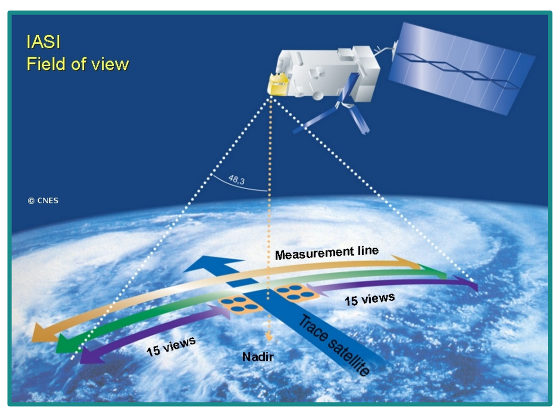
Simulating the IASI spectrum using Radiative Transfer Models

Lucy Ventress, Anu Dudhia, Joanne Walker
University of Oxford
Contact: ventress@atm.ox.ac.uk



Abstract

The Infrared Atmospheric Sounding Interferometer (IASI) is a nadir viewing infrared Fourier transform spectrometer onboard the METOP-A satellite, which is part of the EUMETSAT European Polar orbiting system. It covers the spectral range 645-2760 cm^{-1} with a spectral sampling of 0.25 cm^{-1}, resulting in a large quantity of data. It has become a key instrument in providing temperature and water vapour profiles and its data have been extensively assimilated in Numerical Weather Prediction (NWP) systems. The ability to accurately simulate the IASI spectra using Radiative Transfer Models is essential within the data assimilation process and in continuing to produce accurate retrievals. Here, two Radiative Transfer Models currently used to simulate observations are examined; the Reference Forward Model (RFM) and the Radiative Transfer Model for TOVS (RTTOV). A comparison between the models is carried out to attempt to discover the origin of spectral discrepancies between them. Further, the models are used to simulate real IASI measurements to ascertain how well they are able to replicate the IASI spectrum, given the atmospheric state.

Introduction - Radiative Transfer Models

Radiative Transfer Models are used to simulate accurately top of atmosphere radiances by solving the equation of Radiative Transfer, given atmospheric profiles of the gases present. The spectrum is then convolved with the appropriate spectral response function to obtain the radiance expected from a particular instrument. Here we discuss two Radiative Transfer Models; the RFM[1], a line by line radiative transfer model developed at the University of Oxford, and RTTOV[2], a widely used fast radiative transfer model adapted for IASI.

RFM – Reference Forward Model

- Line by Line Radiative Transfer Model
- Perform accurate calculations of radiances/transmittances at high spectral resolution
- Transmittances, τ, are calculated at each wavenumber

$$\tau(\nu) = \exp\left(-\sum_j k(\nu)_j u_j\right)$$
$$k(\nu)_j = \sum_i S_{ij}\, g(\nu-\nu_i)_j$$

where *k* Is the absorption coefficient, *u* is the amount of absorber in path *j,* and S_{ij} and *g* describe the line strength and shape respectively.

- Radiances, R, are the integral over both atmospheric path and wavenumber,

$$R_\nu(z_{obs}) = \int_\nu \int_{z_s}^{z_{obs}} B_\nu(T(z))\frac{d\tau}{dz}\,dz\,\phi(\nu)\,d\nu$$

where B is the Planck function, T is temperature and φ is the instrument spectral response function.

RTTOV – Radiative Transfer model for TOVS

- Fast Radiative Transfer Model
- Increased computer efficiency
- Transmittances (or effective optical depths, σ^{eff}) are expressed as a function of profile dependant predictors, *X*.

$$\tau_{j,\nu} = \exp(-\sigma^{eff}_{j,\nu}) \qquad \sigma^{eff}_{j,\nu} = \sigma^{eff}_{j-1,\nu} + \sum_{k=1}^{M} a_{j-1,\nu,k} X_{k,j-1}$$

