Retrieval Algorithm Using Super channels

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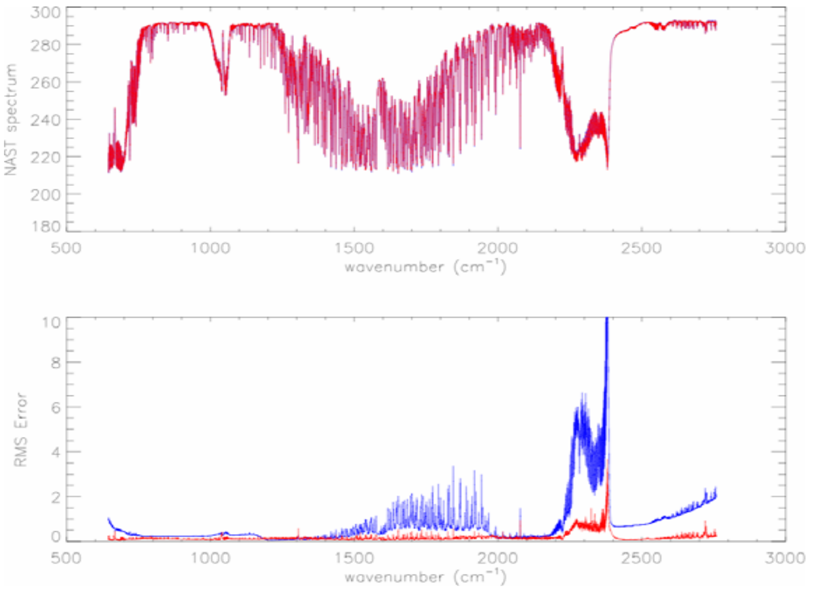
Outline

- **Description of a super channel aglorithm**
  - **Introduction to a Principal Component-based Radiative Transfer Model (PCRTM)**
  - **Description of a super channel physical retrieval algorithm**
- **Example of applying superchannel retrieval algorithm to IASI and NAST-I spectra**
- **Conclusions**

Introduction

- Good New for hyperspectral remote sensing:
  - Modern Hyper/Ultra spectral remote sensors have thousands of channels
  - High spectral resolution provides more details of atmosphere properties
  - Examples hyperspectral sensors:
    - 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
    - FIRST (FAR Infared Spectroscopy of the Troposphere): ~1500x10 (or more)
    - COSAIR (Calibrated Observations of Radiance Spectra from the Atmosphere in the far Infra Red): thousands
    - CLARREO (Climate Absolute Radiance and Refractivity Observatory): thousands

- Challenges:
  - Need fast and accurate forward model
    - Line-by-line radiative transfer model too slow
  - New ways to analysis data are needed
    - Transform data into more compact form (e.g EOF)
  - A Principal Comonent-based Radiative Transfer Model (PCRTM) has been developed
    - Applied successfully to AIRS, IASI, and NAST-I
  - Example of observed IASI spectra and PCRTM calculated spectra is shown on the right corner
    - The blue curve: IASI instrument noise
    - The red curve: difference between observed and PCRTM calculated



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:

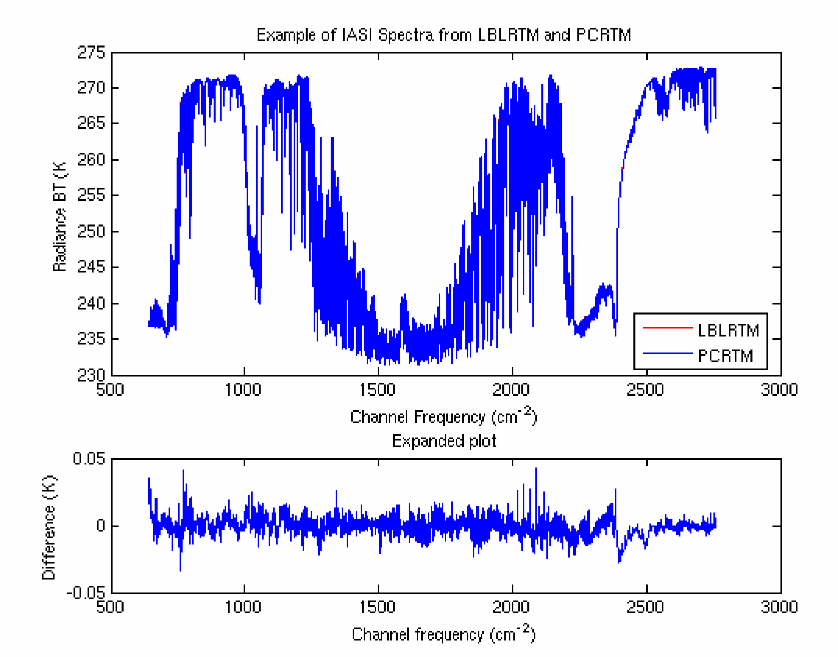
$$\vec{Y} = U^T \times \vec{R}^{chan} \qquad R_i^{chan} = \frac{\sum_{k=1}^{N} \phi_k R_k^{mono}}{\sum_{k=1}^{N} \phi_k}$$

