Validations of Principal Component-based Radiative Transfer Model (PCRTM) Using AIRS and NAST-I Observed Radiances

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Outline

- Introduction
- Overview of PCRTM
- Application of PCRTM to NAST-I simulated and observed data
- Application of PCRTM to AIRS observed data
- Summary and future work

Introduction

- **Modern hyperspectral sensors have thousands of channels**
  - **AIRS : 2378**
  - **IASI : 8461**
  - **CrIS : 1305**
  - **NAST-I : 8632**
- **Provide high information content**
  - **Improved sounding accuracy and vertical resolution**
- **Computationally expensive to performance RT calculations**
  - **Often a subset of channels are used in variational retrievals**
  - **Only a few hundred channels are used in satellite data assimilation**
- **Faster forward models are needed**
  - **Model all the channels efficiently**
  - **PCRTM models PC scores instead of channel radiances**
    - **Not channel-based RT model---less computations**
    - **Radiance can be obtained by EOF transformation**
    - **A factor of 3-40 time faster than channel based RT models**

Overview of PCRTM

- **PCRTM calculates PC scores instead of channel radiance**
  - **PC scores can be thought of as super channels**
  - **Contain all the essential information on a spectrum**
  - **Reduces dimensionality (by 5-50)**
- **PCRTM provides derivatives of PC scores with respect to state vectors directly**
  - **Retrieval can be done in EOF domain directly**
- **All RT are done monochromatically**
  - **Can be extended to handle multiple scattering**
- **Channel radiances (or transmittances) can be obtained by multiplying the PC scores with pre-stored Principal Components (PCs):**

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

- **Can model unapodized spectra efficiently**
  - **The ILS information is captured by eigenvectors**
  - **Channel transmittances or radiances are not modeled directly**
    - **No need to handle negative side lobes etc…..**

Overview of PCRTM (continued)

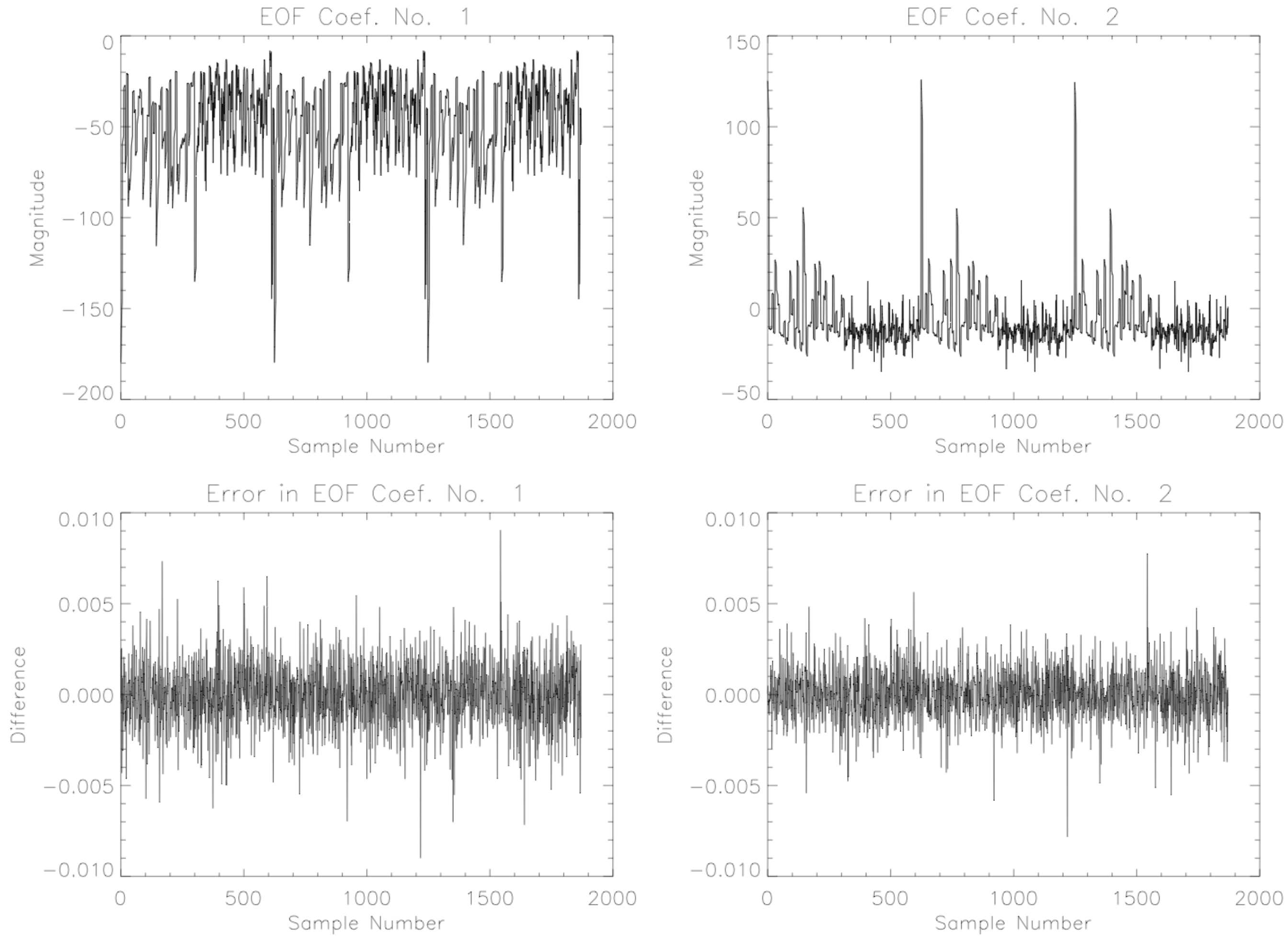
- ***Y_i*** **is the projection coefficient (PC scores) for the *ith* EOF**

$$Y_i = U^T_{N_{ch}\times 1} R^{ch}_{N_{ch}\times 1} = \sum_{j=1}^{N_{ch}} U(j,i) \times R^{ch}(j)$$

