

# Numerical Weather Prediction

A quality control scheme for visibility observations



Forecasting Research Technical Report No. 460

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## **A quality control scheme for visibility observations**

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### **Version History:**

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1.0	14-04-2005	Andrew Lorenc	First Issue version 1.0

## Abstract

Visibility is difficult to forecast due to its highly non-linear dependence on relative humidity, cloud liquid water and aerosol and the often localised nature of areas of poor visibility. The Met Office operational UK mesoscale and North-Atlantic European models carry aerosol as a prognostic variable, and surface visibility reports are assimilated by a 3D-VAR scheme, giving increments to moisture, aerosol and temperature. Visibility is one of 5 weather parameters used as key indicators of model performance.

Until recently visibility observations have undergone no quality control. The high spatial variability of visibility and the relatively poor quality of model forecasts mean that standard techniques like the buddy and background check are inappropriate for use with visibility data. This, together with the known problems associated with the visibility observation network, has motivated the development of the new quality control scheme described here. It has two main parts; a consistency check with collocated observations of other variables and a check to remove visibility observations affected by precipitation.

In the consistency check, the reported relative humidity, temperature and pressure are combined with the model's upper and lower limits for 'realistic' aerosol content to give a range of 'acceptable' visibilities. The range is widened by a factor allowing for the error of representativeness in visibility observations, important close to saturation when sensitivity to aerosol content is weaker and a small error in observed humidity could wrongly cast doubt on the accuracy of the observed visibility.

Typically, around 10-15% of observations are rejected by the consistency check. 3D-VAR minimisation is some 5% faster. A significant reduction is found in the unrealistic peaks in aerosol fields caused by assimilation of low visibilities and low relative humidities. The results of case study and real-time trials show that the scheme's overall impact on forecast skill is minimal - over an extended 3-month trial period, the equitable threat score for visibility was reduced by 1.5%, with an overall neutral ( $<0.1\%$ ) impact on the 5-variable UK NWP index.

The new scheme became operational in the North-Atlantic European model on 22<sup>nd</sup> February 2005.

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# 1. Introduction

Visibility is an important component of meteorological forecasts but is not often included in operational Numerical Weather Prediction (NWP) models as a prognostic or diagnostic parameter. This is mainly due to the complex dependence of visibility on relative humidity, cloud water and aerosol. In the Met Office mesoscale model (Macpherson *et al*, 2001), visibility data are assimilated using the Variational Assimilation System (VAR, Lorenc *et al*, 2000) but with no specific quality control.

In the following pages a new quality control for visibility is described (section 2). Tests on the quality control are outlined in section 3 and results are presented in section 4. Section 5 describes the latest modification to the quality control; to reject visibility observations made during periods of precipitation, by the inclusion of present weather observations in the visibility quality control. Section 5 also explains the motivation and the various code changes that were necessary to include present weather observations. The testing for this modification was completed separately to the general development tests (Section 3) and therefore a brief description of the tests and the results is also given in section 5.

## 2. The visibility quality control

In this section the methods used to observe visibility and the problems that arise are discussed in order to highlight the need for quality control of visibility observations. The system used for pre-processing observations in the Met Office and the motivation for the development of a new quality control for visibility observations is given. The principle and the development of the quality control is described in the latter part of this section.

### 2.1 Visibility Observations

Visibility can be observed manually by an observer or automatically using specific equipment. Visibility is defined as

*‘The greatest distance (in metres) at which an object in daylight can be seen and recognised if the illumination was raised to daylight levels.’ (Royal Met Soc, Specialist group on observing systems, 2003).*

Until recent years all surface observations including visibility have been performed manually with the observer reading the instruments at a set time and making visual estimates of visibility and cloud. Manual visibility observations involve an observer at ground levels checking to see if known reference points are visible around the horizon circle. Automated systems are now much more common and reduce the human involvement required in observing considerably. Even when stations are manned on a 24-hour basis, the tasks of reading the instrument, processing the result, encoding the message and transmitting the data are all automatic. The observer still has the facility to over rule any observation that may be obviously wrong but automatic observations are now an accepted component of weather reports.

Automatic visibility observations are made by forward scatter visimeters, which measure the visibility at a point location. This is in contrast to manual observations that provide the lowest visibility around the station location. The Met Office currently own and maintain 137 Belfort 6230A visibility sensors positioned at weather stations throughout the UK (Tom Butcher, personal communication). These sensors measure the extinction coefficient, which is a measure of the attenuation of luminous flux by both scattering and absorption. Forward scatter meters, however, do not measure absorption relying on the fact that scattering accounts for most extinction. The extinction coefficient is then expressed as the Meteorological Optical Range (MOR). MOR is defined as the length of the atmosphere over which a beam of light travels before the luminous flux is reduced to 5% of its original value. A disadvantage of visimeters is that they are not capable of measuring the minimum visibility in any direction; they can only estimate the visibility at the station point location. Visimeters are therefore unable to detect features such as low-lying fog banks and showers not at the station location.

## 2.2 Motivation for quality control

Automatic stations have to be maintained on a regular basis in order to prevent deterioration in the quality of the observations reported. Visiometers appear to be particularly susceptible to maintenance problems which can seriously affect the quality of the data. Dirt on the lens of the instrument, condensation inside the lens or spiders' webs forming between the sensors of the instrument can cause the visibility to be consistently underestimated (Tom Butcher, personal communication). Other problems can also occur with automatic visibility sensors, in particular there are occasions when visiometers are found to be reporting constant visibilities or have an artificially low upper limit of, for example, 8km (Moseley and Brown, 2003).

As the proportion of automated visibility observations used in the assimilation increases, this fuels the need for the pre-processing of visibility observations to monitor and remove visibility observations in the event of both persistent and intermittent observation errors. Relative humidity has a large impact on visibility as illustrated in Figure 1. In general when the relative humidity is low the visibility is high and when a low visibility is observed the relative humidity observation is likely to be close to saturation. The likelihood, is that those observations that do not follow this pattern will be incorrect.

