Plans for assimilation of MTG-IRS observations at the Met Office

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Introduction

Meteosat Third Generation – InfraRed Sounder (MTG-IRS) on board MTG-S1 satellite will be the first Fourier transform hyperspectral sounder in geostationary orbit at zero degrees longitude with full disk coverage. The instrument makes use of a 2D detector acquiring 160 x 160 spectra over a "dwell". Data are acquired over two bands: LWIR (877 channels between 679.496 and 1210.011 cm^{-1}) and MWIR (1076 channels, between 1599.90822 and 2250.40041 cm^{-1}) for a total of 1953 channels.

Data from MTG-IRS are disseminated by EUMETSAT as principal component scores (PC scores), from original radiances that were "lightly" apodised (EUMETSAT, 2021) to attenuate remote side lobes of the spectral response function (SRF). However, this light apodisation causes undesirable systematic errors in the results from RTTOV fast radiative transfer model used at the Met Office to simulate radiances from satellite instruments. To prevent these errors, the Met Office makes use of the IRSPP package (NWP SAF, 2024) to apply a stronger "Hamming" apodisation on the lightly apodised observed reconstructed radiances. Each Hamming-Apodisation-On-Top-Of-Light-Apodisation (HAOTOLA) MTG-IRS radiance channel has 0.6056 cm^{-1} spectral resolution in LW and 0.6051 in MW. Dwells are grouped into 4 Local Area Coverage (LAC) zones. For LAC4 (Europe), measurements are repeated every 30 minutes. Spatial resolution at sub-satellite point at the equator is 4 km and about 8 km at ±50º N.

Thinning and channel selection

For the global model configuration we will archive the warmest brightness temperature (BT) at 925 cm^{-1} in the central 3x3 FOVs every 5x5 FOVs, with an interpixel distance of about 20±8 km at the equator. For the limited area configuration, we will instead archive the warmest BT every 2x2 FOVs, with an interpixel distance of about 16±8 km at 50º N (see Figure 1). This choice can be revisited through study of optimal correlation length with full resolution data. We will archive the HAOTOLA reconstructed radiances over the 300 channels selected in Coopmann et al. (2022) as well as the original 300 "global" PC scores to be disseminated by EUMETSAT.

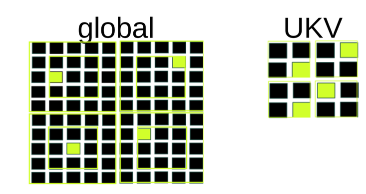

Figure 1: Thinning strategy for MTG-IRS at the Met Office for the global model (left) and the regional (UKV) configuration (right)

Assimilation of reconstructed radiances (RR)

Given a radiance vector $\mathbf{y}^o \in \mathbb{R}^m$ with m channels, it is possible to define $\mathbf{p}_s^o \equiv \mathbf{E}_s^T\mathbf{N}^{-1}(\mathbf{y}^o - \bar{\mathbf{y}}^o) \in \mathbb{R}^s$ a vector of $s < m$ principal component (PC) scores, where $\mathbf{E}_s \in \mathbb{R}^{m\times s}$ is the matrix whose columns are the eigenvectors with s largest eigenvalues, $\mathbf{N} \in \mathbb{R}^{m\times m}$ is the noise normalisation matrix and $\bar{\mathbf{y}}^o \in \mathbb{R}^m$ is the mean spectrum.

The reconstructed radiances $\tilde{\mathbf{y}}^o \in \mathbb{R}^m$ can be defined as $\tilde{\mathbf{y}}^o \equiv \mathbf{N}\mathbf{E}_s\mathbf{p}_s^o + \bar{\mathbf{y}}^o$. It follows we can write

$$\tilde{\mathbf{y}}^o = \mathbf{N}\mathbf{E}_s\mathbf{E}_s^T\mathbf{N}^{-1}(\mathbf{y}^o - \bar{\mathbf{y}}^o) + \bar{\mathbf{y}}^o = \mathbf{C}\mathbf{y}^o + (\mathbf{I} - \mathbf{C})\bar{\mathbf{y}}^o$$

where $\mathbf{C} \equiv \mathbf{N}\mathbf{E}_s\mathbf{E}_s^T\mathbf{N}^{-1} \in \mathbb{R}^{m\times m}$. We can now express $\mathbf{y}^o = H(\mathbf{x}^t) + \boldsymbol{\varepsilon}^o$ where $H(\mathbf{x}^t)$ is the observation operator (see Figure 2) applied to the true state vector $\mathbf{x}^t$ and where $\boldsymbol{\varepsilon}^o$ is the observation error vector. We can then write $\tilde{\mathbf{y}}^o = \mathbf{C}H(\mathbf{x}^t) + (\mathbf{I} - \mathbf{C})\bar{\mathbf{y}}^o + \mathbf{C}\boldsymbol{\varepsilon}^o$.