- The regression coefficients, *a,* are derived from a line by line model using a training set of atmospheric profiles. The line by line model in this case is the LBLRTM[3].
- The radiance calculation becomes

$$R(z_{obs}) = \int_{z_s}^{z_{obs}} \bar{B}_\nu(T(z))\frac{d\bar{\tau}}{dz}\,dz$$

with a spectrally averaged Planck Function and transmittance given by

$$\bar{B} = \int_\nu B\phi\,d\nu \qquad \bar{\tau} = \int_\nu \tau\phi\,d\nu$$

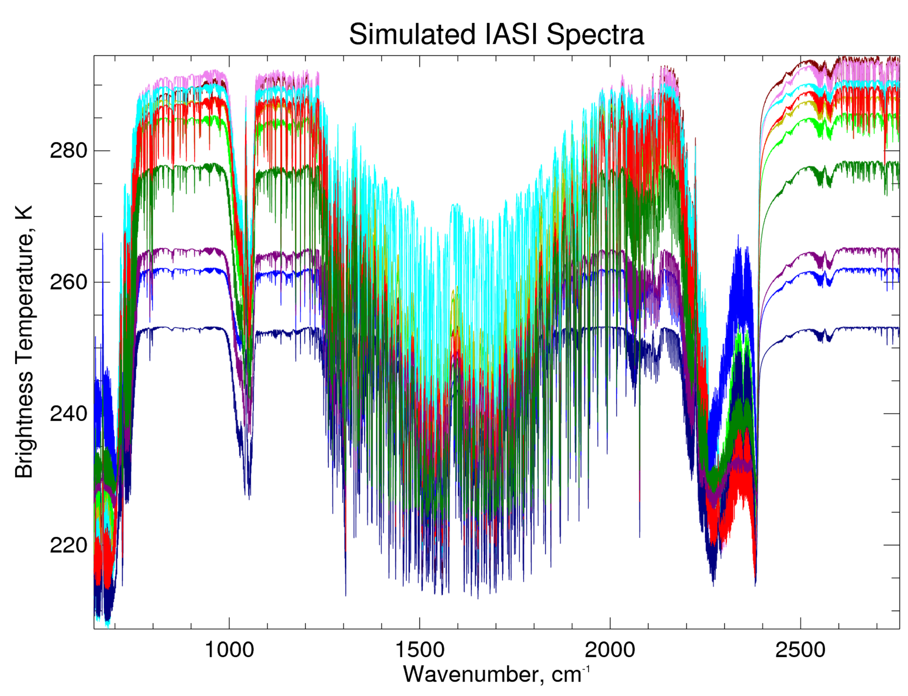


Figure 1: Typical IASI spectra with varying atmospheric states simulated by the RFM. The profiles and surface properties are taken from the 60-level atmospheric profiles from the ECMWF analyses.

Model Comparisons

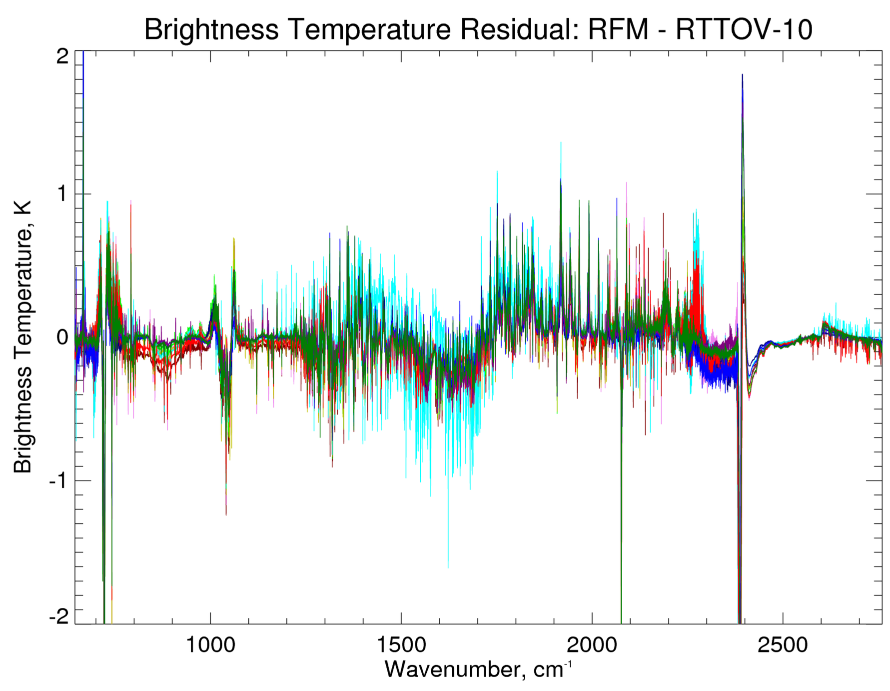


Figure 2: The brightness temperature residual between simulations by the RFM and RTTOV-10 for 10 diverse atmospheric profile sets.