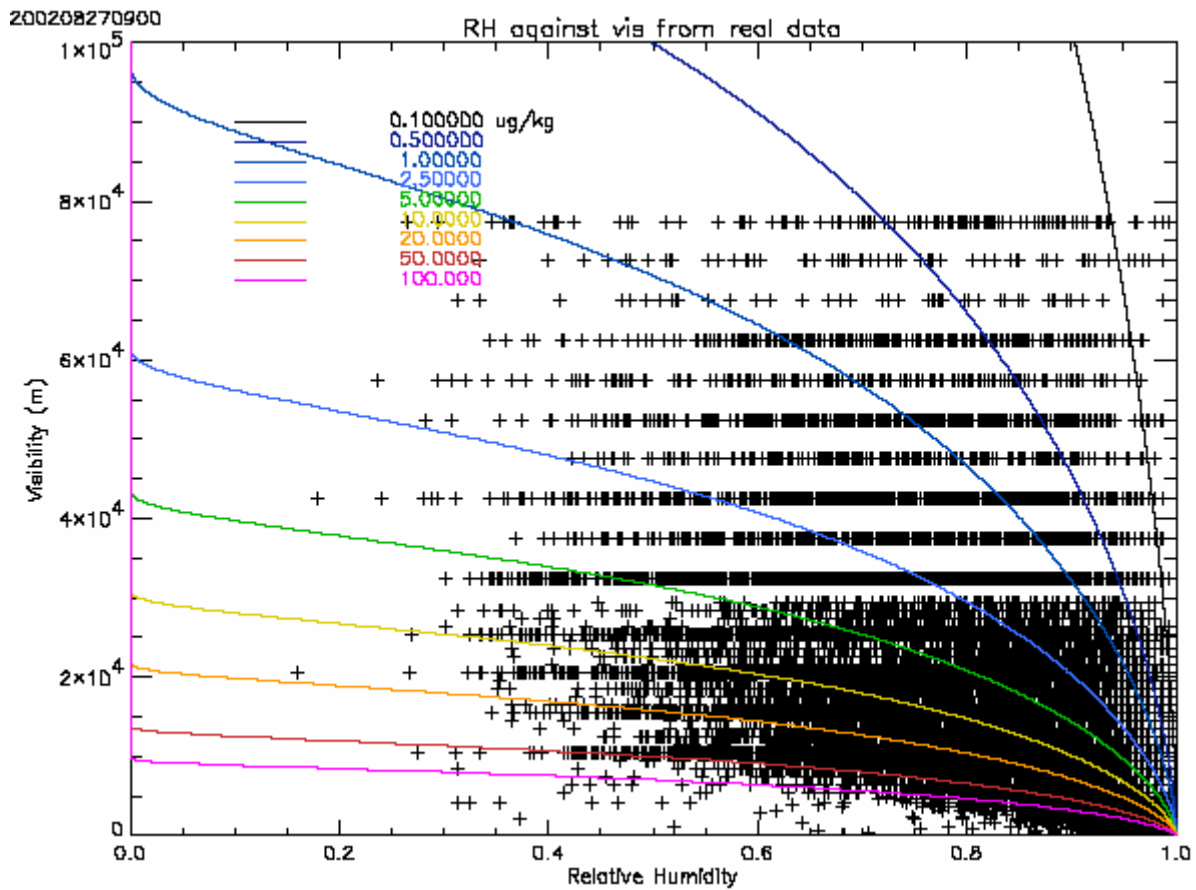


Figure 1 illustrates the relative humidity (RH) observations versus the visibility (vis) observations. Isopleths of the visibility versus the relative humidity have been plotted using the theoretical relationship used in the mesoscale model and a range of aerosol values (Moseley and Brown, 2003).

The background and buddy checks are the main quality controls used in the Observation Processing System (OPS), see Ingleby (1998). These are used to quality control observation types such as temperature and pressure. The background and buddy checks are not appropriate for quality controlling visibility because of its high spatial variability and poor forecast quality at the coarse resolutions available. Hence, there are currently no measures taken within the OPS to remove visibility observations that are inconsistent with other observations on which visibility depends. Data outside the ‘envelope’ of realistic aerosol parameters (Figure 1), together with the known problems with the instruments that measure visibility provide ample motivation to develop a quality control scheme for visibility.

## 2.3 Principle of the visibility quality control

Visibility is calculated in the Unified Model (UM) using the specific humidity, cloud liquid water, temperature, pressure and aerosol. (The UM also allows for the effect of precipitation on visibility, but we ignore this aspect until section 5) The visibility quality control uses relative humidity, temperature and pressure observations and the aerosol parameters specified in the UM to calculate a range of plausible visibility values. The minimum and maximum aerosol concentrations allowed in the UM are  $0.1 \mu\text{gKg}^{-1}$  and  $1000 \mu\text{gKg}^{-1}$  respectively. In the visibility quality control, however, the maximum aerosol is specified to be  $100 \mu\text{gKg}^{-1}$  because  $1000 \mu\text{gKg}^{-1}$  is generally considered too large (S. Moseley, personal communication). The maximum aerosol is used alongside the relative humidity, temperature and pressure observations to define the minimum visibility ( $\text{vis}_{\min}$ ) and the minimum aerosol is used to define the maximum visibility ( $\text{vis}_{\max}$ ). Each observation is tested against the values of  $\text{vis}_{\min}$  and  $\text{vis}_{\max}$  and if the observation  $\text{vis}_{\text{obs}}$  lies outside this range

$$\text{vis}_{\min} < \text{vis}_{\text{obs}} < \text{vis}_{\max}, \quad (2.1)$$

it is rejected. The quality control relies on the accuracy of the other observations in order to calculate a realistic range. Therefore, where any of the relative humidity, temperature or pressure values are rejected previously the reliability of the visibility observation cannot be checked and so no quality control is performed.

## 2.4 Visibility Observation Error

Initial tests of the quality control revealed that in some cases a high proportion (eg 24%) of observations were rejected. This prompted modifications to the scheme to allow it to be relaxed subject to further testing. The method adopted was the inclusion of visibility observation error in the range calculation to allow for representivity errors in the observations. Visibility varies considerably on the sub-grid scale and therefore any point observation of visibility will not be representative of the grid-box average leading to representivity error.

This greater leniency is particularly important where relative humidity observations are close to saturation as this makes the range particularly small (see Figure 3). Extending the range prevents large numbers of visibility observations from being rejected on the basis of the relative humidity observations, which may not be accurate enough close to 100%. The quality control routine inverts a multiple of the visibility error ( $\text{vis\_ob\_err}$ ) given in terms of  $\log_{10} \text{vis}$  to give the factorial error in visibility. This factorial error is then incorporated into the calculation of the upper and lower limits of the visibility range, so that observations are assimilated if

$$\frac{\text{vis}_{\min}}{10^{\text{vis\_ob\_err}}} < \text{vis}_{\text{obs}} < \text{vis}_{\max} * 10^{\text{vis\_ob\_err}}. \quad (2.2)$$

The observation error is estimated in terms of  $\log_{10} \text{vis}$  to be 0.25 and this value is used in (2.2), although larger multiples could be used to flag fewer data. The range of implied representivity error, as stated by Golding (personal communication) and reported by Harcourt (2001), is between 0.18 and 0.34.

## 2.5 Developing the visibility quality control

### 2.5.1 Location of scheme for quality controlling visibility observations

Observations always require some level of pre-processing before being assimilated into the model. In the Met Office, observations are processed in the Observation Processing System (OPS). The OPS is responsible for data extraction, thinning, quality control and the conversion of data into the correct format for further processing.

The quality control schemes ensure that observations that are not consistent are removed before being fed into the variational assimilation scheme. Visibility depends on other surface observations: relative humidity, temperature and pressure; these are quality controlled before being used in the calculation of the visibility quality control. The location of the visibility quality control in the sequence of surface processing steps must consider the processing required for these other observations to avoid introducing inconsistencies into the model.

The observed surface pressure is first adjusted to the level of the model surface before it is then used in the saturation vapour pressure routine required by the relative humidity calculation. The surface temperature correction involves taking the temperature up to a different height (model orography) from that of the dewpoint. The surface temperature is therefore corrected after relative humidity is calculated to avoid introducing inconsistencies between the dewpoint and the temperature values used.

Visibility is therefore quality controlled before the temperature is corrected but after the relative humidity is calculated. This means that the same temperature is used in both the visibility range calculation and the relative humidity calculation.