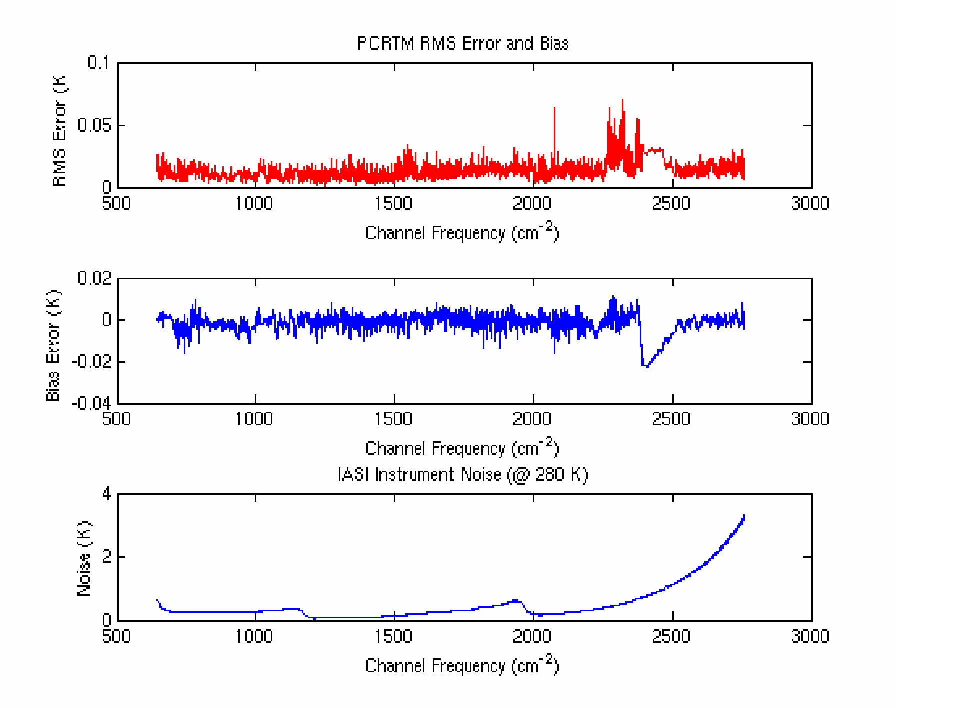
- Very accurate relative to LBL
  - Accuracy of the model can be adjusted
- Very fast
  - No need to perform redundant calculations
- Cloud contributions included
  - Use cloud transmittances and reflectances
  - Use multiple scattering calculation at limited monochromatic frequencies
- Channel radiances (or transmittances) can be obtained easily

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

- Provide analytical jocabian
- Reference, Liu et al “A Principal Component-based Radiative Transfer Forward model (PCRTM) for hyperspectral sensors: theoretical concept” *Applied Optics 2006,* Saunders et. al, “A comparison of radiative transfer models for simulating AIRS radiances”, *J. Geophys. Res.,* 2007

Results of Applying PCRTM to IASI



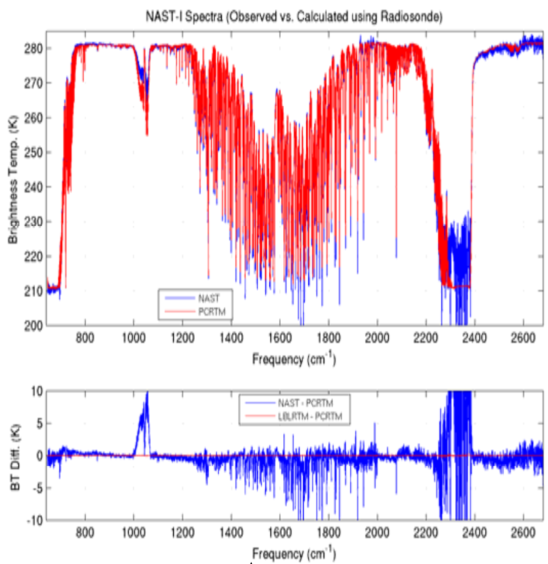


- An Example of the IASI spectrum and the difference between the LBL calculated radiance and the PCRTM calculated radiance
- Errors less than 0.05K

PCRTM accuracy:

