IMPACT OF RAIN ASSIMILATION ON THE ECMWF ANALYSIS AND FORECAST

V Marecal and J.-F Mahfouf
European Centre for Medium Range Weather Forecasts, Reading, UK

1. INTRODUCTION

Future spaceborne missions with nadir pointing lidar and radar should provide vertical profiles of cloud properties such as water content. Such global information should be useful for validating the parameterisation of clouds within operational numerical weather forecasting models. In addition, there is the potential for assimilating the data into the operational numerical weather prediction models to provide a better estimate of the true state of the atmosphere for initialising forecasts. In this note we report on first results of assimilating rainfall data from the recently launched TRMM satellite into the ECMWF analysis and forecast. The passive microwave imager (TMI) provides an estimate of rainfall rate with a 720km swath. A fuller account of the rainfall assimilation technique is provided in Marecal and Mahfouf (2000). One can envisage a similar approach might be taken for assimilation of the cloud data from a future satellite

2. ASSIMILATION OF THE TRMM RAINRATES.

ECMWF uses an operational four dimensional variational (4D-Var) analysis system with an assimilation window of six hours. At present humidity data provided operationally to the assimilation system are specific humidity profiles below 300hPa from radiosonde data, relative humidity from the surface ntetwork, and total column water vapour in non-rainy areas obtained from SSM/I brightness temperatures over the ocean. The 4D-Var assimilation involves minimising the cost function J(x) given by:

$$J(x) = 1/2\,(x - x_b)^T\, B^{-1}\,(x - x_b) + 1/2\,[H(x) - y_o]^T\, R^{-1}\,[H(x) - y_o]$$

where x is the vector which represents the atmospheric state, x_b is the background or first guess from the model for x (given by a short-range forecast), B is the background error covariance matrix of the model, R is the observation error covariance matrix, and H is an observation operator used to compute what the observations (y) would be for model variables x,

$$y = H(x).$$

and y_o are the actual observations. Essentially we are finding a model state which is a weighted mean of the first guess and the observations, where the weighting is given by the error covariances.

Corresponding author address: Virginie Marecal, European Centre for Medium Range Weather Forecasts, Shinfield park, Reading RG2 9AX. email: virginie.marecal@ecmwf.int

Because a direct assimilation of rainrates in 4D-Var would require important technical developments, a simpler 1D-Var approach has been adopted to make a first estimate of the impact of TRMM rainfall measurements on the forecasting system. In this 1D-Var method, observations of surface rainrate R_o with an observation error σ_o (assumed to be 25% of R_o) are used to minimise the cost function:

$$J(x) = 1/2\,(x - x_b)^T\, B^{-1}(x - x_b) + 1/2\,[(R_o - R_b)/\sigma_o]^2$$

where x_b are the first guess of the temperature (T) and humidity (q) profiles which produce the 'first guess' surface rainrate R_b. The result of minimising the cost function is to produce temperature and humidity profiles adjusted with appropriate weighting to give a model rainfall closer to that observed. However, because there is an uncertainty in the vertical distribution of humidity provided by 1D-Var, the adjusted profile itself is not used, but instead the total column water vapour derived from the adjusted 1D-Var profile is assimilated in the full 4D-Var scheme.

The assimilation studies reported here have been carried out with the $T_L319L50$ version of the ECMWF global spectral model which has about 60km horizontal resolution and 50 vertical levels. The model uses specific humidity and temperature as prognostic quantities from which the rainfall rate is diagnosed. The surface rainrates from the TMI microwave imager aboard the TRMM satellite are collected during the 6-hour period of the 4D-Var assimilation window and averaged over the model grid boxes to be consistent with the model resolution. During each six-hour period there are four orbits each with a 720km swath. The result of the 1D-Var analysis is to modify the model first guess rainfall, R_b, to a value closer to the observed rainfall R_o. However, if the observations show rainfall in an area where the model has none, then the 1D-Var approach cannot trigger rainfall, and accordingly the 1D-Var technique tends to have rainfall which is biased low compared with the observations.

