Atmospheric and Surface Property Retrievals from IASI and NAST-I

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and many more….

Presentation Outline

- Introduction
- PCRTM forward model and retrieval algorithm
- Results from IASI and NAST-I
- Conclusions

Introduction

- **Modern hyperspectral sounders have thousands of channels**
  - AIRS (Atmospheric Infrared Sounder): 2378 x 1 x1
  - CrIS (Cross Track Infrared Sounder): 1305 x 3 x 3
  - NAST-I (NPOESS Airborne Sounder Testbed): 8632 x 1 x 1
  - IASI (Infrared Atmospheric Sounding Interferometer) 8461 x 2 x 2
  - GIFTS (Geostationary Imaging Fourier Transform Spectrometer): 1827 x 128 x 128
- **Channel radiances are difficult to calculate**
  - Double integral non-linear equation

$$
\begin{aligned}
R_\nu = \int_{\Delta\nu} \{ & \varepsilon_\nu B_\nu(T_s) t_{s,\nu} + \int_{p_s}^{0} B_\nu(T(p)) \frac{\partial t_\nu(p,\theta_u)}{\partial p} dp \\
& + (1-\varepsilon_\nu) t_{s,\nu} \int_{0}^{p_s} B_\nu(T(p)) \frac{\partial t_\nu^*(p,\theta_d)}{\partial p} dp + \rho_\nu t_{s,\nu} t_\nu(p_s,\theta_{sun}) F_{0,\nu} \cos\theta_{sun} \} \phi(\nu-\nu') d\nu' \\
= \int_{\Delta\nu} \{ & \varepsilon_{\nu s} t_{\nu,N_{bot}} B_{\nu,s} + \sum_{i=N_{bot}}^{N_{top}} (t_{\nu,i-1} - t_{\nu,i}) B_{\nu,i} + (1-\varepsilon_{\nu s}) t_{\nu,N_{bot}} \sum_{i=N_{top}}^{N_{bot}} (t_{\nu,i}^* - t_{\nu,i-1}^*) B_{\nu,i} \\
& + \rho_s t_{\nu,N_{bot}} t_{sun}(p_s,\theta_{sun}) F_{0,\nu} \cos\theta_{sun} \} \phi(\nu-\nu') d\nu'
\end{aligned}
$$

- **Key to utilizing the high information content of hyperspectral data**
  - Fast and accurate radiative transfer model
    - Explore channel-to-channel correlations
  - Efficient and stable retrieval algorithm
    - Use as many channels as possible to beat down the instrument noise

Description of PCRTM

- **Principal Component-based Radiative Transfer Model (PCRTM)**
  - **predicts PC scores (*Y*) instead of channel radiances (*R*)**
  - **PC scores (super channels) are linearly related to channel radiances**

$$\vec{Y} = A \times \vec{R}^{mono}$$

- **The relationship is derived from the properties of eigenvectors and instrument line shape functions:**

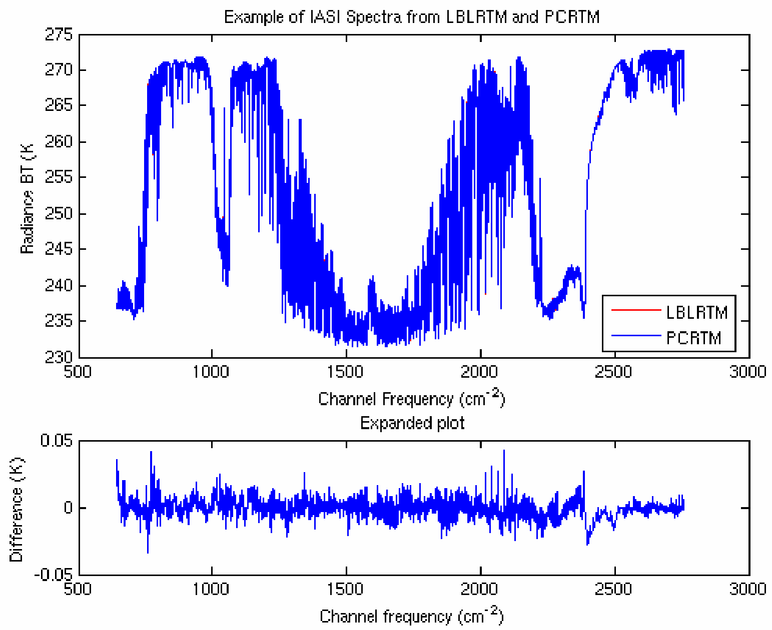
$$\vec{Y} = U^T \times \vec{R}^{chan} \qquad R_i^{chan} = \frac{\sum_{k=1}^{N} \phi_k R_k^{mono}}{\sum_{k=1}^{N} \phi_k}$$

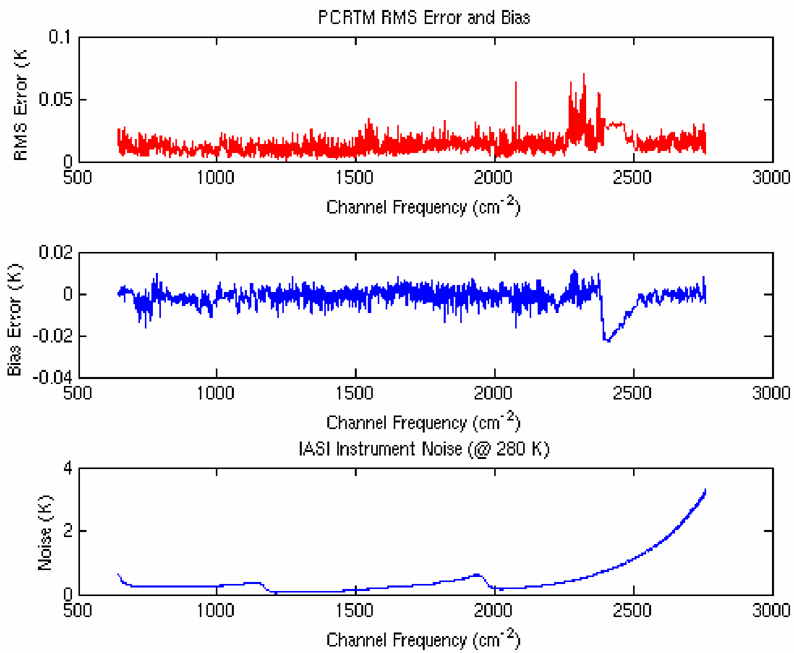
- **Jacobian is provided in EOF space directly**
- **Very accurate relative to LBL**
  - **Accuracy of the model can be adjusted**
- **Cloud contributions included**
- **Channel radiances (or transmittances) can be obtained easily**

$$\vec{R}^{chan} = U \times \vec{Y} = \sum_{i=1}^{N_{EOF}} y_i \vec{U}_i + \vec{\varepsilon}$$

