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METEOROLOGY

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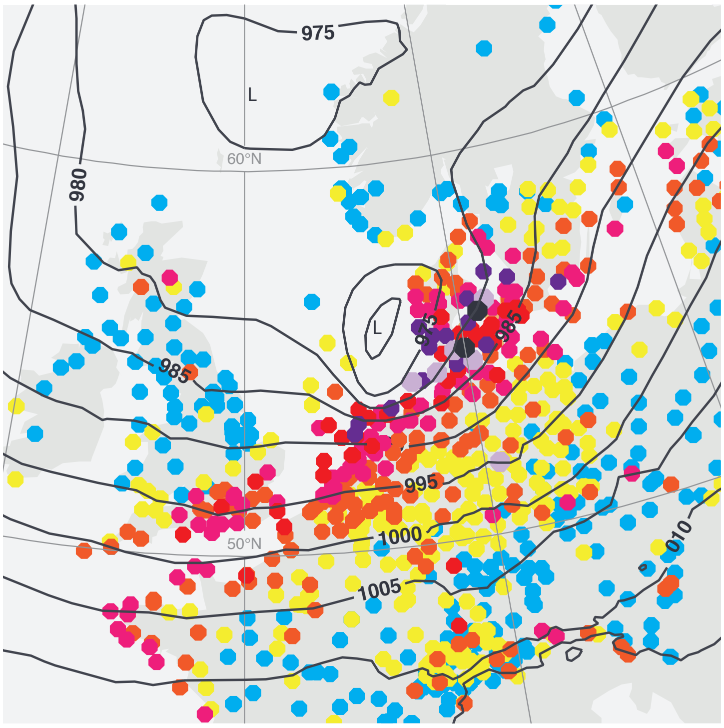

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Impact of the Metop satellites in the ECMWF system

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Recent experiments performed by the satellite section have highlighted the importance of the European Metop-A and Metop-B satellites in the ECMWF Integrated Forecasting System (IFS). Most significantly, the new results show that the combined impact of both Metop-A and Metop-B is superior to assimilating just the instruments on Metop-A. These results are important because they support the case for maintaining both Metop satellites in tandem for as long as possible.

The Metop-A and Metop-B satellites were launched on 19 October 2006 and on 17 September 2012, respectively. The satellites have the same mid-morning orbit, but are separated by 173.8 degrees in their orbital plane, leading to a 49 minute temporal separation. Metop-B is now formally the operational satellite, but Metop-A continues to provide a range of important measurements for operational NWP. The Metop payload includes the following meteorological instruments, providing temperature, moisture and lower level wind information:

- The microwave sounders AMSU-A and MHS.
- The infrared sounder, HIRS.
- The advanced infrared sounder, IASI.
- The radio occultation instrument, GRAS.
- The advanced scatterometer, ASCAT.

In operations ECMWF currently assimilates all of these instruments on Metop-A, and AMSU-A, MHS, GRAS and ASCAT from Metop-B. The operational assimilation of Metop-B IASI is being assessed.

In addition, the Metop satellites include the AVHRR high-resolution imager, which can also be used to retrieve atmospheric motion vector wind information, and GOME-2 for observing ozone. However, these instruments are not considered in this study because they are not currently assimilated operationally at ECMWF.

It should be emphasised that the AMSU-A, MHS and HIRS sounders, which form the ATOVS system, remain important for NWP, despite the introduction of new, more sophisticated instruments. AMSU-A, in particular, is still considered one of the most important systems, and the assimilation of new AMSU-A instruments generally still has a clear positive impact on forecasts.

Although the assessment of the impact of the individual instruments on a satellite is a routine activity within ECMWF, usually conducted prior to operational assimilation of the data, it is much rarer to subsequently investigate the combined impact of an entire satellite. The experiments for this Metop study cover an extended 144 day period, from 1 February 2013 to 24 June 2013. They use 12-hour 4DVAR with the current operational IFS cycle, Cy38r2, with a horizontal resolution of T511, and 137 levels in the vertical. The following configurations have been tested:

- Baseline: All observations assimilated operationally during this period except the measurements from Metop-A and Metop-B.
- Baseline plus Metop-A instruments.
- Baseline plus Metop-A and Metop-B instruments.

The baseline configuration still assimilates data from around 40 satellite instruments, including those on the United States polar satellites, and it represents a good, data rich observing system despite the removal of the Metop satellites.

