

Use of AMSU data in the Met Office UK Mesoscale Model

**Brett Candy, Stephen English,
Richard Renshaw & Bruce Macpherson**

The Met Office, Exeter, United Kingdom

1. Introduction

In common with other global NWP centres, assimilation of radiances from the ATOVS instrument package at the Met Office results in a large benefit to global NWP forecasts (English et al., 2000) and has been used operationally since mid-1999 in the Met Office global 3D-Var system. Recently work has been carried out to assess the impact of using radiances from the AMSU A&B instruments in the UK Mesoscale Model (UK Mes). This is a limited area model with a domain covering the British Isles (the region is shown in the right panel of Figure 1) and to date its assimilation scheme has mainly used conventional observations. For the initial implementation of AMSU data in the UK Mes we have used the pre-processing scheme for ATOVS radiances in the global model as closely as possible to avoid duplication and maintenance of computer code. However some departures are necessary and these are described in the following sections.

The assessment of impact in a limited area model can be a difficult exercise, owing to the small domain in which to accumulate statistics and the need to run enough cases to sample the major weather types that occur in the domain. A two-fold approach was taken for this; running case studies on typical weather events and, prior to operational implementation, an extended trial of one months duration. Results from these studies are presented below.

2. AMSU Data

2.1 Data Receipt

ATOVS data in the region around the British Isles are received via a HRPT station located in the west of Scotland. At the Met Office the data is converted to level 1c brightness temperatures for each instrument using the AAPP program¹. Finally the data is mapped to a common grid (1d level). The HIRS grid is chosen for this, since it is the grid used in the processing of ATOVS data in the global model. The locally received 1d data is routinely monitored against the ATOVS data produced by NESDIS to ensure its quality. For AMSU data the difference between the local and NESDIS data is very small, with channel standard deviations typically less than 0.05K.

2.2 Channel Selection

The current operational implementation of the radiative transfer forward model, RTTOV, in the Met Office 3D-Var system ignores the effects of cloud liquid water and rain droplets on microwave radiances. This simplification can have a big impact on the ability to model certain microwave channels and consequently prior to assimilation a series of tests are required to

¹ For further details see <http://www.eumetsat.de/en/area4/aapp> or <http://www.metoffice.com/research/interproj/nwpsaf/atovs>

identify the presence of precipitation and significant cloud water in the field of view. As reported in English et al. (1997) the following tests are used in the AAPP program:

- *Liquid water path test.* This flags observations with a liquid water path in excess of $\sim 100\text{gm}^{-2}$ and in this case AMSU channels² 4, 5 and 20 are rejected for assimilation.
- *Rain test.* In this case all AMSU channels with weighting functions peaking in the troposphere are rejected (4 to 8 & AMSU-B).

In addition to this the higher frequency (183 GHz) channels are particularly sensitive to scattering effects caused by ice particles, such as cirrus crystals. A cost function is used to identify scenes containing ice particles with the following form:

$$J = (y - y^b)^T R^{-1} (y - y^b)$$

Where y represents the observation vector containing radiances from the three 183 GHz channels, y^b represents the background radiance vector computed from a short-range UK Mes forecast field via the RTTOV forward model operator and R represents the error covariance matrix. For scenes in which the computed cost exceeds a given threshold channels 19 and 20 are not used in the assimilation.

