Met Office

Fabien Carminati

Channel selection for the assimilation of CrIS and HIRAS at full spectral resolution

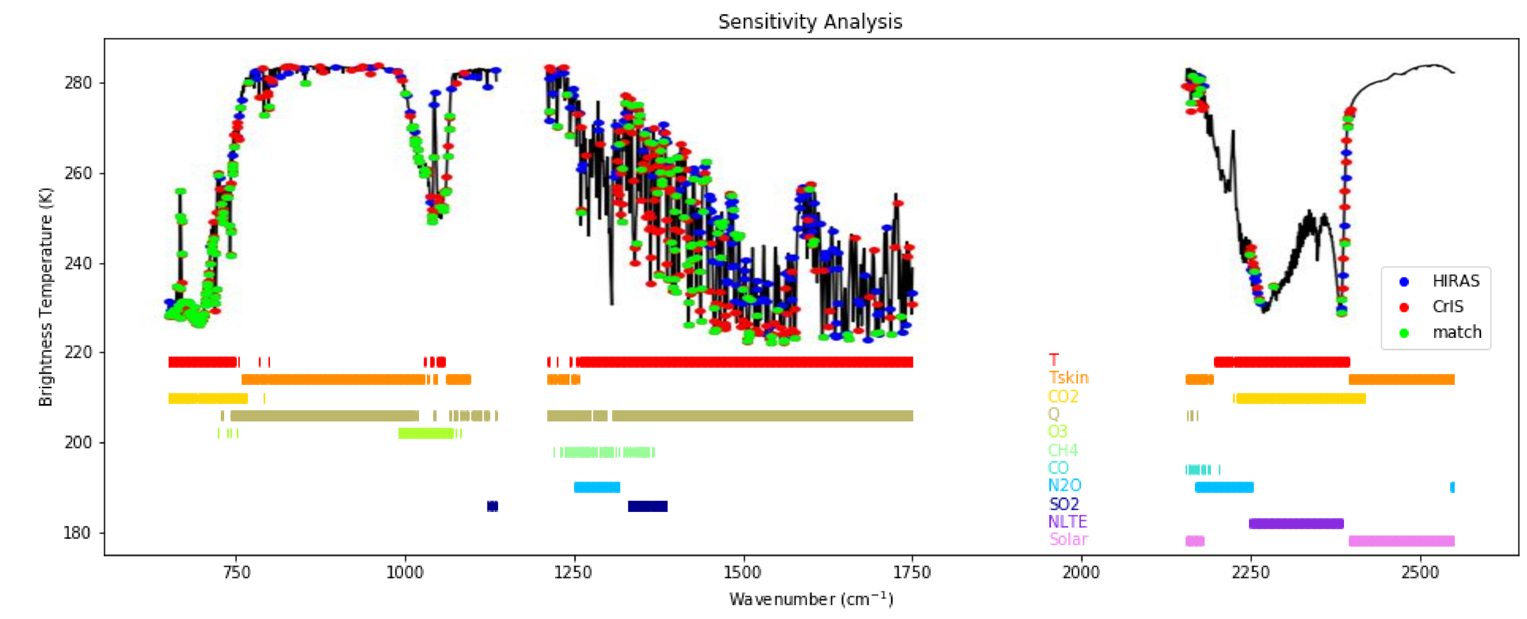
Briefly,

Since May 2020, NOAA have been distributing JPSS CrIS observations at full spectral resolution (FSR) exclusively along with the observations of NOAA 20 CrIS already provided at FSR since launch. The Met Office, that uses both instruments operationally in its NWP global system, has until now adopted a conservative approach in the data usage by converting the incoming data to normal spectral resolution (NSR) similar to that originally used for JPSS CrIS. This work has been aimed at investigating the potential benefit of exploiting these data in their native FSR version. The investigation has also been extended to the potential exploitation of FY-3D HIRAS, an instrument highly similar to CrIS that, like its U.S. counterpart, is also distributed at FSR by CMA.

