Multi-year changes in IASI LST biases and inter-channel error covariances seen in the Met Office Global NWP System

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0. Abstract

There has been recent progress in the Met Office that has led to the introduction of weakly coupled ocean-atmospheric DA (Data Assimilation) into the Global Model. In addition, the model has been updated from GA7.2.1GL8 to GA8GL9 with associated changes to the drag scheme, the roughness over and fractional vegetation cover land surfaces, and convection. It is anticipated that these changes in the model have altered some observational representation and background error characteristics that affect the assimilation of radiances. This poster will present results of an analysis of the last five years of IR skin temperature retrievals using IASI and an analysis of changes in the IASI inter-channel observation error correlations from 2013 to present.

1. LST Biases Motivation:

Predicting the land surface temperature (LST) within an numerical weather prediction (NWP) suite is challenging. Within the NWP DA scheme used at the Met Office, the 6 hour forecast of LST is taken as the background for 1D-Var retrievals and it is assumed unbiased and normally distributed. Figure 1 shows the LST bias (retrieval minus background) for the Global Model in April 2022. These systematic errors are largest in late spring and early summer and have magnitudes of 5 to 15 K dependent on model resolution. The set of observations which have passed quality control and convergence in the 1D-Var are passed to 4DVar where this retrieved LST is used in radiative transfer calculations. The large uncertainties in the quality of LST simulations has meant that radiances are assimilated over land only for channels that peak above 400 hPa and no IASI data is assimilated over land surfaces 1000 m or greater above sea level. Such limitations could be relaxed with a less-biased LST forecast allowing the assimilation of middle to lower tropospheric sounding channels. This work attempts to quantify and identify the sources of these uncertainties.

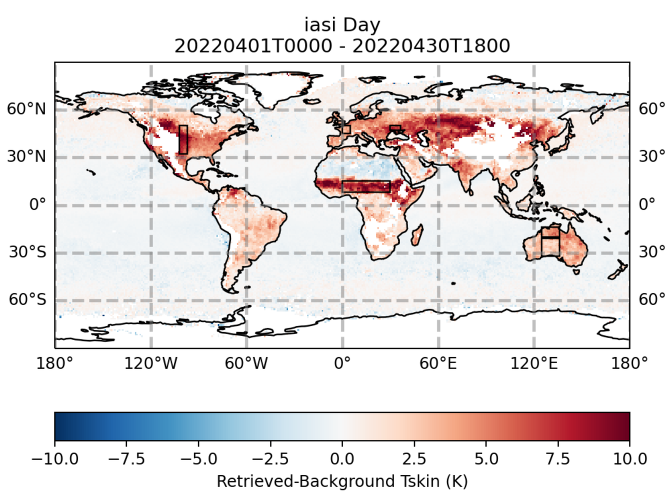

Figure 1: IASI retrievals compared to 6 hour forecast skin temperatures from the Met Office operational global NWP system. Note the regions of interest outlined by boxes in the Great Plains, the Sahel, and in Australia.

2. LST Biases Method:

Operational 1D-Var retrievals of LST for assimilated IASI radiances and their equivalent model states have been retrieved from the operational archive from Jan 2016 to Feb 2023. Only results with retrieved cloud fraction less than 0.02 are presented.

