Comparison of Full-resolution S-NPP CrIS Radiance with Radiative Transfer Model

Xu Liu

NASA Langley Research Center

W. Wu, S. Kizer, H. Li, D. K. Zhou, and A. M. Larar

Acknowledgements

Yong Han NOAA STAR

Outline

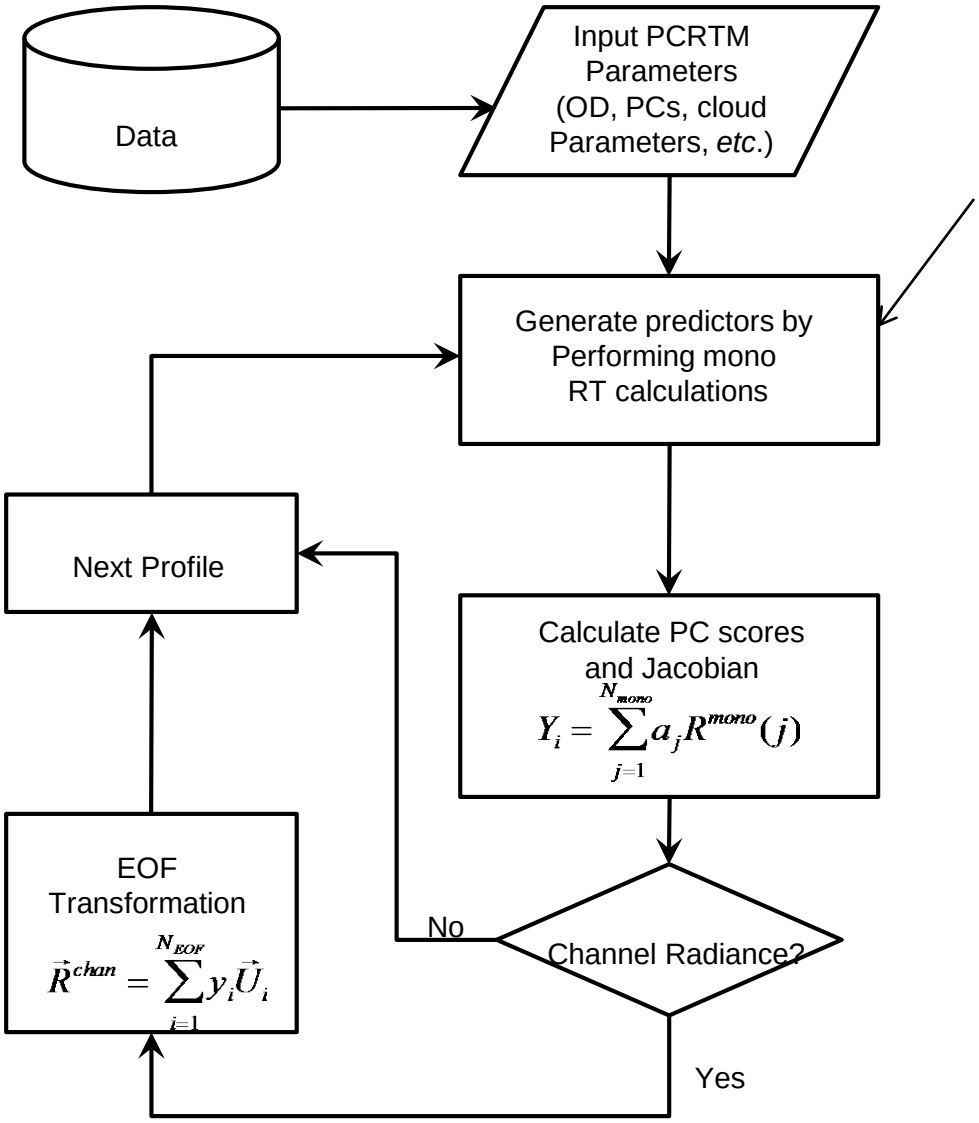
- Introduction
- A Brief Description of PCRTM radiative transfer model
- Information content analysis of nominal and hi-resolution CrIS data using PCRTM
- Conclusion and summary

Introduction

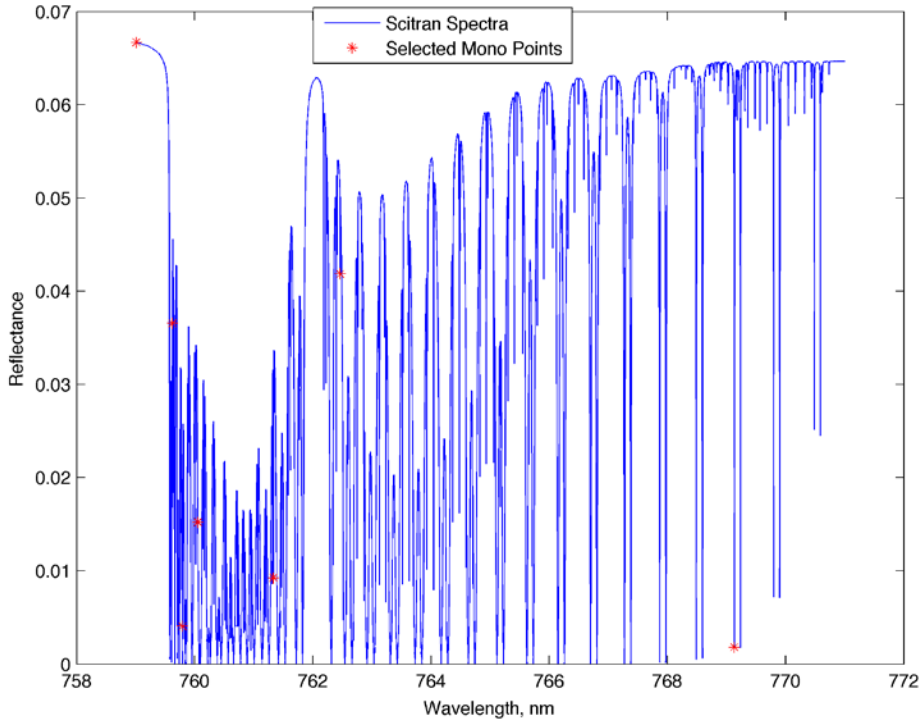
- RT model is one of the key components to a satellite mission
  - End-to-end trade studies
  - Radiance validation and anomaly detections
  - Geophyiscal parameter retrievals and satellite data assimilations
  - Climate OSSE and fingerprinting
- PCRTM explores spectral correlations in the hyperspectral data
  - 2-900 times faster than channel-based RT models
  - Reduce dimensionality of original spectrum by a factor of 10-90
  - Accurate relative to full line-by-line RT calculations
- PCRTM covers 0.31 μm-200 μm spectral range (panchromatic)
  - Trace gases (15 variable gases)
  - clouds, and aerosols with multiple scattering included
  - various surface emissivity and BRDF
  - Non-LTE included
- An optimal estimation retrieval algorithm has been developed
  - Use all spectral channels (compressed into EOF space)
  - Currently retrieved parameters: T, H_2O, CO_2, CO, O_3, CH_4, N_2O, Cloud optical depth/size/phase/height, surface emissivity, and Tskin…
- Goals of this study
  - Compare information content of full-resolution and nominal resolution CrIS data using PCRTM and associated retrieval algorithm
  - Get ready to routinely analyze full-res CrIS data

How does PCRTM work?

Flow diagram of the PCRTM forward model



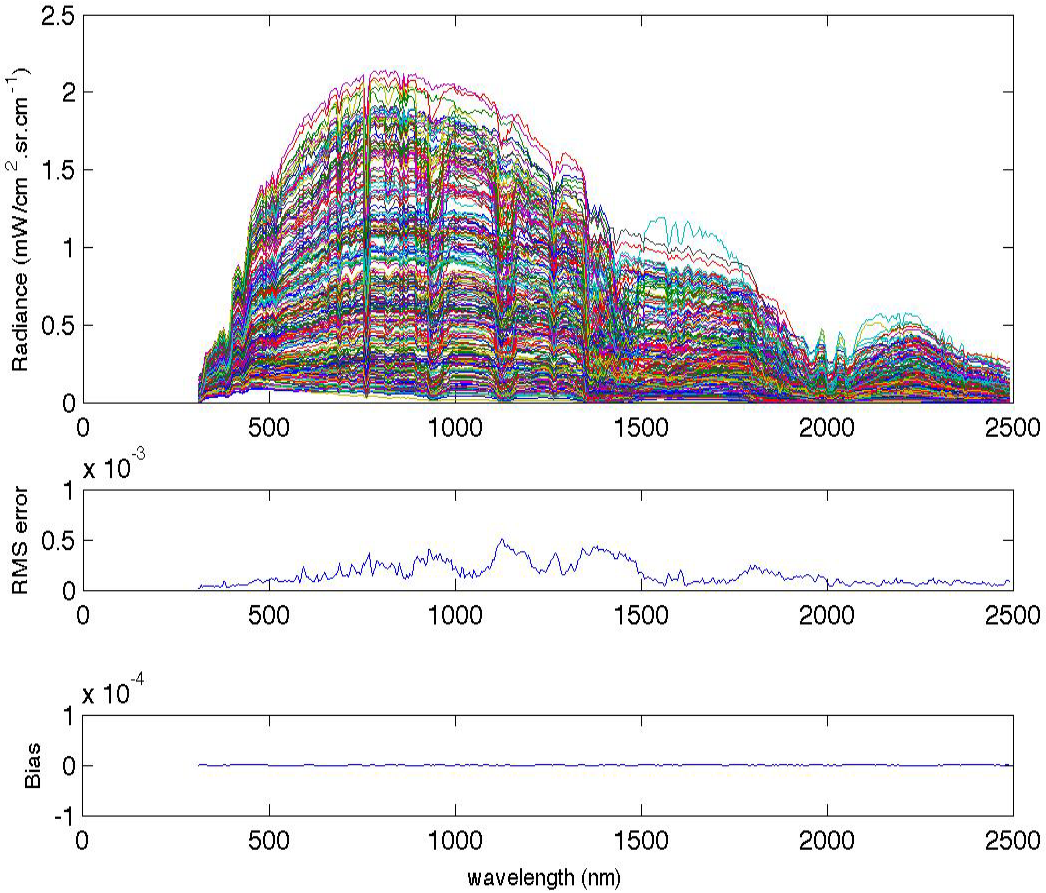
- Regular Monochromatic RT performed
  - This function can be performed by LBL, MODTRAN…
  - Can use lookup table and fast parameterization if needed
- RT needs to be done at minimum number of frequencies
  - Orders of magnitude smaller than LBL and MODTRAN

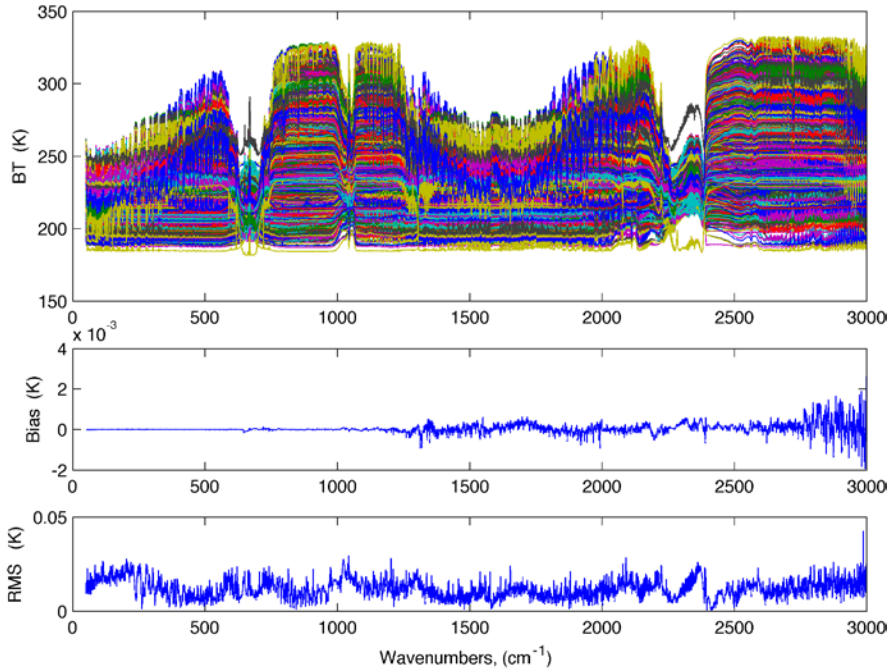


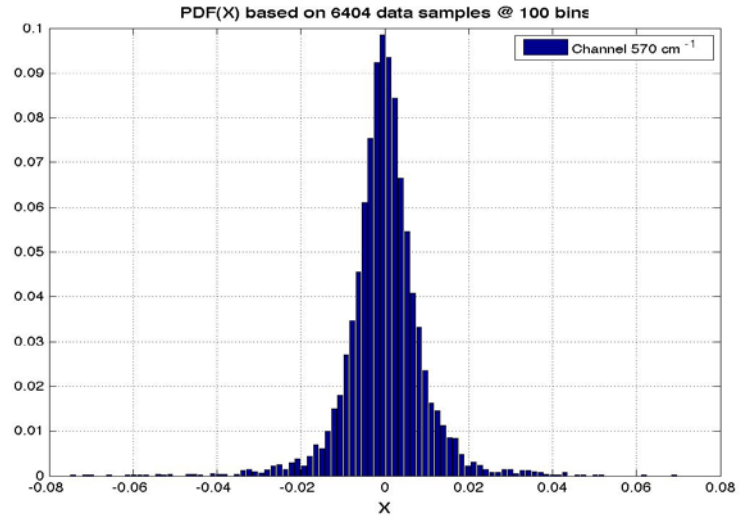
- O_2 A-band (12000 mono RT calculations using LBL)
- Only 7 Mono frequencies are essential when modeling at the OCO and SCIAMACHY spectral resolution