### 2.5.2 Development of the visibility quality control scheme into the OPS

The visibility quality control code was developed by the introduction of routines used in the UM to calculate visibility. The UM visibility routine requires the specific humidity ( $q$ ), which is calculated from the observed relative humidity, and the saturation vapour pressure ( $q_s(T, p)$ ) for the observed temperature and pressure.

$$q = RH * q_s \quad (2.3)$$

The specific humidity is then used in the calculation of liquid water ( $q_l$ ) which is also required by the visibility routine:

$$q_l = (RH_{Tot} * q_s) - q \quad (2.4)$$

The total relative humidity ( $RH_{Tot}$ ) is calculated via the Smith scheme (Smith *et al*, 1992) in two steps. First, the cloud fraction is calculated from the observed relative humidity and then the cloud fraction is used to derive the total relative humidity. Ice content is not included in this calculation due to the rarity of freezing fog events in this country. The dependence of visibility on precipitation rate, although included in the UM, is ignored in this quality control application (see Section 5 for treatment of observed precipitation).



### 3 Testing

The visibility quality control was tested in two ways. A selection of case studies was used to test the behaviour of the code and enable the analysis of the effect of the quality control at different stages of the forecast process. The limited number of case studies did not provide sufficient evidence, however, to make any firm conclusions concerning the effect of implementing the quality control on the forecast. Therefore a real-time trial was also run to assess the effect of the quality control on the skill of the forecast over an extended period and therefore a larger range of conditions.

#### 3.1 Case studies

The visibility quality control was tested on 5 case studies that were selected for their varying visibility conditions. Each case study was run using a 12 hour assimilation period followed by a 36 hour forecast for the 00Z and 12Z analysis times. Each case study was run with

- no visibility assimilation,
- visibility assimilated using no quality control,
- visibility assimilated using a quality control with no observation error,
- visibility assimilated using a quality control with one observation error in equation 2.2 (a more lenient quality control).

The case studies were run with and without the assimilation of visibility data to provide a benchmark for any deterioration or improvement in the forecast as a result of implementing the quality control. The five case studies were selected from 2001 and 2002.

- The 25<sup>th</sup> August 2001 was an example of a clear summer day and the 31<sup>st</sup> December 2001, a clear winter night.
- The 22<sup>nd</sup> September and 14<sup>th</sup> October 2001 were radiation fog episodes.
- The 28<sup>th</sup> March 2002 was a large scale fog episode, which was widely reported in the media due to the number of accidents it caused on the M40 motorway.

#### 3.2 Real-time trial

The trial was run from mid-September 2004 until the end of February 2005, though most results presented here come from the first 31 day period from 13<sup>th</sup> September 2004 until 18<sup>th</sup> October 2004. Version 20/1.4 of the OPS was used throughout. A control and trial were run simultaneously for the whole period. The control run used no quality control, therefore all the visibility data were assimilated. In the trial the quality control was switched on with one observation error specified (see section 4.1.4). The results of this trial are presented in section 4.2.

### 4. Results

The results are divided into two sections. In the first section a brief summary is given of the general findings from running the 5 case studies described earlier. A more in depth analysis of the results from the different runs of the case studies can be found in Sharpe (2004). The second section summarises the results from the verification of the forecasts of the real-time trial.

#### 4.1 Case studies Results

The effect of the quality control was considered at three main stages of the forecast process for each of the five case studies: The effect on the data going into the assimilation, on the assimilation itself and on the forecast.

#### 4.1.1 The effect of the quality control on data going into the assimilation

This was analysed by considering the proportion of observations rejected by the quality control. The quality control that did not include the observation error was the most stringent, rejecting on average approximately 12% of observations. The quality control that did include the observation error rejected approximately 8% of observations, ensuring that inconsistent observations were removed whilst reducing the probability of good data being rejected. The observations rejected followed a distinct pattern, with more observations rejected during night and early morning runs than during day-time runs. This feature of the quality control is illustrated in Figure 2.

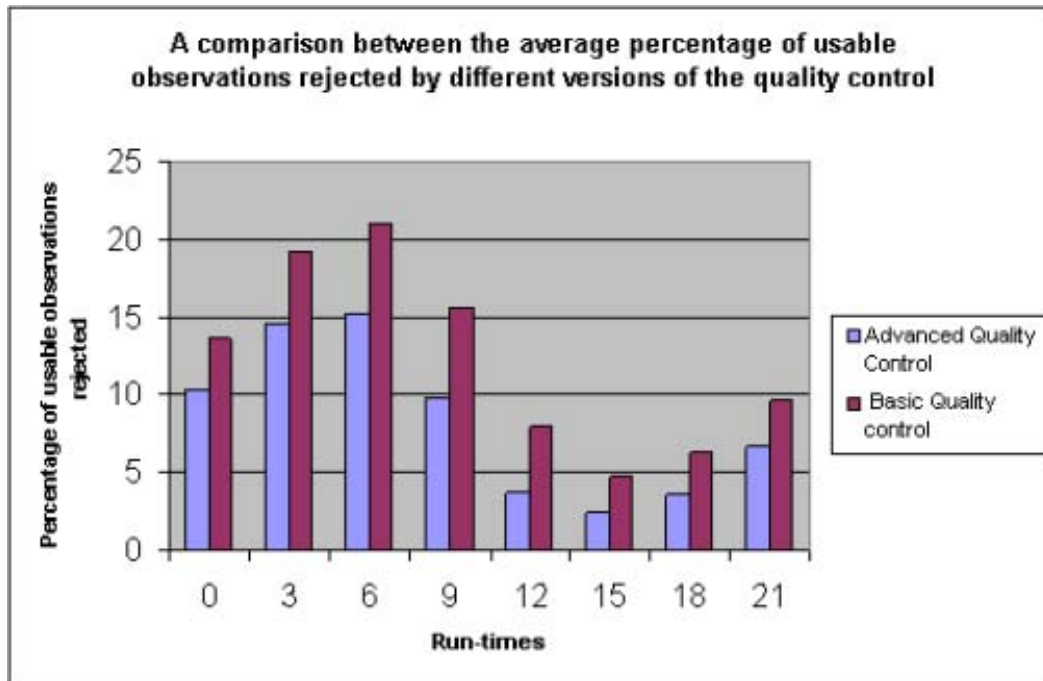


Figure 2 Illustrates the pattern of flag allocation for different run-times for both the quality control without the observation error (basic) and with the observation error (advanced) quality control.

One explanation for this high flag allocation during the morning runs could be due to the relative humidity observations. In general relative humidities are highest when the temperatures are lowest during the period just before sunrise. As the relative humidity observations approached saturation, the ranges of acceptable visibilities calculated by the quality control were reduced significantly (See Figure 3). Therefore a larger proportion of visibility observations were rejected regardless of the accuracy of relative humidity observations. The behaviour of the visibility quality control when the relative humidity observation is close to saturation illustrates the high sensitivity of visibility to relative humidity and the need for accurate relative humidity observations for the reliable quality control of visibility observations. The inclusion of the visibility observation error extended the range and allowed more observations to be assimilated even when the relative humidity was acting to reduce the range. In general the proportions of observations rejected at both ends of the visibility range were similar ie combinations of high relative humidity and large visibility were about as common as low relative humidity and low visibility.

