ASSIMILATION OF METEOSAT RADIANCE DATA WITHIN THE 4DVAR SYSTEM AT ECMWF

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ABSTRACT

Within a four-dimensional variational (4dvar) assimilation system it is possible to take advantage of the high temporal resolution of geostationary radiance data by assimilation of observations at times other than 00, 06, 12, and 18 Z, thereby providing information about the time evolution of the model fields. In this paper the results of initial experiments in the assimilation of Meteosat Water Vapour channel (WV) radiance data within a 4dvar assimilation system are presented. Comparisons are drawn with the direct assimilation of the Meteosat Clear Sky Water Vapour Wind (WVW) product. An initial investigation into the impact of both WV radiance data and WVW's on the assimilation and forecast system is made. Future plans leading to the operational assimilation of the Clear Sky WV radiance product within the ECMWF system are outlined.

1. INTRODUCTION TO 4DVAR

The variational method of data assimilation relies on the minimisation of an objective cost function *J(x)* with respect to an atmospheric state, *x*, which has the form, assuming Gaussian errors:

$$J(x) = J_o + J_b \tag{1}$$

where
$$J_o = ½ \, (y - H (x))^T (O+F)^{-1} (y - H (x)) \tag{2}$$

and
$$J_b = ½ \, (x - x_b)^T B^{-1} (x - x_b) \tag{3}$$

Here x_b is the background state with estimated error covariance *B*, *y* represents the observations with error covariance *O* and forward model error covariance *F*, and *H* is the observation operator. In the case of the incremental formulation of 4dvar, currently in use at ECMWF, the objective cost function is expressed as a function of the increment to be added to the background, δ*x*, such that

$$J(\delta x_0) = J_o + J_b \tag{4}$$

where
$$J_o = ½ \sum (d_i - H_i (\delta x_i))^T (O+F)^{-1} (d_i - H_i (\delta x_i)) \tag{5}$$

and
$$J_b = ½ \, (\delta x_0)^T B^{-1} (\delta x_0) \tag{6}$$

Here, for timestep *i*
$$d_i = y_i - H (x_i) \tag{7}$$

and
$$\delta x_i = M (t_i , t_0) \, \delta x_0 \tag{8}$$

is the increment evolved according to the tangent linear model (M) (Rabier *et al.*, 1996). Consequently, in 4dvar the observation operator H includes a model integration from the time of the background to the time of the observation. Therefore there is an explicit coupling in J_o between changes in specific humidity and the model wind field. However due to the current formulation of B, humidity and other model variables are assumed uncoupled in J_b .

2. BIAS CORRECTION

Routine monitoring of Meteosat WV brightness temperatures against simulated brightness temperatures, calculated from ECMWF first-guess fields, using the fast radiative transfer model, RTTOV-5, has been carried out from November 1996 until the present. For the duration of Meteosat-5 and the early period of Meteosat-6 there was very little mean bias between the measurements and simulations. However, since May 1997 a significant bias has developed, the source of which is not well understood. This bias is apparent for both Meteosat-7 and Meteosat-5 (now positioned at 63°E) data. Consequently these data must be bias corrected before they can be used in the operational assimilation system. The bias correction system currently in use for NOAA TOVS data has been applied to the Meteosat WV radiances. The correction scheme used is a modification of the original scheme described in Eyre (1992). In the new scheme, the air-mass correction is determined on the basis of the following selected model predictors: model thickness 1000 - 500 hPa; model thickness 200 - 50 hPa; model surface skin temperature; and model total column water vapour. The statistics of "observation - first guess" departures are accumulated and a linear regression applied to determine the coefficients of the air-mass bias correction in terms of these predictors. Applying this bias correction procedure to both Meteosat-5 and Meteosat-7 radiance data independently results in good correspondence between the two residual bias fields and results in a composite bias corrected field which is spatially coherent (Fig. 1).