Before we start,

The parts of the spectrum providing the most valuable information for NWP applications needed to be identified. Brightness temperatures have been simulated from 80 diverse profiles at nadir and at 40° zenith angle, and with 15% perturbation applied to O_3, CO_2, N_2O, CO, CH_4, and SO_2, 10% to specific humidity, 1K to temperature and skin temperature, and with and without correction for solar radiation and NLTE (Fig 1).

A channel is retained if the brightness temperature changes by less than 10 K with/without solar radiation and NLTE correction, and by less than 0.8 K when CH_4, CO, or N_2O are perturbed. In total, 1547 CrIS channels and 1611 HIRAS channels are available.



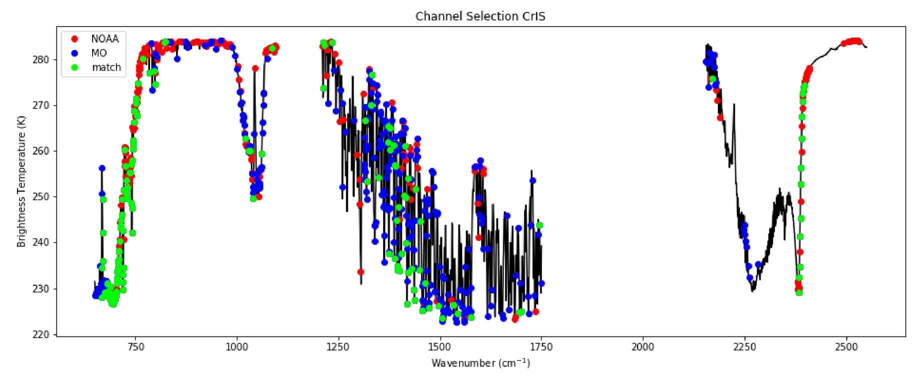


Fig 1 (Top): Simulated CrIS spectrum showing channel sensitivities. The new channel selection is shown in red for CrIS, in blue for HIRAS, and common channels in green.

Fig 2 (Bottom): Comparison of CrIS new channel selection (blue) with the NOAA selection (red). Common channels are shown in green.