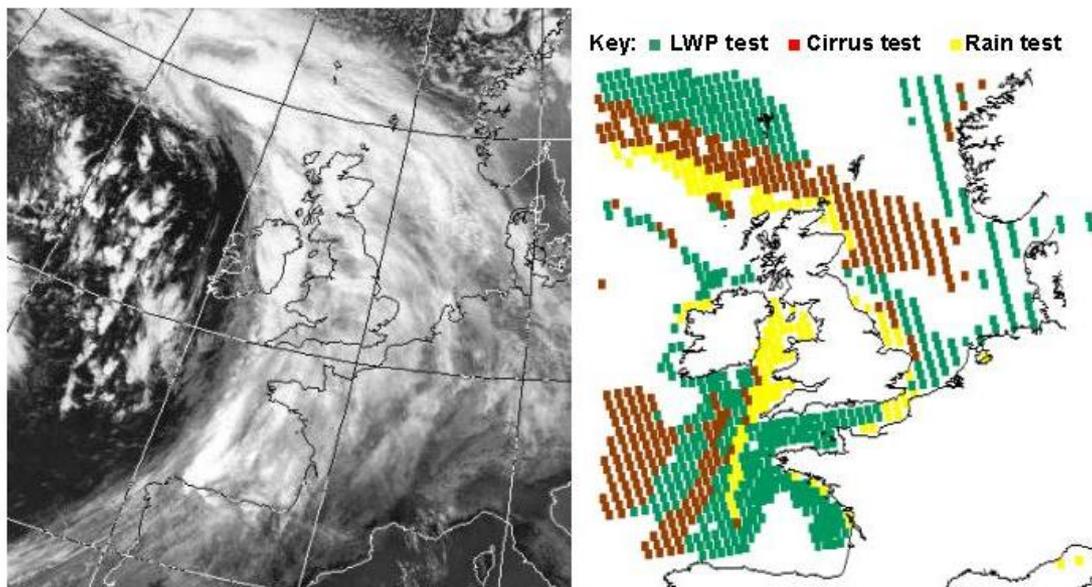


Figure 1: A Case study of an occluded frontal system in the UK Mes area. *Left panel:* Infrared image from the AVHRR instrument (courtesy of the NERC Satellite Receiving Station, University of Dundee, Scotland.). *Right panel:* ATOVS observations failing the screening tests.

Figure 1 shows the classification of data after applying these tests to an overpass. The case is an occluded frontal system in which there is significant precipitation along the cold front lying between northern Spain and Ireland. As expected in a case where most of the region is covered with thick frontal cloud a significant number of observations have been flagged by the screening

² Throughout this paper AMSU channels 1 to 15 refer to the AMSU-A instrument, channels 16 to 20 refer to AMSU-B.

tests. Nonetheless there are still regions in which data from all the AMSU channels can be passed to the assimilation scheme, notably in the Bay of Biscay and in the convective region behind the cold front.

In addition to the above screening tests, over land data from the following channels are not assimilated:

- AMSU channels 4 & 5
- AMSU channels 18,19, & 20 (AMSU-B)

This is because the surface emissivity is more variable over land and this will effect both the ability of the radiative transfer model to simulate radiances whose weighting functions peak close to the surface and also the screening tests using window channels, such as the rain test. Work is ongoing at the Met Office to address this issue, with a view to using more data over land.

2.3 Bias Correction

The final step of preprocessing is to bias correct the radiances against the NWP model background. As in the processing of data for the global NWP model, the method of Eyre (1992) is used. AMSU channels 5 and 9 are used as predictors for an airmass dependent bias correction that is applied after scan dependent biases have been removed. A problem in using this procedure for a model such as the UK Mes, that has a small domain, is to accumulate enough reference data sampling representative weather regimes from which to compute the predictor coefficients. One possible solution is to accumulate the reference data over a long time period, say 1 year, but this assumes that the instrument drift is negligible. Since predictor coefficients are already generated for global ATOVS data using the global Met Office model, our solution is to use these values for bias correction in the UK Mes. This assumes that the two models are unbiased with respect to each other, and routine monitoring of the model bias with respect to observations of radiosondes confirms this, at least for the troposphere. Figure 2 demonstrates that the approach is successful for removing the majority of the bias between the AMSU radiances and the UK Mes background.

3. Data Assimilation

The UK Mes uses a 3D Variational scheme (3D-Var) to assimilate observations (Lorenz et al., 2000). AMSU data are assimilated in the form of bias-corrected radiances, in each case ignoring radiances from channels that fail the screening tests (Section 2.2). At the time of writing the current operational configuration uses the following data:

- station reports of pressure, temperature and visibility.
- upper level winds from aircraft.
- satellite atmospheric motion vectors from METEOSAT.
- profiles of winds, temperature and humidity from radiosondes.
- wind profiler data.

