Assimilation of IASI Radiances at European NWP Centres

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Abstract

Data from the Infrared Atmospheric Sounding Interferometer (IASI) first became available for early monitoring at some European Numerical Weather Prediction (NWP) centres in February 2007. Tests showed that the data were of high quality, with good radiometric and spectral calibration, and high timeliness. By the time the instrument was declared operational in July 2007, it had already been assimilated operationally at ECMWF for over a month.

Although the NWP centres have necessarily been fairly cautious with first implementations, pre-operational testing has shown overall positive impact from the use of IASI data in almost all cases, and in many experiments equalling or even beating any impact previously seen from the introduction of a new instrument.

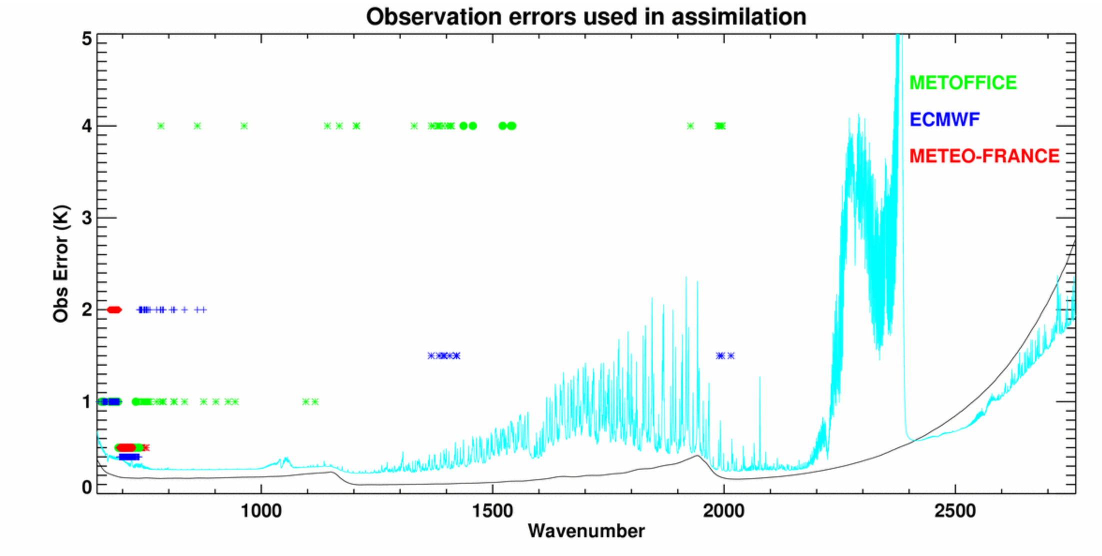
At the present time, IASI is assimilated operationally in the Met Office Global and North Atlantic and European (NAE) model configurations, in the Météo-France ARPEGE (global) and ALADIN (limited area) models, and in the ECMWF model. Work is well underway to make operational use of IASI at met.no in the HARMONIE polar limited area model, and at DWD, where testing has been done in the COSMO-EU limited area model. DWD are also intending to assimilate IASI into the GME global model, but no results are shown here.

