The Impact of Targeted Satellite Observations on Weather Prediction

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Abstract

ATOVS observations, which are passive microwave soundings of temperature and humidity, provide a near-homogeneous global coverage. In this study they are used to investigate the impact of targeting satellite data through several case studies.

Cases are selected because of the sensitivity of their forecasts to a change in ATOVS density at the initialising time. The forecasts are produced from an analysis which is a combination of observations and a background field i.e. a six hour forecast from the previous analysis. Therefore altering the observations used in the assimilation process changes the analysis and hence the forecast. Sensitive regions in the analysis can be identified by tracing back forecast differences which develop as a result of a change in ATOVS density at the initialising time. The size of the target region, the targeting observational network and the density of the observations within the target region are investigated and their forecasts compared to the control forecast which is produced using global high density ATOVS observations at the initialising time.

The other component used in the assimilation process is the background field. This can be altered by changing the density of observations prior to the initialising analysis. This has an impact on the information reaching the background field and hence the analysis. The time window required to enhance the information content of the background field is investigated by comparing forecasts made with high-density observations using different time windows with a control forecast produced using global high density ATOVS for several days prior to the initialising time.

The results from these experiments are presented.

Motivation

Large volumes of satellite data are available for use in Numerical Weather Prediction but only a small fraction of these data are incorporated into the assimilation process, partly due to limits in available processing power. This problem will become more acute as much larger volumes of satellite data become available, e.g. from advanced infra-red sounders. Methods are needed to select observations which contain the most useful information and one such method is targeting observations in sensitive areas. A sensitive area is a region in the atmosphere where uncertainties in the initial conditions can result in large uncertainties in the forecast. Increasing the number of observations in this region should increase the accuracy of the initial conditions and hence the forecast (Lorenz and Emanuel 1998). There are many methods for identifying sensitive regions (Bishop et al. 2001 and Palmer et al. 1999) and several field campaigns, such as FASTEX (Montani 1999) and NORPEX (Langland et al. 1999), have demonstrated the potential benefits of targeting observations. The aim of this research is to identify the possibilities and impact of targeting satellite data. The conventional observational network is quite dense over regions such as Europe but it is still limited or missing in many areas, particularly over the oceans and southern hemisphere. ATOVS observations, which are passive microwave soundings of temperature and humidity (Saunders 1993), provide a near-homogeneous global coverage, and
they are used here to investigate targeting strategies which maximise the benefit obtained from a restricted number of additional observations.

**Experiment Design**

Case studies are used to investigate two aspects of targeting; the size of the target region and the length of time a region should be targeted. The case studies are selected because of the sensitivity of their forecasts to a change in ATOVS density at the initialising time. The forecasts under investigation are produced from an analysis constructed using three-dimensional variational assimilation (3DVAR). 3DVAR (Lorenc et al 2000) combines the observations from a six hour period with a background field (i.e. a short range forecast) to produce an optimal estimate of the current state of the atmosphere, the analysis. This representation of the state of the atmosphere is then used in the forecast model as the initial conditions from which the forecast is made. The forecasts are produced using a global version of the Met Office Unified Model (UM) which has a resolution of ~60x60km$^2$ (Davies et al 2005). The inclusion of targeted observations alters the observations used in the assimilation process changing the analysis and hence the forecast.

The sensitivity of the forecast to a change in ATOVS density is determined by producing two 48 hour forecasts, one from global low density ATOVS (thinning distance=308km) and the other from global high density ATOVS (thinning distance=154km). Areas containing significant differences between the two forecasts can then be designated verification regions i.e. regions of particular interest in the forecast.

The case study under investigation is the forecast of a low pressure system north-west of Scotland, shown in figure 1b. The difference between the forecasts produced using global high and low density ATOVS is greater than 2hPa in the verification region, shown by the green box in figure 1a, and we investigate the reduction in this difference by using targeted high density ATOVS. To identify the sensitive region in the analysis associated with this verification region the differences in the forecasts can be traced back to the analysis time and the surrounding area divided into grid boxes. In turn, each of the grid boxes is filled with high density ATOVS while the surrounding regions contain low density ATOVS. A new forecast is produced and each of these trial forecasts can then be compared to the control forecast which is produced using global high density ATOVS. The grid box containing the sensitive region is defined as the one which produces the forecast which most closely resembles the control forecast in the verification region.
Having established the location of the sensitive region the size of the target region can then be investigated. The size of the grid box containing the high density ATOVS is varied around the known sensitive region and the new forecasts produced are again compared to the control forecast. The smaller the difference between the two forecasts in the verification region the greater the amount of information, relevant to this region, is captured by the additional observations in the target region. The results from these experiments are shown in figure 2.