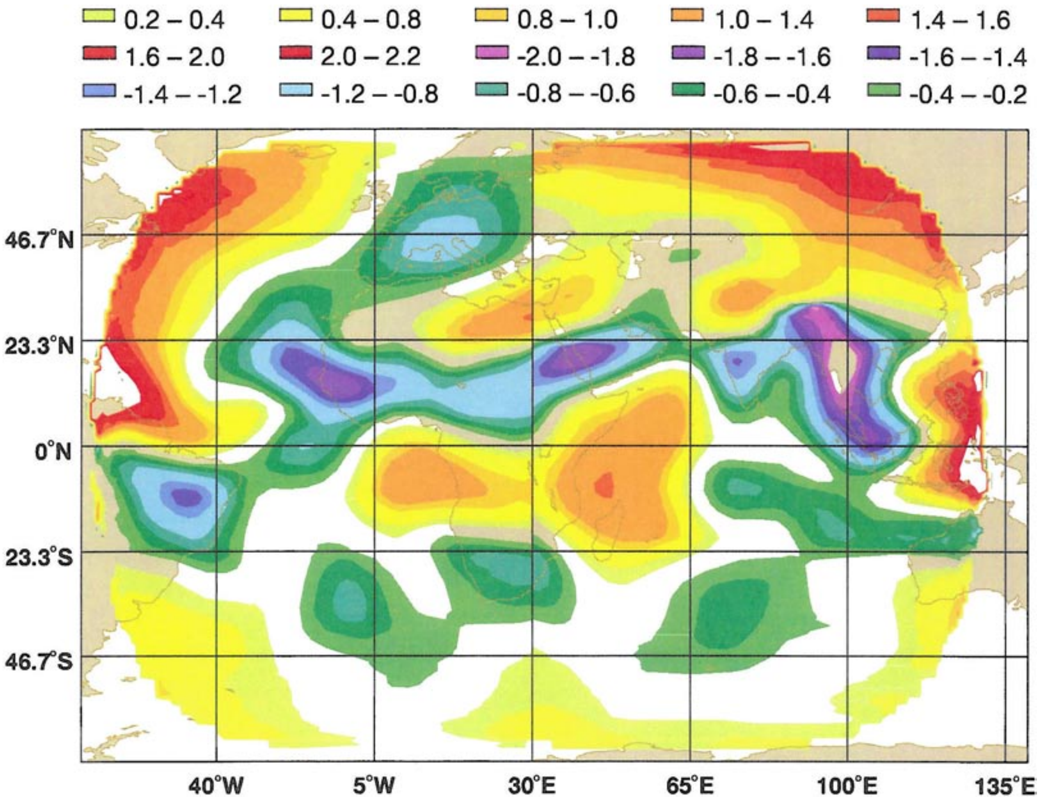

FIGURE 1. Mean difference between Meteosat-5 and Meteosat-7 WV channel brightness temperatures and those simulated from first guess fields for a period from 1st July to 31 July 1998.

3. DESCRIPTION OF EXPERIMENTS

Three experiments have been set up as part of a preliminary investigation into the impact of Meteosat WV channel radiance data on the 4dvar assimilation system. These are a control, an experiment in which Meteosat radiance data are assimilated directly, and one in which the derived Clear Sky WVW product is assimilated. All three experiments cover the period from the 2nd of July, 1998 to the 13th of July 1998, and are extensions of the current operational ECMWF 4dvar assimilation system.

3.1 Control

The control experiment uses RTTOV-5, the new version of the RTTOV radiative transfer model which is based on 43 atmospheric levels and includes a gradient in humidity up to 0.1hPa. (In the previous version of RTTOV there was a gradient in humidity only up to 300hPa. This was clearly inadequate for the assimilation of WV channel radiance data where the peak of the weighting function is typically around 300hPa.) Both Meteosat-5 and Meteosat-7 Cloud Motion Winds are included as for current operations (Lalaurette *et al*., 1998). Also, TOVS radiance data and SSMI Total Column Water Vapour data are assimilated.

