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 $\vec{U}_i$ (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)

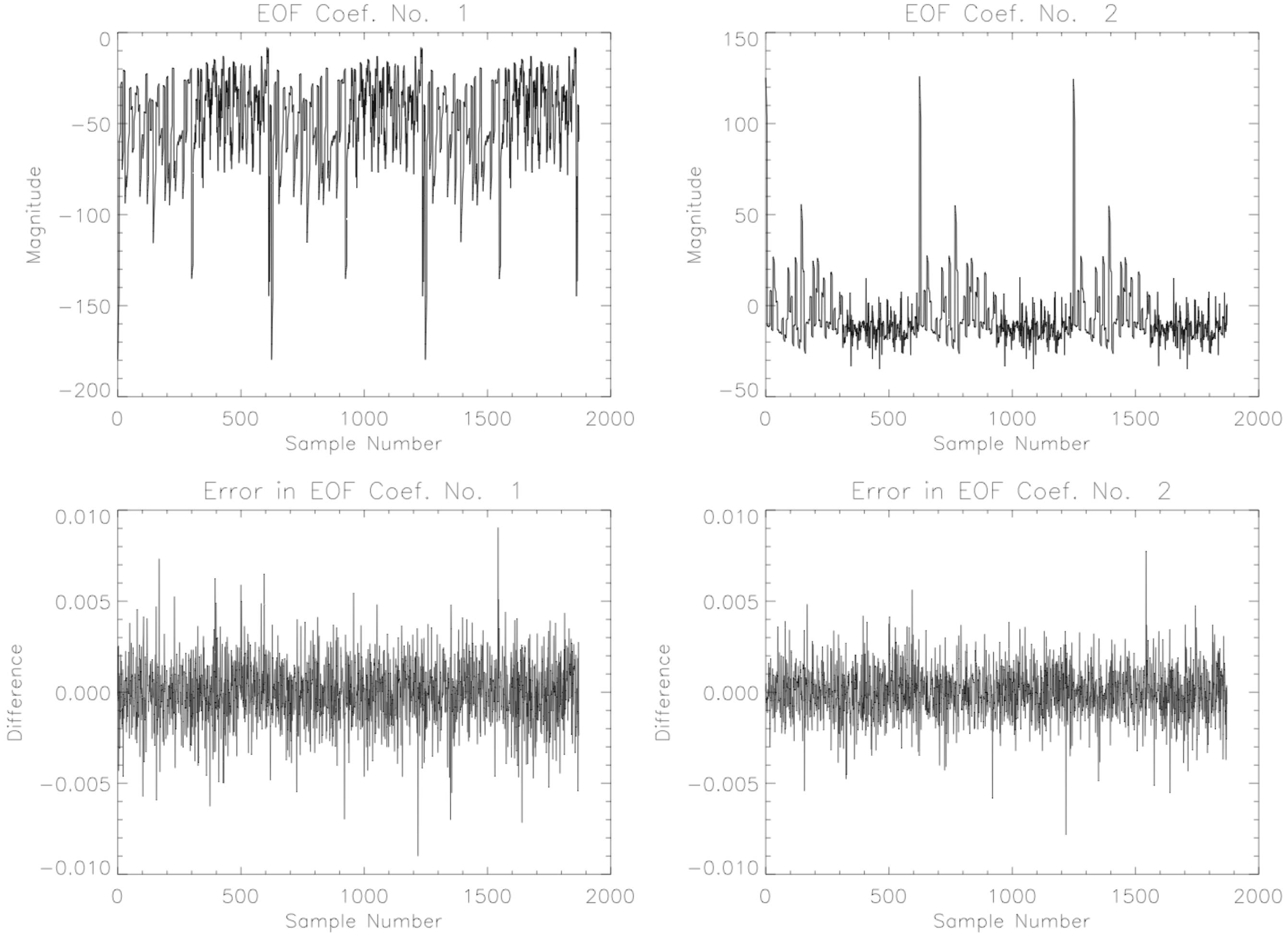
- Y_i is the projection coefficient (PC scores) for the *ith* EOF