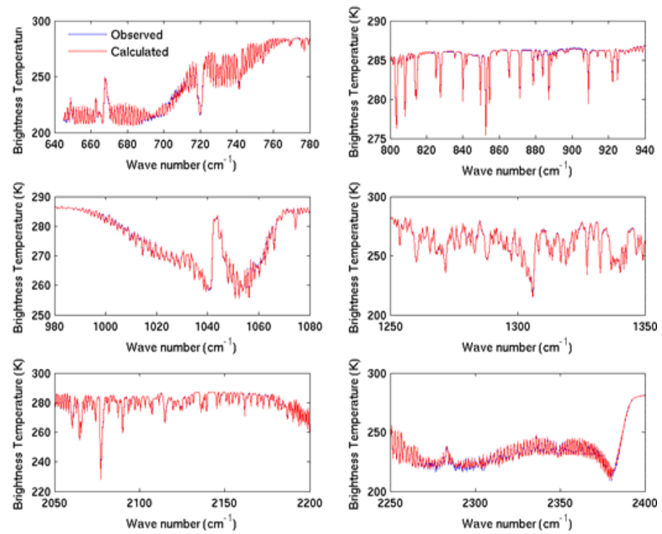
- Top: RMS error
- Middle: Bias error
- IASI instrument noise
- Very good relative to LBL
- Much smaller error relative instrument noise

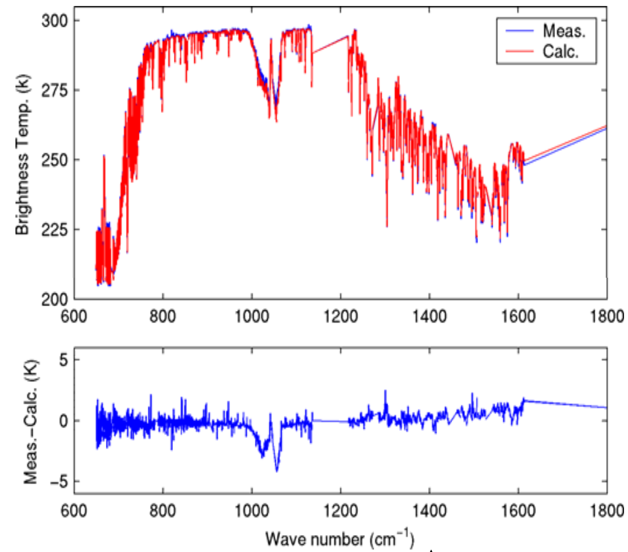
Comparison with NAST-I and AIRS observations



- NAST-I spectrum take over Potenza Italy on September 9th, 2004
- Emissivity fix to 0.98 (not the truth)
- T, H2O taken from LIDAR measurements
- O3 fixed to US standard atmosphere
- PCRTM and LBLRTM calculated radiances agree with each other (< 0.07K)
- main sources of error between the NAST-I observed and PCRTM calculated radiances
  - Spectroscopy
  - Uncertainty in the "true atmospheric state"

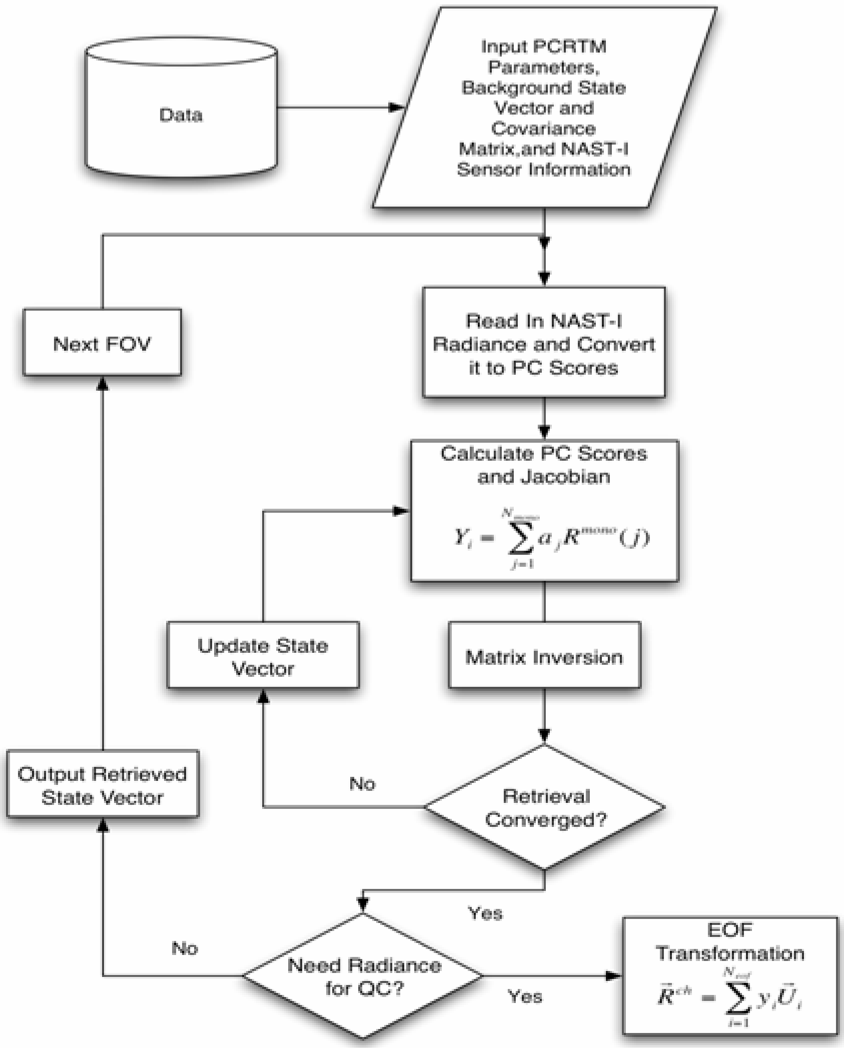
- Comparison of observed and calculated IASI spectra





