Preparation for the next generation hyperspectral infrared sounders MTG-IRS and IASI-NG

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Introduction

The next generation hyperspectral infrared instruments planned to be launched by EUMETSAT will present enormous opportunities for assimilation in NWP models, although aspects such as data volume and the lossy principal component (PC) compression present challenges. ECMWF's day-one plan is to assimilate MTG-IRS reconstructed radiances as if they were raw radiances.

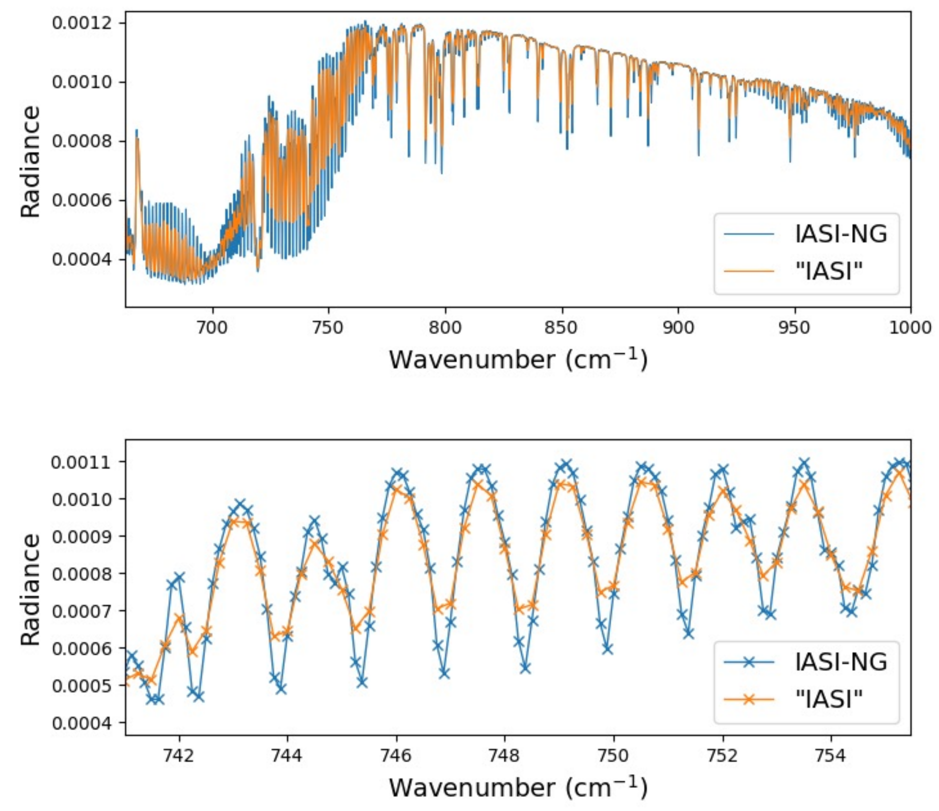
This poster highlights some more speculative approaches to the assimilation of data from IRS and IASI-NG.

Creating "IASI" spectra from IASI-NG

The high spectral resolution of IASI-NG is valuable for atmospheric composition but, provides little additional information that would be useful in NWP. Chris Barnet has proposed to transform IASI-NG radiances in order that they are consistent with the spectral response functions of IASI. This would allow IASI-NG to be assimilated as if it were an IASI instrument.

Compared to simply sub-sampling the channels, this technique would result in **strong noise reduction**.