1. Methodology of IASI radiance assimilation

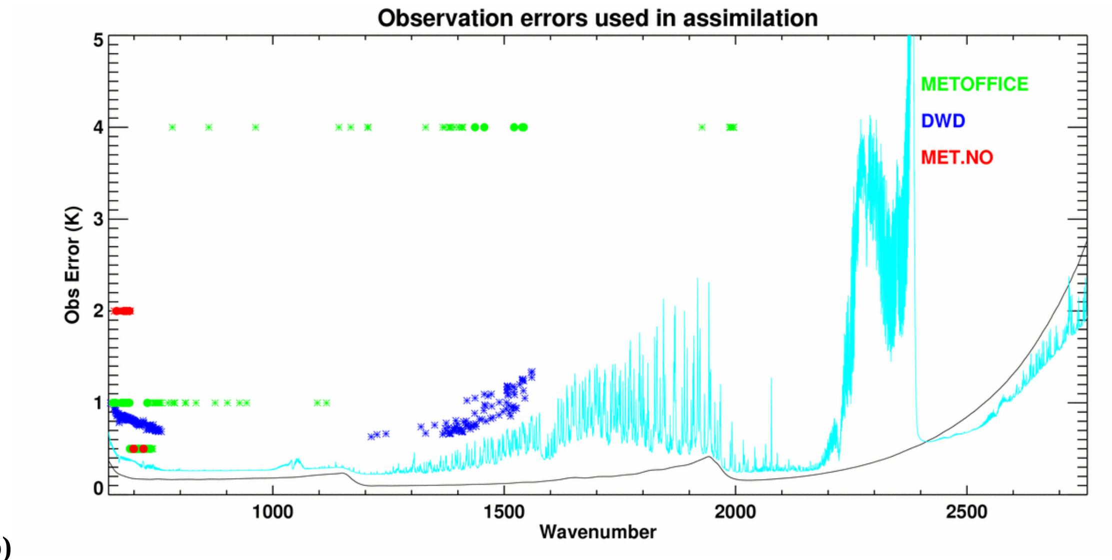
All of the models considered in this paper assimilate IASI brightness temperatures via a 4-dimensional variational assimilation (4D-Var) system, except for HARMONIE and ALADIN which are 3D-Var, and COSMO-EU, which uses a nudging scheme. The nudging scheme operates in model space, so a 1D-Var pre-processor is used to generate a retrieval using IASI observations, and these retrievals are then used to nudge the model towards the state suggested by IASI, with weights which depend on the spatial and temporal distance between the retrieval and the model grid at each time step. The Met Office also operates a 1D-Var pre-processor for quality control, and to retrieve a skin temperature for constraint in 4D-Var.

One of the main constraints of the current assimilation systems is the need to reduce the volume of data to a manageable level. All centres start by choosing just 1 pixel from 4 for each scan position, though the method of selection varies. Data volumes are further reduced by the use of channel selection. All centres use the 300 channel subset of Collard (2007) plus 14 additional monitoring channels chosen by CNES (D. Blumstein, personal communication). ECMWF then add a further 52 channels in the long wave CO_2 band. From this 314 or 366 channel starting point, each centre chooses a subset of channels for assimilation. Data volumes are further reduced by post-quality control thinning to one observation per gridded box of between 80 and 250km.

Figure 1a shows observation errors of the channels assimilated in the global models and 1b shows the same for the limited area models. Observation errors for 3 and 4D-Var are considerably inflated over instrument+forward model error for the stratospheric channels, surface-viewing channels, and in particular the water vapour channels. This inflation is added because it is believed to partially compensate for the lack of inclusion of error correlations, and is often necessary for convergence.



a)



b)

Figure 1: Observation errors by channel for each model. The cyan line is an estimate of instrument + forward model error of 0.2K. The black line is instrument noise at 280K. DWD observation errors are instrument noise at scene temperature + 0.5K for the 1D-Var pre-processor. a) shows the global models and b) the limited area models.

All centres are making much more use of the long wave CO_2 temperature sounding channels than other parts of the spectrum by including more channels and assimilating tropospheric channels with low observation errors; initial implementations at ECWMF and Météo-France only used channels in the long wave CO2 band. None of the centres is currently using any channels in Band 3 – these channels are noisier than the rest of the spectrum, are affected by solar reflection contributions during the day and are thus more complicated to use. Tests at the Met Office also suggested that the active use of short wave channels did not improve their analysis departures in 4D-Var. The use of stratospheric CO2 channels is generally restricted by the height of the model top.

The initial Met Office implementation uses water vapour channels in addition to the temperature sounding channels. ECMWF started to assimilate water vapour channels earlier this year, and Météo-France plan to add them to operations in the near future. DWD have also been assessing the impact of water vapour channels, but at met.no the higher priority is to add surface viewing channels.

