Current Sounding Capability from Satellite Meteorological Observation with Ultra-spectral Infrared Instruments

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and many others …

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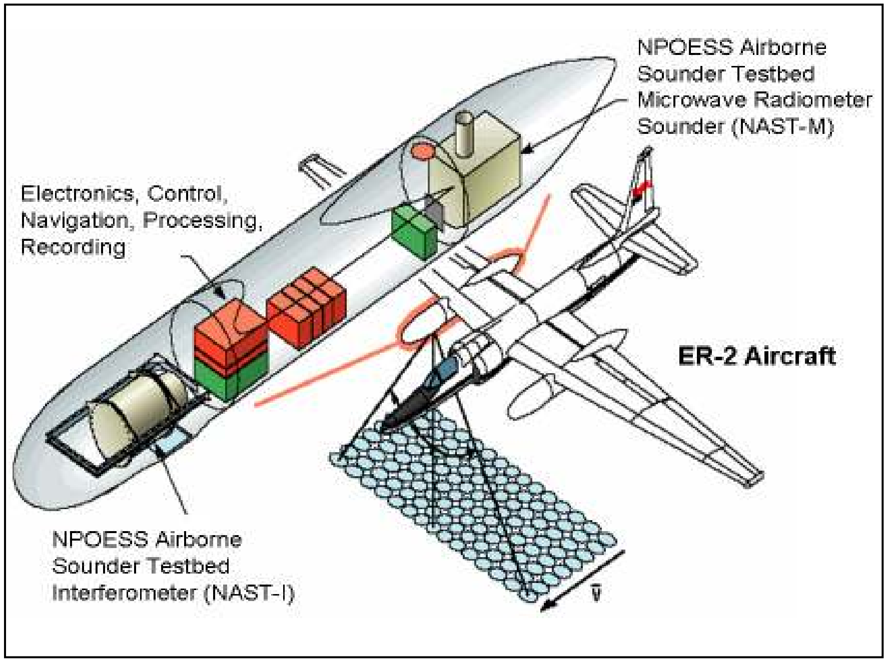
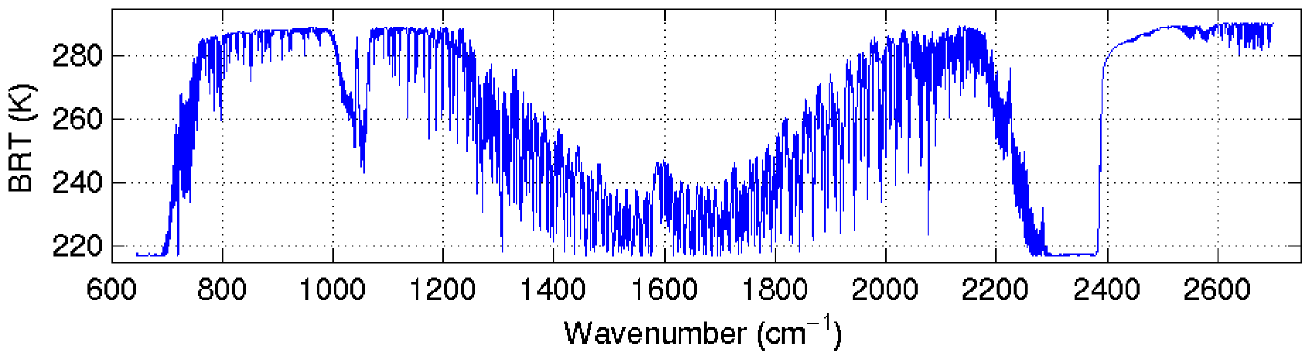
Talk Outline

1. Ultra-spectral IR Instruments
2. IR-only Retrieval Algorithm Introduction
3. Retrieval Simulation Analysis
4. Retrieval Demonstration from Real Satellite Measurements
5. Validation and Inter-comparison (JAIVEx)
6. Future Ultra-spectral IR Instruments on GEO Satellites
7. Summary

NAST-I and S-HIS: Since July 1998

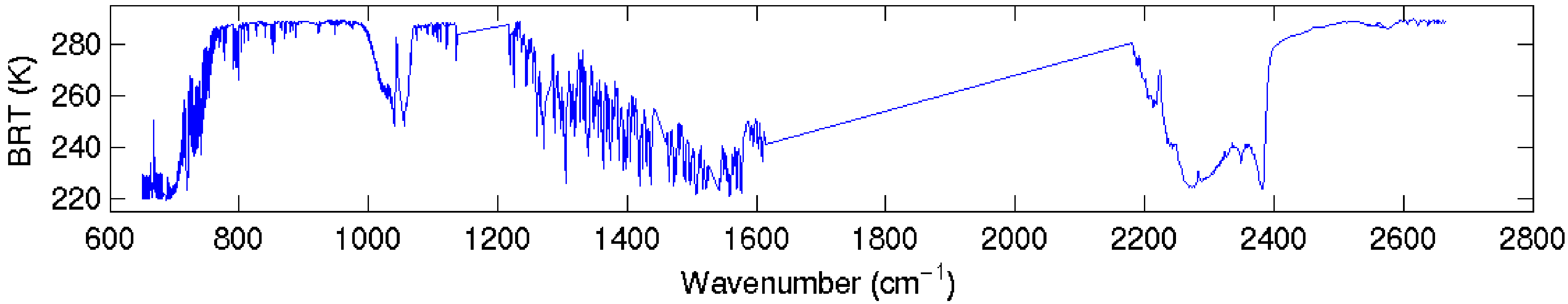
<u>N</u>POESS <u>A</u>irborne <u>S</u>ounder <u>T</u>estbed (NAST) on ER-2, WB-57, Proteus aircraft since July 1998





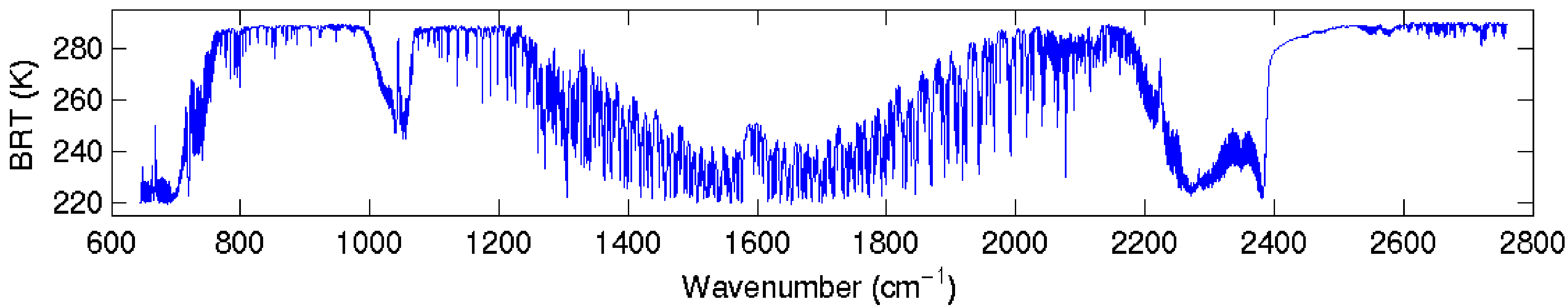
AIRS: Since May 2002

Atmospheric InfraRed Sounder (AIRS) instrument (by NASA) on Aqua Satellite launched on 4 May 2002



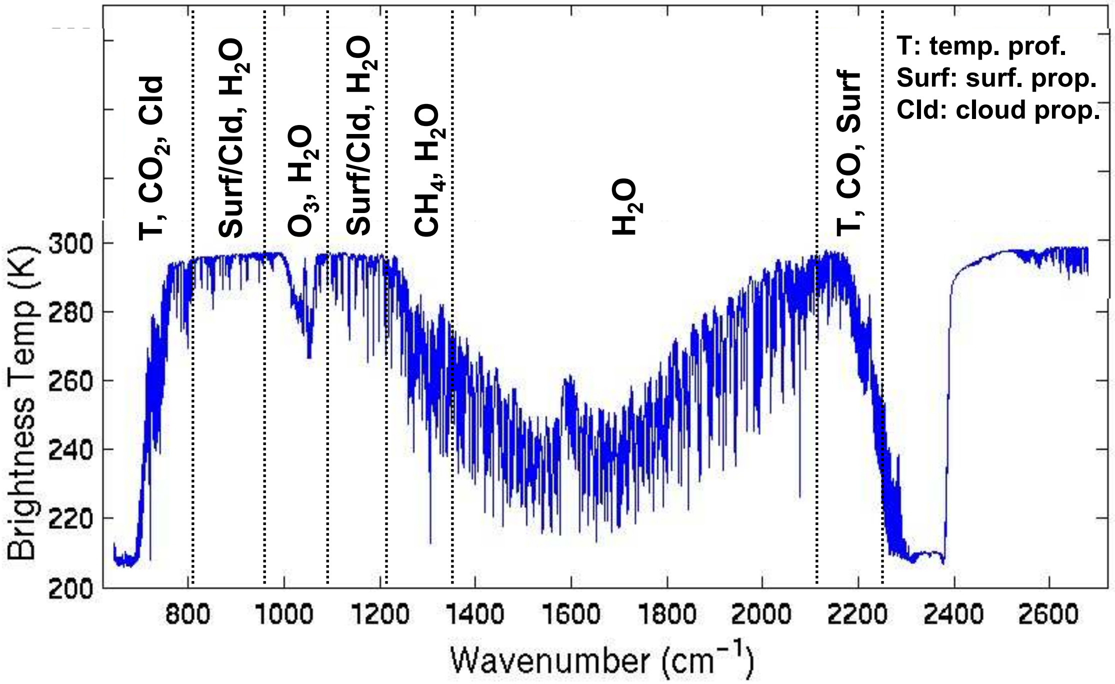
IASI: Since Oct. 2006

Infrared Atmospheric Sounding Interferometer (IASI) instrument (by CNES / EUMETSAT) on MetOp-A Satellite launched on 19 October 2006

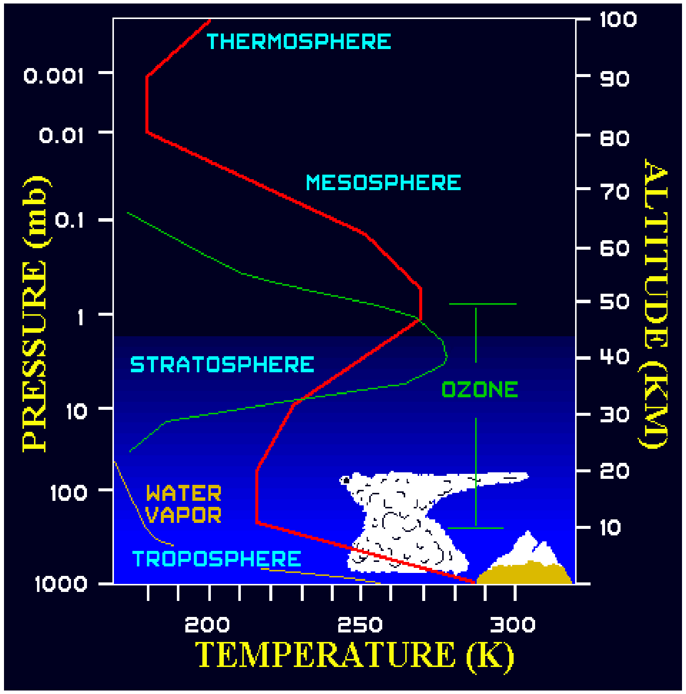


Retrieval Parameters from These Systems

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).

LaRC IR Retrieval Algorithm

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

Using an all-seasonal-globally representative 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:

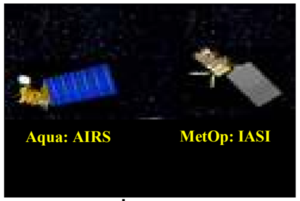
Regress cloud, surface properties & atmospheric profile parameters against radiance EOFs.

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

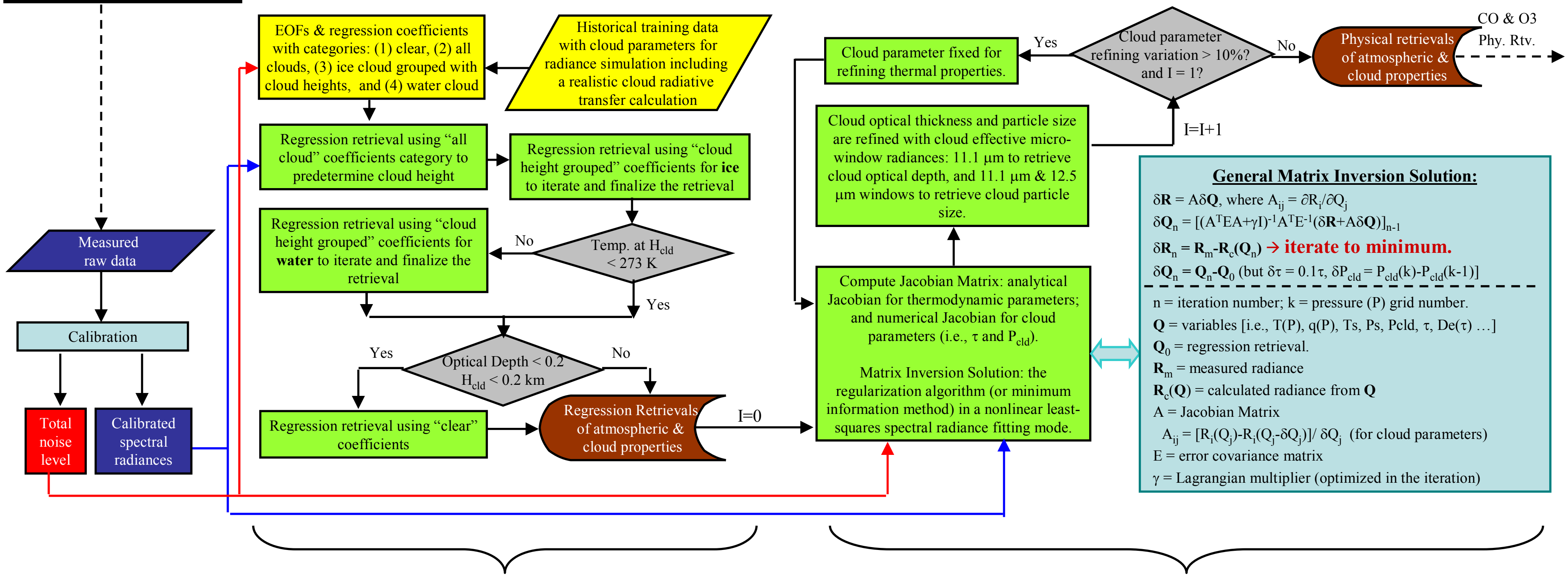
A one-dimensional (1-d) variational solution with the regularization algorithm (i.e., the minimum information method) is chosen for physical retrieval methodology which uses the regression solution as the initial guess.