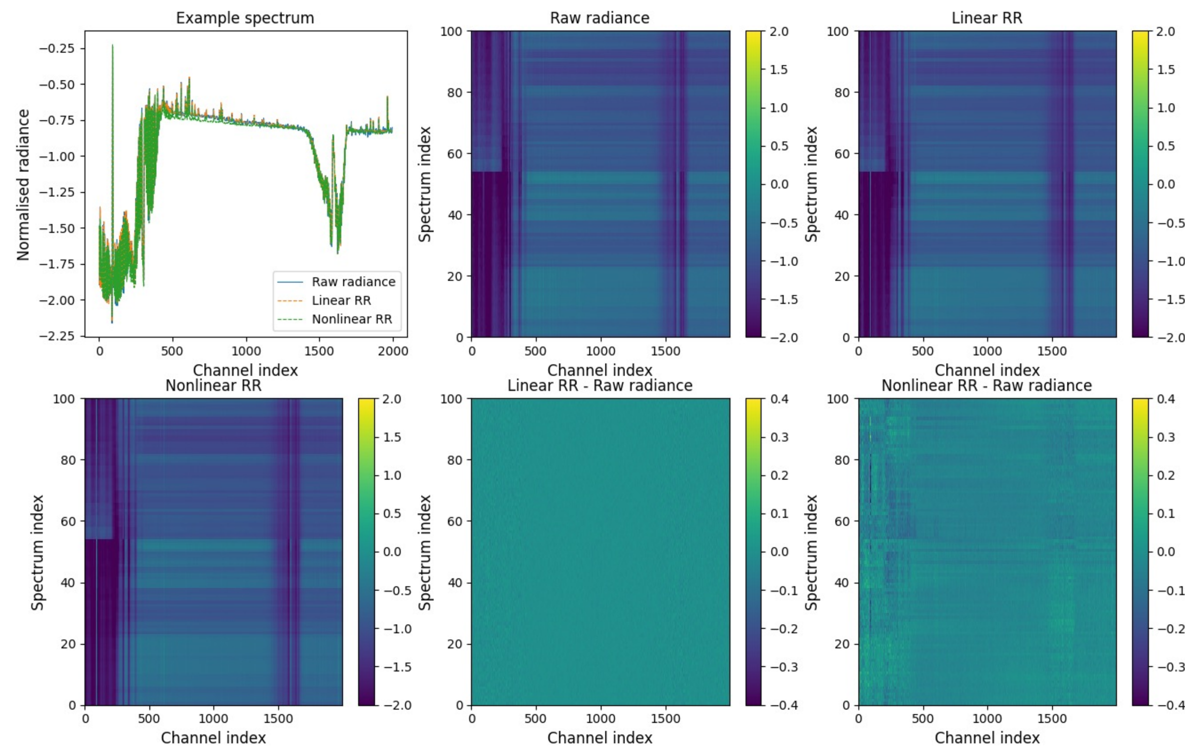
The conversion is a linear operation, but can result in Gibbs phenomenon at the band edges.



Nonlinear radiance reconstruction

IRS data will be disseminated as PC scores. The natural method of reconstructing is to linearly combine the basis eigenvectors according to these weights. Is it possible to use nonlinear methods more accurately recover the original radiances? Here we have trained a simple neural network to recover IASI LWIR radiances from a sample of PC scores which have been truncated to include only the 100 largest eigenvalues.

The neural network architecture has not been optimised, but currently, the nonlinear reconstruction is not performing as well as the linear reconstruction, as can be seen in the figure, where comparisons have been made for 100 spectra not included in the training sample. It remains to be demonstrated whether a nonlinear approach reconstruct radiances more accurately than the usual linear method. Using an end-to-end autoencoder may be more beneficial, but here we are focussed on making best use of data as they will be provided.