This means RR should be assimilated using $\widetilde{H}(\mathbf{x}^t) \equiv \mathbf{C}H(\mathbf{x}^t)$ as observation operator and $\widetilde{\mathbf{R}} = \mathbf{C}\mathbf{R}\mathbf{C}^T$ as observation error covariance matrix. Note that when $\mathbf{R} = \mathbf{N}^2$ we have $\widetilde{\mathbf{R}} = \mathbf{N}\mathbf{E}_s\mathbf{E}_s^T\mathbf{N}$.

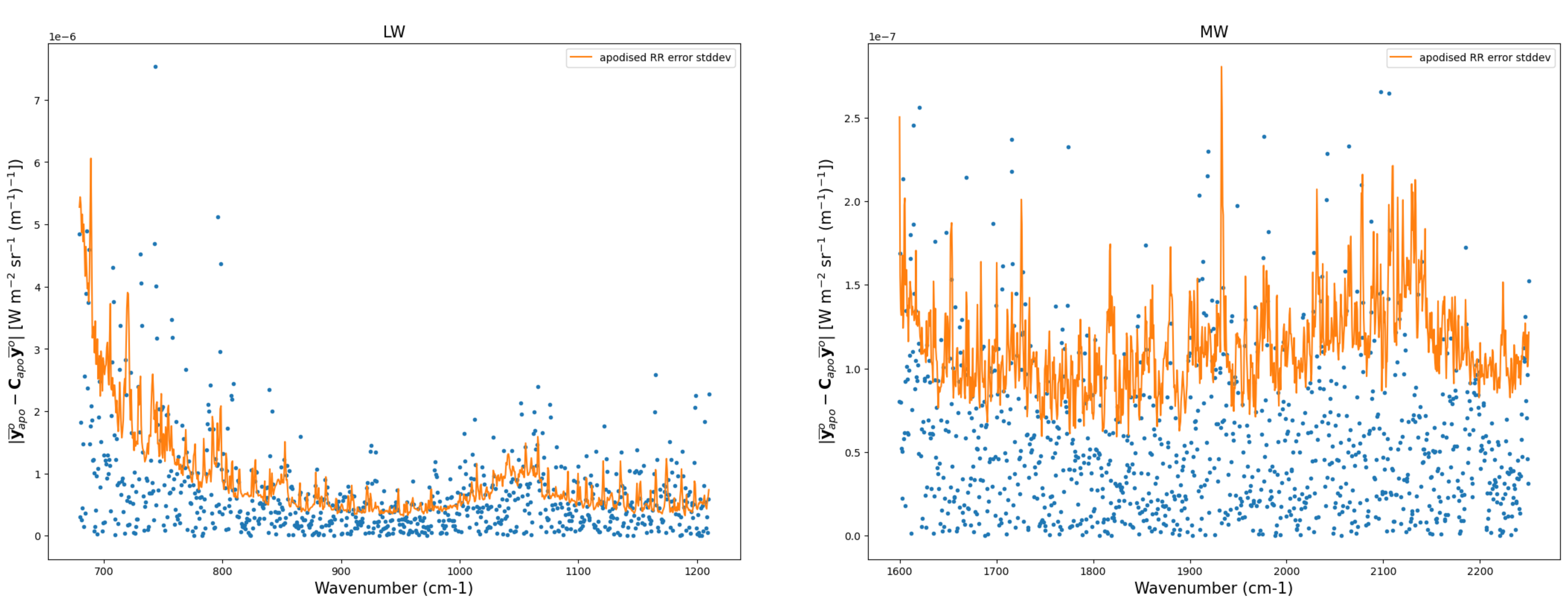

Figure 3: Absolute values of the components of $\bar{\mathbf{y}}_{\mathrm{apo}}^o - \mathbf{C}_{\mathrm{apo}}\bar{\mathbf{y}}^o$ (blue dots) and square root of diag($\mathbf{A}\mathbf{N}\mathbf{E}_s\mathbf{E}_s^T\mathbf{N}\mathbf{A}^T$) (orange solid line).

