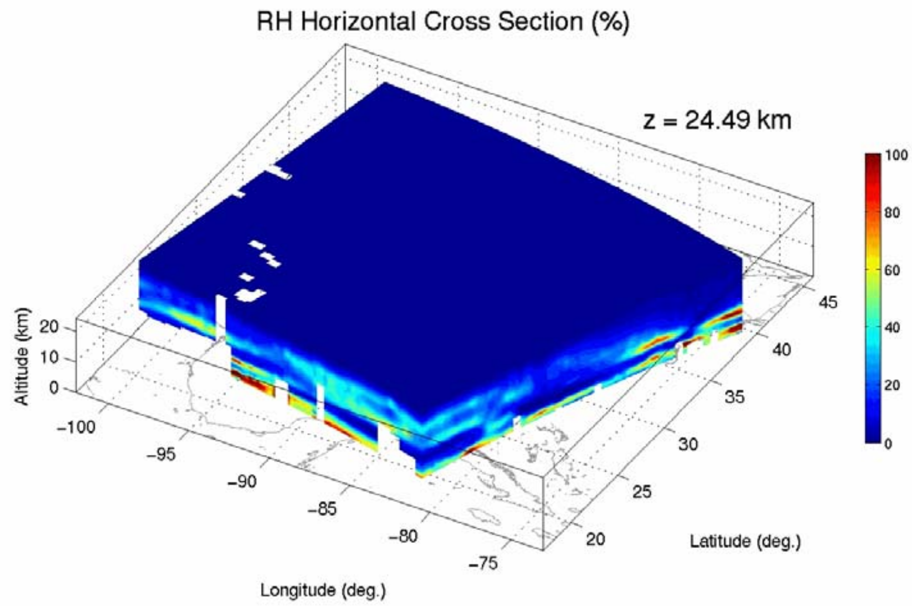


15:32 UTC GOES IR



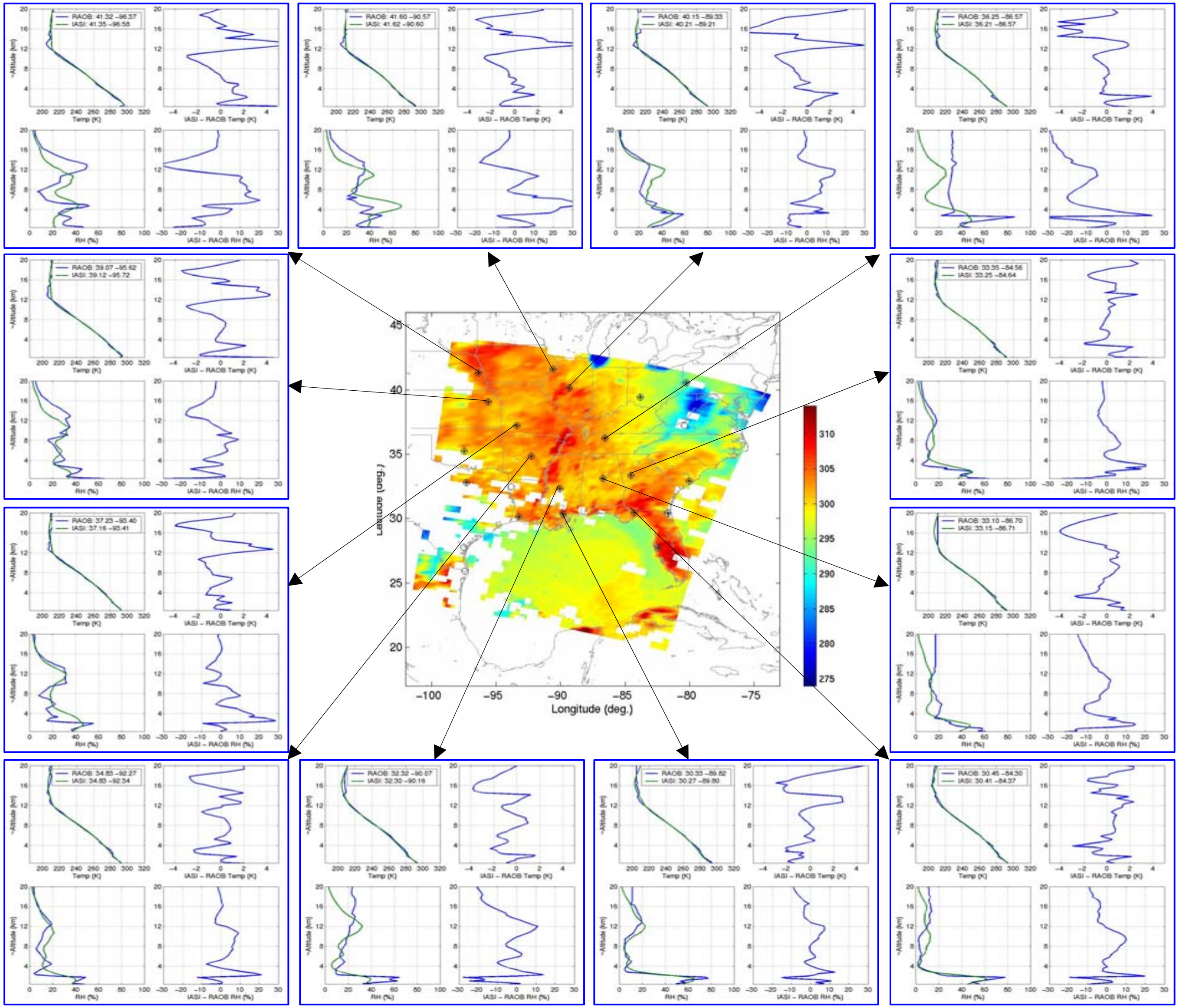
IASI Retrieval: ΔTemp and RH Fields