In general, the data from Metop-B instruments are assimilated in the same way as for Metop-A but with the following main exceptions: Metop-B HIRS is not used currently, and AMSU-A channel 7 is assimilated from Metop-B but not from Metop-A because it is malfunctioning. The latter is significant because it has been demonstrated that the availability of channel 7 on Metop-B AMSU-A is a factor in determining the positive impact of this instrument. The Metop-B AMSU-A, MHS and ASCAT measurements have been assimilated for the entire duration of the experiments, whereas Metop-B IASI and GRAS measurements are assimilated from 20 February 2013 and 25 March 2013, respectively, because of the availability of the measurements.

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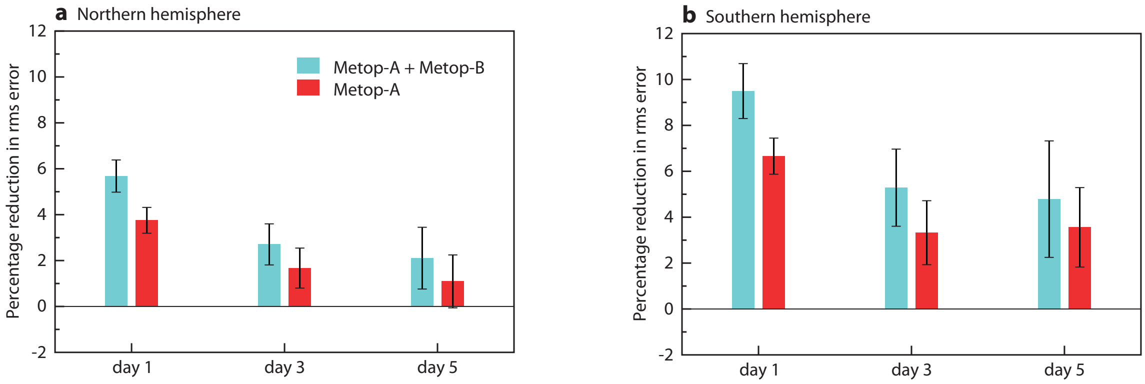

Figure 1 Impact of adding Metop satellites to the baseline system. Shown is the percentage reduction in root-mean-square (rms) error of the 500 hPa geopotential height at days 1, 3 and 5 in the (a) northern and (b) southern hemisphere extratropics as a result of assimilating just Metop-A and both Metop-A and Metop-B. The error bars are the 95% confidence interval, and represent the statistical significance of the improvements with respect to the 'no Metop' baseline experiment.

As the number of satellite instruments has increased, and the resilience of the ECMWF NWP system has improved, it has become increasingly difficult to demonstrate the impact of individual satellite instruments on forecast scores quantitatively, with statistical significance. However, in contrast the suite of instruments on the Metop satellites have a clear, statistically significant impact on 500 hPa geopotential height scores for the northern and southern extratropics in the short and medium range. Figure 1 shows the fractional reduction in the root-mean-square error of 500 hPa geopotential height at days 1, 3 and 5 as a result of adding Metop-A and both Metop-A and B to the baseline system. The results are verified against the ECMWF operational analyses, but verifying against radiosonde observations also gives a statistically significant positive impact. Similar results to those shown for 500 hPa geopotential height are also obtained for other variables, such as mean-sea-level pressure and low level winds.

As with most satellite data, the impact is larger in the southern hemisphere because the in-situ observation network is much better in the north. Although the impact of adding the second satellite is smaller than the first, the additional improvement is statistically significant at the 95% level at days 1 and 3 in both hemispheres, and at day 5 in the northern hemisphere. The impact into the medium-range is a significant result.

While it might have been anticipated that the combined impact of Metop-A and B should be superior to the 'no Metop' baseline, the fact that the two satellites produce a statistically significant impact when compared to one was not obvious prior to this experimentation, particularly given that they share the same orbit. We have not attempted to apportion this combined impact to the various instruments on Metop-B. However, we suspect it represents the accumulation of smaller positive impacts, because the impact of the individual instruments found in preoperational testing is smaller than is shown in the figure. For example, in the preoperational testing, the combined impact of Metop-B AMSU-A and MHS on the day-1 root-mean-square error for 500 hPa geopotential height was a statistically significant improvement, but it was about half the total Metop-B impact shown in the figure. However, it should also be noted that the Metop-B AMSU-A and MHS testing was for a different period.

Overall, the results are very encouraging. At the very least, we would have hoped that the availability of two Metop satellites would make the global observing system more robust through redundancy, by providing like-for-like replacements in the event of instrument failure. However, the results suggest a far more positive scenario.

In summary, having measurements available from two Metop satellites has a clear, statistically significant impact on the forecast skill of the ECMWF system.