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

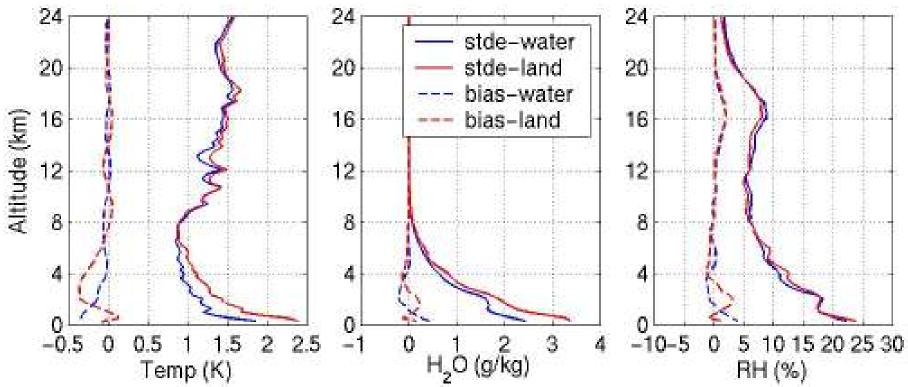


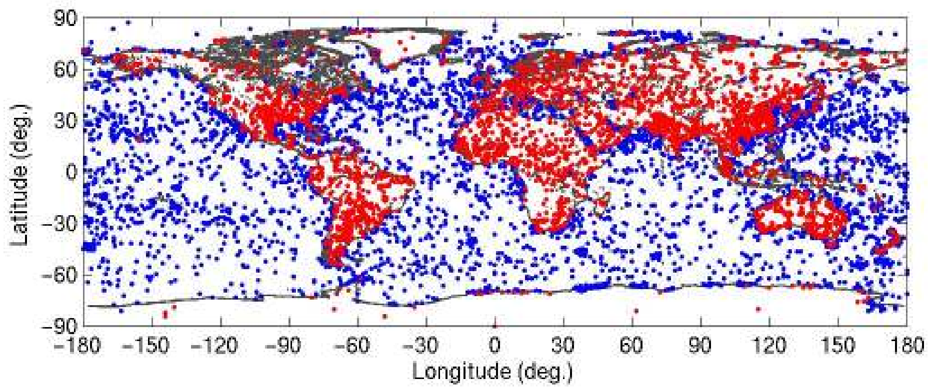
Statistical EOF Physical Regressions

Simultaneous 1-D Var. Iterative Matrix Inversion

IASI Clear Retrieval Analysis

Synthetic analysis: the truth profile (i.e., the radiosonde observation) is known and the retrieval can be directly compared with the truth to define retrieval accuracy due to (1) instrumental noise and (2) retrieval error introduced mainly by so-called "ill-posed" retrieval model. The disadvantage of this approach is that forward radiative transfer model error is not included.





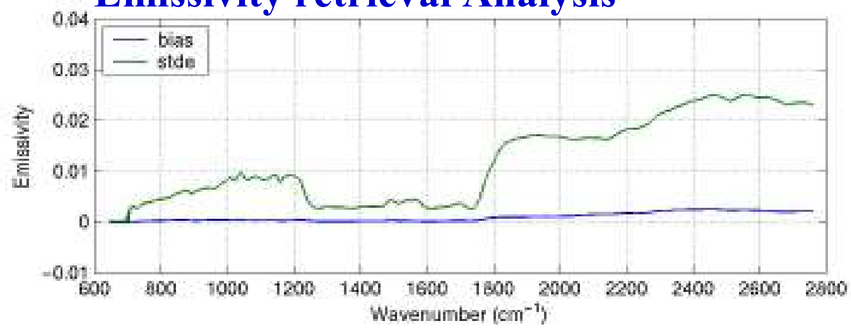
Under Clear Conditions over Water:

No. of Samples:	6262
Ts Bias:	0.05 K
Ts STDE:	0.97 K

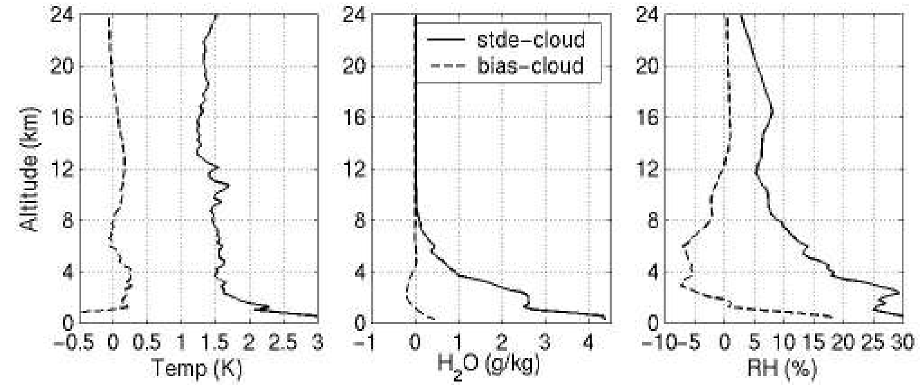
Under Clear Conditions over Land:

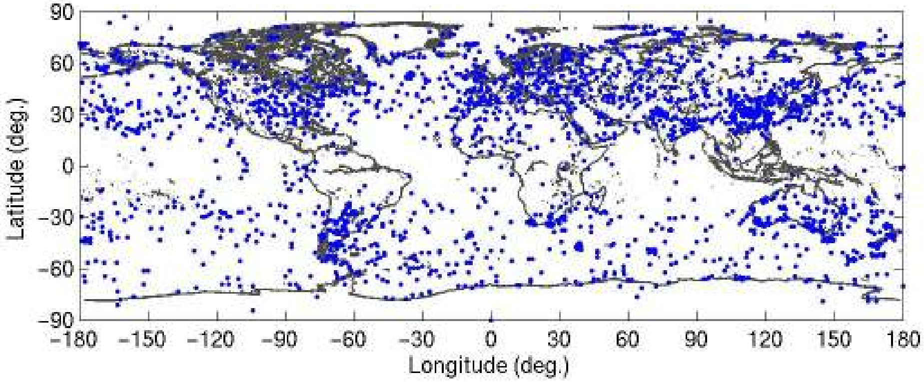
No. of Samples:	5868
Ts Bias:	0.25
Ts STDE:	1.42

Emissivity retrieval Analysis



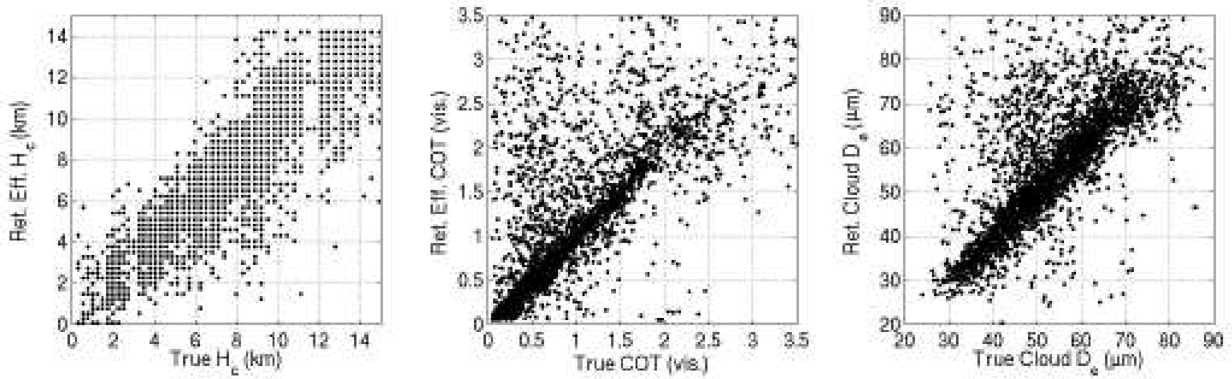
IASI Cloudy Retrieval Analysis





Under Cloudy Conditions:

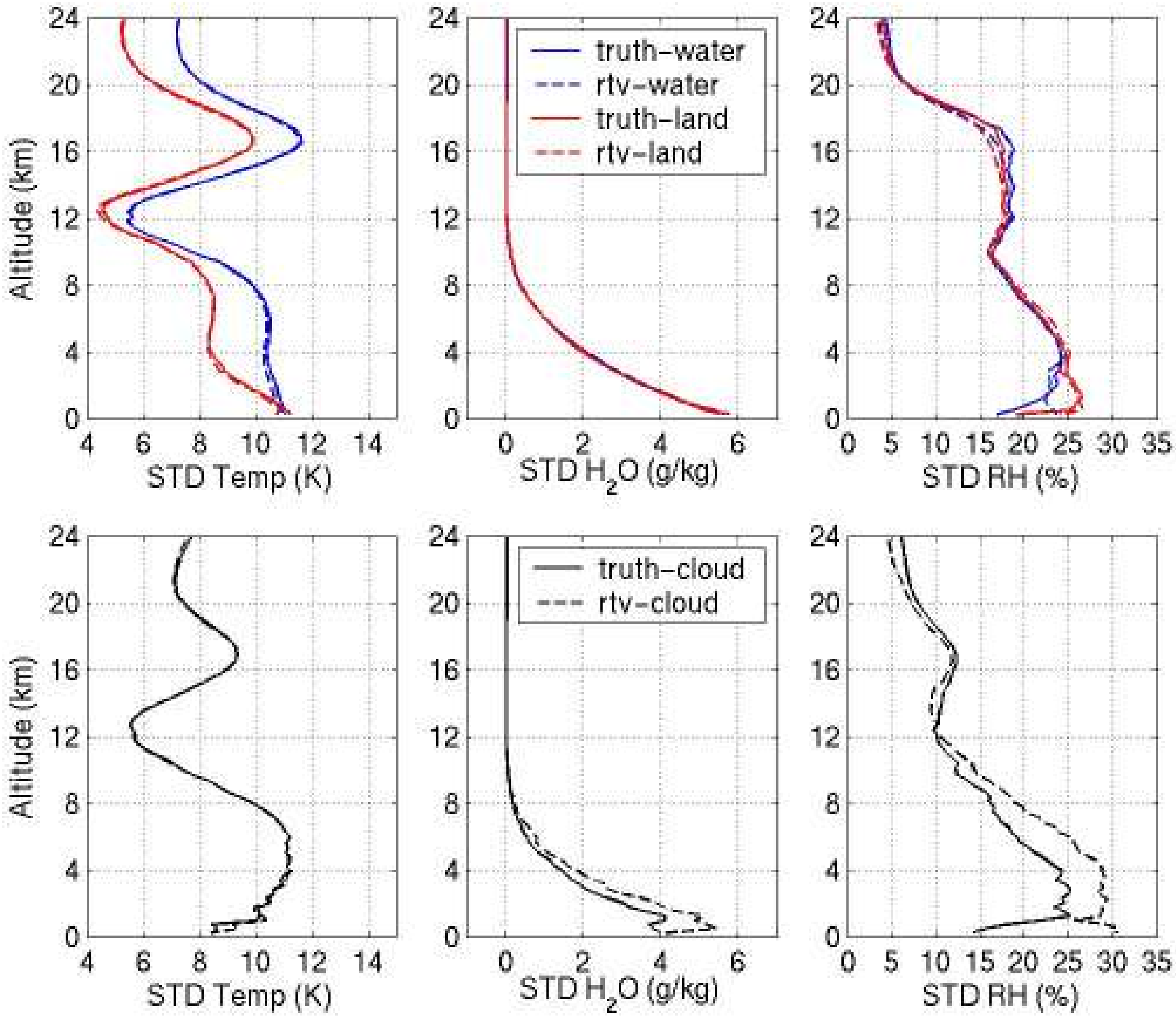
No. of Samples:	3172
Hc Bias:	0.29 km
Hc STDE:	1.66 km
COT Bias:	-0.25
COT STDE:	0.79
De Bias:	-2.48 μm
De STDE:	11.60 μm



Variance of Test Dataset and IASI Retrievals

Under Clear Conditions

Under Cloudy Conditions



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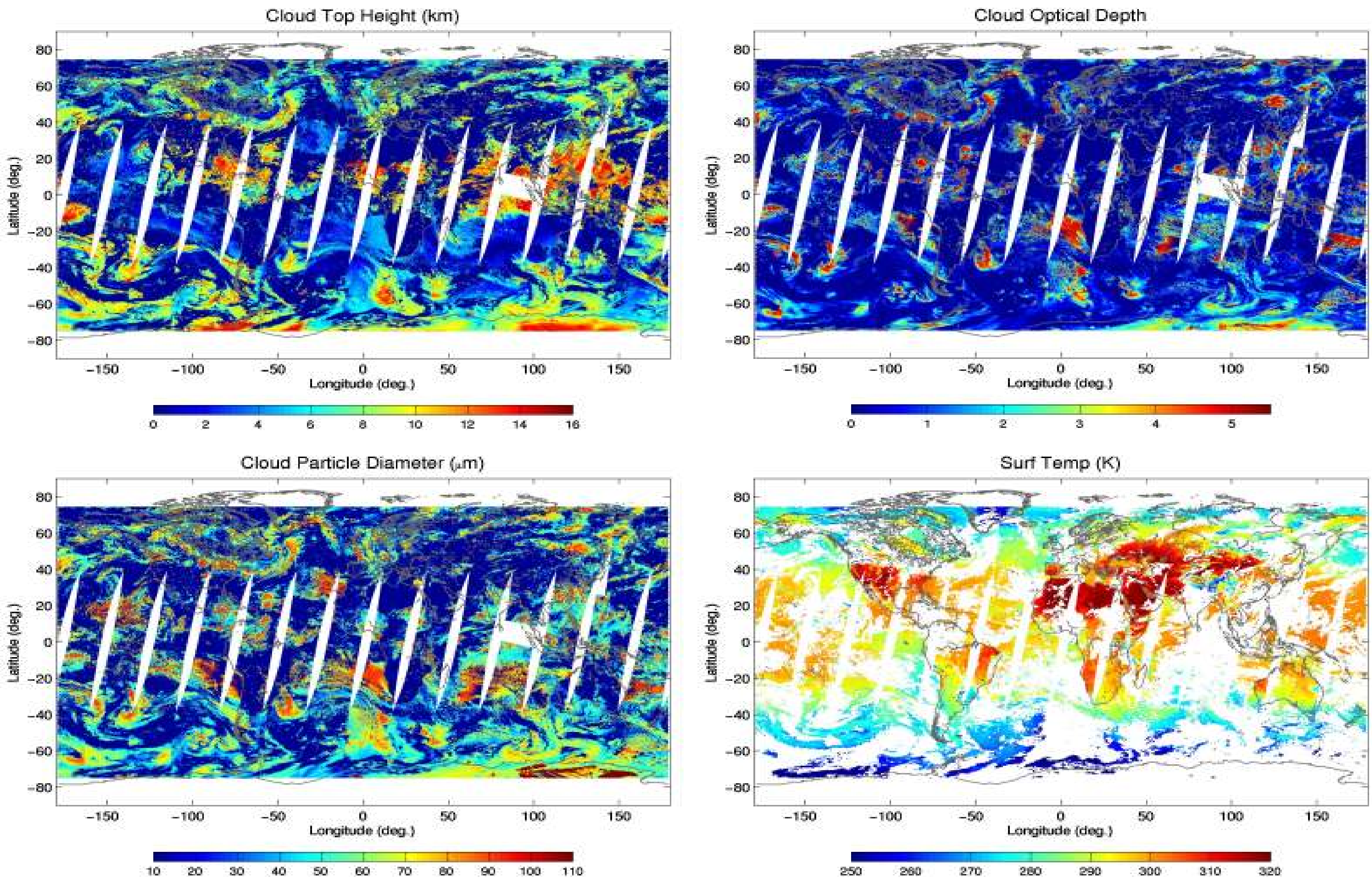
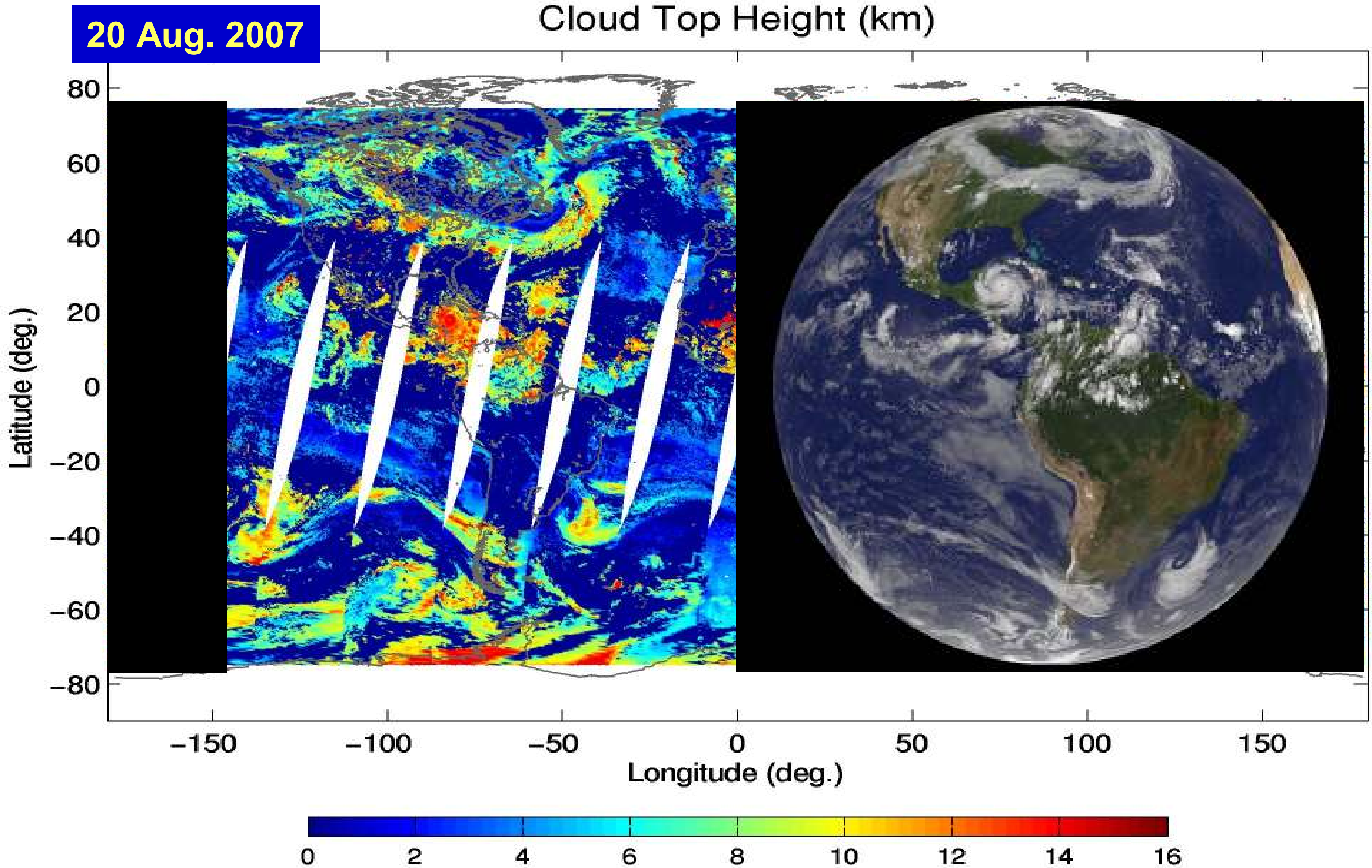
IASI Retrieval Demo: Cloud Parameters & Ts



