Numerical Weather Prediction

A Report on a Study of the Nimrod Visibility Scheme and Recommendations for Improvement

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1 Abstract

The Nimrod visibility forecast has always struggled to meet the user requirement. As this data is now directly available to the public (through the Time and Place mobile phone service), this project was initiated to improve the accuracy of this product.
After an initial description of the visibility scheme, the results of investigations into factors reducing the accuracy are presented. These include deficiencies in the algorithms and errors in the code. In depth studies of the role of aerosol and the spreading of observations in the analysis are then described, the results of case studies of recent fog events are summarised in this report.
The report concludes with recommendations for improving the Nimrod visibility product. These include making use of processed Meteosat data (rather than raw data), considering the use of the Atmospheric Dispersion Group aerosol field, and a method to spread temperature data from observations over orography where hill fog is present. Further potential improvements to both the analysis and forecast techniques are also suggested.

Contents

2 Introduction

The Nimrod visibility forecast has always struggled to meet the user requirement. The current emphasis on improving severe weather forecasts has resulted in higher priority being given to improving the Nimrod visibility forecast. Another reason is that the visibility forecast is now issued directly to the public via the Time & Place mobile phone service.

Because the current Nowcasting team have little knowledge of the visibility scheme, the initial work involved studying it in depth. The bulk of the work has concentrated on the analysis. This is because the forecast, which has been studied as well, is produced by merging the analysis and the mesoscale model forecast. An extrapolation forecast which used to be involved in the merging process was removed several years ago. Therefore, most of the additional skill acquired over the mesoscale model comes from including the latest observations in the analysis.

The visibility analysis is made up of several complex algorithms which require careful study to understand both the algorithms, and their place in the overall logic of the program. The work on the analysis was initially directed towards understanding why there is a significant scatter between observed values and the coincident grid point of the analysis, as observed data should be given the greatest weight in the analysis and hence be fitted fairly closely.

This report begins by outlining the current logic. A variety of problems which have been discovered are described in Section 3. These include both problems with the algorithms and bugs found in the program. Some of these problems have been investigated in more depth and the results are described in Section 4. This is followed by a summary of the conclusions drawn from case studies of widespread fog cases. Finally, recommendations for improving the visibility scheme are made in Section 7.

3 Outline of Program Logic

3.1 Analysis

The visibility analysis is produced in several stages as shown in the flow diagrams in Annex A. First, an analysis of all the latest observational data is produced. This is a combination of synoptic observations and satellite imagery. Independent analyses are produced of visibility, temperature (T) and dew point (T_d). The satellite imagery is used to produce a mask of fog/low cloud regions. Low cloud is defined as an IR temperature > -15°C. The observations which fall into the fog regions are then analysed independently of the observations in the remaining regions.

At each grid point, the nearest three observations in the same mask as the grid point are combined to produce an estimate of the visibility, temperature and dew point at that point. Each of the three observations is assigned a weight based on the horizontal distance to the grid point, and the vertical height difference between the observed station height, and the orographic height at the grid point (a height difference of 20m is equivalent to 5km lateral distance). A much higher weight is given to observations which are very close (in three dimensions) to the grid point.

In order to produce the final analyses, the analyses based purely on observations are merged with the T+1 forecast. The merging is performed using liquid water temperature (T_L) and total water content (q_t), two variables which are conserved during condensation. The conversion routines use forecast air pressure (p) and aerosol mass mixing ratio (m) from the mesoscale model to relate to visibility (vis), T and T_d, to T_L and q_t. Because pressure and aerosol are taken from the Mesoscale Model, and are assumed to be correct, the vis, T and T_d fields are often incompatible with m. Because observed visibility is likely to be more accurate than observed relative humidity (RH) when the visibility is low, if the analysed visibility based on observations is less than 10km, it is believed rather than the dew point. The opposite is true when the visibility field is greater than 10km. This is elaborated on later.

In merging T_L and q_t with the T+1 forecast values of the same variables, the weighting given to each field is determined by an error variance value. The T+1 forecast field is given one value for error variance to cover the whole field. This is determined from a comparison of observed against forecast visibility where either is less than 5km and the other is limited to a maximum value of 10km. Values for the error variance of the analysis of observed variables are determined for each point based on an estimate of observational error and the distance from the nearest observation (the error variance is halved if the satellite imagery suggests that the point is in fog). Typical values of the weights at a grid point coincident with an observation are shown in Table 1. These would return a visibility of 1061m. Values for a grid point around 15 km from an observation are shown in Table 2 and it can be seen how the weight given to the T+1 forecast has increased (values in Table 2 return a visibility of 1369m).

Table 1 Typical values for the merging (at observation point)[1]:

	Analysis of Obs	T+1	Final Analysis
Visibility	1000	5000	
T_L	286.9891596	287.0	286.989418
Q_t	9.82E-03	9.728E-03	9.81937E-03
Error Variance	0.1	3	

Table 2 Typical values for the merging (at point 15km from nearest observation):

	Analysis of Obs	T+1	Final Analysis
Visibility	1000	5000	
T_L	286.9891596	287.0	286.990519
Q_t	9.82E-03	9.728E-03	9.80987E-03
Error Variance	0.47	3	

From the merged T_L and q_t fields, T, T_d, RH and humidity mixing ratio (q) are derived. Hill fog is then inserted by temporarily adjusting q_t where the cloud base from the Nimrod cloud analysis is lower than the orographic height (the q_t data file does not reflect these changes).

Visibility is then rederived from the modified q_t and T, after which an adjustment is made for the effects of precipitation on the visibility.

3.2 Forecast

The T+1 to T+6 forecasts of T_L and q_t are calculated by merging the analysed fields with the Mesoscale model fields. Originally the merging involved an extrapolation forecast as well, as detailed in NWP Technical Report No. 222, 'A New Visibility Analysis / Forecast System for Nimrod' by *Bruce Wright*. Essentially, the temporal trends in T_L, q_t in the model forecasts were applied to the analysis. The extrapolation forecast was removed a few years ago because the additional complexity was of no benefit or possibly caused problems. A trial reinstating this logic has recently been started to determine the extent of the benefits and drawbacks and to see if it is worth reinstating a modified version.

The weights currently used for the merging process depend on the final analysed value of visibility. The weights used are calculated from equation (1) when the visibility is in the range 500m<vis<1km.

$$weight_{anl} = e^{-\left(\frac{FCtime}{240}\times\left(\frac{Vis_{anl}}{1000}\right)^2\right)} \quad (1)$$

where *FCtime* is the lead time of the forecast in minutes and Vis_{anl} is the analysed visibility in metres.

[1] Where T=287K, p=1013hPa and m=14μg/kg.

The weights used outside the above limits are shown in Table 3. They are the values calculated from equation (1) at the limiting visibilities. The weight given to the Model field is always 1-(weight of analysis). This logic was chosen as it allowed the low visibility associated with fog to persist for longer when low visibility was analysed but not forecast by the model.

Table 3 Weights given to the Analysis outside the specified visibility range:

	T+1	T+2	T+3	T+4	T+5	T+6
Vis<500m	0.94	0.88	0.83	0.78	0.73	0.69
Vis>1km	0.78	0.61	0.47	0.37	0.29	0.22

4 Problems with the Visibility Analysis and Forecast

Detailed study of the analysis and forecast has thrown up a variety of problems, both logistical and errors in the code:

4.1 Role of the Aerosol

The four subroutines that are used to convert visibility, T and T_d to T_L and q_t and back again behave differently in how errors in m impact on the final answer, depending on the visibility at a given point.