Accuracy of PCRTM is very good relative to reference RT models

- Bias error relative to LBL is typically less than 0.002 K
- The PDF of errors at different frequencies are Gaussian distribution
- RMS error < 0.03K for IR and < 5E-4 mW/cm^2/sr/cm^{-1} for solar (<0.2%)





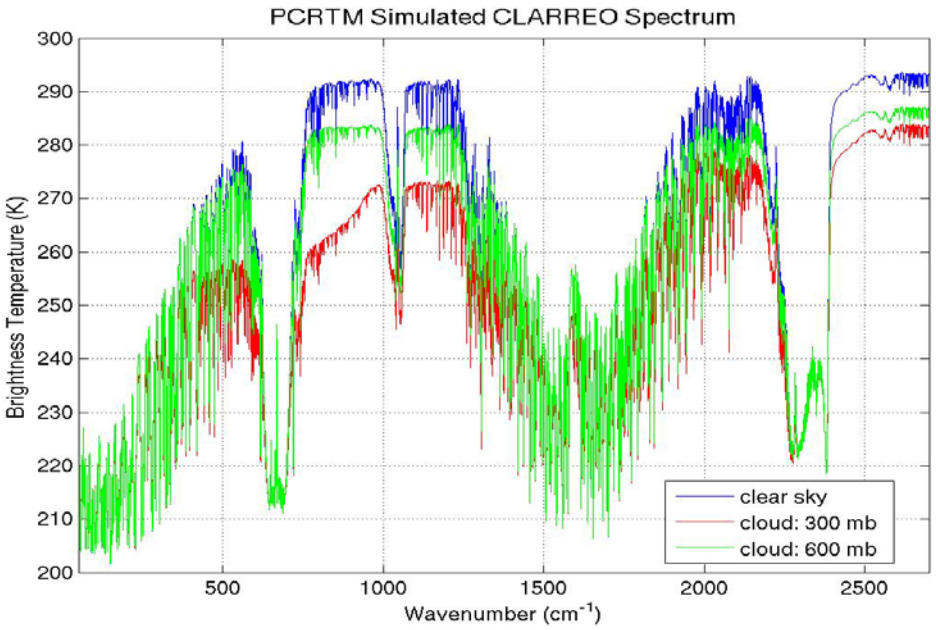


Very Fast computation speed for PCRTM

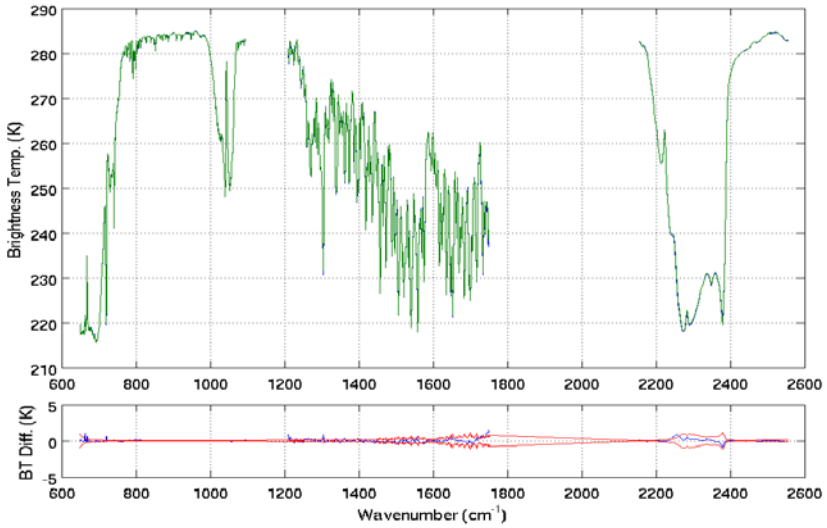
- **Milliseconds to fraction of seconds for IR, fraction of second to seconds for sola**
- **CrIS, CrIS-full-res, IASI, NAST-I and S-HIS have multiple databases corresponding to different ILS**
- **Spectral converage from 310 nm to 200000 nm**

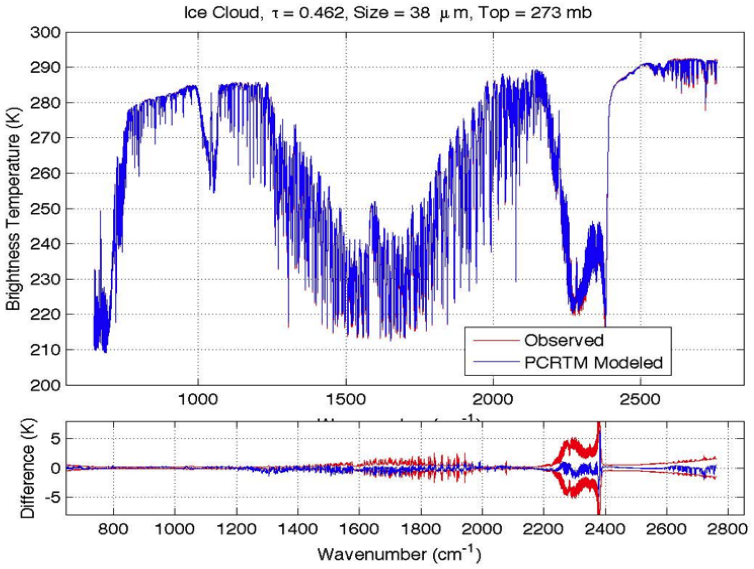
Sensor	Channel Number	PC score (seconds)	PC score + Channel radiance	PC score + PC Jacobian
CLARREO, 0.1 cm^{-1}	19901	0.014 s	0.022 s	0.052 s
CLARREO, 0.5 cm^{-1}	5421	0.011 s	0.013 s	0.039 s
CLARREO, 1.0 cm^{-1}	2711	0.0096 s	0.012 s	0.036 s
IASI, 0.25 cm^{-1}	8461	0.011 s	0.012 s	0.044 s
AIRS, 0.5-2.5 cm^{-1}	2378	0.0060 s	0.0074 s	0.031 s
CrIS, Blackman, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0060 s	0.021 s
CrIS, Boxcar, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0060 s	0.022 s
CrIS, Hamming, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0058 s	0.022 s
NAST-I, 3 bands, 0.25 cm^{-1}	8632	0.010 s	0.013 s	0.045 s
S-HIS 0.5 cm^{-1}	4316	0.008 s	0.008 s	0.038 s
CrIS, Hamming Full resolution	2211	0.009 s	0.009 s	0.033 s

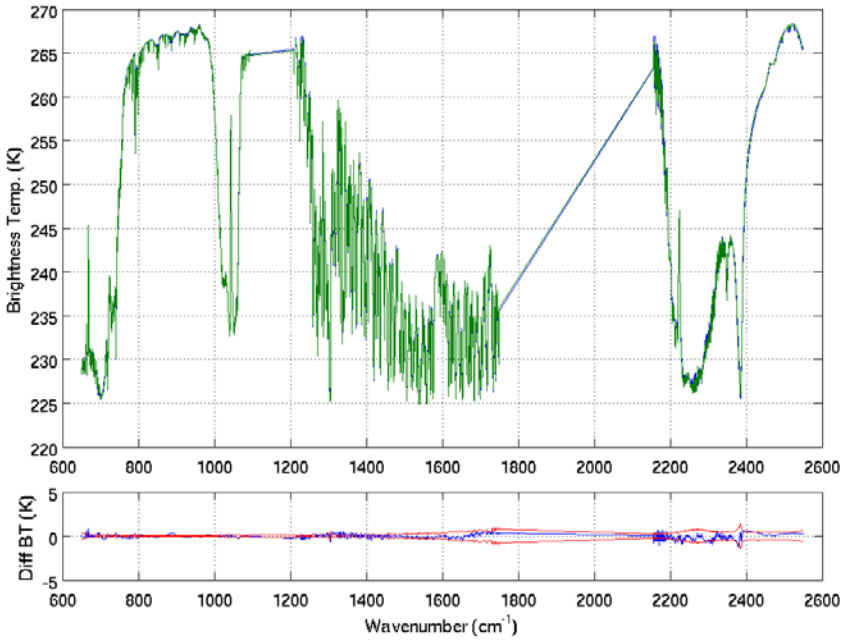
	PCRTM RT	MODTRAN RT	speed up
Ocean 1cm^{-1}	956	259029	270
Land 1cm^{-1}	1339	259029	193
Ocean 4nm	279	259029	928
Land 4nm	354	259029	731
Oc/ld 10 nm	109	3079	28