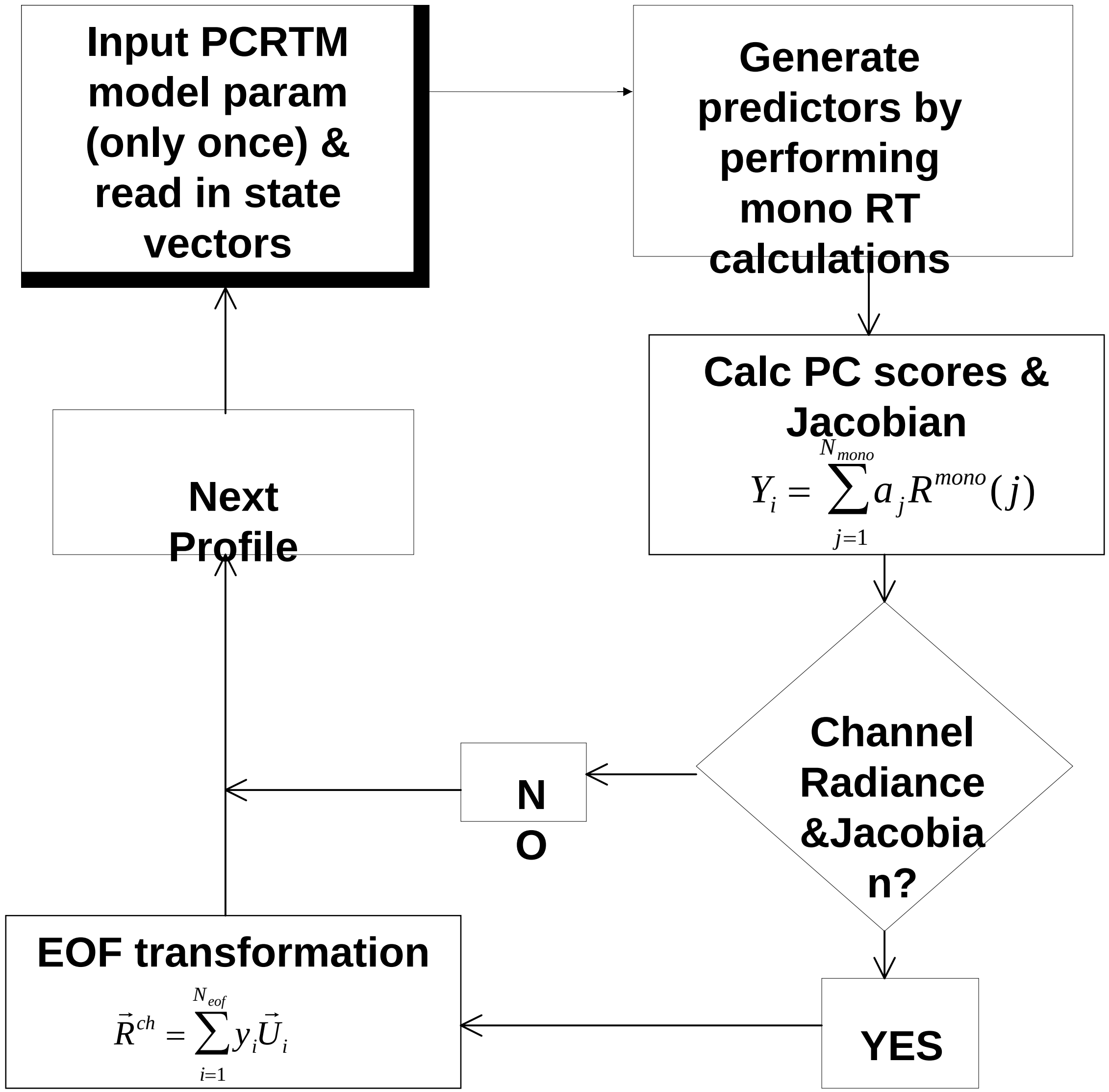
- ***Y*** **is a non-linear function of atmospheric state**
  - **contains essential information about the spectrum**
- ***U*** **captures spectral variations from channel to channel**
  - **does not change from one spectrum to another**
- ***R^{ch}*** **is a convolution of monochromatic radiances with ILS**
  - **ILS does not change from one spectrum to another**
- ***Y*** **can be predicted from monochromatic radiances directly**
  - ***U*** **and *b* (ILS) are constant with respect to each spectrum and are absorbed into constant, *a***

$$Y_i = \sum_{j=1}^{nch} U(j,i) \times \left[\sum_{k=1}^{N} b_k R^{mono}(k) \right] = \sum_{l=1}^{N_{mono}} a_l R^{mono}(l)$$