When the analysed visibility based on observations alone is greater than 10km, T_L and q_t are derived from T and T_d. In this case the final analysis of visibility after merging is derived from T, T_d, m and p. In essence, the visibility is derived from relative humidity using m to define the aerosol concentration. Hence the analysed fields of T and T_d agree quite well with coincident observations, but the analysed field of visibility can disagree if the value of m is in error. The same behaviour occurs in the forecast.

When the analysed visibility based on observations is less than 10km, T_L and q_t are derived from T and visibility using m and p. The derivation involves altering the humidity so that the visibility calculated from RH using the model aerosol concentration agrees with the analysed visibility. This means that when visibility, T, Td are derived from T_L, q_t in the final analysis, the visibility can agree closely with the coincident observations, but T_d can disagree if the model aerosol mixing ratio is in error. This behaviour tends to persists into the forecast, so long as the analysed values predominate in the merged field.

4.2 Hill Fog and Spurious Supersaturation

The hill fog subroutine has been placed in the diagnostic subroutine which runs after the analysis of observations, and as such does not interact with the analysis program. This can lead to hill fog being placed in regions where the observed visibility at that altitude is good. The hill fog correction is dependent on an accurate representation of cloud-base heights in the Nimrod cloud analysis program. Errors in cloud-base height can lead to spurious hill fog in the visibility program output and contribute to the scatter between analysis and coincident observations during verification. It is possible that in some cases both cloud analysis and observation are correct but that the synoptic station is in a valley and not representative of the grid square.

The spreading of observational data makes allowances for orographic height differences between the observation height and the local orography when spreading T, applying a lapse rate where necessary, but not for T_d. This frequently produces regions where $T < T_d$ over high ground. The T_L q_t conversion routines produce missing data values in these regions which default to the T+1 forecast values of T_L and q_t during the merging process which produces the final analysis.

4.3 Spurious Spreading of Fog in Valleys to High Ground

A recent case has highlighted the fact that although the program makes allowances for advection fog, which in a well mixed boundary layer will become thicker over high ground, it does not consider the likelihood that radiation fog will be confined to valleys or low ground. It is possible to spread observations of fog from low-lying sites to high ground. The specific case had radiation fog in the valleys where the observation stations are sited and clear air on the higher ground where no observing sites are located. This fact emerged because of reports from two Met Office staff. They observed high visibility over Exmoor and the Mendips with fog in the valleys below. The visibility analysis had put fog at all altitudes in the south west.

The satellite data, as used by the visibility cloud mask, could not distinguish the fog from the clear sky regions and indicated clear skies everywhere in the south west. Initially this was because it was night but even when the visible data became available it was only after a couple of hours that the cloud mask picked up the fog.

The only factor penalising the spreading of information from low level observations to higher ground is the lower error variance which is used to weight the merging between the analysis of observations and the T+1 forecast. However, over several forecast cycles with the above conditions in a static state, fog will eventually be analysed at all orographic heights.

The use of cloud-top height data will help alleviate this problem as the new cloud-top height scheme searches for low level stratocumulus and fog below an inversion. In cases where the satellite data still cannot be resolved to detect warm fog tops at night (even with the use of RTTOV data), this problem could still occur. It is unlikely that this issue can be resolved until Meteosat Second Generation data becomes available.

4.4 Deleted Observations

The quality control subroutine in the visibility analysis program removes data at any observation point with a height difference from the coincident Nimrod orography greater than 200m. However, an allowance is made for height differences from the local Nimrod orography in the spreading out of observations in the diagnose_fog subroutine by down-weighting the observation proportionally to the height difference. It appears that the height difference quality control check should have been removed when the height penalty was introduced to the observation analysis routine. This means that observation data which could be valuable at a nearby grid point is being routinely deleted from every Nimrod visibility analysis. Approximately 20% of observations in the Nimrod domain are affected. This quality control check has now been removed operationally.

4.5 Errors in the Observations

There is evidence that errors or deficiencies in the observations contribute to the scatter between analysed and observed visibility. The existing quality control subroutine only detects gross errors. A few more subtle errors, for which no account is made during the analysis program, have been detected:

- Some stations were found to be reporting constant visibilities (typically code 60, representing 10 – 11 km).
- Several stations (notably in Germany) appear to have an upper limit to their visibility observations of either 8, 9, 10 or 20km, codes 58, 59, 60, 70)
- Some observations (especially from SHIPs) report visibility with codes in the 90 – 99 range (these represent large ranges of visibilities, hence contain large uncertainties)

These problems contribute particularly to the scatter between analyses and observations at high visibility. However, the constant visibility problem can contribute to the scatter in low visibility cases, for example when low visibility is forecast but the observation is stuck on 10 km.

Bruce Macpherson's group in NWP plan to assimilate visibility observations into the mesoscale model and so they are studying the accuracy of the observations in order to set up quality-control procedures. Hopefully more can be learned from this work.

4.6 SAMOS NT Observations

Following the recent upgrade of the SAMOS software at some observation stations, it was noticed that approximately 80 UK observing stations were being discarded by the visibility analysis program. This error was tracked down to an obsolete quality control check which ensures that two 'e-times' included with the observation data are equal. These appear to be the nominal time of the observation and the actual time ('actual' represented the time the observation had been made, eg 11:57am, and 'nominal' represented the time the observation was for, eg 12 noon). These used to appear equal but this is no longer the case with SAMOS NT observations. The same check was being performed in the rainfall analysis program, but not in other Nimrod programs.

This fault has now been resolved operationally for both the rainfall and visibility analysis programs on Nimrod and Nimr2.

4.7 Model q_t field conversion

The Mesoscale model field of total water content was observed to have an upper limit of 10g kg^{-1} after it had been written in the Nimrod file format. This had the effect of implying too low a relative humidity in some regions during the warmer summer period. This limit has now been increased to 100g kg^{-1}, a number which should not be physically exceeded in the Nimrod area.

5 Results of Further Investigations

5.1 Model Aerosol

To help understand further the role of the model aerosol, the observed visibility has been plotted against RH in Figure 1. Isopleths of visibility vs RH have also been plotted on Figure 1 using the theoretical relationship employed in Nimrod and the mesoscale model and covering the range of m values provided by the model.