- **Liu et al *Applied Optics 2006***

Results of Applying PCRTM to IASI





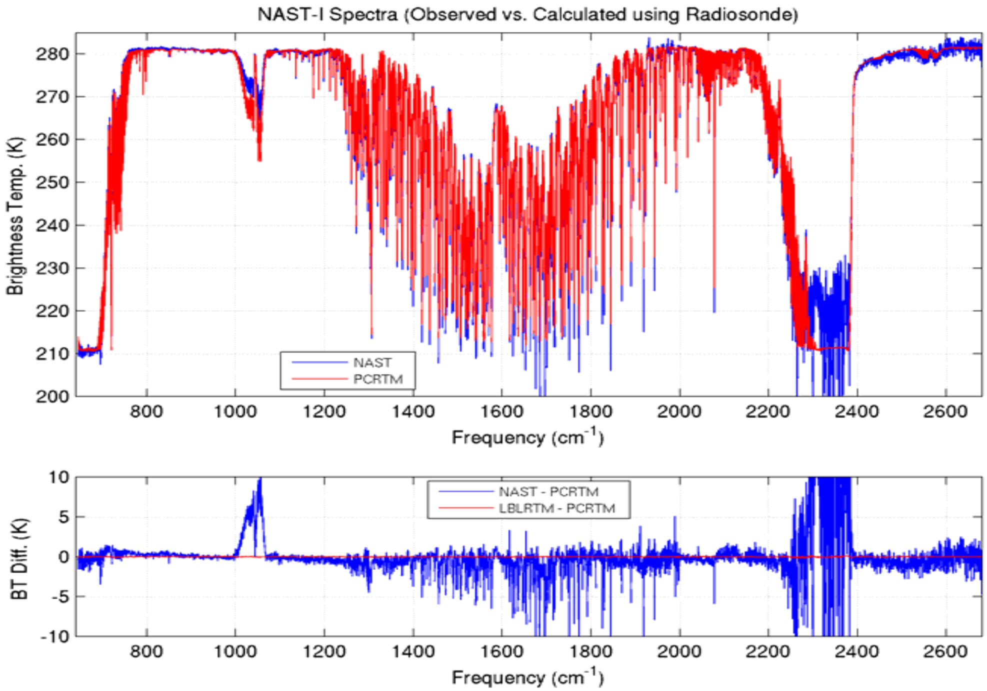
- **An Example of the IASI spectrum and the difference between the LBL calculated radiance and the PCRTM calculated radiance**
- **Errors less than 0.05 K**

PCRTM accuracy:

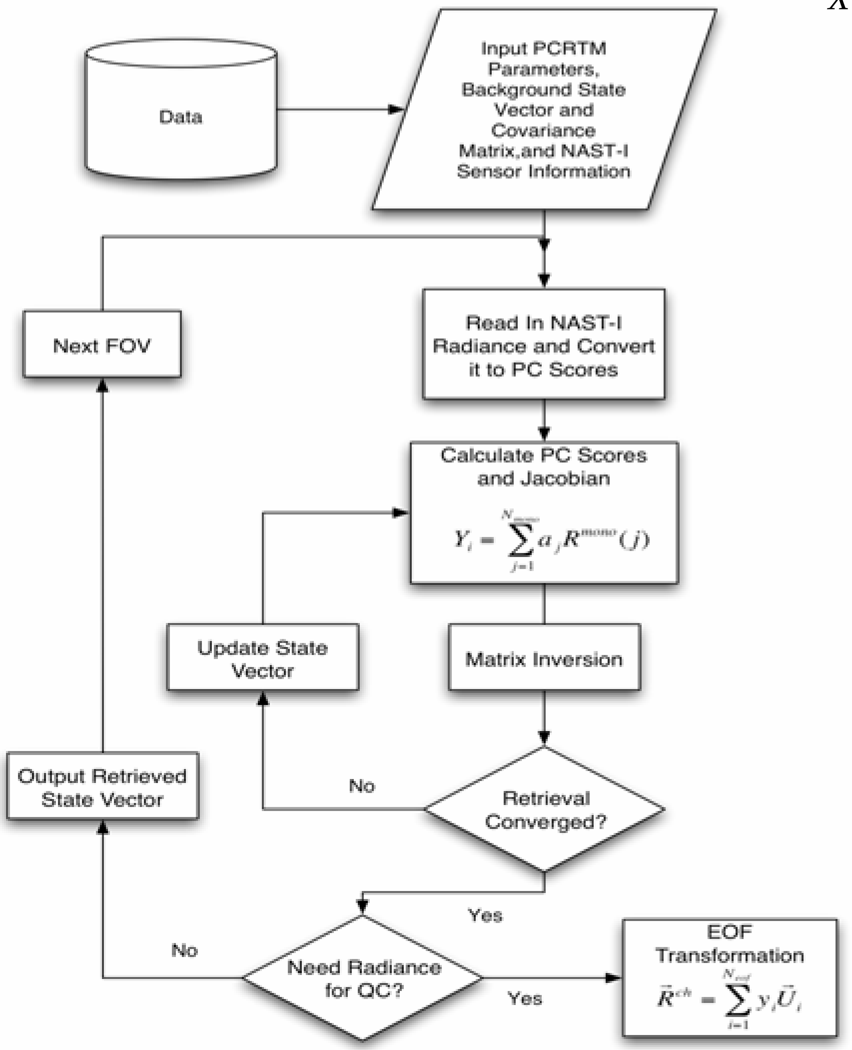
- **Top: RMS error**
- **Middle: Bias error**
- **IASI instrument noise**
- **Very good relative to LBL**
- **Much smaller error relative instrument noise**

Comparison with NAST-I observations

- NAST-I spectrum take over Potenza Italy on September 9th, 2004
- Emissivity fix to 0.98 (not the truth)
- T, H_2O taken from LIDAR measurements
- O_3 fixed to US standard ATM
- PCRTM and LBLRTM calculated radiances agree with each other (< 0.07 K)
- main sources of error between the NAST-I observed and PCRTM calculated radiances
  - Spectroscopy
  - Uncertainty in the "true atmospheric state"



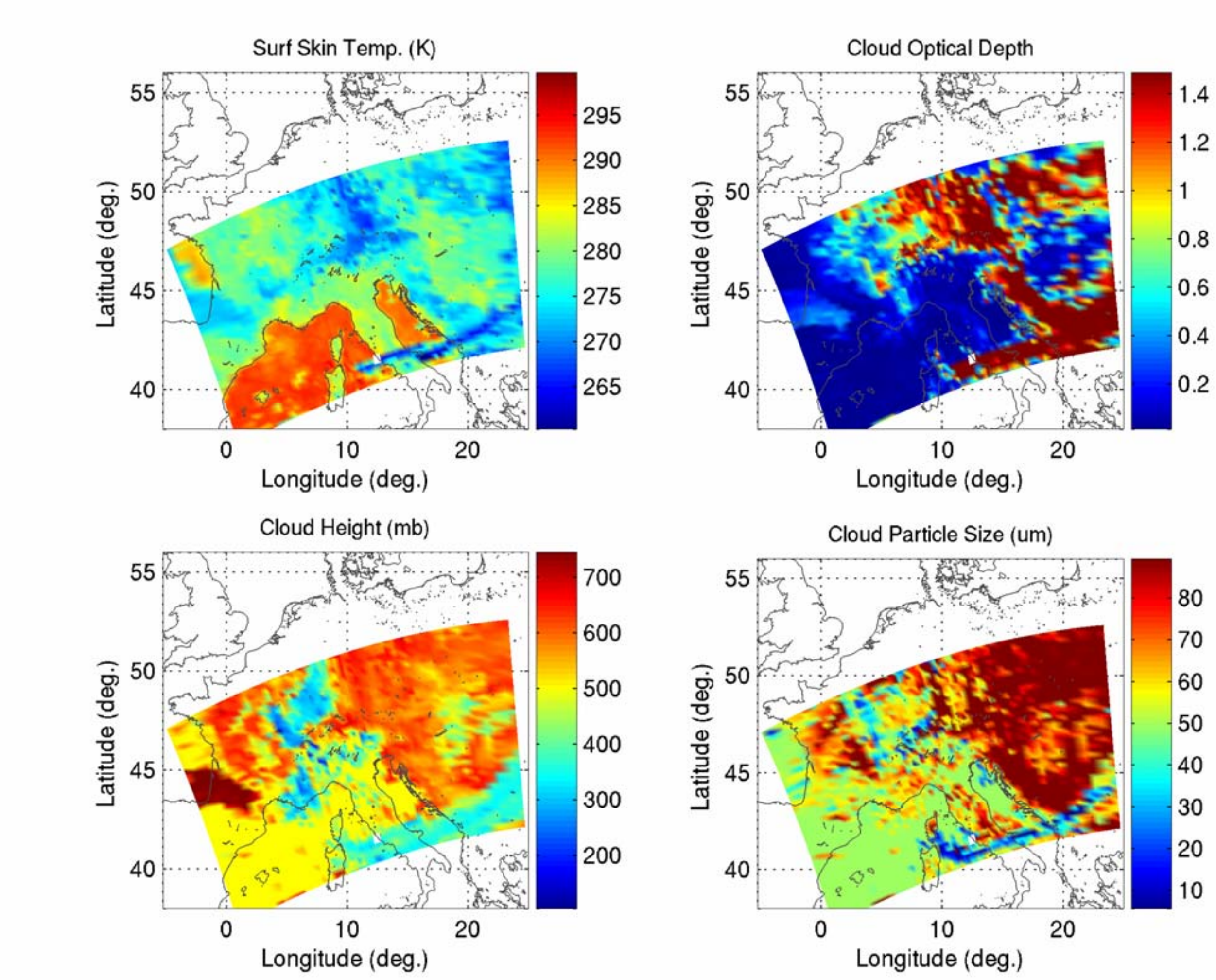
Flow diagram of the PCRTM retrieval algorithm