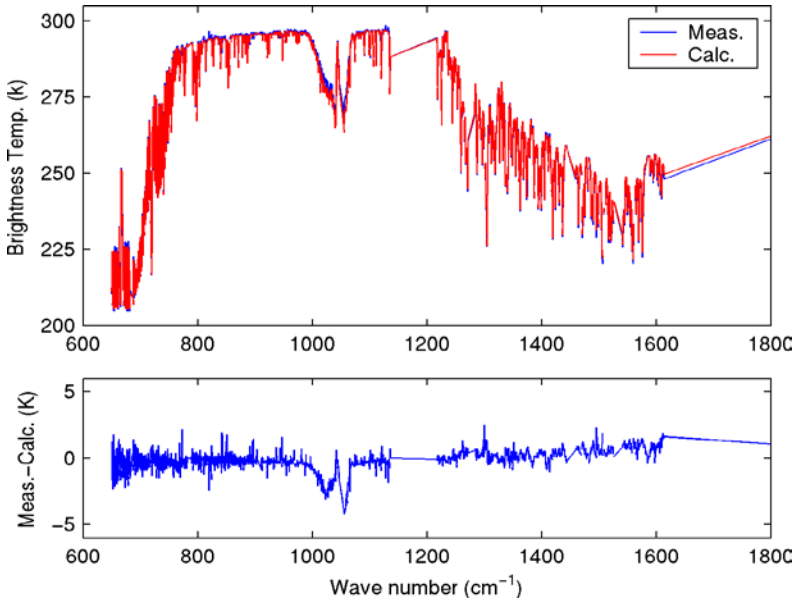


Example of PCRTM calculated and CrIS/IASI/ AIRS observed radiances

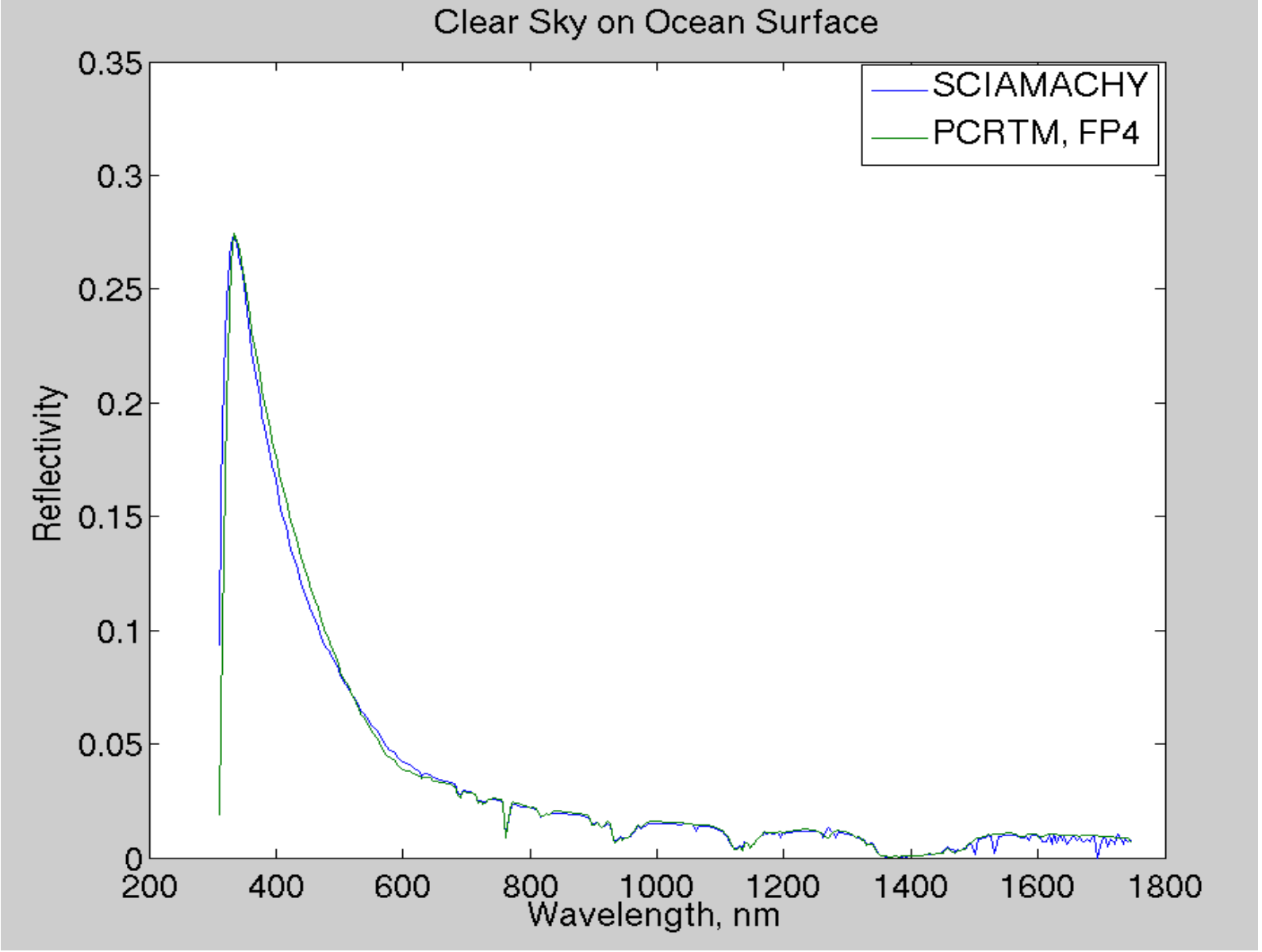




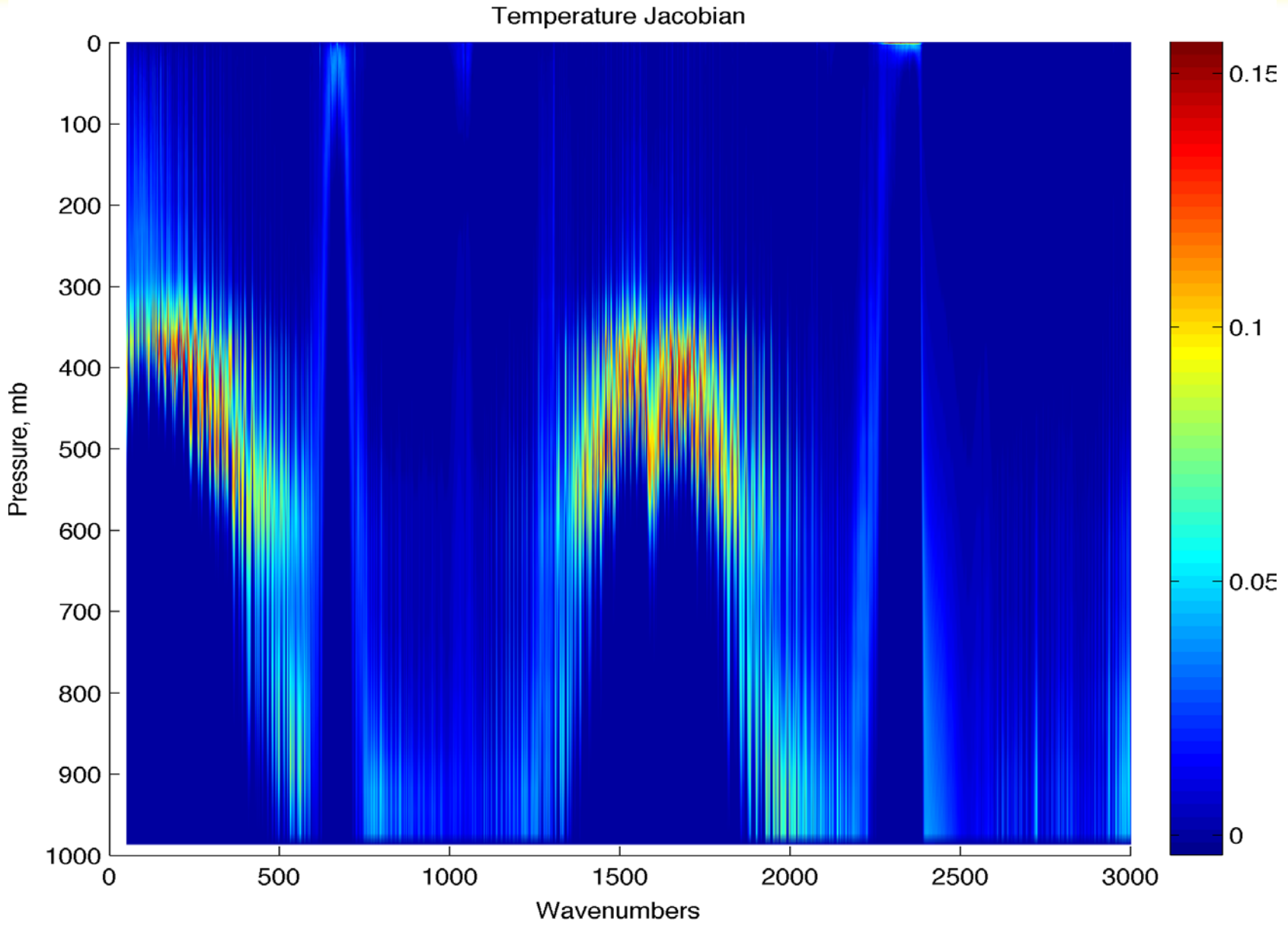




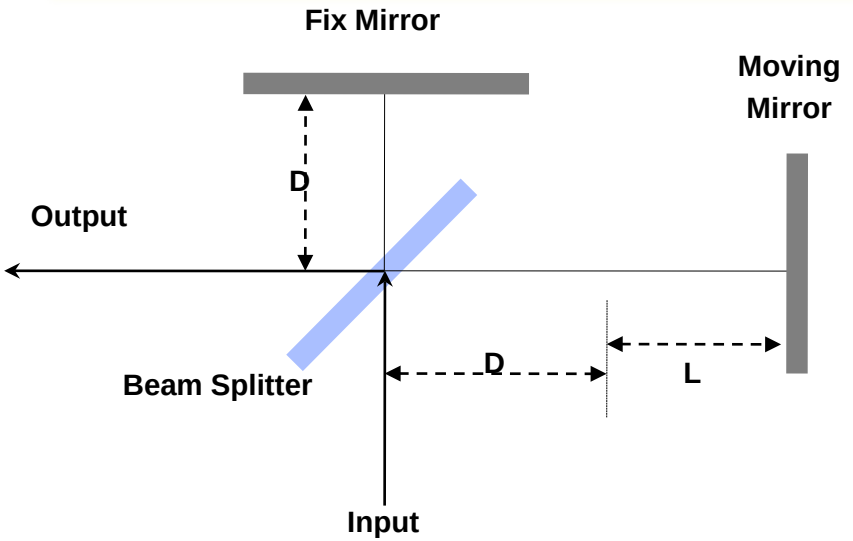
An Example PCRTM simulated spectra and comparison with SCIAMACHY data



Example of PCRTM calculated Jacobian

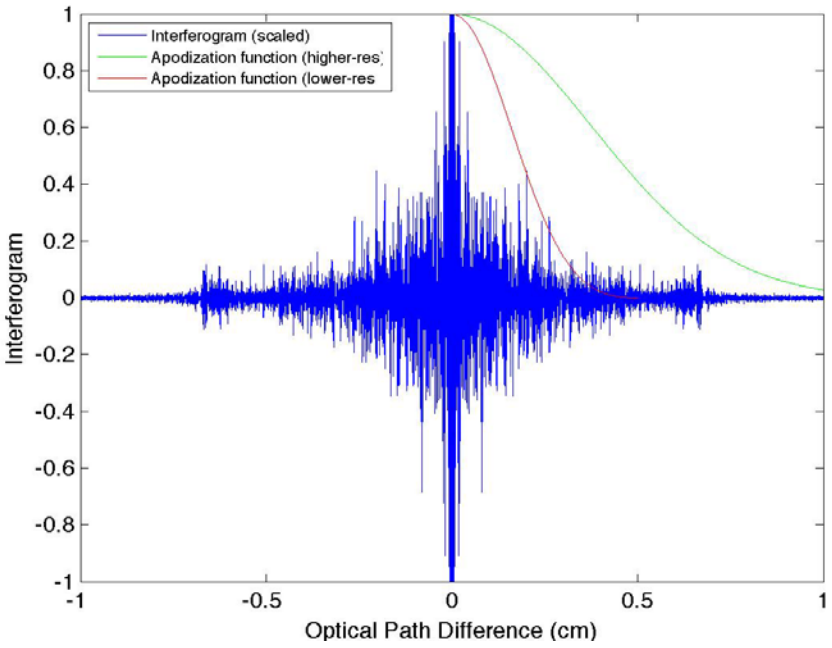


Overview of Cross-track Infrared Sounder (CrIS)

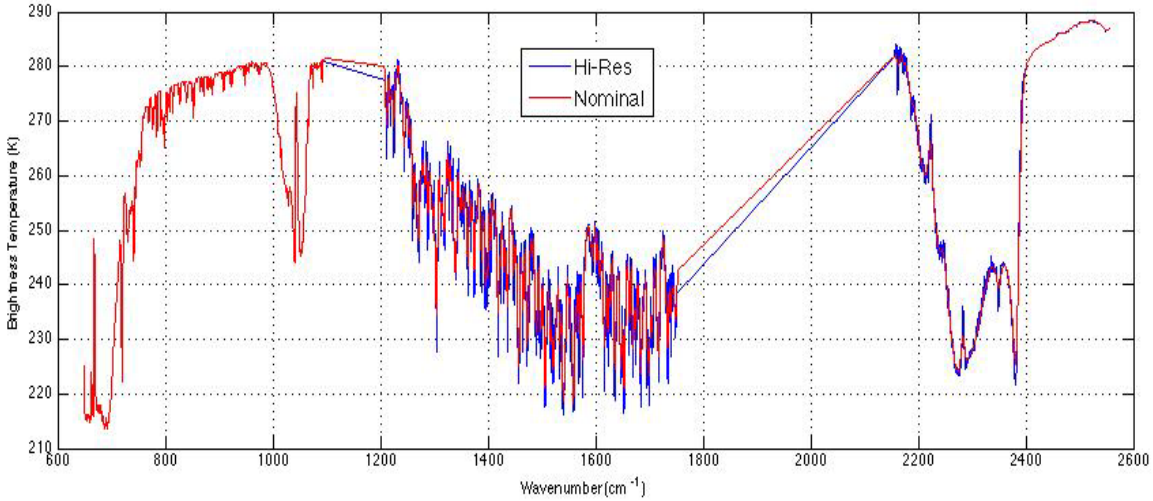


	IASI	CrIS (LW)	CrIS (MW)	CrIS (SW)
MOPD	~2.0 cm	0.8 cm	0.4 cm	0.2 cm
Spectral spacing	0.25 cm^{-1}	0.625 cm^{-1}	1.25 cm^{-1}	2.5 cm^{-1}
Apodized spectral resolution	0.5 cm^{-1} Guassian	0.88 cm^{-1} Hamming	1.76 cm^{-1} Hamming	3.53 cm^{-1} Hamming

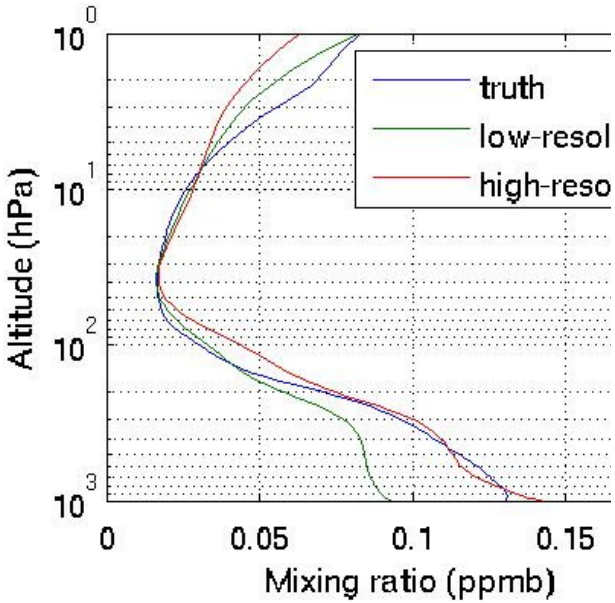
MOPD=2*L (L physical mirror displacement relative to zero optical path difference)