- An example of Observe vs forward model calculated AIRS spectra
- Temperature, H2O and O3 profiles are taking from ECMWF model
- Spikes due to AIRS popping noise not completely removed
- Ozone truth has poor quality

Flow diagram of the PCRTM retrieval algorithm

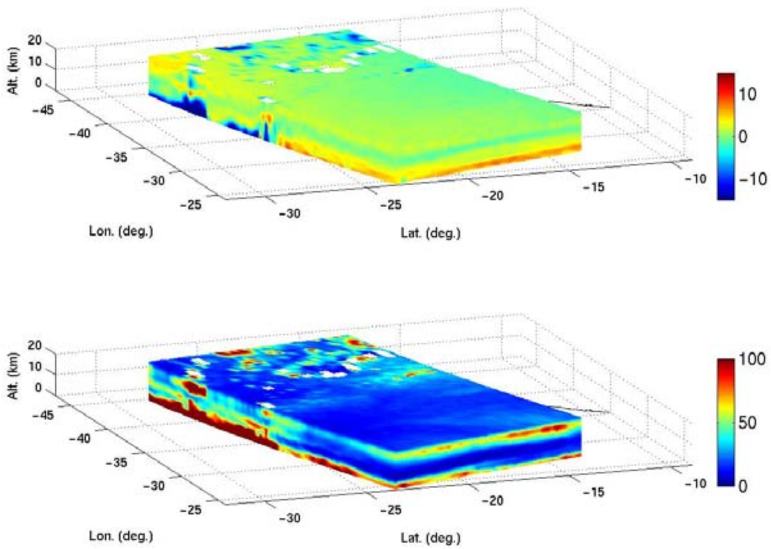


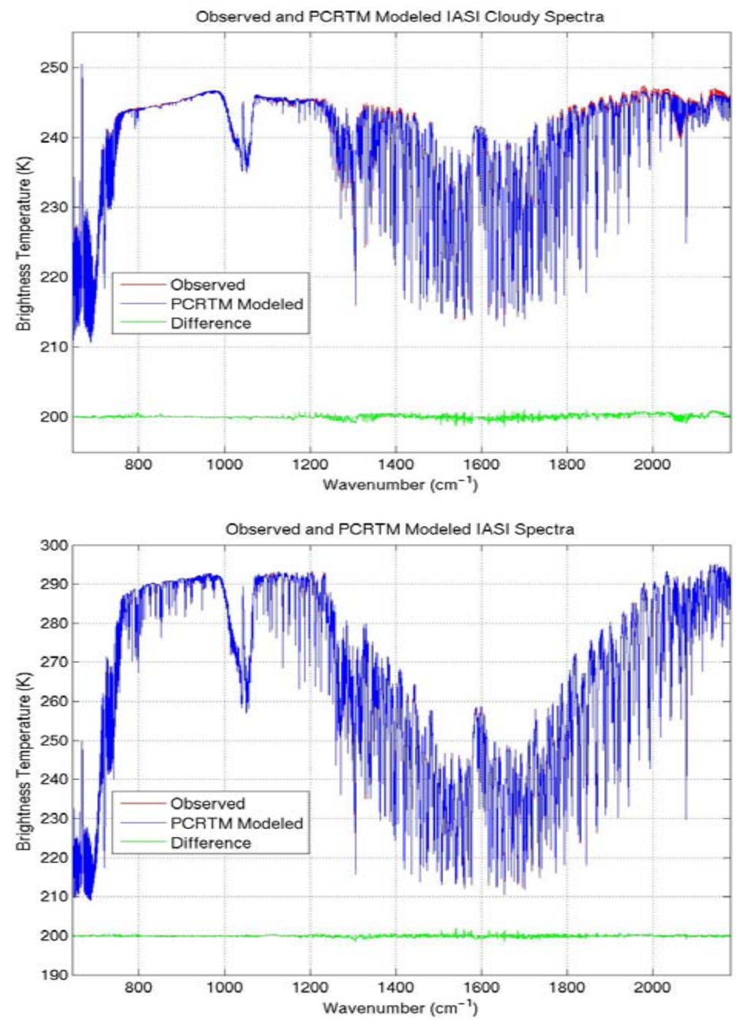
$$X_{n+1} - X_a = (K^T S_y^{-1} K + \lambda I + S_a^{-1})^{-1} K^T S_y^{-1} [(y_n - Y_m) + K(X_n - X_a)]$$