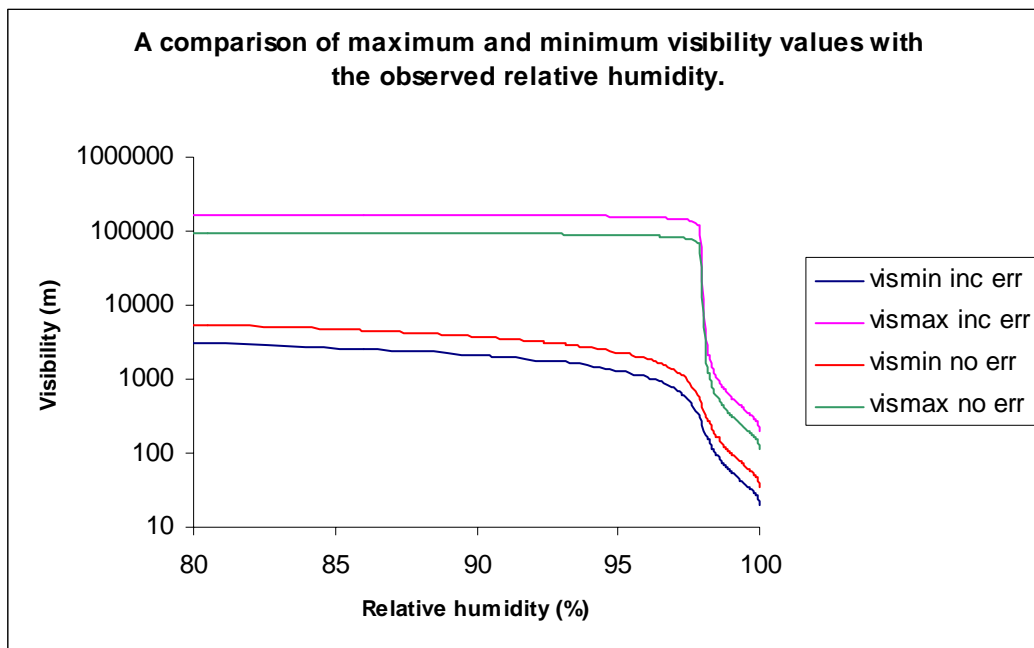


Figure 3 illustrates the large drop in the allowed visibility range as the relative humidity observations approach saturation. The quality control including the error (purple and blue lines) is shown in the same graph as the quality control not including the error (red and green lines) to show the difference in the range as a result of including the observation error.

#### 4.1.2 The effect of the quality control on the assimilation

The effect of the quality control on the assimilation was analysed by considering the number of iterations to convergence with and without the two quality controls. The fit of the background to the observations and the fit of the analysis to the observations were also compared for each of the runs.

In most, but not all cases, the quality control without the observation error reduced the number of iterations to convergence in the variational analysis. The quality control including the observation error, however, reduced the rate of convergence in all cases but not always to a greater extent than that observed when the observation error was not included in the calculation. The percentage reduction in the number of iterations averaged over all the case studies was approximately 6% for both versions of the quality control tested.

The quality controls, with or without the observation error, had very little impact on the fit of the model to the observations. This was indicated by measures such as the root mean square of the background or the analysis minus the observations. The runs with the fewest rejections showed the smallest change in the fit to observations. The fit to background values were very similar for the quality controlled runs with or without the observation error. The analysis values had a better fit when the visibility data was quality controlled. A more satisfactory result would have been that the fit of the background to the observations was improved for the quality controlled data, as this would have indicated that the background verified better against independent observations.

Figures 4 and 5 are examples of the typical visibility fields produced at the analysis time of 12Z or 00Z after a 12-hour assimilation. No visibility data is assimilated over the sea, so any visibility differences observed over the sea are due to the propagation of increments from over the land. Figure 4 is a summer case (25<sup>th</sup> August 2001) and Figure 4 is from an autumn case (14<sup>th</sup> October 2001).

Figure 4a is from the control run where all the data was assimilated and Figure 4b is from the quality controlled run where the observation error was included. Figure 4a and 4b are in general very similar with the areas of low visibility largely in agreement between the two plots. However the blue and purple regions, indicating the low visibility areas, are slightly different when the quality control is used. In particular the region of low visibility stretching North East from the East coast of Britain covers a smaller area in Figure

4b, than in Figure 4a. In Figure 4b, where the quality control is implemented, this region is split into three smaller areas of low visibility.

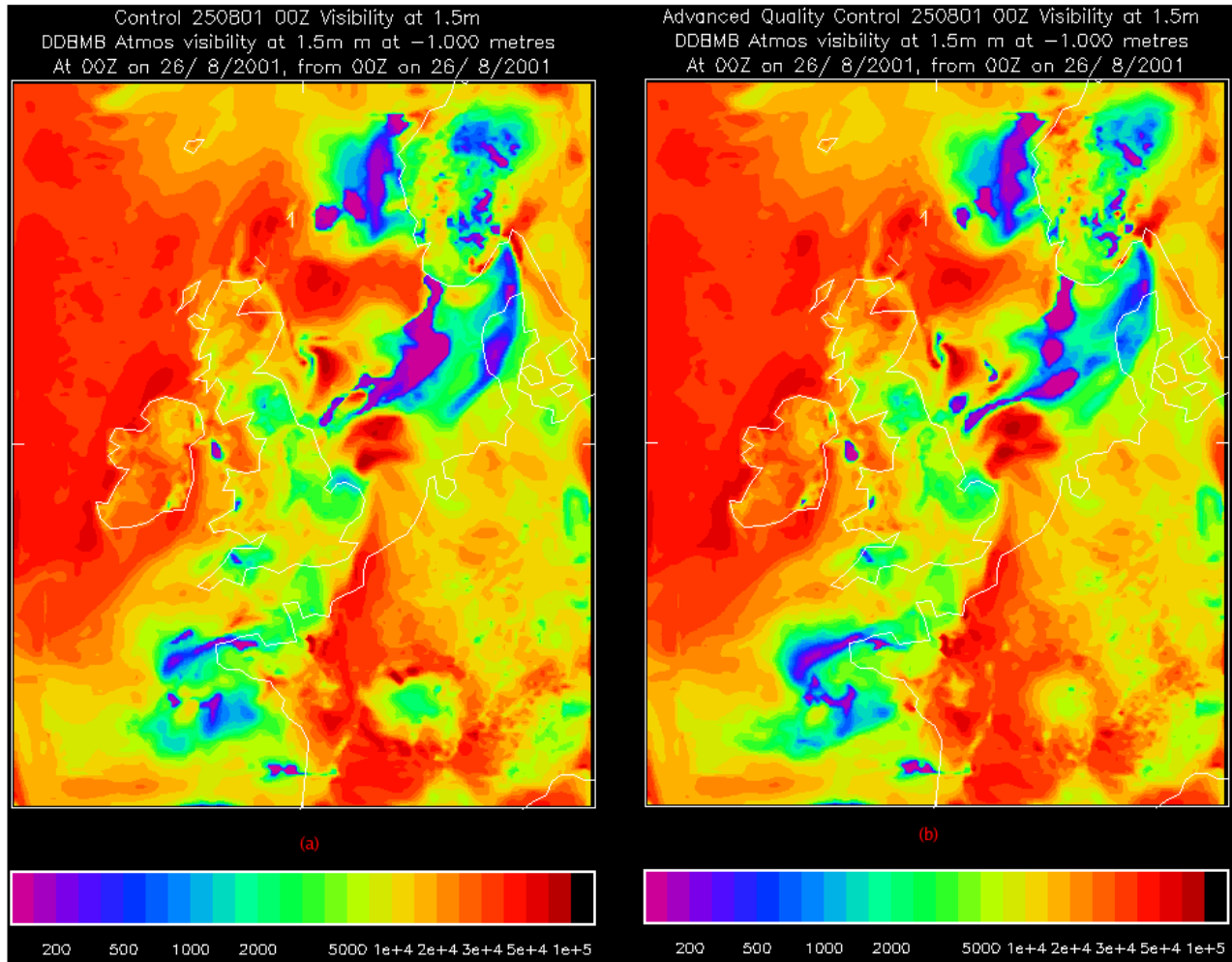


Figure 4 shows the analysis visibility fields from the 25<sup>th</sup> August 2001 for the 00Z analysis time with all the visibility data (a) and with quality controlled visibility data (b). In plot (b) approximately 12% of the observations were removed by the quality control. The colour bar is displayed below the plots indicating that the scale is logarithmic.