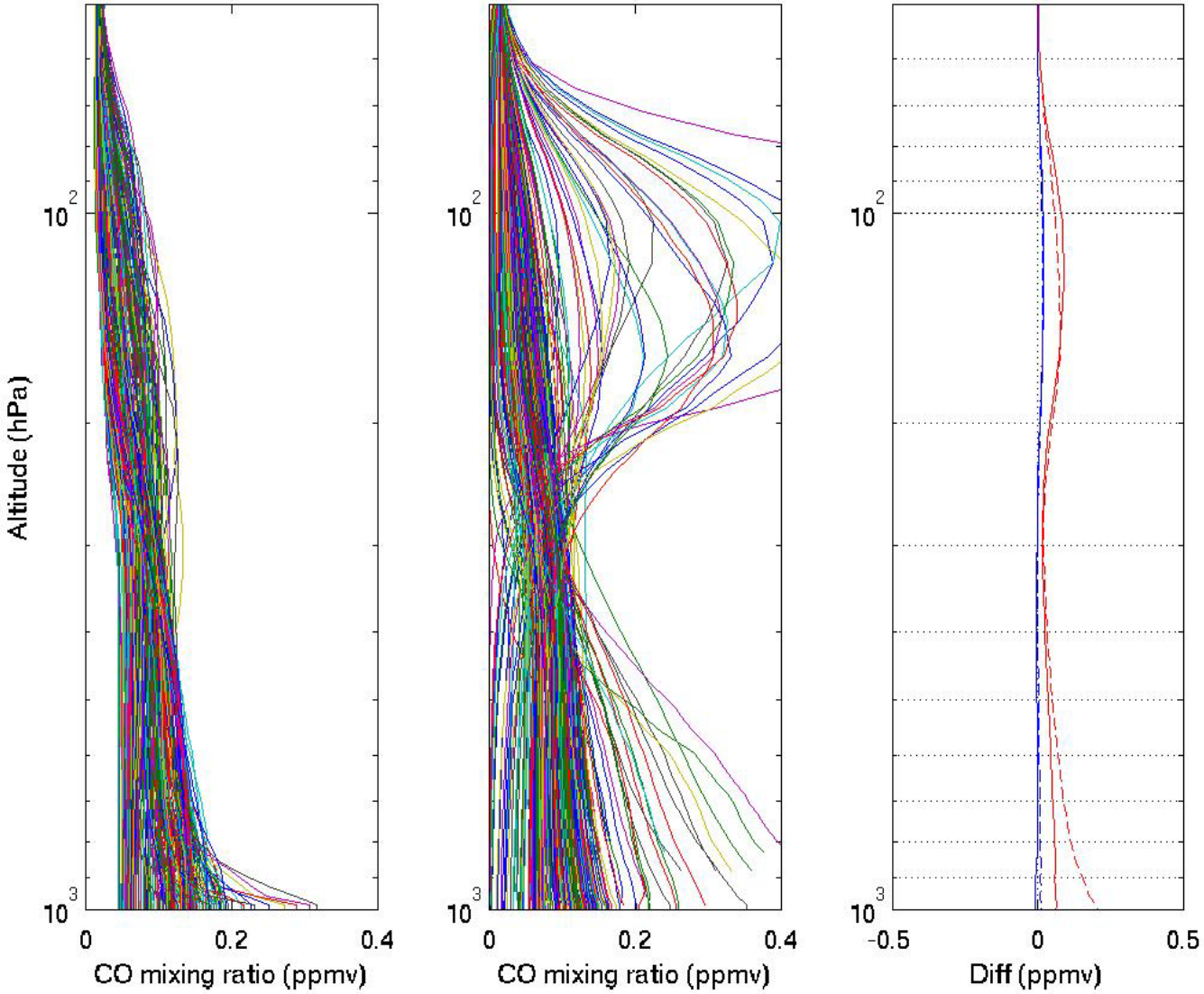


- Nominal CrIS spectrum has 1317 spectral channel (unapodized)
- Hi-Res CrIS spectrum has 2211 spectral channels