IASI vs. GOES-12: Cloud



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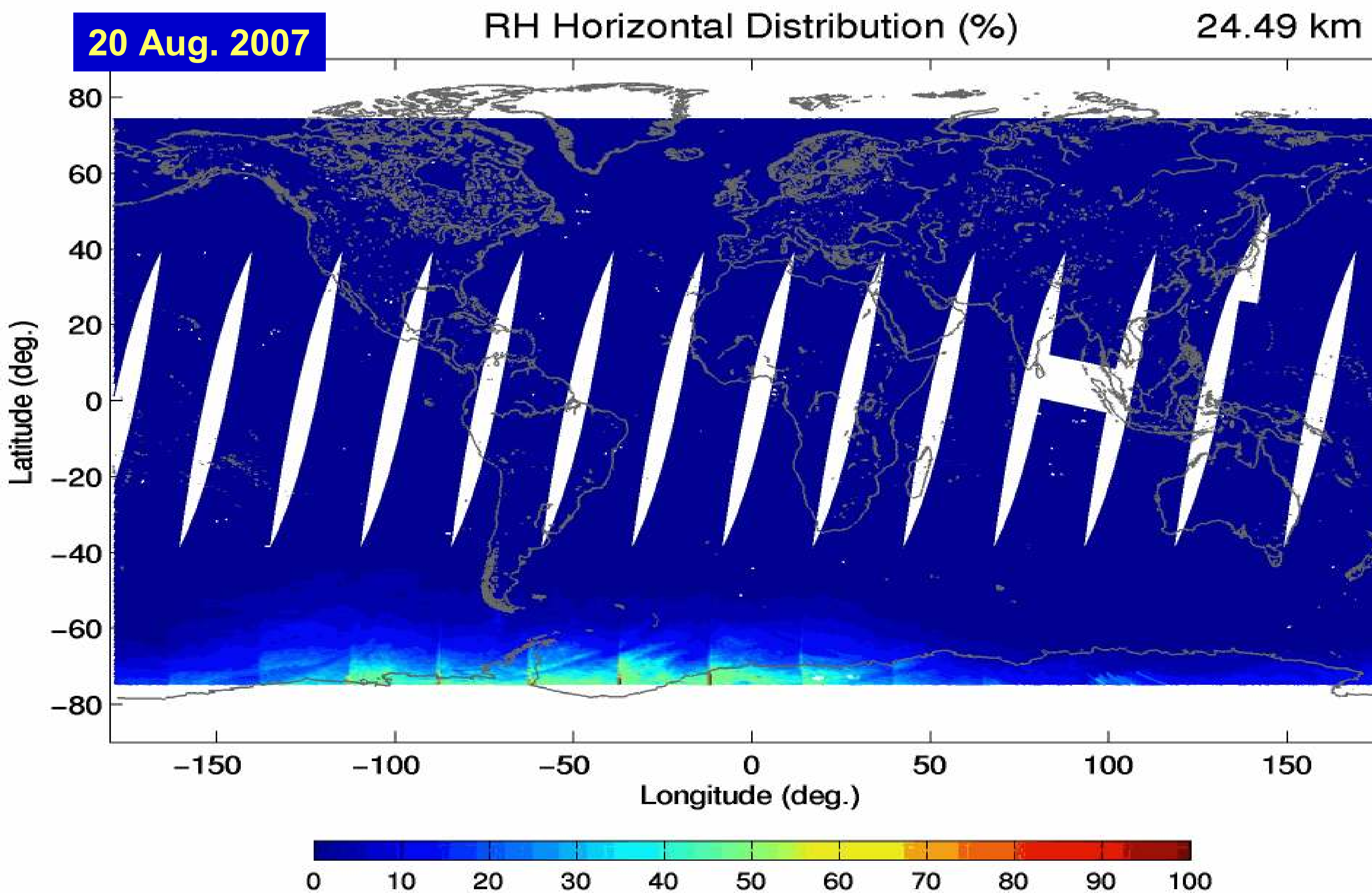
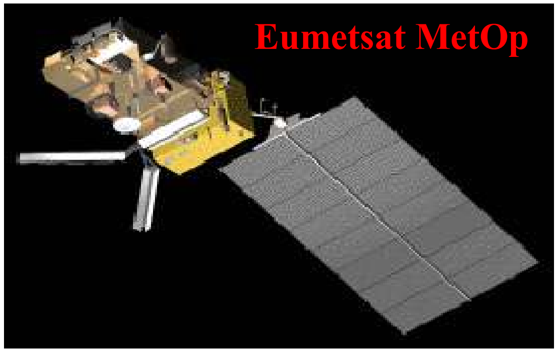
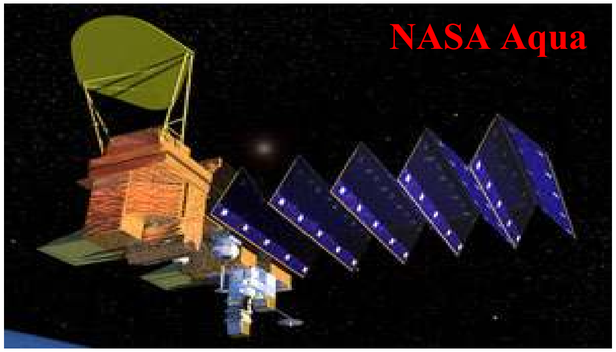
IASI Retrieval Demo: Moisture Distribution

20 Aug. 2007



Joint Airborne IASI Validation Exp. (JAIVEx)





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:

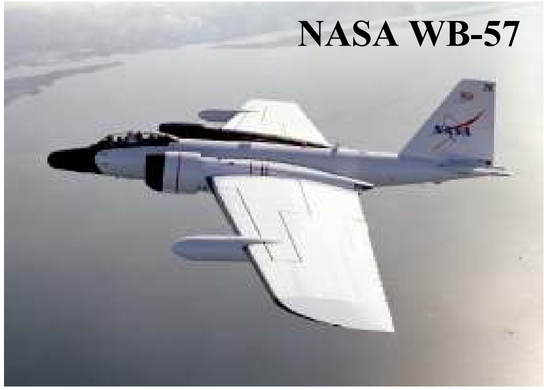
- **Metop (IASI, AMSU, MHS, AVHRR, HIRS).**
- **A-train (Aqua AIRS, AMSU, HSB, MODIS; Aura TES; CloudSat; and Calipso).**

Ground-sites:

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

Participants:

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



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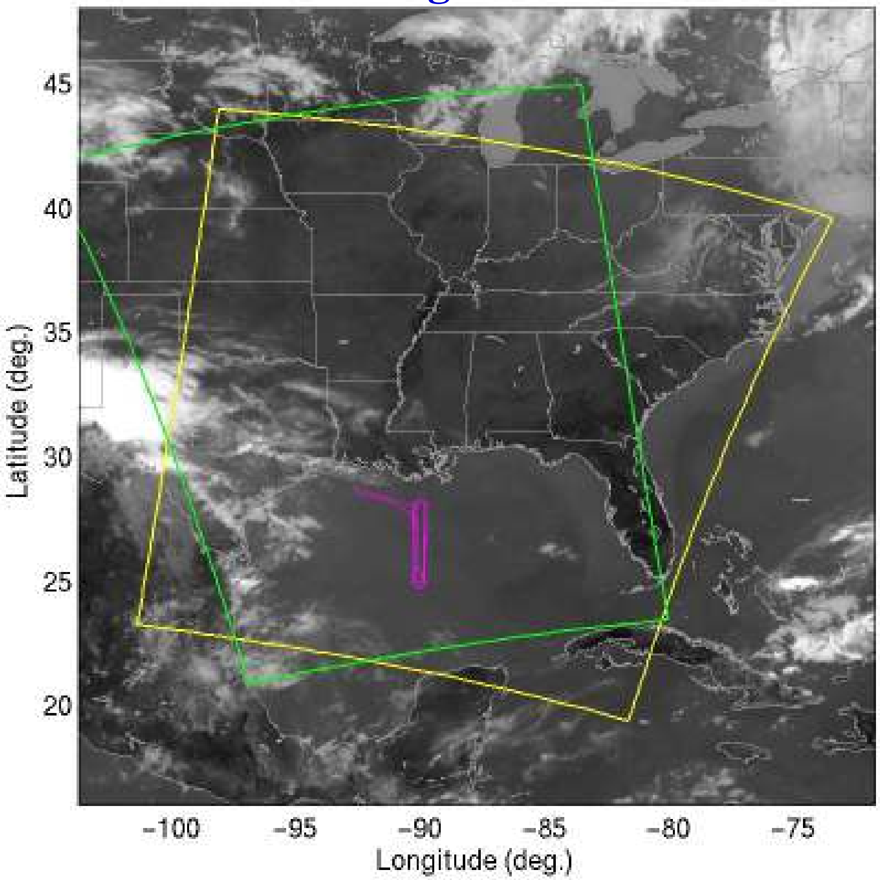
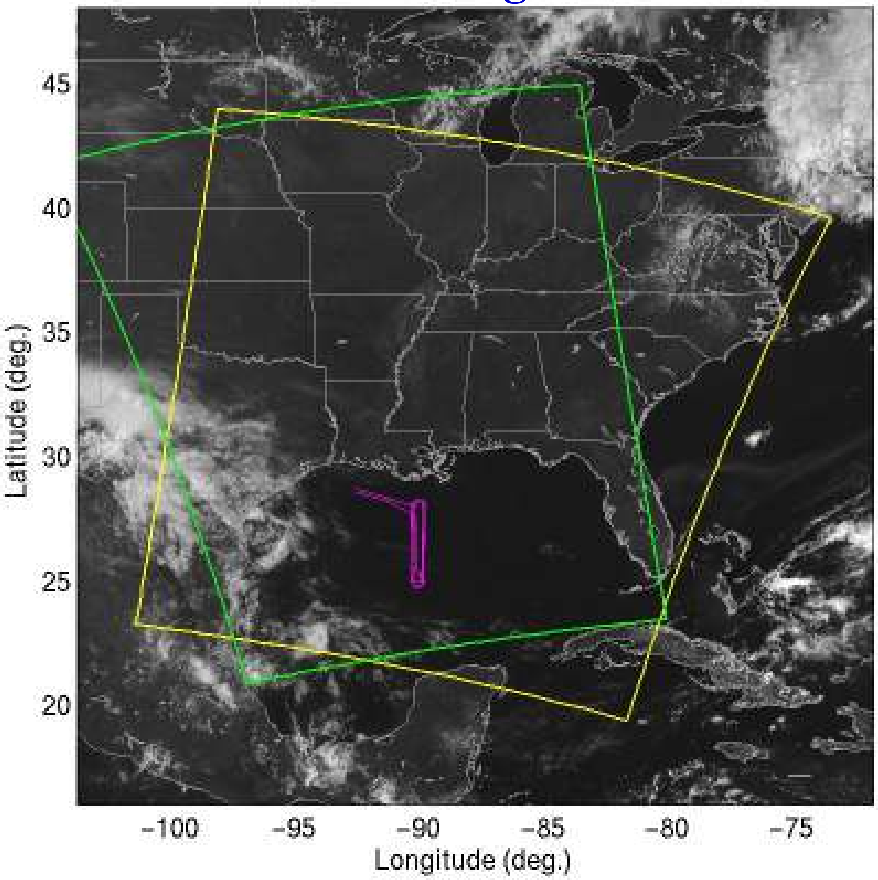
JAIVEx Case Study - Validation (2007.04.29)