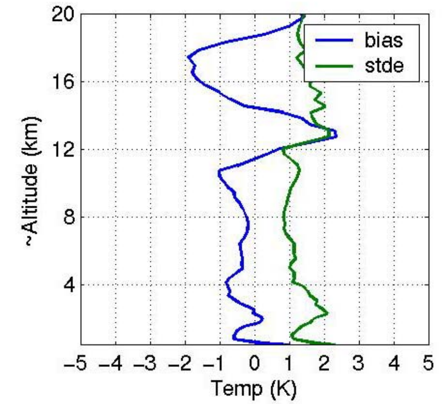
Langley Research Center

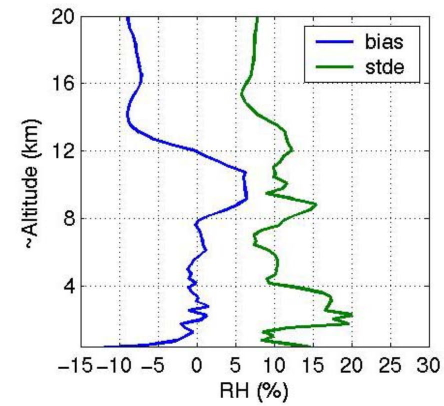
IASI Retrievals vs. Radiosondes



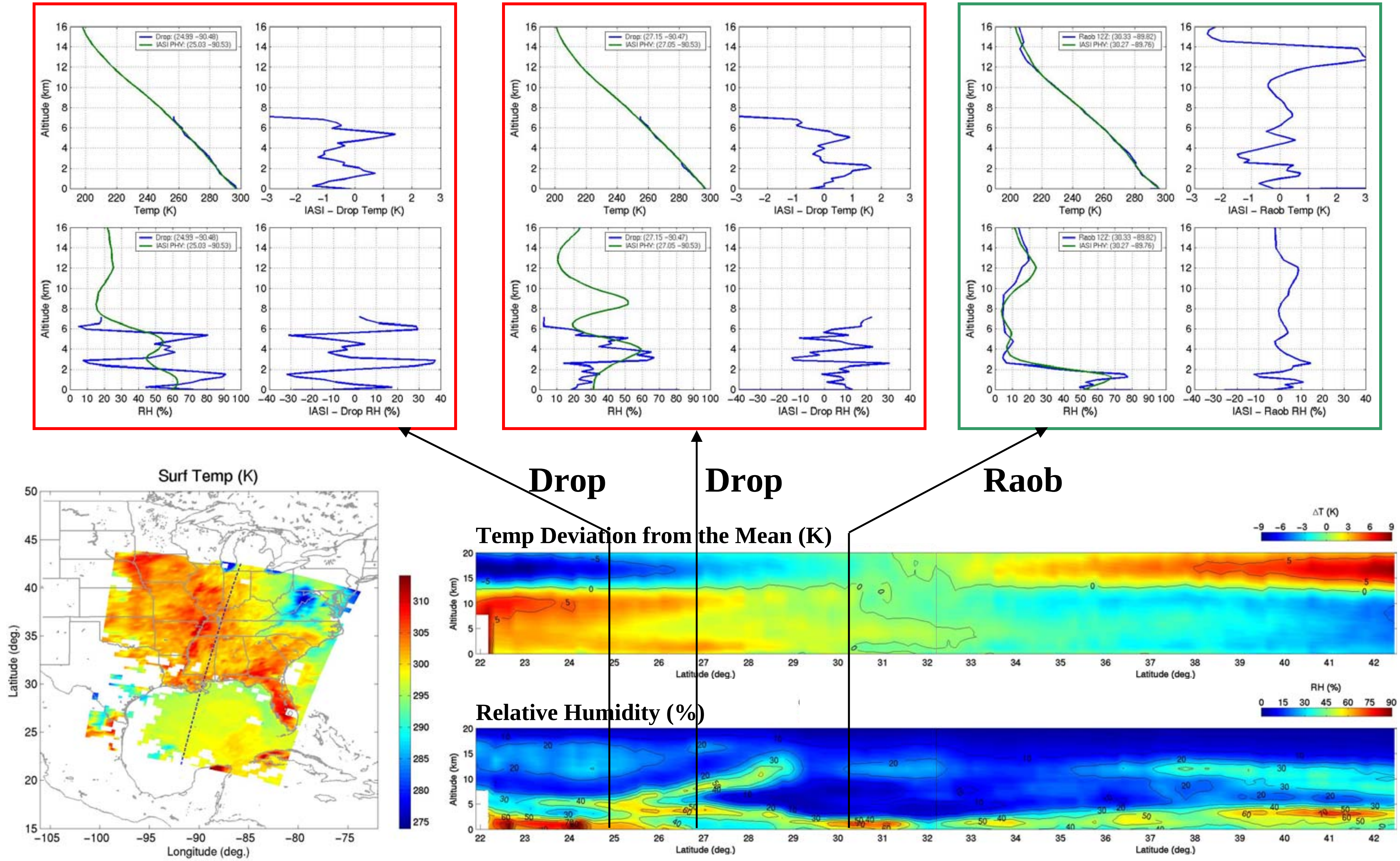
Note:
12:00 UTC = 07:00 Local
15:48 UTC = 10:48 Local

Radiosonde and IASI retrieval comparison and statistical profiles over 20 radiosondes