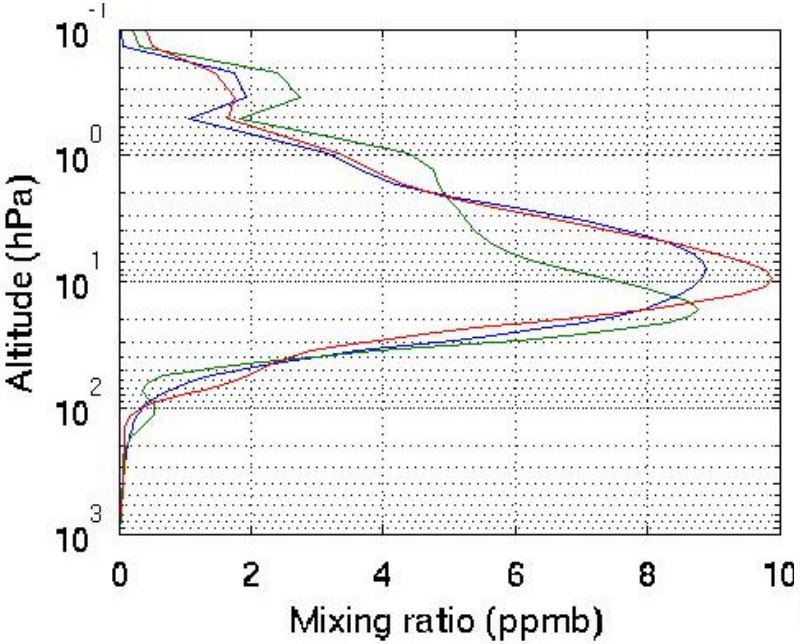


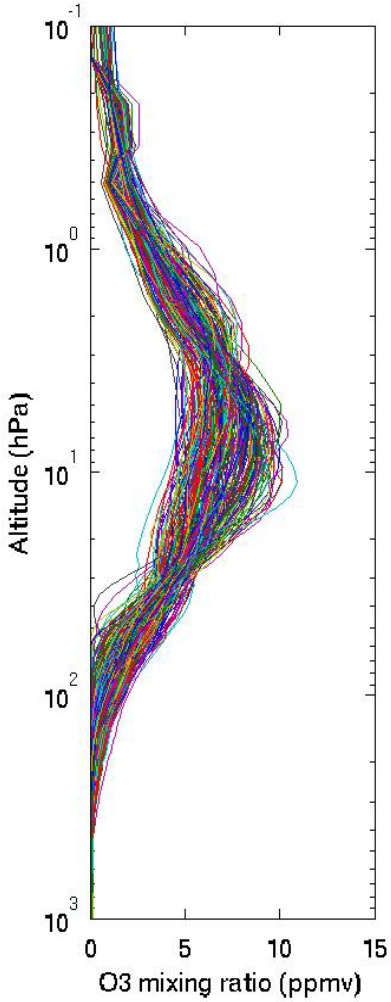
Hi-Res CrIS data improves CO Retrievals

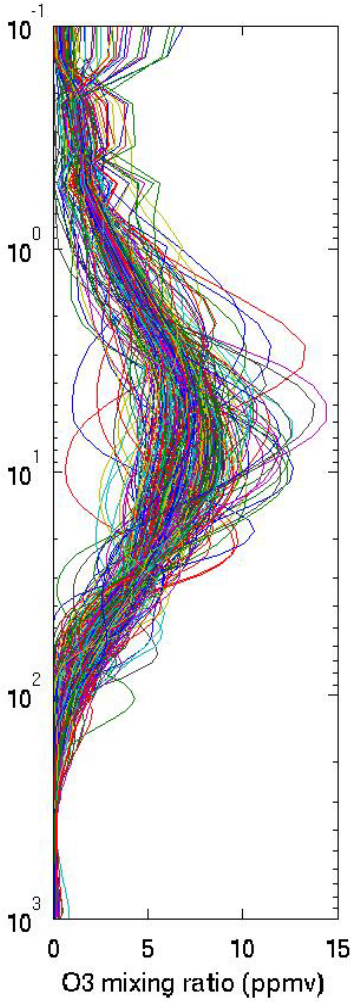


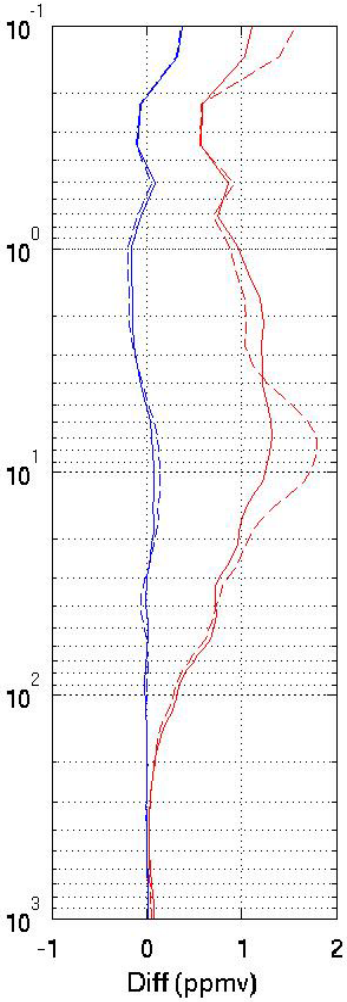


Hi-Res CrIS data improves O3 Retrievals

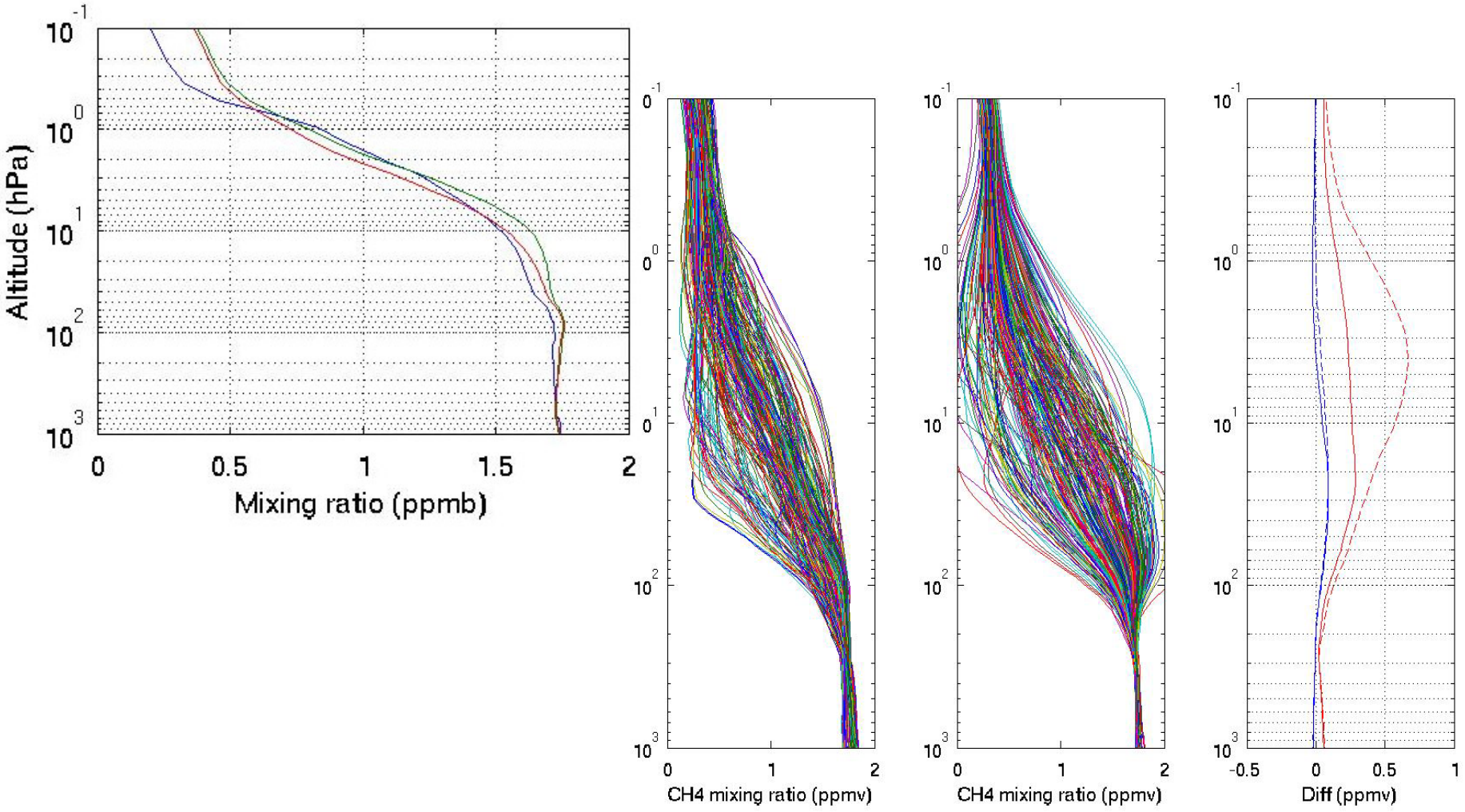




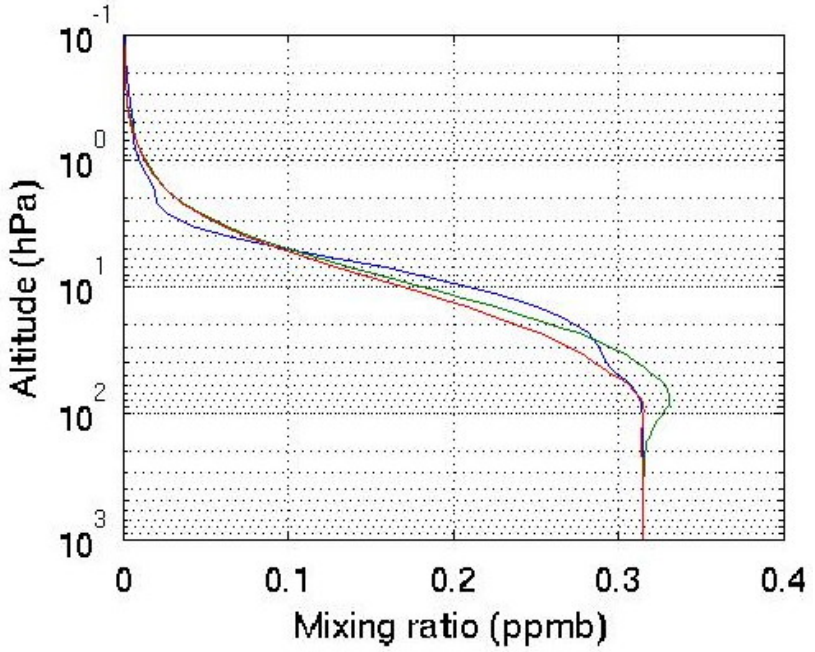


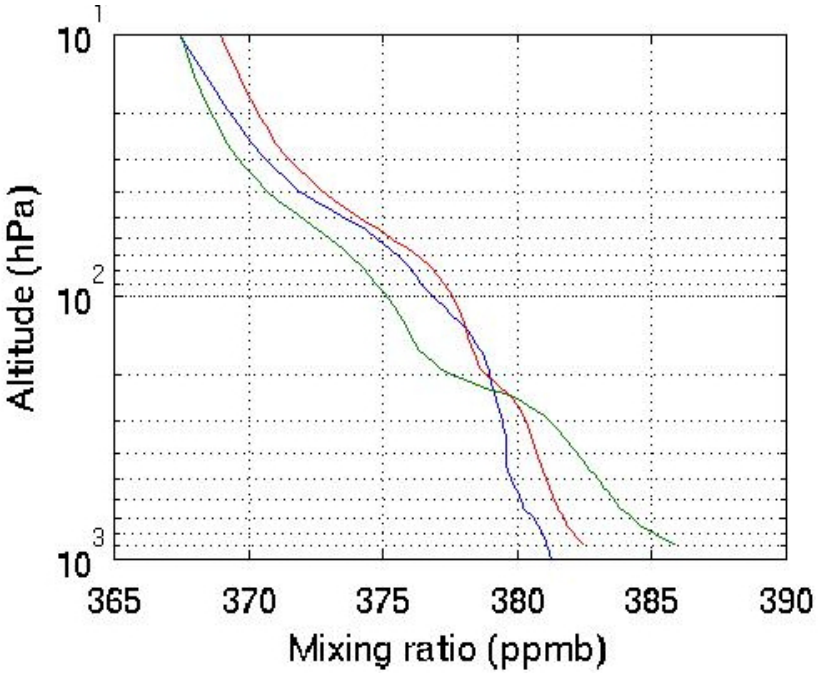


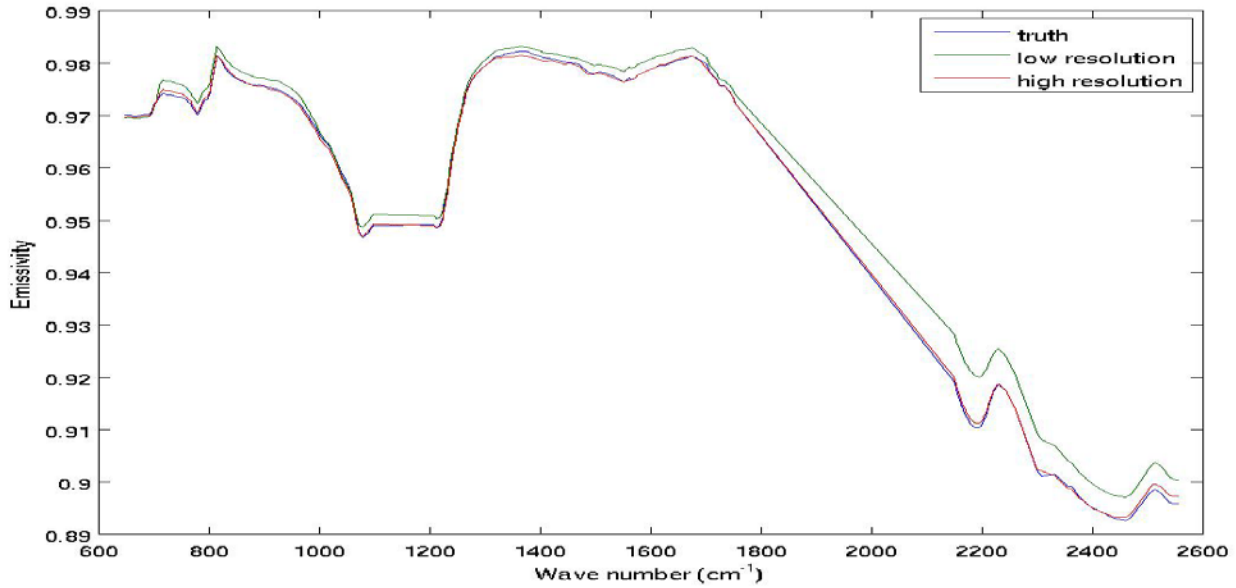
Hi-Res CrIS data improves CH4 Retrievals



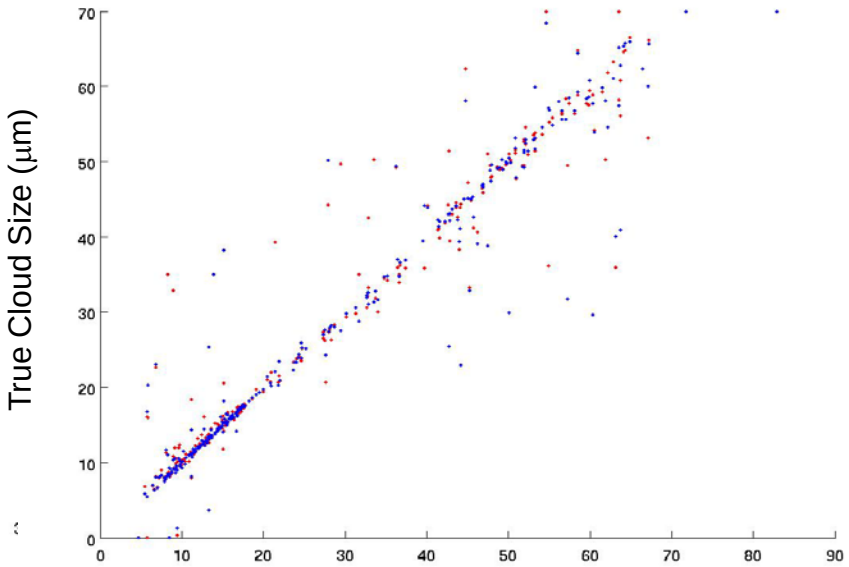
Examples of improved N2O, CO2, and surface emissivity retrievals

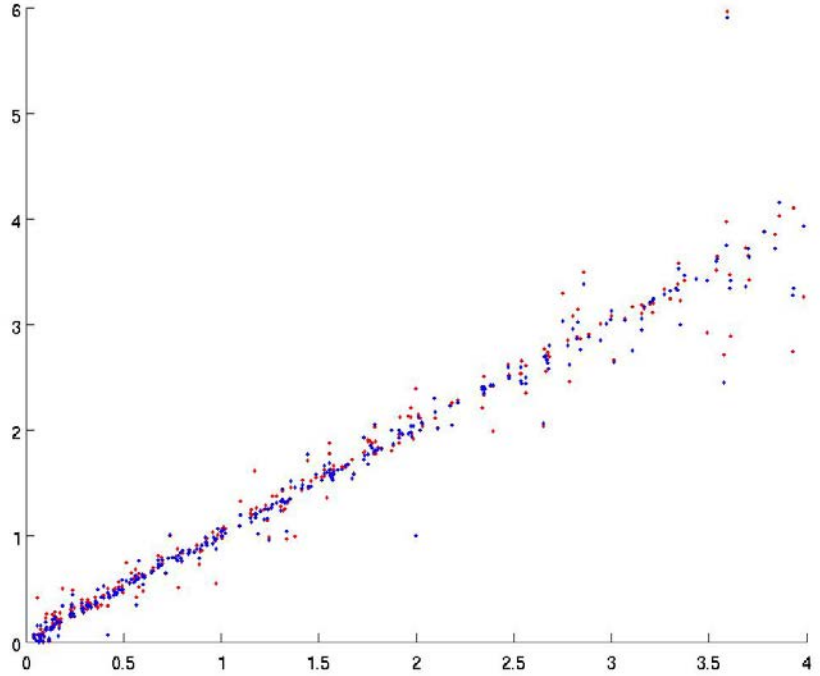




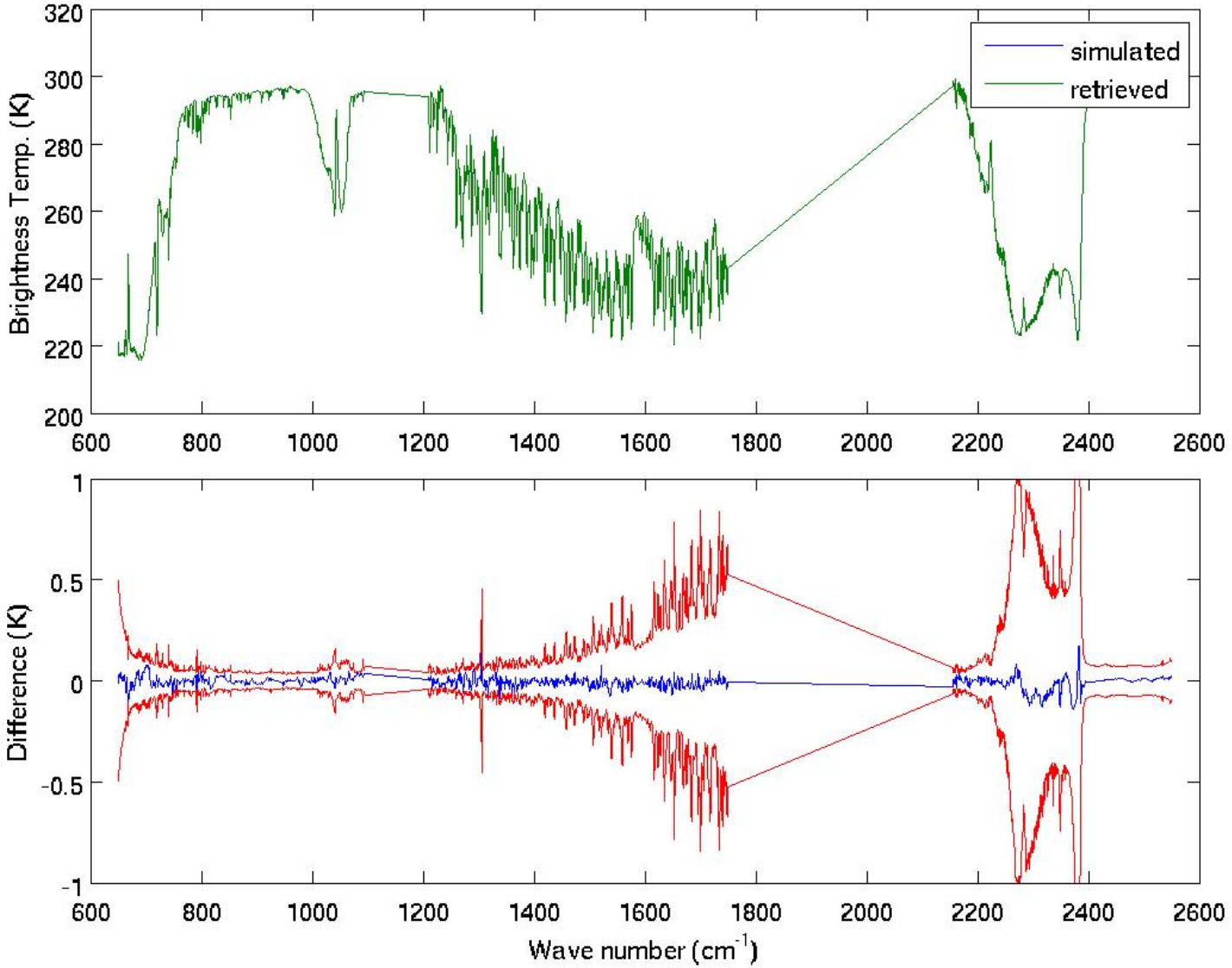


Example of cloud optical depth, particle size and cloud temperature/height retrievals