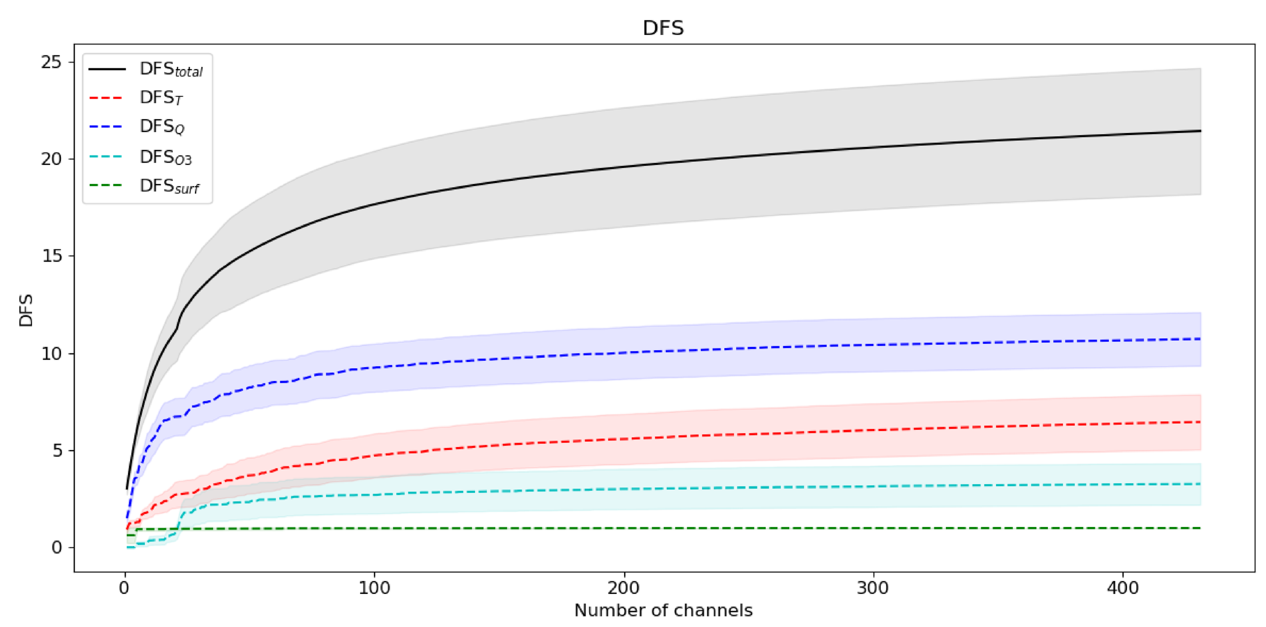


Fig 3: Mean total degree of freedom after each iteration of CrIS channel selection along with temperature, humidity, ozone, and surface components of the total. The shading shows the standard deviation.

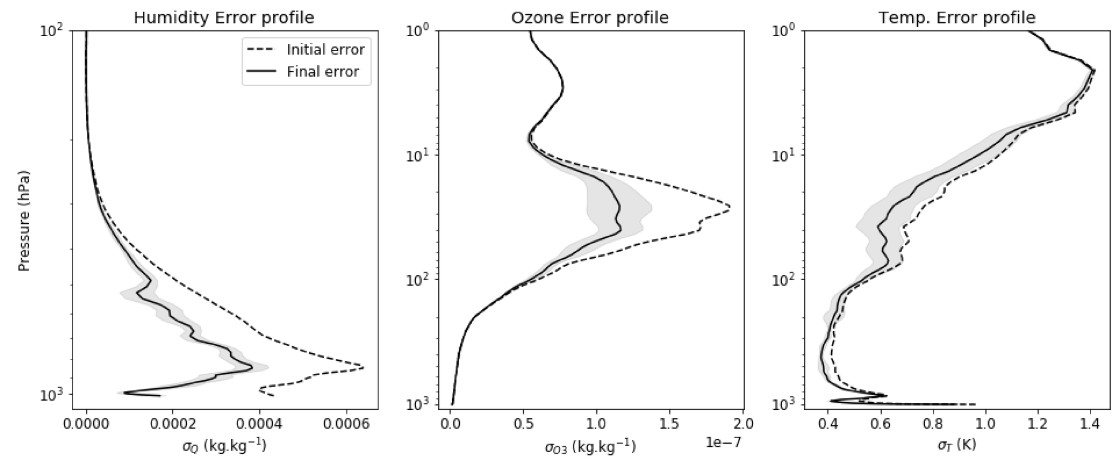


Fig 4: Analysis error standard deviation in humidity, ozone, and temperature after the first and last iteration of CrIS channel selection. The shading shows the standard deviation.

The selection,

The degree of freedom for signal (DFS, Fig 3) is used to isolate an optimal channel subset providing the maximum information content across a range of atmospheric profiles, as follows: $\mathbf{DFS} = \mathrm{Tr}(\mathbf{I} - \mathbf{AB}^{-1})$

where $\mathbf{I}$ is the identity matrix, $\mathbf{A}$ the analysis error covariance matrix. A is defined such as: $\mathbf{A} = \left(\mathbf{B}^{-1} + \mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{H}\right)^{-1}$

with $\mathbf{H}$ the Jacobian matrix. The background error covariance $\mathbf{B}$ has been derived from the ECMWF model using a climatological correlation and a global sample of error profiles. The observation error covariance $\mathbf{R}$ has been estimated with a posteriori consistency diagnostic of the background and analysis departures (Desroziers et al., 2005). $\mathbf{R}$ is reconditioned with the ridge regression method (Weston et al., 2014).

The information gained from the addition of new channels drives the error reduction in $\mathbf{A}$. With 431 selected channels, the information content reduces the error in the analysis by to 79, 39, and 22% for humidity, ozone, temperature, respectively (Fig 4). CrIS and HIRAS have 49 % of selected channels in common (Fig 1). For CrIS, this new channel selection has 35% channels in common with the selection provided by NOAA (Fig 2).

