

Improved use of AMSU-B data in the UK Met Office regional models

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1. Introduction

Regional Numerical Weather Prediction (NWP) models provide enhanced detail for forecast quantities such as cloud cover, visibility and rainfall. Previous work at the Met Office has shown that improving the humidity analysis through the assimilation of AMSU radiances improves the accuracy of these quantities. This paper highlights several new developments in the assimilation of AMSU-B radiances for regional models, including the use of data at the full resolution of 16km and in the selection of which channels to use in the analysis. The channel selection method uses the cloud liquid water in each profile estimated from a 1D-Var scheme. Comparisons are presented from 3D-Var runs which show that the size of the moisture increments in the boundary layer due to AMSU-B observations is similar to those from radiosondes.

2. Regional Model Domains and Operational Use of ATOVS Data

At the Met Office, in addition to the global NWP model, two regional models are run operationally which provide enhanced detail for the region around the United Kingdom. The domains for the two regional models, which are denoted the North Atlantic Model (NAE) and the UK Mesoscale Model (UK Mes), are shown in Figure 1. Both domains have a resolution of 12km with 38 vertical levels. Boundary conditions are supplied from the global model and both models use a 3D-Var scheme to form analyses. At the time of writing a model with a resolution of 4km and reduced domain around the UK is about to enter operations with the intention of replacing the UK Mes.

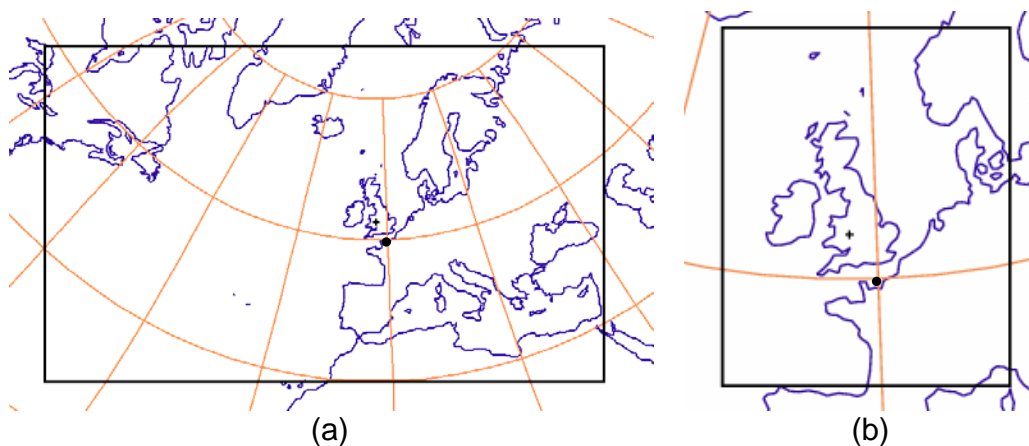


Figure 1: The domains of the a) North Atlantic European Model (NAE) and b) UK Mesoscale Model (UK Mes). In both cases the centre dot signifies 50°N, 0°E.

AMSU radiances are used in the operational 3D-Var scheme for both model domains and details were reported at ITSC-13 (Candy et al., 2004). Data from AMSU-A and AMSU-B are mapped to a common grid with a resolution of 40 km and channel selection decisions are made using radiances from both instruments. Both the UK Mes and the NAE run operationally with a data cutoff of around 2 hours (i.e. the data processing for the 0Z analysis commences at 2Z) and so the timely arrival of observations is important. For the UK Mes AMSU data are received via a local antenna based at the Met Office headquarters, whilst for the NAE domain data from a network of ground stations spread around the North Atlantic arrives via the Eumetsat Advanced Retransmission Service (EARS). Typical time delays between an observation being made in space and arriving at the Met Office via the EARS service are of the order of 30 minutes.

3. Improvements to use of AMSU-B data

In the current operational use of AMSU-A and B we treat each observation as if it originates from a single instrument. This ignores the higher resolution of 16km available for the AMSU-B radiances which is closer to the scales resolved in the regional models. Also quality control tests, such as detecting precipitation in the field of view, are currently done using AMSU-A data. This approach relies on the continued working of AMSU-A onboard each NOAA spacecraft. So part of the aim of the work described in this paper is to identify a series of tests to perform gross rejection and channel selection using the AMSU-B data alone, thus making the scheme more resilient to instrument failures.