$$X_{n+1} - X_a = (K^T S_y^{-1} K + \lambda I + S_a^{-1})^{-1} K^T S_y^{-1} [(y_n - Y_m) + K(X_n - X_a)]$$

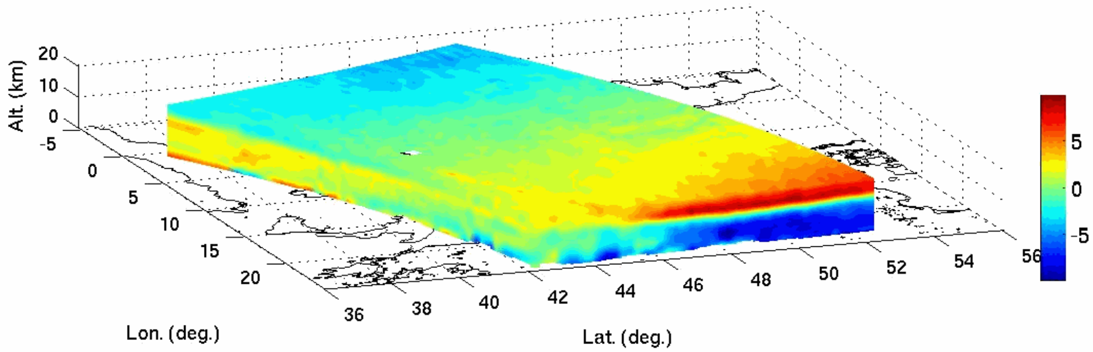
- **All parameters retrieved simultaneously**
  - **No need to estimate errors of non-retrieved parameters**
- **Very robust**
  - **Can start from either climatology or regression first guesses**
- **Single FOV retrieval**
  - **High spatial resolution**
  - **Cloud parameters retrieved explicitly**
  - **Multiple scattering effect included**
- **Provide error covariance matrix of state vector without extra calculations**
  - **Provides info needed by 3D/4Dvar**
  - **Error correlations included**
  - **Compressed state vector and associated error covariance matrix**
- **Both radiance and state vectors are in EOF domain**
  - **Small matrix and vector dimensions**
  - **Simply minimizing cost function**
  - **No *ad hoc* tuning parameters**

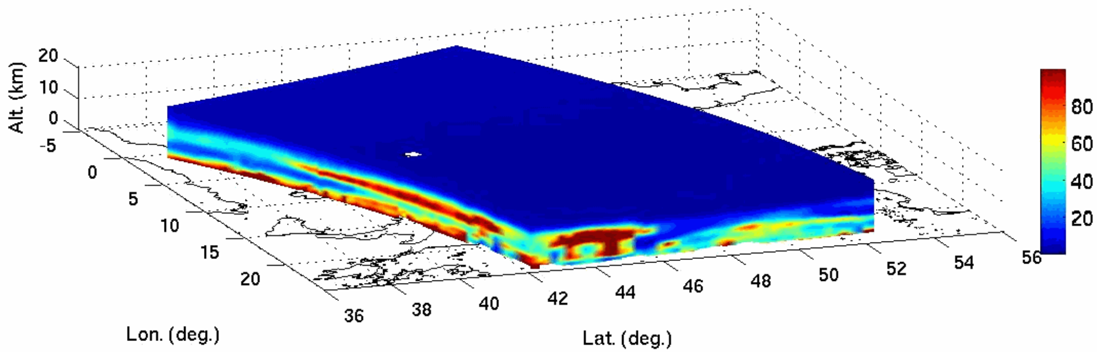
Retrieved Surface Skin Temperature and Cloud Properties Near Anglet France (Nov. 4, 2007)



3-D Atmospheric Temperature, H_2O, O_3, and CO Structure over Anglet France

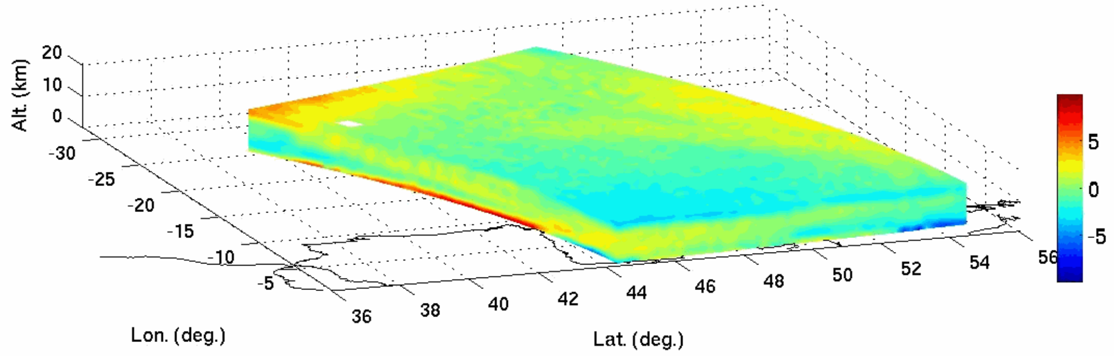
- A movie showing IASI T, H_2O, O_3, and CO cross-sections on November 4, 2007
  - T and H_2O as a function of altitude
  - T and H_2O along satellite track
  - T and H_2O x-track
  - CO and O_3 as a function of altitude