The channel selections are further restricted over land and sea ice, except for ECMWF where channels are used over sea ice as though the points were open ocean. Table 1 shows the number of channels assimilated for each surface type at each centre. Despite the large amount of land and sea-ice present in the HARMONIE model, met.no have found difficulties in using observations over land and sea-ice because of concerns that there is a poor surface description.

	Sea	Land	Sea-ice
Met Office	**151 T/surf** **32 WV** **(for MW cloud same channels as land)**	**57 T** **6 with WV sensitivity**	
Météo-France	**Up to 64 T** **9 WV under test**	**Up to 50 T**	**Up to 32 T**
ECMWF	**Up to 165 T** **Up to 10 WV**		**Up to 165 T**
DWD	**Up to 122 T** **93 WV under test**		
met.no	**Up to 41 T**	**Up to 9 T**	

Table 1Current channel usage by surface type at the different centres

All centres are currently using only observations unaffected by cloud. In most cases, the McNally and Watts (2003) method is used to select clear channels above cloud. At ECMWF a modified cross-band version is employed to improve the selection of water vapour channels (Collard and McNally, 2009). The Met Office cloud detection uses the Bayesian approach of English et al. (1999) and two simple tests developed at NOAA-NESDIS (Z. Cheng, personal communication) to search for clear scenes rather than clear channels. An additional test from collocated AMSU data is used to screen low-peaking channels (English et al., 1997). These differing methods result in roughly the same number of observations assimilated in the window region, but the McNally and Watts (2003) method allows the use of a much greater number of high-peaking channels.

DWD and the Met Office use a Harris and Kelly (2001) bias correction scheme with static predictors including a constant term, scan angle, two airmass predictors and, in the case of DWD, surface temperature and total column water vapour. The other centres all use the adaptive bias correction scheme of Auligné et al (2007), with a constant term, four airmass predictors and view angle to the power of 1, 2 and 3. The success of particular bias predictors depends very much on the individual model and will not be discussed further here.

2. The impact of IASI data in NWP

It is not an easy task to compare the impact of IASI in different models, because each centre uses different measures to assess improvements in the forecasts. However, almost all experiments which have been run with reasonably mature processing methodologies have shown what is considered to be good positive impact. Collard and McNally (2009) discuss the impact of IASI for the ECMWF system and Hilton et al. (2009) for the two Met Office model configurations.

In the three global models, impacts from IASI were generally large and positive overall. There were particular benefits in the southern hemisphere, but the Met Office system had strong scores in the northern hemisphere also. IASI observations were found to have strong impacts at medium range. The impact from IASI was at least as good as the initial Atmospheric InfraRed Sounder (AIRS) implementation, partly because initial experience with AIRS had suggested that the system would benefit from a more comprehensive usage of the long-wave CO_2 band, which on IASI also has lower instrument noise. Met Office tests suggested that the impact of IASI clear fields of view was similar to the impact from a single Advanced Microwave Sounding Unit + Microwave Humidity Sounder (AMSU+MHS) used in clear and cloudy regions. The impact of IASI was considered particularly strong given that it is assimilated on top of an already comprehensively observed system including AIRS, ATOVS on several satellites, and the Special Sensor Microwave Imager Sounder (SSMIS).

In the Met Office system, many fields showed small improvements, with height forecasts verifying particularly well against analyses especially in the stratosphere, while wind fields in the tropics and southern hemisphere, 500hPa height in the tropics and northern hemisphere Pressure at Mean Sea Level (PMSL) showed good improvements against radiosondes. Figure 2 shows the change in root mean squared (RMS) forecast error for the variables used to measure impact in the Met Office system. The weighted skill for these variables is used to construct the NWP index which is used as an overall guide to forecast impact. NWP index impact was generally consistent in time through the trial period.

