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**

HT-FRTC capabilities today

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

Met Office

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.

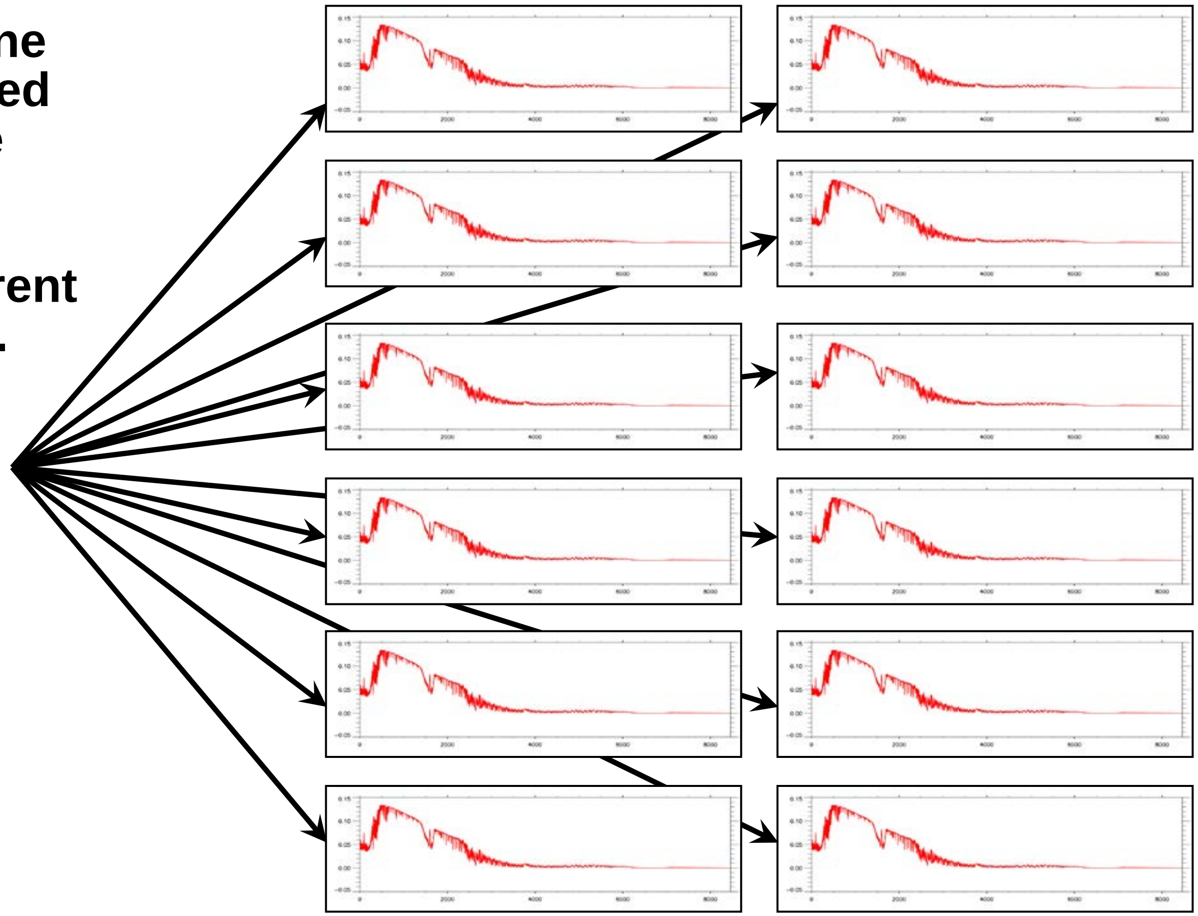
A hyperspectral radiance calculation takes less than one millisecond.

The HT-FRTC is used in a 1D-Var retrieval system in principal component space

HT-FRTC TRAINING STEP

Our accurate line-by-line (scattering) code is used to simulate line-by-line radiance (/transmittance/flux) spectra for many different atmospheres/surfaces.

Line-by-Line Code

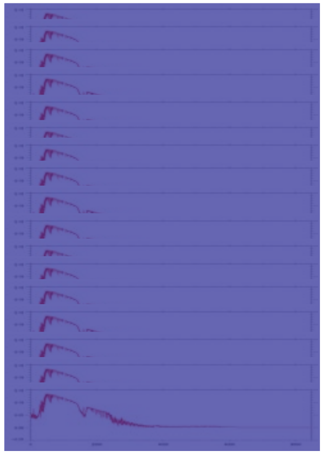


Includes different viewing angles and altitudes.

Currently a diverse set of 1,000 ECMWF profiles is used.

HT-FRTC TRAINING STEP

Met Office



n profiles/ surfaces

m line-by-line frequencies

The line-by-line radiance spectra are arranged together in a large m x 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 x **SVs** x **PCs**

Represent the basic characteristics of the atmosphere

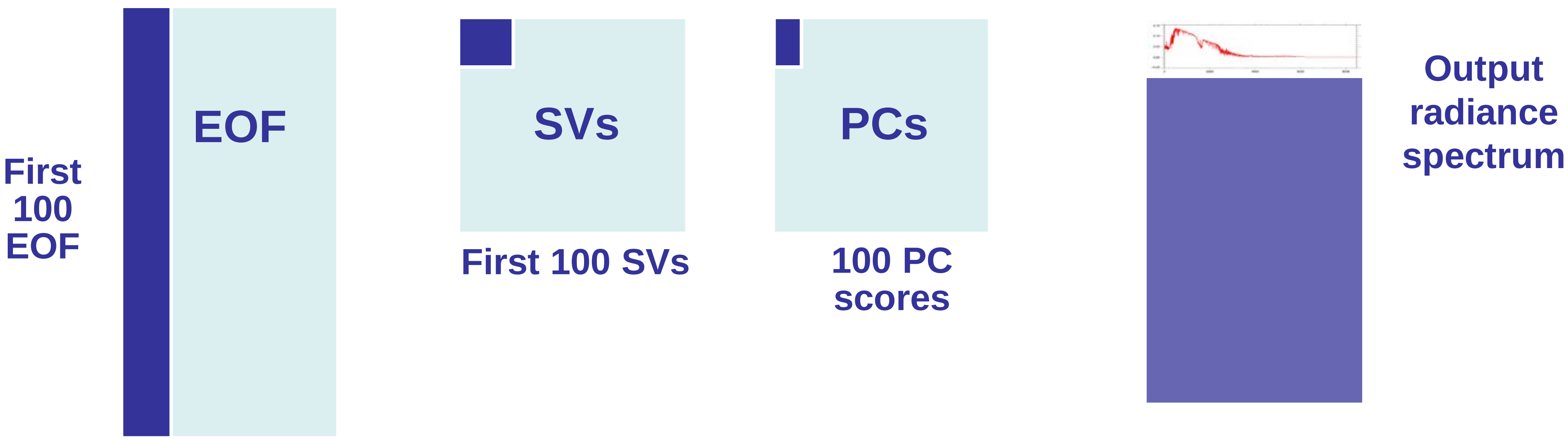
Sorted by size, give significance of each EOF

Depend on the actual atmospheric/ surface state

HT-FRTC TRAINING STEP

Met Office

The radiance spectra can be represented almost perfectly using only the leading EOF.



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**.