GOES-12 IR image



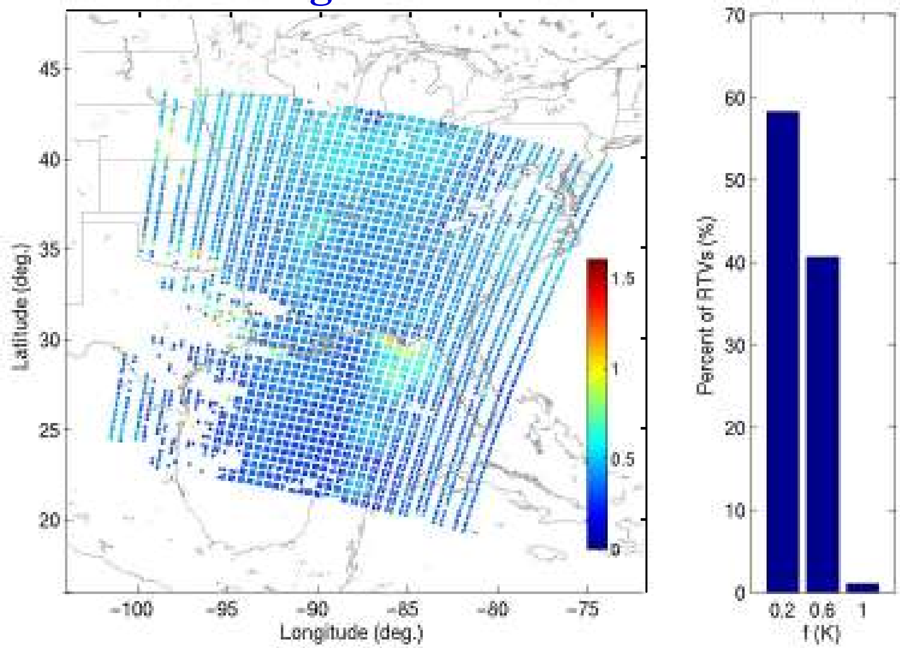
GOES-12 visible image



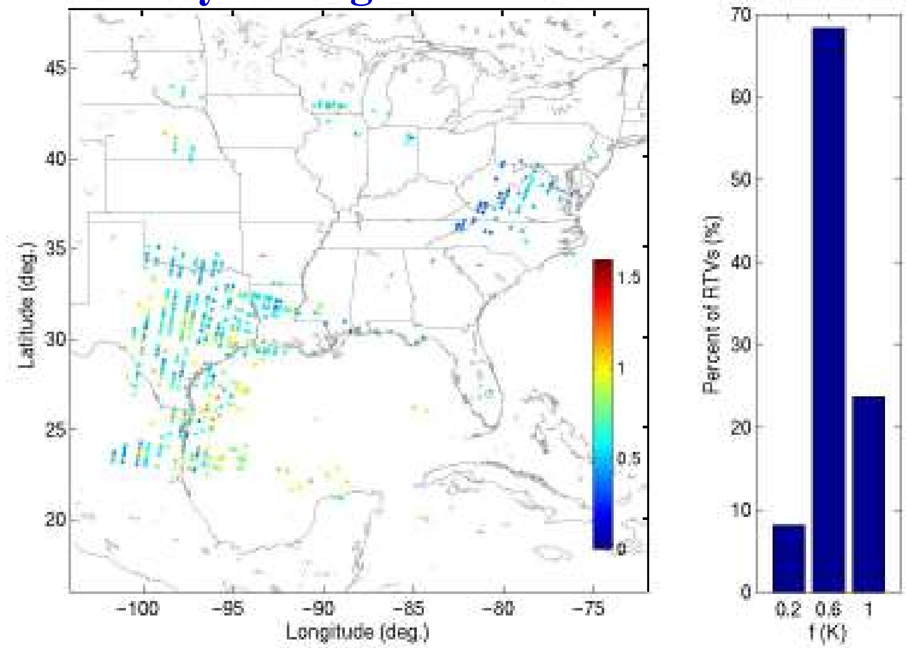
Retrieval Consistency Check: fitting residual

<u>**Fitting Residual:**</u> **STD of the difference between measured and retrieval simulated brightness temperature over physical retrieval channels.**

Clear Fitting Residual

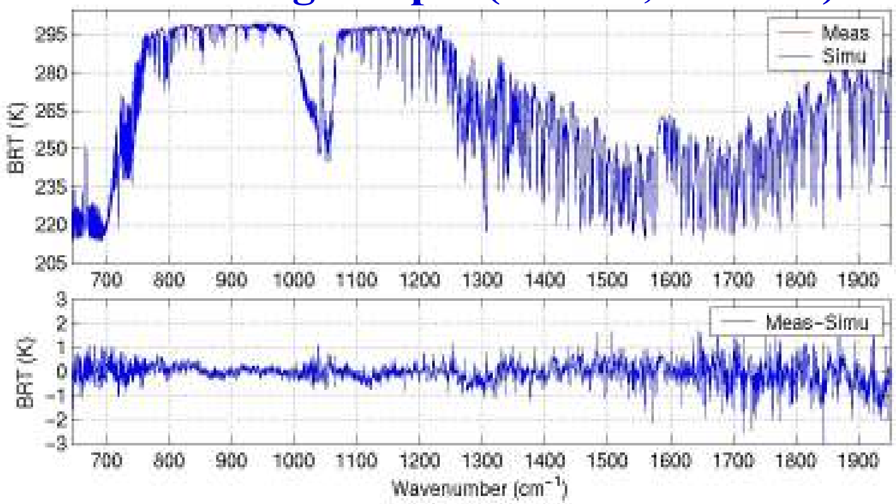


Cloudy Fitting Residual

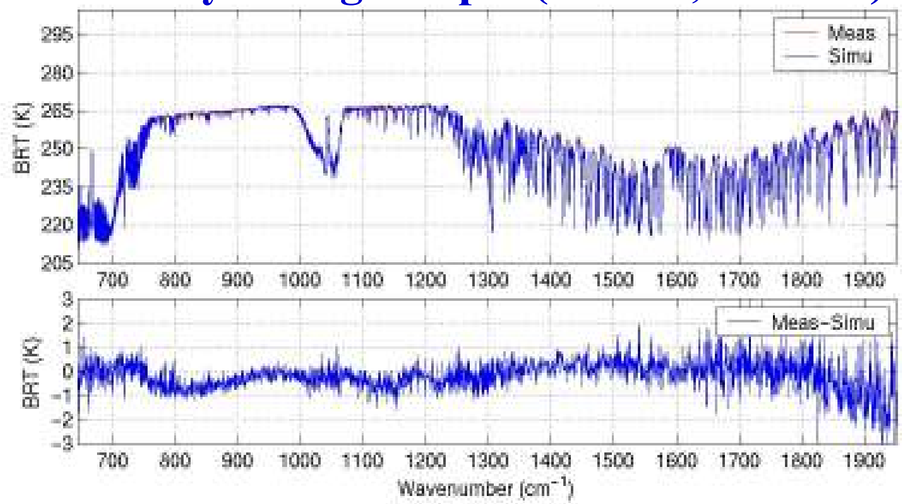


Retrieval Consistency Check: Fitting Statistics

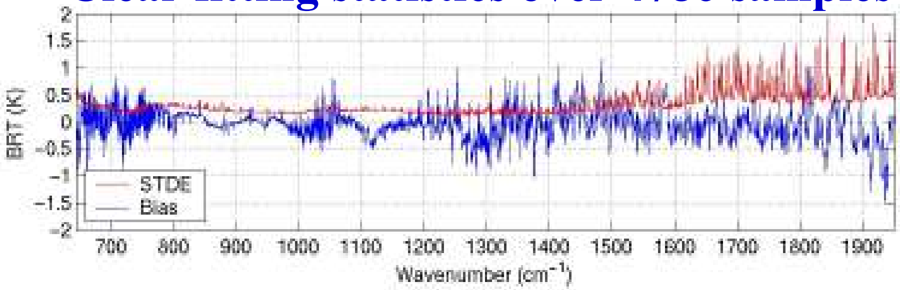
Clear fitting sample (35.36N, 93.67W)



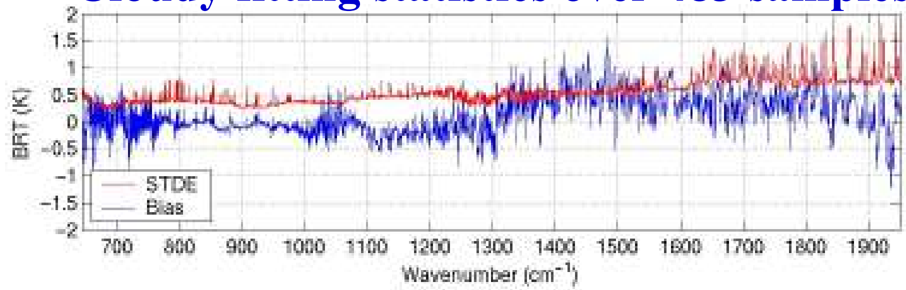
Cloudy fitting sample (27.51N, 96.18W)



Clear fitting statistics over 4786 samples

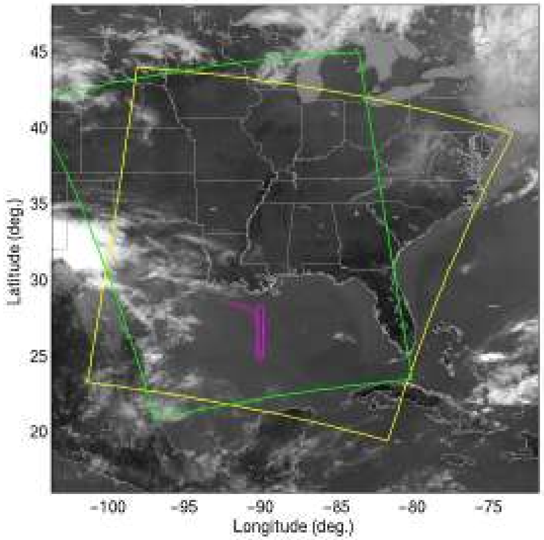


Cloudy fitting statistics over 483 samples

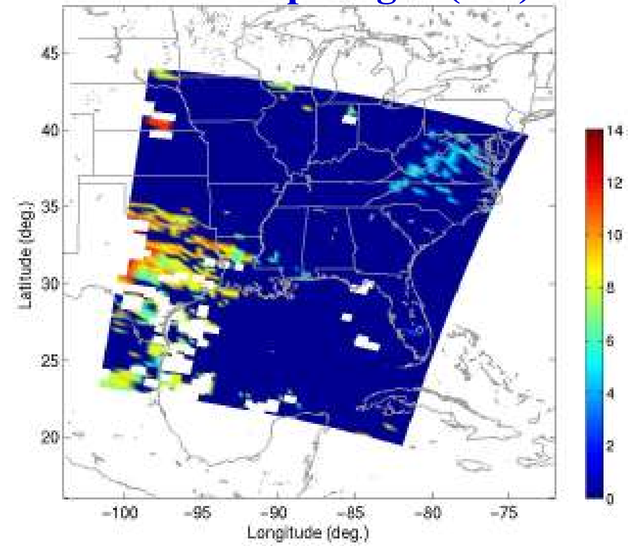


IASI Retrieval: Cloud Parameters

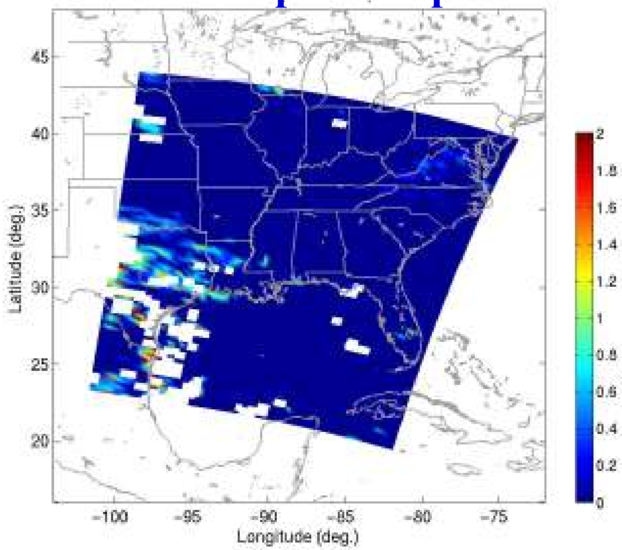
GOES-12 IR image



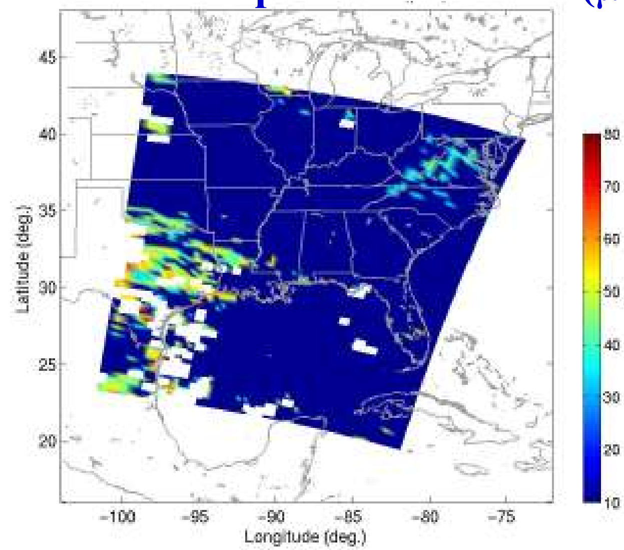
Eff. cloud top height (km)



Cloud eff. Optical depth

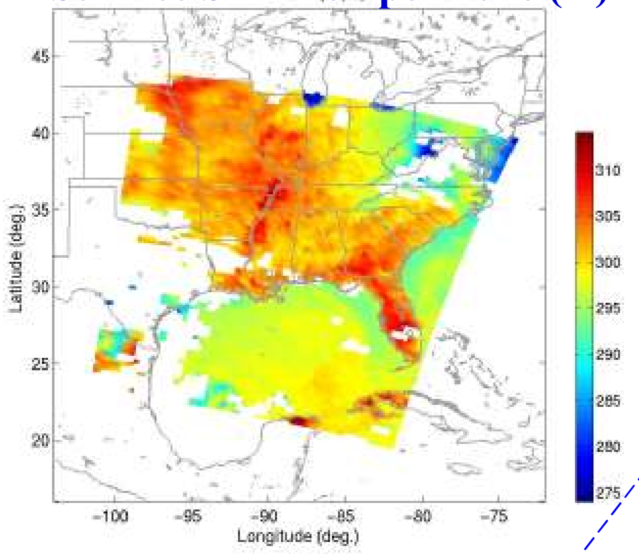


Cloud eff. particle diameter (μm)

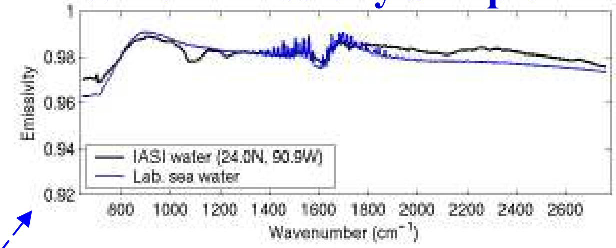


IASI Retrieval: Surface Parameters

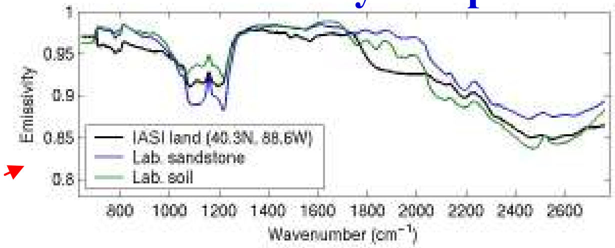
Surface Skin Temperature (K)