Spectral response function of reconstructed radiances

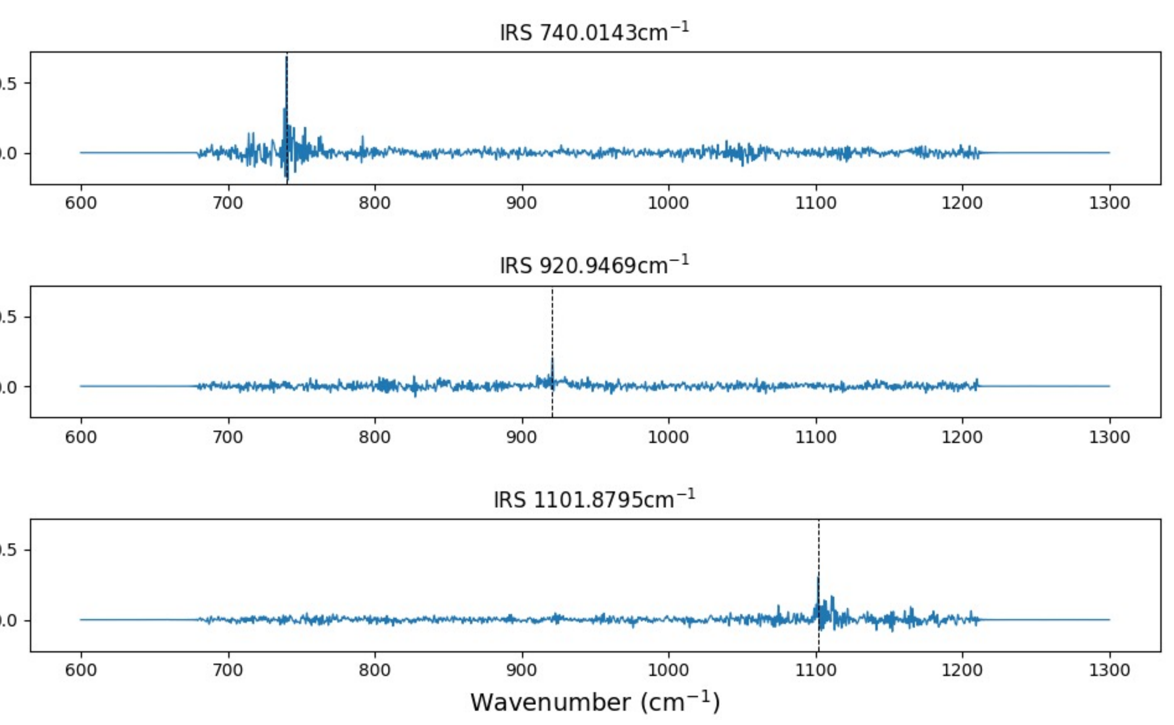
RTTOV computes optical depths (and hence radiances) quickly, having been trained on slow line-by-line (LBL) simulations. For each channel of an instrument, the spectral response function (SRF) is used to filter the LBL spectrum so it is an appropriate representation of a measured spectrum. Here, the SRF filter for all channels of an instrument is represented by the matrix **S**.

Reconstructed radiances for a given channel, computed from a reduced PC basis, implicitly contain spectral contributions quite different from those determined by the instrument's SRF. Simulating reconstructed radiances from a LBL spectrum is done as follows (having assumed that the compression/reconstruction operation does not impart a bias):

$$\mathbf{r}' = \mathbf{N}\mathbf{E}\mathbf{E}^{\mathrm{T}}\mathbf{N}^{-1}\mathbf{S}\mathbf{r}_{LBL}$$

Here, **r**' is the reconstructed radiance, **N** is the instrument noise covariance, **E** is the truncated eigenvector basis, **S** is the SRF filter and $\mathbf{r}_{\mathrm{LBL}}$ is the high spectral resolution line-by-line radiance.

It is possible to view the rows of the matrix $\mathbf{S}'=\mathbf{N}\mathbf{E}\mathbf{E}^{\mathrm{T}}\mathbf{N}^{-1}\mathbf{S}$ as an effective spectral response function for reconstructed radiances. In theory, this could be used to train RTTOV coefficients to produce simulations more consistent with reconstructed radiances, but leaving most of the rest of the assimilation chain untouched. Example rows of **S**' for three MTG-IRS channels are shown here:



Unfortunately, these SRFs are very spiky and have strong negative values, so RTTOV coefficients (non-HT-FRTC) cannot be trained from these.

Reconstruction from full spectra

Potentially, reconstructed radiances could be simulated accurately by first applying RTTOV to simulate *all channels*, and then performing the linear conversion to produce simulated reconstructed radiances.