Projection Coefficients and Fitting Errors



Forward Model Flowchart

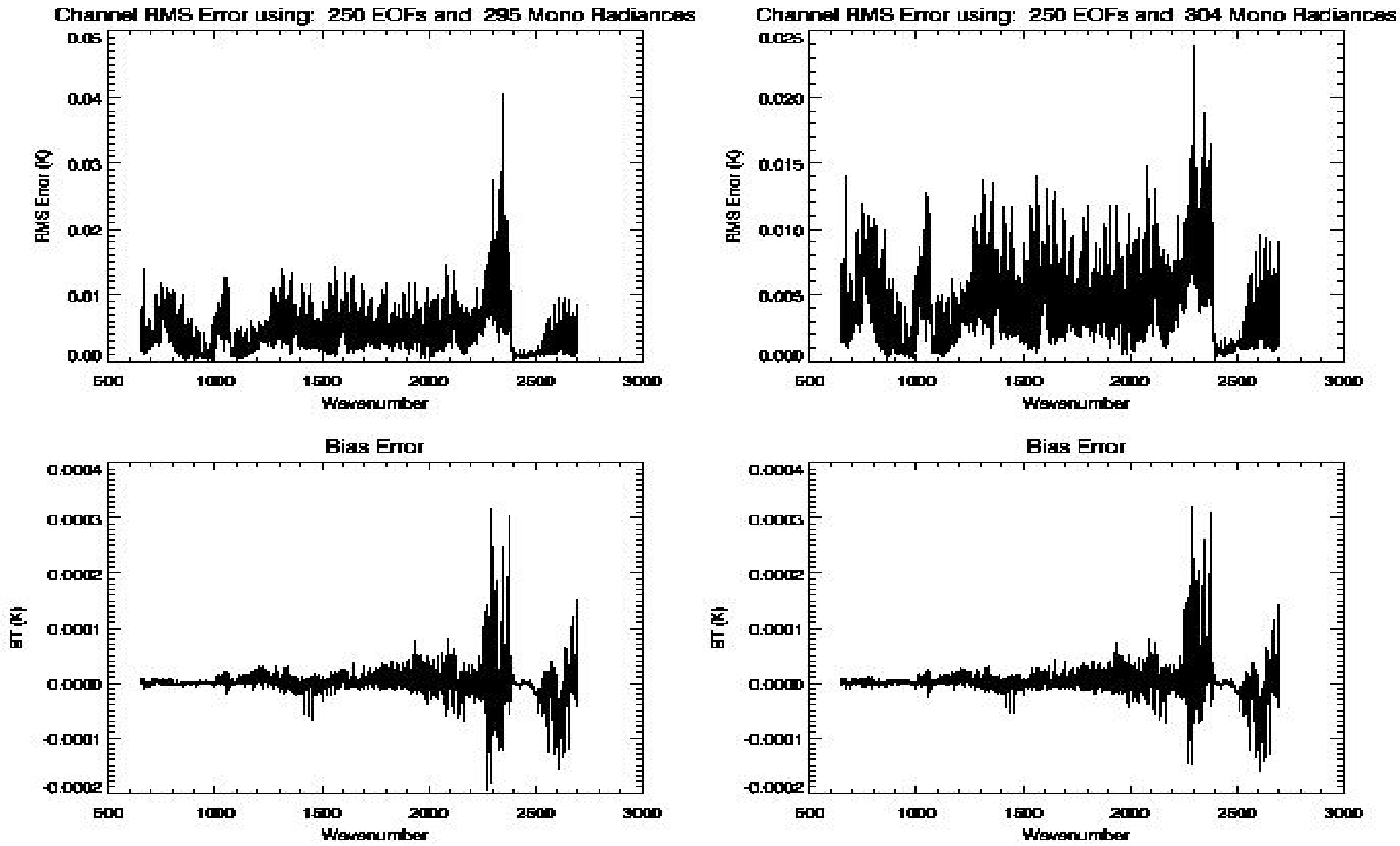


Radiative Transfer Calculation is Simple

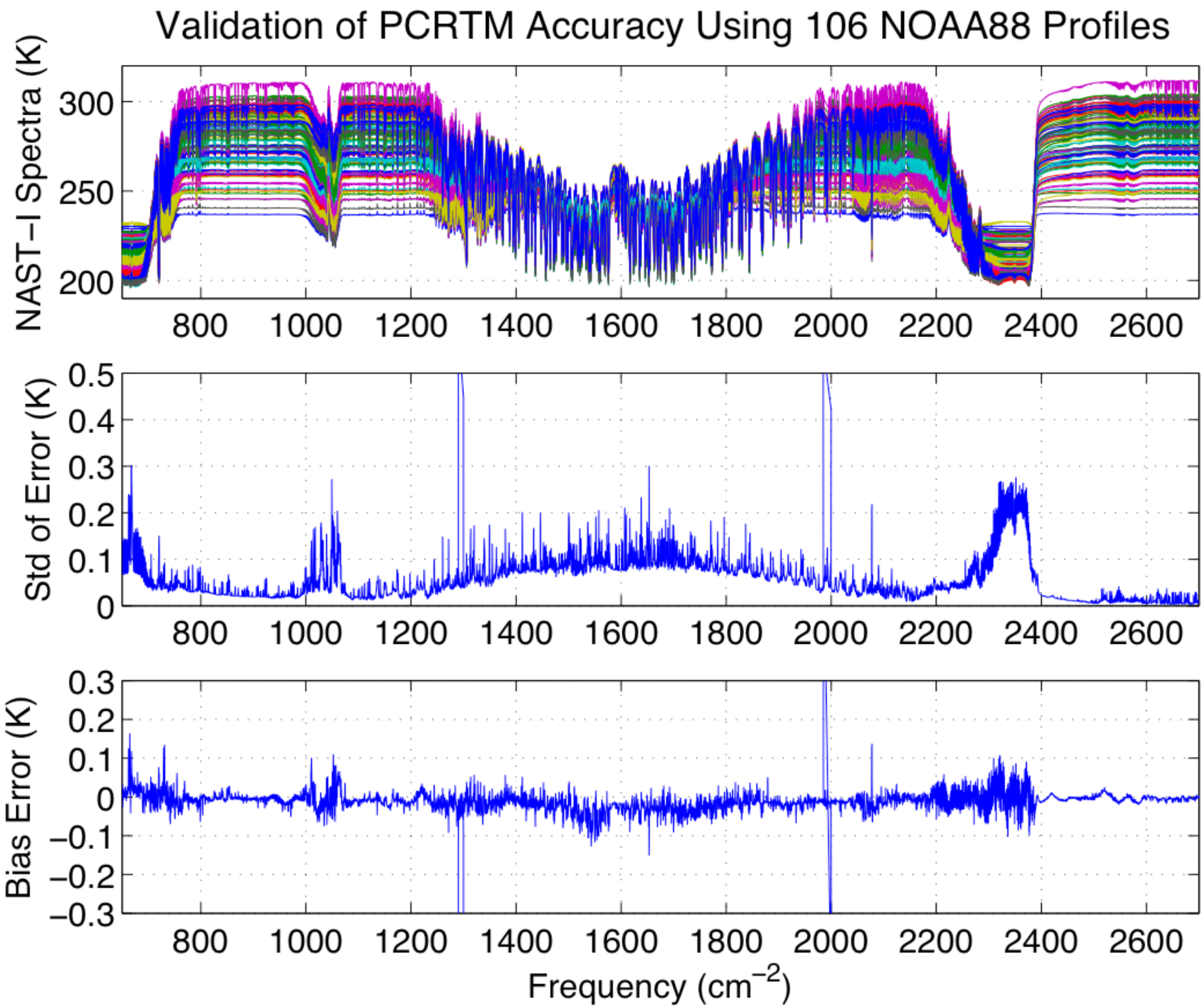
- **Radiative Transfer coding is very simple (see example for calculating upwelling radiances):**