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

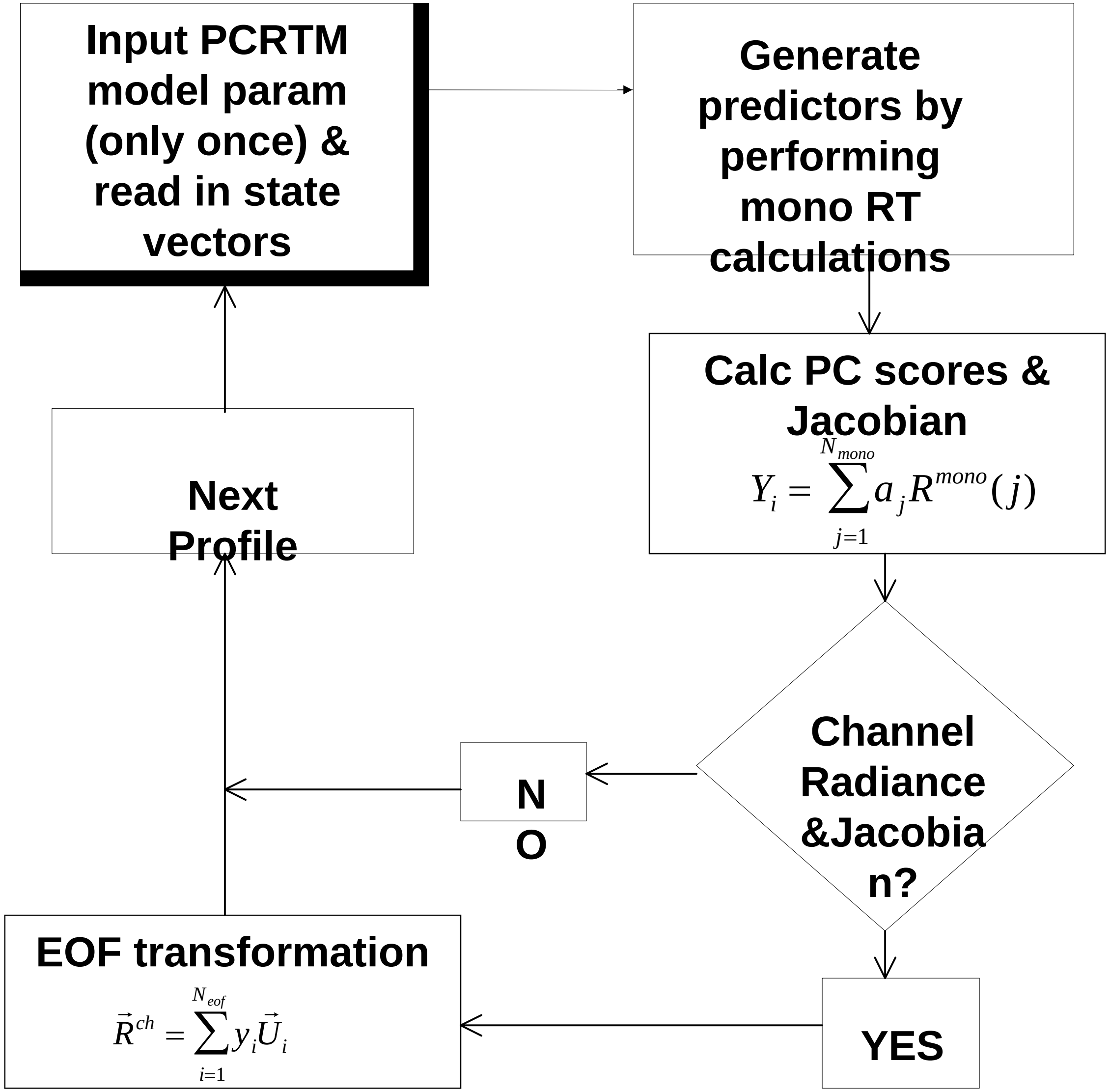
- *Y* is a non-linear function of atmospheric state
  - contains essential information about the spectrum
- *U* captures spectral variations from channel to channel
  - does not change from one spectrum to another
- R^{ch} is a convolution of monochromatic radiances with ILS
  - ILS does not change from 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



Input PCRTM model param (only once) & read in state vectors

Generate predictors by performing mono RT calculations

Calc PC scores & Jacobian

$$Y_i = \sum_{j=1}^{N_{mono}} a_j R^{mono}(j)$$

Channel Radiance &Jacobian?