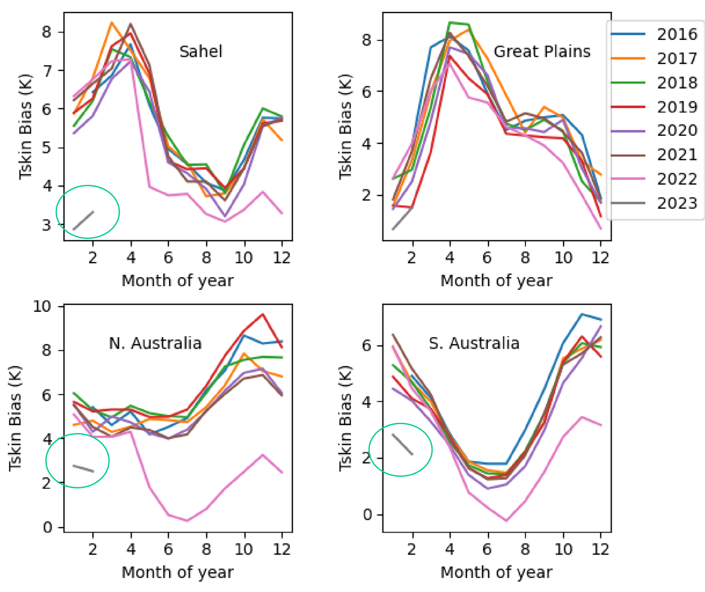

Figure2: Annual cycles of LST retrieval bias at four regions of interest for 2016 to 2023. Green ovals to emphasize continued reductions in bias during early 2023.

3. LST Biases Results:

Figure 1 shows retrieved-background LST (R-B) bias for a selected month when the biases over the Great Plains and the Sahel are maximal. Similar patterns occur in the NH Spring of all years since 2012. Figures 2 and 3 focus on the annual cycles and time series of R-B for the four areas of interest outlined in Figure 1. For all these areas except the Great Plains, there is a significant reduction in R-B LST bias. Note the reductions can be seen in the first two months of 2023. For all four areas there seems to be a change in the pattern that is brought on with the introduction of the most recent PS45 package of changes to our operational suite denoted by the vertical dashed line in May 2022. The other previous changes (denoted by vertical dashed lines) seem to have lead to much less significant changes in the annual cycle of LST bias at these four sites.

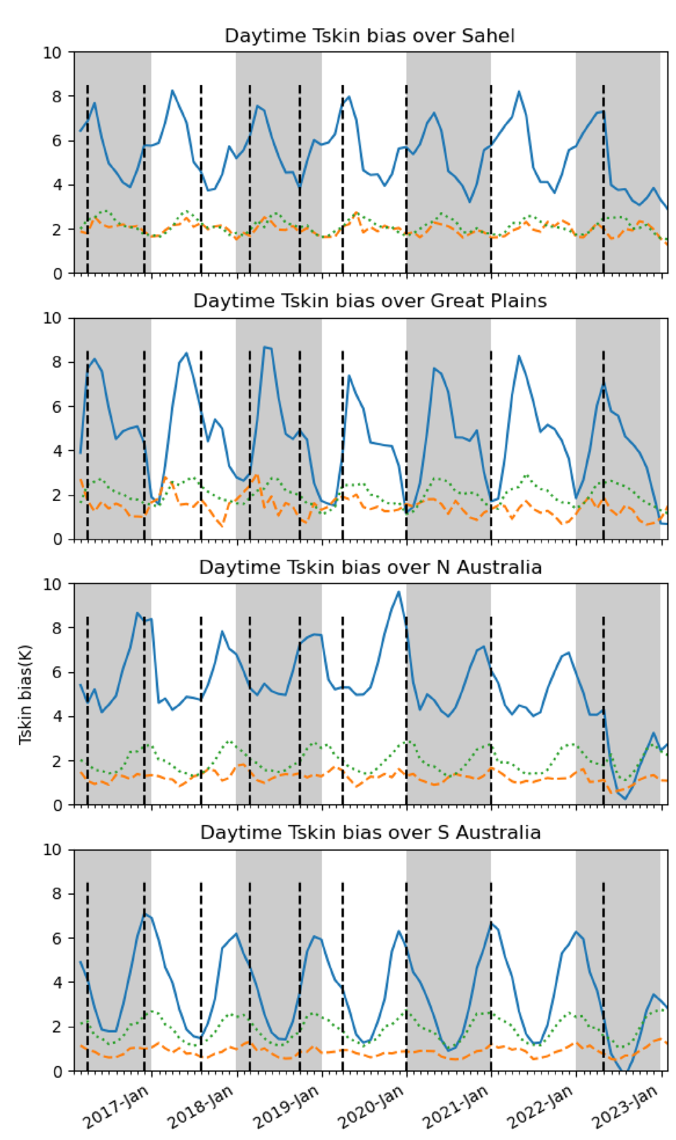

Figure3: Time series of LST retrieval bias at four regions of interest for 2016 through Feb 2023.