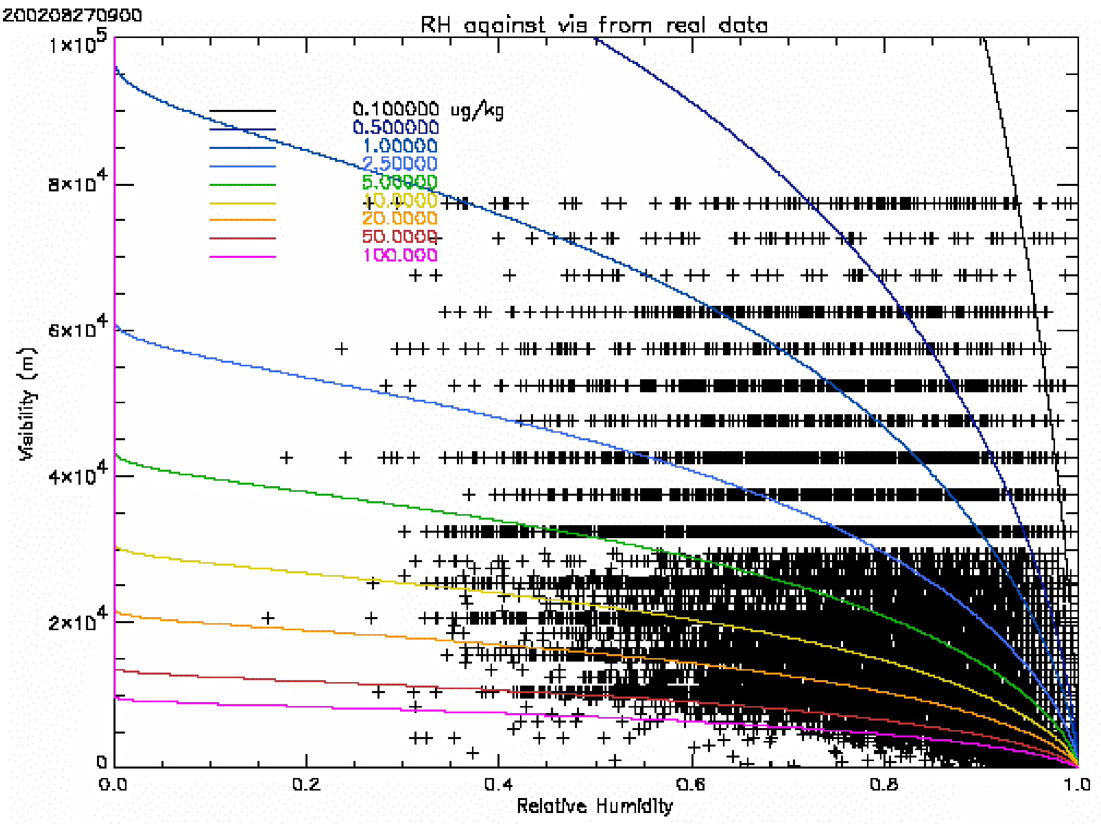


Figure 1: 36723 observations of visibility plotted against relative humidity (derived from the observations of T and T_d). The coloured lines show the theoretical relationship between visibility and relative humidity for the labelled aerosol mass mixing ratios.

This figure shows that the general trend of the observations fits with the theory, especially the lower envelope of the dense region of plotted points.

Figure 1 also shows that most points fall in a region of visibility/RH consistent with the values of m found in the model fields. However, some of the points on the above graph fall in regions which imply unphysical values of m. For example, a visibility around 2 km with a relative humidity of 37% and a visibility around 70 km with an RH > 98% can be found on this plot. Observational error is the most likely explanation error for these points

Although the distribution of m values appears reasonable, an indication that the individual forecast m values are not very accurate is given by the large changes in the Nimrod visibility fields which have been noted when a new model run becomes available. This is especially noticeable in the regions where observations are sparse and is mainly due to the changes in the aerosol field.

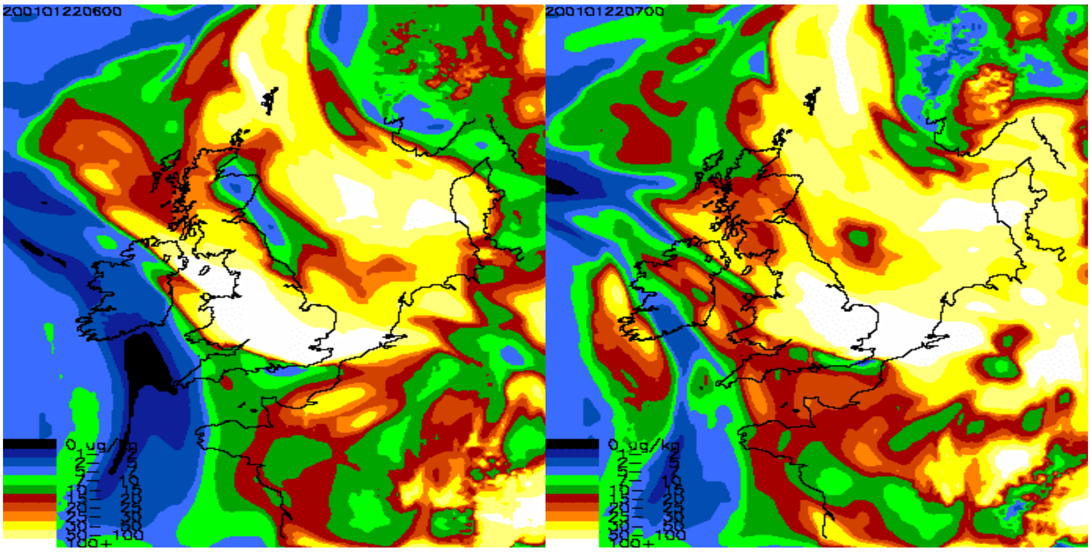


Figure 2: Mesoscale Model aerosol mass mixing ratio fields for (left) 06Z 22/1/01 (T+6) and (right) 07Z 22/1/01 (T+1). The change from the 00Z model run to the 06Z run is significant in places. High Aerosol levels are placed in the 07Z image in regions where low levels were previously found (West Ireland, East Scotland, Scandinavian Sea and parts of Continental Europe).

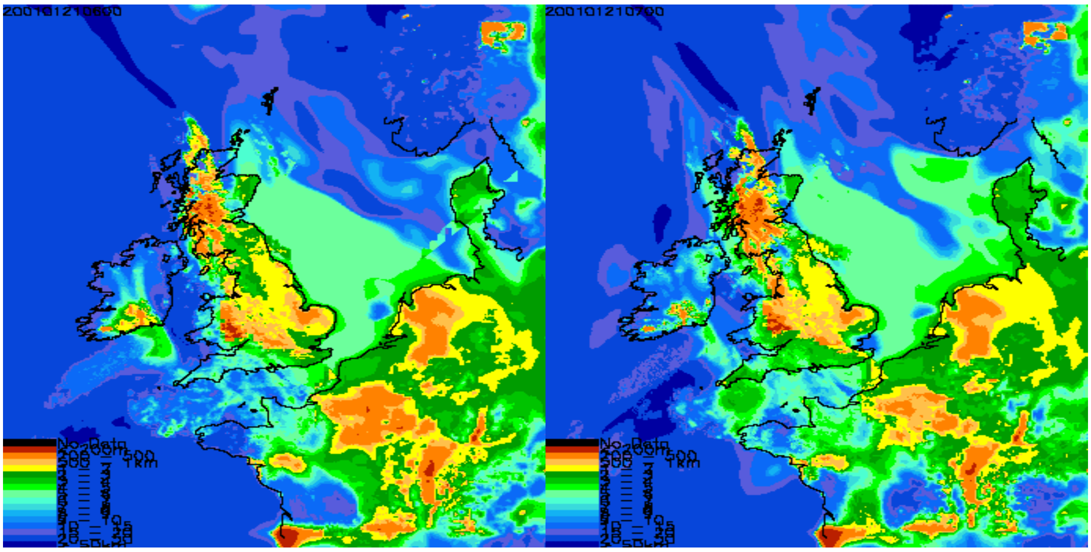


Figure 3: Nimrod visibility T+1 forecast for 06Z (left) and T+2 forecast 07Z (right) 22/1/01 generated using model data from the two different mesoscale model forecast runs shown in Figure 2. Lower visibilities are evident in the regions where the aerosol field has changed to show higher aerosol mass mixing ratios.

Figure 2 shows how the mesoscale model aerosol field can change when a new model run becomes available to the Nimrod programs. Particularly noticeable, is the much higher values of m over SW England. Figure 3 shows how this change has affected the Nimrod visibility forecasts; the area over SW England has lower visibilities forecast with the new model data. In some small regions this change is from >10km to 1-2km. Model T_L and q_t values are much more consistent from run to run, indicating they are likely to be more accurate than m.