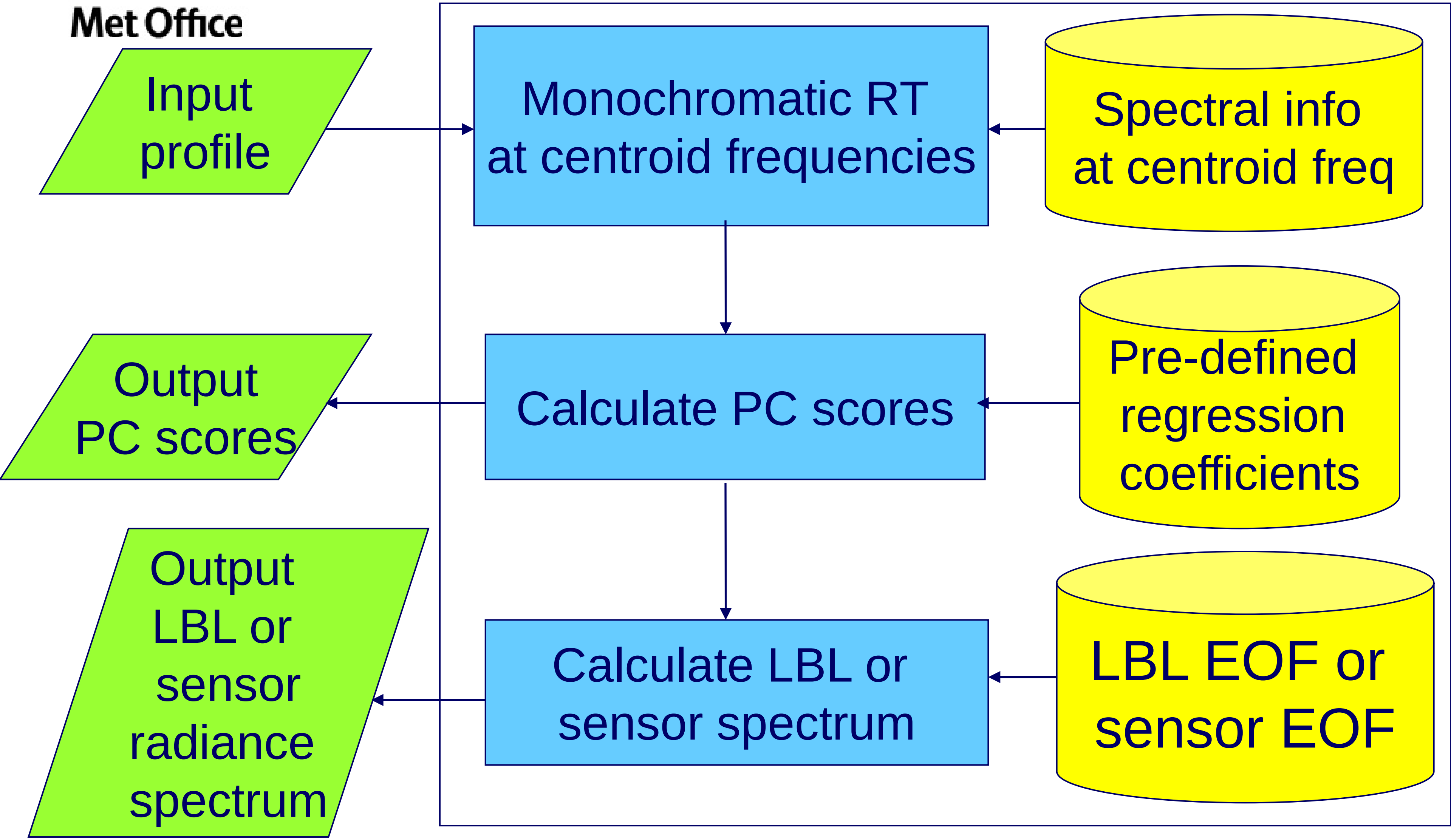
HT-FRTC TRAINING STEP

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



HT-FRTC FAST MODEL STEP

The fast model step calculates the PC scores and **takes 1 millisecond** for a clear-sky profile.

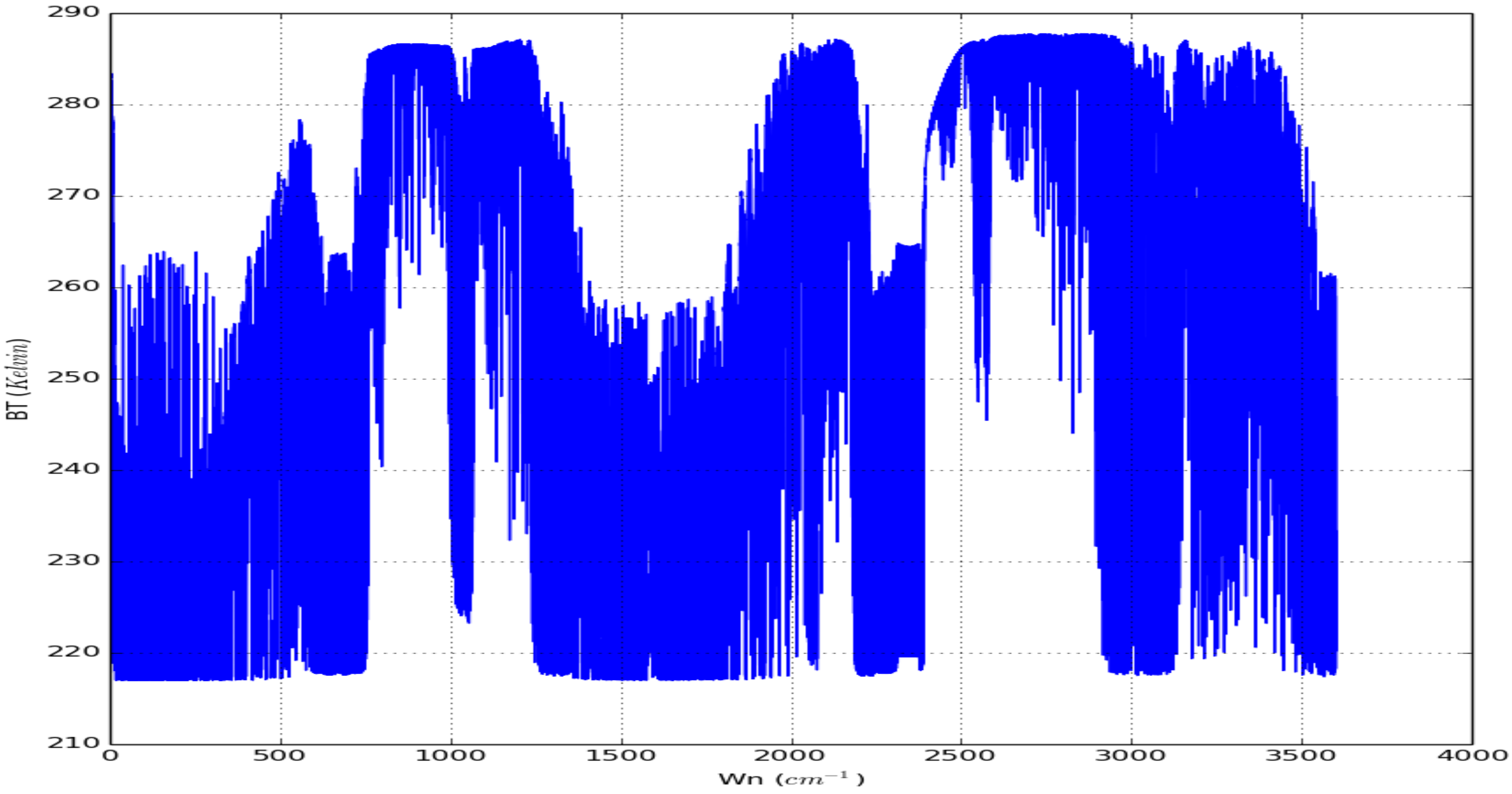
From these PC scores

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

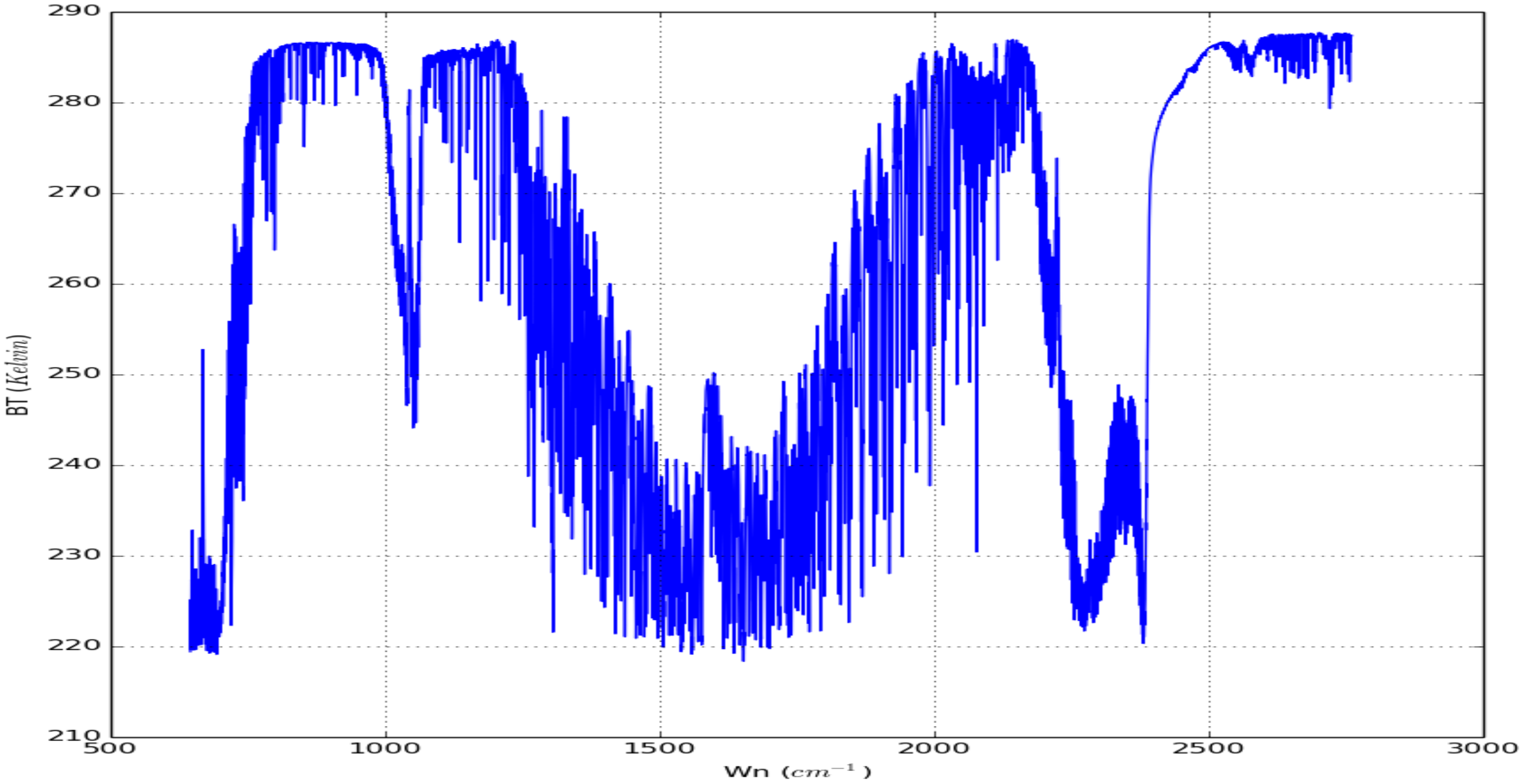
b) any number of **hyperspectral** or **broadband** sensor spectra can be generated by multiplication with sensor specific EOFs.