Figure 5 shows a similar pattern to Figure 4 with the control visibility field (Figure 5a) and the quality controlled visibility field (Figure 5b) showing similar regions of lower visibility. In general the quality controlled field shows smaller areas of low visibility compared with the control, however the lowest visibility regions are broadly the same.

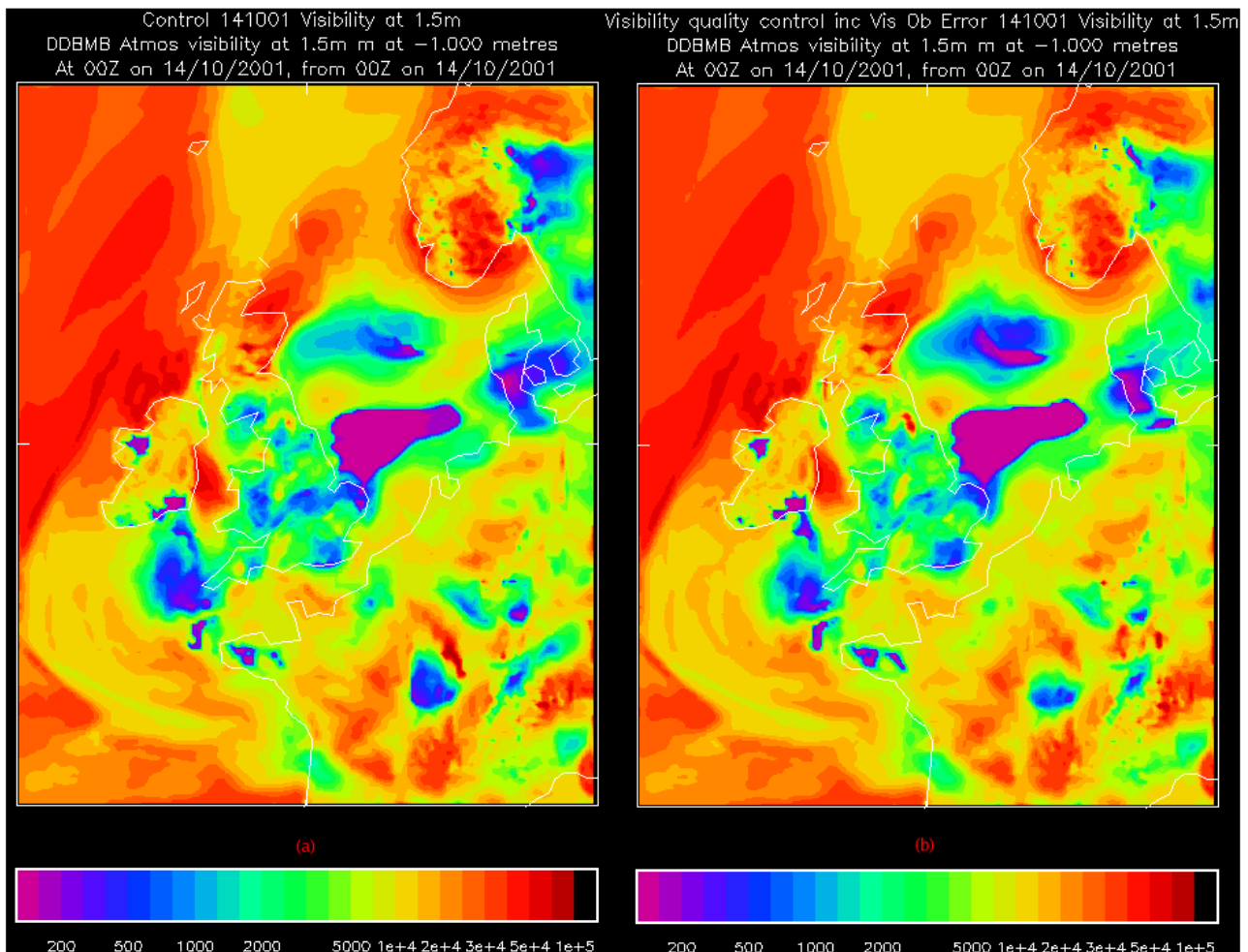


Figure 5 shows the analysis visibility fields for an episode of radiation fog from the 14<sup>th</sup> October 2001 for the 00Z analysis time with all the visibility data (a) and with quality controlled visibility data (b). In plot (b) approximately 12% of the observations were removed by the quality control. The colour bar is displayed below the plots indicating that the scale is logarithmic.

#### 4.1.3 The effect of the quality control on the forecast

The effect of the quality control on the forecast is the most important factor in the implementation of a quality control. This was analysed by comparing the Equitable Threat Scores for visibility for each of the forecasts generated by each case study. The aerosol fields for each of the runs were also compared.

Figure 6 provides a visual comparison of the average scores for the different runs of the code for each case study alongside a composite for all of the case studies. Figure 6 shows that for the case studies used the average forecast skill, when using the quality control with and without the visibility observation error, were almost equal. There was a slight decrease in skill compared with the control run for both quality controls; however, the reduction was less when the observation error was included in the calculation. The number of cases and the small size of the skill reduction mean that the signal cannot be regarded as statistically significant.

