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):

\[
\tilde{R}_{ch} = \sum_{i=1}^{N_{EOF}} y_i \tilde{U}_i + \tilde{e}
\]

• 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 $i$th EOF

\[
Y_i = U_{N_{\text{ch}} \times 1}^T R_{N_{\text{ch}} \times 1}^{\text{ch}} = \sum_{j=1}^{N_{\text{ch}}} U(j,i) \times R^{\text{ch}}(j)
\]

• $Y$ 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
• $R^{\text{ch}}$ 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, $a$

\[
Y_i = \sum_{j=1}^{N_{\text{ch}}} U(j,i) \times \left[ \sum_{k=1}^{N} b_k R_{\text{mono}}(k) \right] = \sum_{l=1}^{N_{\text{mono}}} a_l R_{\text{mono}}(l)
\]
Projection Coefficients and Fitting Errors

![EOF Coef. No. 1](image1)
![EOF Coef. No. 2](image2)
![Error in EOF Coef. No. 1](image3)
![Error in EOF Coef. No. 2](image4)
Forward Model Flowchart

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

Generate predictors by performing mono RT calculations

Calc PC scores & Jacobian
\[ Y_i = \sum_{j=1}^{N_{\text{mono}}} a_j R_{\text{mono}}(j) \]

Channel Radiance & Jacobian n?

EOF transformation
\[ \hat{R}^{ch} = \sum_{i=1}^{N_{\text{eof}}} y_i \hat{U}_i \]

Next Profile

YES

NO

N

O
Radiative Transfer Calculation is Simple

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

\[ \text{Initialize } R_{v}^{up} : \]
\[ R_{v}^{up} = \varepsilon_{v} B_{v}(T_{s}) \]

\[ \text{Do } l = nBot, nTop, -1 \]
\[ \frac{\partial R_{v}^{up}}{\partial \tau_{l}^{0}} = [B_{v}(T_{l}) - R_{v}^{up}] t_{0 \rightarrow l} \sec(\theta) \]
\[ \frac{\partial R_{v}^{up}}{\partial T_{l}} = \frac{\partial R_{v}^{up}}{\partial \tau_{l}^{0}} \frac{\partial \tau_{l}^{0}}{\partial T_{l}} + (1 - t_{l \rightarrow l}) t_{0 \rightarrow l, -1} \frac{\partial B_{v}(T_{l})}{\partial T_{l}} \]
\[ \frac{\partial R_{v}^{up}}{\partial H_{2}O_{l}} = \frac{\partial R_{v}^{up}}{\partial \tau_{l}^{0}} \frac{\partial \tau_{l}^{0}}{\partial H_{2}O_{l}} \]
\[ R_{v}^{up} = R_{v}^{up} t_{l \rightarrow l} + (1 - t_{l \rightarrow l}) B_{v}(T_{l}) \]

Enddo
PCRTM Applied to NAST-I Instrument
LBLRTM/PCRTM Comparisons using profiles independent of training set

Validation of PCRTM Accuracy Using 106 NOAA88 Profiles
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, CH₄, N₂O, CO₂)
    - Pay more attention to Jacobians
  - Include multiple scatterings