The sensor specific EOFs are just the (LBL) EOFs convolved with the IRF and they are also fixed and can be precalculated.

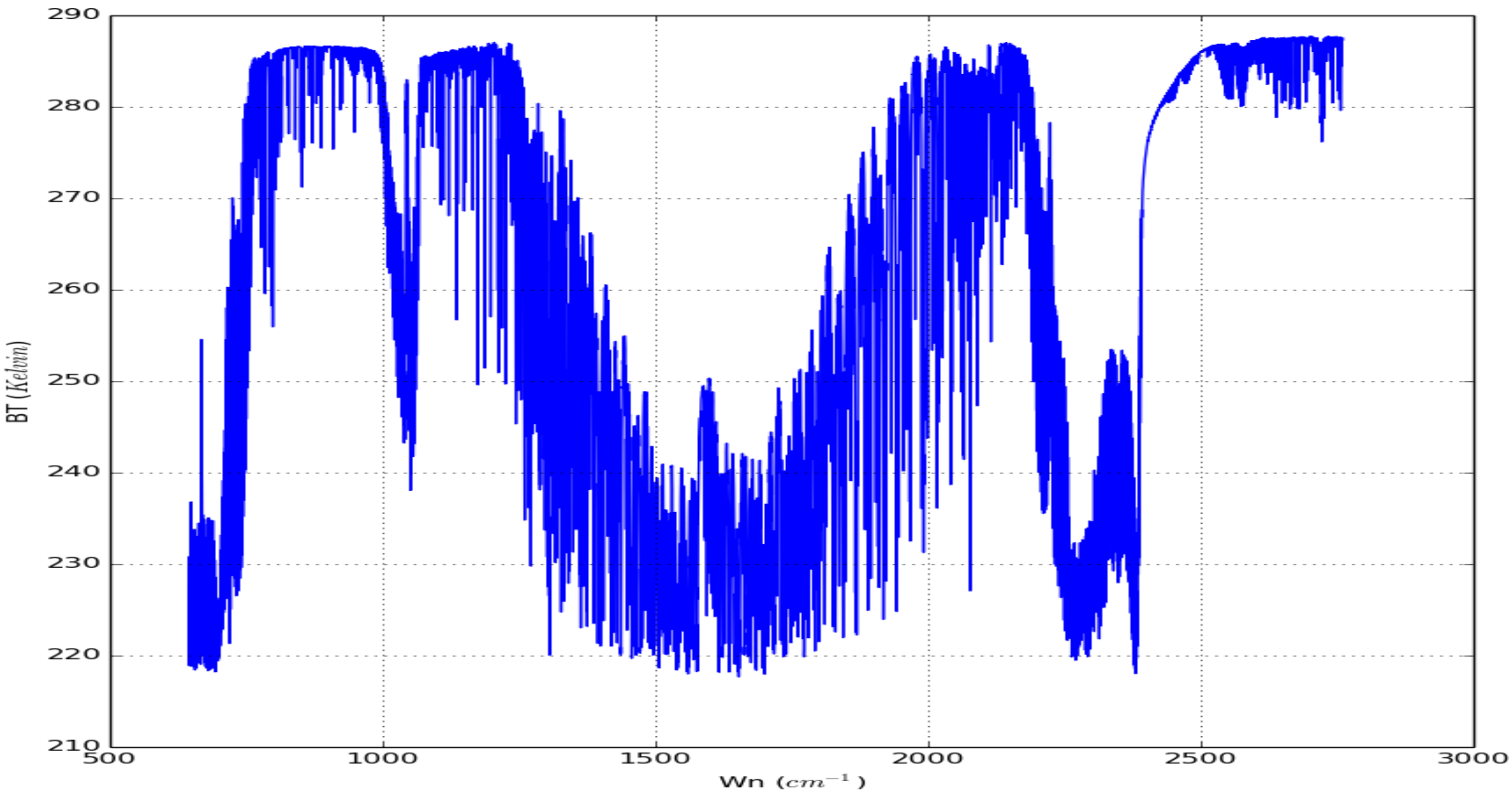
“Line-by-line” calculation using HT-FRTC