3.2 Clear Sky Radiance Assimilation

In the radiance assimilation experiment, the segment processed clear sky radiance data from both Meteosat-5 and Meteosat-7 are assimilated. The clear sky radiance product comprises 32 x 32 pixels, corresponding to approximately 150 x 150 km at the sub-satellite point (SSP), increasing to a maximum of approximately 250 x 250 km at 50° from the SSP. See Kelly *et al*. (1996) for further details. No thinning is carried out with the exception that no over-lap is allowed between the two satellites. In the over-lap region, Meteosat-7 data are used for longitudes ≤ 30°E and Meteosat-5 data are used for longitudes > 30°E. Before being passed to the main assimilation, the radiance data are preprocessed in a 1dvar retrieval in which those profiles which have an “observation - first guess” difference greater than 8K are rejected, as are those which fail to converge within the 1dvar system.

3.3 Clear Sky Water Vapour Wind Assimilation

In this experiment the clear sky WVW product provided by EUMETSAT is assimilated. Again, data from both Meteosat-5 and Meteosat-7 are used. These data are received every 90 minutes and assimilated in hourly windows. They are thinned (Rohn *et al.*, 1998) and as for the radiance data, no overlap is allowed. Data are not used over land if the height assignment is **<** 500mb and Meteosat-7 data is not used over land for latitudes > 35°N. Finally, data are only assimilated if they have a quality indicator, assigned by EUMETSAT, greater than 0.8. Note that in this experiment the WVW’s are assimilated as a single level vector using the EUMETSAT height assignment provided. This is a simplistic use of the data which will be improved in the future (Kelly *et al.*, 1998).

4. INITIAL IMPACT INVESTIGATIONS

Although the clear sky radiance product and the clear sky WVW product may be considered to contain similar information, when viewed in the context of a 4dvar assimilation system, they cannot be considered to contain *identical* information. The information contained in the radiance product regarding the evolution of the wind field is implicit and depends on the time evolution of the clear sky radiance product rather than its instantaneous state. Conversely, the WVW’s contain explicit information, influenced by assumptions implicit in their derivation. Since this derivation relies on explicit tracking of clear sky targets the coverage is not uniform and there are areas where it is not possible to produce a wind product. Despite these differences it is possible to make general comparisons and draw preliminary conclusions regarding the relative impact of these two data types.