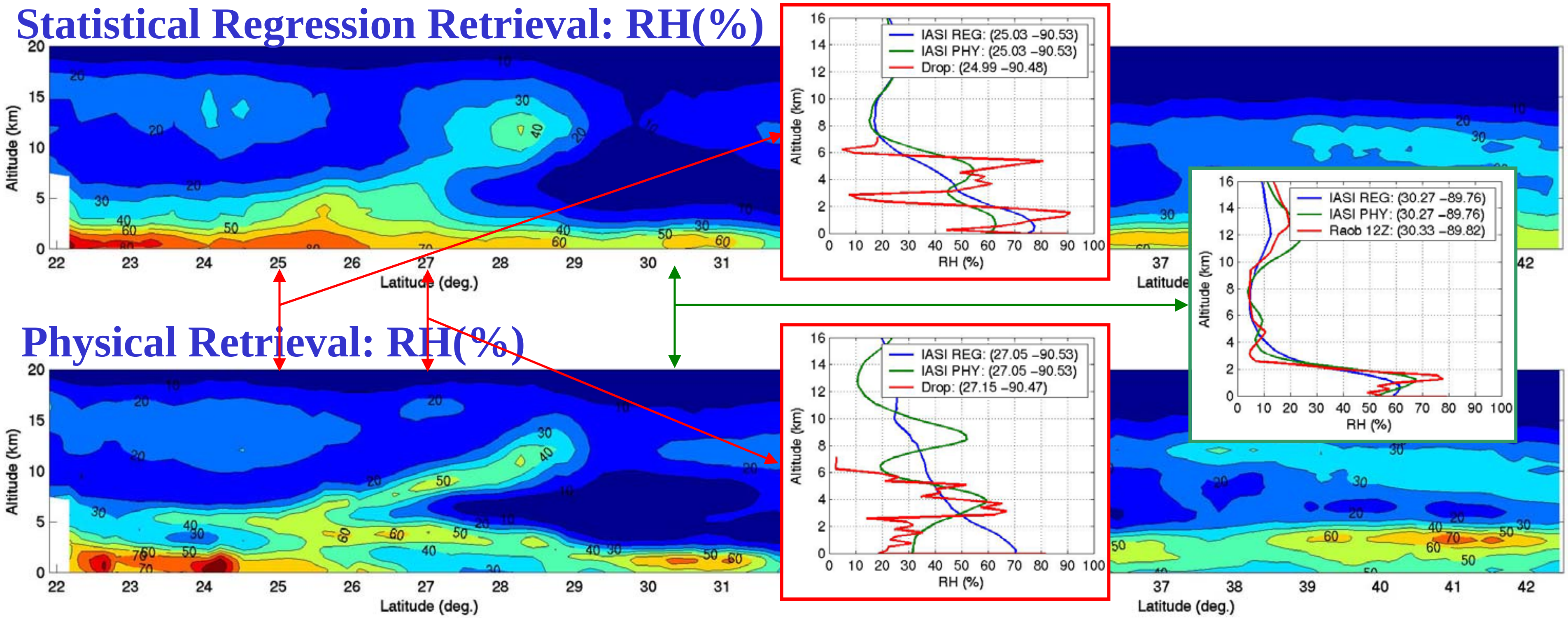




High-Vertically-Resolved Retrievals



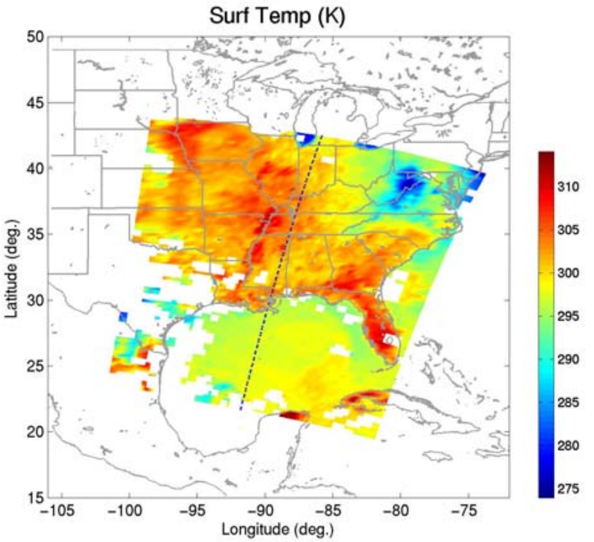
IASI Regression vs. Physical Retrieval



1. The retrieval improvement based on the EOF statistical regression through physical iterative retrieval is only contributed by IASI measurements as the minimum information methodology used.

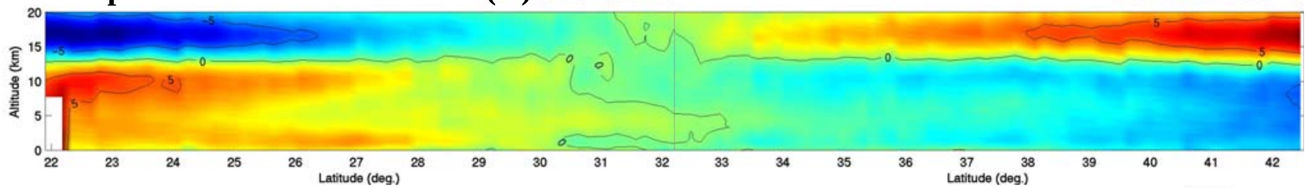
2. A high-vertically-resolved atmospheric structure is captured very well by IASI measurements and/or retrievals; not only in the troposphere, but also in the boundary layer.