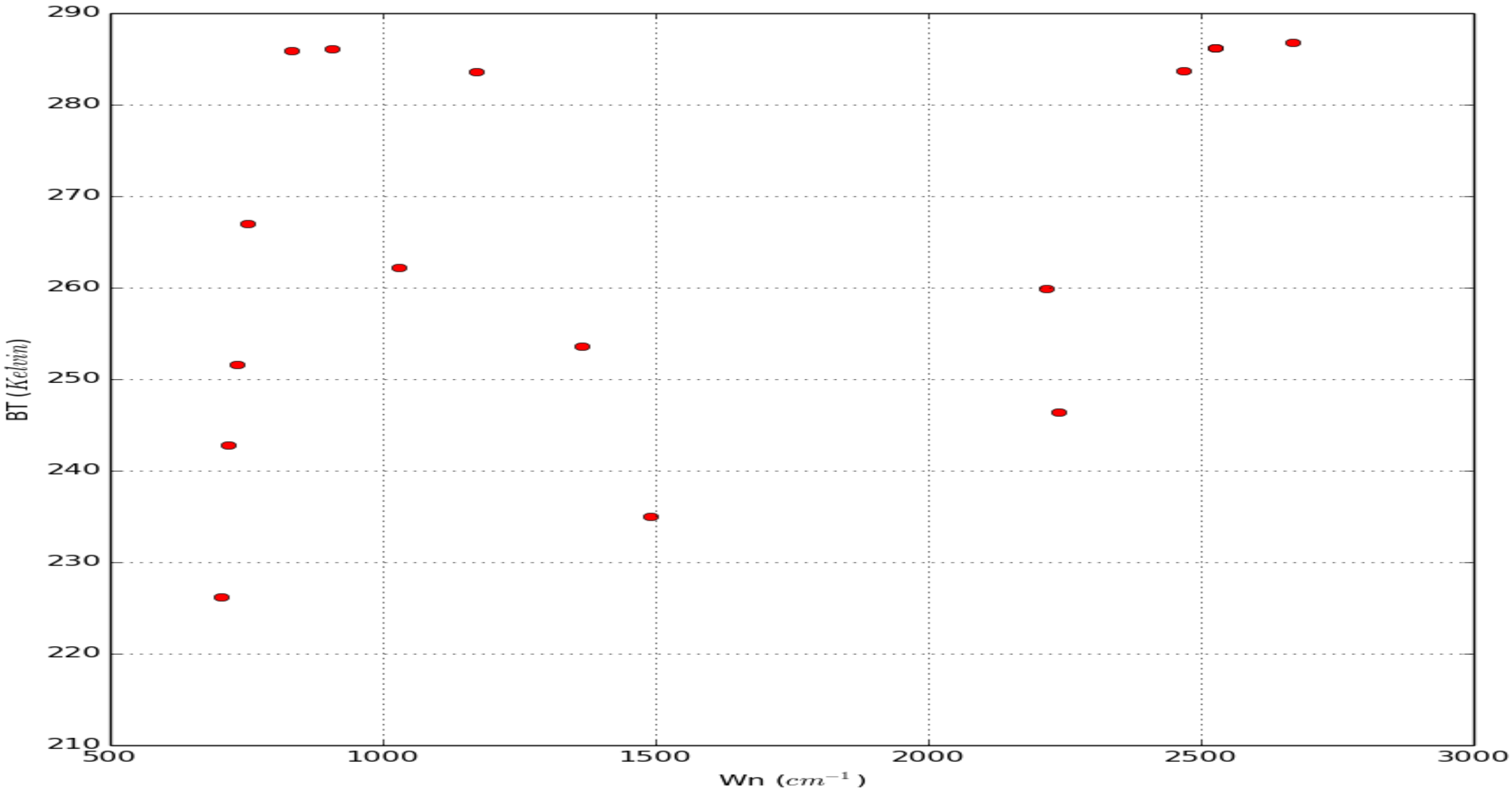
IASI using the **same** PC scores



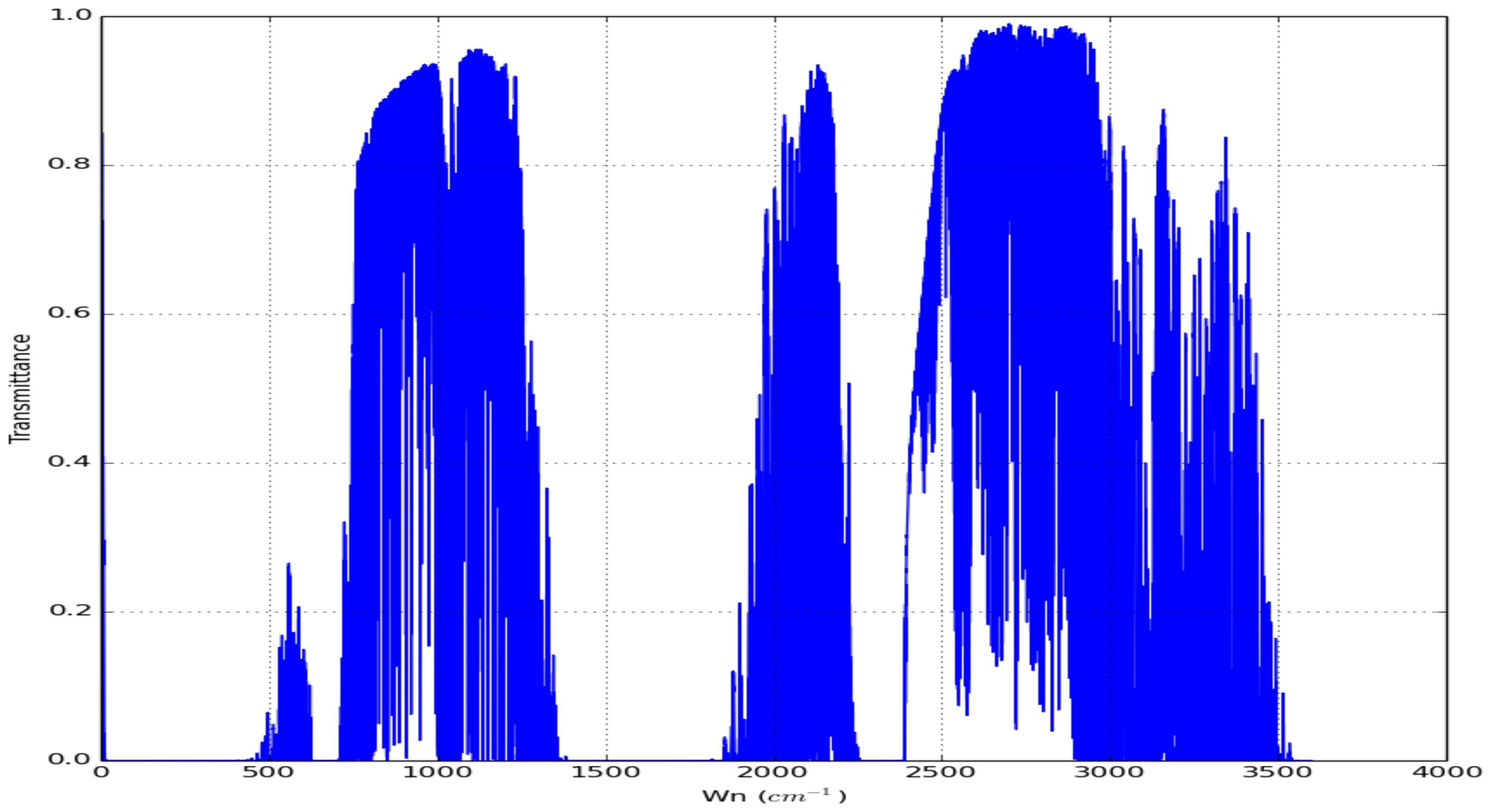
IASI-NG using the **same** PC scores



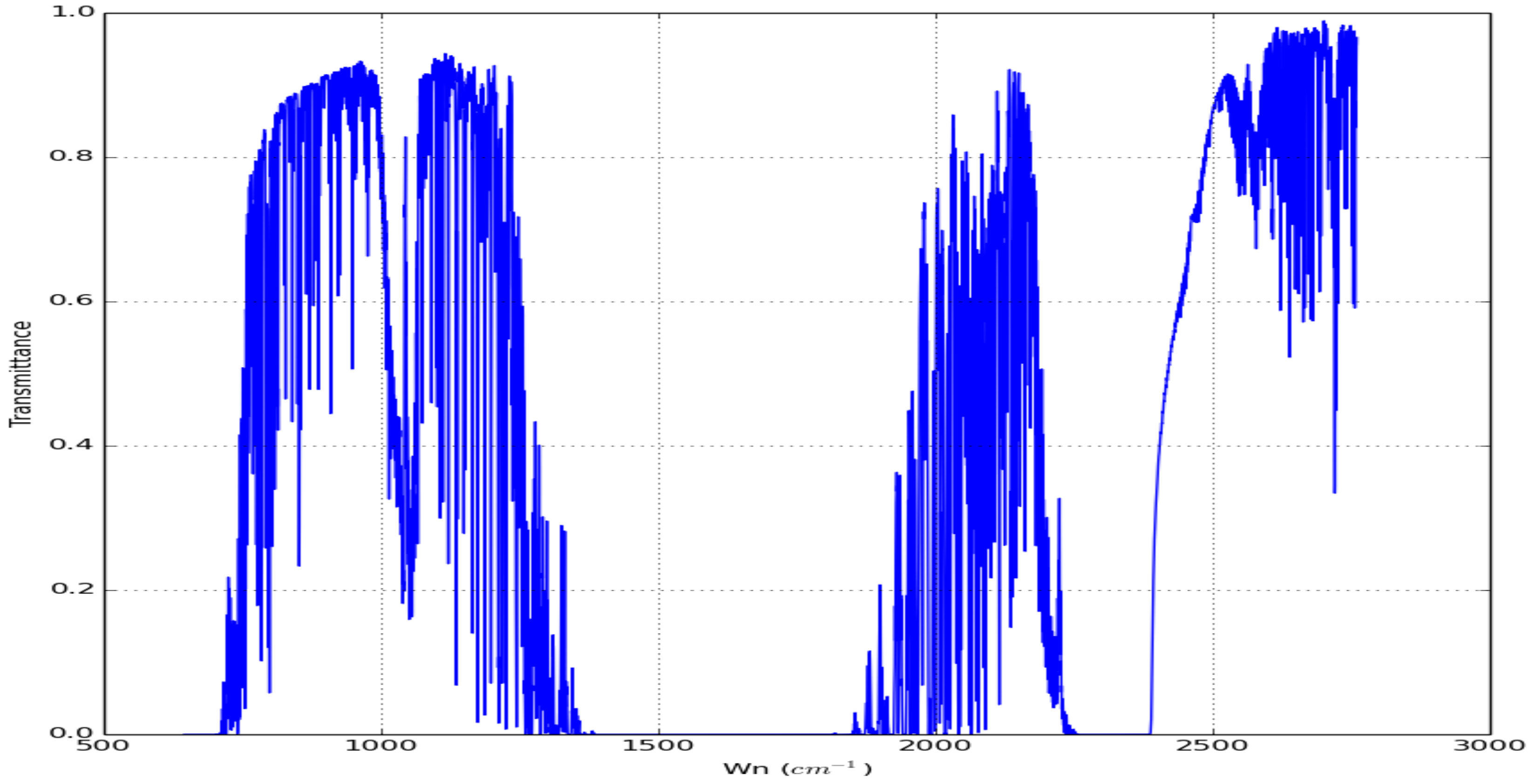