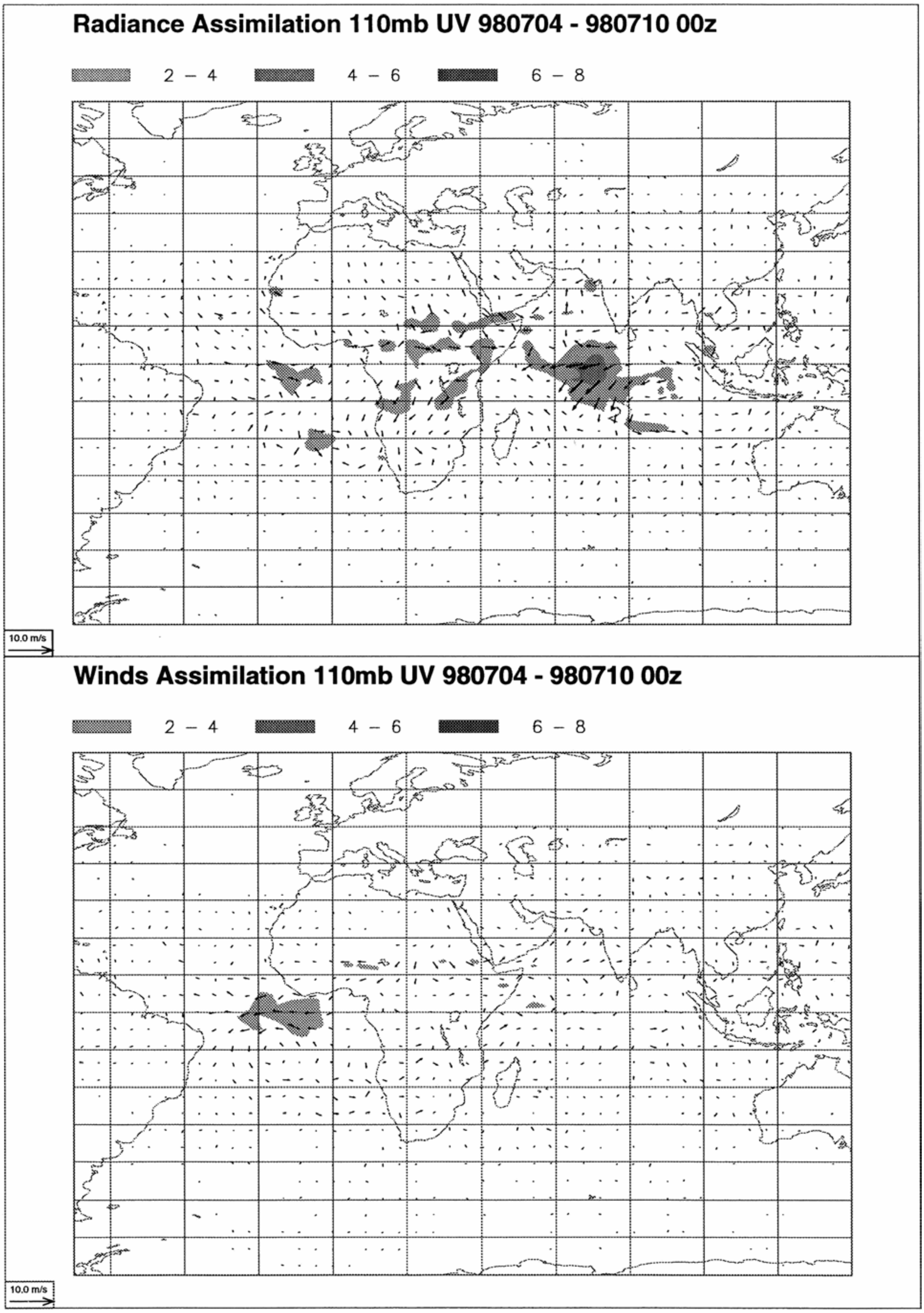

FIGURE 2a. 110mb vector wind difference fields for the radiance experiment minus the control (upper panel) and the wind experiment minus the control (lower panel). The differences are calculated from mean fields for the period 4th July 1998 to 10th July 1998.