4. LST Biases Discussion:

Attributing the improvements seen in LST bias seen in these areas is tricky. There were numerous changes included in PS45. Discussions have focussed on the impact of increases in the roughness lengths of vegetation and increases in the fractional cover of vegetation types. Examination of the differences in LST bias between July 2022 and July 2023 and between Feb 2022 and Feb 2023 along with the changes in surface cover show that the areas with large LST bias changes were also areas where there were changes in the cover classification brought in as part of PS45. This analysis seems to show that the reduced bias is associated with a decreasing surface roughness for heat and a resulting increase in skin temperature.

5. LST Biases Next Steps:

- Continue to monitor LST bias within the operational suite.
- Investigate use of lower-peaking channels in right conditions.
- Push to have LST bias included in model evaluation suite so each new change is evaluated for impact on LST bias.
- Work internally to improve our modelled LST.

6. R matrix Motivation

The investigation of the changes in the IASI interchannel error covariance matrices (**R**) with time is motivated by the fact that we have just undergone a set of relatively major model and DA changes with PS45 in May 2022 and we plan to go operational with an entirely new model LFRic in a couple of years. The current operational **R** was diagnosed from 2012 data, and there have been many changes since then including a major resolution change, a major reformulation of the background error covariances, the introduction of many new instruments and the adoption of variational bias correction for radiance assimilation.

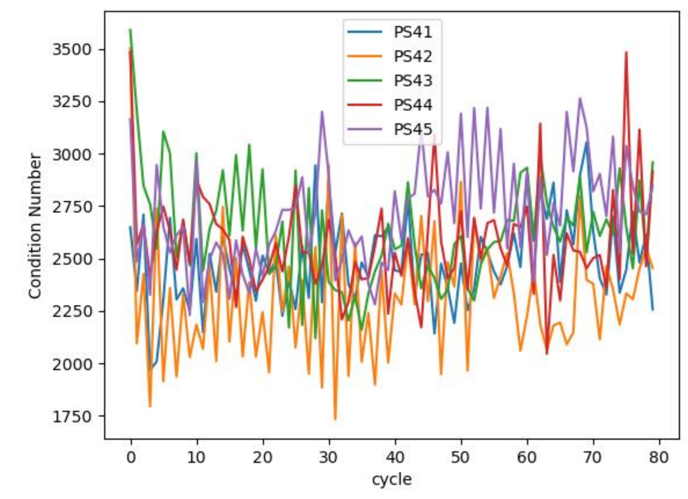

Figure4: Condition number of raw R-matrices during 80 cycles used for each PS.

7. R matrix Methods

This work draws heavily on Weston et al (2014) (W14) which describes the production of Met Office's current **R**. First, Desroziers et al (2005) is applied to eighty 6hr cycles from five versions of the Met Office Global NWP System starting with PS41 (Sept 2018) and ending with PS45 (May 2022).

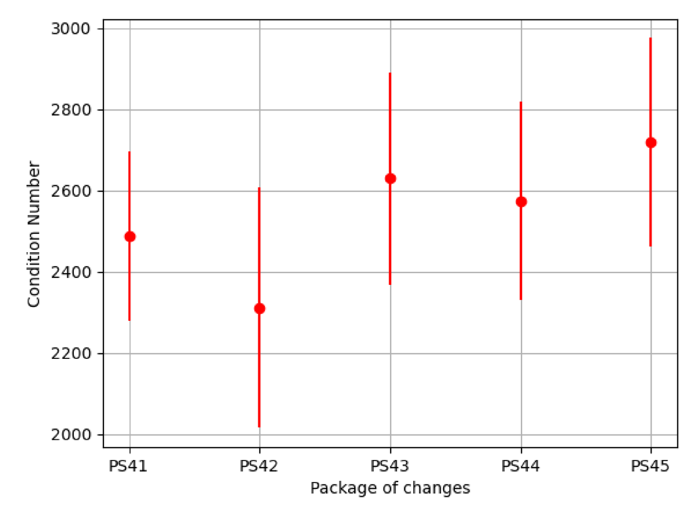

Figure5: Mean condition number of 80 raw R-matrices for diagnosed for each PS. Error bars show the standard deviations of the cond num.