YES

EOF transformation

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

NO

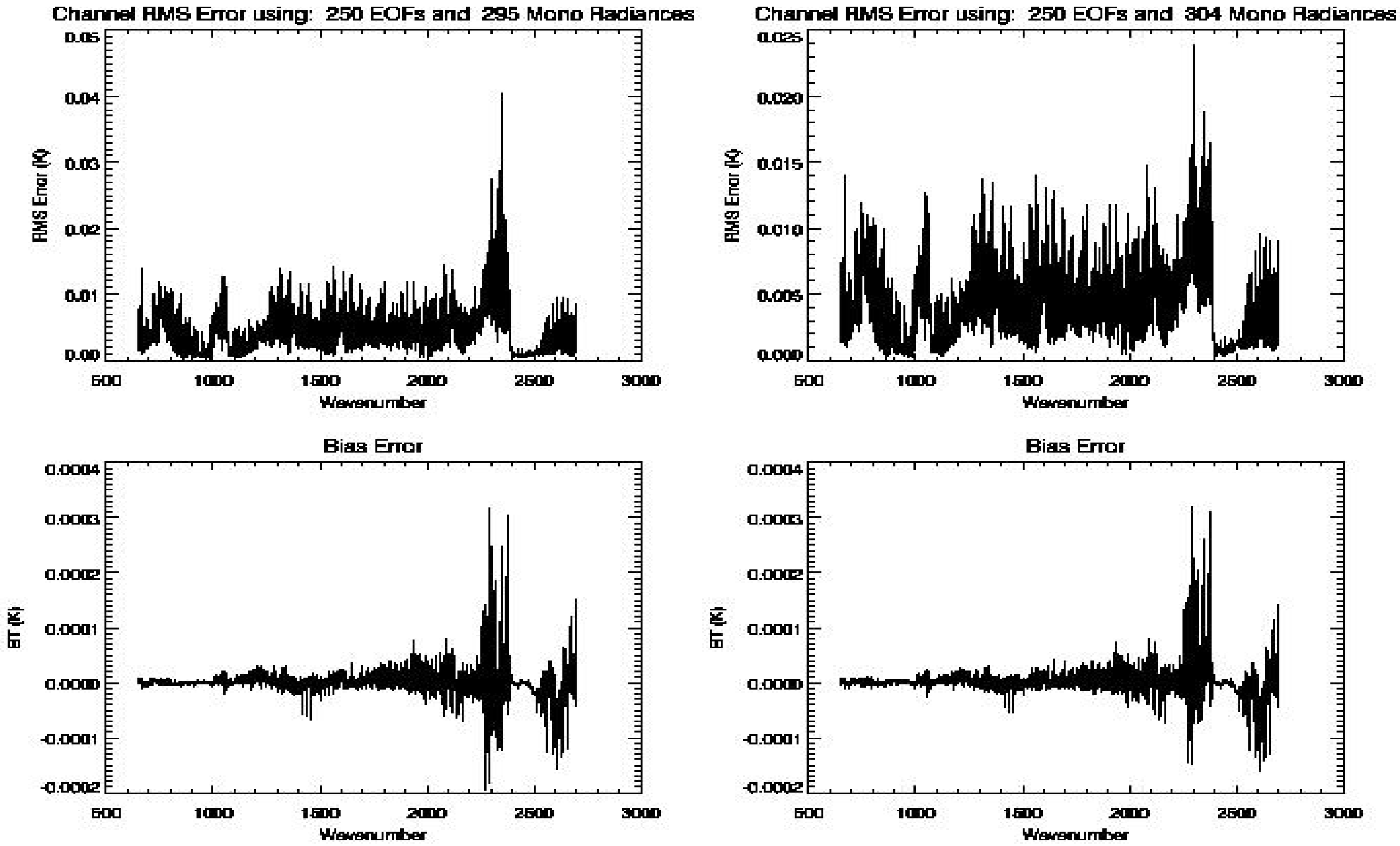
Next Profile

Radiative Transfer Calculation is Simple

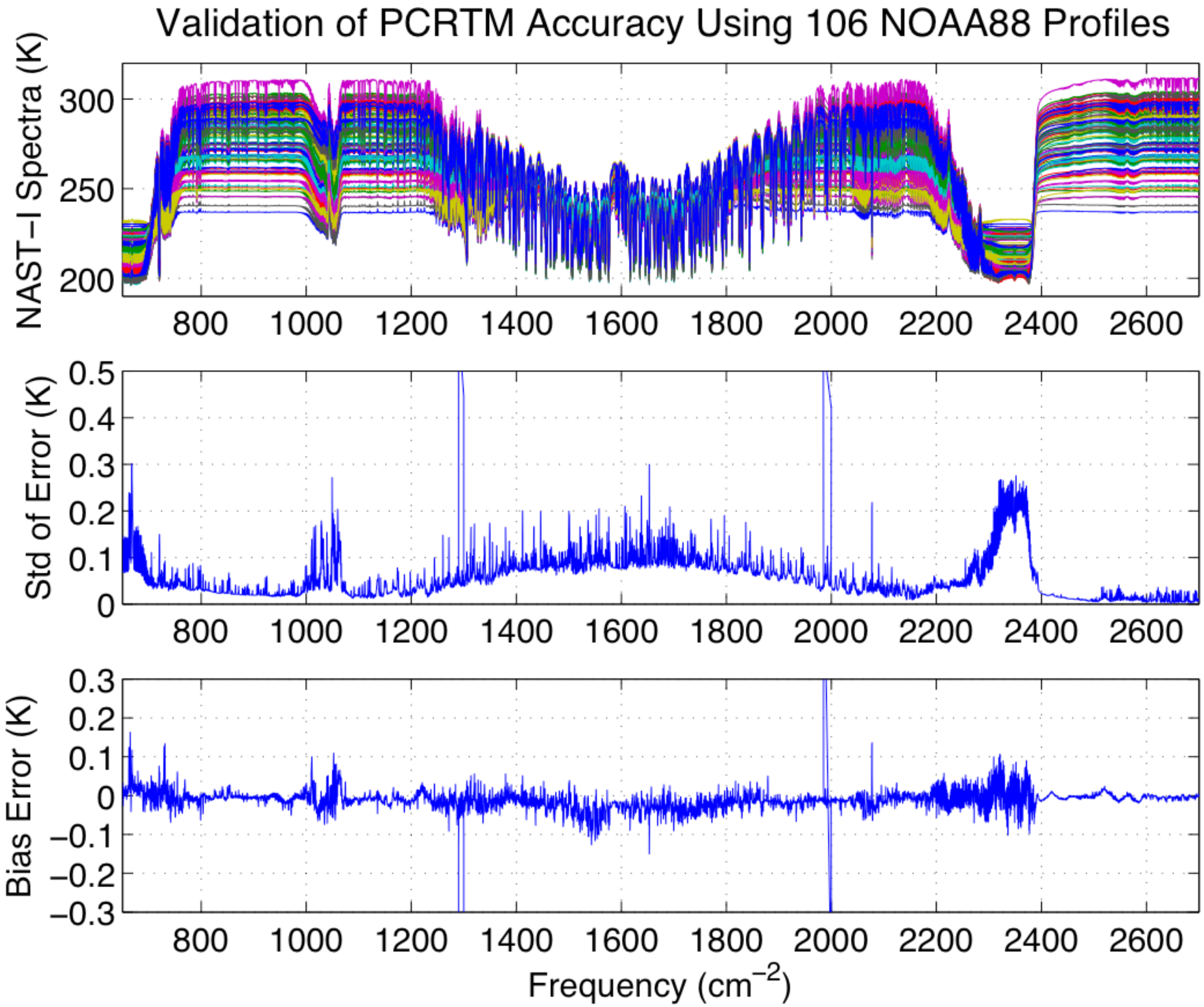
- **Radiative Transfer coding is very simple (see example for calculating upwelling radiances):**