MODIS using the **same** PC scores



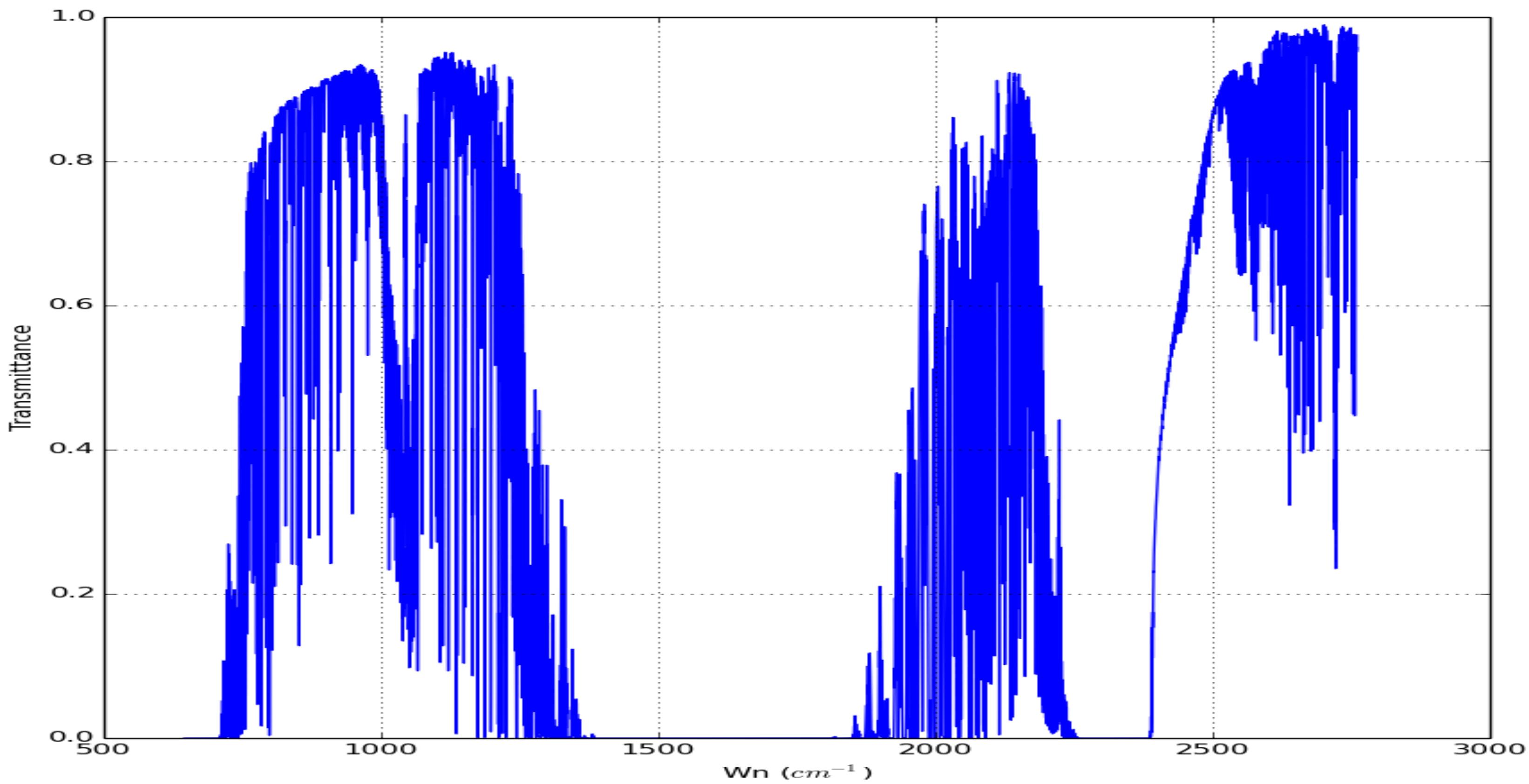
“Line-by-line” transmittance calculation using HT-FRTC



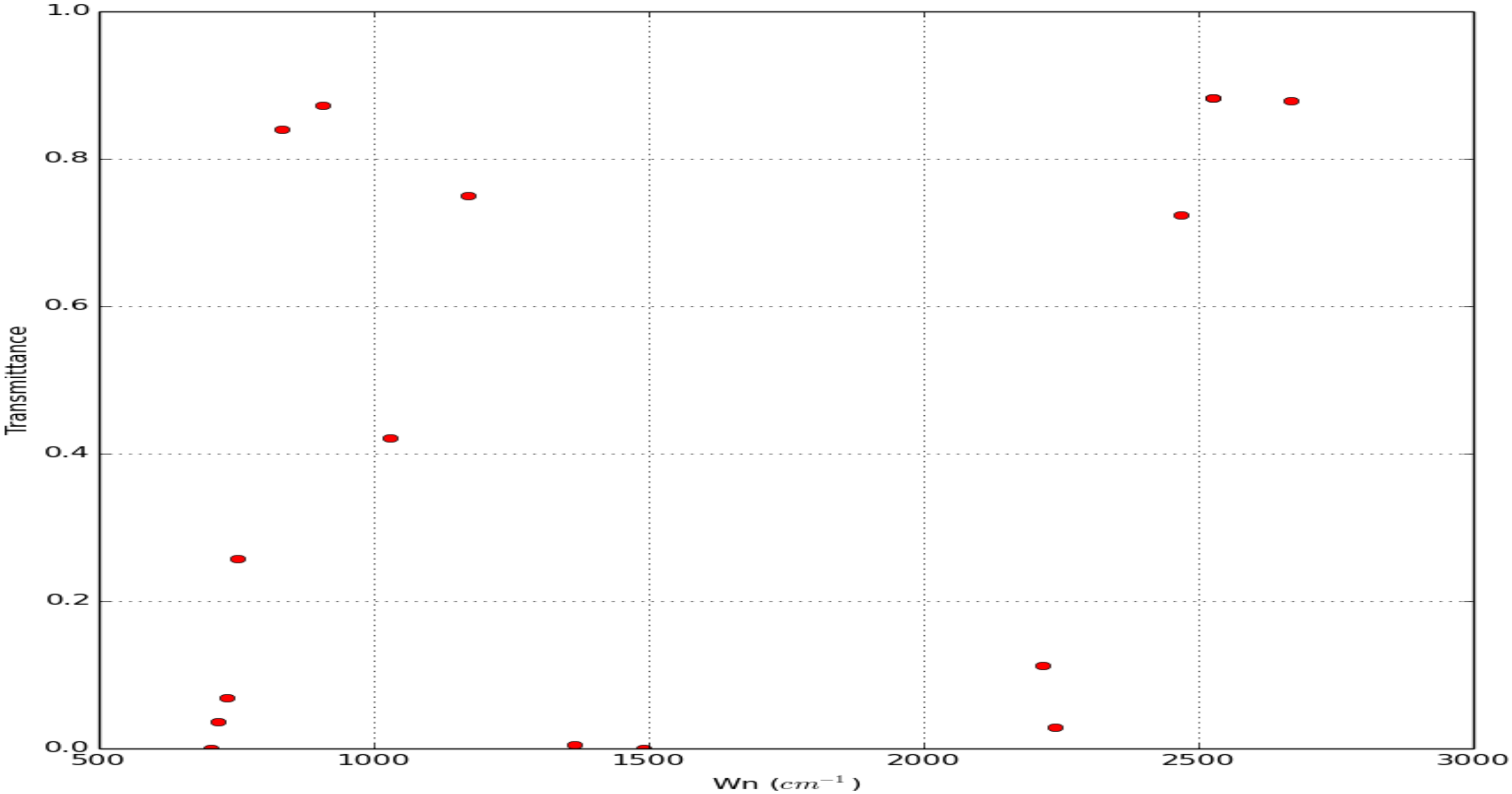
IASI transmittances using the **same** PC scores