3. PERFORMANCE DURING TWO WEEK PERIOD.

Two experiments were carried out one for a 'Control' run and a second where 'TMI' rainrates are assimilated for the two weeks 18 August 1998 to 2 September 1998 which coincided with the hurricane Bonnie. An analysis over the whole tropical region for the two week period revealed that the total column water vapour for the 'TMI' analysis differed from the 'Control' analysis, with, as expected, the regions where water vapour was removed being larger than those where it was augmented. A measure of the impact of the data assimilated is provided by the root mean square (RMS) increments in the water vapour column being introduced by each assimilation cycle at each grid box. This RMS error was found to be significantly lower for the 'TMI' experiment when compared with the 'Control' indicating that the TMI analyses were closer to the true state of the atmosphere. Another performance indicator is to compare the rainfall rate for the two analyses with the TMI observations. Again a significant improvement was found; the 'Control' experiment had a mean rainfall rate 2mm/day greater than observations with an RMS error of 17.1mm/day, but the 'TMI' analyses reduced the mean error to 1.73mm/day with an RMS error of 16.2mm/day.

4. COMPARISONS WITH HURRICANE BONNIE.

The analysis of the track of the Hurricane Bonnie over the period 20 August - 27 August was improved in the 'TMI' experiment compared to the 'Control' experiment. Figure 1 shows the five-day forecast of the track of this hurricane produced on the 21 August for both experiments. The 'TMI' forecast had a better track than the 'Control' with a trajectory shifted westward and a reduced advection speed. These comparisons show that an improved humidity structure can also have an appreciable affect on the dynamics.

4. FUTURE WORK

These initial tests have shown a significant improvement in analysis when the TMI rainfall data are introduced into the model by assimilating a more realistic total water vapour column. The next step is to study the sensitivity to the observation error of rainfall which has been assumed to be 25% of the observation and to extend the analysis to other time periods. The encouraging improvement shown by assimilated adjusted total water vapour column, suggests that it would be worth while investing the resources to develop a scheme in which the surface rainrate was directly assimilated into model.

The study above gives some indication of how profiles of cloud properties could be assimilated into the model. At present satellite observations of clouds are only assimilated to derive cloud motion winds; the satellite images of cloud cover are not used. A future satellite providing vertically resolved cloud information should be much more valuable.

The TMI data was available over a wide swath which encompassed many model grid boxes, but in contrast to this the narrow swath of the radar and lidar will only provide a slice of cloud profile characteristics which is much narrower than the size of grid box. One issue will be how representative this slice is of the mean values across the grid box, but this may be compensated by the fact that cloud is much more widespread than precipitation. The ECMWF model currently carries cloud water content as a prognostic variable and so there is scope for assimilating the satellite derived profiles of cloud water content into the model.

References:
V Marecal and J.-F Mahfouf: Variational retrieval of temperature and humidity profiles from TRMM precipitation data. Submitted to Monthly Weather Review.

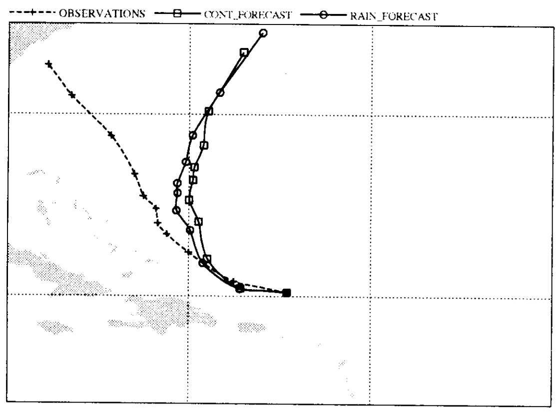

Figure 1: Forecast of Bonnie track from 21 August 1998 at 12UT. Squares correspond to the control experiment, circles to the TMI assimilation experiment and + to the observed track. Symbols are displayed every 12 hours.