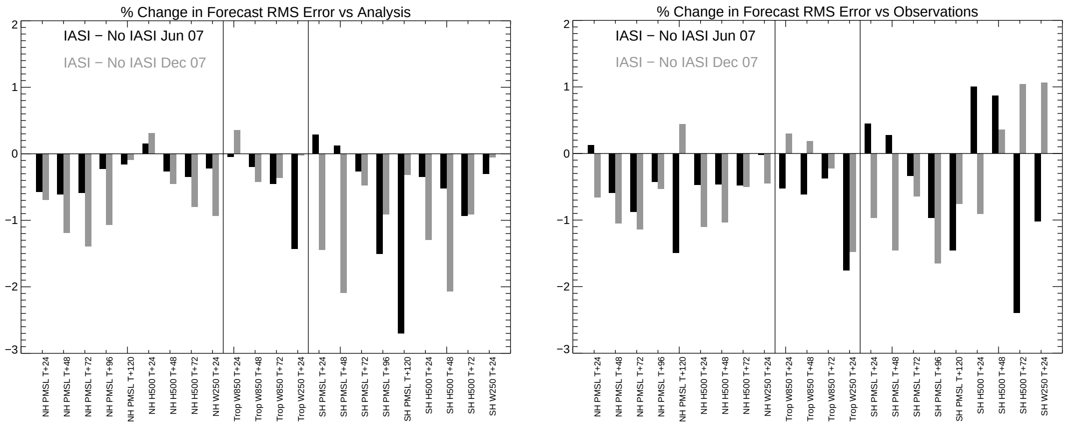


Figure 2: Met Office Comparison of percentage change in forecast RMS error for June 2007 and December 2007 trial periods. The left panel is verified against analyses, the right against observations.

The ECMWF system showed particularly strong impact for the 500hPa height anomaly correlation in the southern hemisphere, especially at days 3 to 5 (Figure 3). There were also improvements in southern hemisphere winds and short-range relative humidity forecasts during the southern hemisphere winter. Météo-France also showed good impact in the southern hemisphere 500hPa height anomaly correlation, especially at 3-4 days (Figure 4). The observations assimilated over land and sea-ice also show positive impact in their system.

Impacts in the limited area models are less consistent but the overall picture is again of a positive impact from assimilation of IASI data. The Met Office implementation in the NAE delivered neutral forecast impact scores, which are measured using surface weather variables such as precipitation accumulations and visibility. The pre-operational trial did, however, show evidence of improvements to the upper air fields. At met.no, experiments show very pleasing impact from the assimilation of just a few IASI channels, with improvements in geopotential height, temperature and to a lesser extent winds (Figure 5). At DWD, the RMS error in geopotential height, temperature and relative humidity are all improved by IASI assimilation through much of the troposphere, especially at T+48 (Figure 6).