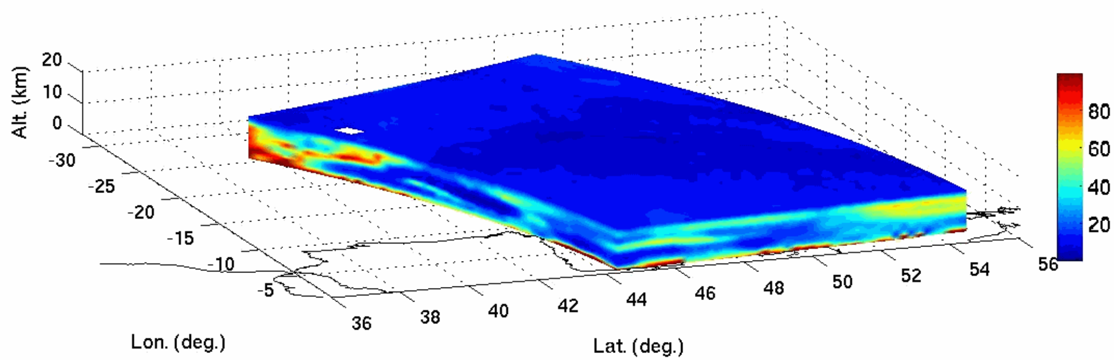




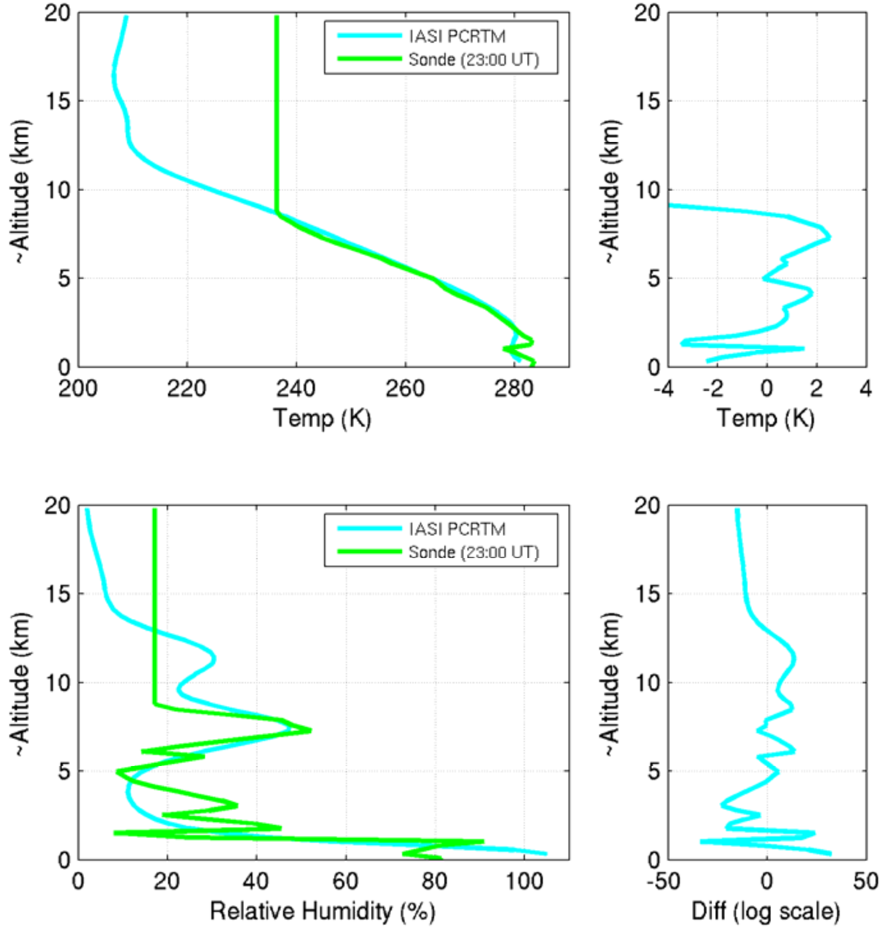
3-D Atmospheric Temperature, H_2O, O_3, and CO Structure over Anglet France

- **Another movie showing IASI T, H_2O, O_3, and CO cross-sections on November 4, 2007**
  - T and H_2O as a function of altitude
  - T and H_2O along satellite track
  - T and H_2O x-track
  - CO and O_3 as a function of altitude

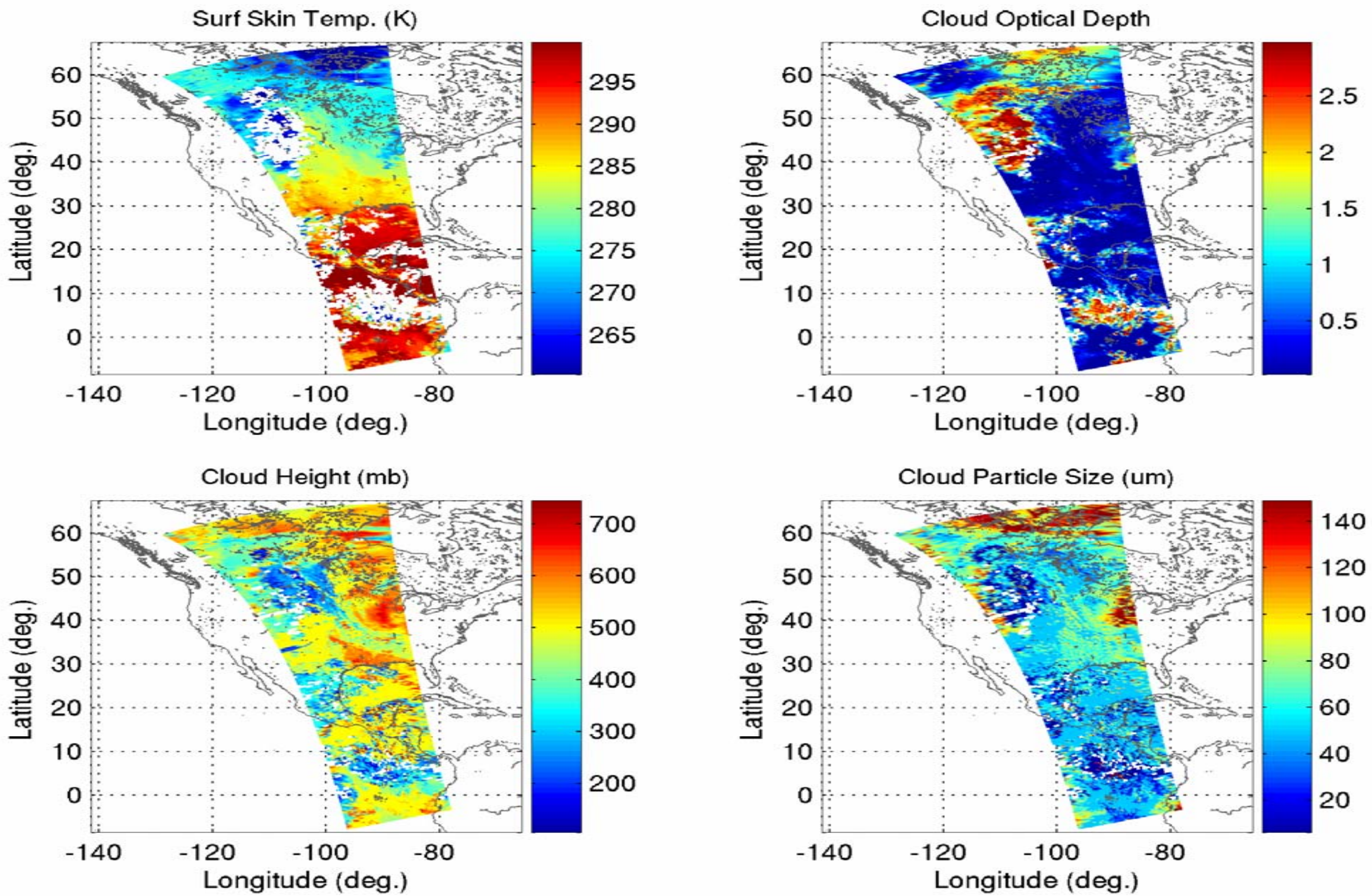




Comparison of T and RH Between PCRTM Retrieval and Radiosonde Near Anglet France (Nov. 4, 2007)