Let's test it,

Assimilation experiments in the Met Office global system (UM N320L70 VAR N108/N216L70 and N216L70 44-member ensemble) have been conducted to evaluate the impact of using FSR CrIS observations over NSR and determinate which selection is the most performant. In line with operational practice, channels affected by large model uncertainties have been omitted so that only 279 channels (NWP-based) and 308 channels (NOAA) have been assimilated.

The overall RMSE calculated across diverse forecast variables and lead times against ECMWF analyses (Fig 5) improves by 0.47% (NOAA) and by 0.37% (NWP-based). The background fit to observations (Fig 6) shows a clear advantage to the NWP-based selection. Most of the sounding channels of independent microwave and infrared instruments degrade by up to 1.5% with the NOAA selection, but improve by up to 0.8% with the NWP-based selection. The assimilation of HIRAS observations (305 assimilated channels), is detrimental to the system with degradations of both forecast variables RMSE and background fit to observations.

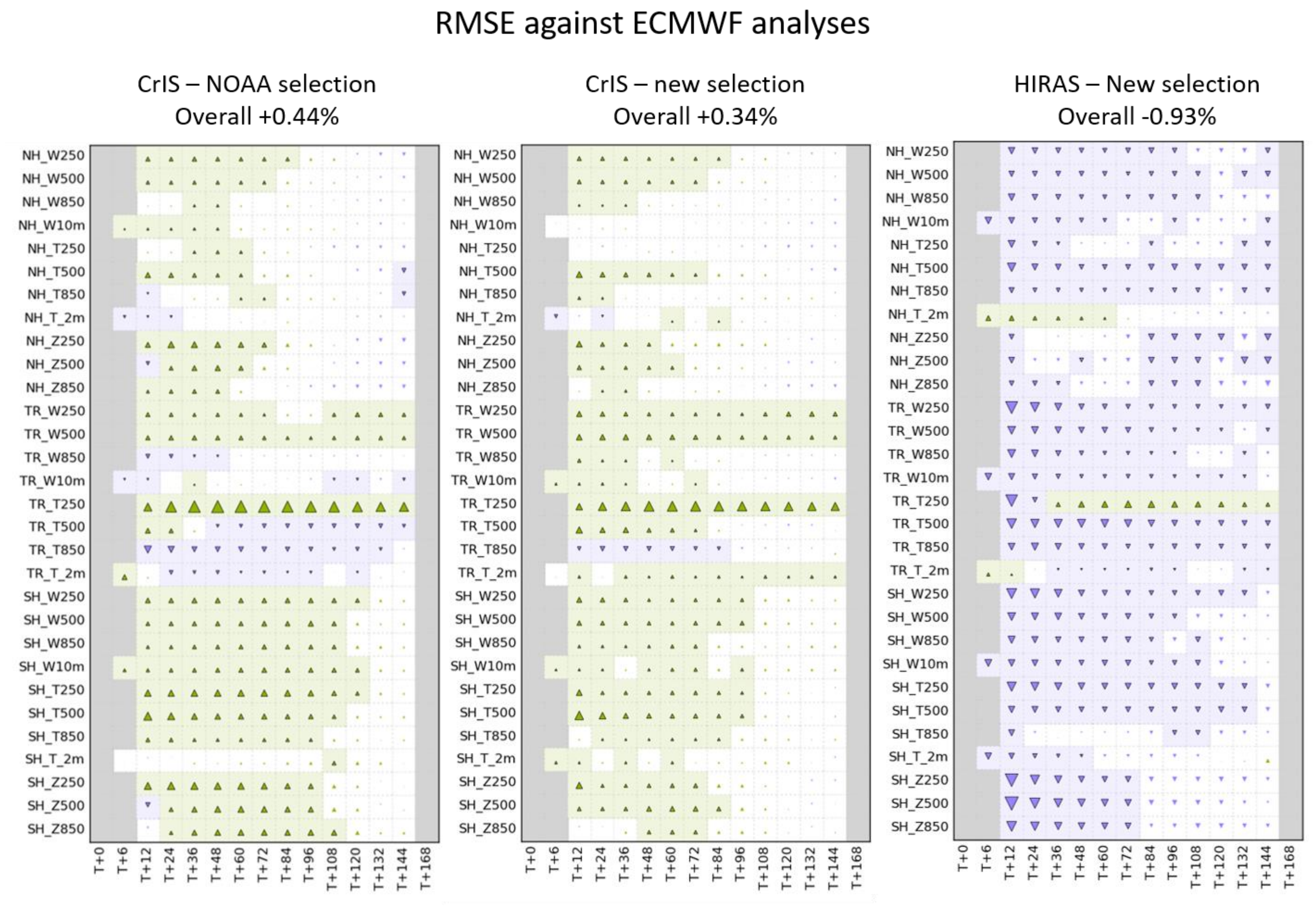