- 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 (no need for cloud clearing)
  - 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
  - Only 100 super channels needed
  - Simply minimizing cost function
  - No ad-hoc tuning parameters

– Reference: *Liu et al. Q. J. R. Meterol. Soc. 2007*

Cloudy Retrieval Over Angra dos Reis

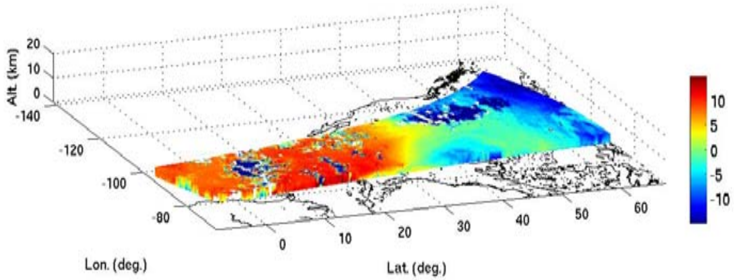


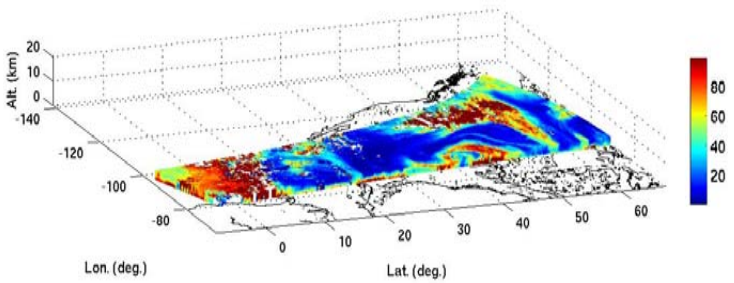


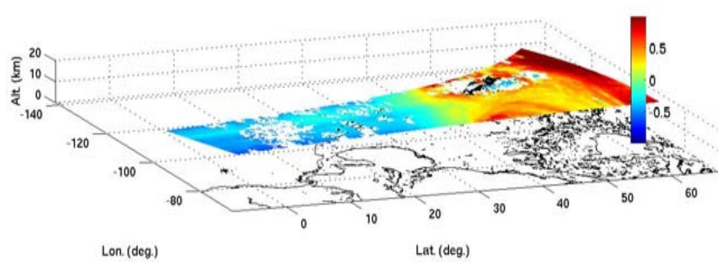
- Top left: a 3-D plot of retrieved temperature and moisture profiles taken on April 15th, 2008 near Angra dos Reis, Brazil
- Top right: Observed and fitted IASI spectra (ice cloud) taken on April 15th, 2008 near Angra dos Reis, Brazil
- Top right: Observed and fitted IASI spectra (Clear sky) taken on April 15th, 2008 near Angra dos Reis, Brazil

Highlights of Research (JAIVEX Campaign Retrievals)

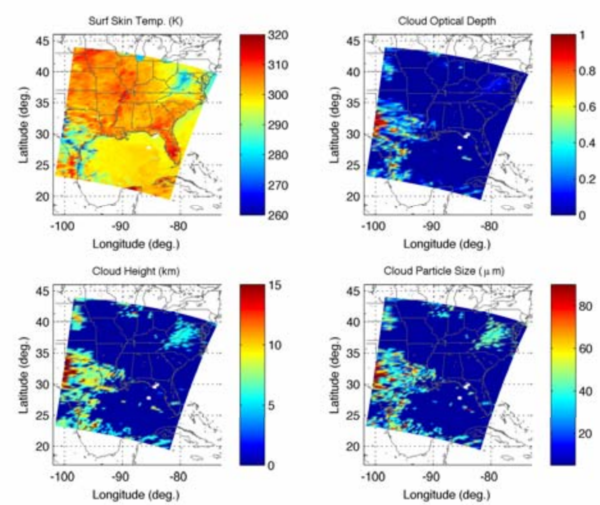
- ***Temperature, moisture, and ozone cross-sections*** from 4/19/07
- Plots are deviation from the mean
- Fine water vapor structures captured by the retrieval system
- NAST-I under flew over the CART ARM site
- A very cloudy sky condition