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

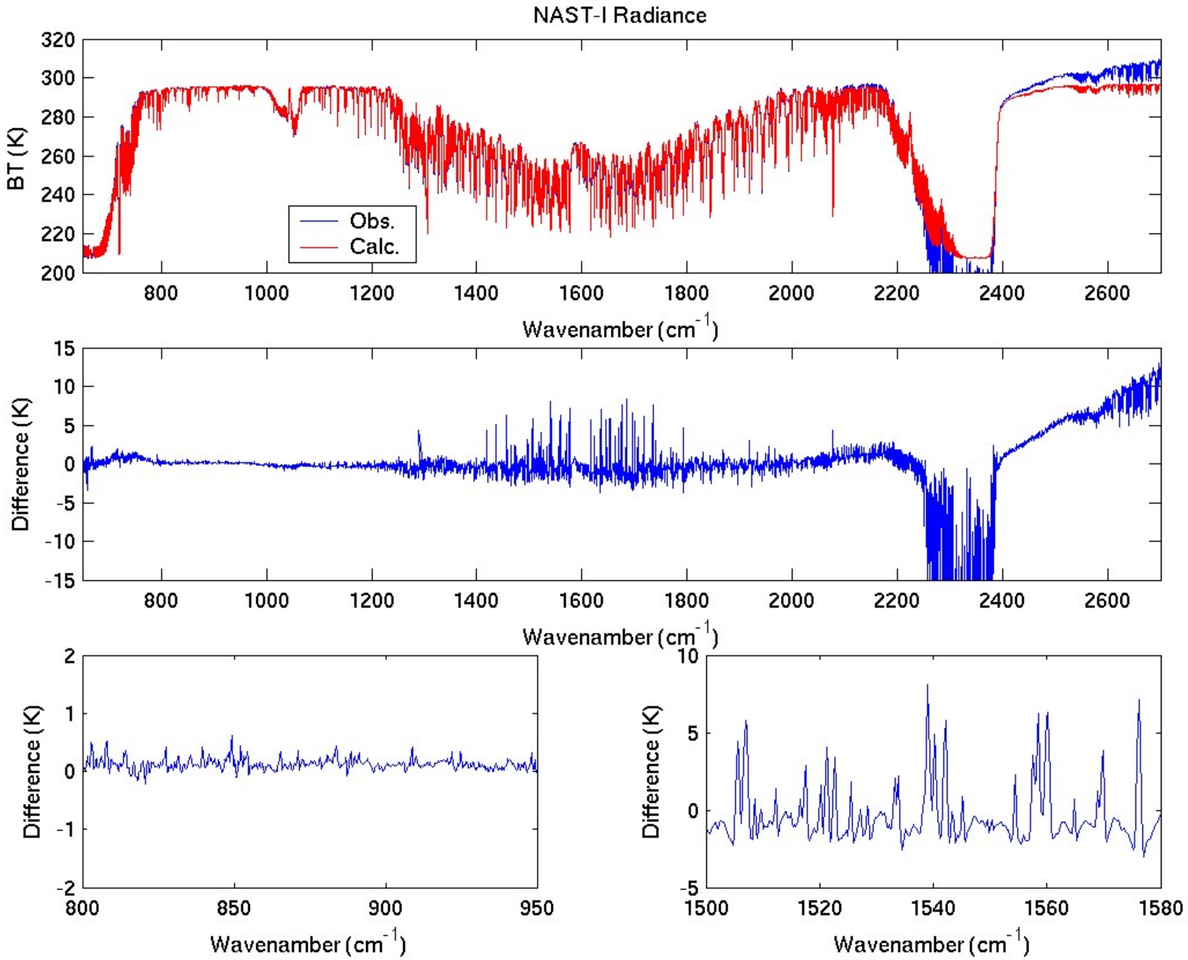
PCRTM Applied to NAST-I Instrument



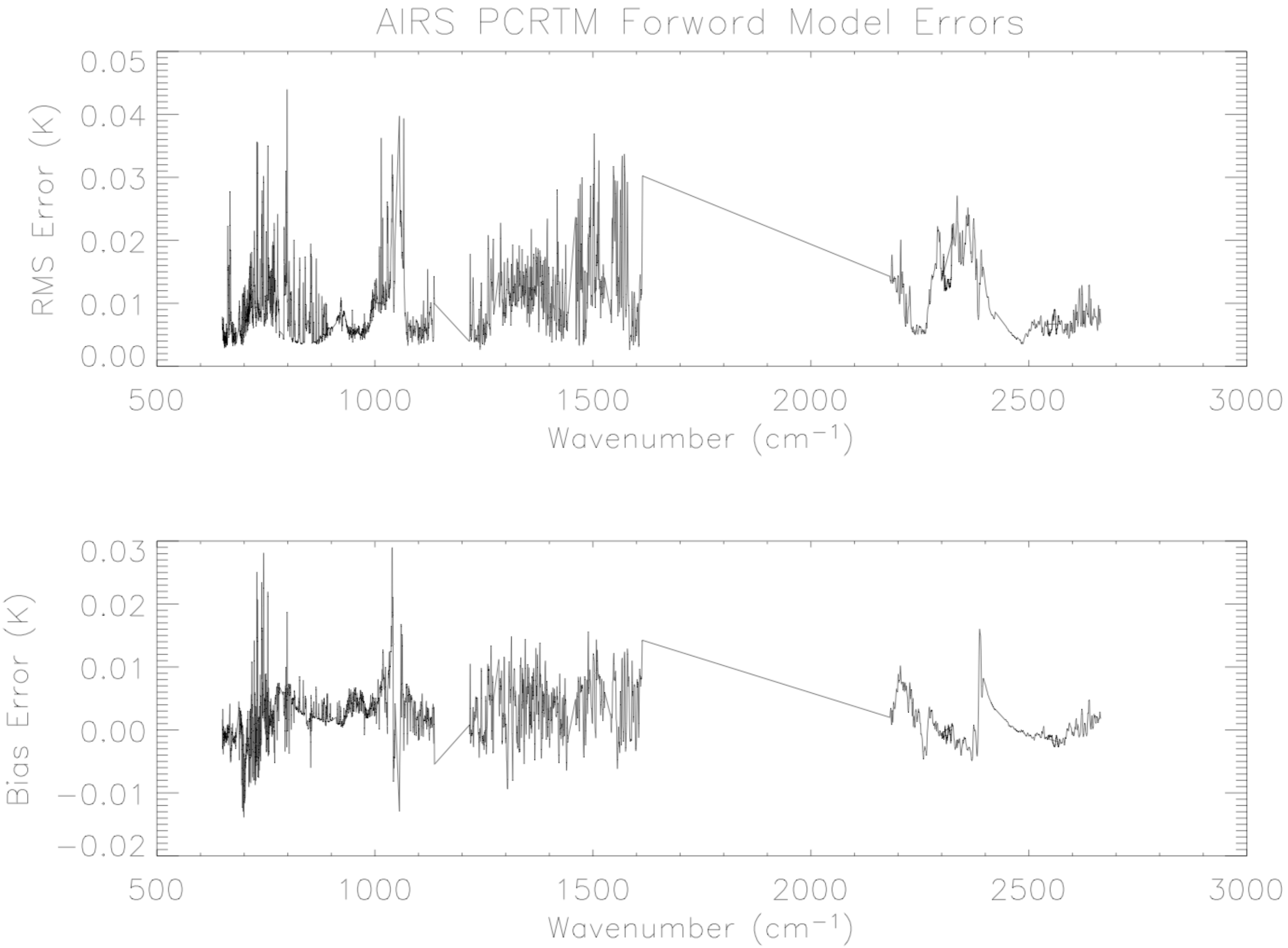