The average modular forecast difference between the trial and control forecasts initially decreases rapidly as the size of the target region increases, however, once a threshold of approximately $1.0 \times 10^6 \text{ km}^2$ is reached the additional information gained by covering a larger area
appears to have little impact on the forecast in the verification region. The results indicate that the size of the target region is most cost-effective when $1.0 \times 10^6 \text{km}^2$.

Another component used in the assimilation process is the background field and this is a six hour forecast from the previous analysis. This background field can be altered by changing the density of observations prior to the initialising analysis. This has an impact on the information reaching the background field and hence the analysis. The time window required to enhance the information content of the background field is investigated and demonstrates the potential of targeting not only at the initiating analysis but also at earlier analyses. As the time window for targeting is varied new forecasts are produced and these are compared to the control forecast produced using global high density ATOVS several days prior to the initialising time. Comparing the differences between the trial forecasts and the control forecast in the verification region indicates how long a region should be targeted prior to the initialising analysis. The results from this case study are shown in figure 3. The results show the average modular forecast difference, in the verification region, plotted against the number of hours during which high density ATOVS observations are included in the assimilation process. One assimilation cycle collects observations over a six hour time window. Therefore when high density ATOVS observations are included for 24 hours prior to the initialising analysis this corresponds to 30 hours in total, 6 for the construction of the initialising analysis plus the 24 hours prior to that cycle. The results in figure 3 indicate that a targeting time window of 30 hours (i.e. 24 hours prior to the initialising analysis) appears to capture the majority of the improvement to the background field.

Another important aspect of targeting observations is the density of the observations used in the target region. As the thinning distance of ATOVS observations is decreased and the density of observations increases the accuracy of the analysis is expected to increase due to the inclusion of additional information. However, beyond a certain threshold the analysis begins to be degraded due to the effects of horizontal correlations in the observation errors (Liu and Rabier 2002). It is therefore important to establish the optimal thinning distance, to reduce forecast errors in general but also to provide an upper limit of ATOVS density for use in the target regions. The optimal thinning distance has been investigated by finding the average global forecast error over a 3 week period for a range of different thinning distances. The forecast error is calculated by verifying forecast fields for a range of variables against the analysis. These forecast errors are then combined to produce an average over the whole range of variables. The average forecast errors are then compared with the forecast error from a new control experiment which has a thinning distance of 308km. Figure 4 shows the difference between the trial and control forecast errors as a percentage of the control forecast error. The results follow the expected pattern. Initially the forecast error drops as the thinning distance in reduced and more observations are included. This is shown by the negative values in the plot which demonstrate that the new
forecast error is smaller than the control forecast error. However, once the thinning distance reaches approximately 120km the graph upturns demonstrating that the drop in the forecast error is decreasing again. When the thinning distance reaches 50km the percentage change to the control forecast error becomes positive demonstrating that the forecast error for this thinning distance is actually greater than the control forecast error. Although the higher number of observations provide more information, the horizontal error correlations have become strong enough to degrade the analysis and hence the forecast. These preliminary results suggest that the optimal thinning distance for ATOVS observations is 120-150km and therefore the current operational thinning distance of 154km is a good estimate.

Figure 4: Relative change in forecast error as the thinning distance of ATOVS is varied.

Conclusions

These experiments demonstrate that a forecast can be produced using targeted high density ATOVS which, in the verification area, closely resembles the control forecast. It demonstrates that similar forecasts can be obtained using targeted observations but with a much lower computational cost. For the case study shown here the most cost-effective size of the target region is $1.0 \times 10^6 \text{km}^2$. By adding high density ATOVS to a target region of this size the forecast difference drops, on average, by approximately 50%.

When investigating the length of time to target a region with additional observations the results indicate that a targeting time window of 24 hours obtains the majority of the additional information in the background field, enhancing the quality of the analysis. By including global high density observations for a period of 24 hours prior to the production of the initialising analysis, the forecast difference, in the verification region drops by an average of 60%. This therefore suggests that there may be a substantial benefit to forecasts when including targeted high density ATOVS for 24 hours prior to the initialising analysis.

The preliminary results from the ATOVS density experiments indicate that the current thinning distance of 154km provides a balance between the positive effect of including more observational information and the negative effect of horizontal correlations in the observation errors. Further investigation is required to determine if there are scenarios where the minimum thinning distance of 120km can be safely exceeded.

References