In addition, rain rate information from the UK rain radar network is supplied to the forecast model via a latent heat nudging scheme (Jones & Macpherson, 1997). A nudging scheme is also employed to supply moisture information from a cloud product derived from geostationary satellite images and surface reports (Macpherson et al., 1996).

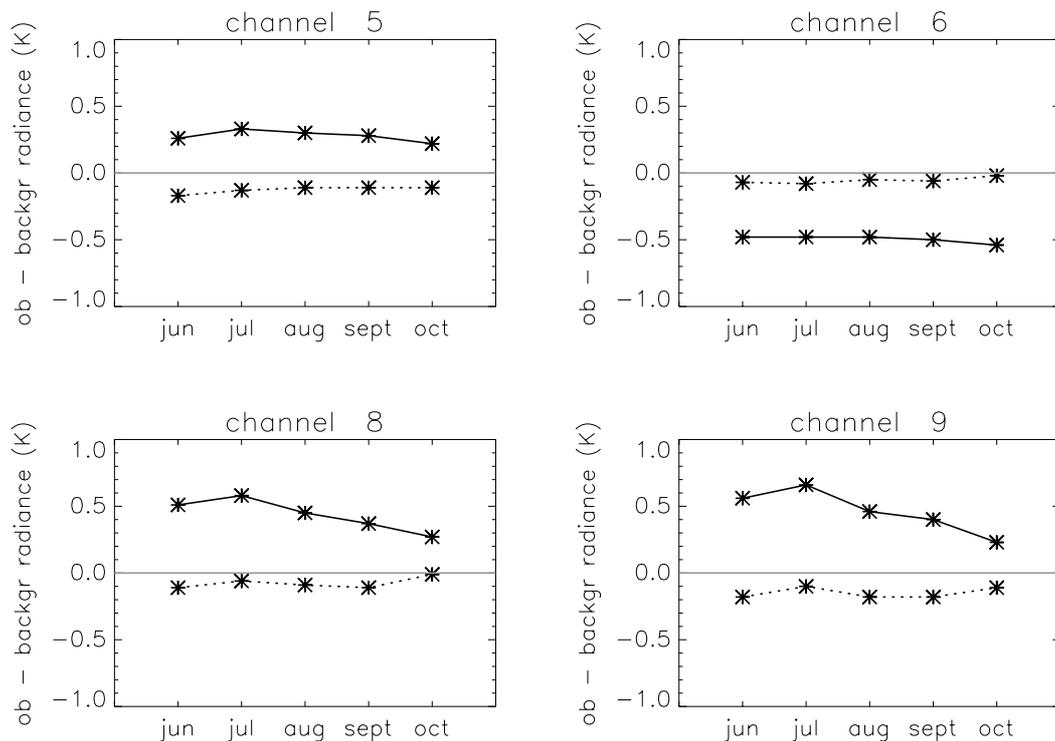


Figure 2: The monthly mean observation minus background difference over the UK Mes domain for several NOAA-17 AMSU channels during 2003. Uncorrected radiances are shown as solid lines and corrected radiances are shown as dashed lines.

4. Forecast Impact Experiments

4.1 Rationale

In a model such as the UK Mes the task of impact assessment for a new observation type can be a difficult exercise, owing to the small model domain. It is important to include enough cases so that a) the accumulated statistics on forecast performance are meaningful and b) a range of representative weather systems are sampled. We have taken a two-fold approach for AMSU data, firstly running a set of case studies that represent typical weather situations over the UK, including one that resulted in a poor operational forecast. Secondly an extended trial of AMSU data was also performed for the duration of one month. The extended trial allows us to measure the impact after the NWP system has adjusted to the presence of AMSU data. This trial was run in near real time in order to use boundary condition information from the operational global NWP model.