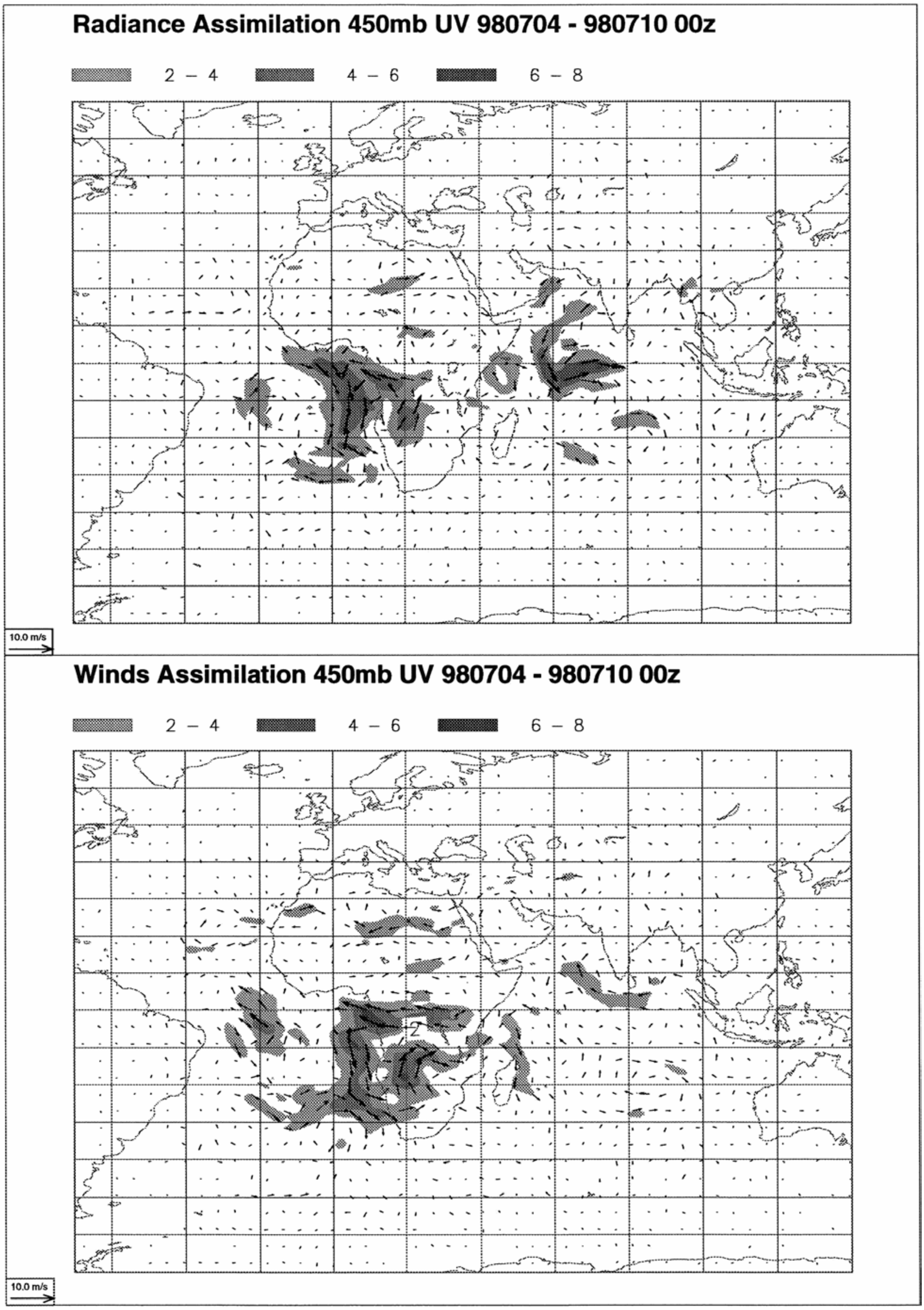

Figure 2b. 450mb vector wind difference fields for the radiance experiment minus the control (upper panel) and the wind experiment minus the control (lower panel). The differences are calculated from mean fields for the period 4th July 1998 to 10th July 1998.

4.1 Mean Analysis Differences

For each experiment the mean analysis fields have been generated for the period from 4th July 1998 to 13th July 1998. The first two days of each experiment have been excluded to avoid any “spin up” problems while the model adjusts to the new data. Mean difference fields were then generated between the radiance assimilation and the control, and the winds assimilation and the control.

To investigate the impact of each data type on the model dynamics the obvious field to consider is the vector wind field. Fig. 2 shows the vector wind difference field for the radiance experiment minus the control, and the wind experiment minus the control. Two levels are shown corresponding to 110mb and 450 mb. The contours show the speed associated with the vector difference field. As shown, where there is an impact from the WVW’s there is often a similar impact from the radiance data. However the radiance experiment does show greater influence in some areas (the Indian ocean for example) which may be related to data coverage in the WVW product. Also, the vertical response is different for the two experiments. In the case of the WVW’s experiment, the data is assimilated at a single level which is dictated by the height assigned to the product by EUMETSAT. Any vertical spreading of information comes primarily from the vertical correlation of the background error in the vector wind field. In contrast, the vertical information provided by the direct assimilation of WV channel radiance data comes both from the weighting function implied by RTTOV-5, and also from the vertical correlation in the background error in specific humidity. These differences result in a very different vertical response between the two experiments with the radiance experiment typically showing a larger vertical spread of information extending from 500mb to 200mb or higher and the winds experiment having more localised changes centred around 450mb.

These features are also apparent in the response of the specific humidity field. Whilst the radiance assimilation shows a large scale moistening in the region 200-300mb, the winds assimilation shows a smaller scale moistening at lower altitudes, typically 350mb. At lower altitudes both experiments show significant changes to the moisture field but there is no mean drying or moistening. A similar pattern is seen in the temperature fields with a large scale cooling from 200-300mb from the radiance data but more localised temperature changes resulting from the assimilation of the WVW’s.