The use of model aerosol forecasts by the visibility scheme is a problem for the new European version of Nimrod recently made operational because the aerosol field is not immediately available from the global model. A standard field of m (14μg/kg) has been used instead. It can be seen from Figure 1 that this lies towards the centre of the dense area of observations. The main effect of this change is felt where there are few observations and where the visibility exceeds 10 km. In such regions, variations in visibility can be dominated by variations in m. There is little effect on the analysis and the early part of the forecast sequence in denser regions of observations and where the visibility is less than 10 km, because the observations dominate the output fields.

5.2 Investigation of the Spreading the Observations in the Analysis

The method of spreading the observations is purely numerical and the accuracy of the analysis has only been assessed at grid points coincident with observations. Therefore, at locations distant from observations the analysis resulting from spreading the observations may be no more accurate than the model because the spatial variation produced by the model may be more physically realistic. To investigate this, a real time trial was set up which excluded a selection of five observations from each analysis. The data from the resultant analyses was compared to the actual observed data from the excluded stations using the RMSF or RME statistics to quantify the accuracy of the simple spreading technique.

$$RMS = \sqrt{\frac{\sum_{i=n}^{n} (F_i - O_i)^2}{n}} \tag{2}$$

$$RMSF = e^{\sqrt{\frac{\sum_{i=1}^{n} \left(\ln\left(\frac{F_i}{O_i} \right) \right)^2}{n}}} \tag{3}$$

The results from station 03210 (St Bee's Head), originally included in the trial, have been excluded from those presented as they were found to be anomalous. This was caused mainly through a discrepancy between the reported station height (124m) and the coincident Nimrod orographic height (0m). The large height difference meant that when the observation was included in the analysis, the weight given to it in the coincident grid square was very low (only a fifteenth of the weight achieved when artificially setting the orographic height to the station height of 124m), so the that analysed value was mainly based on surrounding observations and the previous hour's T+1 forecast. It became apparent that the height difference is not correct. It has been found that the Nimrod orographic height field is not aligned with the Nimrod land-sea mask, the former being one grid-length (5km) to the east of the latter. Comparison between these fields and the station locations (and an Ordnance Survey map) suggest that it is the orographic height field is misplaced. It assigns a 0m height to the grid square containing St Bee's Head on the assumption it is a sea point.

Stn No	Stn h	Nim h	V1All	V1Ver	V1MM	N1	V2All	V2Ver	V2MM	N2
10616	502	457	1.881	3.366	5.267	485	2.211	2.401	2.299	1038
07038	132	127	1.123	2.448	3.069	393	1.855	2.211	1.882	1046
03772	24	25	1.182	1.516	2.136	268	1.955	2.085	2.199	1336
03693	2	1	1.478	2.276	3.168	373	1.497	1.510	1.515	1221
Mean			1.42	2.46	3.41		1.88	2.05	1.97	

Table 4: RMSF differences between observed and analysed visibility at selected stations. Stn No contains WMO station IDs, Stn h contains the station height in m ASL, Nim h contains the Nimrod Orographic height in m ASL, V1... values represent data when the observed visibility at the station was <10km, all other points are in the V2... columns. All, Ver and MM refer to the origin of the field data. All is the Nimrod analysis which included all available observations. Ver is the Nimrod analysis which excluded these observations, and MM is the Mesoscale Model forecast field.

Stn No	Stn h	Nim h	V1All	V1Ver	V1MM	N1	V2All	V2Ver	V2MM	N2
10616	502	457	1.284	1.405	1.360	491	1.253	1.478	1.427	1043
07038	132	127	0.305	1.057	1.500	397	0.250	0.798	1.449	1049
03772	24	25	0.187	0.941	1.336	268	0.169	0.886	1.446	1341
03693	2	1	0.352	1.669	2.293	377	0.307	1.284	1.806	1226
Mean			0.53	1.27	1.62		0.50	1.12	1.53	

Table 5: RMS differences between observed and analysed temperature at selected stations. See Table 1 for explanation of headings.

Stn No	Stn h	Nim h	V1All	V1Ver	V1MM	N1	V2All	V2Ver	V2MM	N2
10616	502	457	1.594	1.771	1.494	491	0.507	1.466	1.679	1043
07038	132	127	1.176	1.323	1.451	397	0.371	1.208	1.648	1049
03772	24	25	2.298	2.441	0.892	268	0.165	1.306	1.387	1341
03693	2	1	1.804	1.728	1.821	377	0.311	1.414	1.731	1226
Mean			1.72	1.82	1.42		0.34	1.28	1.61	

Table 6: RMS differences between observed and analysed dew point temperature at selected stations. See Table 1 for explanation of headings.

Table 4 shows that where the observed visibility is <10km, the analysis including the co-located observations has about half the RMSF value of the analysis without the co-located observations. The Model RMSF is about 1.5 times larger than the latter. This suggests that although there is a loss of accuracy in spreading the visibility observations around, the results are still better than from the model. Station 10616 produces a noticeably larger RMSF in all 3 cases, suggesting there may be a problem with the observation.

When the visibility is greater than 10km, including the coincident observation produces a slightly lower RMSF on average but the difference may not be significant. The model forecast produces a similar RMSF to excluding the observation. Station 10616 is still the least accurate, but the difference from the other stations is much less. It is noted below that there is a greater difference in accuracy for T and T_d between the 3 cases than for visibility. Although it follows there must be differences in the accuracy of RH between the three cases, because higher visibilities are being considered, the RH will tend to be low and then visibility only varies slowly with RH (see the isopleths on Figure 1). This suggests the RMSF values for vis > 10 km are dominated by errors in the model aerosol, which will be the same in each case.

The scatter plots for the case where the coincident observation is included, Figure 4 (Left-Top), show the effect of fitting to visibility observation when vis < 10 km and the significant increase in scatter when vis > 10 km. The much larger scatter for station 10616 is also apparent. Figure 4 (Left-Bottom) shows the scatter plots when the coincident observation is excluded and Figure 4 (Right) the scatter plots for the model forecasts. Comparing these for individual stations it can be seen they have quite a similar pattern. This could be another sign of the influence of the model aerosol dominating.

Table 5 shows that including the coincident temperature leads to a much lower RMS error than excluding it. Interpolation (ie excluding the observation) produces a lower RMS error than does the model forecast. This order of merit does not show any variation between vis < 10km and vis > 10km which fits with our knowledge that the scheme does not depend on visibility when analysing temperature data. The results for station 10616 are even more anomalous than for visibility. In particular, the RMS error when the coincident observation included is 1.3°C, compared to 0.2 - 0.35°C for the other stations. The RMS values in the case of the coincident observation excluded or the model are comparable with those from other stations. Therefore, the anomaly appears to be a feature of the Nimrod analysis and not a problem with the observation. It seems most likely that it is related to the difference in height between this station and the coincident Nimrod topography but this has yet to be investigated. (Scatter plots for temperature are not shown).

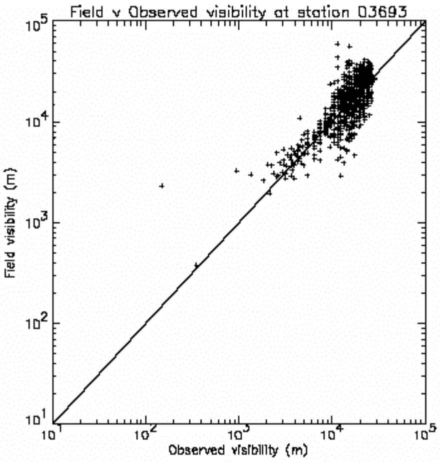
Table 6 shows that when vis < 10 km and the coincident observation is included, the average RMS error for the dew point (1.7°C) is larger than for air temperature (0.5°C). It is similar to the RMS error with the coincident observation excluded and higher than the model RMS error. When vis > 10 km the RMS error with the coincident observation included drops to around 0.35°C on average. In this case the RMS error with the observation excluded is much higher but less than for the model. The only possible explanation for this behaviour is the adjustment made to the humidity when vis < 10 km to take up errors in the model aerosol field.