Retrieved Cloud Parameters and Surface Skin Temperature (April 19, 2007, JAIVEX)

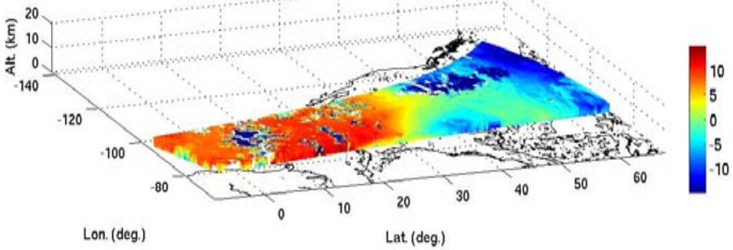


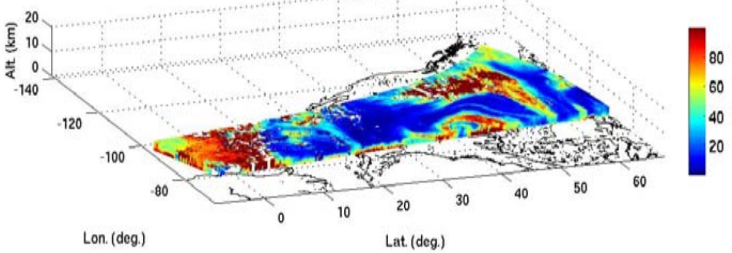
Cloud height background=500 hPa

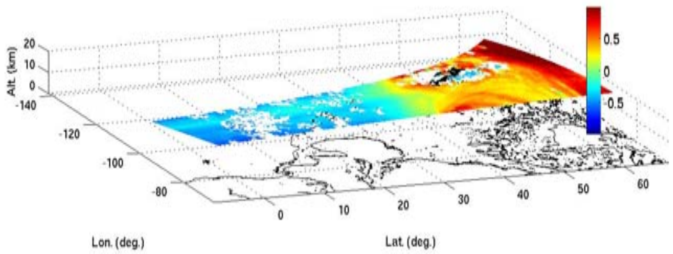
Cloud particle size backgroud = 50 μm

Results from JAIVEX Campaign (April 19, 2007)

- Fine water vapor structures captured by the retrieval system
- NAST-I under flew over the CART ARM site
- A very cloudy sky condition



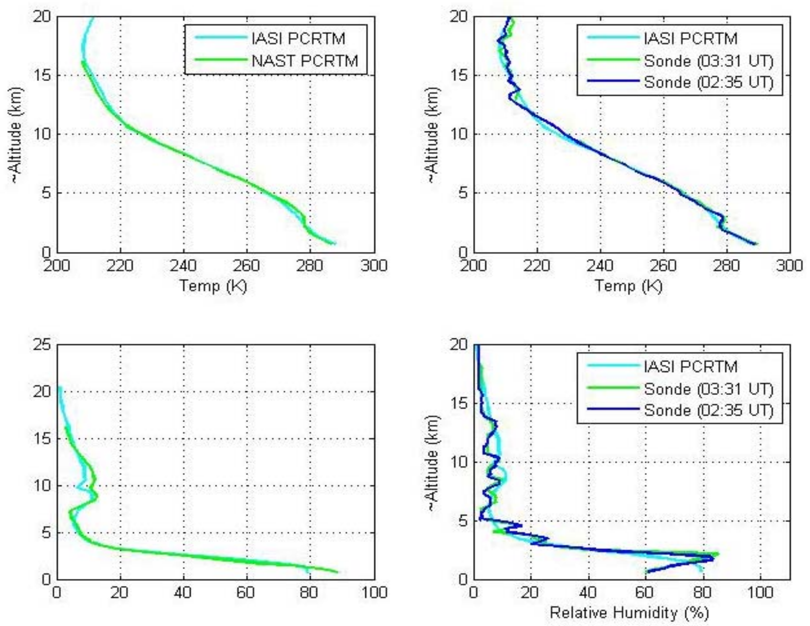




- Cross-section of retrieved ozone at ~ 16 km
- Plot is deviation from the mean
- High latitudes have higher ozone amounts than low latitudes
- Fine horizontal structure captured
- Can be correlated with T and H_2O

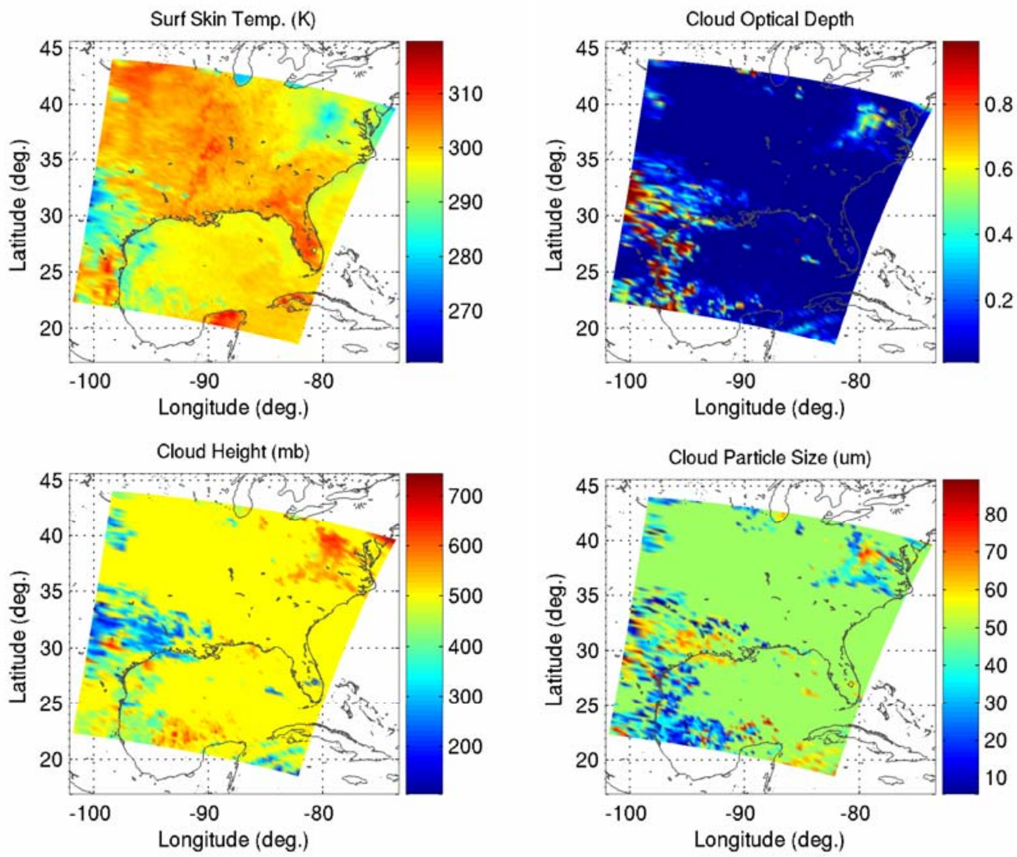
Comparison of IASI and NAST-I retrieved profiles with radiosondes