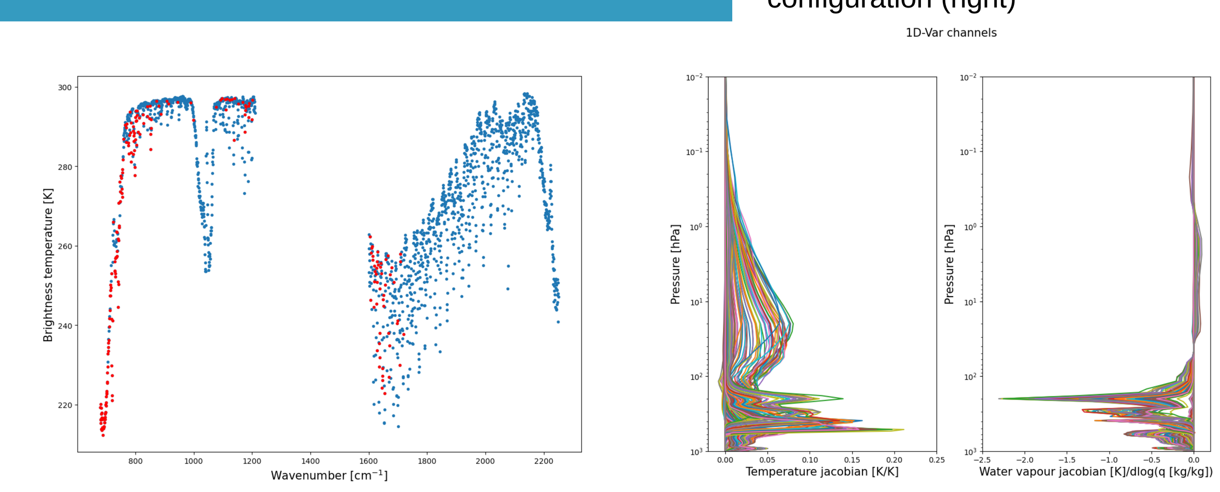

Figure 2: Brightness temperatures calculated using RTTOV and coefficients for HAOTOLA apodized MTG-IRS radiances (left) and temperature and humidity jacobians (right) for the 218 channels (highlighted in red on the left panel) used for 1D-Var retrievals

Assimilation of radiances vs. RRs

For the purpose of assimilation, we can approximate $\tilde{\mathbf{y}}^o$ with $\mathbf{y}^o$ when

$$\mathbf{0} \le \|\bar{\mathbf{y}}^o - \mathbf{C}\bar{\mathbf{y}}^o\|_2 \ll \sqrt{trace(\widetilde{\mathbf{R}})}$$

so that $\mathbf{C} \cong \mathbf{I}$. For MTG-IRS, EUMETSAT only apply a light apodisation: to simulate RRs with RTTOV we need to apply a further Hamming apodisation onto the RRs. We can define the HAOTOLA matrix $\mathbf{A}$ as $\mathbf{A}(i,i) = 0.54$, $\mathbf{A}(i,i-1) = \mathbf{A}(i,i+1) = 0.23$. If we define $\mathbf{y}_{\mathrm{apo}}^o \equiv \mathbf{A}\mathbf{y}^o$; $\tilde{\mathbf{y}}_{\mathrm{apo}}^o \equiv \mathbf{A}\tilde{\mathbf{y}}^o$; $\bar{\mathbf{y}}_{\mathrm{apo}}^o \equiv \mathbf{A}\bar{\mathbf{y}}^o$; $\mathbf{C}_{\mathrm{apo}} \equiv \mathbf{A}\mathbf{C}$ and $\widetilde{\mathbf{R}}_{\mathrm{apo}} \equiv \mathbf{A}\widetilde{\mathbf{R}}\mathbf{A}^T$ we can approximate $\tilde{\mathbf{y}}_{\mathrm{apo}}^o$ with $\mathbf{y}_{\mathrm{apo}}^o$ when

$$\mathbf{0} \le \left\|\bar{\mathbf{y}}_{\mathrm{apo}}^o - \mathbf{C}_{\mathrm{apo}}\bar{\mathbf{y}}^o\right\|_2 \ll \sqrt{trace(\widetilde{\mathbf{R}}_{\mathrm{apo}})}.$$

Figure 3 shows the absolute values of the components of $\bar{\mathbf{y}}_{\mathrm{apo}}^o - \mathbf{C}_{\mathrm{apo}}\bar{\mathbf{y}}^o$ and the standard deviation of $\widetilde{\mathbf{R}}_{\mathrm{apo}}$ when $\mathbf{R} = \mathbf{N}^2$. In this case it results $\left\|\bar{\mathbf{y}}_{\mathrm{apo}}^o - \mathbf{C}_{\mathrm{apo}}\bar{\mathbf{y}}^o\right\|_2 = 3.06\ 10^{-5}\ (\mathrm{LW}), 2.35\ 10^{-6}\ (\mathrm{MW})$ and $\sqrt{trace(\widetilde{\mathbf{R}}_{\mathrm{apo}})} = 3.70\ 10^{-5}\ (\mathrm{LW}), 3.83\ 10^{-6}\ (\mathrm{MW})$ in units of W m^{-2} sr^{-1} (m^{-1})$^{-1}$.