One of the key tests prior to assimilation is to detect the presence of rain in the field of view and a common approach to do this with microwave data is to compare two channels separated in frequency in the form of a scattering index. Bennartz and coworkers (2002) suggested such an index between AMSU-B channel 1 and channel 2 and this has been tested in our assimilation scheme by comparing with radar data. Figure 2 shows that high values from the scattering index denotes the rain associated with an extratropical cyclone over the UK.

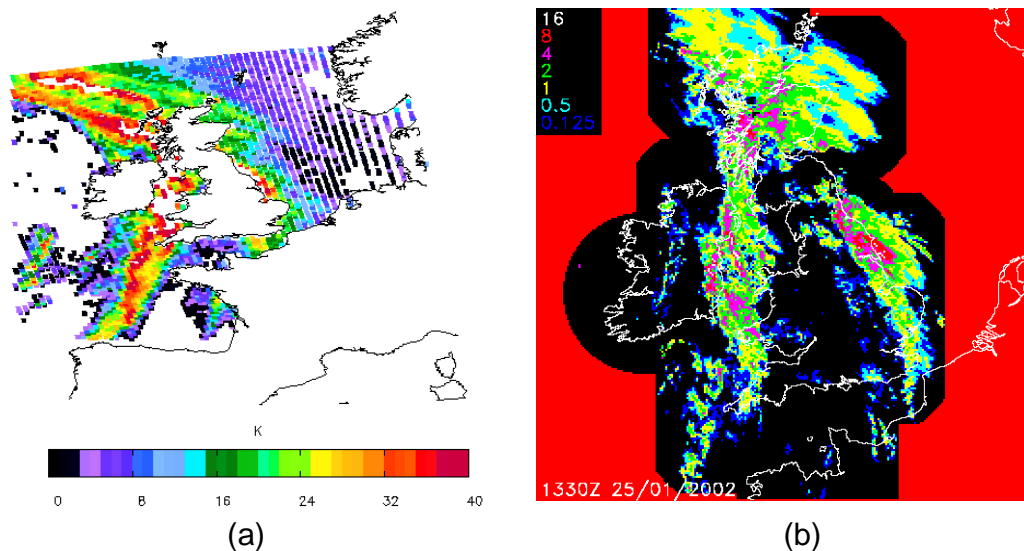


Figure 2: Values of the Bennartz et al. (2002) scattering index (panel a) compared to the corresponding rain rates from the UK radar network (panel b).

In addition to rain detection it is also necessary to reject the use of a given channel when there is a significant radiative effect from cloud liquid water droplets. This is because the current operational 3D-Var system does not contain cloud water as a control variable. Figure 3 shows the modelled radiative impact of cloud liquid water for each AMSU-B channel for an ensemble of profiles from the UK global model. As can be seen the lower frequency channels are more strongly influenced by cloud liquid water droplets and consequently a cloud liquid water threshold is required for each channel beyond which the channel is not used in the analysis.