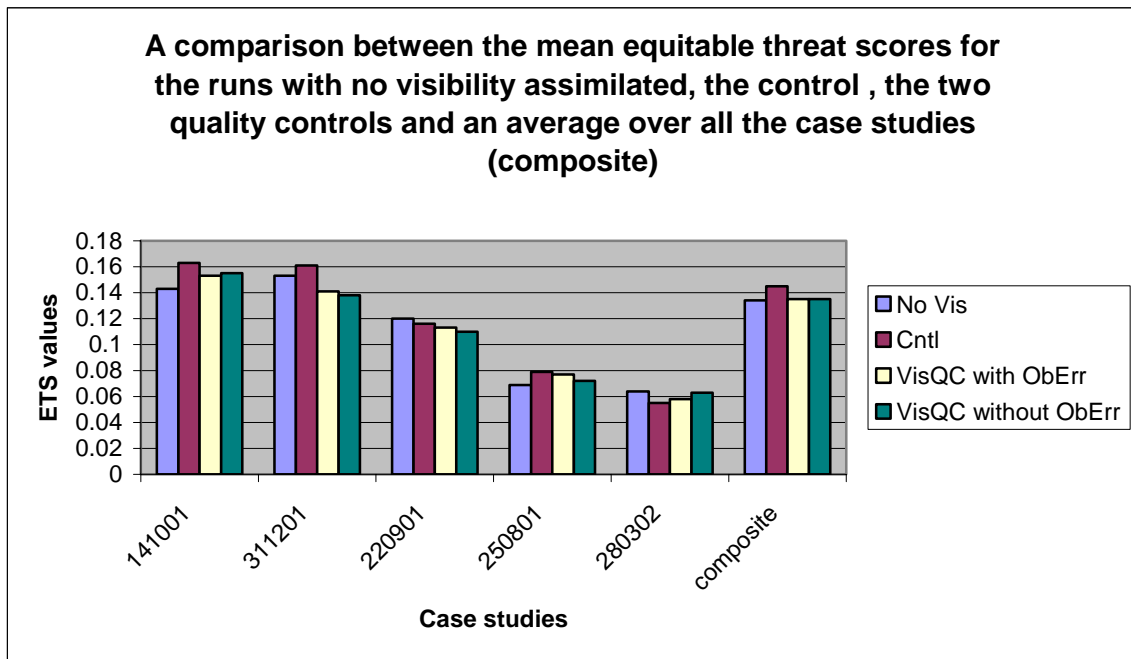


Figure 6 summarises the Mean ETS scores for the visibility forecast for each case study alongside an average for all the case studies. Each column represents a different run of the model. The blue columns represent the runs with no visibility and the Red columns the control runs. Yellow columns represent the visibility quality control with the observation error and green columns the visibility quality control without the observation error.

In mist and fog cases without the visibility quality control where the model estimate of relative humidity is too low, perhaps due to bad observations, VAR increases the aerosol to very large values in an attempt to produce the low visibilities observed (Cusack, personal communication). The way in which the quality control affects the total aerosol and the aerosol increments is another relevant way of assessing its performance. The two versions of the quality control tested were found to successfully reduce the total aerosol and aerosol increments for the case studies by the removal of inconsistent observations. The quality control that included the observation error reduced increments by approximately 10% and the more stringent quality control that did not include the observation error reduced the increments by approximately 15%.

Figure 7 is an example of the forecast visibility fields that are produced following a 12 hour assimilation and two 36 hour forecasts. Figure 7 shows the visibility fields for the t+6 forecast produced for the 14<sup>th</sup> October 2001 for the control (Figure 7a) and quality control (Figure 7b). The forecasts are in general very similar, showing broadly the same areas affected by low visibility in both forecasts. One noticeable difference between the two forecast fields is the merging of the low visibility region over Denmark and the region of low visibility extending down the east coast of the U.K. This does not happen in the control run.



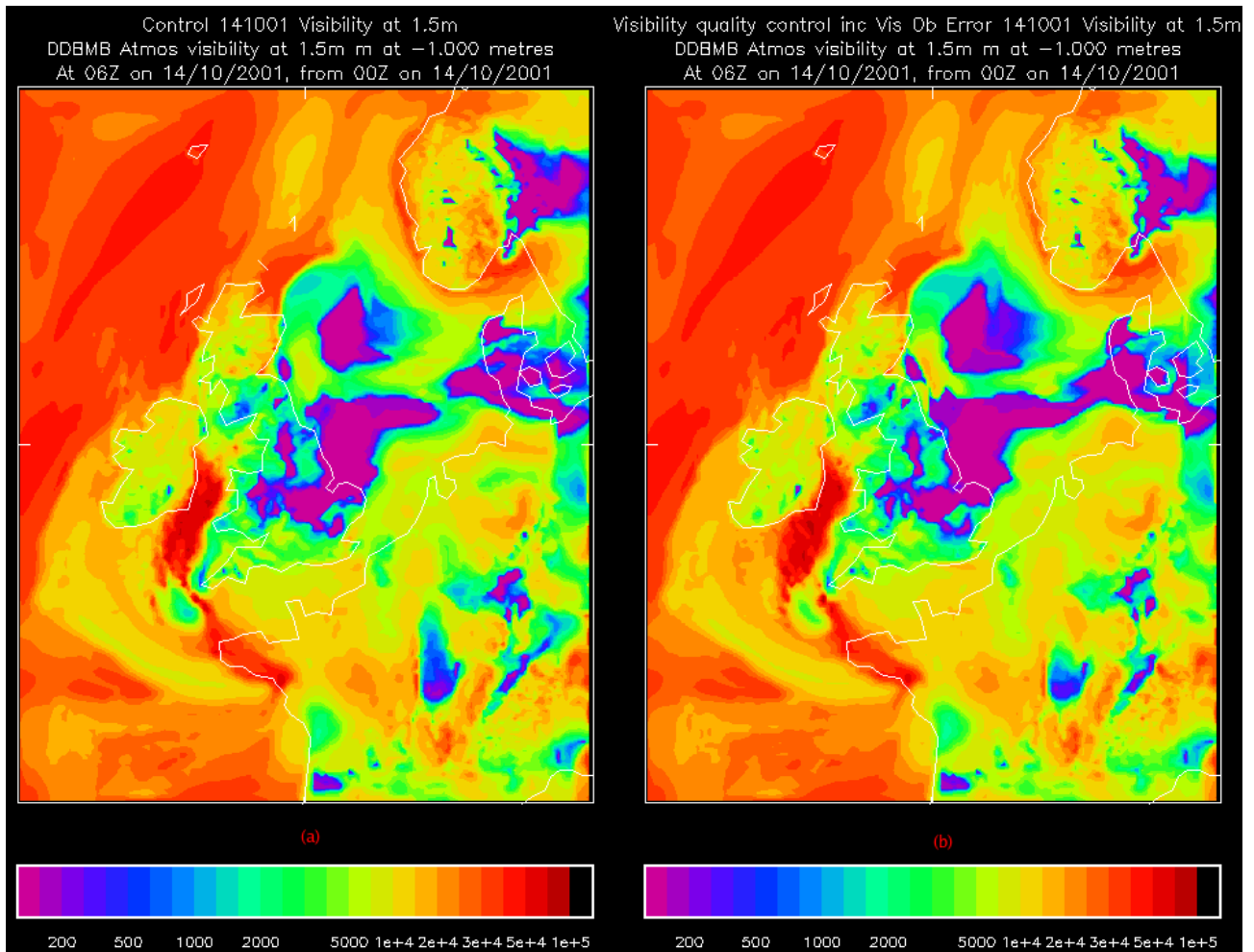


Figure 7:  $t+6$  forecast visibility fields for an episode of radiation fog from data time 00 UTC, 14<sup>th</sup> October 2001 with all the visibility data (a) and with quality controlled visibility data (b). In the analysis leading to plot (b) approximately 12% of the observations were removed by the quality control. The colour bar is displayed below the plots indicating that the scale is logarithmic.

#### 4.1.4 Summary of the results from the case studies

The case studies have been used to analyse the behaviour of the visibility quality control in a number of known different meteorological conditions. The case studies were run using the quality control with and without the observation error and compared with runs using no quality control and runs with no visibility observations at all. While the five case studies did not provide sufficient evidence to implement the quality control, either with or without using the observation error, they did however provide the basis for further investigation into the effect of the quality control in the longer term; in the form of a real-time trial.