LBLRTM/PCRTM Comparisons using profiles independent of training set



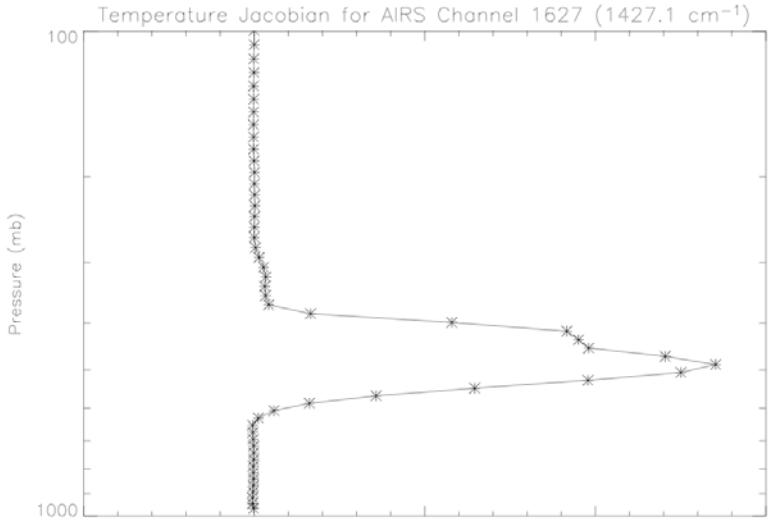
Comparison of NAST-I Observation with PCRTM