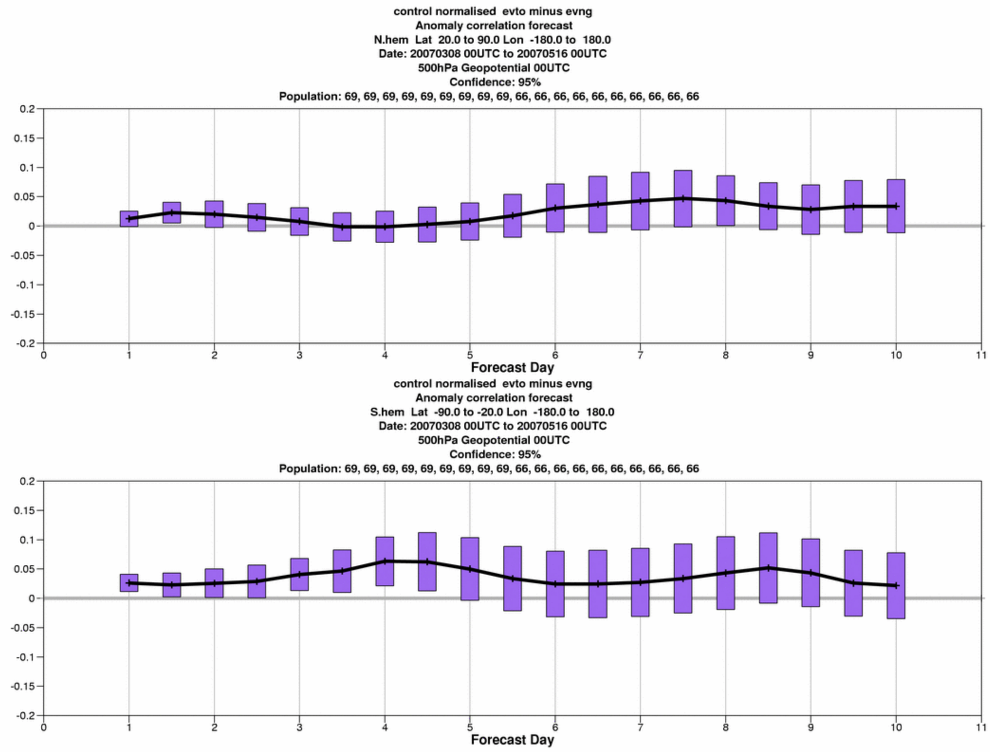


Figure 3: ECMWF 500hPa geopotential height anomaly correlation forecast improvement for 8th March to 5th May 2007, normalised by forecast error from the control run. Top panel northern hemisphere; bottom panel southern hemisphere. Scores above the zero line indicate an improvement from assimilation of IASI data. The blue bars represent 90% confidence intervals.

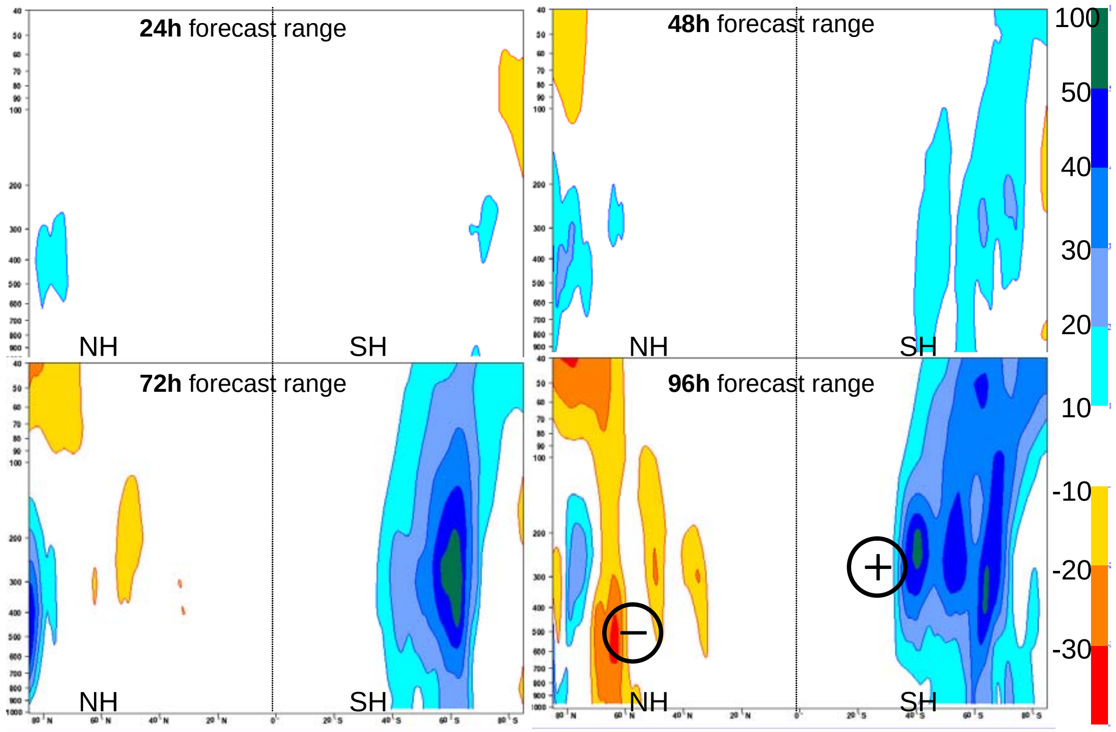


Figure 4: Météo-France change in RMS Error in geopotential height verified against three weeks of ECMWF analyses, "No IASI" – "IASI". Blue areas show positive impact.

