The Havemann-Taylor Fast Radiative Transfer Code (HT-FRTC) for hyperspectral, broadband and line-by-line radiance and flux simulations

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Original motivation for the HT-FRTC: Principal component radiative transfer for hyperspectral instruments (Xu Liu 2006, Havemann 2006)

Traditional radiative transfer models are too time-consuming to deal with modern IR hyperspectral sensors such as:

- IASI (Infrared Atmospheric Sounding Interferometer): ~ 8000 channels, AIRS, CRIS, IASI_NG, MTG-IRS
- ARIES (airborne interferometer): ~ 5000 channels

or SW hyperspectral imagers such as:

- AVIRIS (Airborne Visible/Infrared Imaging Spectrometer): ~ 200 channels + high spatial resolution
- Hyperion EO1 (SW Imaging Spectrometer): ~ 200 channels + high spatial resolution
The HT-FRTC uses line-by-line sensor-independent principal components.

Works from the microwave through the infrared and the short-wave

Does treat water vapour, ozone, carbon dioxide and 50 other trace gases as active gases (LBLRTM 12.2)

Does treat any spectrally resolved surface emissivity / reflectance.

Incorporates an exact treatment of scattering as well as the Chou-scaling approximation

Does include 20 different aerosols as well as water and ice clouds and liquid and frozen precipitation
HT-FRTC capabilities today

Works for any sensor-height, for up and down-looking instruments (air / space borne or ground-based)

Is able to compute radiances, fluxes and transmittances.

Includes the solar and lunar source and can account for spherical earth.

A hyperspectral radianc calculation takes less than one millisecond.

The HT-FRTC is used in a 1D-Var retrieval system in principal component space
Our accurate line-by-line (scattering) code is used to simulate line-by-line radiance (/transmittance/flux) spectra for many different atmospheres/surfaces.

Includes different viewing angles and altitudes.

Currently a diverse set of 1,000 ECMWF profiles is used.
The line-by-line radiance spectra are arranged together in a large $m \times n$ matrix.

Perform Singular Value Decomposition (SVD) on this matrix to obtain the Empirical Orthogonal Functions (EOF), Singular Values (SVs) and Principle Component Scores (PCs)

The SVD is given by

$$A_{mxn} = U_{mxn} \times \Sigma_{nxn} \times V^t_{nxn}$$

**EOF**

Represent the basic characteristics of the atmosphere

**SVs**

Sorted by size, give significance of each EOF

**PCs**

Depend on the actual atmospheric/surface state
The radiance spectra can be represented almost perfectly using only the leading EOF.

\[ \text{Output radiance spectrum} = \text{PCs} \]

First 100 EOF
EOF

First 100 SVs
SVs

100 PC scores
PCs

HT-FRTC TRAINING STEP
The EOF in HT-FRTC are generated at full line-by-line resolution and therefore are not sensor specific. The EOF are fixed.

The training of the HT-FRTC does not involve any information about any specific sensor and therefore does not need to be repeated for a new / modified sensor.

The Principal Component Scores depend on the atmosphere and surface and contain the full information of the complete radiance spectrum.
HT-FRTC TRAINING STEP

A linear regression applied to the training set relates each of the Principal Component Scores to a few hundred monochromatic radiances.

The selection of the monochromatic radiances is done by applying a k-means clustering algorithm to all the line-by-line radiances.

The centroids of the largest clusters are included in the regression.
HT-FRTC FAST MODEL STEP

- **Input profile**
- **Monochromatic RT at centroid frequencies**
- **Spectral info at centroid freq**
- **Pre-defined regression coefficients**
- **Calculate PC scores**
- **Output PC scores**
- **Calculate LBL or sensor spectrum**
- **Output LBL or sensor radiance spectrum**
- **LBL EOF or sensor EOF**
The fast model step calculates the PC scores and takes 1 millisecond for a clear-sky profile.

From these PC scores

a) a spectrum at full line-by-line resolution can be generated by multiplication with the (LBL) EOFs

b) any number of hyperspectral or broadband sensor spectra can be generated by multiplication with sensor specific EOFs.

The sensor specific EOFs are just the (LBL) EOFs convolved with the IRF and they are also fixed and can be precalculated.
“Line-by-line” calculation using HT-FRTC
IASI using the **same** PC scores
IASI-NG using the **same** PC scores
MODIS using the **same** PC scores
“Line-by-line” transmittance calculation using HT-FRTC
IASI transmittances using the same PC scores
IASI-NG transmittances using the **same** PC scores
MODIS transmittances using the same PC scores
Bias and standard deviation for IASI for a set of independent profiles
Broadband IR transmittance calculations in Principal Component space

- Model fields for the transmittance calculations based on UK Met. Office forecast model so that vertical extend of atmosphere is taken into account.
- Resolution of 648 by 400 grid points.
- Time taken for the transmittance calculations across the whole area: ~3 minutes
Temperature retrievals:
- clear-sky
- ice cloud: full scattering
- ice cloud: Chou scaling
- grey cloud
LW Cloudy Retrievals from IASI

Relative humidity retrievals:
clear-sky ice cloud: full scattering
ice cloud: Chou scaling
grey cloud
LW Cloudy Retrievals from IASI

Approximations underpredict brightness temperatures at short-wave end.

Chou scaling cannot be used for cirrus property retrievals (underpredicting ice water content by 30-50%).
Retrievals with the HT-FRTC

Poster in Session 8 p12:

Jean-Claude Thelen, Stephan Havemann, Anthony J. Baran, Jonathan P. Taylor

LW and SW atmosphere and surface retrievals in Principal Component Space from IASI, ARIES and other sensors using the Havemann-Taylor Fast Radiative Transfer Code (HT-FRTC)
LW Cloudy Retrievals: Relative humidity from ARIES and IASI
### LW Cloudy Retrievals from ARIES and IASI: Cirrus properties

<table>
<thead>
<tr>
<th></th>
<th>Background values</th>
<th>Run 7</th>
<th>Run 8</th>
<th>Run 9</th>
<th>IASI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cirrus IWC</strong></td>
<td>10 mgm-3</td>
<td>26±8 mgm-3</td>
<td>23±14 mgm-3</td>
<td>24±6 mgm-3</td>
<td>20±7 mgm-3</td>
</tr>
<tr>
<td><strong>Cirrus cloud top pressure</strong></td>
<td>Flight level</td>
<td>302±1 hPa</td>
<td>315±6 hPa</td>
<td>323±7 hPa</td>
<td>313±15 hPa</td>
</tr>
<tr>
<td><strong>Cirrus cloud thickness</strong></td>
<td>10 hPa</td>
<td>14±3 hPa</td>
<td>13±6 hPa</td>
<td>18±4 hPa</td>
<td>11±5 hPa</td>
</tr>
<tr>
<td></td>
<td>(200 m)</td>
<td>(280±60 m)</td>
<td>(260±120 m)</td>
<td>(360±80 m)</td>
<td>(220±100 m)</td>
</tr>
<tr>
<td><strong>Cirrus cloud fraction</strong></td>
<td>1.00</td>
<td>1.06±0.03</td>
<td>0.98±0.04</td>
<td>1.01±0.03</td>
<td>0.96±0.05</td>
</tr>
</tbody>
</table>
Questions?
Bias and standard deviation for IASI for a set of independent profiles PC-RTTOV (Marco Matricardi)