$$
\begin{aligned}
&\mathit{Initiallize}\ R_\nu^{up}: \\
&\quad R_\nu^{up} = \varepsilon_\nu B_\nu(T_s) \\
&\text{Do } l = nBot, nTop, \text{-}1 \\
&\quad \frac{\partial R_\nu^{up}}{\partial \tau_l^0} = [B_\nu(T_l) - R_\nu^{up}]t_{0\to l}\sec(\theta) \\
&\quad \frac{\partial R_\nu^{up}}{\partial T_l} = \frac{\partial R_\nu^{up}}{\partial \tau_l^0}\frac{\partial \tau_l^0}{\partial T_l} + (1 - t_{l\to l})t_{0\to l-1}\frac{\partial B_\nu(T_l)}{\partial T_l} \\
&\quad \frac{\partial R_\nu^{up}}{\partial H_2O_l} = \frac{\partial R_\nu^{up}}{\partial \tau_l^0}\frac{\partial \tau_l^0}{\partial H_2O_l} \\
&\quad R_\nu^{up} = R_\nu^{up} t_{l\to l} + (1 - t_{l\to l})B_\nu(T_l) \\
&\text{Enddo}
\end{aligned}
$$

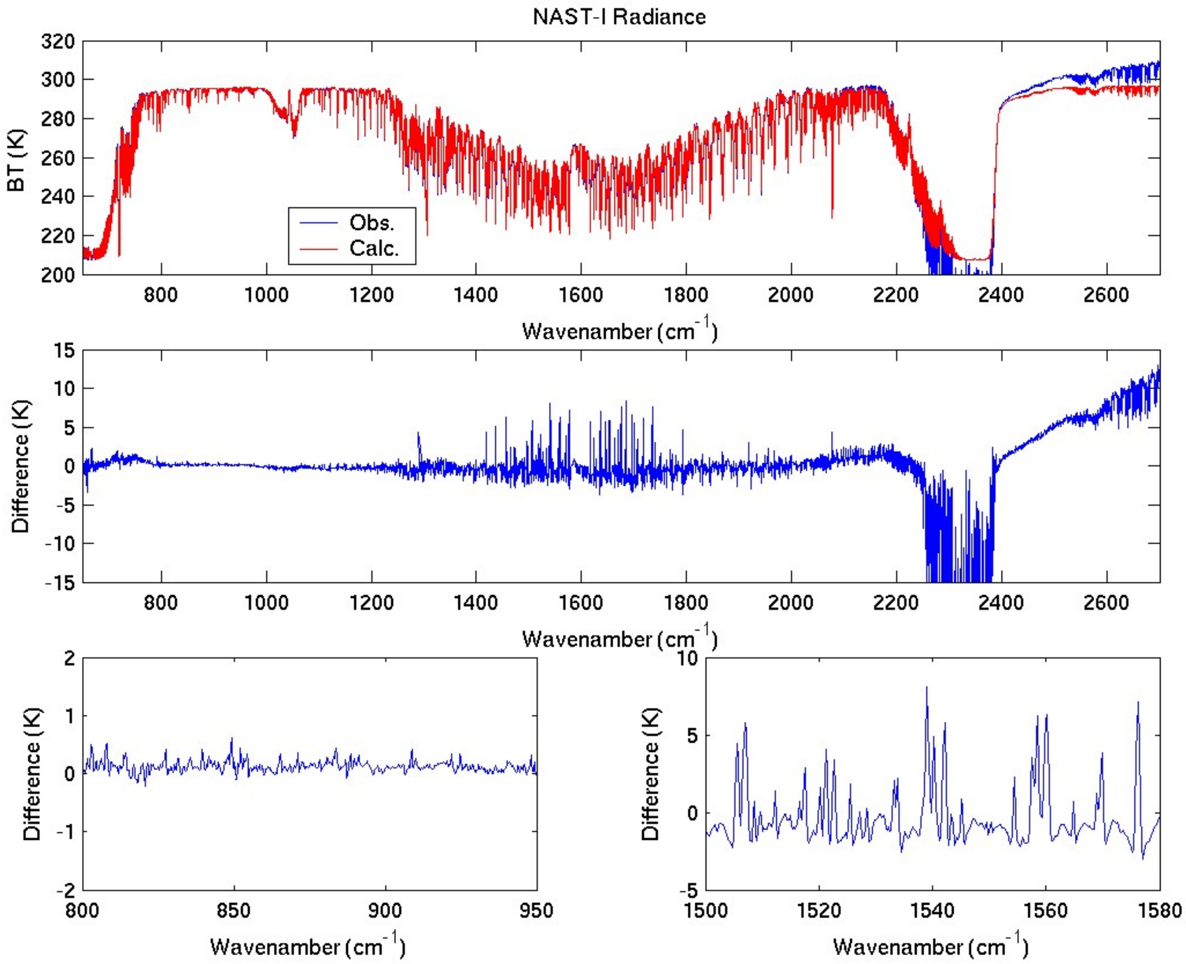
PCRTM Applied to NAST-I Instrument



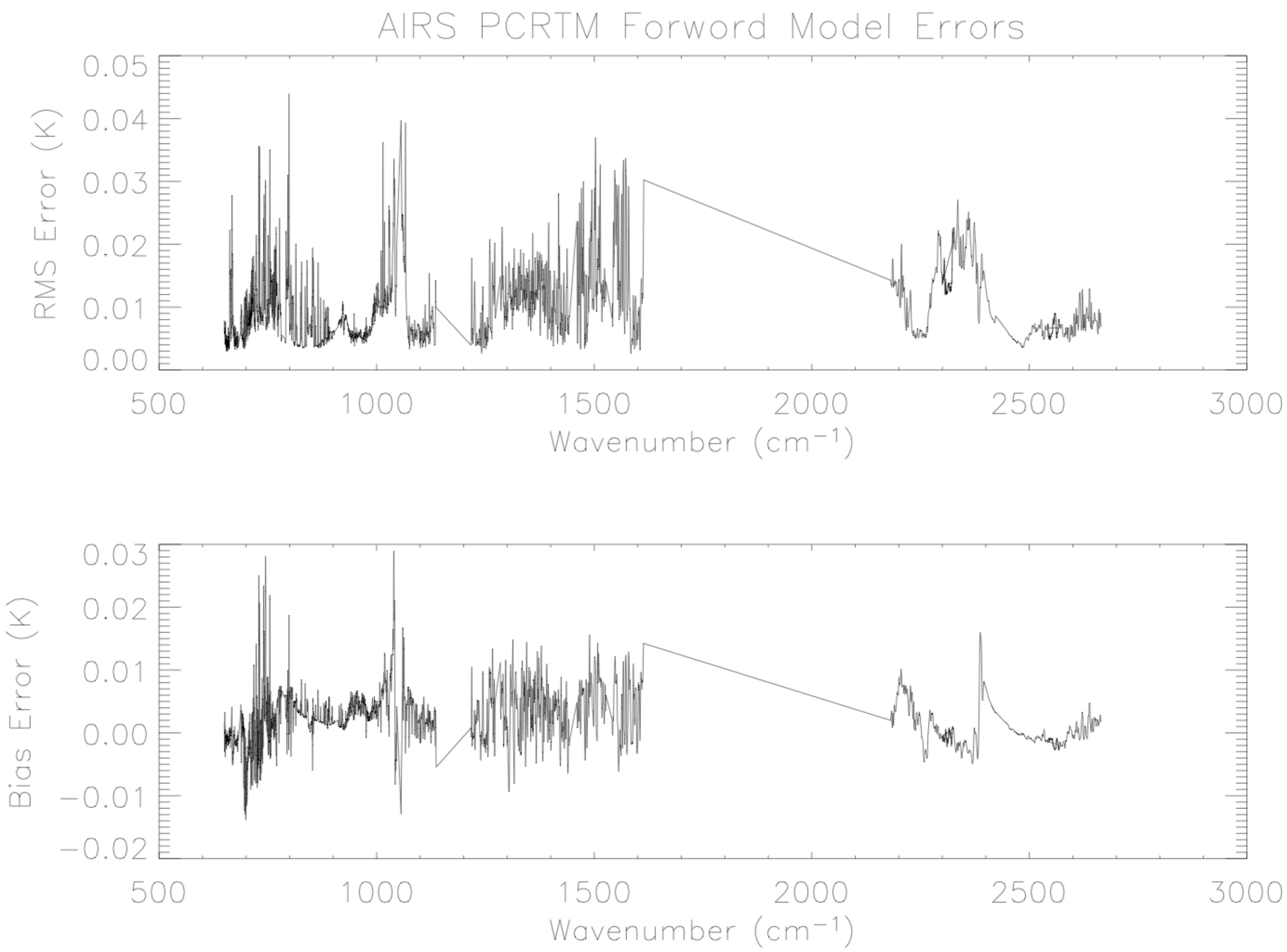
LBLRTM/PCRTM Comparisons using profiles independent of training set