Comparisons between RTTOV-10 and the RFM were carried out using a subset of the 60-level atmospheric profiles from the ECMWF analyses[4]. The same atmospheric profiles were input to both models for T, H20, O3, CH4, N2O, and CO and a constant emissivity was assumed. The resulting residual is shown in figure 2, which shows good agreement between the models in the window regions but some large differences across the absorbing regions of the spectrum.

Figure 3 shows the locations in the IASI spectra affected by various atmospheric gases. Unsurprisingly, it can be seen that the spectral regions with large residuals coincide with the areas affected by the major absorbers, noticeably the water vapour continuum. In particular, the spectral lines with the largest residuals (e.g. 2077cm^{-1}) appear to correspond to high altitude CO2 lines indicating a potential difference in the models assumptions.

Several possible differences between the models were investigated to see if they contributed to the discrepancies produced. These included;

- Accounting for the non-voigt lineshape of CO2
- Misspecification of the pressure levels
- The handling of the Planck Function across an atmospheric layer
- The fine mesh size used in the Instrument Line Shape (ILS) convolution
- The use of a truncated ILS in the RFM

However these were shown to have minimal effect upon the residual, causing changes of only O(0.2K).

It should be noted that the RTTOV-10 coefficients were calculated using the LBLRTM not the RFM and hence, some discrepancies may also be caused by differences in the line by line models.

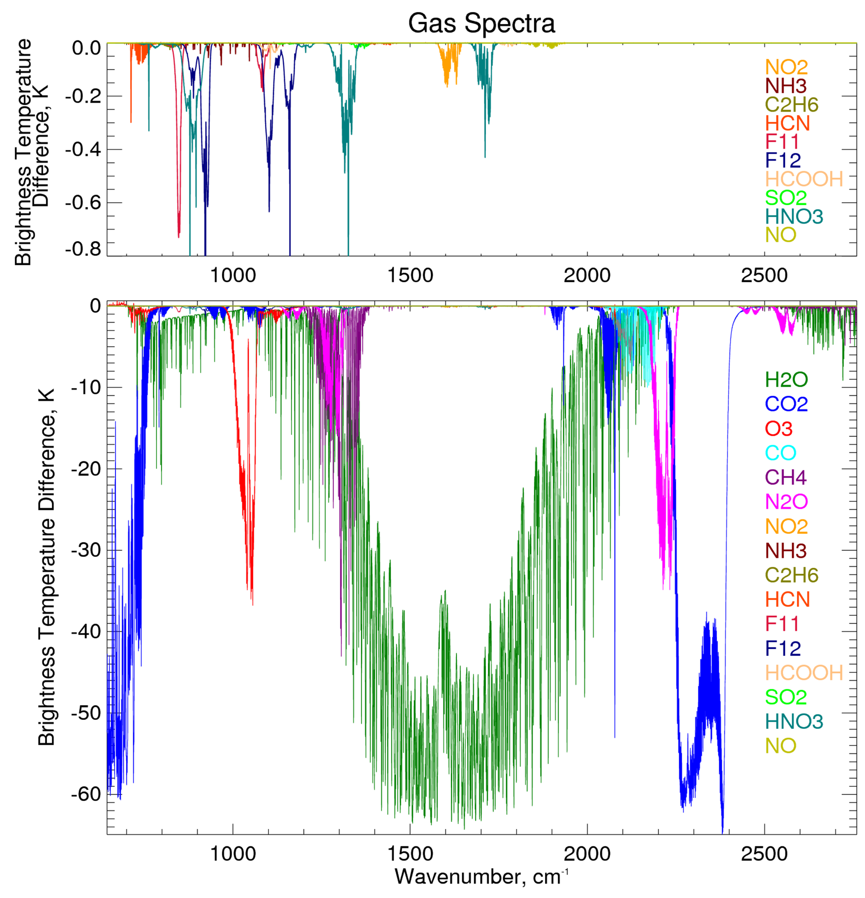


Figure 3: The pseudo brightness temperature difference caused by the presence of various absorbing gases in a standard mid-latitude daytime atmosphere.

