The rise and rise of GNSS-RO

Met Office

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Operational GNSS-RO Impact

The number of GNSS Radio Occultation observations has increased rapidly since 2019 from **~2000 occultations / day** to **~12000 occultations / day** currently. New data sources include COSMIC-2, Sentinel-6 and data from commercial providers (Spire, PlanetIQ).

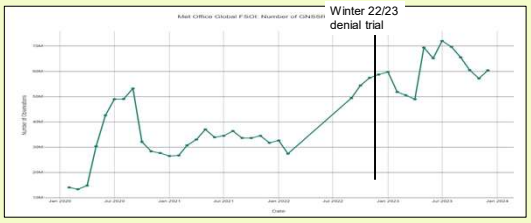

Figure 1: Time series showing the number of GNSS-RO observations assimilated per month.

We see a corresponding improvement to the Forecast Sensitivity to Observations Impact overtime. FSOI tends to under-estimate GNSS-RO impact due to the short-range tropospheric focus.

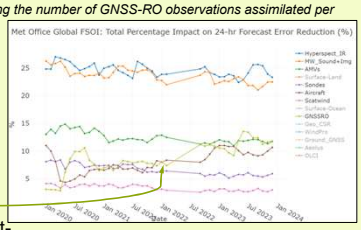

Figure 2: Time series of FSOI since January 2020. Note the increase in contribution from GNSS-RO in mustard green. (Figure courtesy of James Cotton).

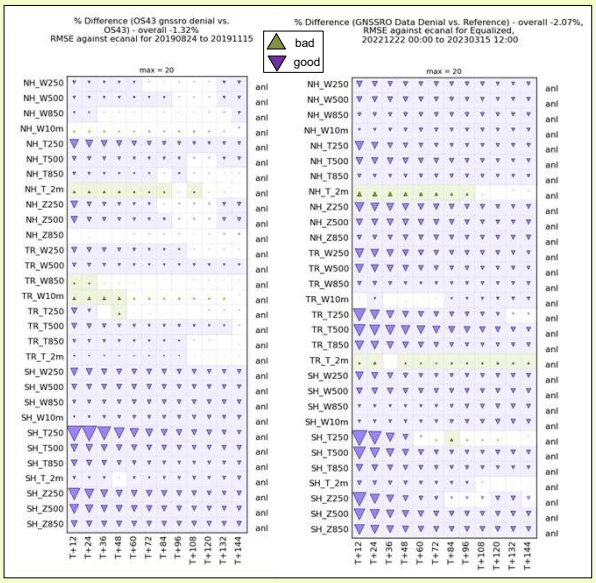

Figure 3: Met Office scorecards showing the forecast skill evaluation against ECMWF analyses for GNSS-RO data denial experiments in (left) Autumn 2019 and (right) Winter 2022/23.

Comparing data denial studies from Autumn 2019 and Winter 2022/23 (Figure 3) shows a marked increase in forecast skill from GNSS-RO. The mean RMSE improvement for the selected forecast variables and lead times has improved

2019 **1.3 %** → 2022/23 **2.07 %**

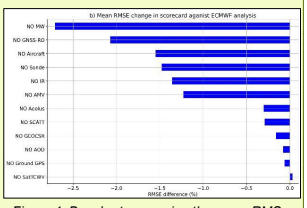

Figure 4: Bar chart comparing the mean RMS improvement for a range of data denial trials for Winter 2022/23, verified against ECMWF analyses. (Figure courtesy of Nahidul Samrat and Brett Candy).

GNSS-RO is now the second most impactful observation type in the Met Office Global model (after microwave radiances).

GNSS-RO as an anchor

Experiment	RO assimilated ?	RO available for VarBC?
Control	Yes	Yes
RO denial trial	No	No
RO denial but VarBC coefficients taken from Control	No	Yes
As control but VarBC coefficients taken from RO denial trial	Yes	No

The role of GNSS-RO for anchoring the radiance variational bias correction (VarBC) has been explored through several experiments.

We will focus on the comparisons between these two trials

Comparing VarBC coefficients with and without GNSS-RO - there are marked changes for some channels suggesting **a significant impact of RO as an anchor**. These changes are bigger than in the equivalent sonde data denials.