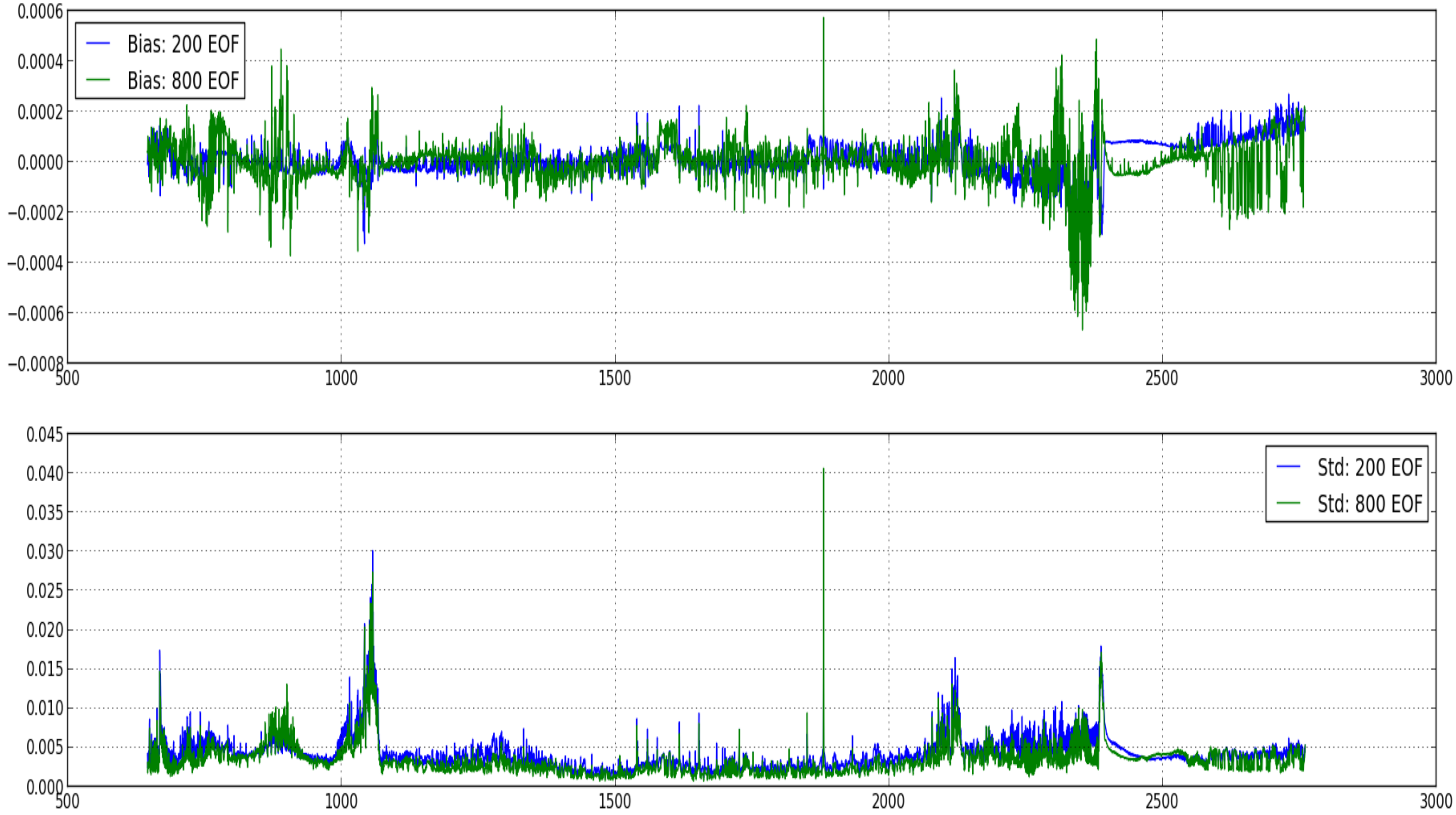
IASI-NG transmittances using the **same** PC scores



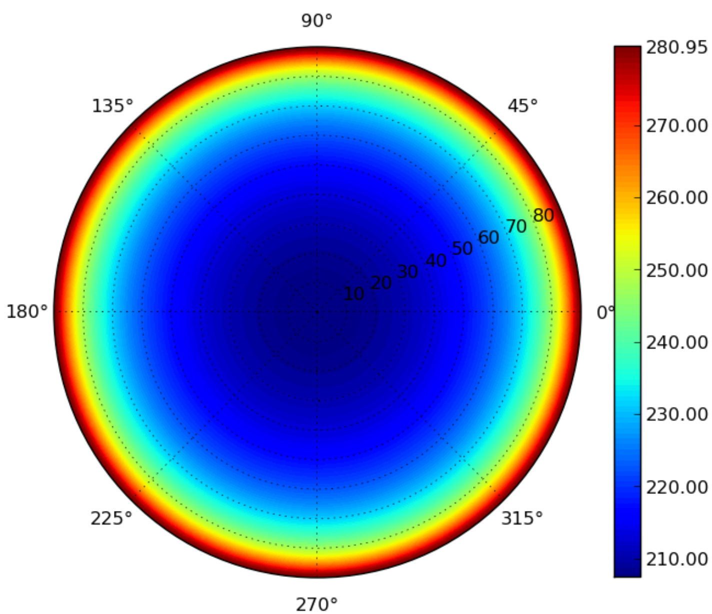
MODIS transmittances using the **same** PC scores



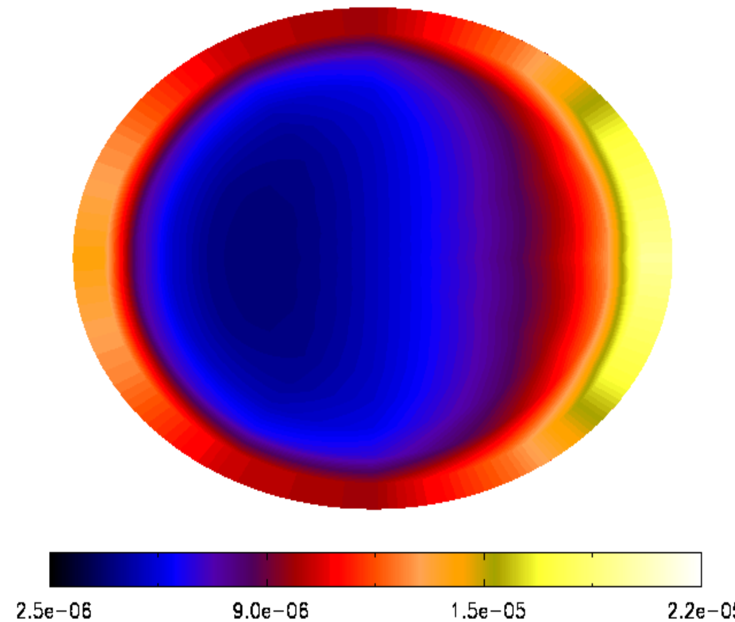
Bias and standard deviation for IASI for a set of independent profiles