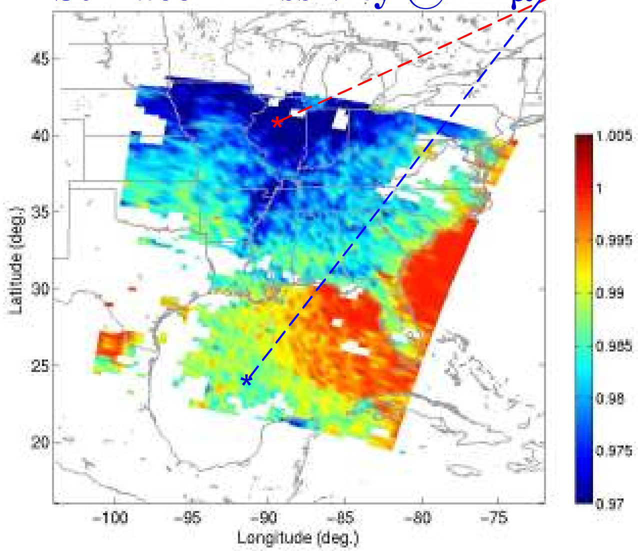
Water Emissivity Sample



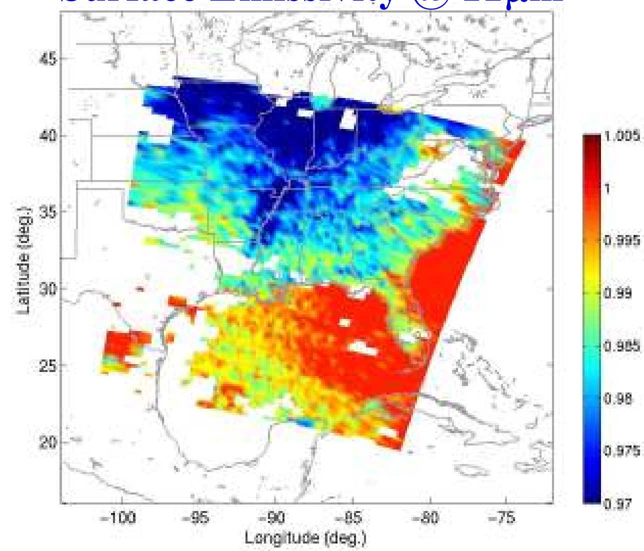
Land Emissivity Sample



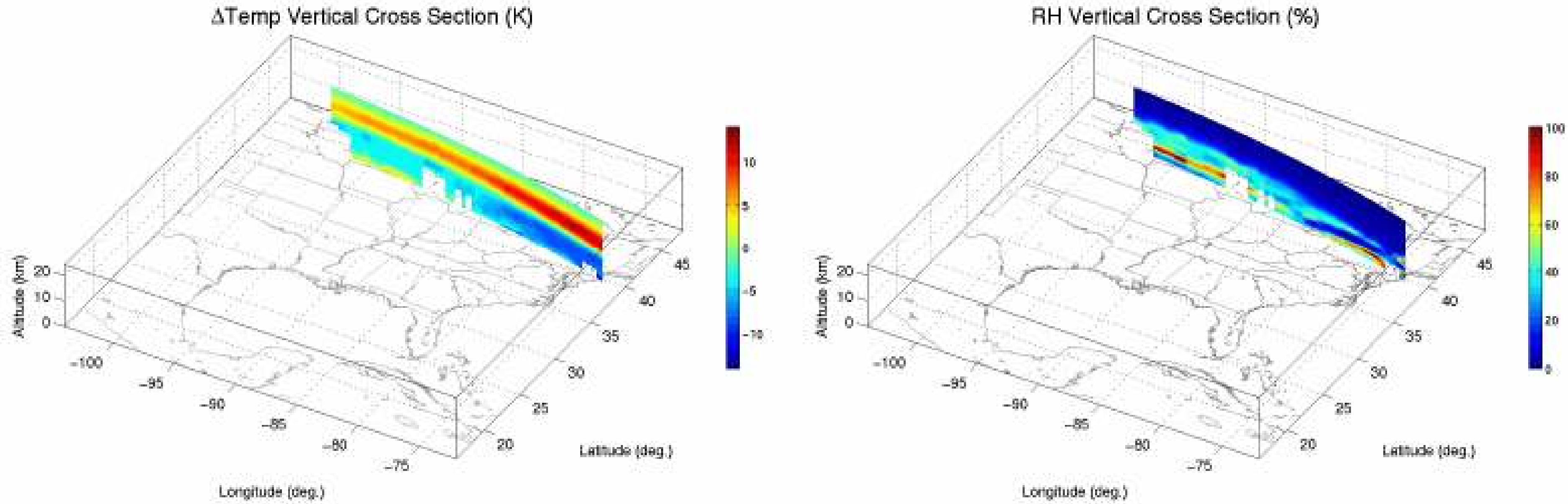
Surface Emissivity @ 12 μm



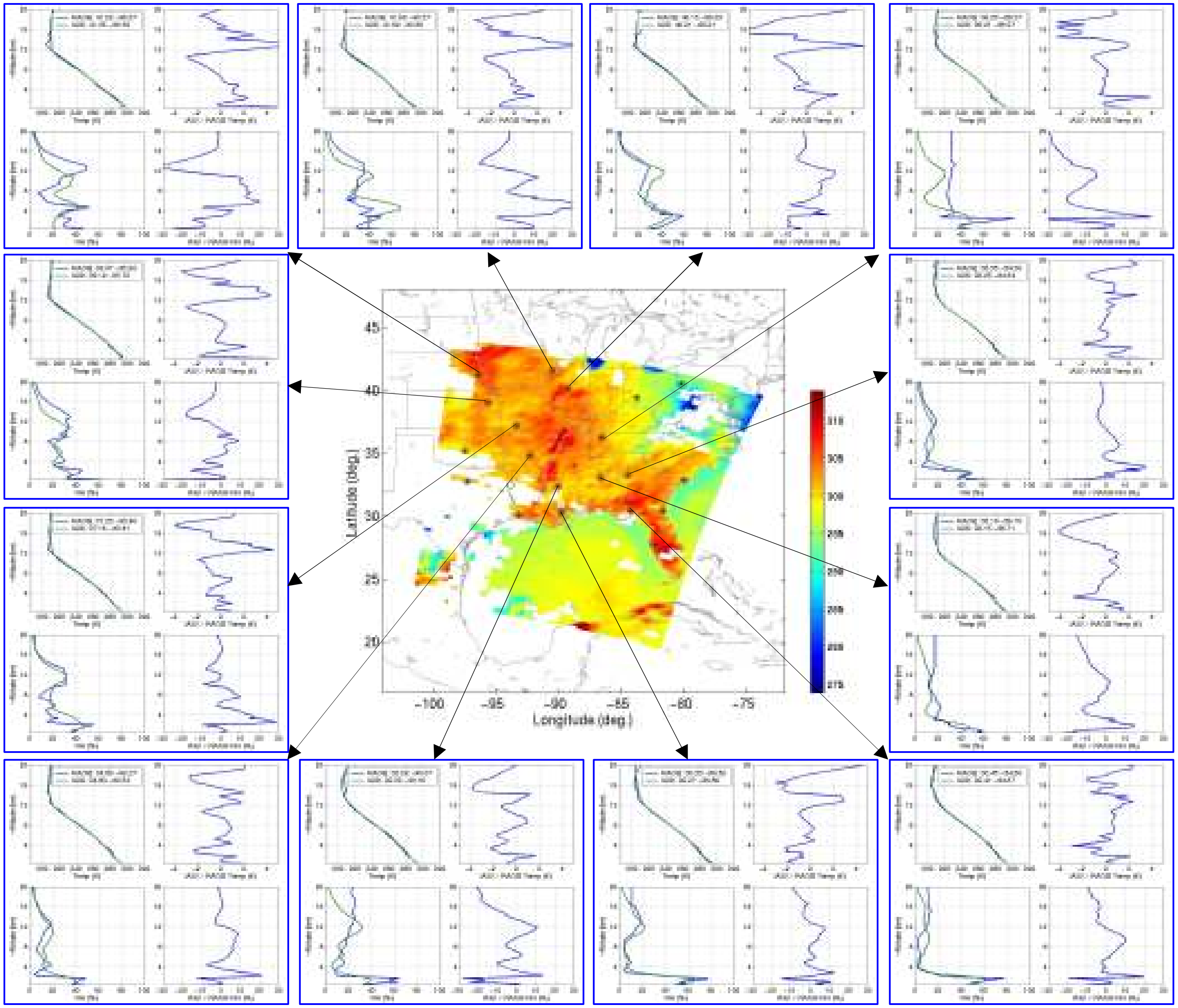
Surface Emissivity @ 11μm



IASI Retrieval: ΔTemp and RH Fields

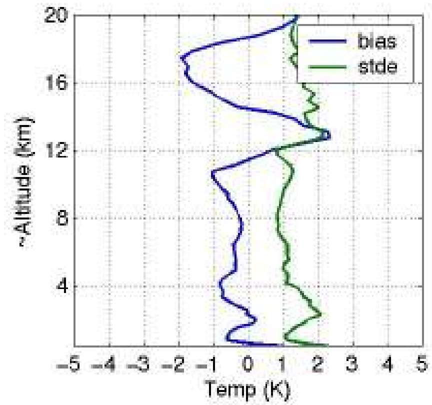


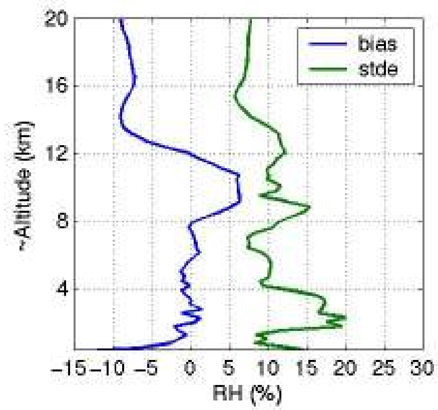
IASI Retrievals vs. Radiosondes



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

Radiosonde and IASI retrieval comparison and statistical profiles over 20 radiosondes





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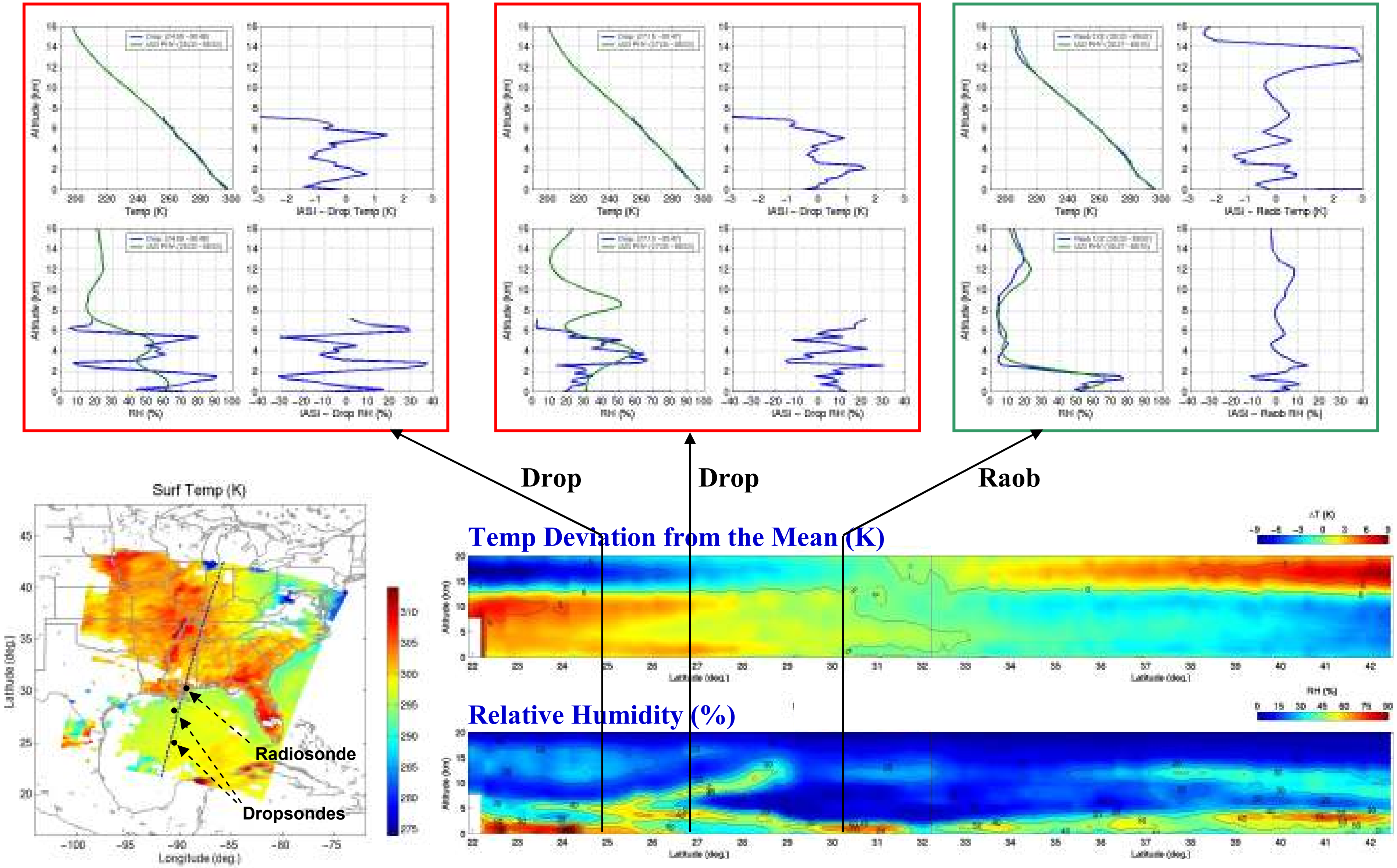
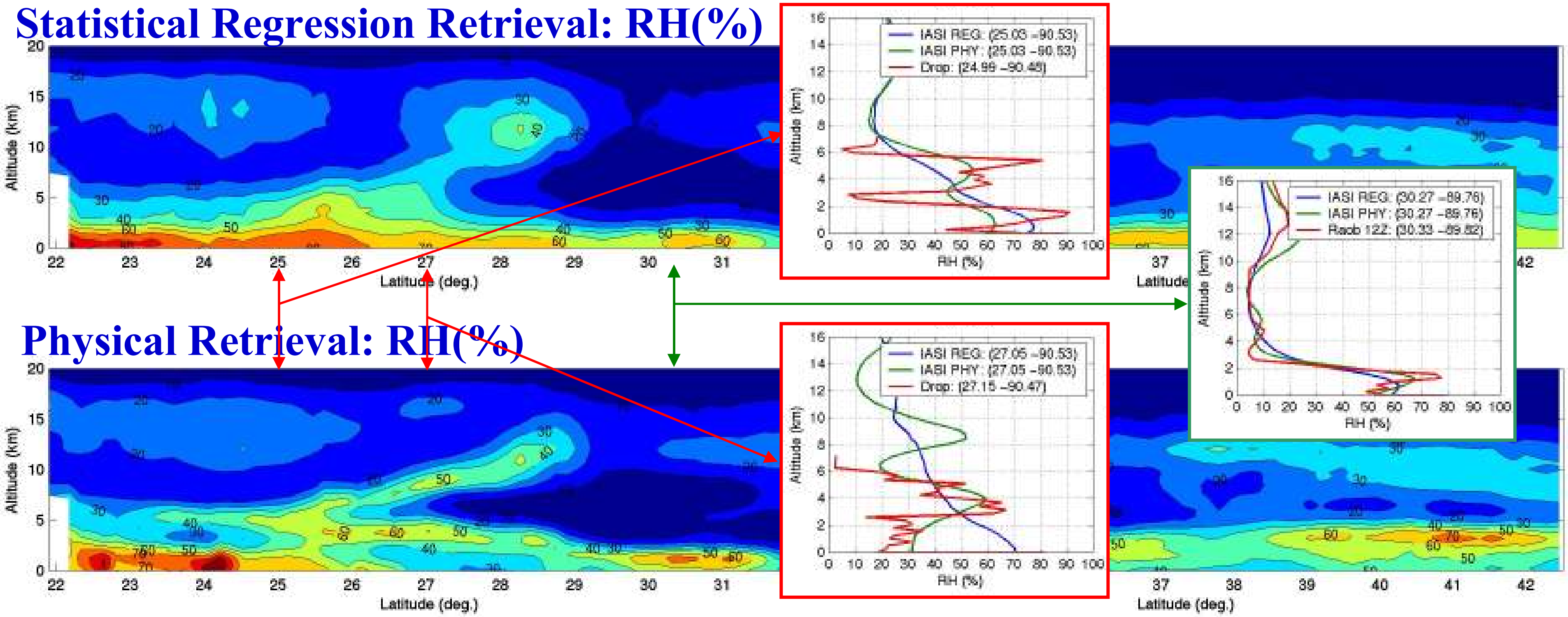
High-Vertically-Resolved Retrievals