8. R matrix Results

Figures 4 and 5 show the variability and mean values of the condition number of the raw **R** from the eighty cycles sampled for each PS. There are significant differences in the mean **R** for PS42 and PS45, but there is a good deal of variability within the cycle **R** for each PS. It is uncertain whether the within-PS variation shown here are due to changes in the model/DA or due to the weather conditions of the periods sampled. Note that the condition numbers here are all much higher than the value of 1956.6 given in W14 suggesting that the representation error has risen over the last decade.

The raw R-matrices need to be conditioned in order for them to be used in our DA system. This is done by first producing an average R-matrix for each PS. Then an eigenvalue decomposition is performed on these average R-matrices. Finally, all of the eigenvalues are incremented by an amount calculated with (9) of W14 such that a target condition number is achieved. Figure 6 shows the impact on the diagonal of the R-matrix of such conditioning to a target condition number of 64.5 for each PS. Matrices with higher initial condition numbers need larger increases in their diagonals to achieve the target condition number. Figure 7 compares the conditioned covariances diagnosed from PS45 with those used in Met Office Operations which were the product of W14 and are based on data from a period more than 10 years earlier. There is a noticeable increase in the covariances in the new matrix relative to the operational one.

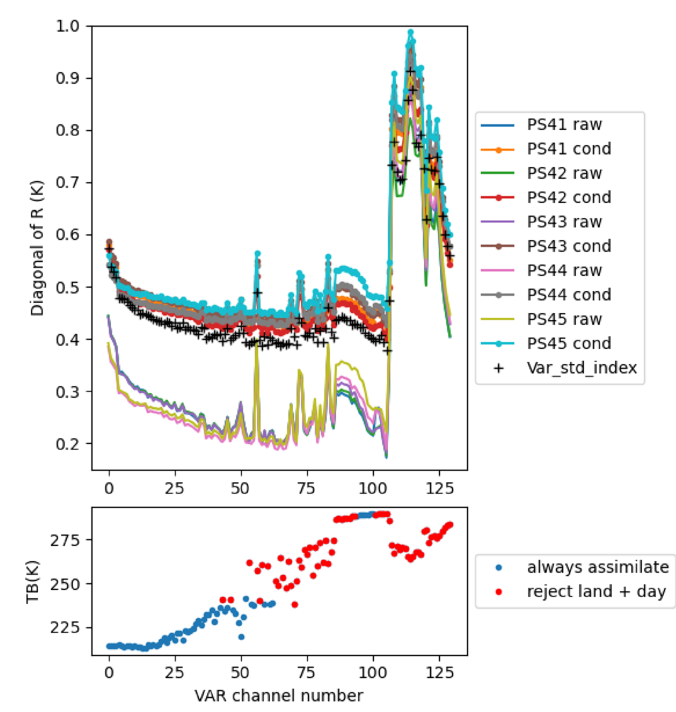

Figure6: (top panel) R-matrix diagonal elements for each PS before and after conditioning to a target condition number of 64.5. Operational values used in VAR are shown in black. (bottom panel) Typical observed brightness temperature spectrum.

9. R-matrix Conclusions:

- The R-matrix is sensitive to the period over which it is diagnosed both due to changes in the weather (see Fig. 4), potentially due to changes in the instrument itself, and due to changes the model/DA system being used.
- The R-matrix currently in operational use within the Met Office appears to be sub-optimal; proof will need to await performance in NWP trials with R-matrices diagnosed from more recent data.