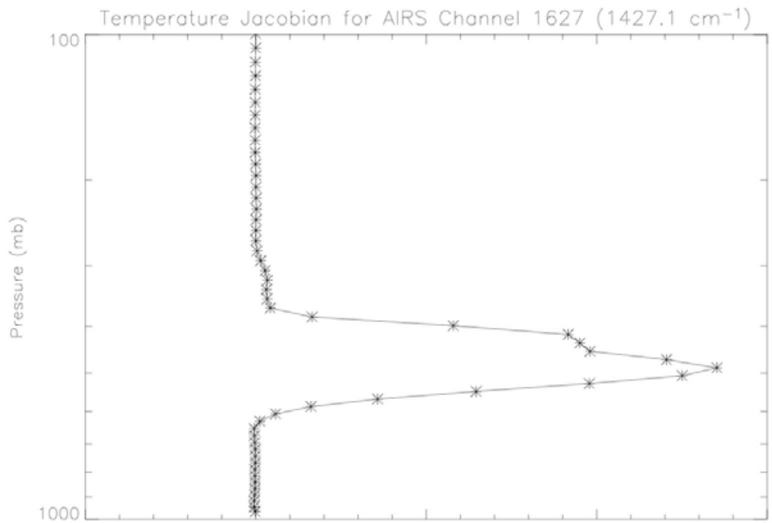
Comparison of NAST-I Observation with PCRTM

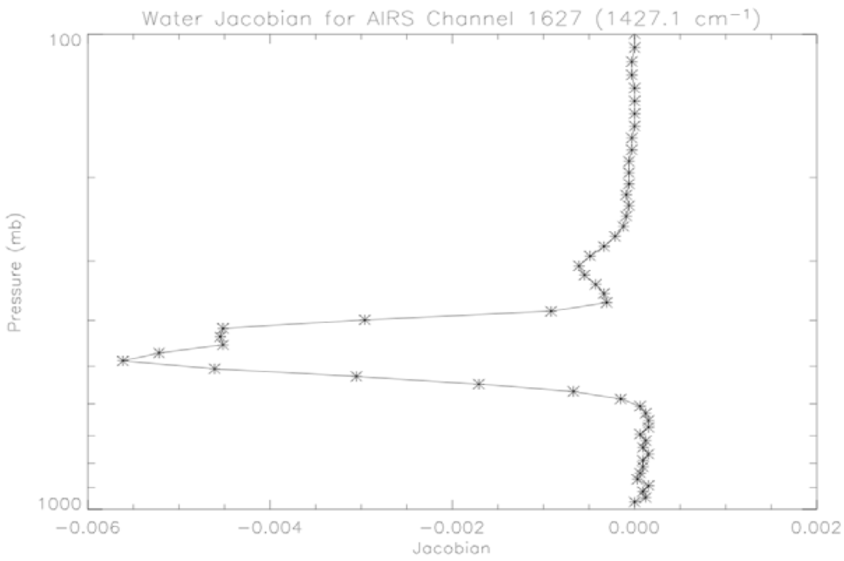


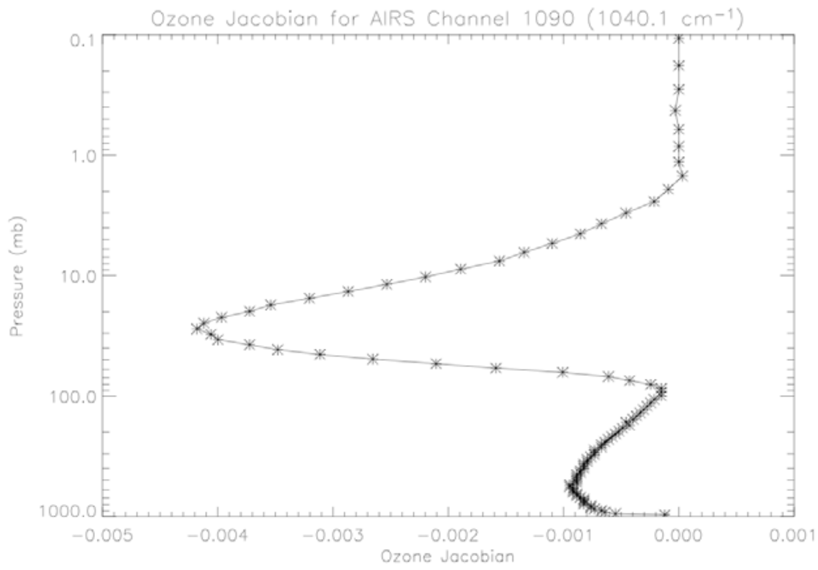
Example of PCRTM Applied to AIRS Instrument