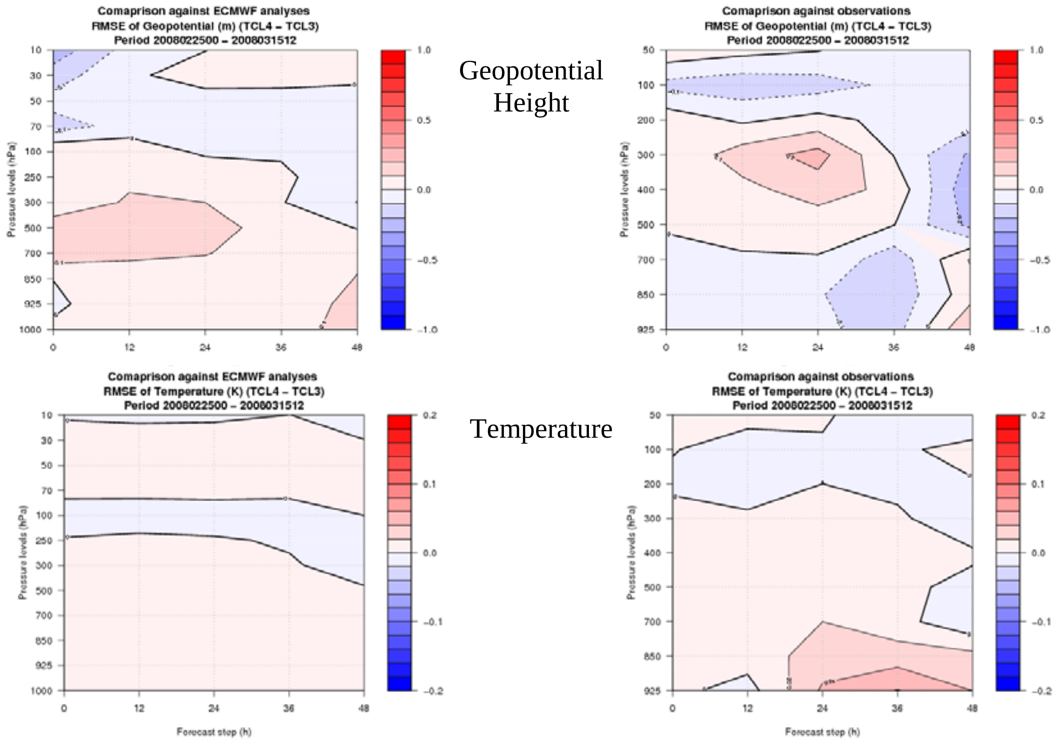


Figure 5: Met.no change in RMS error for temperature and geopotential height on pressure levels with forecast range verified against ECMWF analyses (LH panel) and observations (RH panel). Red areas show positive impact.