Simulating IASI data

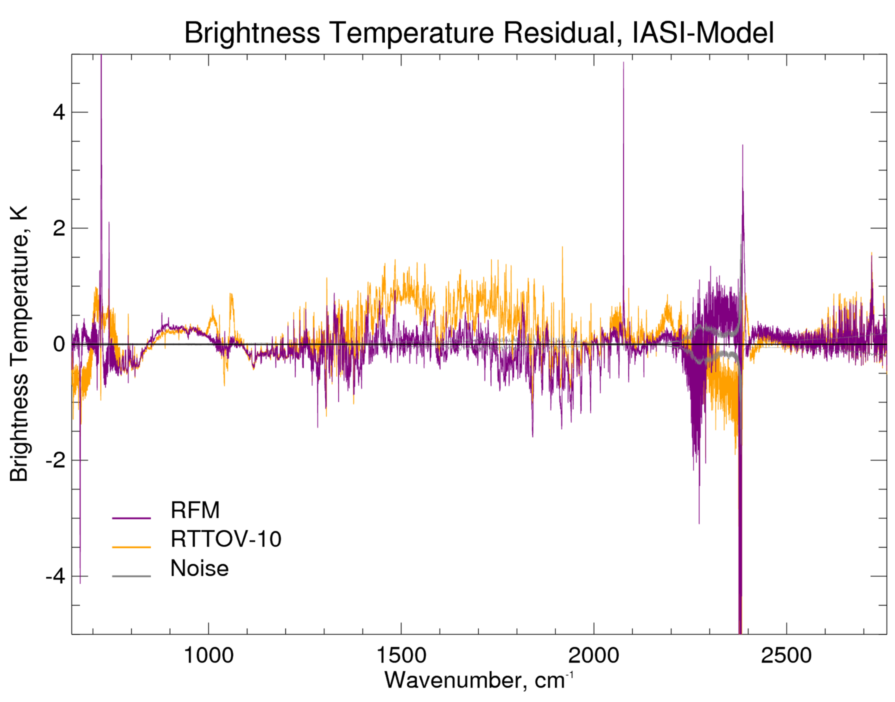


Figure 4: The brightness temperature residual between a mean IASI spectra and simulations from the RFM and RTTOV-10 using partially retrieved atmospheric profiles. The noise associated with the IASI spectrum is also plotted.

In order to continue to produce accurate retrievals it is essential for Radiative Transfer Models to be able to accurately simulate satellite instrument data. Therefore, a comparison has also been performed between IASI spectra and simulations from both the RFM and RTTOV-10.

For comparisons to IASI data, the simplest case of a clear-sky, mid-latitude region over the ocean was chosen. A mean spectrum from all IASI measurements within a 2° x 2° grid box was calculated in order to reduce the noise.

The initial model input came from the ERA Interim database, which provides atmospheric profiles for T, P, H2O, and O3 along with surface properties. However, due to the averaging process these do not necessarily represent the atmosphere correctly. To improve the estimate of the atmospheric state a simple partial retrieval was carried out using the RFM and the brightness temperature difference between the measurements and the models can be seen in figure 4.

Similarly to the model comparisons, we can see the high altitude CO2 absorption lines, which the RFM does not appear to model well. Since the retrieval was carried out using the RFM, the RFM residual is smaller than that from RTTOV-10, as would be expected, however both still remain much larger than the instrument noise.

Conclusions and Future Work

- It is important to continue to improve Radiative Transfer Models in order to carry out accurate retrievals on satellite data.
- There are some high altitude spectroscopic disparities between both the models and with IASI which must be corrected for.
- Currently, much work must still be done to establish the reason for the large discrepancies between models in the major absorbing regions of the spectrum. In particular, the region affected by the water vapour continuum will be investigated next.

References

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