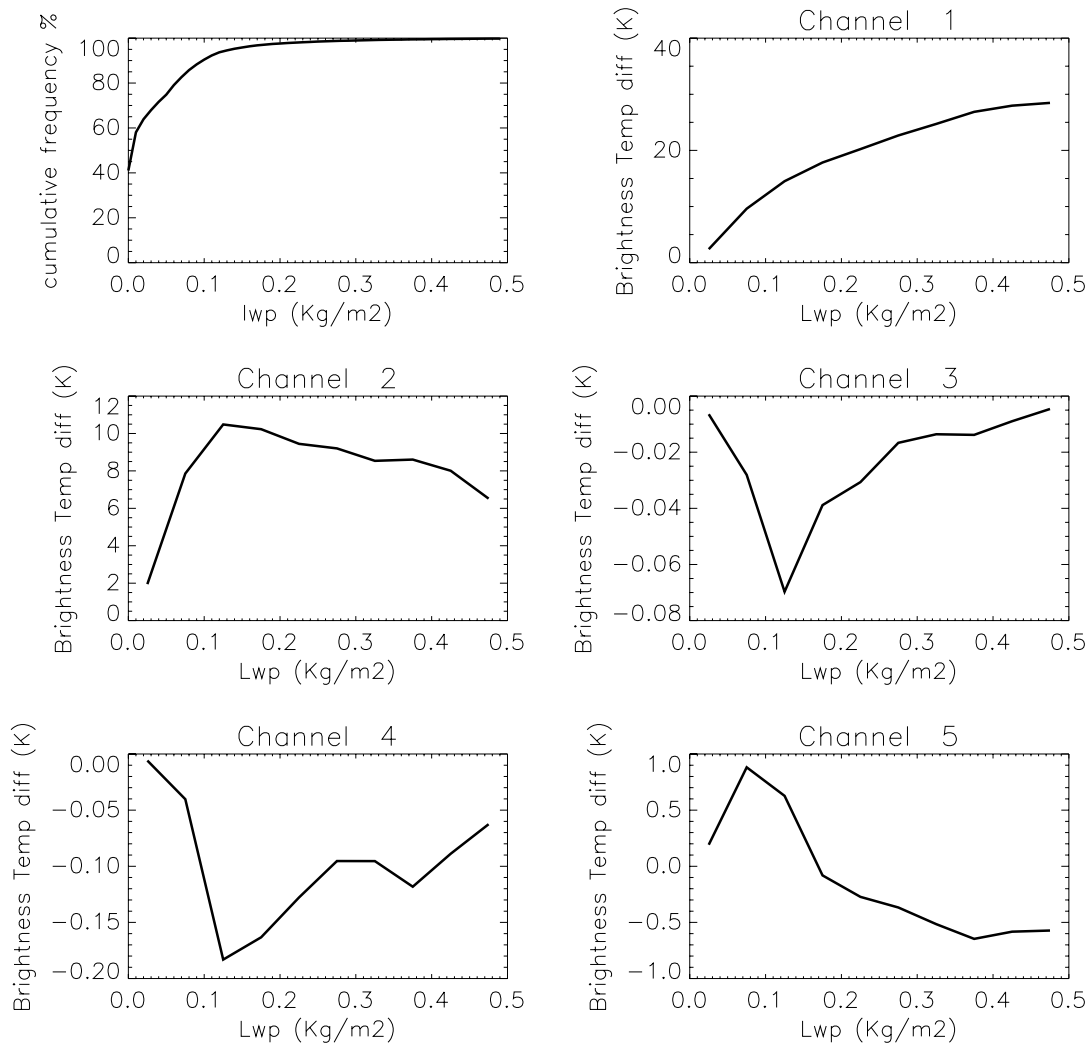


Figure 3. The mean radiative impact of cloud liquid water on each AMSU-B channel. Data is based on an ensemble of extratropical profiles from the Met Office global model (total number 11000). The radiative transfer model RTTOV7 was used to simulate the brightness temperatures.

Several methods have been developed to determine the cloud liquid water in the field of view using microwave channels, e.g. Grody et al. (1999) or English et al. (1997). However these methods use AMSU-A channels and so for AMSU-B data another technique is required. In the

processing of satellite data at the Met Office several parameters which are required in the 3D-Var analysis are retrieved using a 1D-Var scheme and the next section describes how this scheme is modified to retrieve cloud liquid water.

4. Retrieval of Cloud Liquid Water

The current 1D-Var scheme in operational use at the Met Office performs a number of roles, including the retrieval of parameters that are necessary for accurate radiative transfer modelling but are not analysed within 3D-Var. An example of this is skin temperature. The moisture control variable used is water vapour (in the form of $\ln(q)$). As part of an investigation into the use of SSMIS data in cloudy regions Deblonde and English (2003) proposed modifying this to describe the total water content q_{total} , by adding a term representing the cloud liquid water, q_l . It is defined as

$$q_{total} = q + q_l \quad (1)$$

with jacobian

$$\frac{dy}{dq_{total}} = \frac{dy}{dq} \frac{dq}{dq_{total}} + \frac{dy}{dq_l} \frac{dq_l}{dq_{total}} \quad (2)$$

where y represents the top of the atmosphere brightness temperature. The partial derivatives of q and q_l with respect to q_{total} are modelled as parabolic functions to avoid sharp changes in gradient as cloud begins to form. Cloud is allowed to form once the relative humidity exceeds 95%. During each iteration q_{total} is split into its two constituents and these are then used as inputs to the radiative transfer model. At the end of the minimisation the summation of q_l across each atmospheric layer yields the retrieved cloud liquid water in the form of a liquid water path (lwp).