4.2 Rerun of a Poor Operational Forecast

On 1st October 2002 duty forecasters reported that a convective event moving across the English Channel from France had been underdeveloped by the model, leading to an underestimation in the strength of the resulting showers. Since the event was triggered in the Bay of Biscay, moisture information from AMSU-B could have been useful and to test this we reran the case including AMSU data in addition to the data used operationally. The assimilation/forecast system was run

for 36 hours prior to the rain developing over England and during this time eight overpasses were made over the area of interest by AMSU instruments onboard NOAA-16 and 17. Figure 3 shows the integrated water vapour in the model domain for the operational run and the trial including AMSU radiances. The zone of very humid air in the Bay of Biscay can clearly be seen and it is encouraging that the use of AMSU radiances has helped to moisten it.

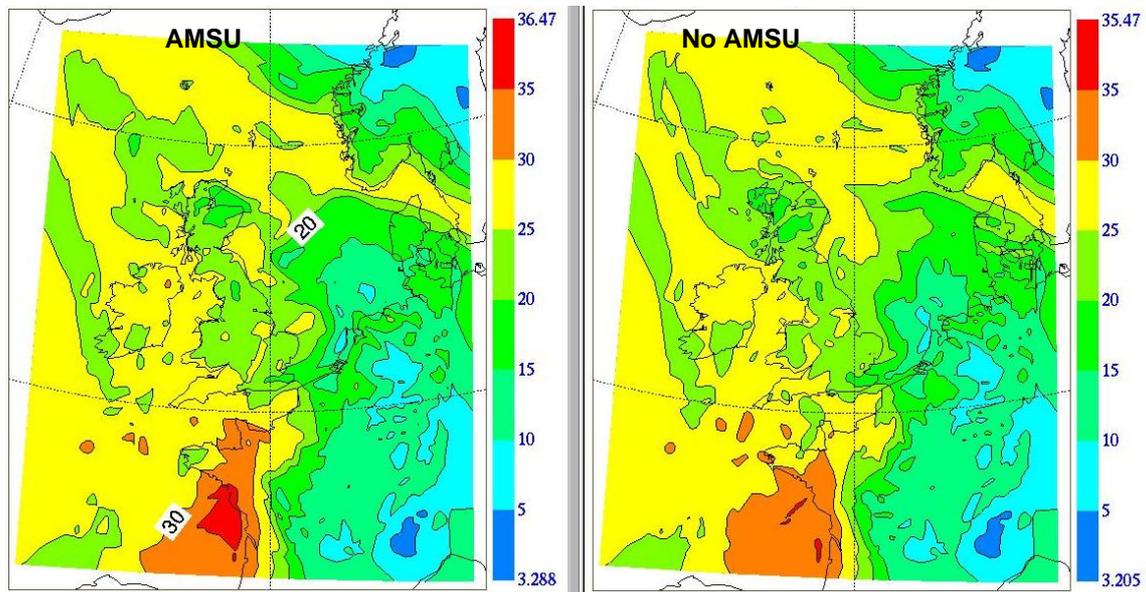


Figure 3: A comparison of the humidity analyses expressed as integrated water vapour (kgm^{-2}). *Left Panel:* Model run including AMSU assimilation. *Right Panel:* Model run without AMSU. Regions shaded in red indicate areas of integrated water vapour in excess of 30 kgm^{-2}

The resulting short-range rain forecast when the convective system is over Southern England is shown in Figure 4. The use of AMSU has increased the extent of the rain band which is encouraging. However the rain band is still underdeveloped when compared to the verifying radar data.