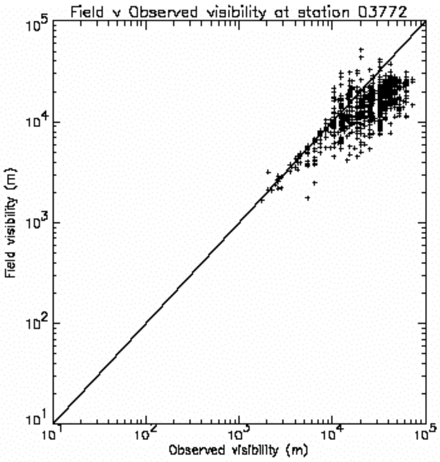
Figure 5 shows the scatter plots of analysed against observed dew point. The Left-Top four plots are for the coincident observation included. It can be seen that the majority of points lie close to the 1:1 line but some points lie up to 5°C away, presumably as a result of the adjustment. The Left-Bottom four plots are for the coincident observation excluded and the Right four are for the model forecast. It can be seen that interpolating between observations (ie Left-Bottom four plots) removes some of the outliers apparent in the model forecast. It is also noticeable that station 10616 looks no different to the other stations.

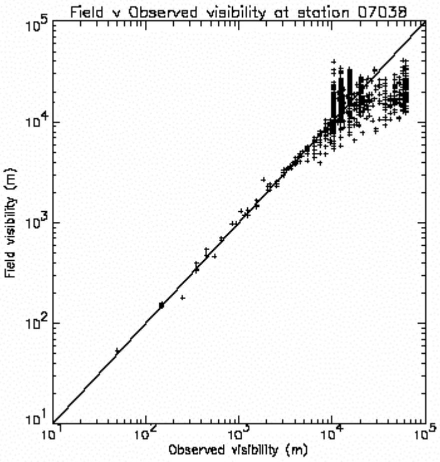
Although some useful lessons have been learned from the statistics, possibly more should have been gathered to help determine whether interpolating the (observation - model) differences would produce a better answer. This does not look likely for visibility less than 10 km, and it looks most likely for dew point.

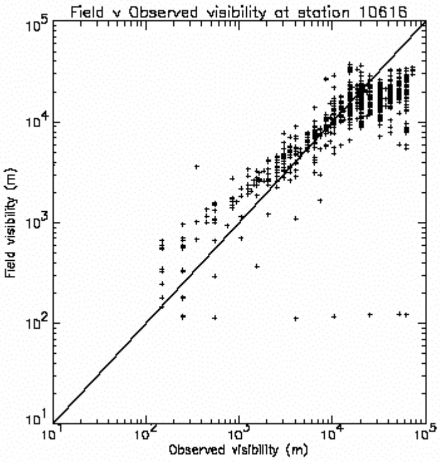
5.3 *Spatial Extrapolation of T_L and q_t in the Analysis*

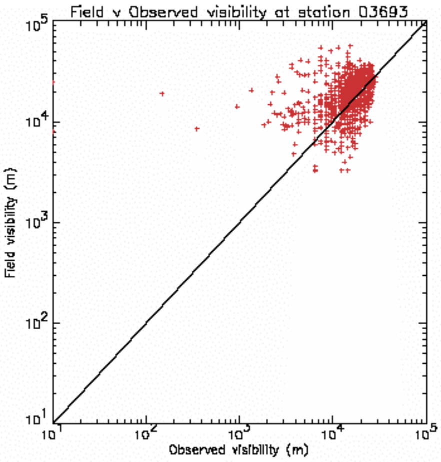
The spreading out of observations technique used in the visibility program does not allow any interaction between the different variables. It would be more consistent to spread the variables T_L and q_t instead. Preliminary tests suggest that because these variables, especially q_t, do not vary linearly over distance, a linear spreading routine will return poorer results from these two variables than from the current use of vis, T and T_d. The spreading technique was developed to keep the emphasis on visibility during the analysis. This means that the analyses of temperature and dew point suffer a little as a result.

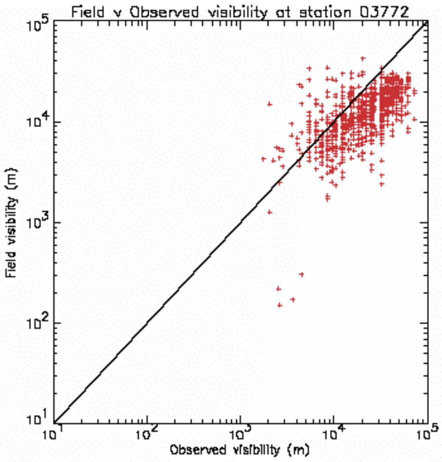

Field v Observed visibility at station 03693
Field visibility (m)
Observed visibility (m)

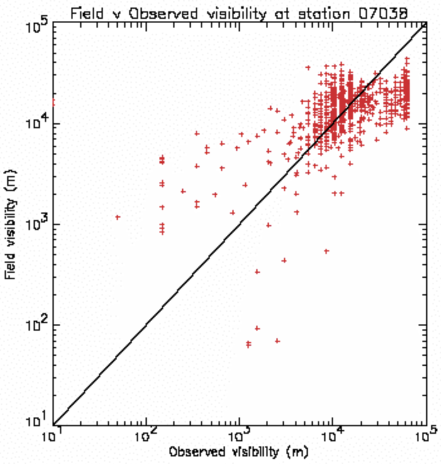

Field v Observed visibility at station 03772
Field visibility (m)
Observed visibility (m)

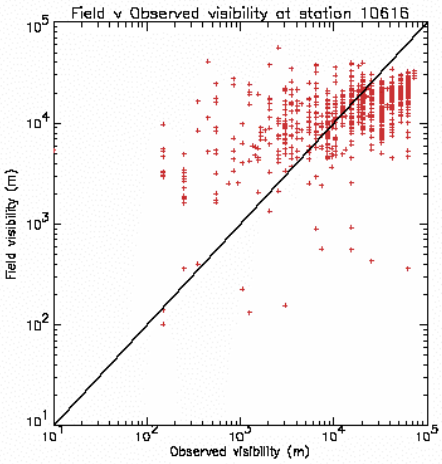

Field v Observed visibility at station 07038
Field visibility (m)
Observed visibility (m)


Field v Observed visibility at station 10616
Field visibility (m)
Observed visibility (m)


Field v Observed visibility at station 03693
Field visibility (m)
Observed visibility (m)


Field v Observed visibility at station 03772
Field visibility (m)
Observed visibility (m)


Field v Observed visibility at station 07038
Field visibility (m)
Observed visibility (m)


Field v Observed visibility at station 10616
Field visibility (m)
Observed visibility (m)