On the basis of the results from the five case studies the quality control including the observation error was selected as the version that should undergo further testing. This was due to the added leniency compared with the quality control that omitted the observation error, therefore reducing the probability of rejecting good data yet ensuring the most inconsistent observations were removed. The increased leniency of the quality control with the observation error counters the effect of the relative humidity observations near saturation, which act to reduce the allowed visibility range considerably. The visibility quality control including the observation error reduced the aerosol increments by an average of 10% and the number of iterations to convergence by 6% but only rejected on average approximately 8% of visibility observations for these five case studies. It should be noted, however, that the flagging for the more lenient quality control varied between a maximum in the morning of approximately 15% to a minimum in the afternoon of approximately 3%.

## 4.2 Real-time trial results

The real-time trial consisted of a control and trial suite, run simultaneously over an extended period. The visibility forecasts were verified using the Equitable Threat Scores for each forecast time (T+6, T+12, T+18 and T+24) at each threshold (200m, 1000m and 5000m). The following is a summary of the results from the first 31 days of the trial.

### 4.2.1 Mean Scores

The mean ETS values for visibility forecasts from the real-time control and trial runs were the same after 31 days, each with a value of 0.081. These values indicate that the implementation of a visibility quality control on the mean skill of the whole forecast is negligible (see the fifth column of Figure 6). The other mean scores for 6 hour precipitation and total cloud amount also showed very little change with differences between the control and trial of approximately 0.001.

### 4.2.2 Forecast time scores

The scores for the each forecast time for both the control and trial runs were averaged over the three thresholds and the results plotted along side each other in Figure 8. In general the skill of the visibility forecasts deteriorates between T+6 and T+24 with very little difference between the control and the trial scores. At T+6 and T+24 the control has marginally more skill than the trial. At T+12 and T+18, however, the trial has slightly more skill than the control. These differences are very small, however and therefore may not be significant.

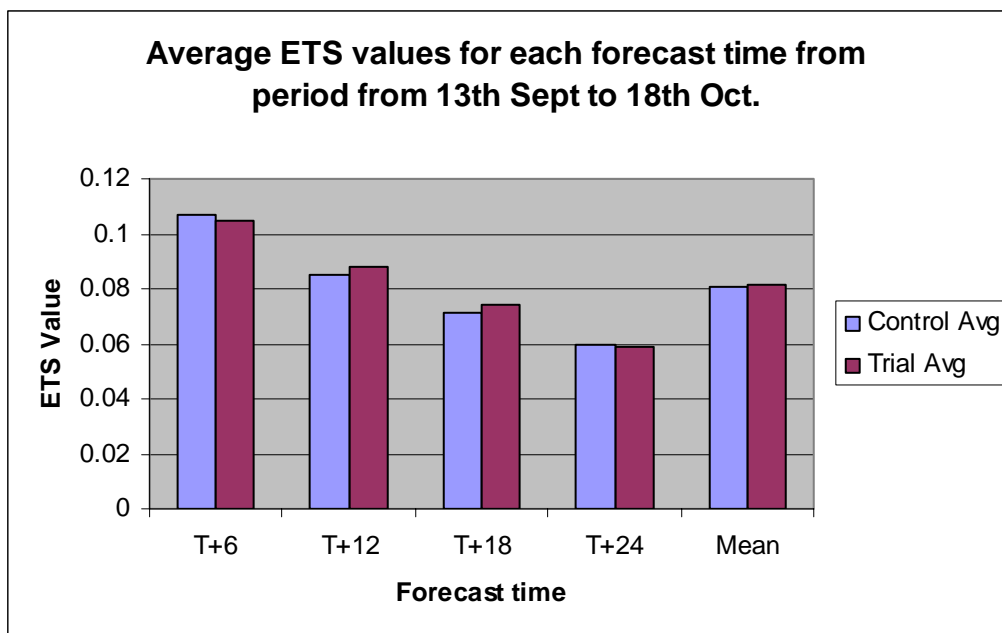


Figure 8: Real-time trial results - average ETS value over the period from 13th September to 18th October 2004 for each of the forecast times

### 4.2.3 Threshold scores

The scores at each threshold were averaged for all the forecast times and the results illustrated in Figure 9. In general the forecast for the 200m threshold has the least skill and the 5000m threshold has the most skill with the 1000m threshold in between the two. At each of the 200m and 1000m thresholds the trial forecast has marginally more skill than the control.



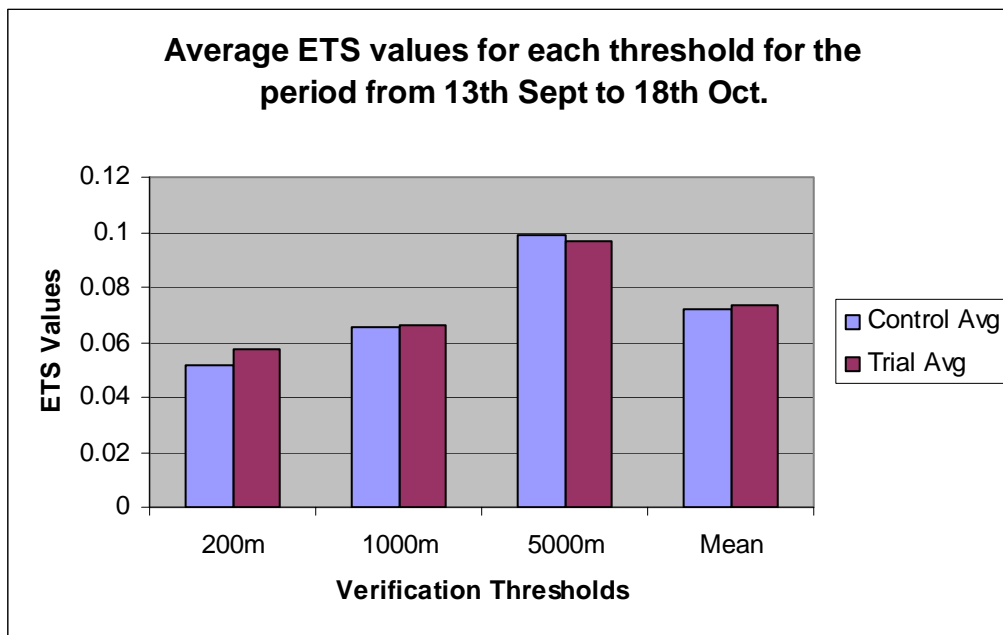


Figure 9: Real-time trial results - average ETS value over the period from 13th September to 18th October 2004 for each of the thresholds

#### 4.2.4 Summary of the results from the real-time trial

The real-time trial has been used to establish the effect that the visibility quality control has on the forecast skill when included over an extended period. The control run contained no quality control and therefore assimilated all the visibility data. The trial assimilated visibility data with the quality control switched on and set to include one observation error.

After 31 days the time trial results indicate that there was very little difference in the skill of the forecasts generated by the control or the trial runs. At each threshold and forecast time the differences were sufficiently small to indicate that the implementation of the quality control could be considered a neutral impact.

The trial eventually ran for a period of 148 days of which 96 were verified. The difference in ETS between the forecasts remains of similar magnitude (0.001) and can therefore still be considered a null impact.

## 5.0 Including Present Weather observations in the visibility quality control

The problems associated with visibility observations made during periods of precipitation have prompted further modifications to the visibility quality control code.

In this section the motivation for the inclusion of present weather observations in the visibility quality control is given as well as an outline of the modifications to the code that were necessary to include a new observation type in the OPS. The tests and results for this addition to the code are also given here.