- Retrieved atmospheric Temperature and moisture profiles from IASI and NAST-I
- All parameters retrieved
  - T, H_2O, O_3,CO
  - Surface emissivty
  - Surface skin temperature
  - Cloud optical depth
  - Cloud height
  - Cloud particle size
- Good agreement between IASI and NAST-I
- Good agreement with radiosonde



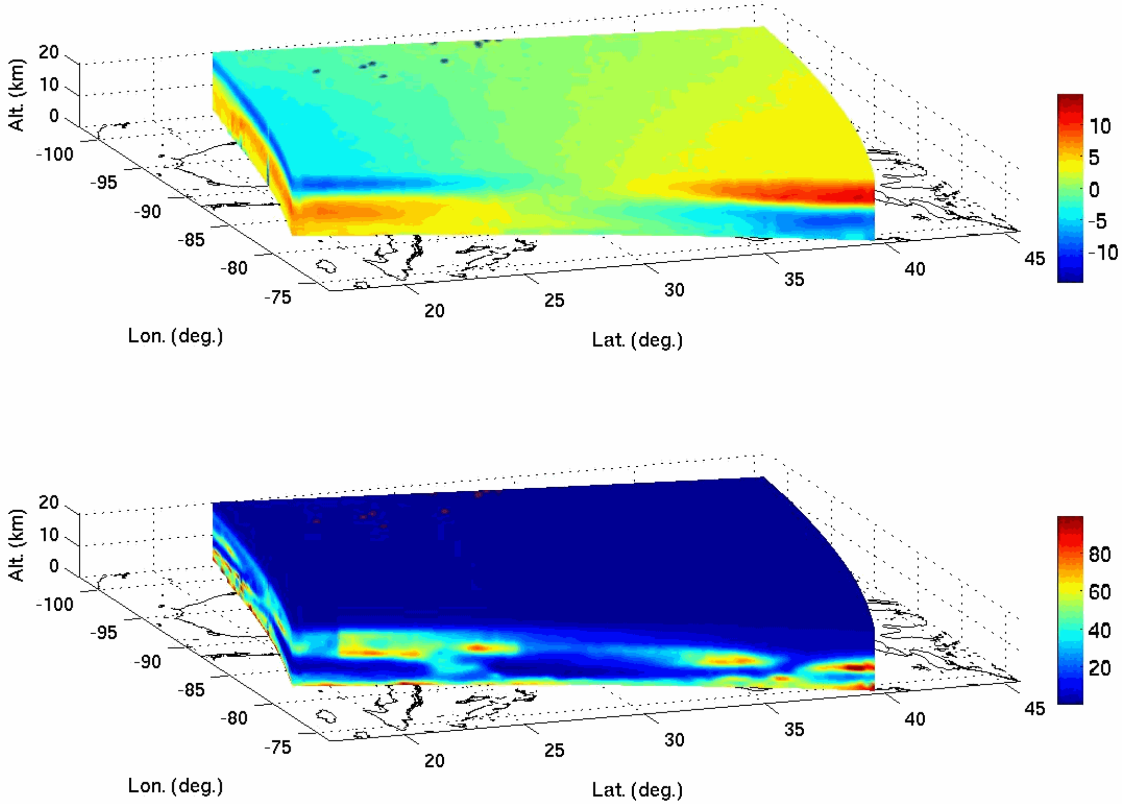
Ts and cloud properties for April 29, 2007

- Retrieved surface skin temperature and cloud properties from IASI
- NAST-I under flew over the gulf of Mexico
- Relatively clear day
- Only drop sondes available from the UK aircraft



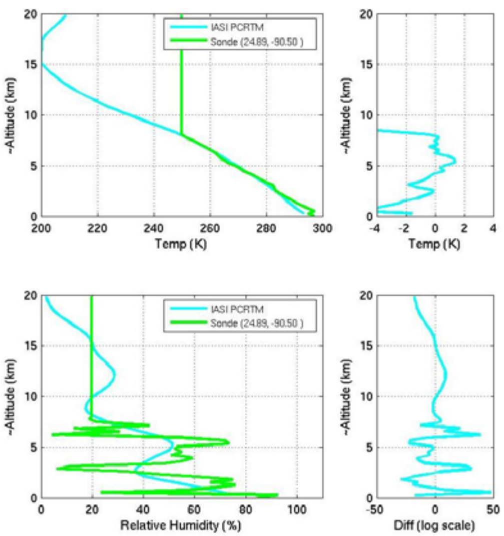
Results from JAIVEX Campaign (April 29, 2007)

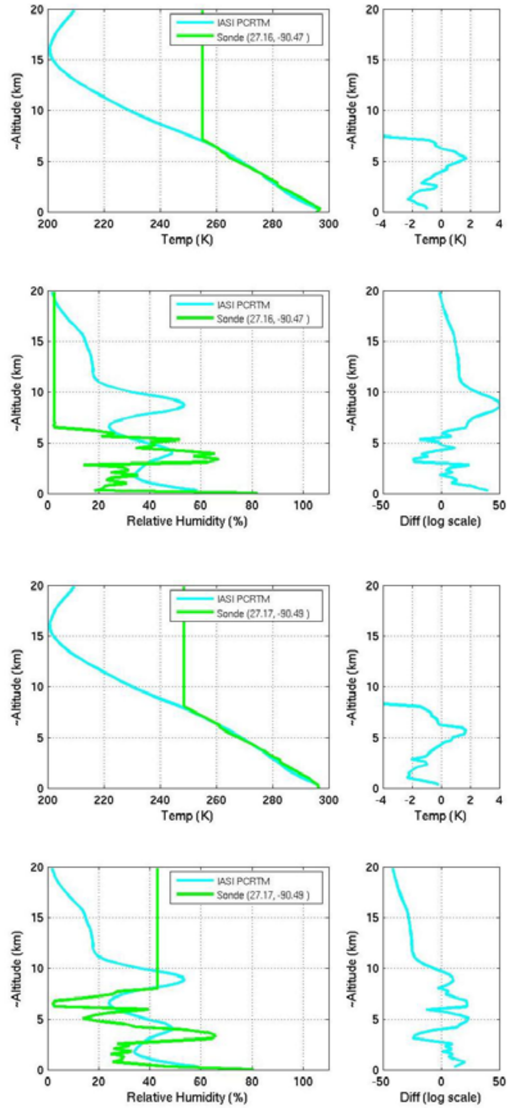
- A movie showing 3-D atmospheric structures of T and H_2O
- NAST-I under flew over the gulf of Mexico
- Notice the fine moisture circulation pattern