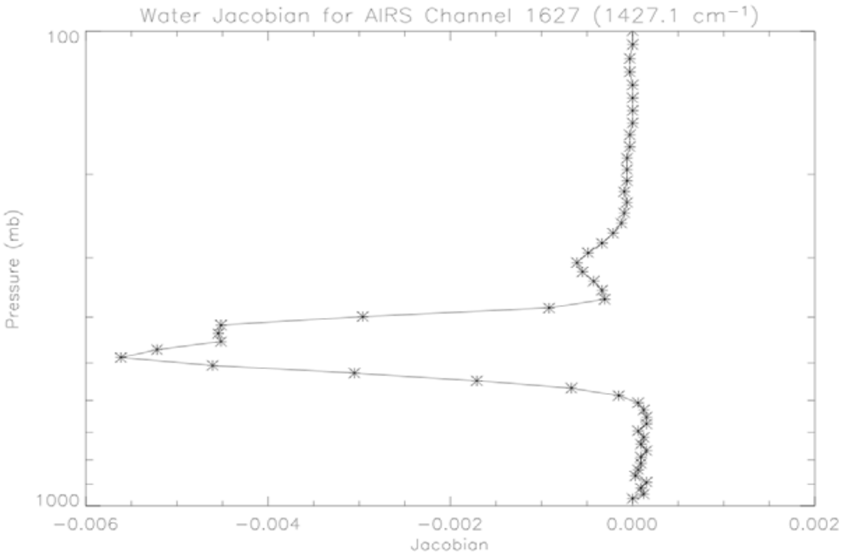


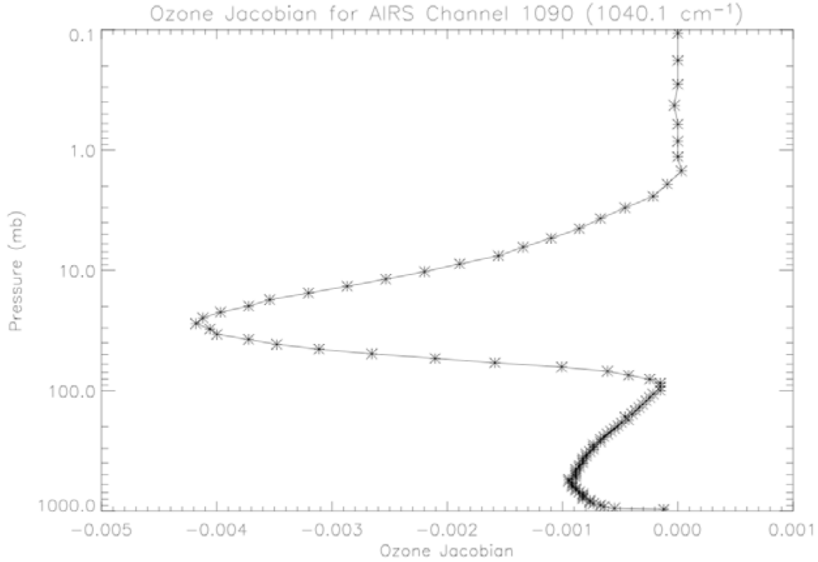
Example of PCRTM Applied to AIRS Instrument