4.2 Verification

One way to verify an assimilation experiment is to compare with observations. For both the radiance assimilation and the winds assimilation the RMS fit of the model first guess to the conventional observations was similar. However, after assimilation of the WV radiance data, the RMS fit of the model first guess to the Meteosat WV data itself was significantly improved (Fig. 3a). This is encouraging as it demonstrates that the model has drawn well to the radiance data without degrading the fit to the conventional observations. The assimilation of the WVW’s has not, however, significantly altered the RMS fit to the Meteosat WV channel data (Fig. 3b). Furthermore, after assimilation of WV channel radiance data significantly less residual bias remains between the measurements and the first guess fields as shown in Fig. 4, further confirming that the model has drawn well to these data. A number of forecasts have been run for each experiment. In both cases scores were essentially the same compared to the control although a greater number of samples are required for a meaningful comparison.

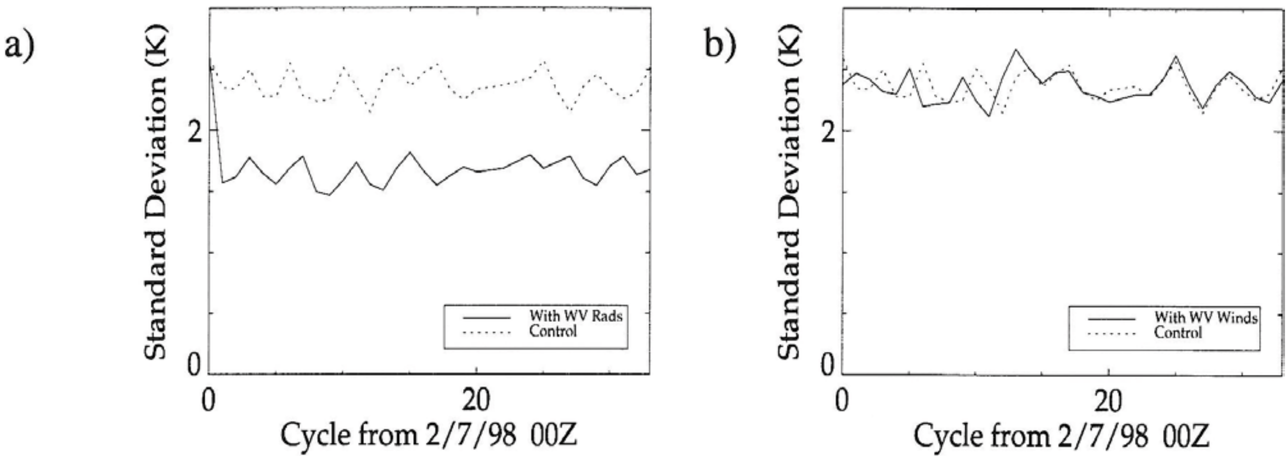

FIGURE 3. Standard deviation of the difference between Meteosat-7 WV channel brightness temperatures and simulated brightness temperatures based on first guess fields a) after assimilation of WV radiances b) after assimilation of WV winds.