IASI Regression vs. Physical Retrieval

Statistical Regression Retrieval: RH(%)

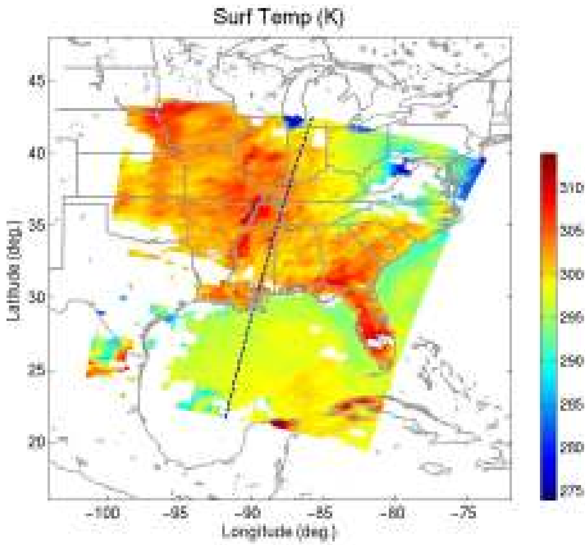
Physical Retrieval: RH(%)

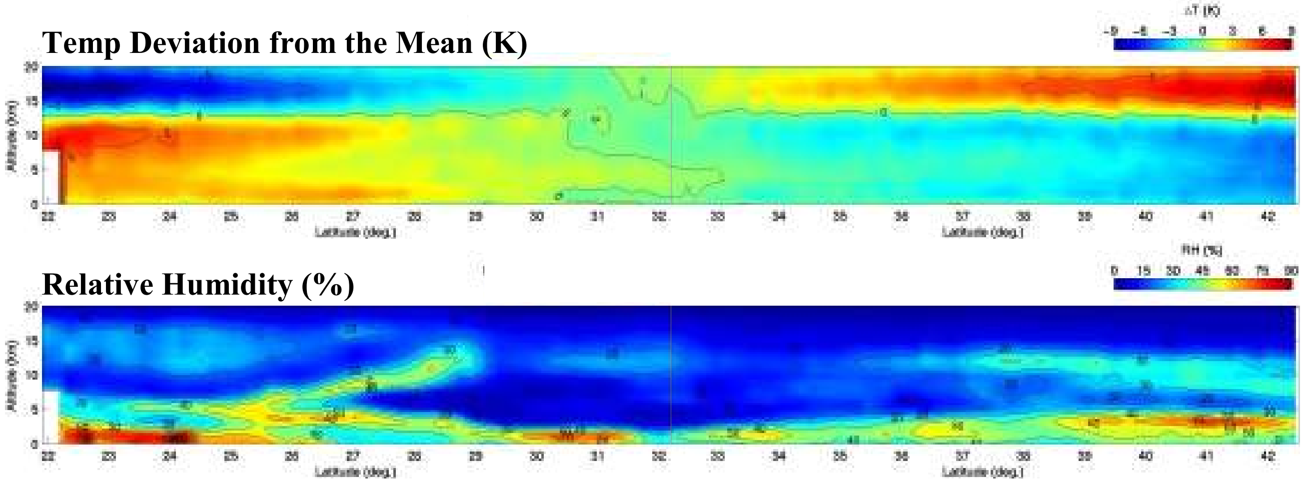


1. **The retrieval improvement based on the EOF statistical regression through physical iterative retrieval is only contributed by IASI measurements as the minimum information methodology used.**
2. **A high-vertically-resolved atmospheric structure is captured very well by IASI measurements and/or retrievals; not only in the troposphere, but also in the boundary layer.**

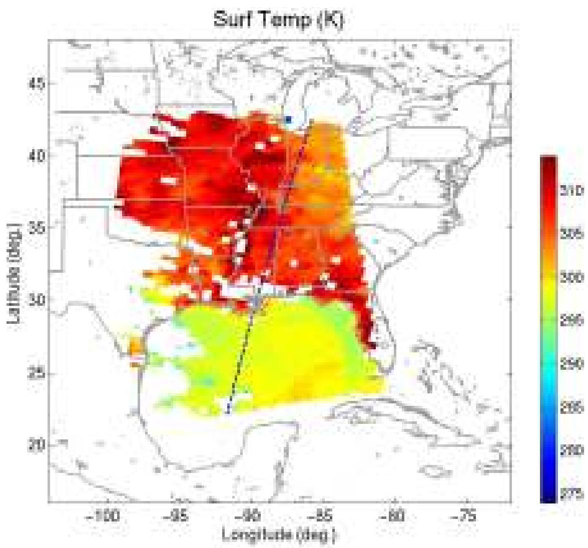
IASI (15:48 UTC) vs. AIRS (19:30 UTC)

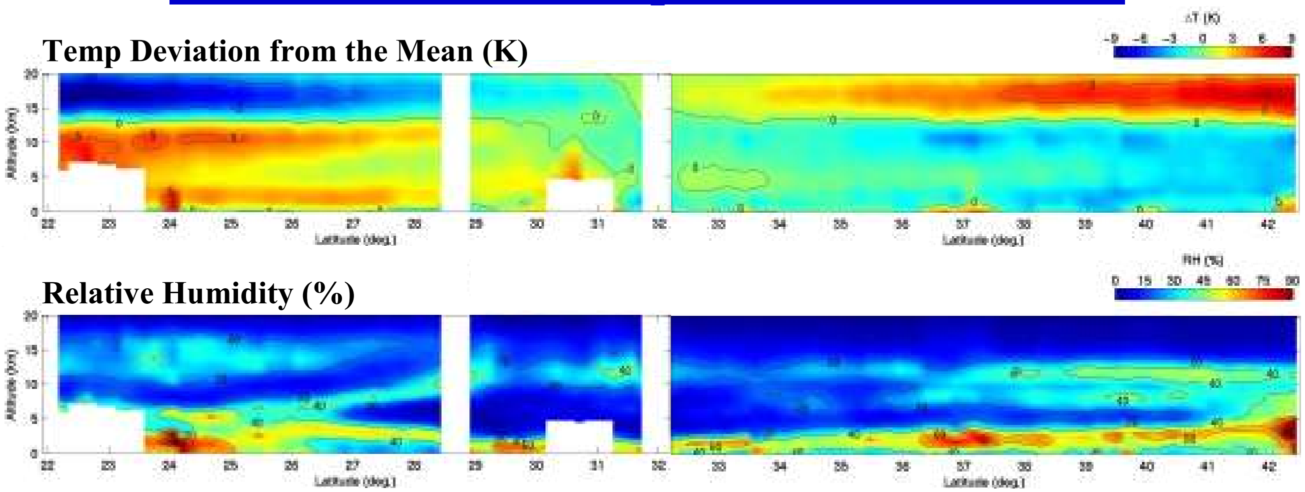
IASI Retrieval



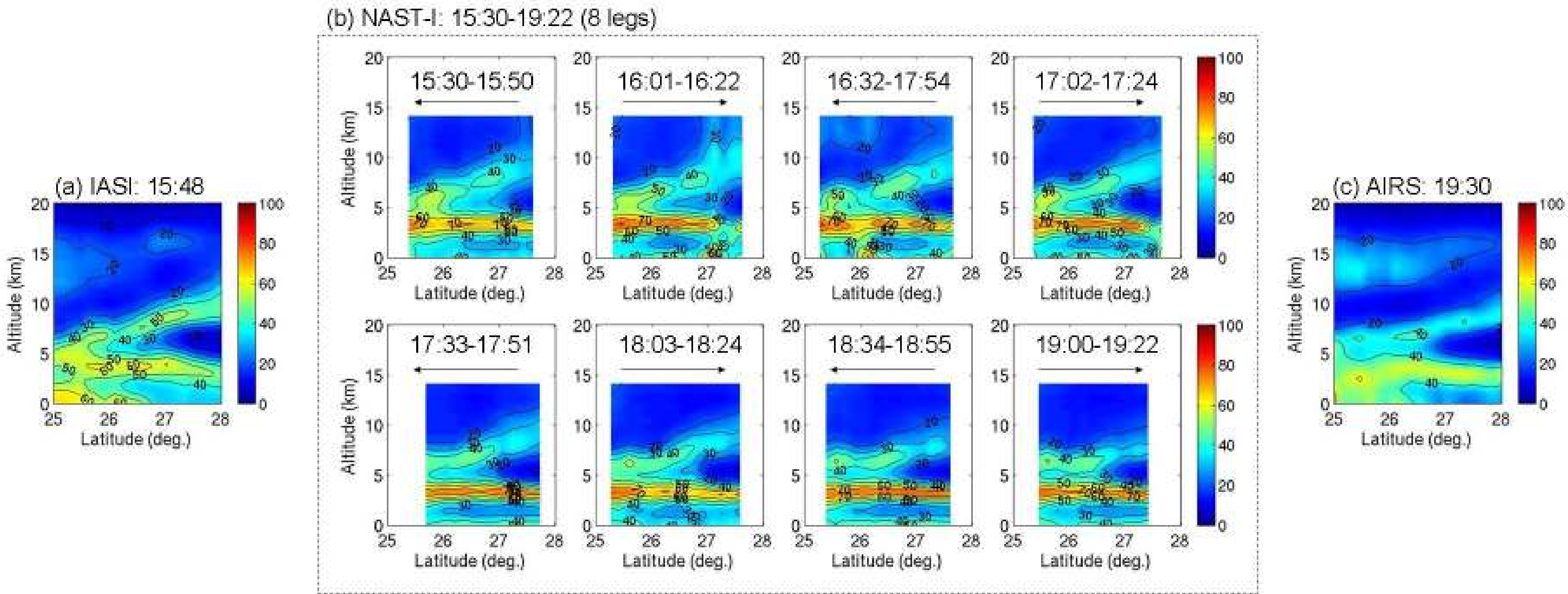


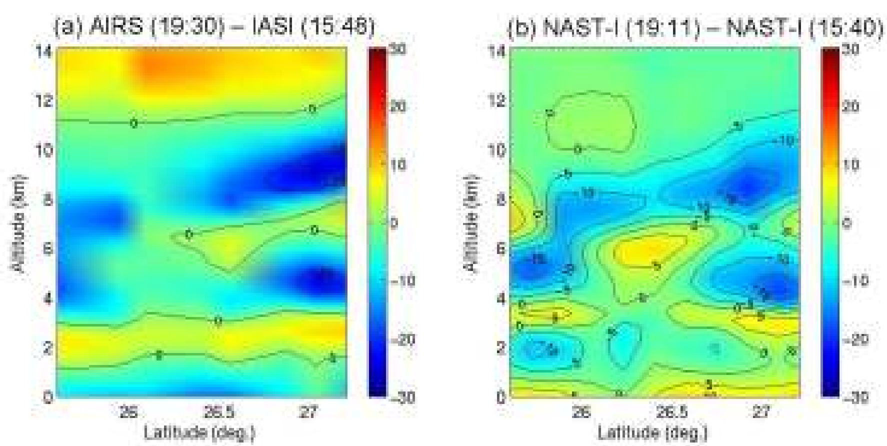
AIRS Retrieval Interpolated to IASI FOV





NAST-I: Connection between IASI and AIRS





Difference is mainly due to

- **instrument difference between IASI and AIRS,**
- **spatial resolution difference between NAST-I and IASI (or AIRS), and**
- **retrieval uncertainty including radiative transfer models difference.**

Summary and Future Work

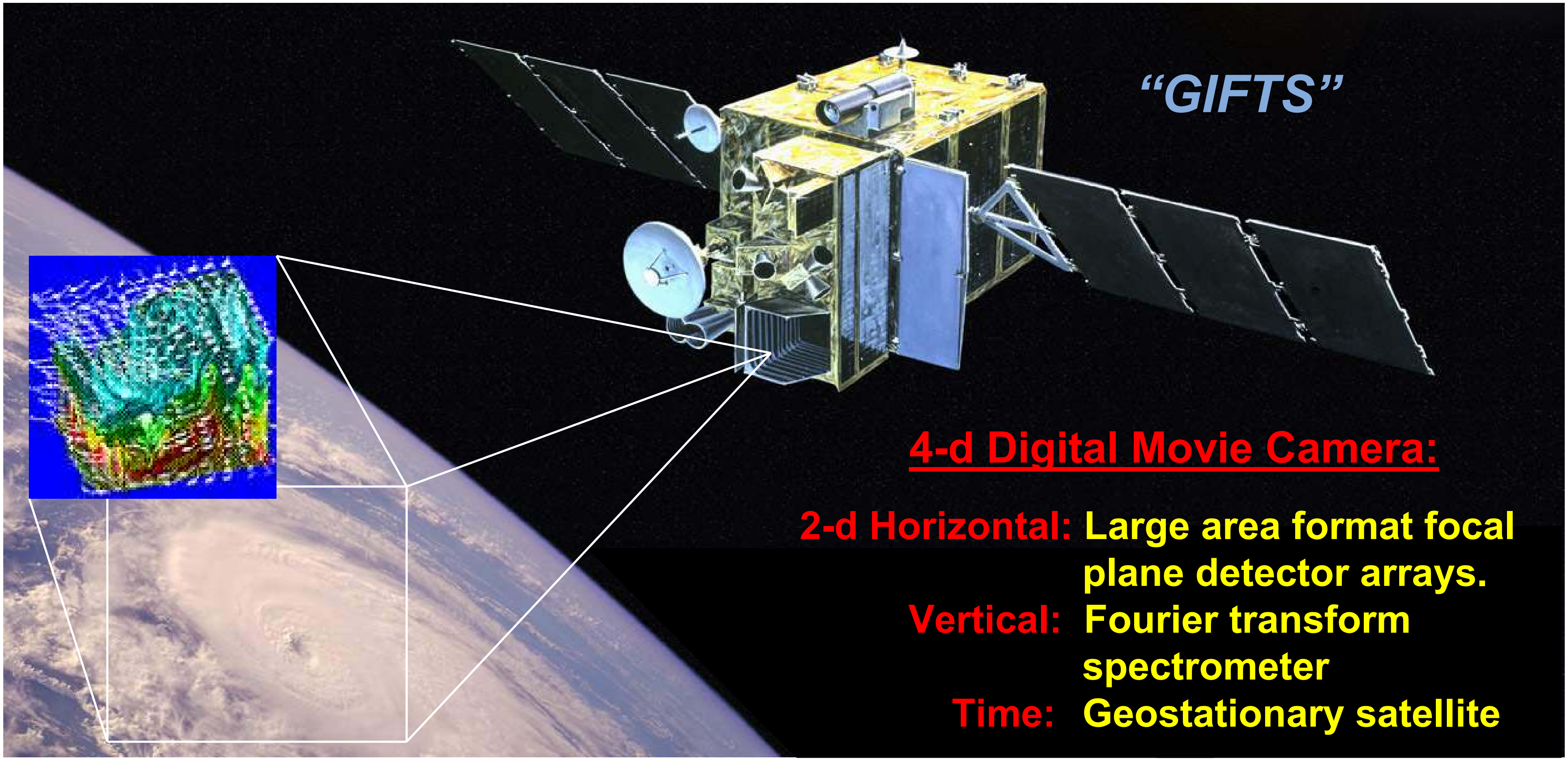
1. A state-of-the-art IR-only retrieval algorithm has been developed with an all-seasonal globally representative EOF physical regression and followed by 1-D Var. physical iterative retrieval for IASI, AIRS, and NAST-I.
2. The benefits of this retrieval are to produce atmospheric structure with a single FOV horizontal resolution (12 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 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.