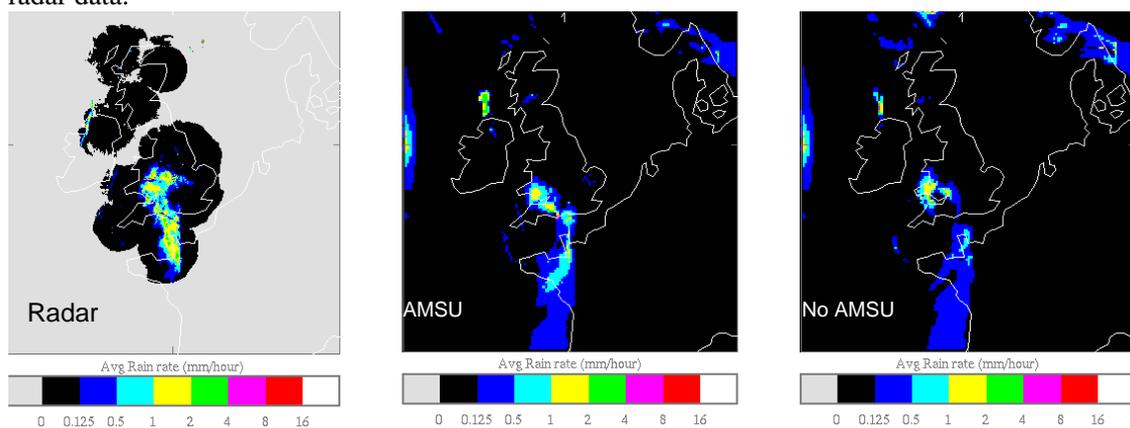


Figure 4: Short-range forecasts of model rain (accumulated between T+5 & T+6 and expressed as an average rain rate) compared to verifying data from the radar network.

4.3 Case Study Set

Twelve cases were chosen which incorporated a range of synoptic situations around the UK (e.g. active front, widespread stratocumulus sheets, etc.). For each case an experiment was run with twelve hours of assimilation including AMSU data, then a 36-hour forecast, and a further 12 hours of assimilation with another 36-hour forecast. Forecasts were then verified using station reports and statistics were produced from all forecasts for the following key meteorological parameters:

- windspeed at 10 m height & temperature at 1.5 m height as skill scores with respect to persistence.
- visibility, cloud cover and 6-hour precipitation accumulation as equitable threat scores (ETS).

The results from the experiment runs are compared to a set of control runs in which AMSU data were not assimilated in Table 1. The impacts are small with four of the parameters being either improved or neutral when AMSU is added.

Parameter	Control ETS / Skill	Trial ETS / Skill	Change
10m wind	0.750	0.750	0.000
1.5m temp	0.700	0.700	0.000
visibility	0.122	0.124	+0.002
cloud cover	0.266	0.263	-0.003
precipitation	0.322	0.323	+0.001

Table 1: Forecast accuracy compared between a set of experiment runs in which AMSU radiances were assimilated and control runs without AMSU data. Statistics were derived using forecasts generated from twelve diverse case studies.

There are several issues concerned with verifying by station reports. These include the sparse nature of their locations and that they are all located on land. Such problems may explain the small improvement to model precipitation forecasts when the moisture channels of AMSU are included. To test this idea the ETS for precipitation was recalculated using radar data as the verification source. Accumulations of precipitation over three hours from the model were compared with accumulations generated from the radar data, using frames such as that displayed in Figure 4. Note that a series of corrections are applied to the radar data to improve its accuracy (Harrison et al., 2000). Figure 5 presents these results as a function of forecast lead time. For the very short-range the precipitation skill of the model has been reduced when AMSU is assimilated, though at T+24 there is an improvement, according to the radar data.

4.4 Extended Trial

Prior to operational implementation an extended trial of one months duration was run. As before verification of the forecast fields was performed against station reports and the results are shown in Table 2. In this case three parameters improved slightly due to the inclusion of AMSU (visibility, surface temperature & cloud cover), whilst two were neutral (precipitation & surface windspeed). Humidity forecast fields were also compared and the mean difference is shown in Figure 6 as a vertical profile. This shows that the principle effect of the radiances is to moisten the

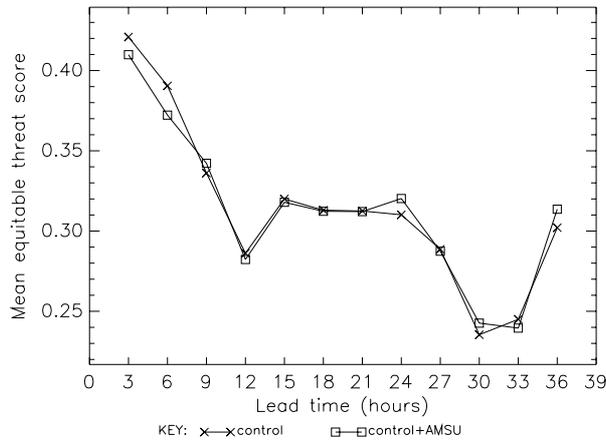


Figure 5: Equitable threat score of three-hour precipitation accumulation computed using radar observations as the verifying data. Rain/no rain threshold was set at an accumulation of 0.5mm.

