Assimilation of Hyperspectral IR Radiances Using Principal Component-based Radiative Transfer Model

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Outline

• Principal of PCRTM

• Preliminary results for a Hurricane case
  – Compare results from CRTM and PCRTM

• Future plan
Principal Component-based Radiative Transfer Model (PCRTM) developed at NASA Langley Research Center (led by Dr. Xu Liu) specifically designed for hyperspectral sensors’ data. **Should Not confused with Community Radiative Transfer Model (CRTM)**

\[ \text{PC-scores} = U \tilde{R} \]

- U is an MxM matrix formed by eigenvectors of a data covariance matrix C.
- \( \tilde{R} \) is a vector of M channel radiances.

\( \text{PC-scores} \) can be truncated to a smaller dimension \( N < M \) (degree of truncation depends on how correlated between channels).

PCRTM directly models/calculates \( \text{PC-scores} \), instead of channel radiances.

Could have different choices for
(1) offline training of the covariance matrix C (represent data variability);
(2) “predicting” \( \text{PC-Scores} \) from selected “predictors”.
(\( \text{PCRTM uses optimally-selected monochromatic radiances as predictors} \))

\[ R = U^T \text{PC-scores} \] (radiances can be calculated from PC-scores)
How does PCRTM work?

Flow diagram of the PCRTM forward model

- Regular Monochromatic RT performed
  - By LBL, MODTRAN…
  - Can use lookup table and fast parameterization if needed
- RT needs to be done at minimum number of frequencies
  - Remove redundancy due to channel correlation

Xu Liu et al, Applied Optics 2006
PCRTM has been successfully trained for
• IASI, AIRS, CrIS
• NAST-I, CLARREO IR and Solar

<table>
<thead>
<tr>
<th>Sensor</th>
<th>No. of Mono wave-number</th>
<th>Maximum no. of PC stored</th>
<th>No. of channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>IASI (3-band)</td>
<td>251+219+210=680</td>
<td>100+100+200=400</td>
<td>8461</td>
</tr>
<tr>
<td>AIRS (3-band)</td>
<td>161+99+165=425</td>
<td>100+100+100=300</td>
<td>2378</td>
</tr>
</tbody>
</table>

• Hyperspectral data are spectrally correlated
  – Channel-to-channel spectral correlations are captured by eigenvectors
  – Leading EOFs (first 50~100) captures all essential information of thousands of channels
  – Reduce dimensionality of original spectrum by a factor of 10-90
  – Radiative transfer done monochromatically at very few frequencies

• PCA has been used to reduce instrument noise and to compress spectra

• PCRTM can be used to assimilate radiances or PC-scores.
Accuracy of PCRTM is very good relative to reference LBLRT models

- Bias error relative to LBL is typically less than 0.002 K
- RMS error < 0.03K for IR
PCRTM vs. CRTM (speed)

Result is sensitive to compiler. Numbers below are from ifort compiler Intel Quad core Q9550 CPU, 2.83GHz, Linux system. No parallelization performed.

### PCRTM

<table>
<thead>
<tr>
<th>Sensor</th>
<th>PC scores</th>
<th>Radiance + PC scores</th>
<th>PC score + Jacobian (PC)</th>
<th>Radiance &amp; Jacobian (in PC and channel)</th>
<th>Channel Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. AIRS</td>
<td>0.0053 s</td>
<td>0.0054 s</td>
<td>0.016 s</td>
<td>0.04 s</td>
<td>0.01 s</td>
</tr>
<tr>
<td>8. AIRS (subset-281)</td>
<td>0.003 s</td>
<td>0.003 s</td>
<td>0.009 s</td>
<td>0.011 s</td>
<td>0.001 s</td>
</tr>
</tbody>
</table>

### CRTM

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Radiance</th>
<th>Radiance &amp; Jacobian</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. AIRS</td>
<td>0.055 s</td>
<td>0.35 s</td>
</tr>
<tr>
<td>8. AIRS (subset-281)</td>
<td>0.006 s</td>
<td>0.042 s</td>
</tr>
</tbody>
</table>
CRTM vs. PCRTM (Jacobian w.r.t. T/Q)

6.74µm (WV channel)
GSI/WRF assimilation/forecast experiments

- 147x88, 72-km, L36, 20 hPa model top
- continuous cycling Aug 21 – Aug 27 (Hurricane Isaac case)
- GTS + AIRS radiances (77 channels out of AIRS-281 subset)
- spun-up air-mass bias coefficients and scan bias from Aug 01 - Aug 20 runs using NCEP FNL as references
- 2 experiments: CRTM vs. PCRTM

0000 UTC Aug 01 0600 UTC Aug 01 1800 UTC Aug 20

0000 UTC Aug 21 0600 UTC Aug 21 1800 UTC Aug 27

6-h update cycling exps

Use Variational Bias Correction

NCEP FNL OBS
NCEP FNL OBS
NCEP FNL OBS

20-day O-B information for scan bias calculation

cycled air-mass bias coefficients

AIRS 6h coverage

Use Variational Bias Correction

6h WRF fcst OBS
Cloud detection for the hyperspectral IR data

In GSI cloud-detection algorithm, peak of channel **weighting function** used to characterize channel's vertical height.
More obs are rejected as cloudy with PCRTM.
13.54µm

Need to understand why different sign of bias.
Scan-bias statistics (aggregated over 20 days)
72-hr track forecasts (4 times/day)
Absolute mean track errors

![Graph showing track errors over forecast range](image)

- **PCRTM 184.05 km**
- **CRTM 188.37 km**

**Forecast Range**
- 0-24h
- 30-48h
- 54-72h
Future Plan

• Further investigate the cause of discrepancy b.w. CRTM and PCRTM
  – bias, cloud detection

• Directly assimilate PC-scores
  – Explore the potential of assimilating full-spectra data
  – QC/bias-correction in PC-score space?

• Retrieve/use cloud properties and surface parameters in data assimilation system