IASI (15:48 UTC) vs. AIRS (19:30 UTC)

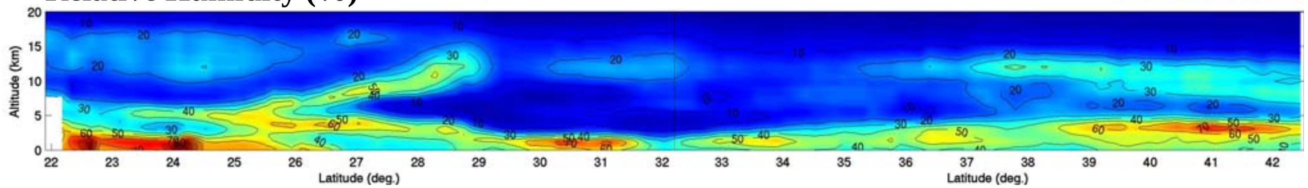


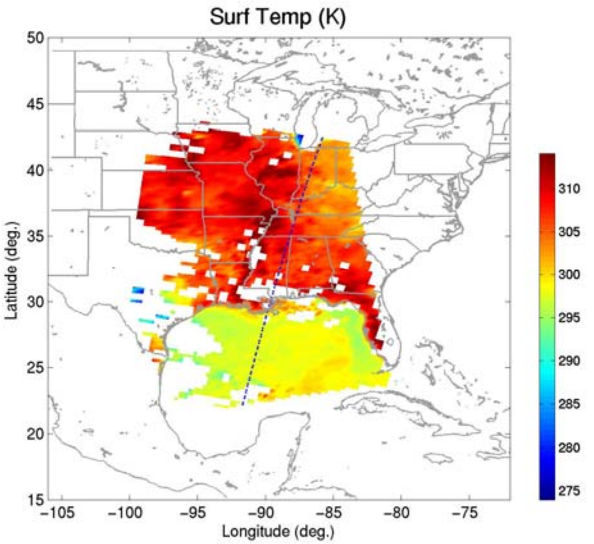
IASI Retrieval

Temp Deviation from the Mean (K)



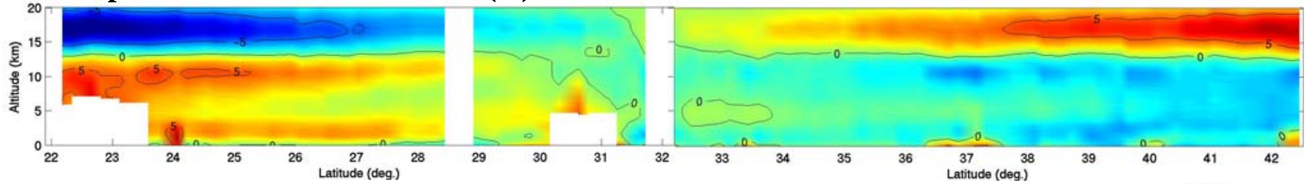
Relative Humidity (%)