### 5.1 Motivation

During episodes of precipitation the visibility is reduced. The only mechanism by which the assimilation can change visibility is by making adjustments to the aerosol and humidity; however, this is not the correct way to represent such a reduction in visibility during precipitation events. The most effective way of preventing this incorrect solution to the problem is therefore to remove those visibility observations that are made during precipitation. This information is provided via present weather observations. Therefore the visibility

quality control code must be modified to include this new observation type and to check for precipitation at the location and time of the observation.

## **5.2 Modifications to quality control**

In the visibility quality control scheme a check is carried out to reject those visibility observations that were made during precipitation at the observation location. Present weather codes are defined between 0 and 99 (or 100 and 199 where the station is automatic). The codes between 00 and 49 (or 100 and 149) indicate that no rain is observed at the station location at the time of the observation. The scheme has therefore been modified to flag those observations with codes in the ranges 50 to 99 (or 150 and 199).

As discussed by Moseley (2003), the impact of light rain on visibility is very slight, so flagging of all reports made in precipitation may lead to an unnecessarily high loss of data. A refinement to the scheme will be considered for the future in which reports made in light rain are retained, but those made in drizzle, moderate or heavy rain or snow are flagged.

## **5.3 Testing**

The changes to the code described in section 5.2 were tested using four case studies selected for their differing meteorological conditions.

- 20th December, 2002: is an example of a period where several active fronts were passing over the UK.
- 10th January, 2003: a clear winter night.
- 29th January, 2003: an unsettled period where there was mixed snow and rain.
- 20th February, 2003: radiation fog.

Each case study was run using a 12 hour assimilation followed by a 36 hour forecast for the 00Z and 12Z run-times. The control jobs consisted of the visibility quality control switched on with 1 observation error specified. The test jobs also included the quality control and observation error with the only difference being the consideration of the present weather codes in the rejection of observations.

## **5.4 Results from including present weather observations**

When the present weather observations are included in the code for the visibility quality control the average percentage of observations rejected by the quality control rises from approximately 11% (for the quality control including the visibility observation error) to approximately 16% for the four case studies chosen. It should be noted that the visibility observations made during periods of precipitation are rejected whether or not they are inconsistent with observed relative humidity, temperature and pressure. Therefore a significant increase in the number of rejections is expected.

The number of iterations to convergence for the four case studies was reduced by the inclusion of present weather by about 4% compared to the control run. The fit to observations was not really affected by the inclusion of present weather. The percentage of observations rejected and the number of iterations to convergence can vary considerably depending on the case studies chosen for testing the modification. The results given above represent the behaviour in just four examples and should therefore be considered with some caution.

There was no improvement to the skill of the forecast as a result of running the quality control with the present weather data for these four case studies. On average the forecasts generated were verified to have less skill than the forecasts that did not use present weather data. This result should not be given significant weight, however, because the four case studies used do not provide sufficient evidence to judge the effect of this change on the forecast skill. It is also possible that the quality control could lead to a short term detriment in the visibility forecast by preventing the assimilation adding aerosol in order to lower the visibility where the model misses the rain. However the quality control should prevent the forecast degrading further when the rain moves away at a later time. The exclusion of these observations from the assimilation eradicates the problems associated with the assimilation scheme's inability to modify visibilities that are

affected by precipitation. Therefore the removal of visibility observations made during periods of precipitation is a sensible modification to the quality control code to be recommended on scientific grounds.

## **6.0 Conclusions and Future work**

### **6.1 Conclusions**

A visibility quality control has been proposed, developed and tested. The testing of the quality control comprised a series of case studies and a real-time trial.

The case studies indicated that the quality control sometimes rejects a large proportion of observations. This was attributed to the occasions when the relative humidity was close to saturation resulting in a very narrow range of allowed visibilities. In order to alleviate this, the visibility observation error was incorporated into the quality control calculation to extend the range and therefore reject fewer observations. The observation error extends the range enough to account for the uncertainty in the observations but maintains the functionality to reject bad or inconsistent data.

The real-time trial confirmed that the implementation of the quality control including the observation error did not have a detrimental effect on the skill of the forecast over the course of several months.

The introduction of present weather observations to the visibility quality control did cause an increase in the flagging rate but did not have a large effect on the forecast skill for the four case studies tested. This modification prevents the spurious adjustments to humidity and aerosol made by the assimilation in an attempt to produce a reduction in visibility actually caused by precipitation. The inclusion of present weather observations in the visibility quality control can therefore be recommended on the basis that observations are being removed from the model that the assimilation cannot deal with properly.

On the basis of the evidence presented here, it was recommended that the visibility quality control including the observation error and present weather observations should be implemented into the operational model. This took place in the North-Atlantic European (NAE) model on 22<sup>nd</sup> February 2005.

### **6.2 Future work**

Once the quality control has been running operationally for a few months in the NAE some investigation may be necessary into the optimum tuning of the scheme. For example, the number of observation errors used in equation 2.2 may need to be increased.

A rejection list for visibility is also being devised to flag stations that are frequently reporting observations that differ markedly from the model background. This would be updated every month or perhaps every quarter. This list will work alongside the visibility quality control and help ensure that only good data are used in the model.

## 7.0 References

- HARCOURT, S.A., (2001). 'Assimilation of visibility observations.' Var Scientific Documentation Paper No 31.
- HARCOURT, S.A., MACPHERSON, B., (1999). 'The analysis of visibility observations in the UKMO's 3D-Var data assimilation scheme.' Proceedings of the third International Symposium on Assimilation of Observations in Meteorology and Oceanography. Technical Document WMO/TD – No. 986.
- INGLEBY, N. B. (1998). 'Generic Quality Control.' OPS Scientific Documentation Paper No. 2.
- LORENC, A.C., ANDREWS, P.L.F., BALLARD, S.P., BARKER, D.M., BELL, R.S., BRAY, J.R., CLAYTON, A.M., DALBY, T.D., INGLEBY, N.B., LI, D., PAYNE, T.J., SAUNDERS, F.W., (2000). 'The Met Office Global 3-Dimensional Variational Assimilation scheme.' Quart J. R. Met. Soc VOL.126 NO.570, 2000 pp2991 – 3012.
- MACPHERSON, B., ANDREWS, P.L., HARCOURT, S.A., INGLEBY, N.B., CHALCRAFT, B.V., MAYCOCK, A., RENSHAW, R.J., PARRETT, C.A., ANDERSON, S.R., SHARPE, M., HARRISON, D.L., GIBSON, M (2002). 'The Operational Mesoscale Data Assimilation System 1999-2001: Implementation of 3DVar and Later Upgrades.' Forecasting Research Technical Report No 374.
- MOSELEY, S., (2003). 'An improved visibility scheme for Nimrod.' Forecasting Research Technical Report No. 409.
- MOSELEY, S., BROWN, R., (2003). 'A report on a study of the Nimrod visibility scheme and recommendations for improvement.' Forecasting Research Technical Report No. 410.
- SHARPE, C.T., (2004). 'The observation, assimilation and forecasting of visibility data.' MSc Dissertation in association with the Met Office and Reading University, 102 pages.
- SMITH, R.N.B., GREGORY, D., WILSON, C.A., (1992). 'Calculation of saturated specific humidity and large-scale cloud. Unified Model Documentation Paper No. 29.