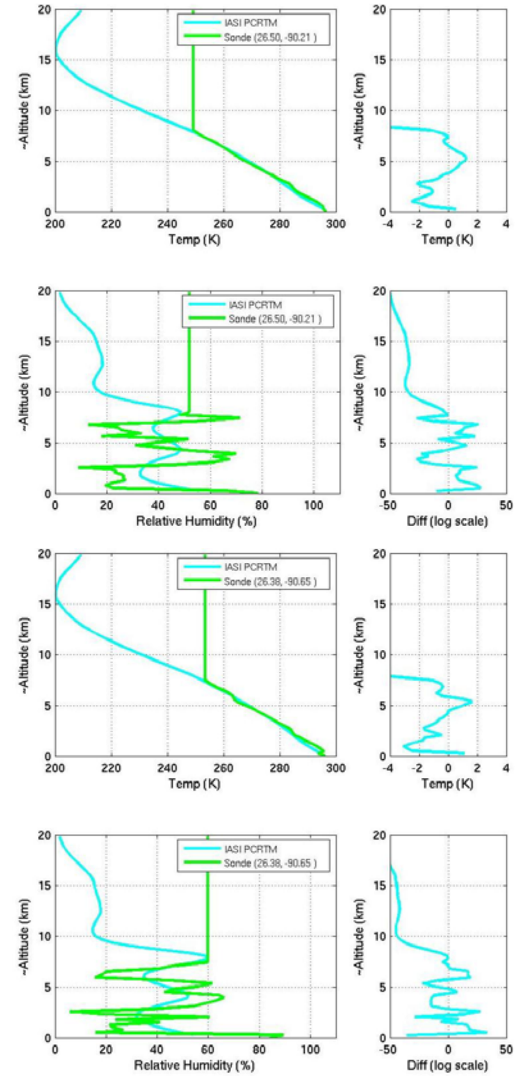


Comparison of retrieved T & RH profiles with dropsondes for April 29, 2007

- Moisture profiles highly variable
- Changes on the scale of a few km
- PCRTM IASI retrieval can capture various H_2O layers
- Agreement should improve if careful footprint matching is done

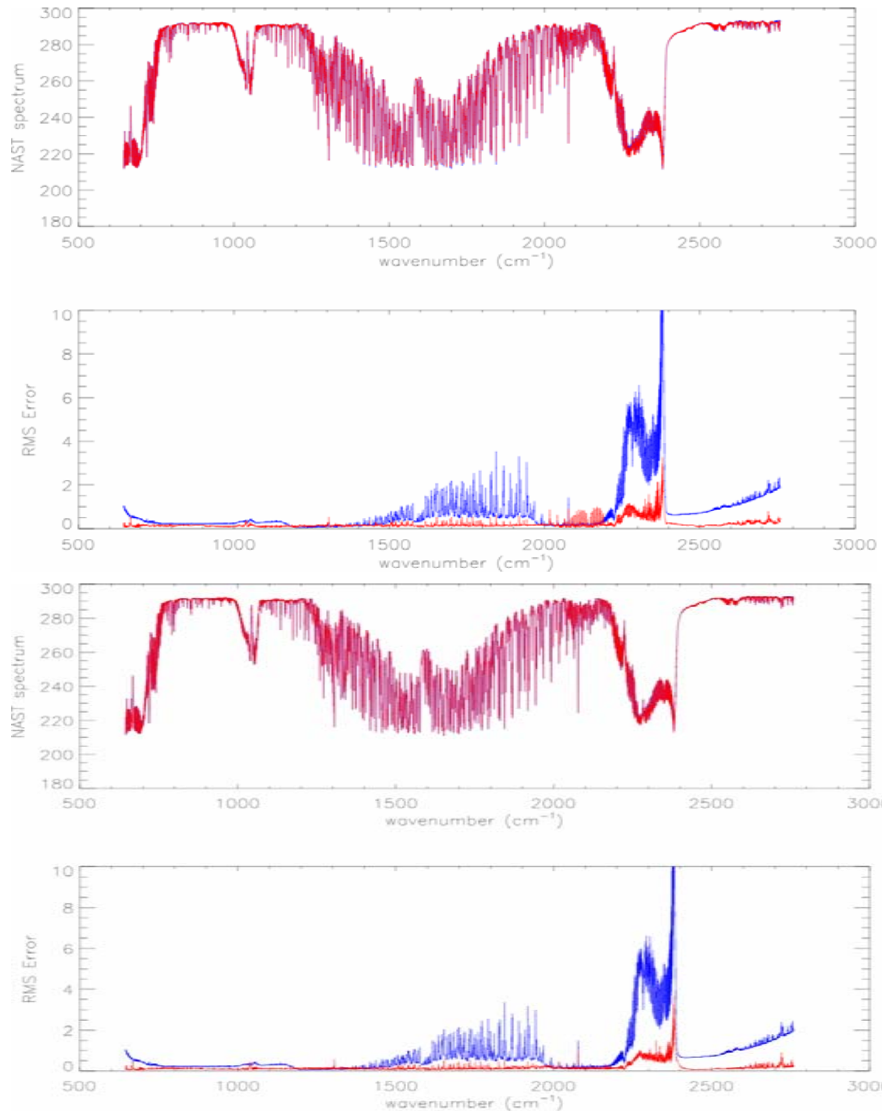






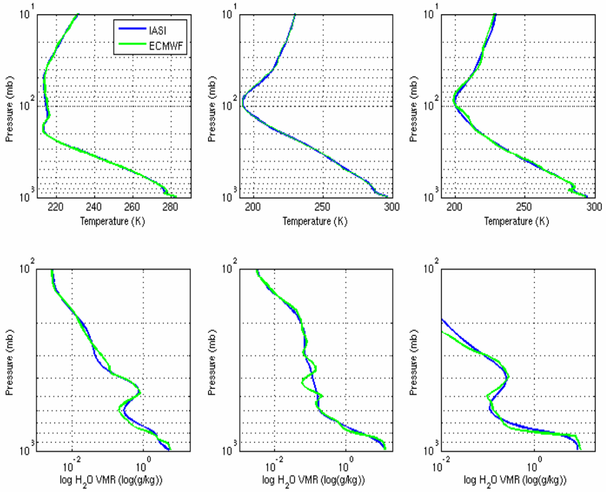
Spectral residuals and CO retrievals

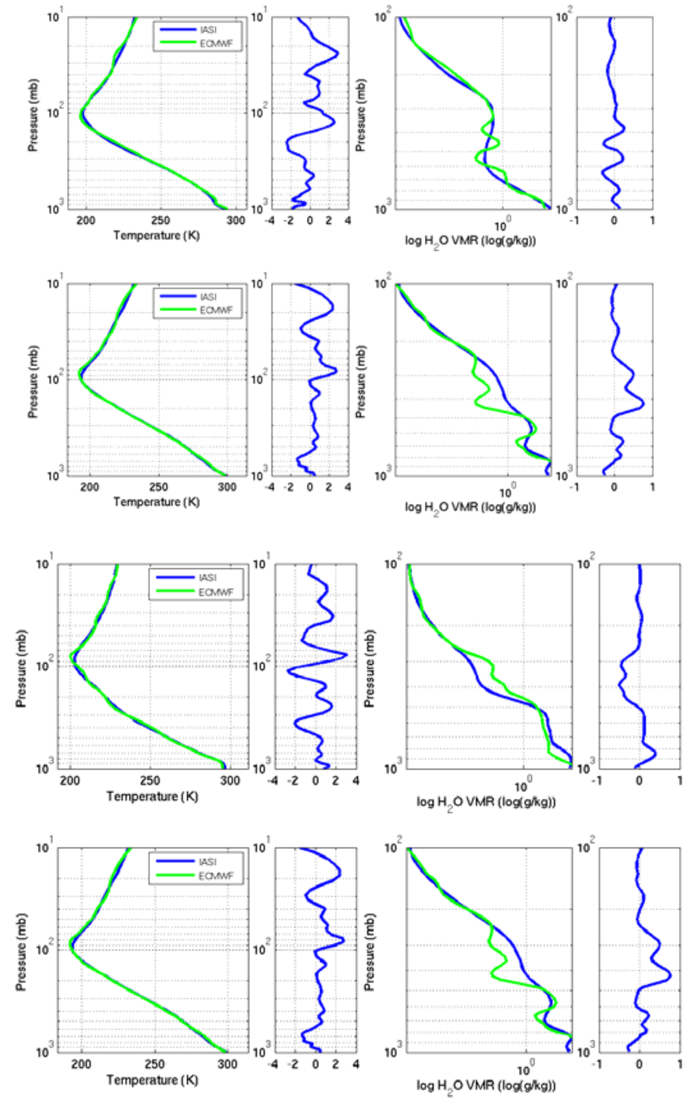
- **Red curve and blue curve in the top panel are IASI observed spectrum and PCRTM modeled spectrum**
- **Red curve in the bottom panel is the rms error**
- **Blue curve in the bottom panel is the IASI instrument noise converted to the brightness temperature unit (K) using the scene temperature shown in the upper panel**