Examples of PCRTM Jacobian for AIRS Instrument

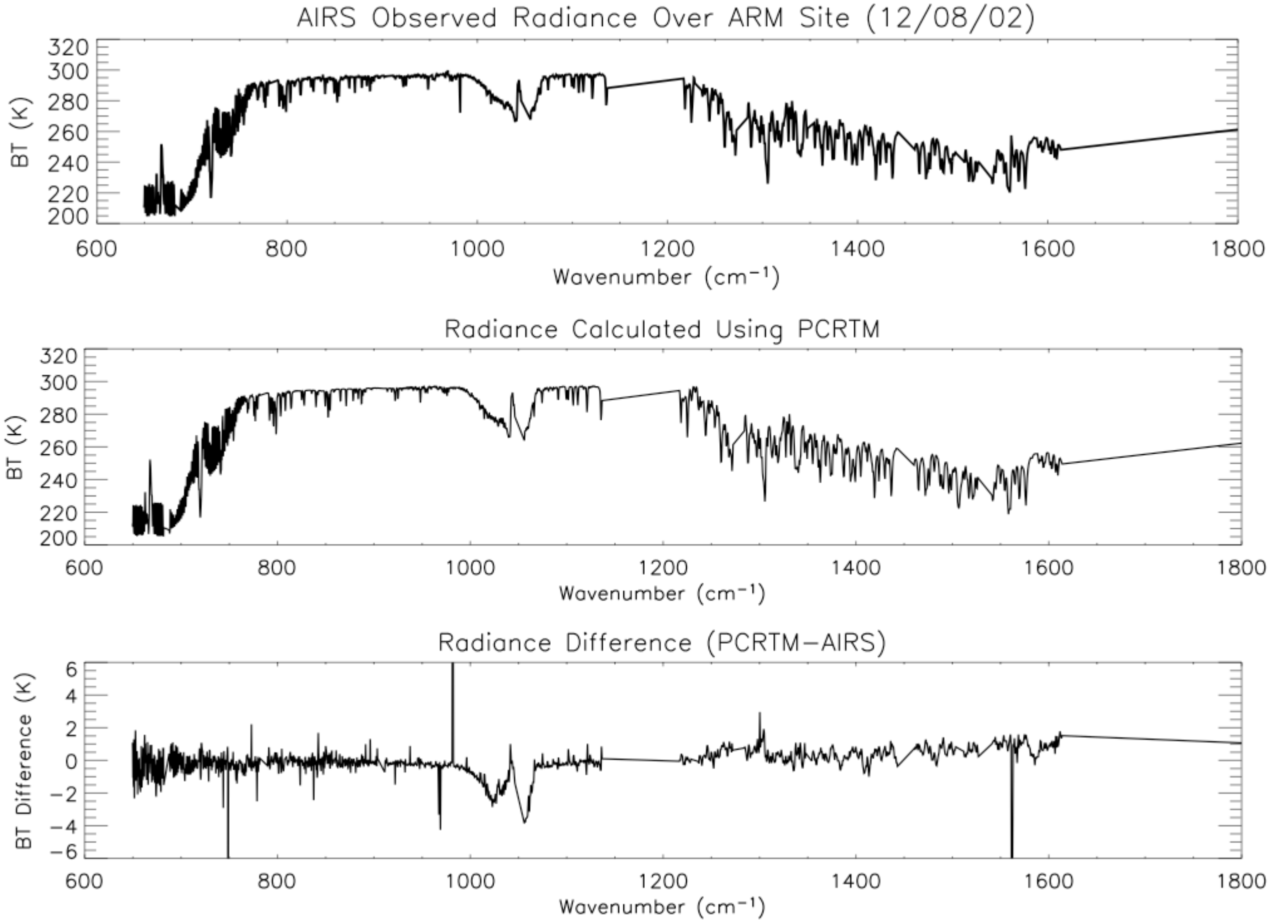






Jacobians for AIRS Instrument

Comparison of Observed AIRS Radiance and PCRTM Calculated Radiance



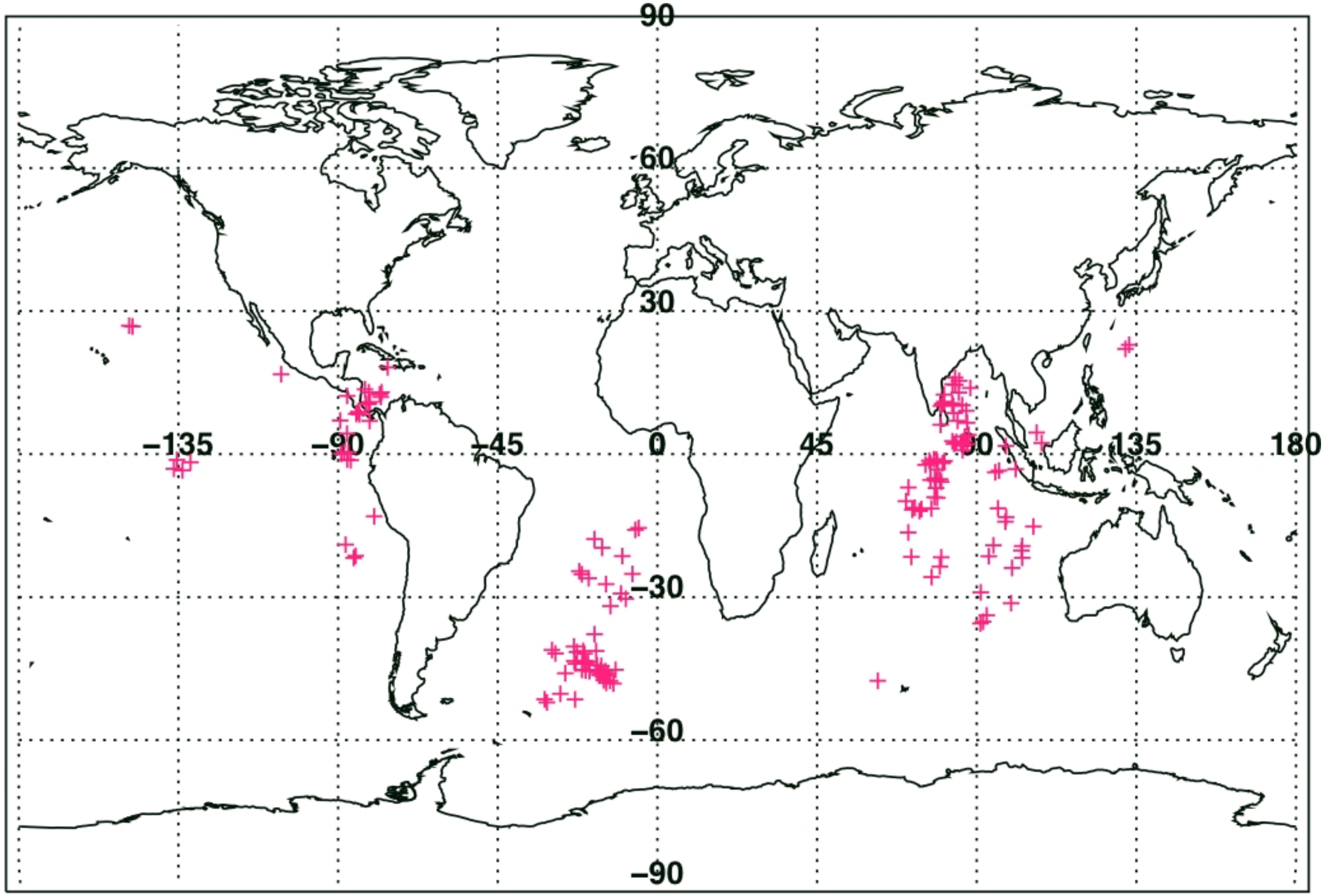
AIRS Observed Radiance Over ARM Site (12/08/02)