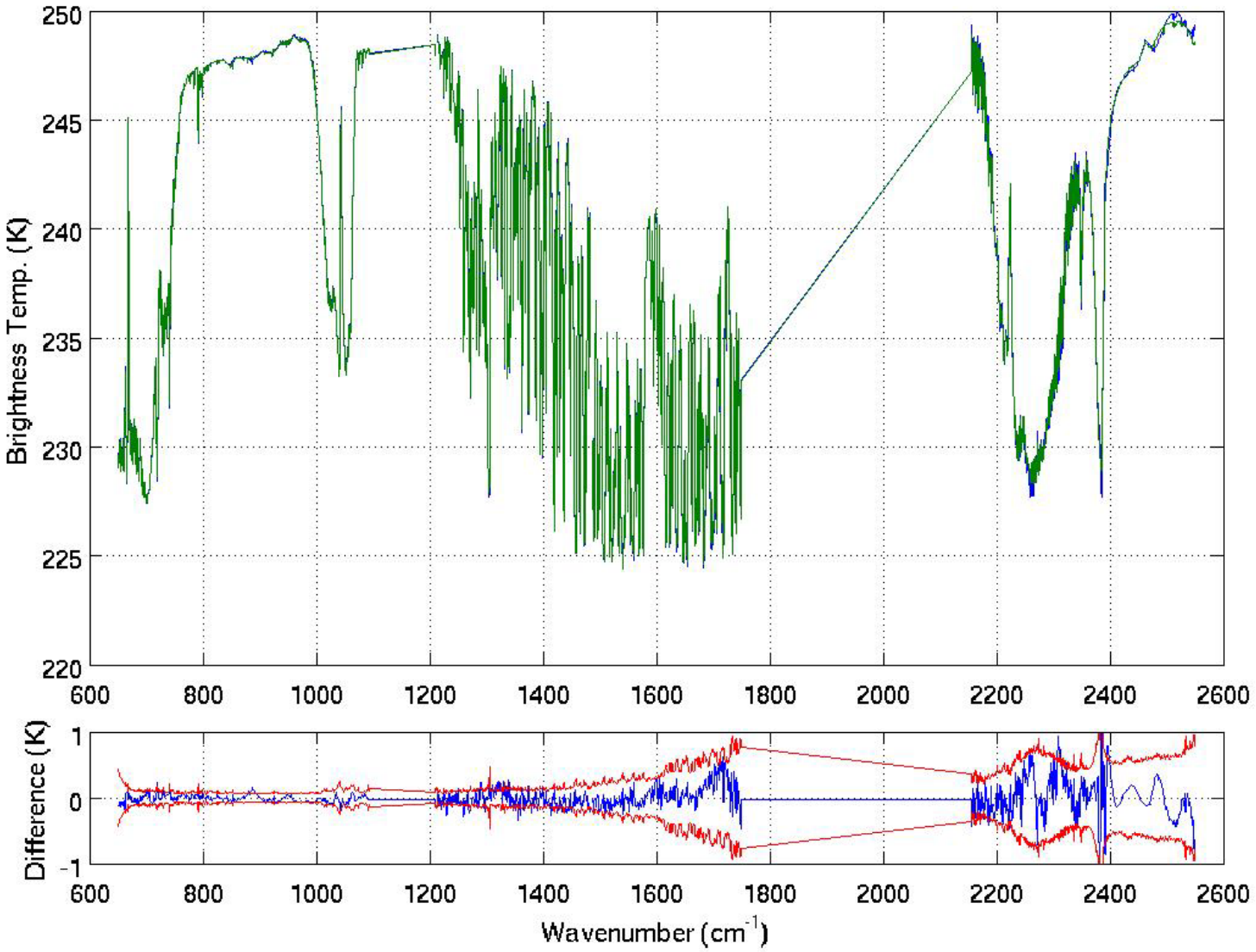




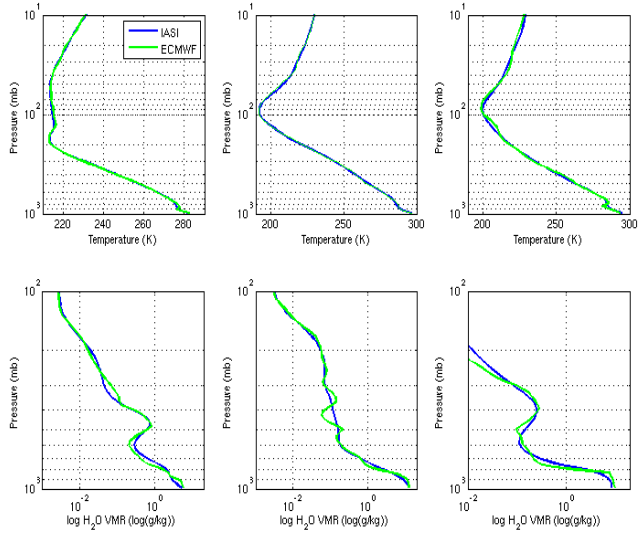
Spectral residues from simulation-retrieval studies

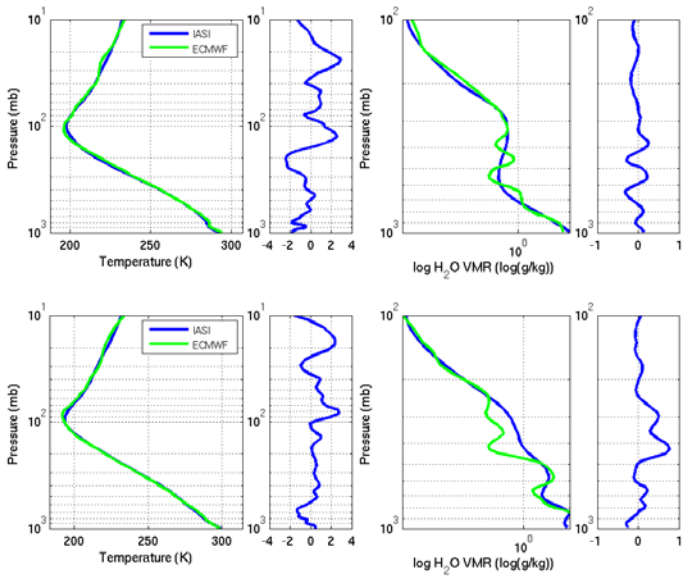


Spectral residues from real CrIS Hi-Res data

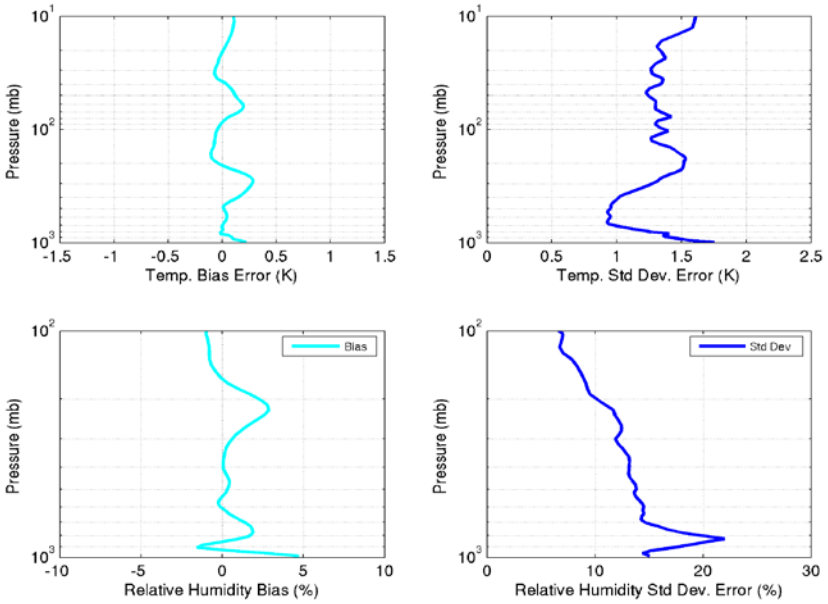


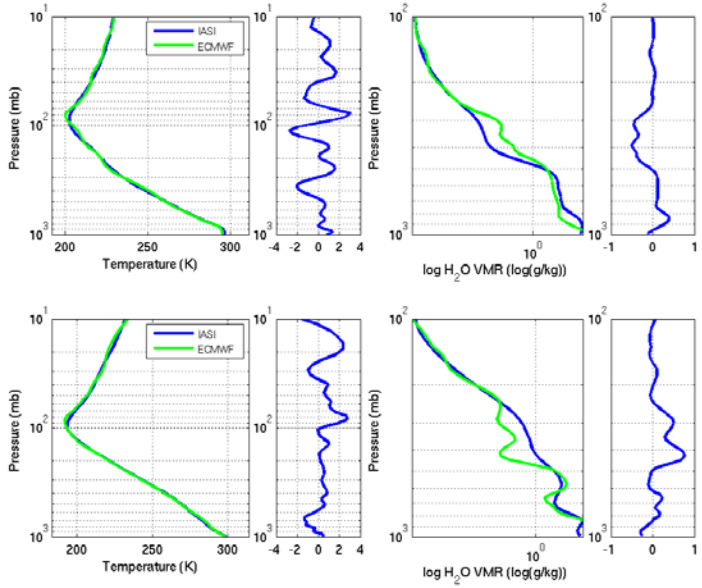
Examples of PCRTM retrieved temperature and moisture profiles with ECMWF





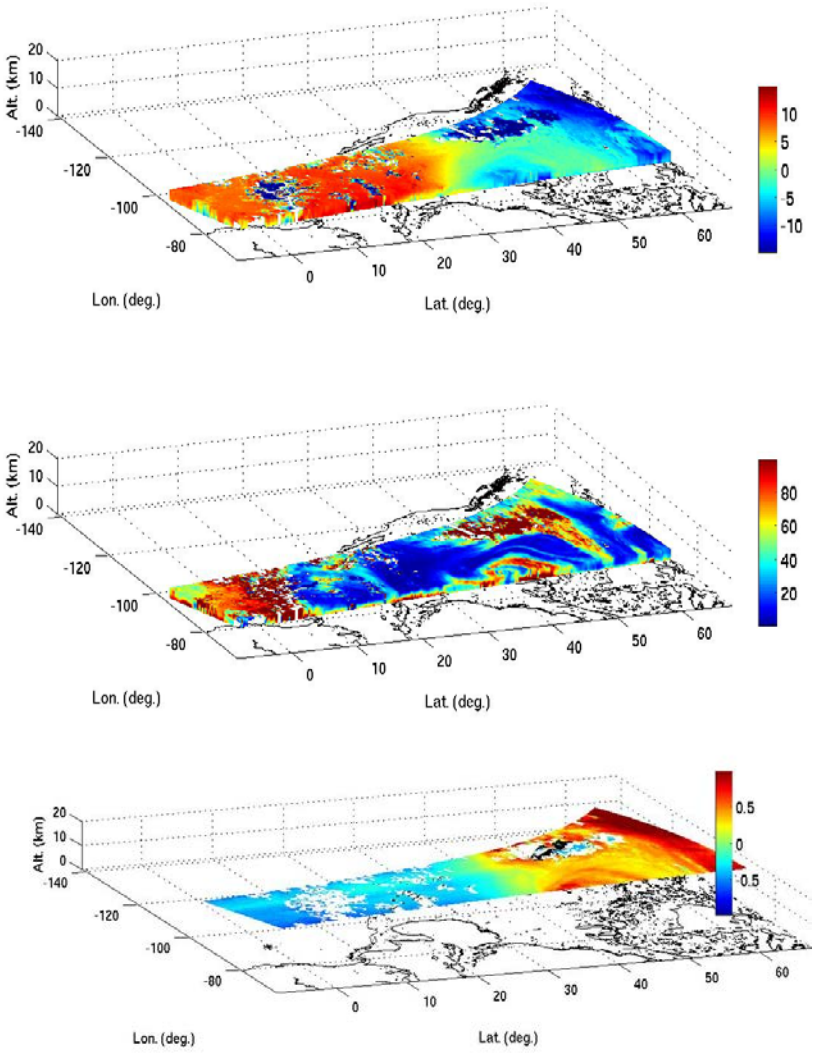
Statistics (101 levels , no vertical averaging)