Fig 5: Change in RMSE against ECMWF analyses for key atmospheric variables up to T+168. Green triangles indicate a reduction of RMSE, purple an increase. Significance is given by shading.

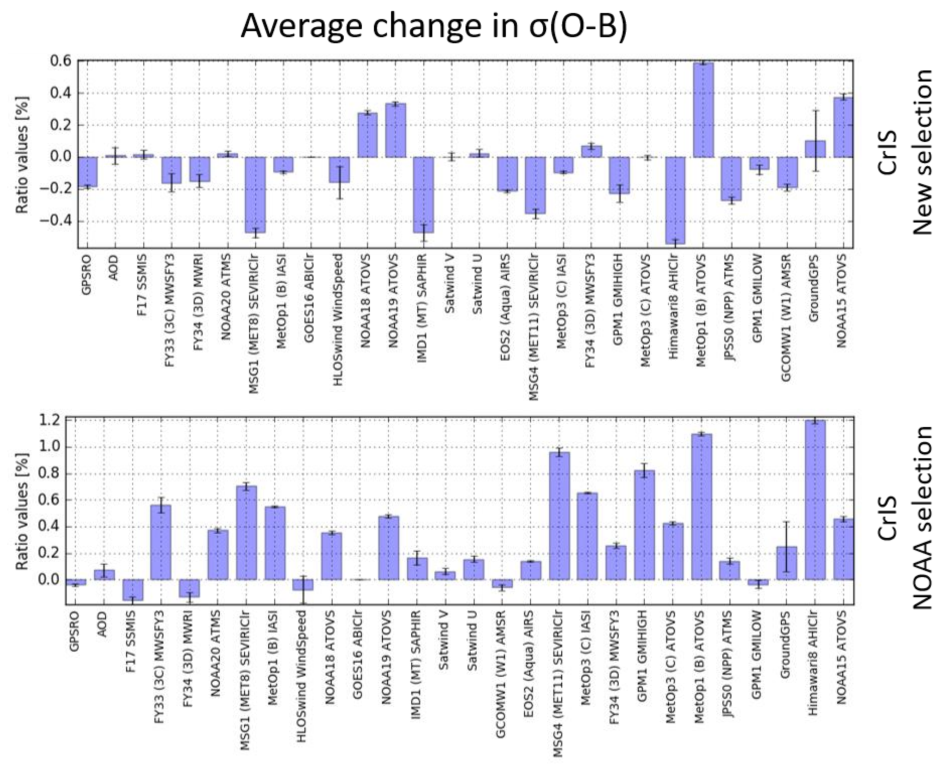


Fig 6:Change in background fit to observations expressed as the mean ratio of the standard deviation in background departure.

Bottom line,

The various metrics used in this study show that the assimilation of CrIS FSR in the Met Office NWP system has a beneficial impact compared to the operational NSR setup and, while the NOAA channel selection yield better overall forecast verification against analyses and observations, the NWP-based channel selection outperforms the NOAA selection in the verification against independent instruments. No benefit were found in the assimilation of HIRAS observations.

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom

+44 (0) 3301 350824

fabien.carminati@metoffice.gov.uk

@fab_carminati

Desroziers et al., 2005, https://doi.org/10.1256/qj.05.108

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