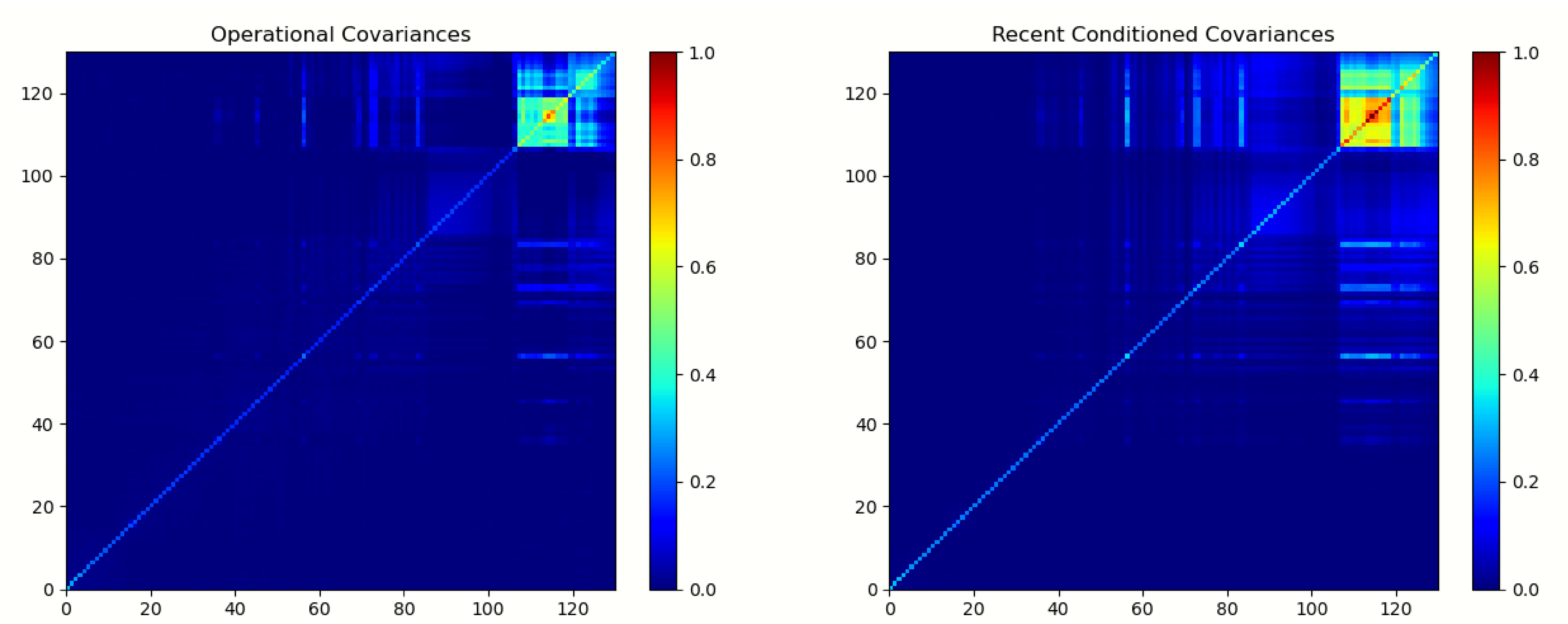

Figure7: Operational and PS45 R-matrices of covariances after conditioning to a target condition number of 64.5.

References:

Collard AD. 2007. Selection of IASI channels for use in numerical weather prediction. *Q. J. R. Meteorol. Soc.* 133: 1977–1991.

Desroziers G, Berre L, Chapnik B, Poli P. 2005. Diagnosis of observation, background and analysis-error statistics in observation space. *Q. J. R. Meteorol. Soc.* **131**: 3385–3396.

Weston P, Bell W, Eyre J. 2014. Accounting for correlated error in the assimilation of high-resolution sounder data. *Q. J. R. Meteorol. Soc.* 140: 2420–2429.

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