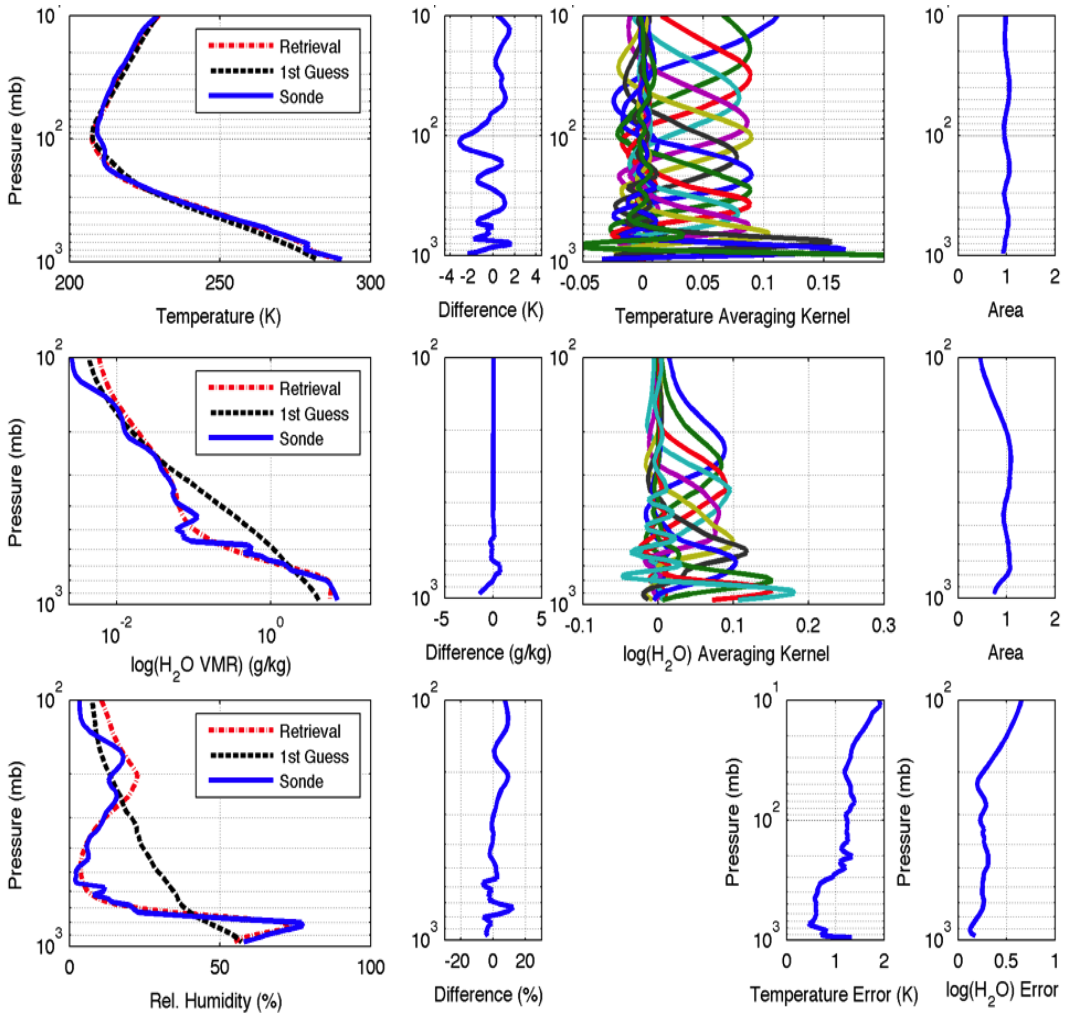




Validation of PCRTM retrieval with radiosondes (averaging kernel and error estimate provided)

- Temperature, moisture, and ozone cross-sections
- Plots are deviation from the mean
- Fine water vapor structures captured by the retrieval system
- A very cloudy sky condition



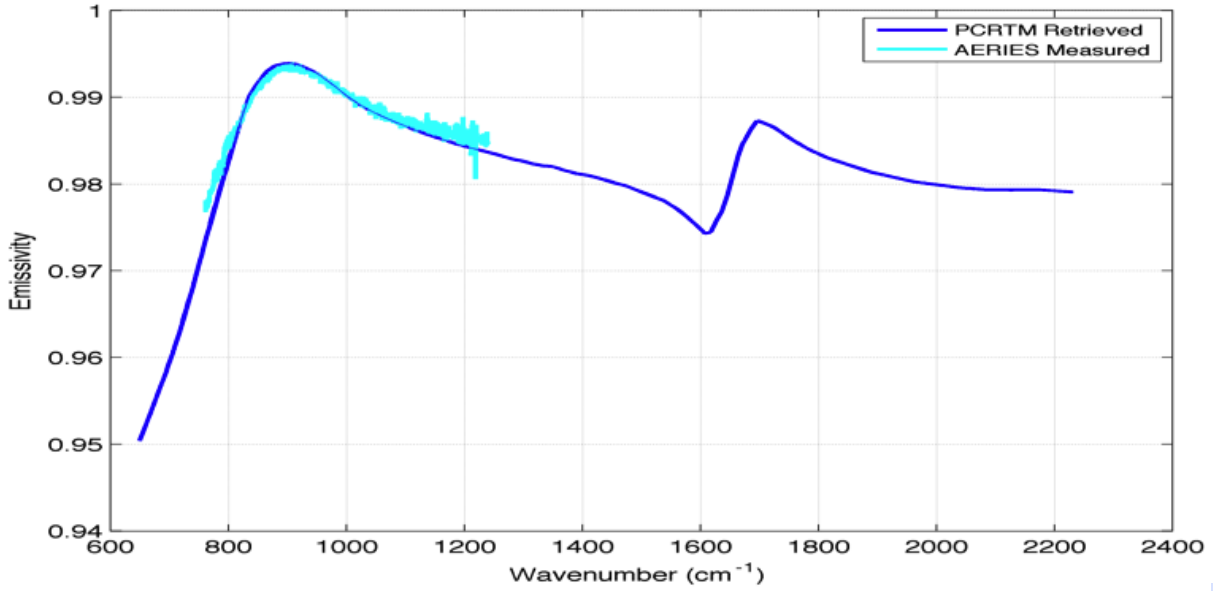


Examples of surface skin temperature and surface emissivity

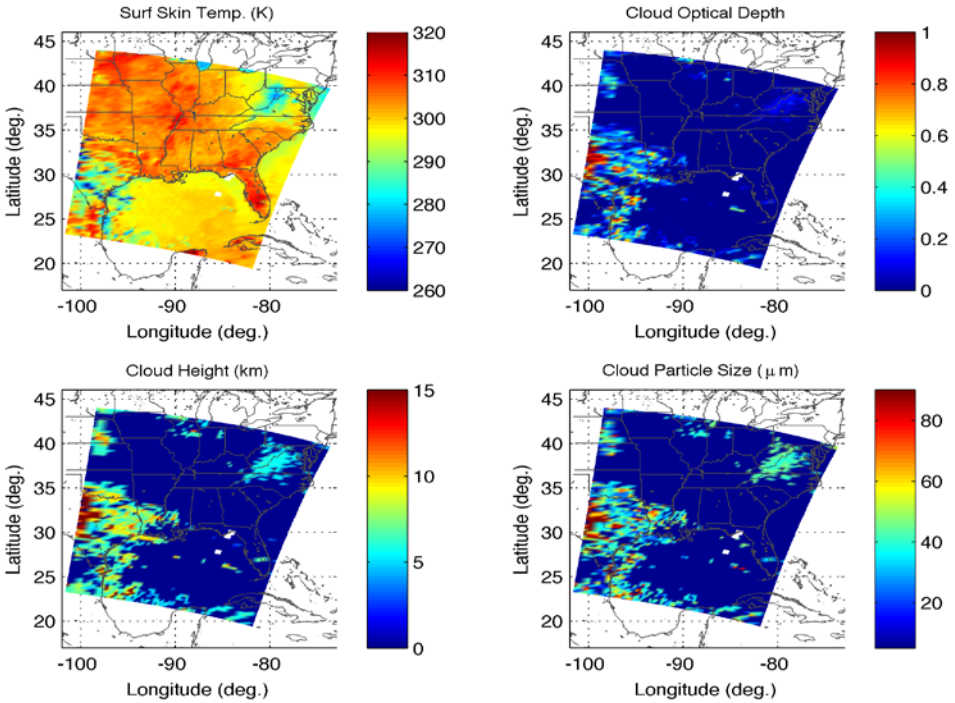
Comparison of PCRTM retrieved surface skin temperature with ARIES measured Tskin

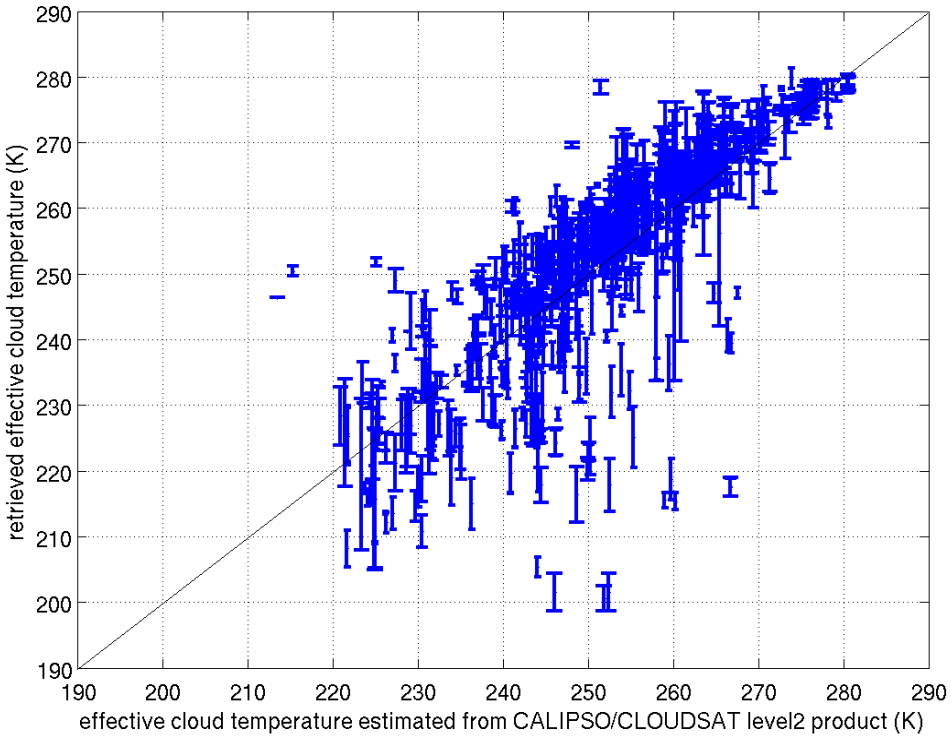
Date	Location	Surface Pressure (hPa)	ARIES Measured skin temperature (K)	IASI-retrieved surface skin temperature (K)
19 April 2007	ARM CART site	972.0	284.7	284.8
29 April 2007	Gulf of Mexico	1021.7	297.8	297.6
30 April 2007	Gulf of Mexico	1017.5	298.6	298.1
4 May 2007	Gulf of Mexico	1009.9	297.4	297.1

Comparison of retrieved ocean emissivity with ARIES aircraft measurements

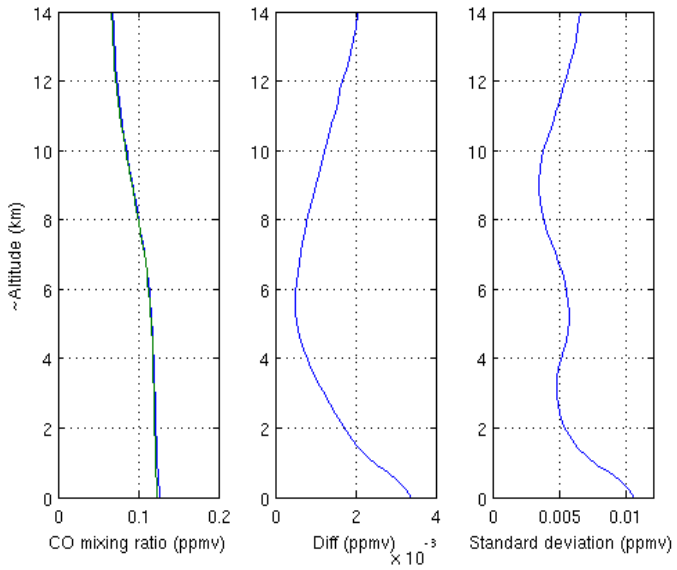


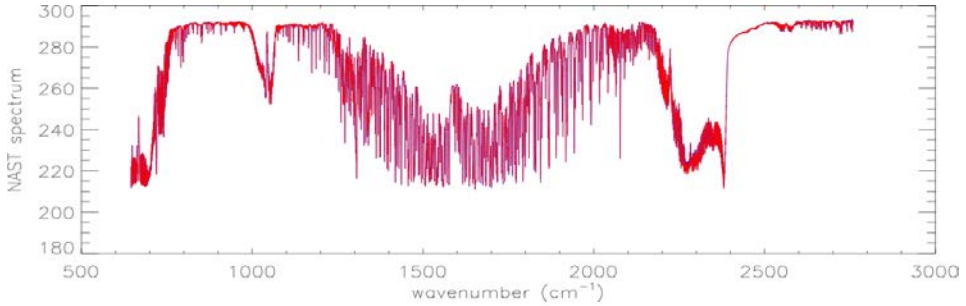
Validation of retrieved cloud properties