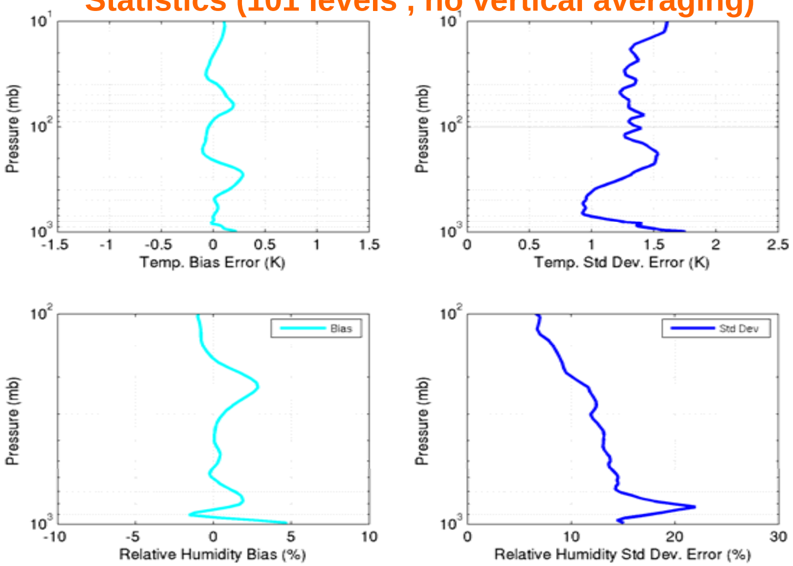
- **Notice that the feature near 2020-2250 cm^{-1} are removed when CO profile is explicitly retrieved in the inversion algorithm**

Comparison of IASI retrieved profiles with ECMWF

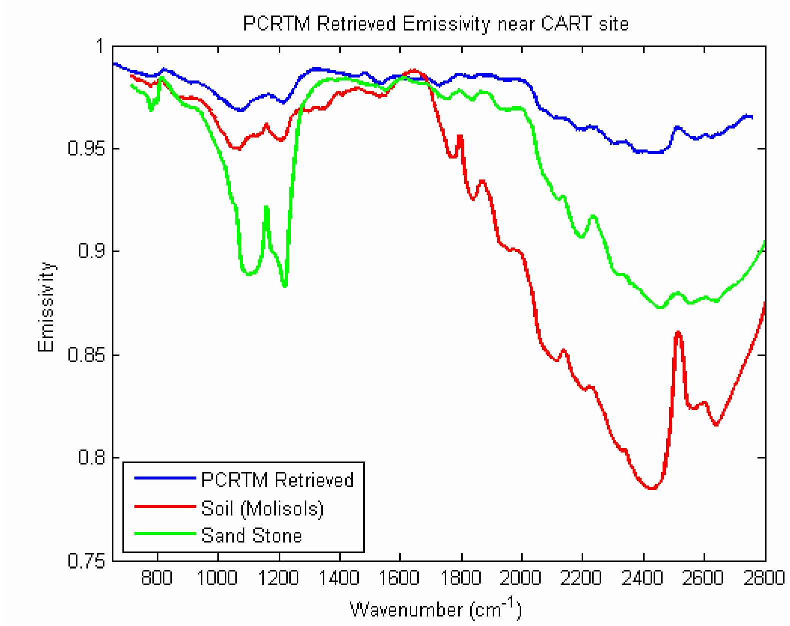


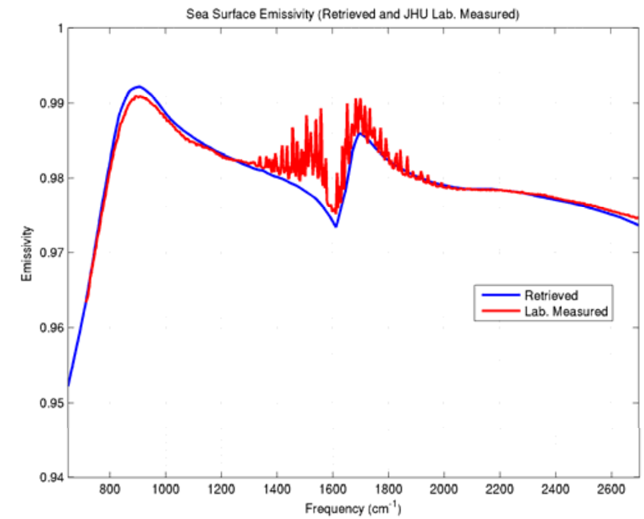


Statistics (101 levels , no vertical averaging)



Examples PCRTM Retrieved land and ocean emissivities





- **Over CART ARM Site on April 19, 2007 using IASI data**
- **Soil (or quartz, or ?) + vegetation**
  - **→ produce ARM CART site observed emissivity**
- **Retrieval is not sensitive to emissivity at frequencies where the IASI does not see the earth's surfaces**
  - **→ 645-750 cm^{-1}, 1400-2000 cm^{-1}**

- **NAST-I retrieved sea Emissivity**
  - **→ On Sept. 9, 2004 near Italy**
  - **→Wind speed and scan angle dependencies included**
- **Retrieval is not sensitive to emissivity at frequencies where the IASI does not see the earth's surfaces**
  - **→ 645-750 cm^{-1}, 1400-2000 cm^{-1}**

Conclusions

- PCRTM is a physical based fast radiative model
  - Accurate relative to LBL
  - Very fast in speed
  - Cloud effect modeled (including multiple scattering)
  - Provides forward model and Jacobians in both spectral and EOF domain
- A Single FOV physical retrieval methodology has been developed
  - Small dimensions for both observation and state vectors
  - Retrieves all state vector simultaneously
  - Cloud parameters retrieved explicitly
    - No need for cloud clearing
    - High horizontal resolution relative to cloud clearing method
  - Converges quickly even from climatology first guess
  - Provide error covariance of retrieved parameters
- PCRTM retrieval method has been applied to IASI and NAST-I
  - Capturing high vertical and horizontal atmospheric structure
  - Coherent spatial field retrieved for all parameters
  - Compare well with radiosondes and ECMWF profiles
- Excellent IASI data
  - Provide atmospheric and surface properties
    - T, H_2O, O_3, CO, cloud O, cloud height and cloud effective size
    - Surface skin temperature and surface emissivities
  - Consistent with NAST-I retrievals
  - Agree well with radiosondes and drops sondes
- Application of PCRTM retrieval algorithm
  - Incorporate into 3D/4DVAR NWP system
  - Assimilate the PCRTM retrieved parameters in NWP system (error cov provided)