What is the impact?

Mostly the trial using GNSS-RO for VarBC shows neutral or improved fits to the satellite radiances.

Figure 5 shows the change in standard deviation in the background departures for NOAA-20 ATMS and Metop-B IASI.

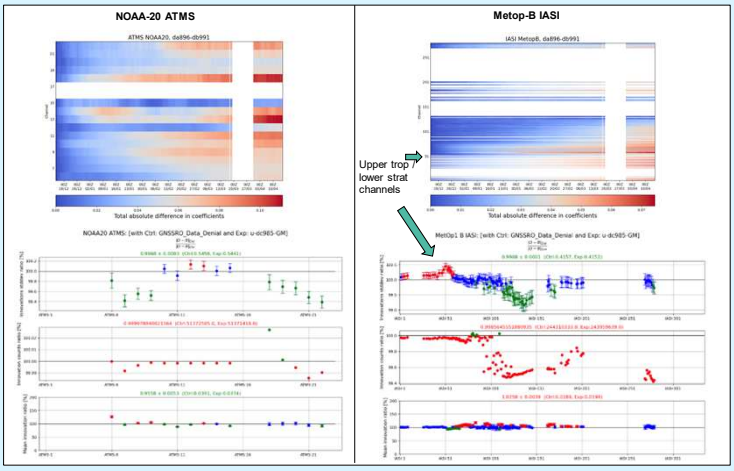

Figure 5: (Top) Comparisons of the VarBC coefficients from trials with and without GNSS-RO in the assimilation for NOAA-20 ATMS and Metop-B IASI (Figures courtesy of Fabien Carminati). (Bottom) The change in fit to the same instruments when VarBC coefficients are taken from a trial assimilating GNSS-RO compared to one without.

Upper troposphere / lower stratosphere hyperspectral IR channels were an exception with a significant increase in standard deviation in the background departures.

There are some encouraging improvements in forecast skill (Figure 6) when including GNSS-RO for VarBC.
Positive impacts can be seen across the Northern and Southern Hemispheres and the Tropics.

Most notably these improvements are seen in:
Tropical temperatures at all lead times.
Extra tropics high-level temperatures at short range.

The Southern Hemisphere sees some very small detriment in:
Low level winds.

The results, overall, are modest and a bit mixed, positive throughout the Tropics and high level temperatures and negative impacts on the high-level height fields.

Results indicate that GNSS-RO is important for VarBC but the main impact comes from the direct assimilation of the observations.

Further investigations are underway to understand the results.

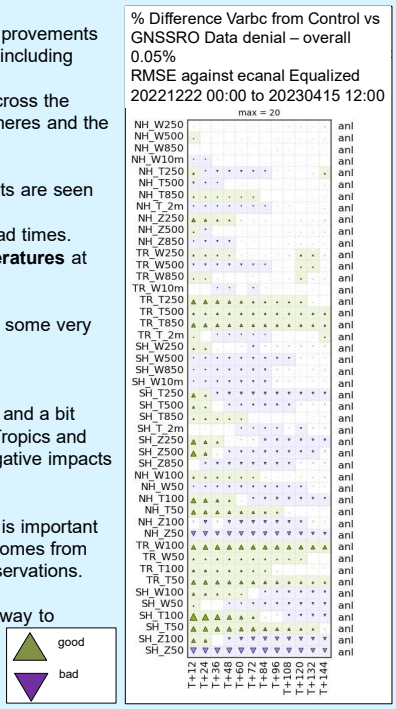

Figure 6: Met Office scorecard showing the forecast skill evaluation against ECMWF analyses for the GNSS-RO denial trial using RO for VarBC compared to the normal GNSS-RO denial trial.

Conclusion

The number of GNSS-RO observations has increased significantly since 2019.
By denying the use of GNSS-RO in the NWP we were able to see the large impact which GNSS-RO has on the system. Comparing to other observation types GNSS-RO is now the second most impactful observation in the Met Office Global model.
Significant changes to VarBC coefficients between the GNSS-RO data denial and control indicate the impact of GNSS-RO as an anchor observation. The direct assimilation of GNSS-RO is very important.

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