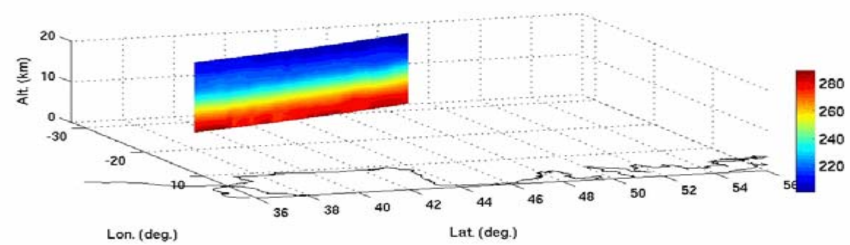


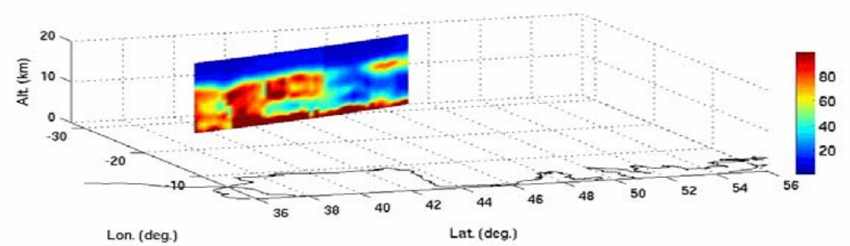
- Retrieved atmospheric Temperature and moisture profiles from IASI and NAST-I during JAIVEX campaign
- All parameters retrieved
  - T, H_2O, O_3,CO
  - Surface emissivty
  - Surface skin temperature
  - Cloud optical depth
  - Cloud height
  - Cloud particle size
- Good agreement between IASI and NAST-I
- Good agreement with radiosonde
- Figure below is the ***cloud and surface properties*** retrieval on 4/29/07

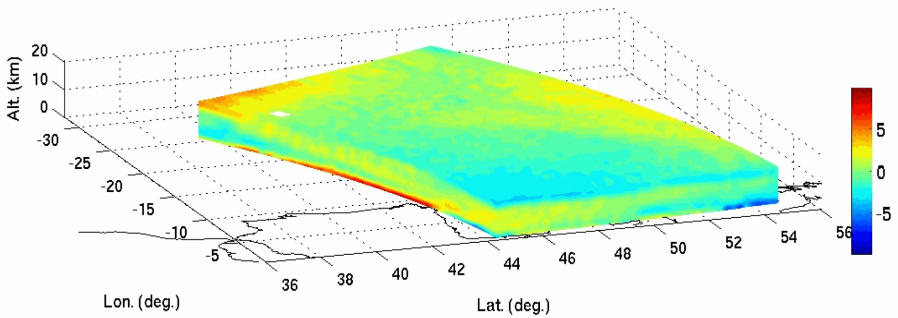


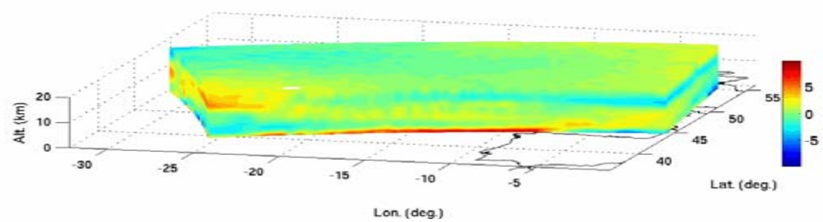
3-D Atmospheric Temperature and Moisture Structures

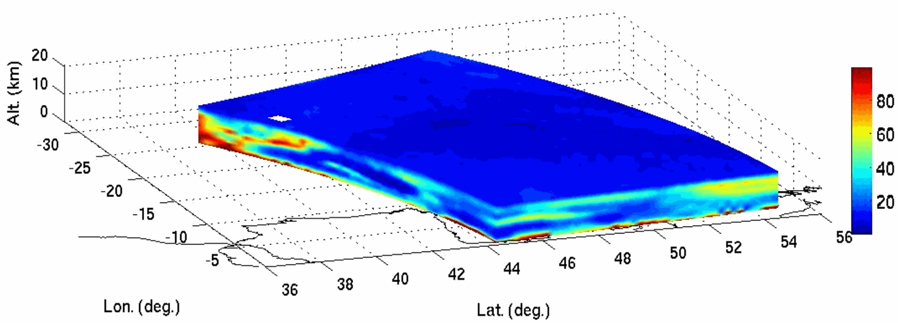
- 3 movies showing IASI temperature and moisture cross-sections on November 4, 2007 over Anglet France
  - T and H_2O as a function of altitude
  - T and H_2O along satellite track
  - T and H_2O x-track
- Note fine atmospheric features capture
  Coherent spatial features