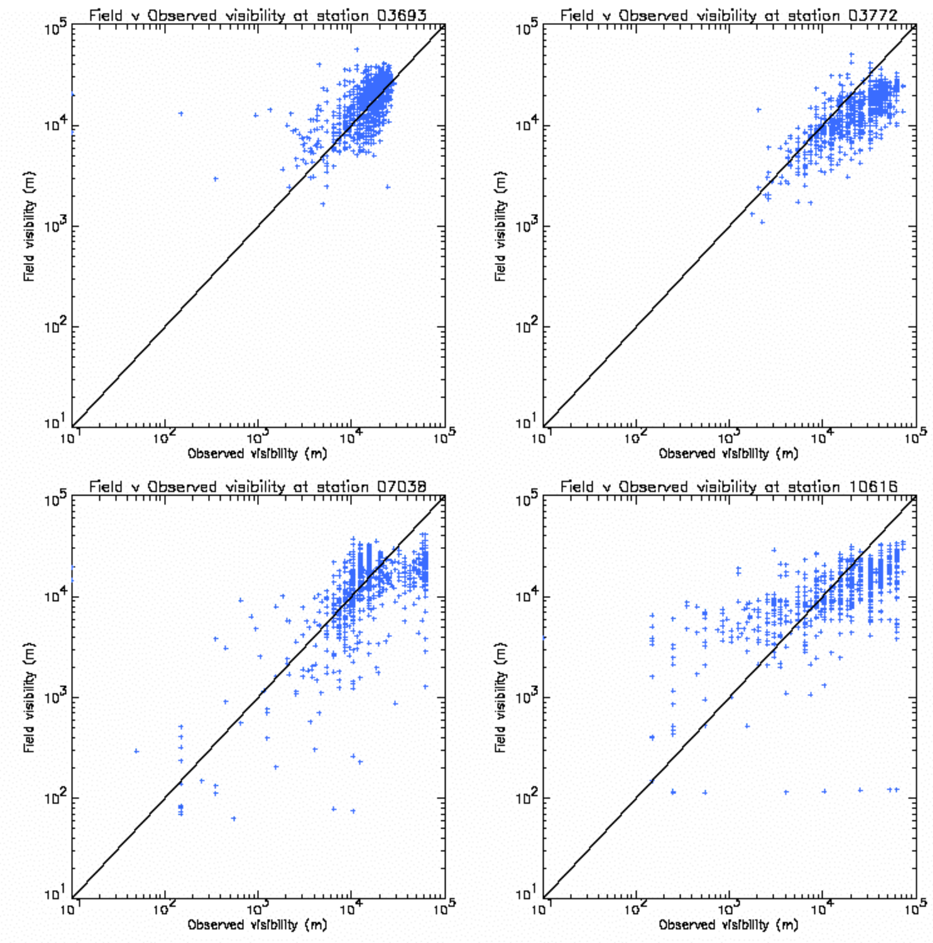
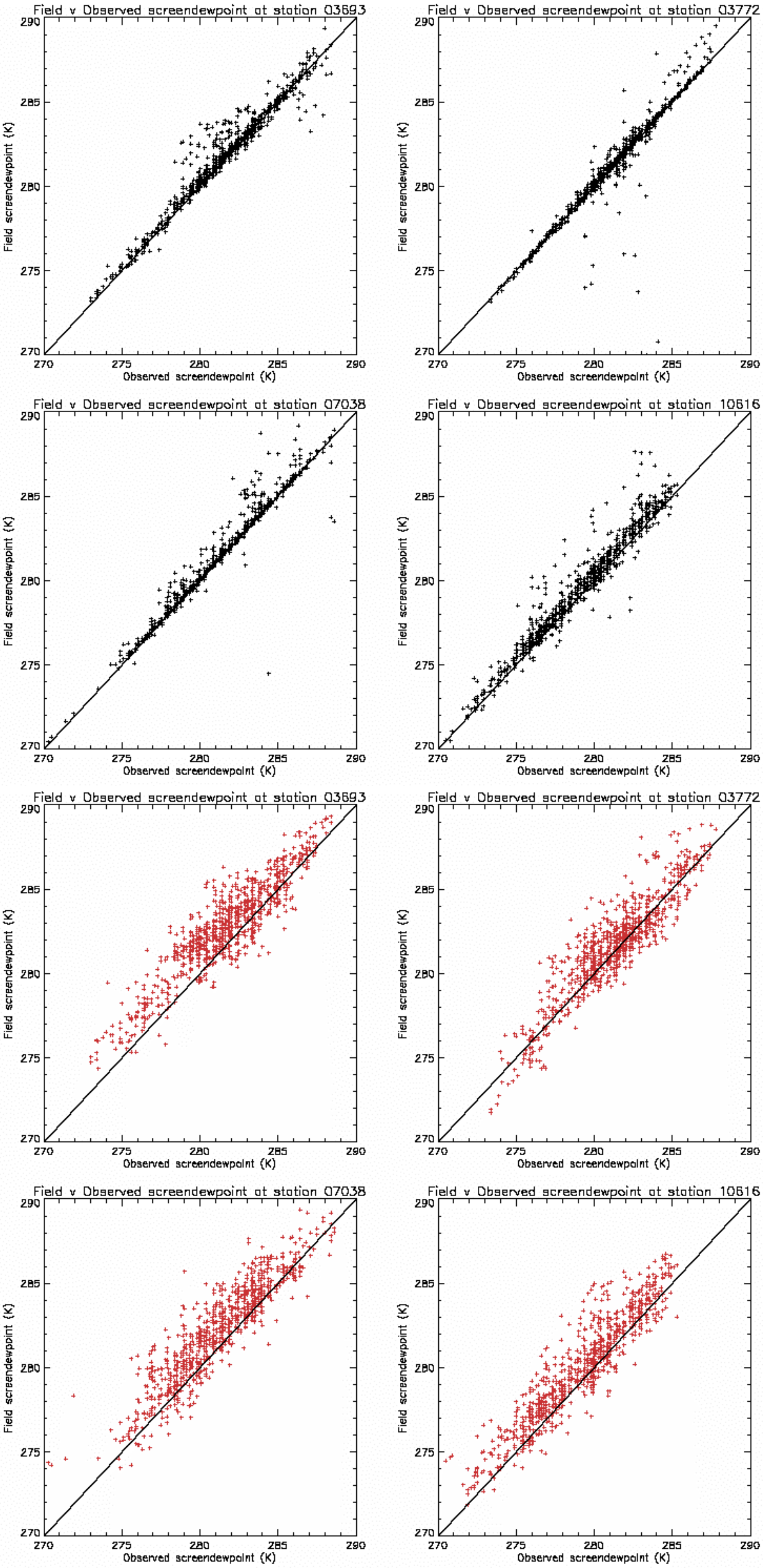


Figure 4: Scatter plots showing observed visibility against field visibility on logarithmic axes at four selected stations. Left-Top (black): Nimrod visibility analysis processed using all observations. Left-Bottom (red): Nimrod visibility analysis processed excluding selected observations. Right (blue): MM forecast


Field v Observed screendewpoint at station 03693
Field v Observed screendewpoint at station 03772
Field v Observed screendewpoint at station 07038
Field v Observed screendewpoint at station 10616
Field v Observed screendewpoint at station 03693
Field v Observed screendewpoint at station 03772
Field v Observed screendewpoint at station 07038
Field v Observed screendewpoint at station 10616
Field screendewpoint (K)
Observed screendewpoint (K)
270
275
280
285
290