Parameter	Control ETS / Skill	Trial ETS / Skill	Change
10m wind	0.740	0.740	0.000
1.5m temp	0.590	0.593	+0.003
visibility	0.113	0.117	+0.004
cloud cover	0.414	0.415	+0.001
precipitation	0.364	0.364	0.000

Table 2: Forecast accuracy compared between an extended run in which AMSU radiances were assimilated and a control run without AMSU data. Statistics were derived from data generated over one month.

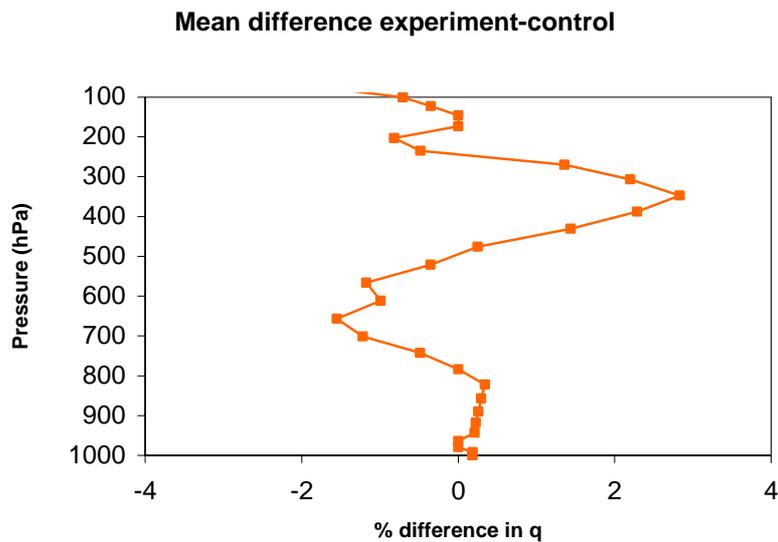


Figure 6: The mean difference (expressed as a percentage change) between the T+3 hour humidity fields for the extended trial. Experiment refers to the run with AMSU radiances.

model above 500 hPa and dry the model below this level. Note that the humidity fields are unchanged below 800 hPa which is consistent with the weighting functions of the 183 GHz channels on AMSU-B. The mean observation minus background difference for radiosonde data, taken from the operational monitoring database for the same period as the trial, shows that generally the radiosonde data have similar biases with respect to the model, namely that the model is too dry aloft and too moist below 400 hPa. This is very encouraging, implying that the radiosondes and radiances are trying to adjust the model in the same direction.