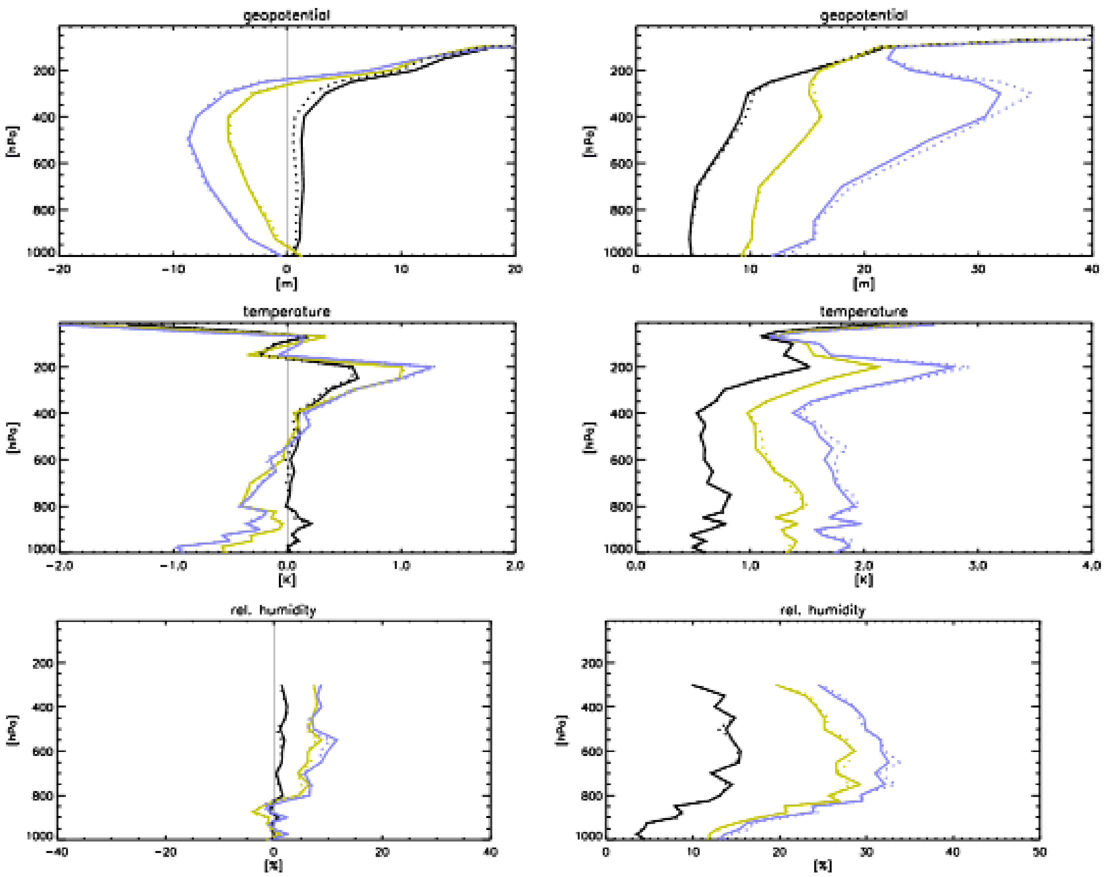


Figure 6: DWD COSMO-EU change in bias (RH panel) and RMS error (LH panel) for geopotential height (top row), temperature (middle row) and relative humidity (bottom row) verified against observations. The dashed lines are the control, the solid lines include IASI data. Black is T+0, yellow T+24 and blue T+48.

3. Impact of water vapour channels

All centres except met.no have done some impact testing with water vapour channels. The impact is found to be generally weak but positive. The assimilation of water vapour channels tends to give relatively low weight to the observations, either through significant inflation of the observation errors (e.g. to 4K where Obs-FirstGuess fit is around 1.5K), or through the use of ten channels or fewer, or both.

Met Office testing indicated that about 15-20% of the overall impact of IASI on the NWP index derives from use of the water vapour channels, mostly through improvements to tropical wind scores. There is little evidence for direct improvement in relative humidity itself, except at upper levels in the southern hemisphere.

At Météo-France, positive impact on temperature and relative humidity is observed at forecast ranges longer than T+60 over Europe, and also an improvement in RMS for stratospheric heights, especially in the southern hemisphere. Only nine water vapour channels were added with an observation error of 4K, so actually this is a good result from the inclusion of relatively little data.

Tests at ECMWF on inclusion of water vapour channels have shown strong sensitivity to the analysis used for verification at ranges up to around one day. When the control (no water vapour channels) analysis is used, results suggest a reduction in the short-range forecast skill measure, but if the experiment analysis is used, the short-range forecast skill measure increases. This effect is amplified by the normalisation by forecast error in plots such as Figure 3because of the very small errors at short range.