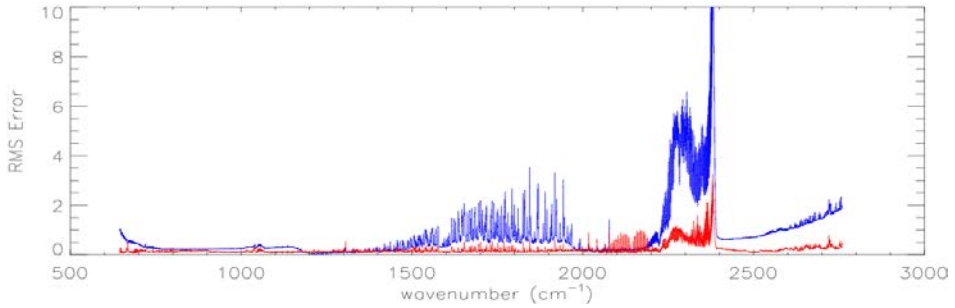


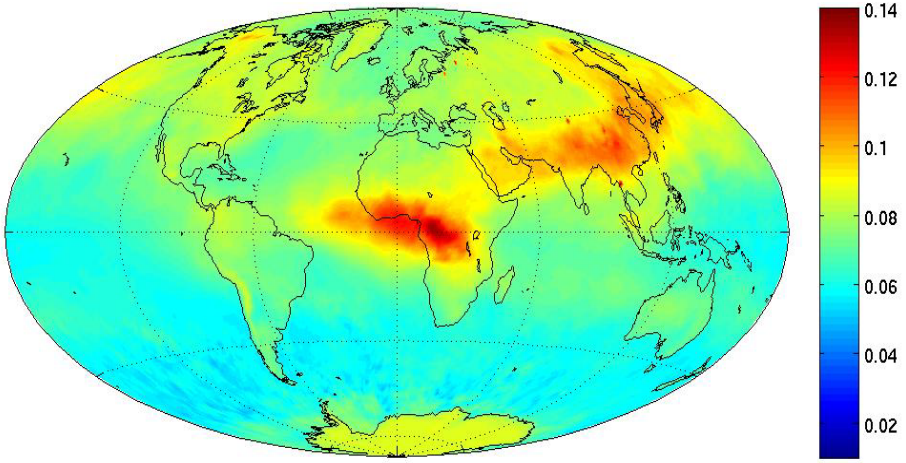


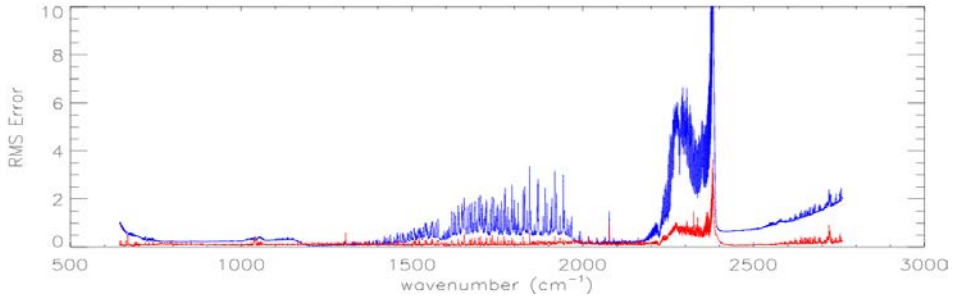
Example of trace gas retrievals (CO retrieval sensitivity study and global CO retrieved from real IASI data)





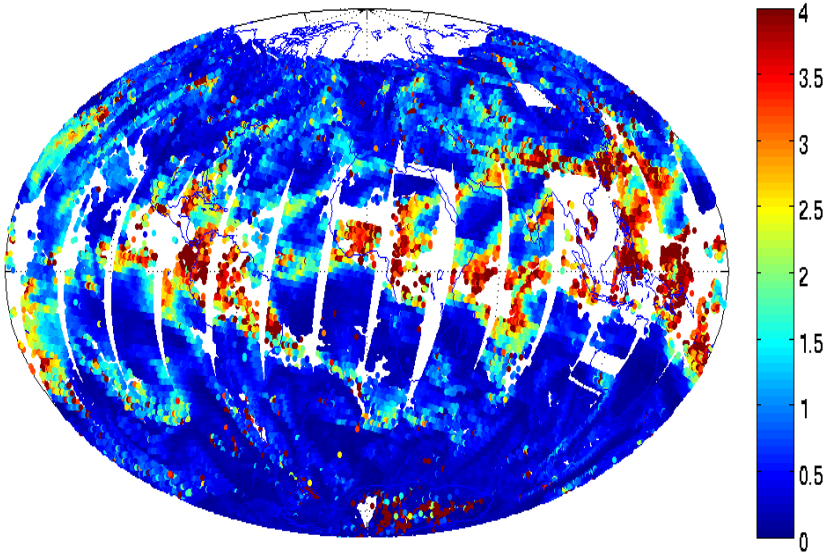


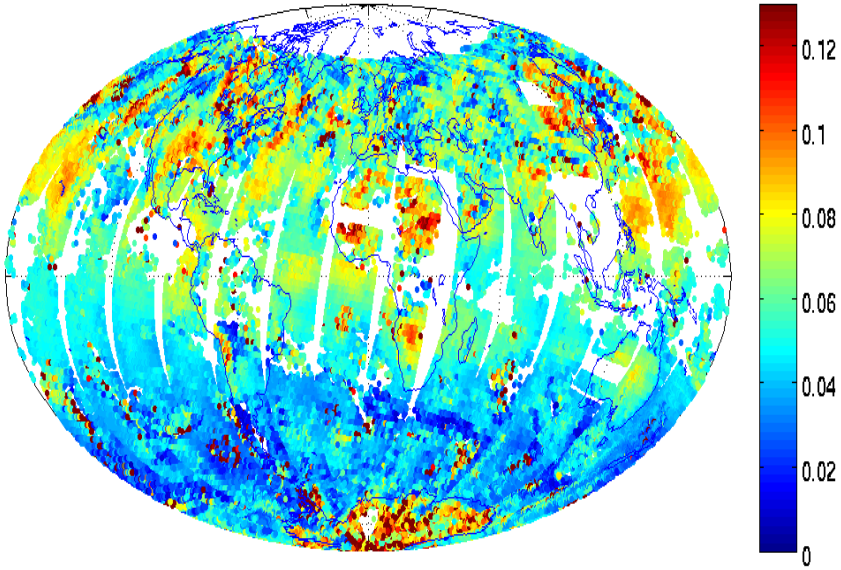




- Notice that the feature near 2020-2250 cm-1 are removed when CO profile is explicitly retrieved in the inversion algorithm

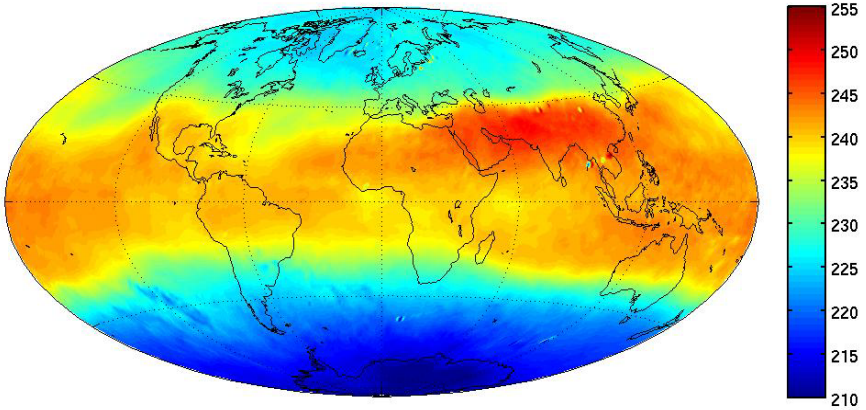
Example of H2O and CO retrievals from CrIS



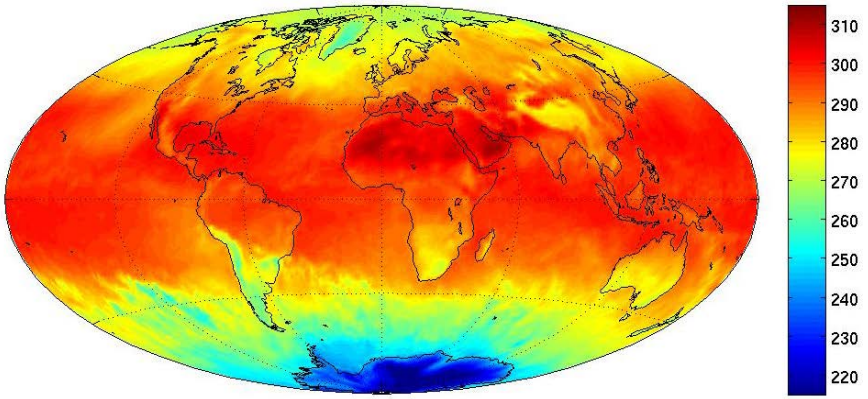


Example of retrieved global distribution of climate related properties retrieved using the PCRTM algorithm

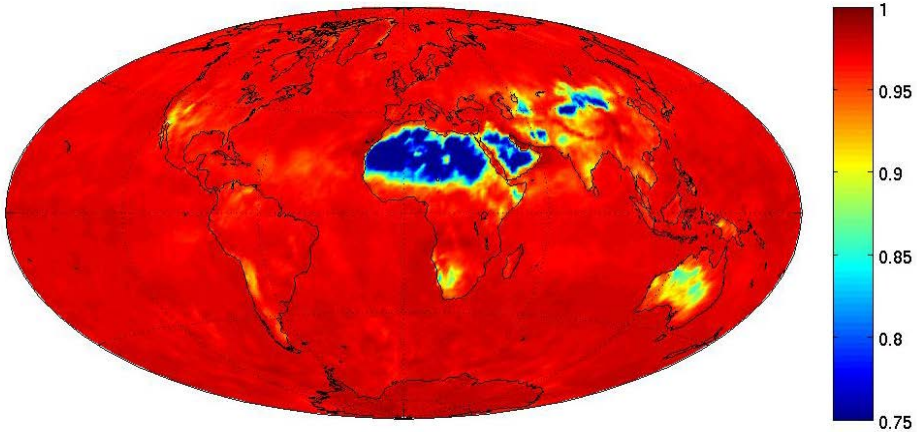
Atmospheric temperature at 9 km for July 2009



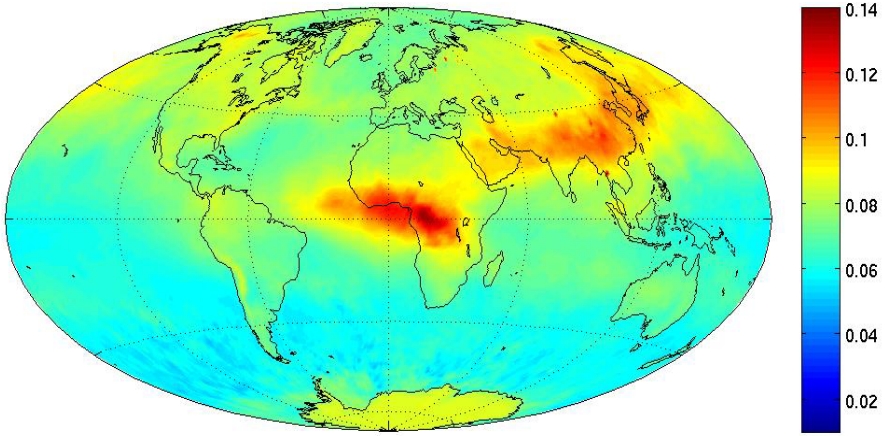
Surface skin temperature for July 2009



Surface emissivity for July 2009



Atmospheric carbon monoxide mixing ratio for July 2009



Summary and Future Work

- A fast and accurate radiative transfer model PCRTM has been developed
  - Calculate radiance/reflectance/transmittance from 0.31 μm-200 μm
  - End-to-end sensor performance simulations
  - Has been applied to: AIRS, IASI, CrIS, NAST-I, S-HIS, SCIAMACHY
  - The PCRTM physical retrieval algorithm is ready to analyze full CrIS
    - Does not use cloud-clearing (CC) assumption
      - CC is used by current AIRS and CrIS operational algorithms
      - One retrieval for every 9 FOVs
    - Retrieves cloud properties simultaneously with numerous other products
      - T, H_2O, CO_2, CO, O_3, CH_4, N_2O, Cloud optical depth/size/phase/height, surface emissivity, and Tskin…
    - Provide products at higher spatial resolution
      - One retrieval for each FOV
- Future work
  - Routinely analyze full resolution CrIS data (available later this year)
  - Perform validation of the products with correlative measurements
  - Generate climate data record from multiple sensors (CrIS/AIRS/IASI)
  - Use multi-spectral regions to improve retrieval information