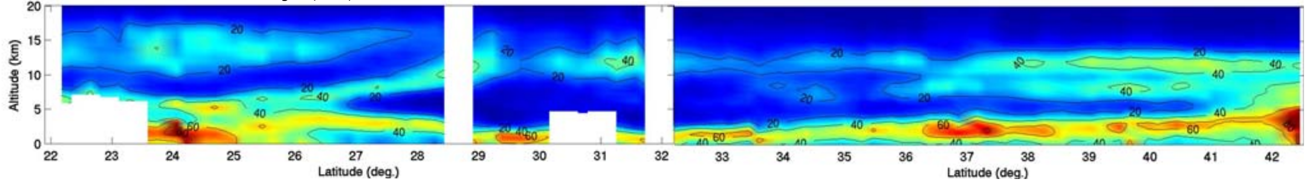


AIRS Retrieval Interoperated to IASI FOV

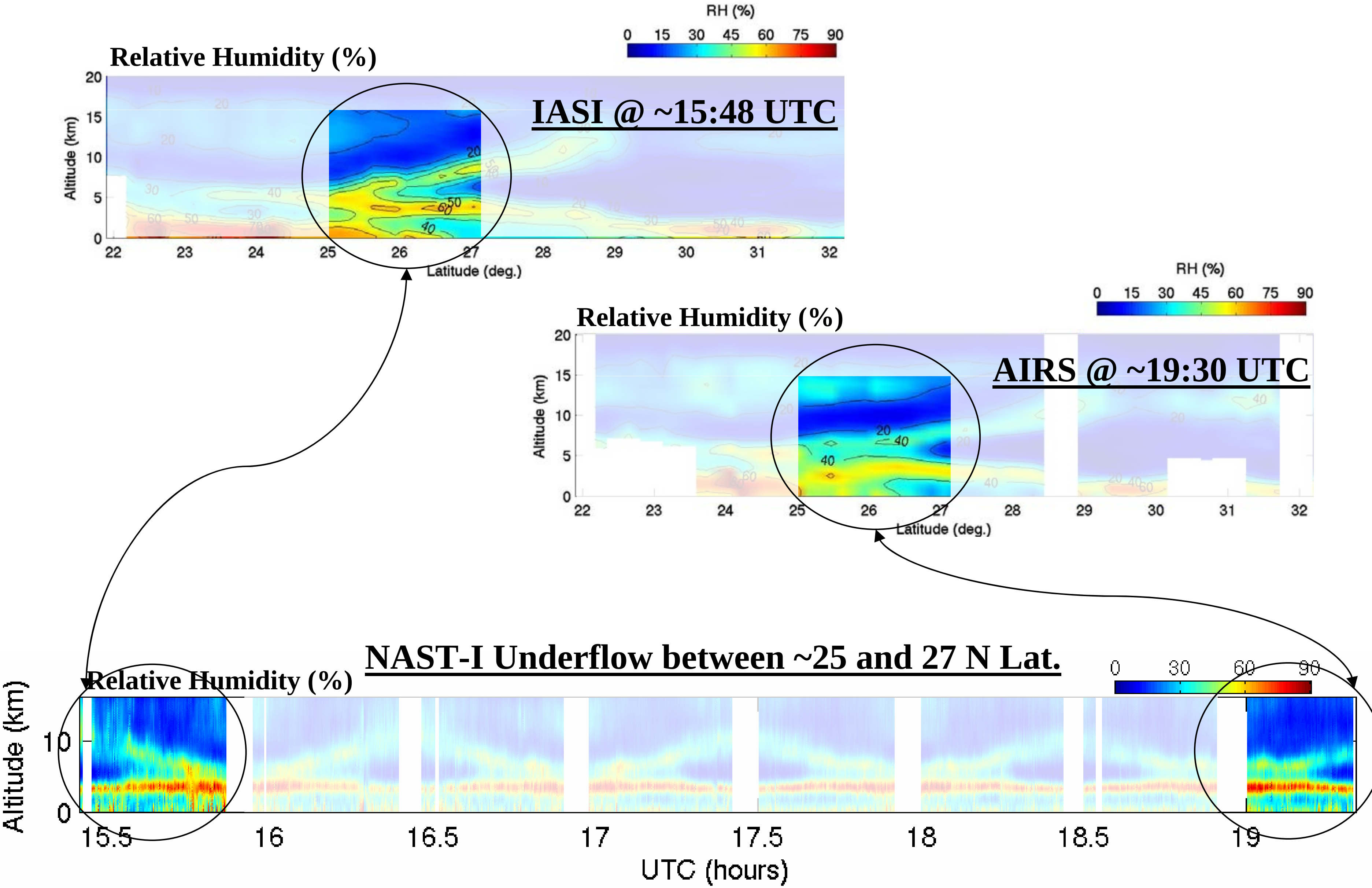
Temp Deviation from the Mean (K)



Relative Humidity (%)



NAST-I: Connection between IASI and AIRS



Summary and Future Work

1. A state-of-the-art IR-only retrieval algorithm has been developed with an all-seasonal-global EOF Physical Regression and followed by 1-D Var. Physical Iterative Retrieval for IASI, AIRS, and NAST-I.
2. The benefits of this retrieval are to produce atmospheric structure with a single FOV horizontal resolution (~15 km for IASI and AIRS), accurate profiles above the cloud (at least) or down to the surface, surface parameters, and/or cloud microphysical parameters.
3. Initial case study and validation indicates that surface, cloud, and atmospheric structure (include TBL) are well captured by IASI and AIRS measurements. Coincident dropsondes during the IASI and AIRS overpasses are used to validate atmospheric conditions, and accurate retrievals are obtained with an expected vertical resolution.
4. JAIVEx has provided the data needed to validated retrieval algorithm and its products which allows us to assess the instrument ability and/or performance.
5. Retrievals with global coverage are under investigation for detailed retrieval assessment.   It is greatly desired that these products be used for testing the impact on Atmospheric Data Assimilation and/or Numerical Weather Prediction.

International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008.
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2008.