Sky brightness



IR



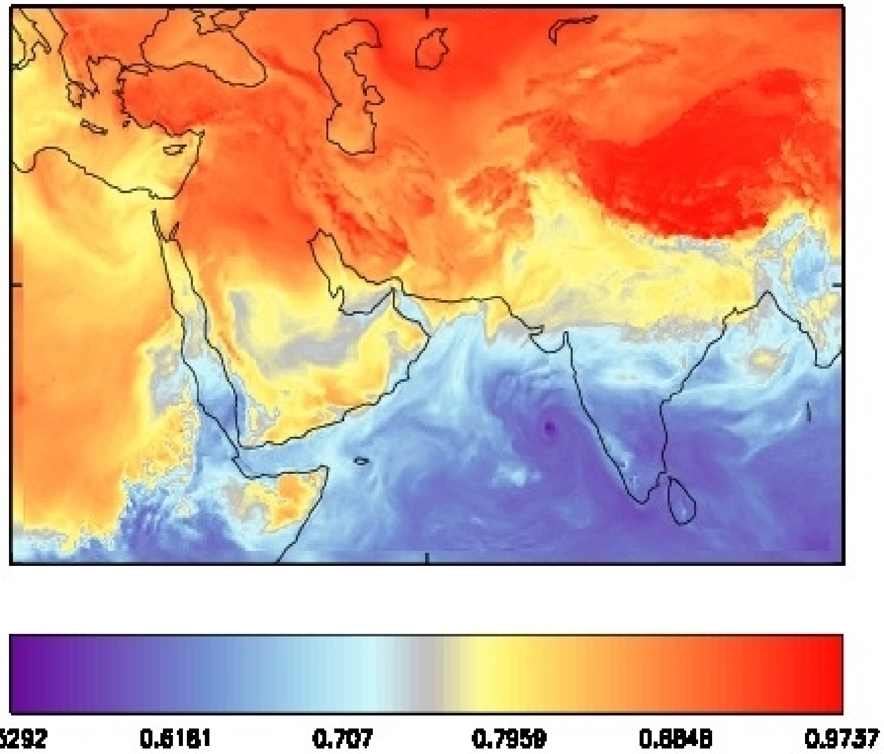
(diffuse) SW

Broadband IR transmittance calculations in Principal Component space

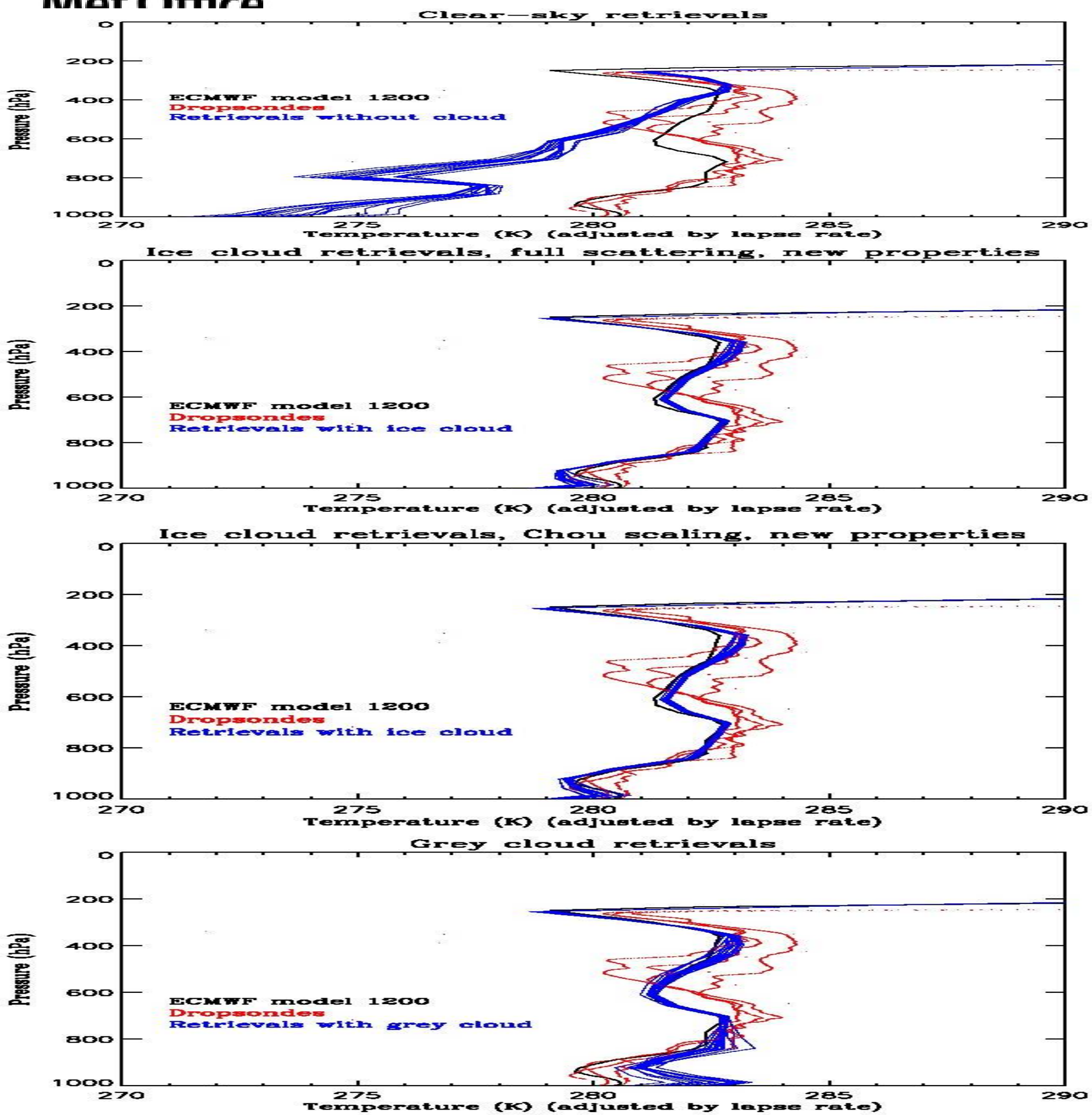
• **Model fields for the transmittance calculations based on UK Met. Office forecast model so that vertical extend of atmosphere is taken into account.**

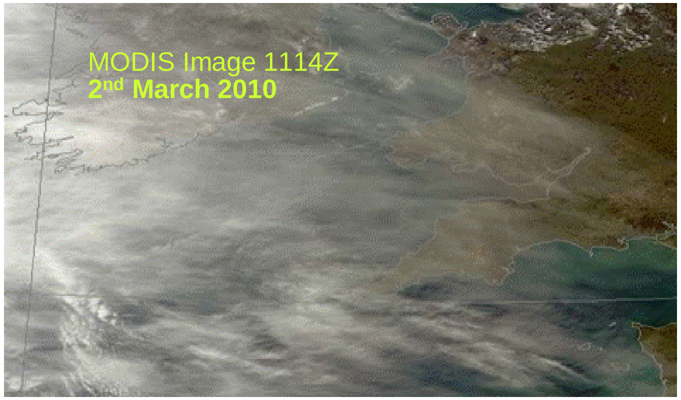
• **Resolution of 648 by 400 grid points.**

• **Time taken for the transmittance calculations across the whole area: ~ 3 minutes**



LW Cloudy Retrievals from IASI



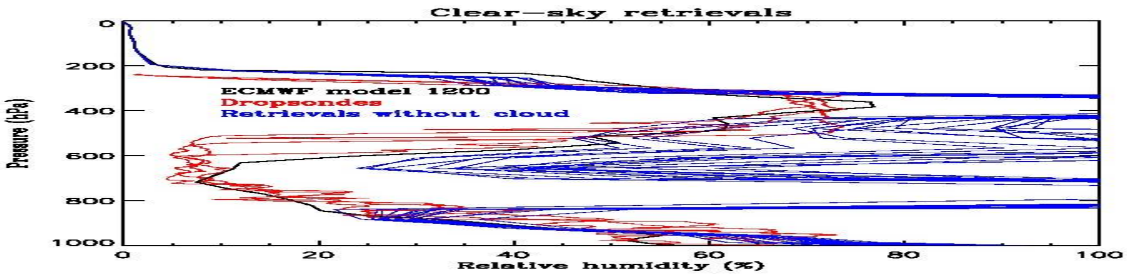


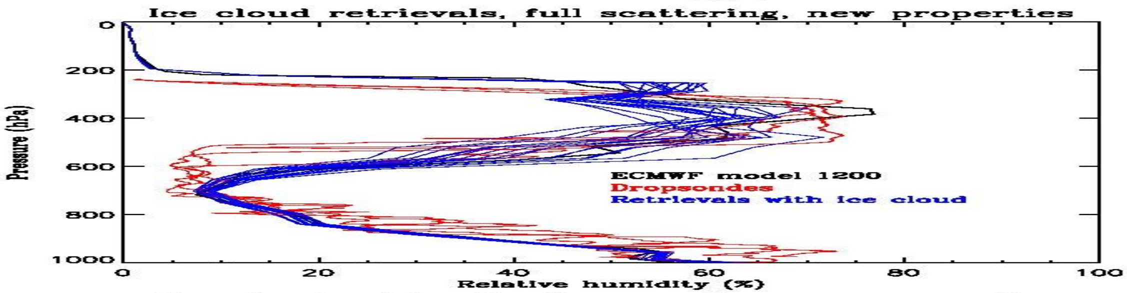
Temperature retrievals:

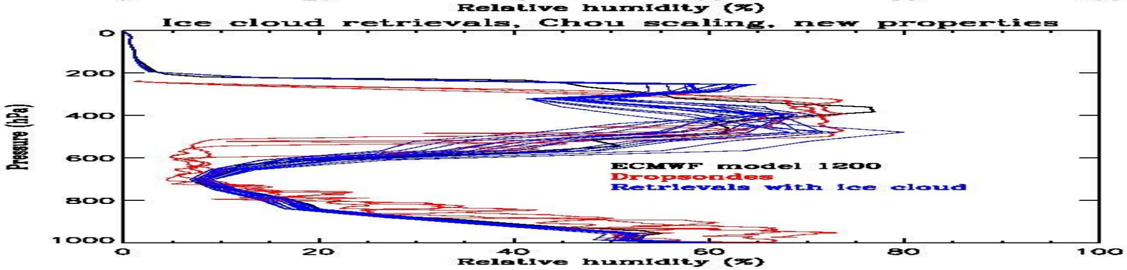
clear-sky
ice cloud: full scattering
ice cloud: Chou scaling
grey cloud