This indicates that when only instrument errors are considered, the RR should be assimilated with $\mathbf{C}_{\mathrm{apo}}H(\mathbf{x}^t)$ as observation operator and $\widetilde{\mathbf{R}}_{\mathrm{apo}}$ as observation error covariance matrix. However, when additional systematic and representation error components are accounted for it may be safe to assimilate RRs as if they were ordinary radiances.

Assimilation of MTG-IRS test data

The Met Office is replacing the currently-operational Observation Processing System (OPS) with the JEDI-based Observation Processing Application (JOPA), a system to read, process and quality control both direct and remotely sensed observations based on the Joint Effort for Data assimilation Integration (JEDI) framework. Figure 4 shows the quality-controlled observation minus short-range forecast BTs for MTG-IRS channel 68 from JOPA (left panel) for the six-hourly cycle centred at 1200 UTC on 24th June 2021 that are passed to VAR to be assimilated using the hybrid 4D-Var data assimilation system. The mid and right panels of Figure 4 show the resulting temperature and humidity analysis increments, respectively, generated by VAR. Note that for these assimilation experiments we considered MTG-IRS RRs as if they were ordinary radiances. As observation error covariance we used the square of the noise normalization matrix with radiance values converted into BT units by using the BT corresponding to the mean spectrum radiance. Furthermore, an additional fraction of the difference between MTG-IRS and IASI variances as used in JOPA were added to the MTG-IRS variances when IASI variances were larger, to account for additional systematic and representation errors.

Assimilation results with test data are as expected and we are looking forward to assess MTG-IRS real data when available.

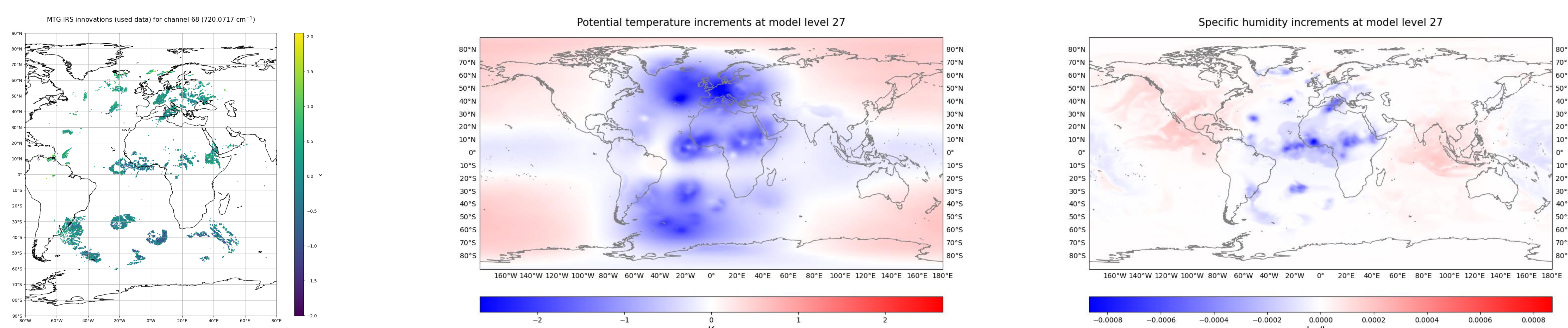

Figure 4: MTG-IRS innovations for channel 68 (centred at 720.07 cm^{-1}, left panel) and temperature (mid panel) and humidity (right panel) analysis increments on model level 27 (5.22 km above mean sea level pressure)

References

Coopmann, O., Fourrié, N. & Guidard, V.(2022) Analysis of MTG-IRS observations and general channel selection for numerical weather prediction models. Quarterly Journal of the Royal Meteorological Society, 148(745), 1864–1885. Available from: https://doi.org/10.1002/qj.4282

EUMETSAT (2021) MTG-IRS Level 1 Algorithm Theoretical Basis Document. Document Number: EUM/RSP/TEN/16/878765, Issue: v2 e-signed. Available from: https://user.eumetsat.int/s3/eup-strapi-media/MTG_IRS_Level_1_Algorithm_Theoretical_Basis_Document_v2_7b42d5efaa.pdf

NWP SAF (2024) IRSPP User Manual. Document ID: NWPSAF-MO-UD-053, Version 1.4. Available from: https://nwp-saf.eumetsat.int/site/download/documentation/irspp/NWPSAF-MO-UD-053-IRSPP_User_Manual.pdf

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