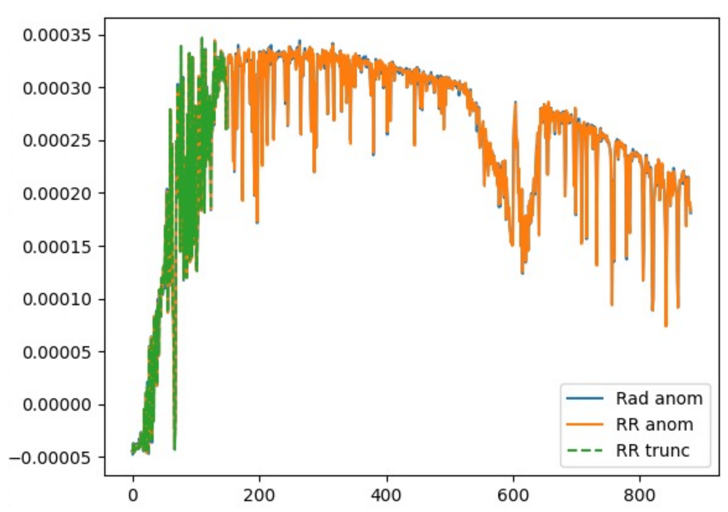
$$\mathbf{r}'_{RTTOV} = \mathbf{r}_{\mathrm{m}} + \mathbf{N}\mathbf{E}\mathbf{E}^{\mathrm{T}}\mathbf{N}^{-1}(\mathbf{r}_{RTTOV}\text{-}\mathbf{r}_{\mathrm{m}})$$

This is potentially computationally costly in an operation assimilation context, but the adjoint is trivial.

A curious result

If a spectrum of dimension *n* is compressed into *m* PC scores, the operation to reconstruct a subset of *m* radiances is *reversible* (this can be achieved by truncating **N**).

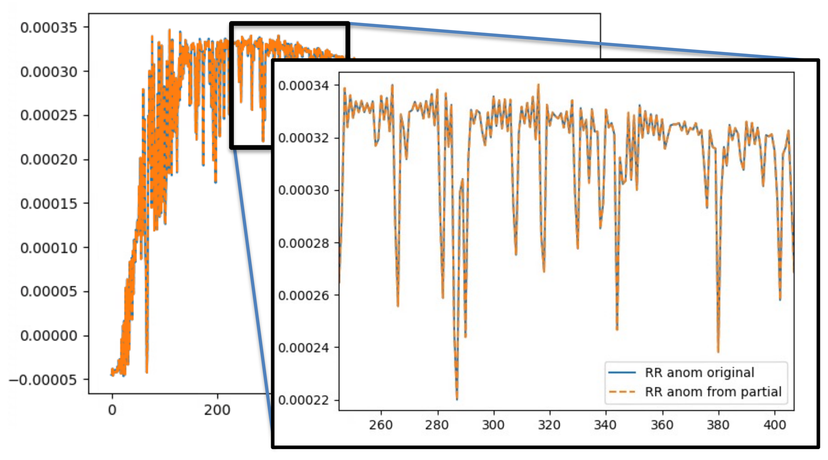
For IRS, reconstruct the first 150 channels from 150 PC scores.



The reversible nature of the rank-preserved truncated reconstruction shows that the full reconstructed radiance spectrum can be produced from a subset of *m* RR channels.

$$\mathbf{r}' = \mathbf{N}\mathbf{E}(\mathbf{N}_{trunc}\mathbf{E})^{-1}\mathbf{r}'_{trunc}$$

Is (for example) all the stratospheric information somehow present in the window channel RRs? How should we perform a channel selection based on this?



Future work

ECMWF will initially assimilate IRS data using reconstructed radiances and classical RTTOV (with observation errors derived from radiances). For IASI-NG, the initial configuration will be a channel selection very similar to IASI. The ideas presented here may be pursued later if they show promise.

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