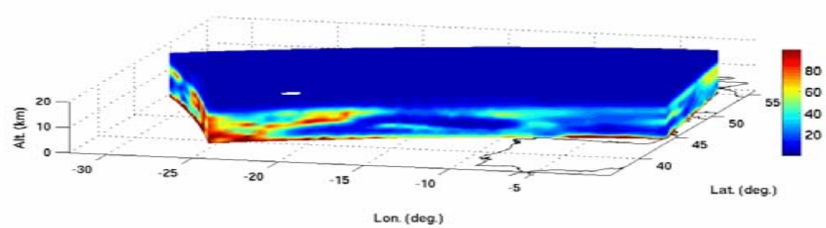




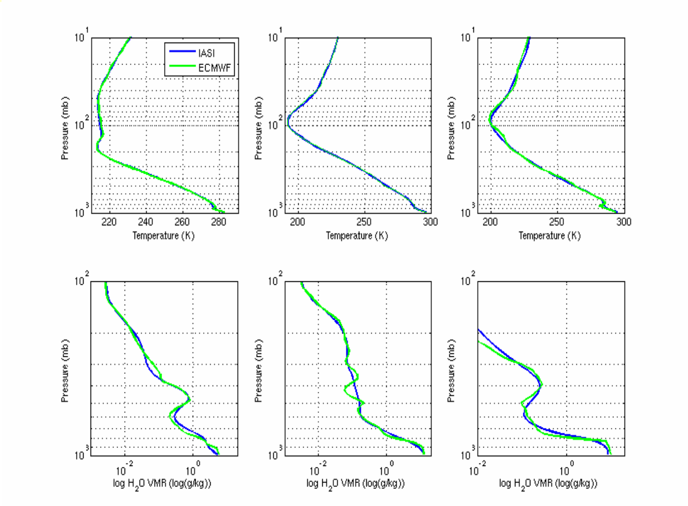


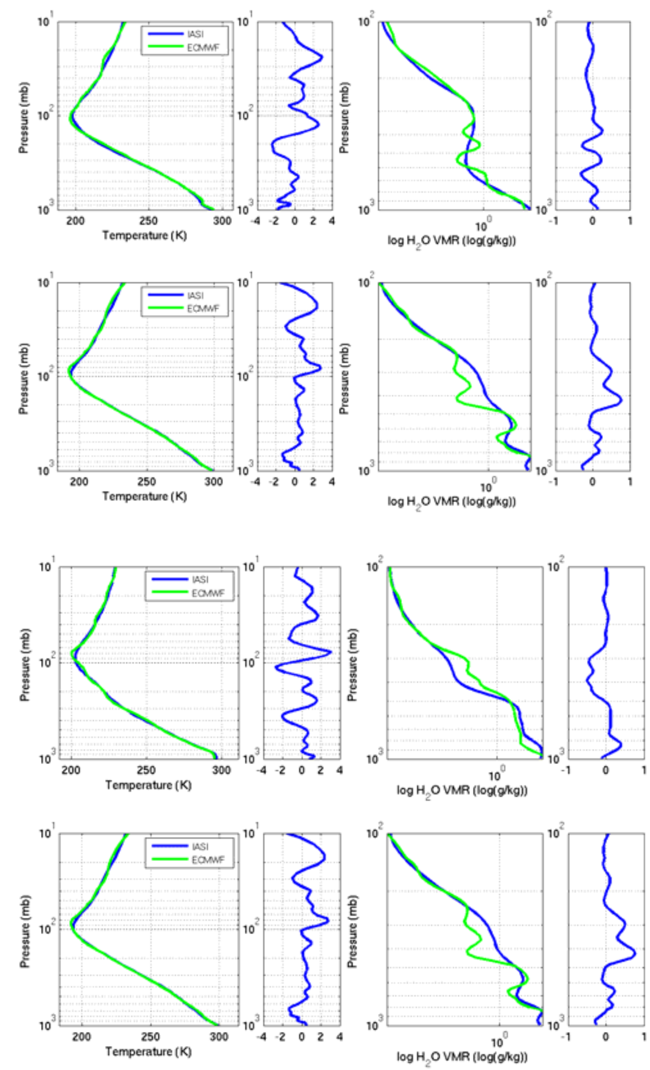




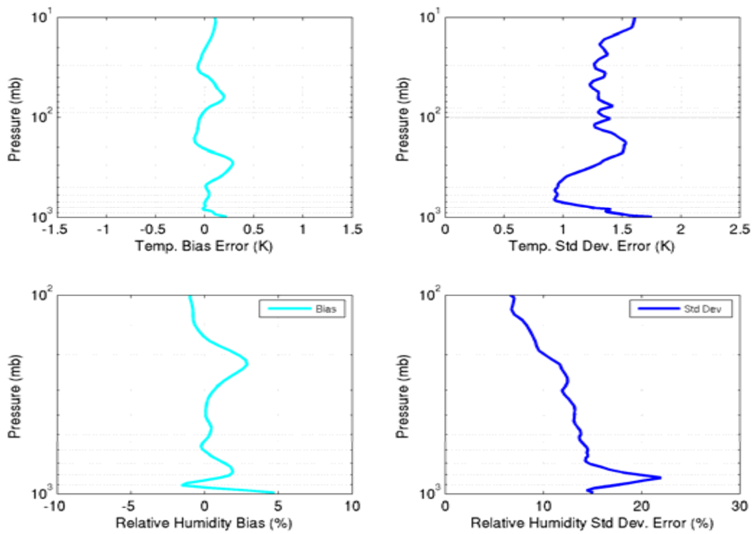


Fine Atmospheric Features Captured from IASI Retrievals

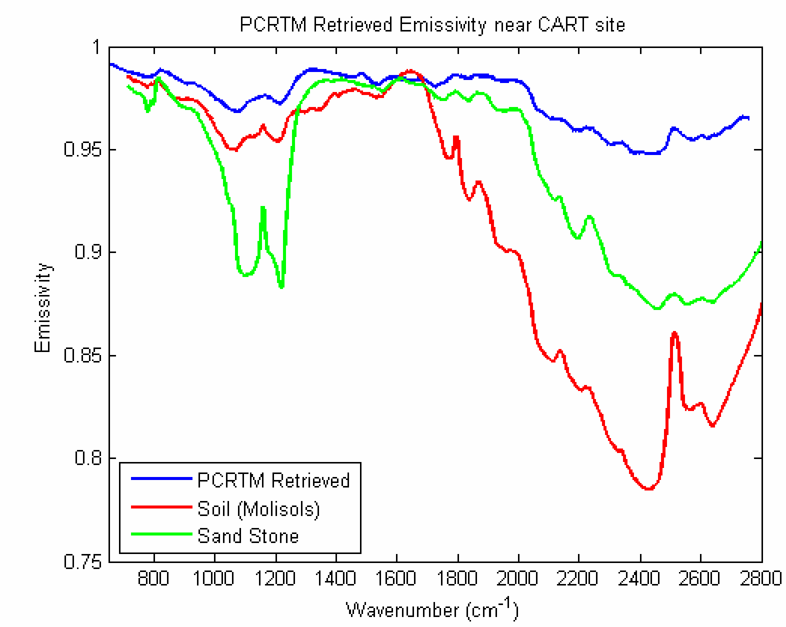


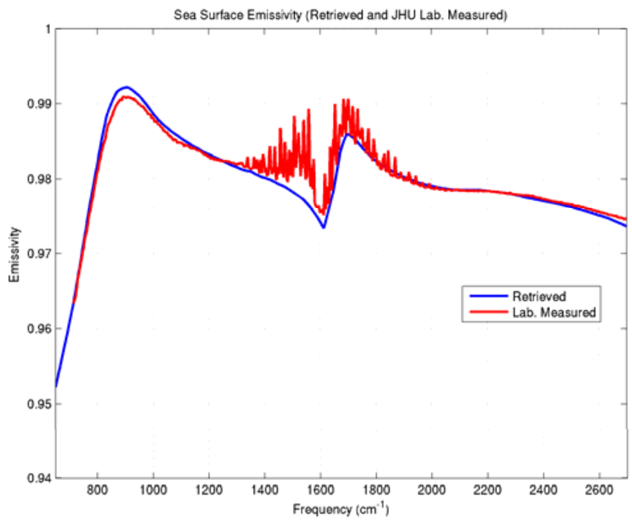


Statistics (101 levels , no vertical averaging)



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, 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, 1400-2000 cm^{-1}

Summary and Conclusions

- Super channel forward model and retrieval algorithm has been developed
  - PCRTM handles thousand of channels
    - 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
  - Super channel retrieval algorithm provides atmospheric and surface properties
    - T, H_2O, O_3, CO vertical profiles
    - cloud optical depth, cloud height and cloud effective size
    - Surface skin temperature and surface emissivities
- Super retrieval algorithm has been tested with IASI and NAST-I data
  - JAIVEX field campaign provides good data for algorithm testing
  - Spatial resolution can be enhanced using single field of view retrievals
    - Perform cloud parameter retrievals using single FOV
    - No need to make assumptions about variations between adjacent FOVS as required by cloud clearing approach
  - Retrieval using more than 8000 channels with efficient computational time
    - Only possible with super channel approach
  - Retrievals agree well with radiosondes, drops soundes and ECMWF profiles
- Lessons learned from IASI, NAST-I, and AIRS are beneficial to future hyperspectral sensors
  - CrIS, CLARREO……