Radiance Calculated Using PCRTM

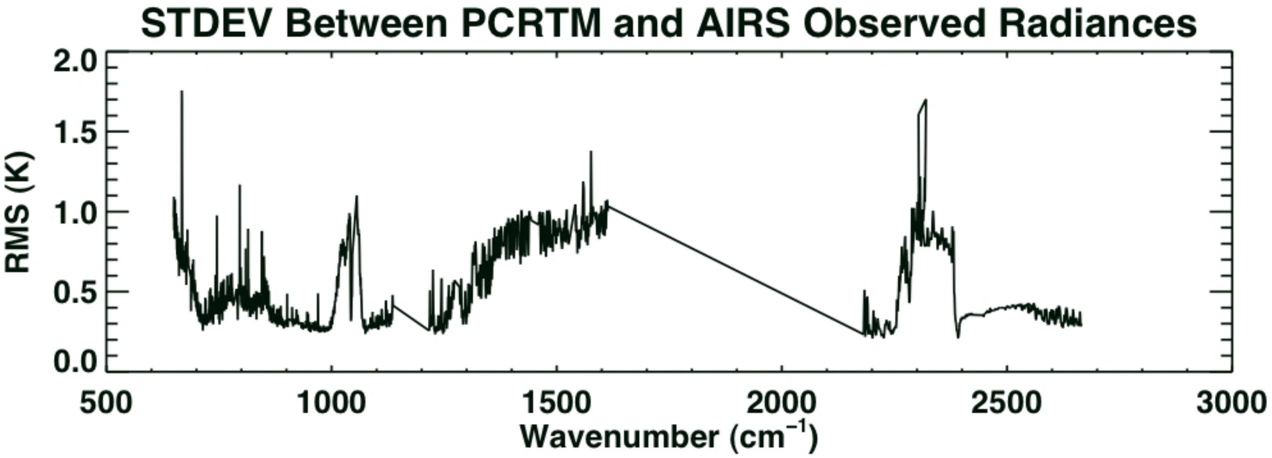
Radiance Difference (PCRTM–AIRS)

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

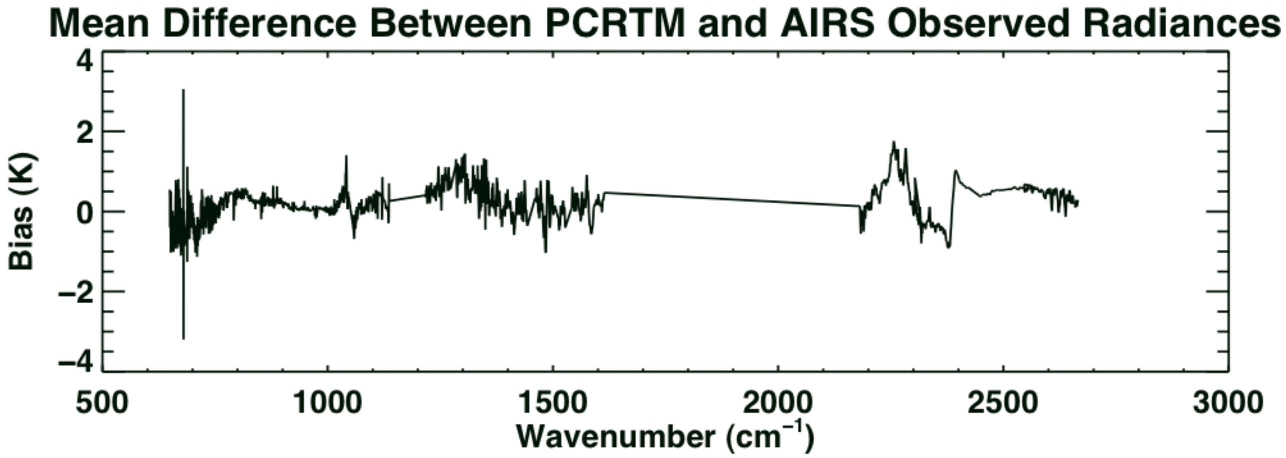
Location of Clear AIRS Observation



Differences between AIRS Observed and PCRTM-Calculated Spectra



STDEV Between PCRTM and AIRS Observed Radiances



Mean Difference Between PCRTM and AIRS Observed Radiances

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