Prior to launch, IASI was expected to deliver a large quantity of information from use of water vapour channels, and thus far it has not been possible to fully exploit this capability. However, these problems are not unique to IASI. The weight given to the water vapour band of advanced sounders is as high as, or higher than, other humidity-sensitive satellite sensors. It is widely found that increasing the weight to water vapour channels is difficult, and the assimilation of upper tropospheric water vapour channels is especially challenging. Many models are known to show biases in upper tropospheric humidity (e.g. Newman et al., 2008), with very few observations to constrain them. It is likely that model biases, in conjunction with some features of the assimilation code itself make it difficult to assimilate all the information from the IASI water vapour band. This is an ongoing concern for all of the centres.

4. Current areas of research and main concerns for the future

In addition to further exploiting the water vapour band, all centres have identified the use of observations over land and sea-ice as a high priority. Observations are assimilated over land at the Met Office and Météo-France, and are under test at met.no, but the channel selection is restricted to high-peaking channels only. It is of particular importance to be able to assimilate observations over land and sea-ice in northern hemisphere limited area models. Concerns over the surface definition and performance of the cloud detection scheme are currently limiting progress.

Recent experiments at ECMWF have shown that the assimilation of land observations, in conjunction with a 0.98 spectrally invariant emissivity, leads to a positive impact in short-range forecasts in the northern hemisphere, especially over Siberia. It is believed that the tight quality control of window channels which occurs as part of the cloud detection scheme helps to reject observations where the emissivity definition is particularly poor.

Observations are assimilated over sea ice at Météo-France and ECMWF, treating the emissivity as though the observation was over the sea. The channel selection is restricted to higher-peaking channels in the Météo-France system, but at ECMWF all channels used over sea are also used over ice – as with the observations over land it is believed that tight quality control helps to constrain the selection of observations. At both centres, the observations assimilated have been shown to be beneficial within the forecast system.

Increasing the use of high-peaking channels to improve stratospheric analyses was also identified as an area for future improvements by most centres, although it is often hard to use channels which are sensitive to the temperature at the top of the model as there can be large model biases. At met.no, plans to increase the number of channels assimilated include also the use of water vapour channels, but the highest priority is extending the use of surface-viewing channels over the sea, once improvements to the surface analysis scheme are in place.

The Met Office, ECMWF and Météo-France all plan to use cloud-affected radiances in the near future. The new schemes all rely on the prior estimation of a cloud fraction and cloud top pressure for use in 4D-Var. The Met Office (Pavelin et al., 2008) and Météo-France (Pangaud et al., 2009) schemes are similar in that the retrieved cloud parameters are used as a fixed constraint in 4D-Var. At the Met Office, the channel selection is limited to channels for which Jacobians are only slightly sensitive to the levels below the cloud top, and at Météo-France, the McNally and Watts channel selection is augmented only where the cloud is below 650hPa. The ECMWF scheme (McNally, 2009) is slightly different from the others in that only fully overcast scenes are considered but all channels are used, and the cloud top pressure is added to the 4D-Var control vector. The change in data usage from the use of cloud-affected radiances will be biggest at the Met Office, where currently only fully clear fields of view are assimilated.

One further area of research under consideration is the use of reconstructed radiances, or the assimilation of principal components. However, this is thought to be of lower priority than improving data coverage through the use of observations over land and cloud. Centres are waiting for further stability in the development of principal component-based radiative transfer models and proven benefit to atmospheric retrieval schemes. Research has been done at ECMWF and the Met Office into the use of reconstructed radiances, but with little evidence of any forecast improvement. Further work is required on the treatment of correlated errors and bias correction before further testing is likely to yield any conclusive results.

5. Conclusion

The assimilation of IASI data has shown positive benefit to forecast skill at five European weather centres. The increase in forecast skill is generally as big as, or bigger than, that from the introduction of AIRS or a single AMSU-B+MHS system. The impact has been particularly impressive given the wealth of data already assimilated in operational models. The rapid progress with the use of the data can be put down largely to the high quality and stability of the IASI data itself and the experienced gained from AIRS assimilation.

The operational assimilation schemes are all still in a relatively juvenile state, and there is still much to be gained from improving the way IASI data are used over the coming years. High priority is attached to using data affected by cloud, exploiting observations over land and sea ice, extracting more information from the water vapour band, and improving the use of stratospheric and surface channels.

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