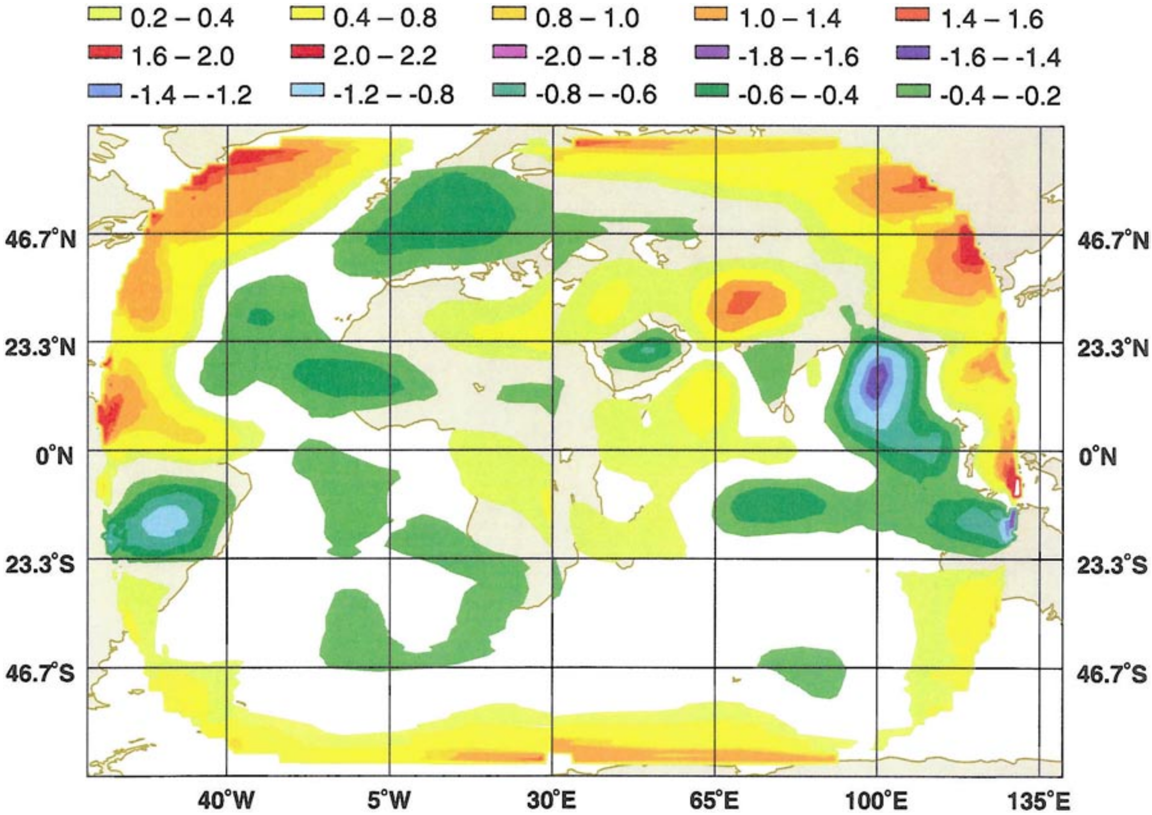

FIGURE 4. Mean difference between Meteosat-5 and Meteosat-7 WV channel brightness temperatures and those simulated from first guess fields for a period from 2nd July to 13th July 1998, after assimilation of WV channel radiance data.

5. SUMMARY AND FURTHER WORK

These preliminary results clearly show that the direct assimilation of geostationary WV channel radiance data, within a 4dvar variational assimilation system, may be used indirectly to correct the model dynamics in the upper troposphere. A broadly similar response may be obtained from the assimilation of the associated Clear Sky Water Vapour wind product however differences in data coverage and height assignment will result in differences in impact. Before a full investigation can be carried out there are several areas where improvements are required for optimal use of both the radiance and the wind data. Some problems that will affect the WV radiance data assimilation are as follows. There are known deficiencies in the specification of the 4dvar background error for specific humidity under certain conditions. This will be corrected in the near future. Furthermore, in the specification of the background cost, humidity is uncoupled to other model variables in the current operational configuration. Including a correlation between temperature and humidity in tropical regions would be desirable. Finally, although RTTOV-5 has an improved gradient for the WV channel, there is still room for improvement and this should be investigated. With regard to the WVW product, it would be desirable to develop a more sophisticated method for describing the vertical distribution of information (Kelly *et al.*, 1998) which more realistically represents the thick layer from which the information has come. Another change planned at ECMWF which will interact with this work is the move to a model with many more levels (~60) which will take place in the near future. Once these improvements have been completed and more detailed impact studies carried out it is hoped that the operational assimilation of Meteosat WV radiance data can be implemented at ECMWF.

6. REFERENCES

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