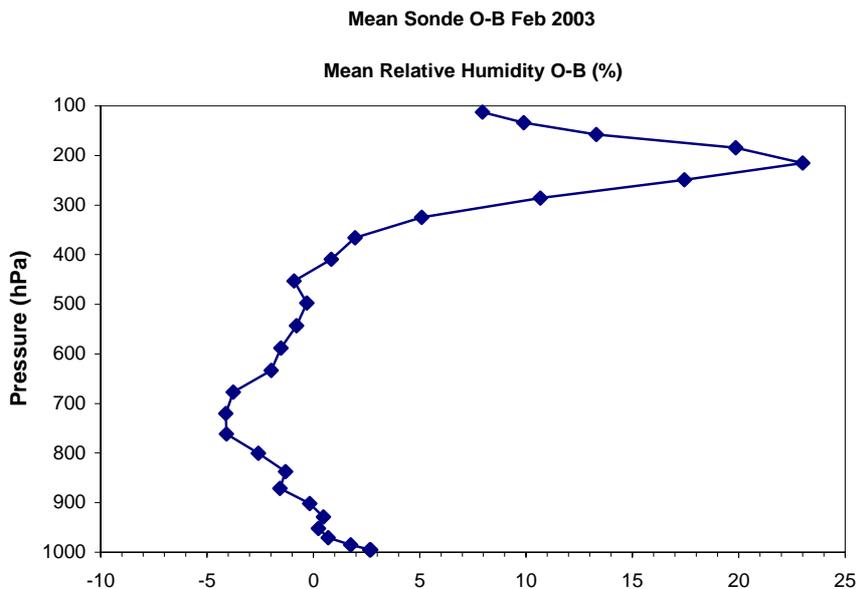


Figure 7: The mean difference between radiosonde observations of relative humidity and the operational UK Mes 3-hour background fields. Data is from 1030 radiosondes for the same period as the extended trial.

5. Conclusions

A series of impact studies have been performed to assess the impact of radiance data from the AMSU instrument in the UK Mes. The observations are pre-processed in a similar manner to those used in the Met Office global model. Generally the impacts on key forecast parameters were either small and positive or neutral. An extended trial of one months duration revealed that the mean analysis increments on the moisture field from the AMSU-B radiances are consistent with the information contained in the radiosonde data. A particularly encouraging result was the improvement of the moisture analysis for a convective event that was poorly handled by the operational model. Based on these results the operational use of AMSU data in the UK Mes commenced in March 2003.

Future work will focus on improving the impact on precipitation forecasts by using more AMSU data in areas of high liquid water path. This could be achieved by retrieving cloud liquid water information in 1D-Var preprocessing and passing it as fixed profiles into the 3D-Var assimilation. Deblonde & English (2003) discuss how cloud liquid water can be implemented in the 1D-Var

framework. Additionally we will investigate the use of channels whose weighting functions are affected by moisture in the boundary layer.

References

- Deblonde, G., and English, S. J. 2003. One-Dimensional Variational Retrieval from SSMIS Simulated Observations. *J. Appl. Meteorol.*, 42(10), 1406-1420.
- English, S. J., Renshaw, R. J., Dibben, P. C., and J. R. Eyre. 1997. The AAPP module for identifying precipitation, ice cloud, liquid cloud and surface type on the AMSU-A grid. *In Tech. Proc. 9th International TOVS Study Conference; Igls; Austria; 20-26 February 1997; Ed. J. Eyre.* Published by ECMWF, Reading, RG2 9AX, UK, pages 119-130.
- English, S. J., Renshaw, R. J., Smith, A. J., Poulsen, C., Whyte, K., Hutchings, J. K., and Jones, D. C. 2000. Current Status In The Assimilation of TOVS and ATOVS Radiances at the UK Met. Office. *In Tech. Proc. 11th International TOVS Study Conference; Budapest; Hungary; 20-26 September 2000; Ed. J. LeMarshall and J. D. Jasper;* Published by BMRC, PO Box 1289K, GPO Melbourne, Vic., 3001, Australia, pages 79-89.
- Eyre, J. R. 1992. A bias correction scheme for simulated TOVS brightness temperatures. *ECMWF Tech. Memo.*, 186. Published by ECMWF, Reading, RG2 9AX, UK.
- Harrison D. L., Driscoll, S. J., and Kitchen, M. 2000. Improving precipitation estimates from weather radar using quality control and correction techniques. *Met. Apps.*, 6, 135-144.
- Jones, C. D., and Macpherson, B. 1997. A Latent heat nudging scheme for the assimilation of precipitation data into an operational mesoscale model. *Met. Apps.*, 4, 269-277.
- Lorenc, A. C., Ballard, S. P., Bell R. S., Ingleby, N. B., Andrews, P. L. F., Barker, D. M., Bray, J. R., Clayton, A. M., Dalby, T., Li, D., Payne, T. J., and Saunders, F. W. 2000. The Met Office Global 3-Dimensional Variational Data Assimilation Scheme. *Q. J. Royal Meteorol. Soc.*, 126.
- Macpherson, B., Wright, B. J., Hand, W. H., and Maycock, A. J. 1996. The Impact of MOPS Moisture data in the UK Meteorological Office Mesoscale Data Assimilation Scheme. *Mon. Wea. Rev.*, 124, 1746-1766.