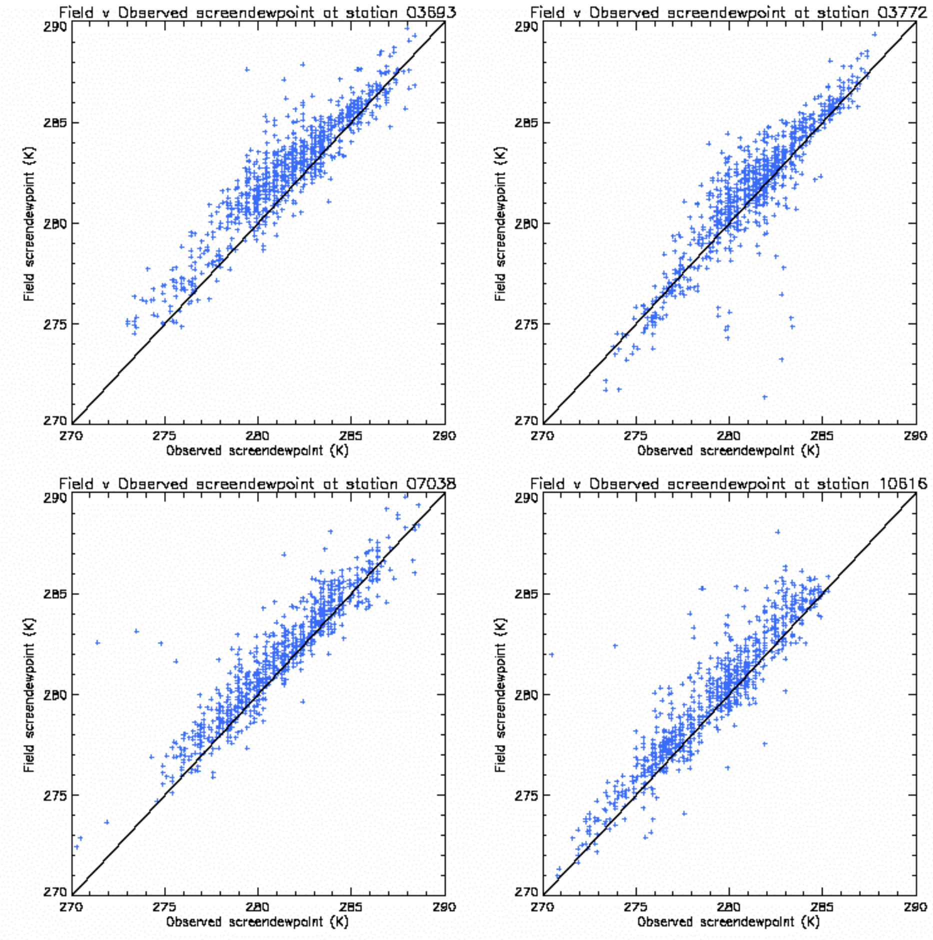


Figure 5: Scatter plots showing observed T_d against field T_d at four selected stations. Left-Top (black): Nimrod visibility analysis processed using all observations. Left-Bottom (red): Nimrod visibility analysis processed excluding selected observations. Right (blue): MM forecast

6 Summary of Conclusions from Case Studies

Case study material was assembled for several cases of widespread fog. The cases examined so far include 31 Jan - 1 Feb 02, 15 - 16 Feb 02, 14 Jan 01 and 23 Dec 00. For a variety of reasons the effort which had been intended has not been put into analysing these. The following conclusions can be drawn from the analysis performed so far -

(i) There was a problem in the analysis where radiation fog over land extended to the coast. Coastal observations of thick fog were then spread spuriously well out to sea. This occurred in the majority of cases.

(ii) The mesoscale model tended to over forecast the areal extent of thick fog. This appeared partly because the model formed fog too quickly. The mesoscale model also tended to clear thick fog too quickly. This happened for two days in a row during the 15 -16 Feb 02 case.

(iii) The Nimrod forecast produced by merging the analysis and model forecasts consistently improved the model forecasts out to at least T+3 hours.

(iv) The extrapolation forecast was examined for 31 Jan - 1 Feb 02 It tended to follow the mesoscale model in clearing the fog too quickly.

(v) On the 14th Jan 01 the aerosol mixing ratio was so high that even the analysis had too low a visibility. The observed visibility was around 10 - 20 km but the analysis reduced this to 5 - 6 km when calculating the visibility from the RH and the mesoscale model had 1 - 2 km.

7 Recommendations for Improvements

The recommendations for improving the visibility scheme, especially for fog situations have been grouped into three classes. First there are improvements produced by removing the errors which have been discovered. Secondly, there are recommended improvements, where it is felt there is sufficient evidence that the development will be beneficial. Finally, there are suggestions for improvements which are likely to be beneficial but which require further investigation to clarify the benefit. These will require prioritisation.

7.1 Correction of Errors

The errors which have been corrected are -

(i) The spurious quality control on the observation time which caused SAMOS NT observations to be rejected.

(ii) The rejection of observations which differ in height by more than 200 m from the co-located Nimrod orographic height.

(iii) The spurious upper limit of 10 gKg^{-1} on the mesoscale model mixing ratio.

(iv) The error in the program which reprojects the AVHRR data onto the Nimrod grid.

The remaining error which should be corrected is the 1 or 2 pixel misalignment of the land/sea mask and the orographic height field, which can cause an unrealistically low weight to be applied to some coastal observations.

7.2 Recommended Improvements

It does not seem sensible for the visibility analysis to continue to use its own cloud mask, now that the general Nimrod cloud mask has been improved by allowing for the effect of the atmosphere on the Meteosat IR temperatures. Nor does it seem sensible to continue to discriminate between high and low cloud using the IR temperature when an improved cloud-top height algorithm is being introduced. Therefore, it is recommended that the Nimrod cloud mask and cloud top height be used in the visibility scheme. Another reason for doing this is that a much more reliable cloud mask will be available when MSG is introduced and hopefully a more accurate cloud top height field.

A trial has been set up to compare the accuracy of the mesoscale model aerosol forecast with that developed by the Atmospheric Dispersion Group, which is also running operationally. The mesoscale model forecasts are being archived for grid points co-located with sites where aerosol measurements are made. The mesoscale model and Atmospheric Dispersion Group aerosol forecasts will be compared with the measurements in collaboration with them.

The temperature adjustment for orographic height should use the moist adiabatic lapse rate after reaching saturation point, instead of continuing the use the dry adiabatic lapse rate as at present. The dew point should be limited to the saturation value during adjustment along a wet adiabat.

7.3 Potential Improvements

Initial tests suggest that reintroducing the extrapolation forecast has the potential to improve the visibility forecasts. However, a more elaborate technique may be needed than that used originally, for example treating land and sea areas separately. Testing needs to be carried out to evaluate which technique will produce the best improvement over the current scheme which only merges the analysis and model forecasts.

A method of dealing with valley radiation fog, in a way which will prevent the misdiagnosis of fog over high ground, would be beneficial to the visibility analysis. This is a difficult problem to solve and the main hope may be a much improved cloud mask based on MSG data.

More information is available from the observations than is currently being used. Better use of some of this information could help improve the analysis and these methods should be investigated:

- Use of information about the reliability of the observations to allow more reliable observations to be spread further than the less reliable observations.
- Better use of the present weather report, e.g. the presence of shallow fog when visibility is high (initially for use in the evaluation of the Nimrod visibility forecast) and whether the sky is discernible would give an indication to the depth of the fog.
- Make allowances for low precision observations of visibility (codes 90-99)

Consider making the weight for merging the persistence into the forecast a function of the time of day and year, as fog clearance by solar radiation can only occur during daylight hours and radiation fog development occurs mainly at night. At present, when fog is analysed in Nimrod but is not present in the mesoscale model forecast, it will be cleared on about the same time scale, due to merging, irrespective of whether it is day or night.