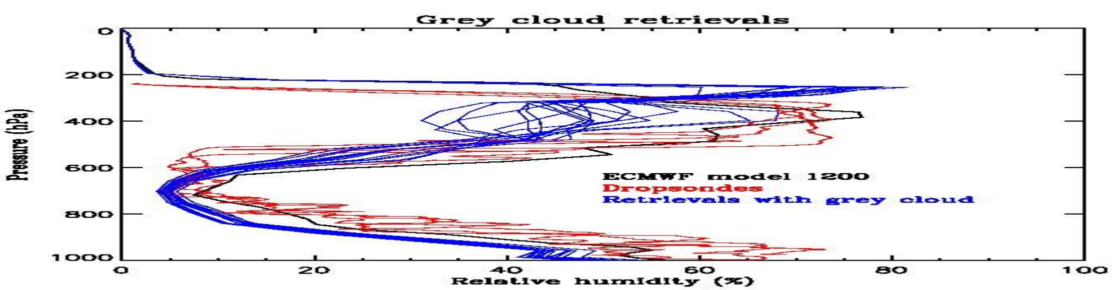
LW Cloudy Retrievals from IASI

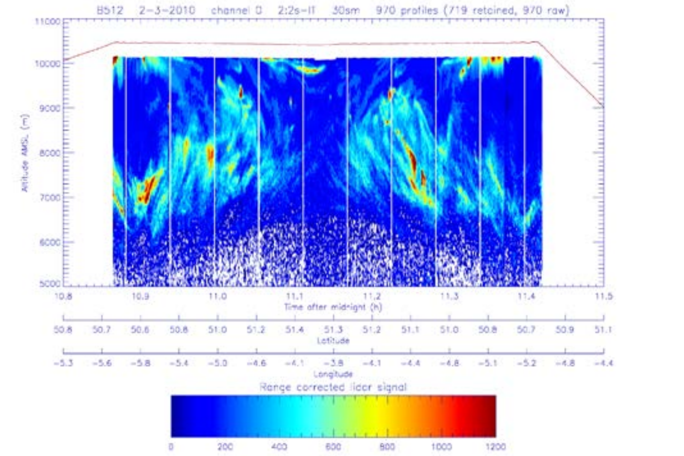
Met Office







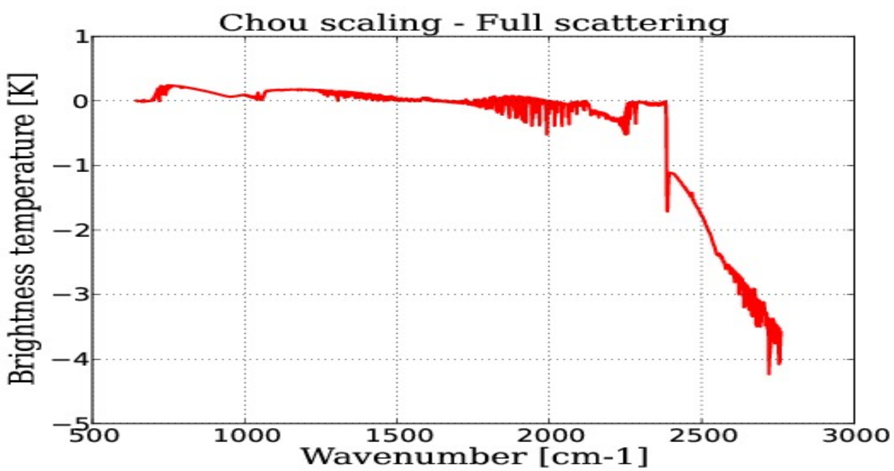


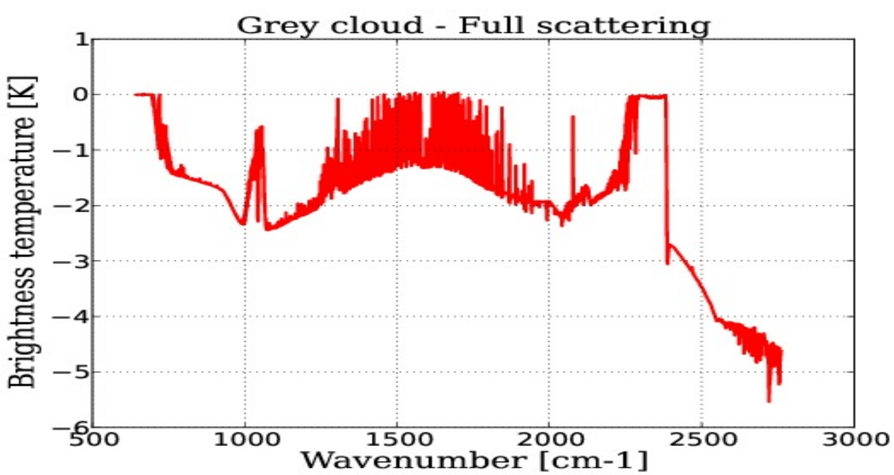


Relative humidity retrievals:

clear-sky
ice cloud: full scattering
ice cloud: Chou scaling
grey cloud

LW Cloudy Retrievals from IASI





Approximations unterpredict brightness temperatures at short-wave end

Chou scaling cannot be used for cirrus property retrievals (underpredicting ice water content by 30-50%)

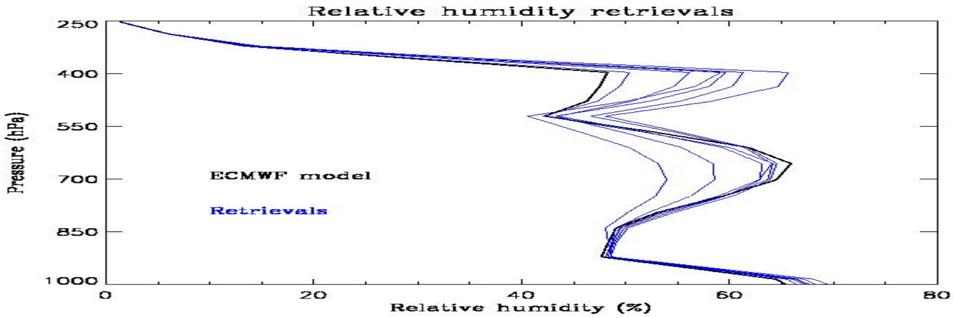
Retrievals with the HT-FRTC

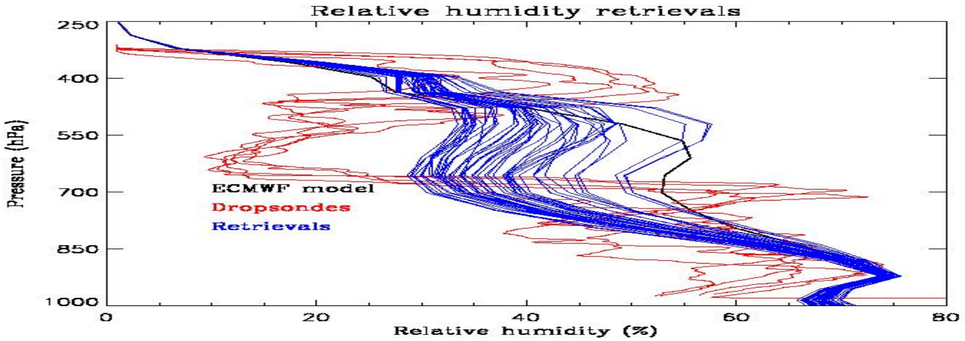
Poster in Session 8 p12 :

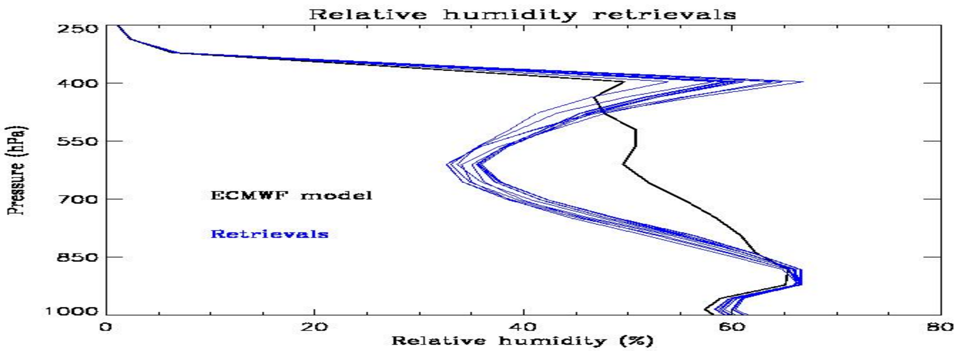
Jean-Claude Thelen, Stephan Havemann, Anthony J. Baran, Jonathan P. Taylor

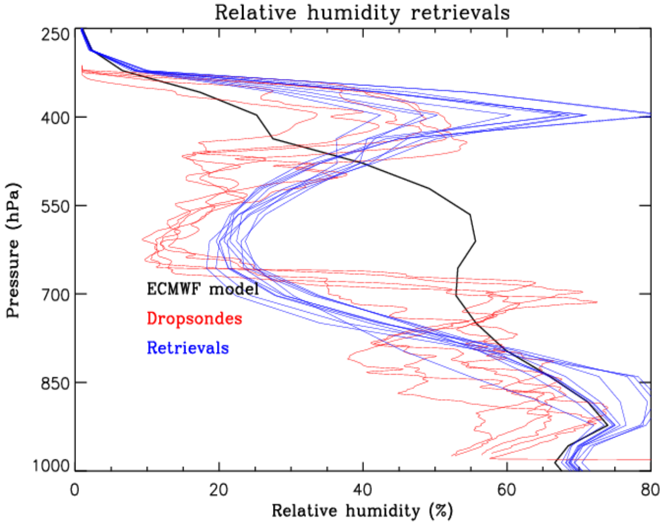
LW and SW atmosphere and surface retrievals in Principal Component Space from IASI, ARIES and other sensors using the Havemann-Taylor Fast Radiative Transfer Code (HT-FRTC)

LW Cloudy Retrievals: Relative humidity from ARIES and IASI









LW Cloudy Retrievals from ARIES and IASI: Cirrus properties

	Background values	Run 7	Run 8	Run 9	IASI
Cirrus IWC	10 mgm-3	26±8 mgm-3	23±14 mgm-3	24±6 mgm-3	20±7 mgm-3
Cirrus cloud top pressure	Flight level	302±1 hPa	315±6 hPa	323±7 hPa	313±15 hPa
Cirrus cloud thickness	10 hPa (200 m)	14±3 hPa (280±60 m)	13±6 hPa (260±120 m)	18±4 hPa (360±80 m)	11±5 hPa (220±100 m)
Cirrus cloud fraction	1.00	1.06±0.03	0.98±0.04	1.01±0.03	0.96±0.05

Met Office

Questions?

Bias and standard deviation for IASI for a set of independent profiles PC-RTTOV (Marco Matricardi)