Fine-scale atmospheric horizontal features with high vertical resolution from satellite global observations with advanced ultra-spectral instruments have been realized for the first time.

Geosynchronous Imaging FTS (GIFTS)

Revolutionary Technology for Observing Atmospheric Temperature, Moisture, Winds, and the Transport of Pollutant Gases

An Opportunity for Greatly Improved Environmental Forecasts

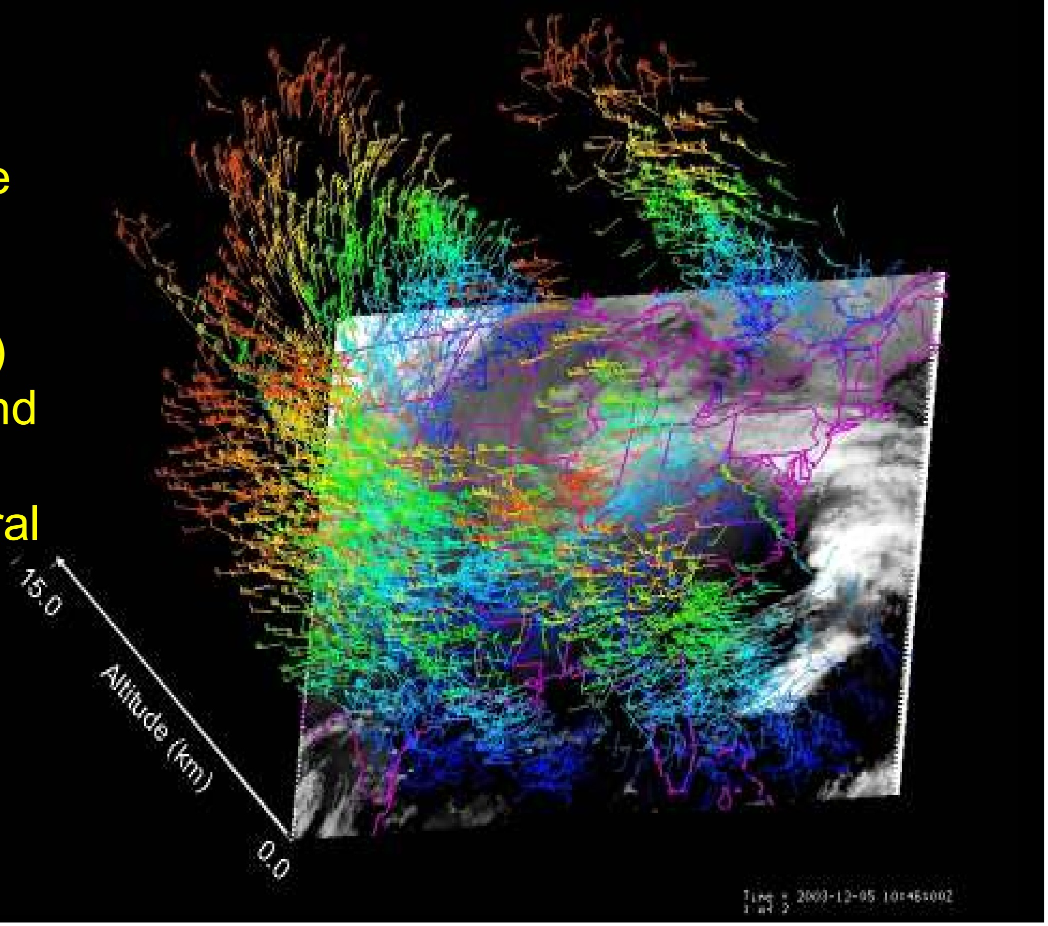


GIFTS Science Objective Demo

Wind Profile Objective:

High resolution, vertical (1-2 km) and horizontal (50 km), cloud and water vapor wind profiles with a 4 m/s accuracy.

An algorithm to derive clear-sky, altitude-resolved atmospheric motion vectors (AMV) is being developed and evaluated using simulated ultra-spectral data based on the GIFTS instrument [Velden et al., 2004; 2005].



GIFTS Science Objectives

Science Products:

- Water vapor (soundings, fluxes, winds): $\varepsilon <$ 20% per 1-2 km layers
- Temperature (sounding, stability): $\varepsilon <$ 1°K per 1-2 km layers
- Wind Velocity: $\varepsilon <$ 4 m/s per 2 km layers
- Carbon monoxide concentration (2 Layers): $\varepsilon <$ 10% per 5 km layers
- Ozone concentration (4 Layers): $\varepsilon <$ 10% per 8 km layers
- Surface Temperature: $\varepsilon <$ 0.3°K for sea; $\varepsilon <$ 1°K for land
- Aerosol Concentration and Depth: $\varepsilon <$ TBD
- Clouds (altitude, optical / microphysical properties, “winds”)

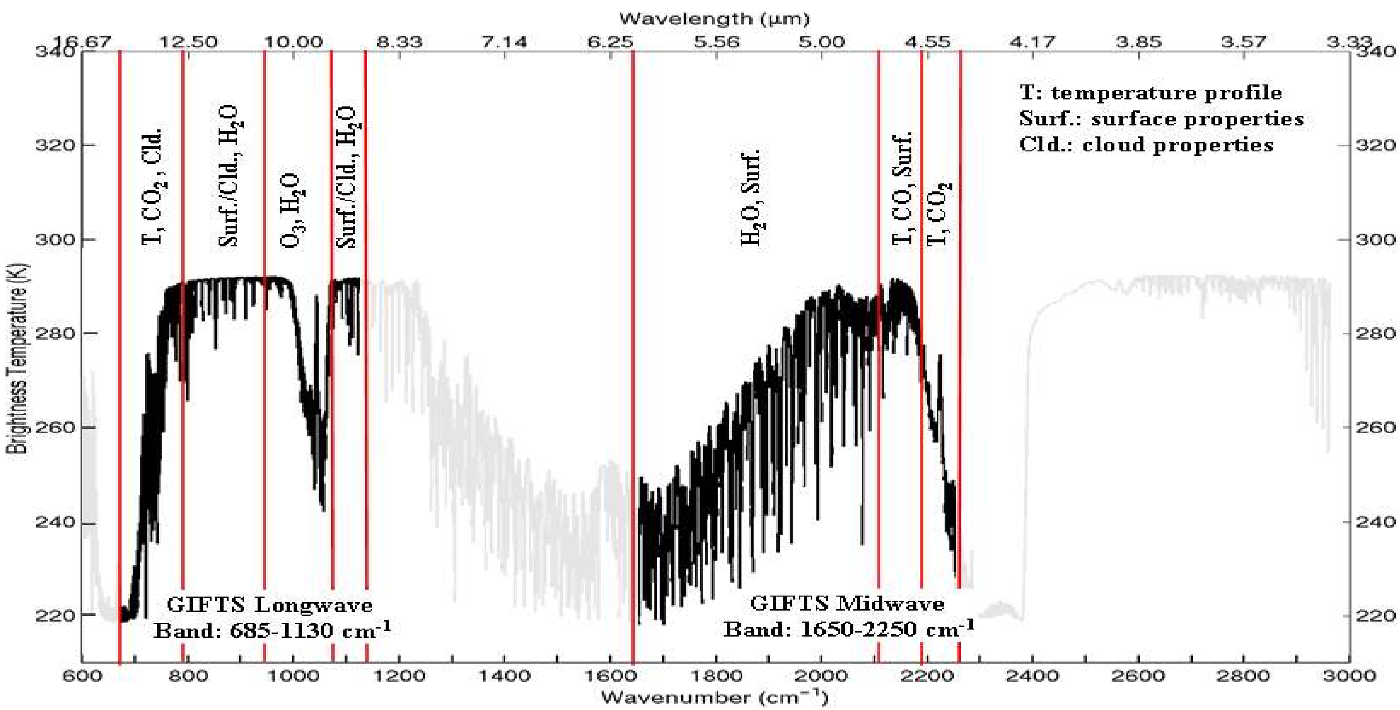
GIFTS Sampling Characteristics:

- Two 128x 128 Infrared focal plane detector arrays with 4 km footprint size
- A 512 x 512 Visible focal plane detector arrays with 1 km footprint size
- Field of Regard 512 km x 512 km at satellite sub-point
- 11 second full spectral resolution integration time per Field of Regard
- ~ 80,000 Atmospheric Soundings every minute

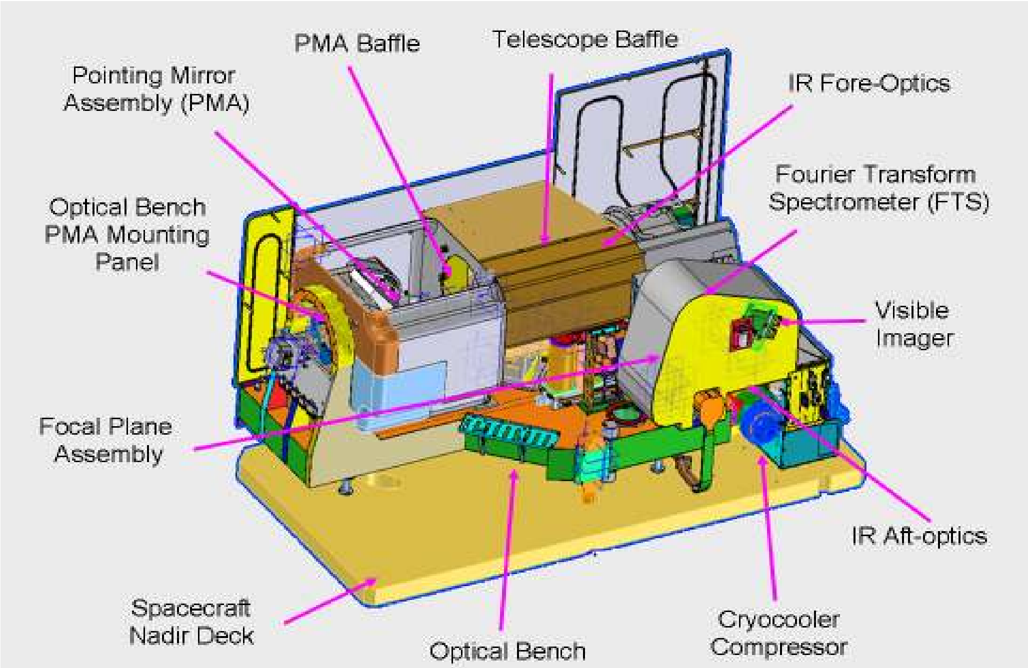
GIFTS Spectral Radiance Accuracy

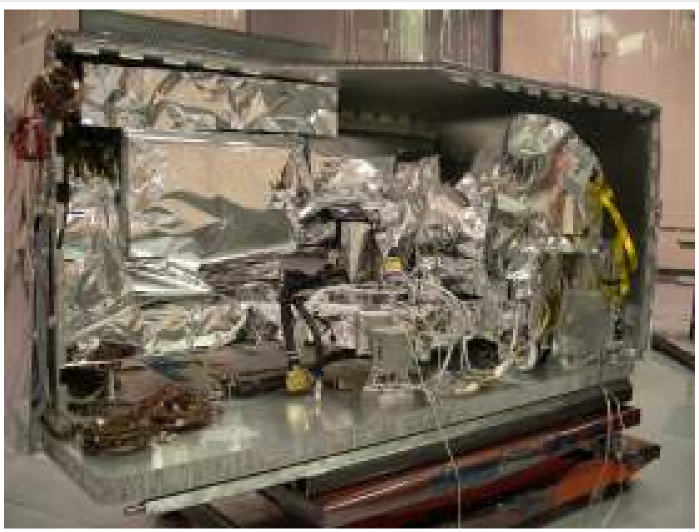
Spectral Radiance Accuracy Objective:

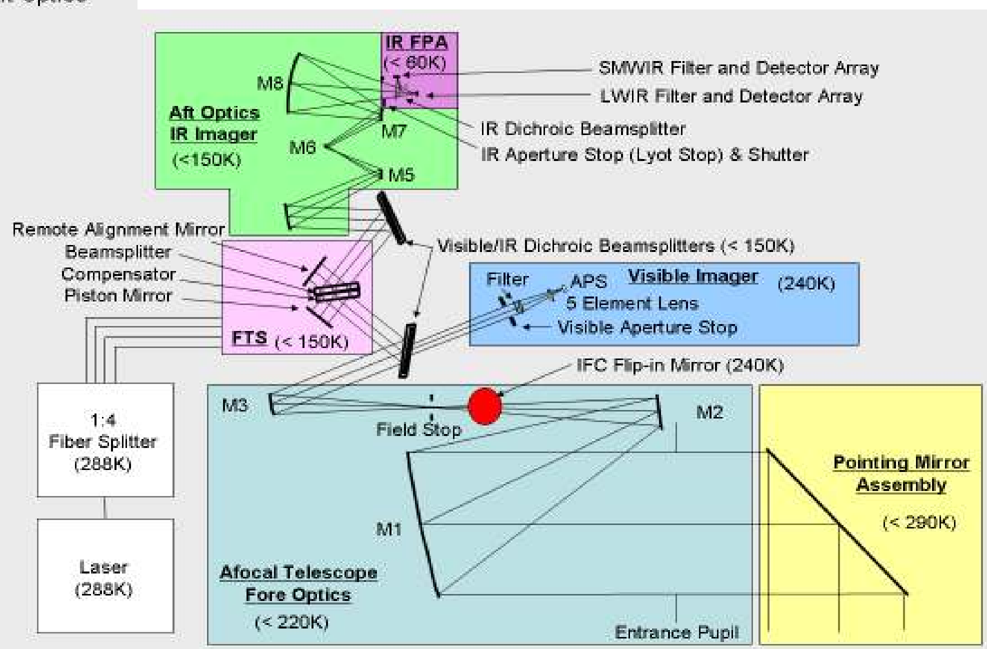
- **Spectral Coverage:** 680-1150 cm^{-1} and 1650-2250 cm^{-1}
- **Spectral Resolution:** 0.6 cm^{-1}, unapodized
- **Spectral Stability:** 1 part per 106 (3 sigma)
- **Absolute Radiometric Accuracy:** 1.0 K (3 sigma)
- **Radiometric Noise:** LW Band: 0.4 (mW/m^2 cm^{-1} str)
  SW Band: 0.06 (mW/m^2 cm^{-1} str)