Initial tests of using this moisture control variable in retrievals with AMSU-B channels revealed that there was too much cloud being produced in the upper troposphere. In reality any cloud at these levels would be composed of ice crystals and so an additional term was added to represent ice in Equation 1, with the ratio of liquid to total condensate based on a temperature dependent parametrization. The parametrization is based on aircraft measurements in clouds (Jones, 1995). Currently the ice is ignored in the radiative transfer calculations during minimisation.

Comparisons were performed between liquid water path estimates from 1D-Var and those from the Grody AMSU-A algorithm. To do this observations made within the NAE domain from AMSU-A and AMSU-B were mapped to a common grid. Three sets of experiments were then carried out in which a 1D-Var retrieval was performed on each ocean scene where precipitation was not detected. The experiments used the following channels:

- a) Temperature sounding channels only (AMSU-A 5 to 14)
- b) as a) + AMSU-B channels
- c) as b) + AMSU-A 1 & 2

Figure 4 compares the estimates from these three experiments with those from the Grody AMSU-A algorithm. Experiment (a) gives the poorest fit which is not surprising as the channels used contain little information on cloud liquid water, whilst the addition of AMSU-B channels in Experiment (b) significantly improves the 1D-var estimates. The best fit occurs when the 23.8 and 31.4 GHz channels are included in the 1D-Var minimisation. This is not too surprising as it is

these channels which are used in the AMSU-A algorithm. From these comparisons it is concluded that the liquid water path product using AMSU-B channels alone is sufficiently accurate to be of use in selecting which channels to use in forming the analysis.

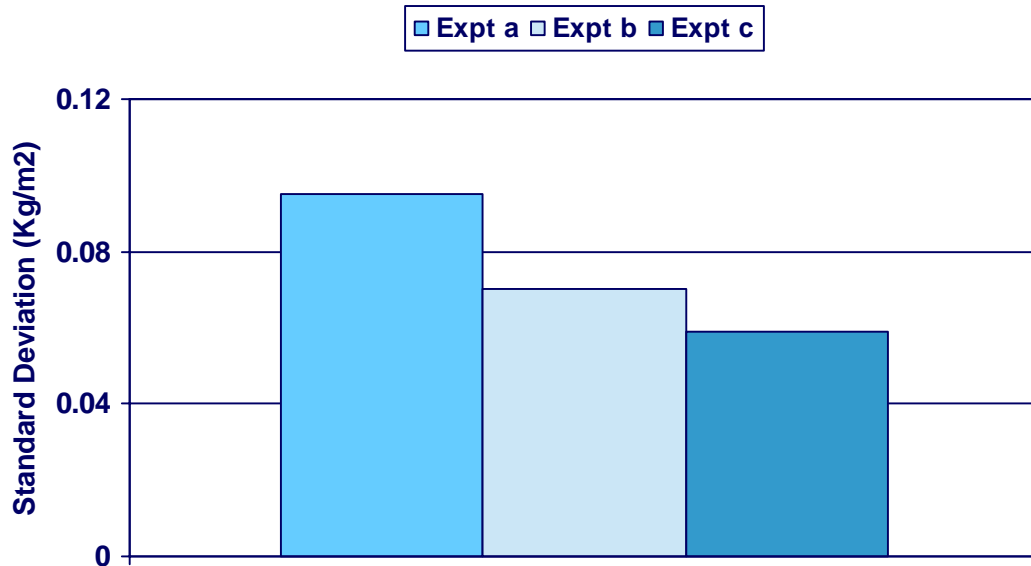


Figure 4. A comparison of the fit of 1D-Var retrieved liquid water path to values estimated from the Grody AMSU-A algorithm. Data are from the NAE model domain and the different channels used in each experiment are defined in the text.