Examples of PCRTM Jacobian for AIRS Instrument

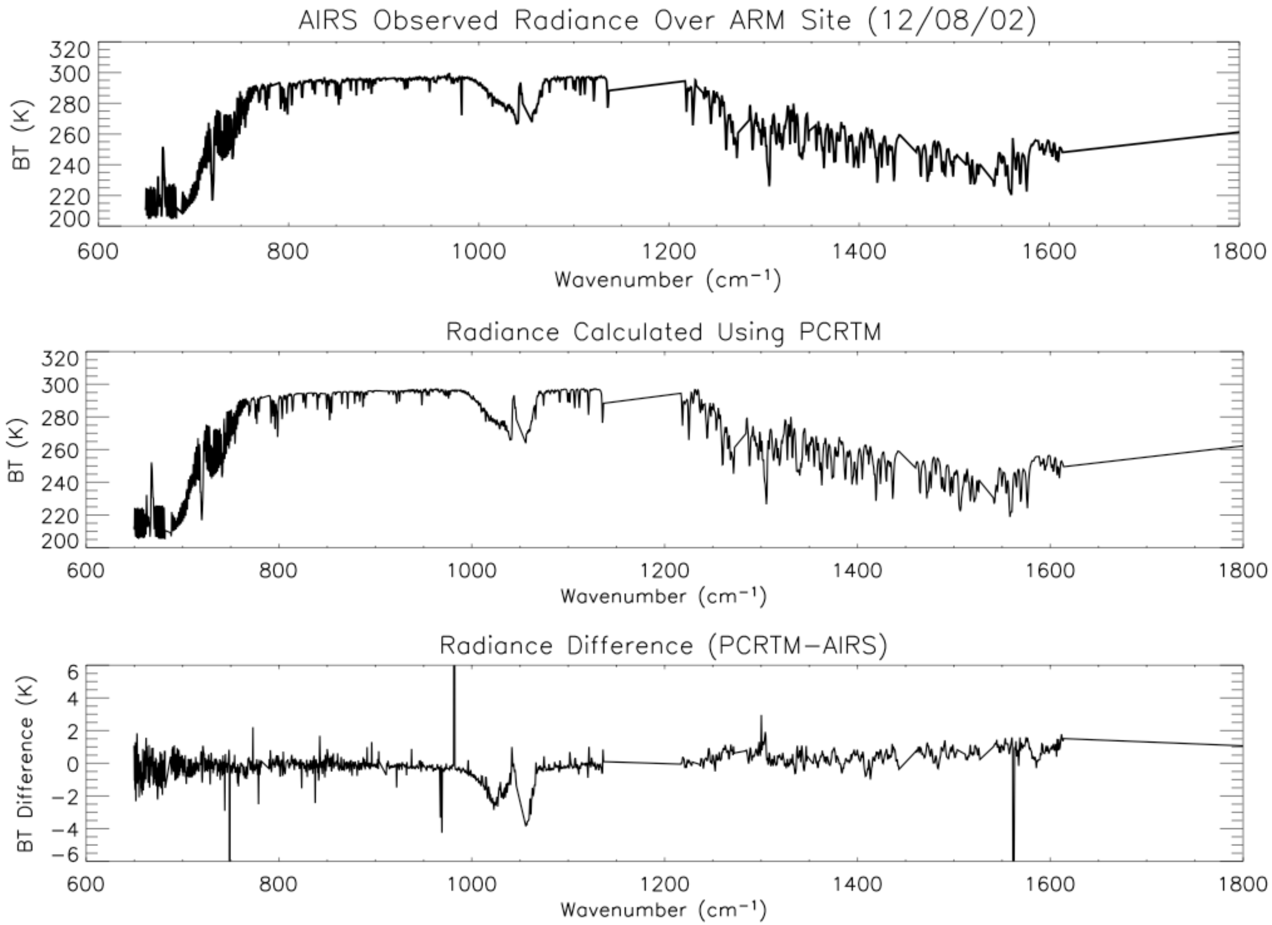






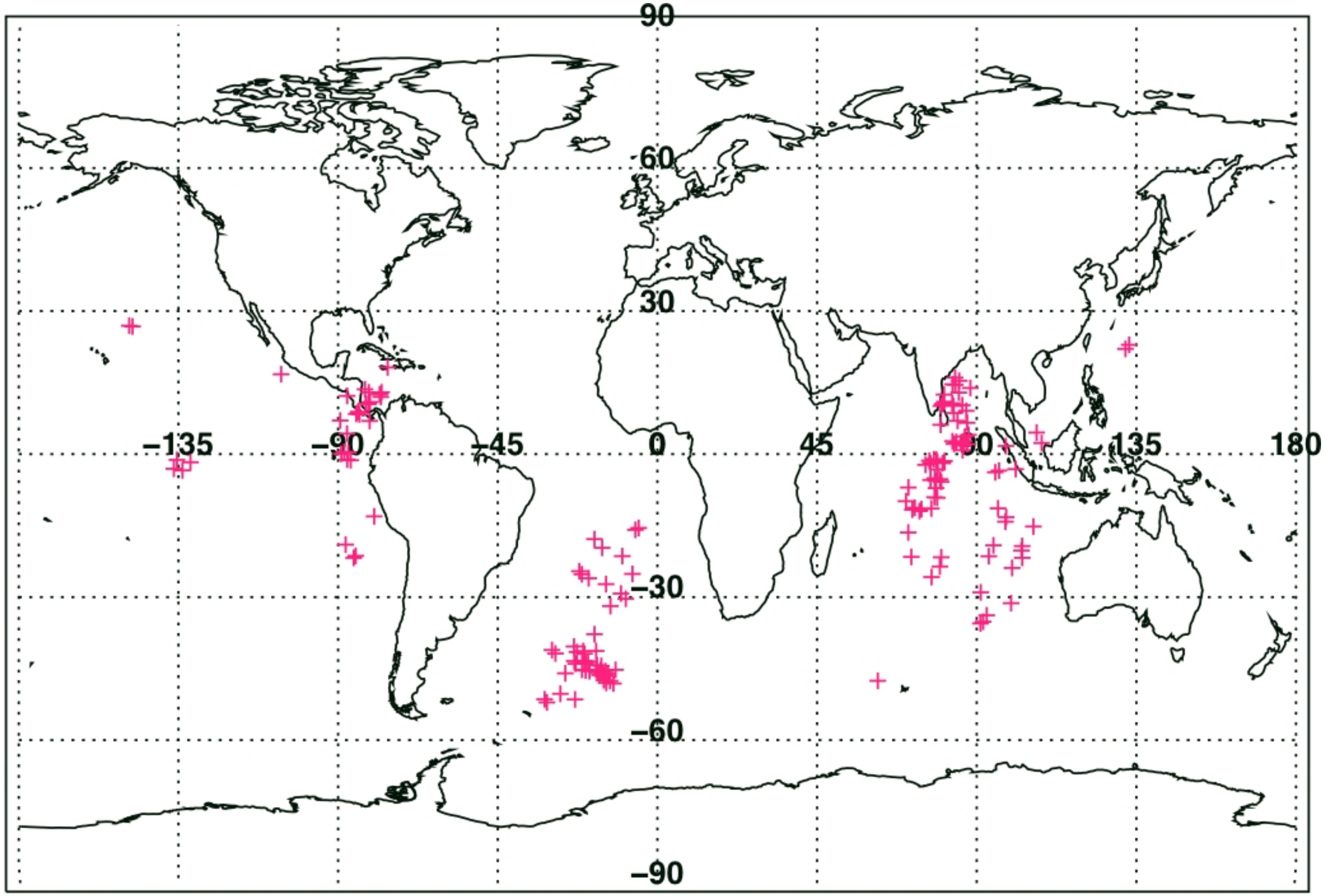
Jacobians for AIRS Instrument

Comparison of Observed AIRS Radiance and PCRTM Calculated Radiance

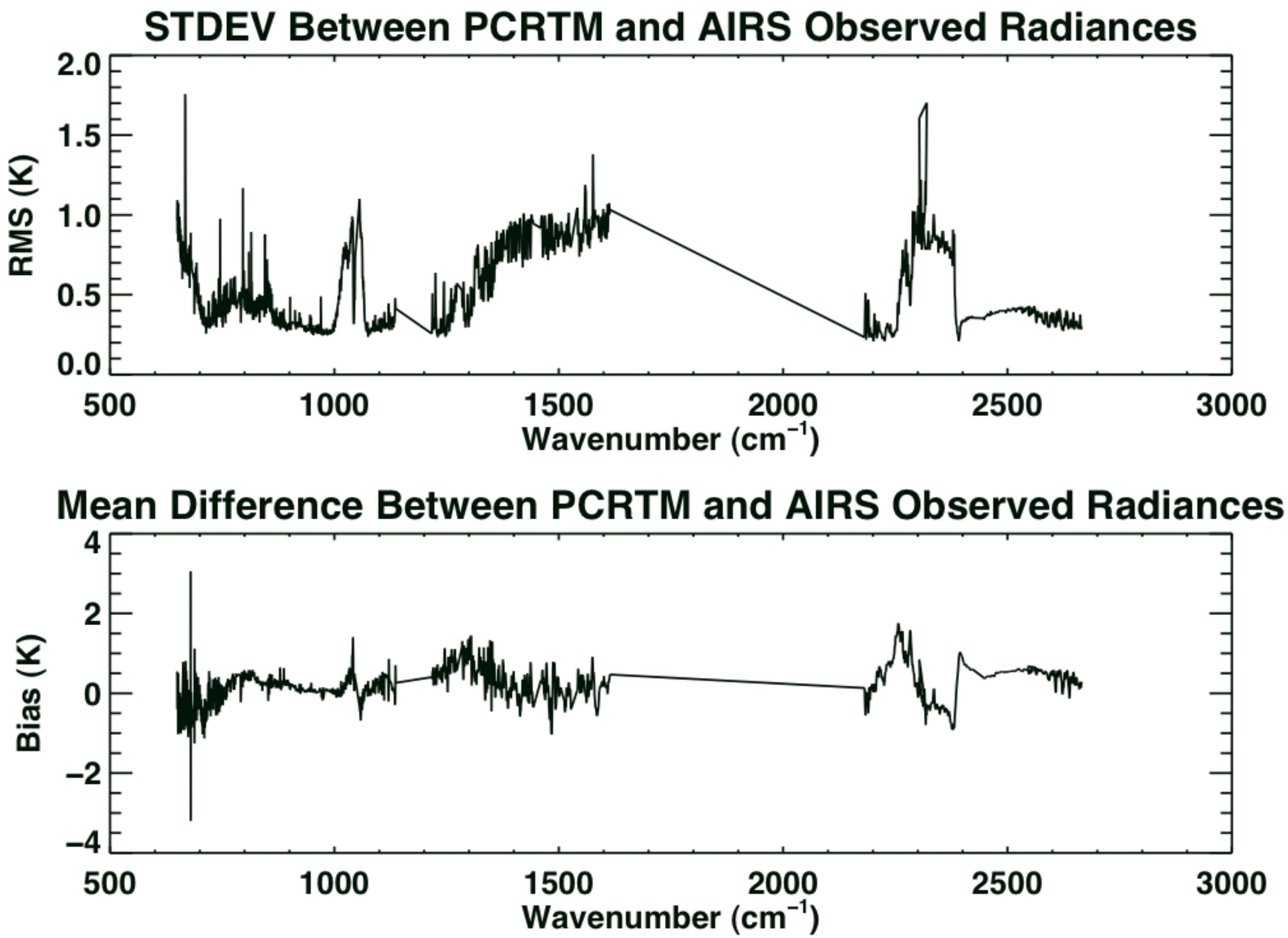


- **Ozone truth is from ECMWF model which may not be accurate**
- **Spikes are due to instrument popping noise which have not been removed**

Location of Clear AIRS Observation



Differences between AIRS Observed and PCRTM-Calculated Spectra



Summary and Future Work

- PCRTM has been implemented for AIRS, NAST-I and IASI instruments
  - Comparisons with real AIRS and NAST-I radiance are good
  - Significant improvement in speed with respect to channel-based fast RT models
- PCRTM is a suitable for variational retrievals
  - 3-40 times faster than channel based RT models
  - Deals with all ILS or SFR
  - Provides both PC-scores (Super Channels) and associated Jacobians
  - Channel radiance and Jacobians can be generated if needed
  - Great potential in NWP data assimilation and cloudy sky retrievals
- Future work
  - Train under more diverse conditions
    - more variability in trace gases (CO, CH_4, N_2O, CO_2)
    - Pay more attention to Jacobians
  - Include multiple scatterings

International TOVS Study Conference, 14th, ITSC-14, Beijing, China, 25-31 May 2005. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2005.