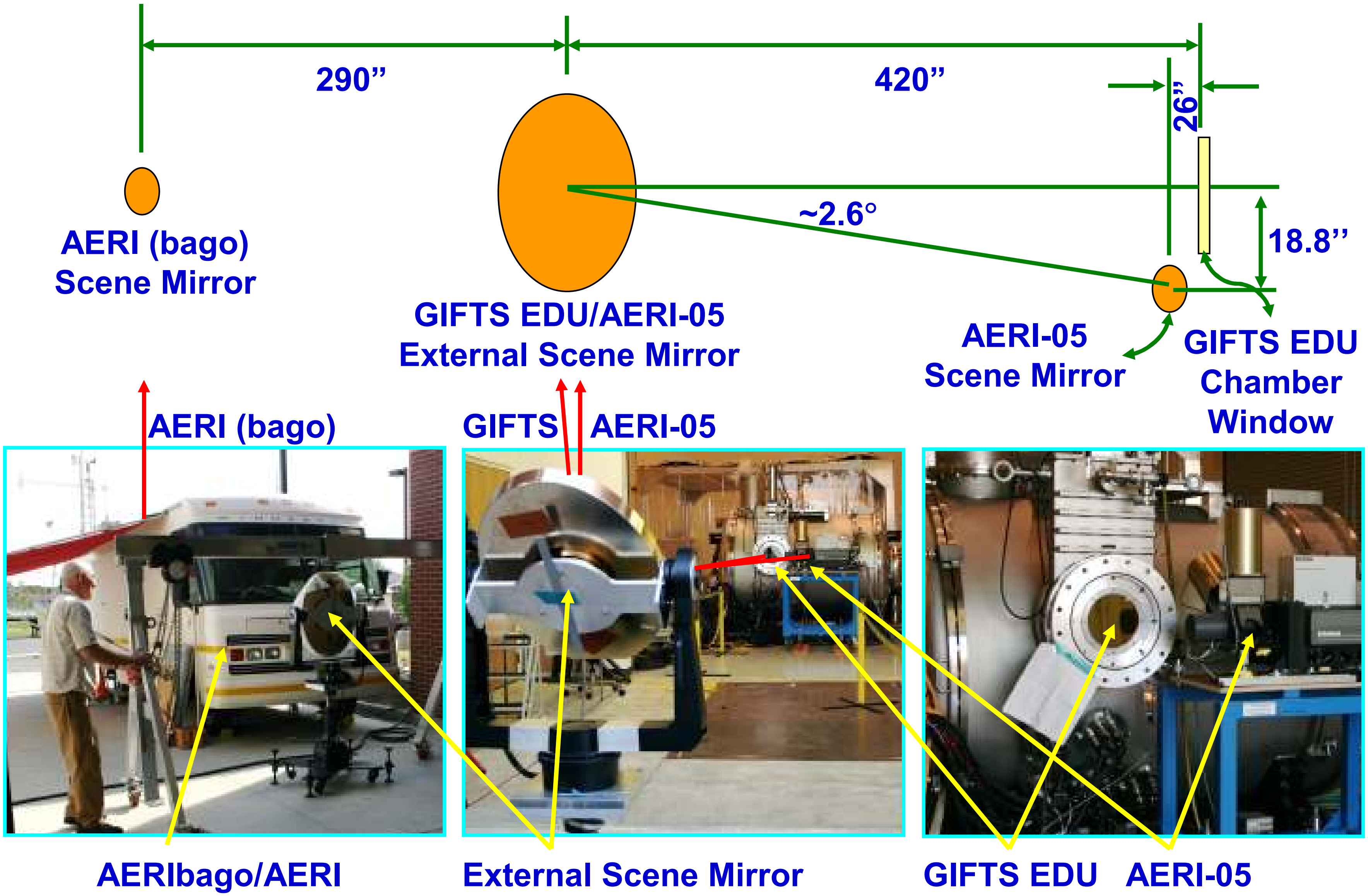
Components & Optical System Ray Trace





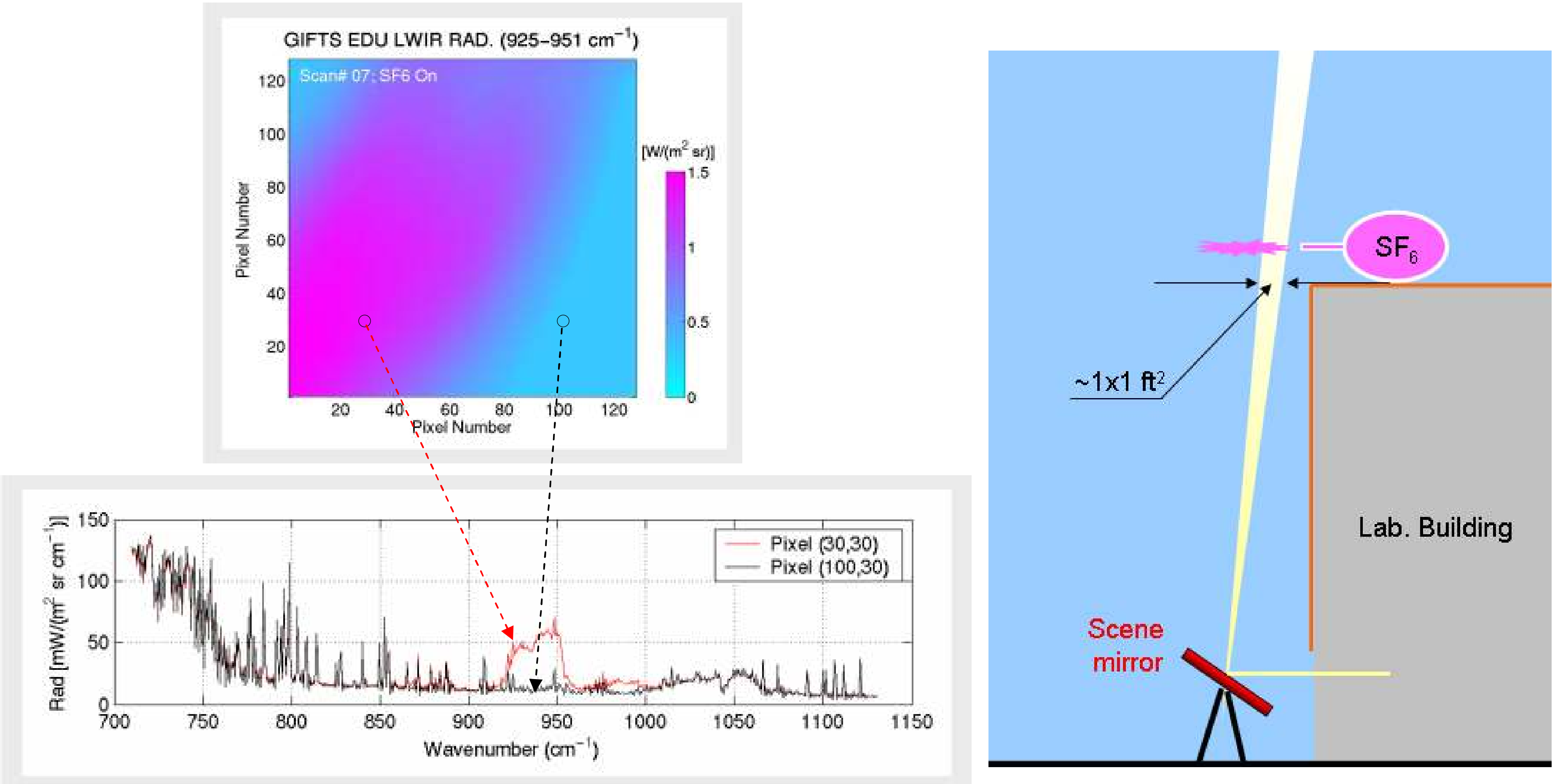


GIFTS EDU Ground Based Experiment



Ground Based Experiment: OME

To demonstrate GIFTS 4-D observation ability with the GIFTS EDU on the ground, an experiment called Outgas Monitoring Event (OME) is designed to monitor both temporal and spatial variations of the atmosphere with the GIFTS EDU when Sulfur Hexafluoride (SF_6) gas is released in the near field



Langley Research Center

Ground Based Experiment: OME

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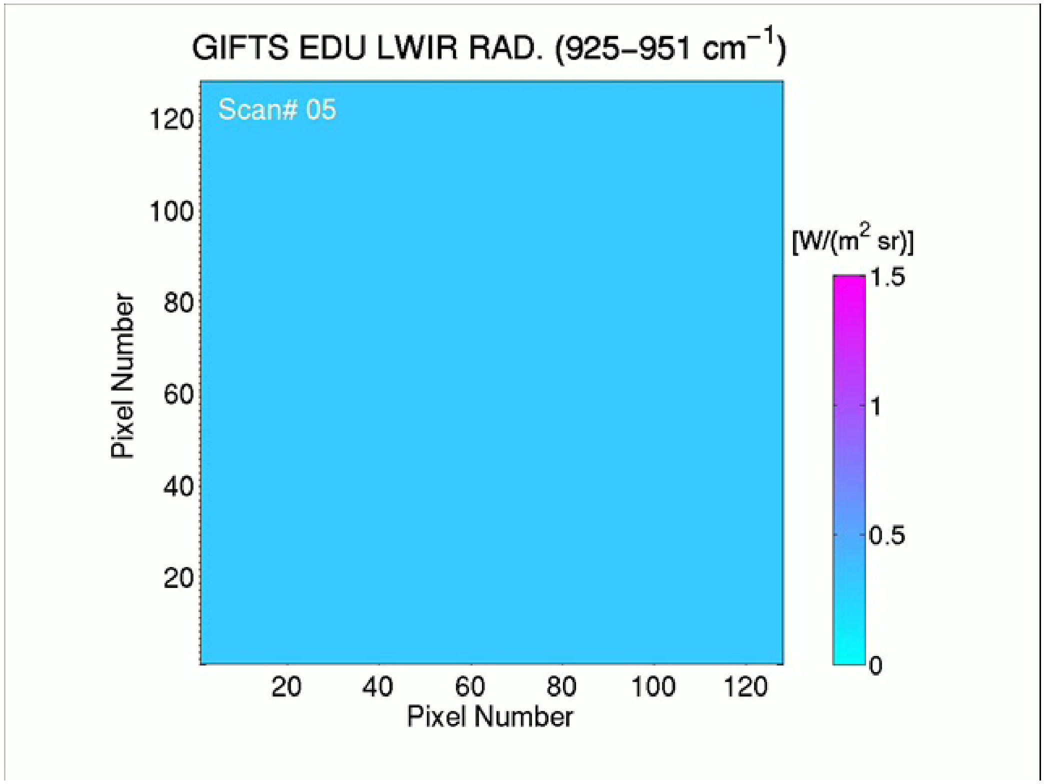
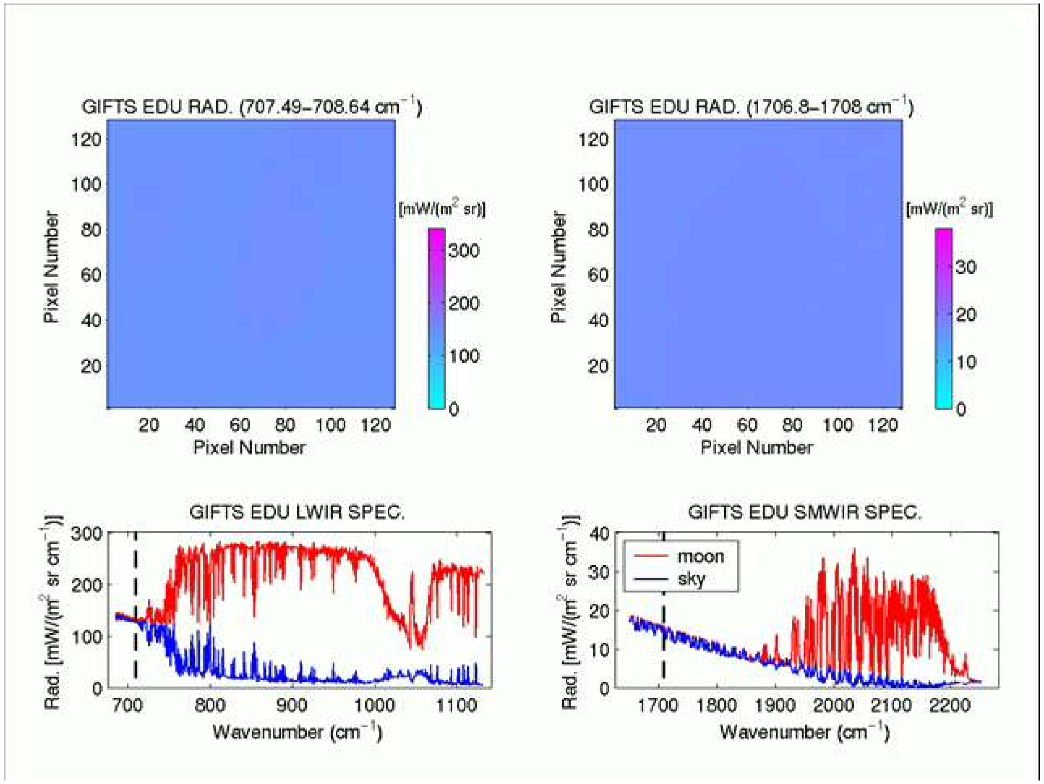


Illustrations of SF6 outgas measurements provided by the GIFTS EDU on 18 September 2006 – a demonstration of the GIFTS image tracking ability.

Langley Research Center

Ground Based Experiment: MTE

One of the fundamental advantages of the GIFTS concept is illustrated by the spectral images shown in the video below, an example of the lunar and atmospheric images obtained with two GIFTS infrared detector arrays indicating that the lunar and atmosphere image is a function of wavenumber.



Illustrations of lunar and atmospheric measurements provided by the GIFTS EDU on 11 September 2006 – a demonstration of the GIFTS imaging spectrometer measurement ability.

Fine-scale atmospheric horizontal features with high vertical resolution from satellite global observations with advanced ultra-spectral instruments have been realized for the first time.

GIFTS EDU imaging and tracking capability demonstrates that <u>quasi-continuous measurements</u> of the moisture flux can be obtained for timely forecasts of storm intensity changes.