5. Data Impact in UK Mes 3D-Var

The impact of assimilating AMSU-B channels at full resolution and operational (40km) resolution was investigated by comparing the increments produced at the end of the 3D-Var minimisation. The case is the same time as the radar image in Figure 2. In each minimisation only the 183 GHz channels are used and all data are rejected if the precipitation is detected in the scene and the lowest peaking 183 GHz channel is rejected if the liquid water path estimate exceeds a threshold. For the data at operational resolution the English (1997) test is used, whilst at full resolution 1D-Var is used as described above. Figure 5 shows the humidity increments at 800 hPa and it can be seen that the broad features are similar, although the magnitudes are higher when using the data at full resolution (at full resolution the data volume provided to 3D-Var increases by a factor of 4).

In addition to the use of full resolution another improvement is to introduce the low frequency AMSU-B channels (1 & 2) into the 3D-Var assimilation. As can be seen from Figure 3 these channels are very sensitive to liquid water in the field of view. Consequently as an initial test a tight lwp threshold was used (5 gm^{-2}) above which these channels were not assimilated. Figure 6 shows that even with such a tight limit a useful amount of data pass the threshold in a case with active fronts. The impact of using these channels is highlighted in Figure 7 where the mean and standard deviation of the analysis increments are compared using (a) only the 183 GHz channels and using (b) all AMSU-B channels. In each case statistics are derived from locations in Figure 6. The plots show that the low frequency channels are adding information about the humidity field

within the boundary layer. This should help with the forecasting of marine fog and also for severe convective outbreaks in which the correct analysis of low-level moisture is important.

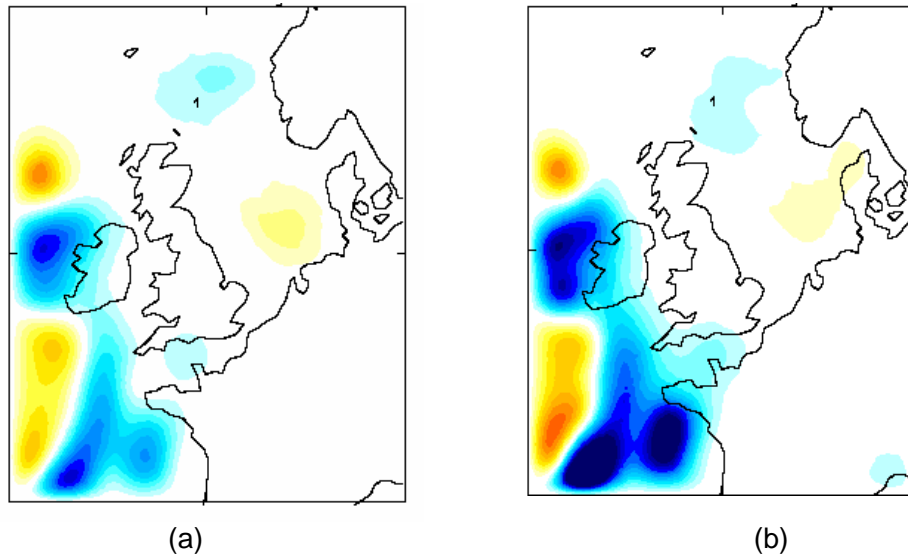


Figure 5. Humidity analysis increments at 800 hPa when AMSU-B 183 GHz channels are assimilated at a) 40km resolution and b) full (16km) resolution. Blue shades represent a reduction in humidity, whilst red shades represent an increase.

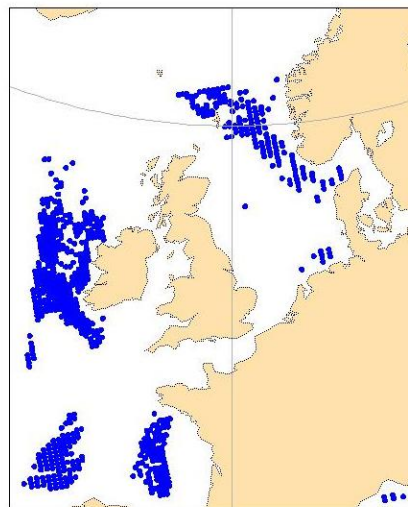


Figure 6. Locations where the low frequency AMSU-B channels can be used in the 3D-Var analysis after data screening using the retrieved liquid water path. This is the same case as described in Figure 2.

It is also instructive to examine how the analysis increments compare with those from other observation types. Figure 8 shows the moisture increments from the same case as before when using relative humidity observations from radiosonde ascents. As would be expected there is more vertical structure in the sonde increments, but both the AMSU-B data and the sonde data are trying to dry the lower troposphere, with similar magnitude. This is very encouraging as it

suggests that the information over the land from sondes and over the ocean from AMSU-B is complementary.

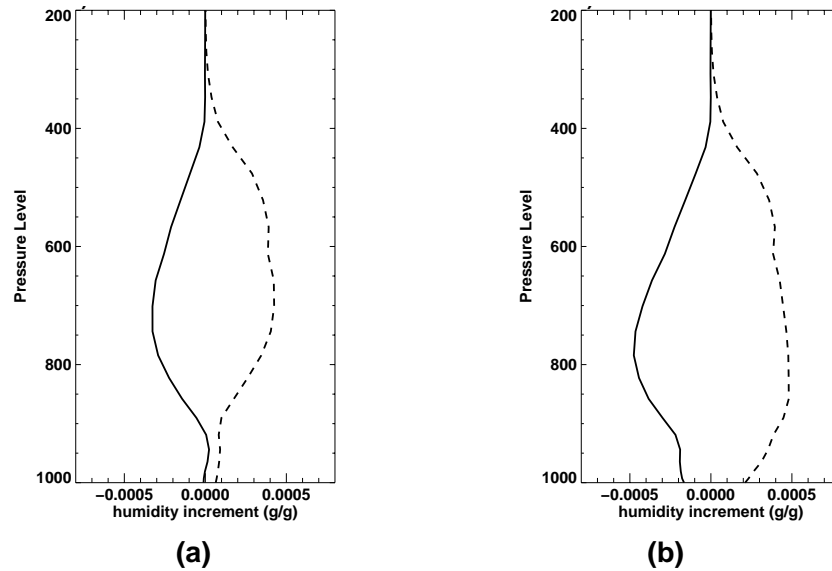


Figure 7. The mean (solid) humidity increment and standard deviation arising from the assimilation of AMSU-B channels. In Case (a) only the 183 GHz channels are used and in case (b) all AMSU-B channels are used. Data points are shown in Figure 6.

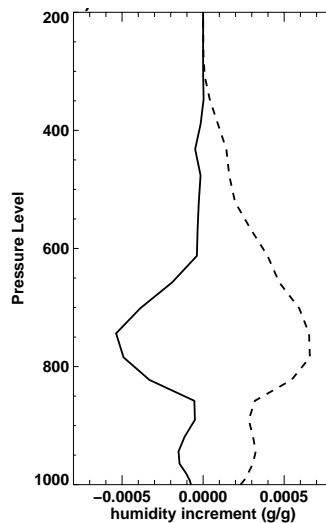


Figure 8. The mean (solid) humidity increment and standard deviation for the same 3D-Var case as in Figure 7, but this time assimilating Sonde relative humidity data from 25 ascents across the UK Mes domain.

6. Conclusions

Two improvements to the use of AMSU-B data within Met Office regional models have been discussed. Firstly using the data at full resolution and secondly in extending the channel usage beyond the 183 GHz channels. Channel selection is determined from the liquid water path in the field of view and this is in turn estimated via a 1D-Var retrieval. This method of channel selection is more flexible than our current scheme as it does not require radiances from the AMSU-A instrument to be present in the data stream. Consequently in the future we will investigate its use in the global model, especially for processing AMSU-B radiances from NOAA17 where there is no available AMSU-A data.

A test of the new scheme in 3D-Var shows that a similar spatial pattern of increments are produced at high resolution when compared to the current operational resolution (40 km), though of stronger magnitude. Introducing the 89 and 150 GHz channels into the 3D-Var assimilation adds humidity information within the boundary layer, which will potentially be of use in improving forecasts of coastal fog and low cloud. A comparison between analysis increments arising from AMSU-B data with those from radiosonde ascents suggests that there is complementary information from these two observation types.

In the near-future the improvements to AMSU-B data usage will be tested in a series of case studies in both the UKMes and wider NAE domains. These will attempt to encompass the range of weather situations that exist over the model domains, including cases that were poorly forecast. The aim of these studies will be to assess the impact of the AMSU-B improvements on model humidity analyses and subsequent forecasts of cloud and precipitation.

References

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