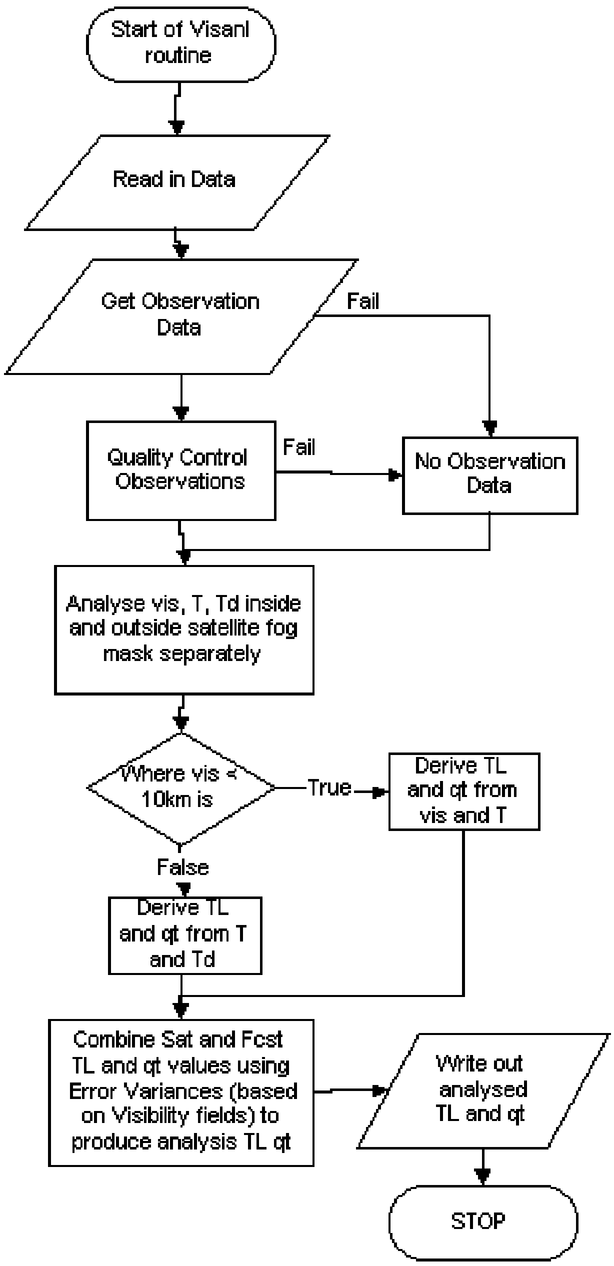
If the Atmospheric Dispersion Group aerosol forecast proves no better than the mesoscale model forecast, the forecast aerosol field could be modified using currently observed values of visibility, temperature, dew point and air pressure. The aerosol concentration would at least then be compatible with the observed visibility and relative humidity. One complication with this proposal is how to carry the modifications to the model aerosol field into the forecast.

In situations where fog is clearing by solar radiation, the weight given to persistence should be a function of the distance of each pixel to the edge of the fog bank. This would predict the expected behaviour of fog clearance by solar radiation.

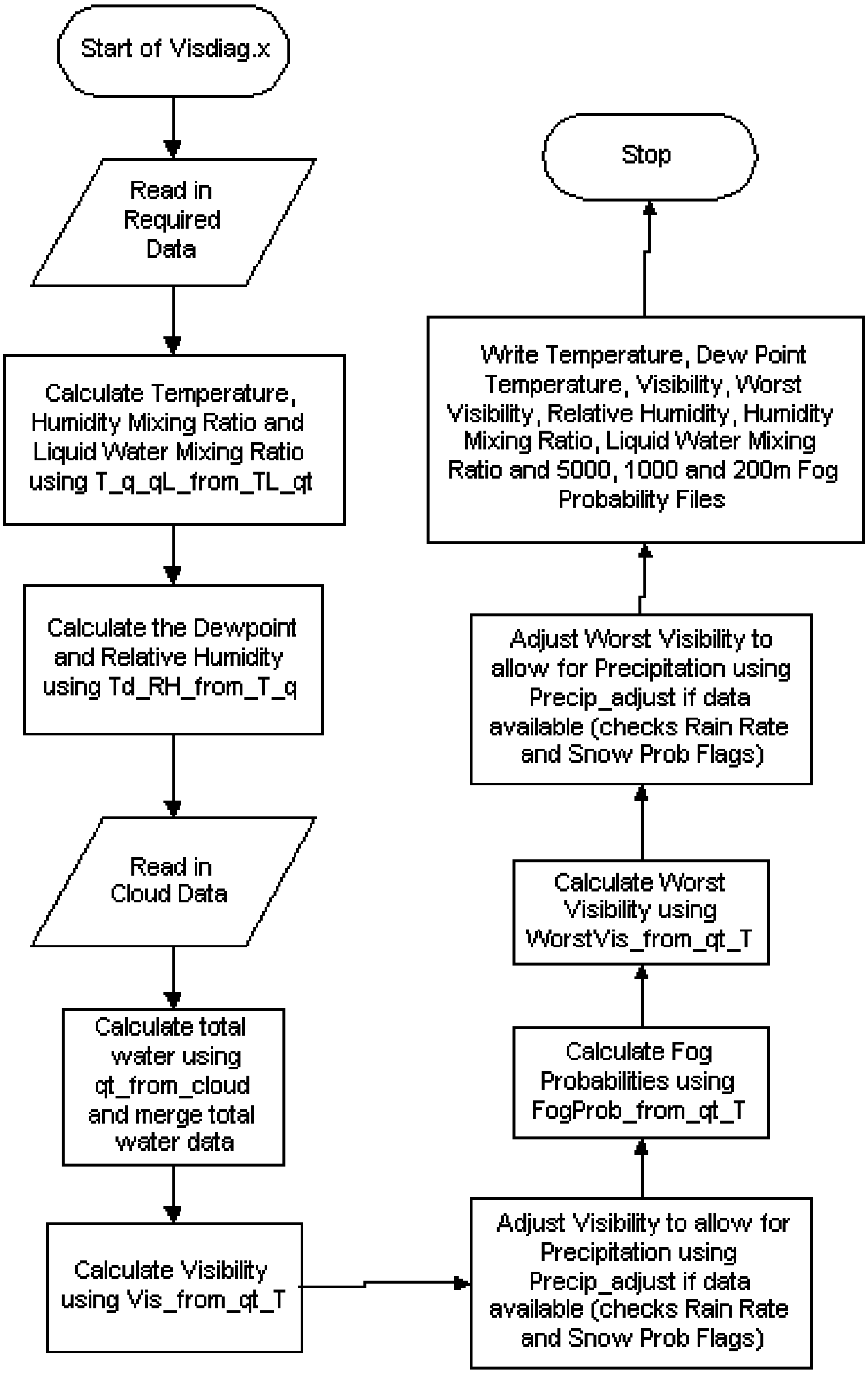
In order to best use the extra information which will soon become available from the MSG project, consideration is required of the accuracy and use of the 3.7 – 10.8μm temperature difference for diagnosing fog characteristics. This temperature difference is a function of the liquid water path through the fog and mean drop size. A low mean drop size will produce a lower visibility for a given liquid water content. If the MSG cloud-top height and cloud mask fields are sufficiently accurate for low level clouds, this information could be used to infer areas of fog in regions where surface observations are sparse. This would probably require delineation of cloud-top height to within a few hundred metres above the surface. The availability of 15 minute satellite observations will allow trends in fog cover to be inferred, allowing a more sophisticated fog forecasting technique to be considered.

8 Annex A: Flowcharts of Program Logic

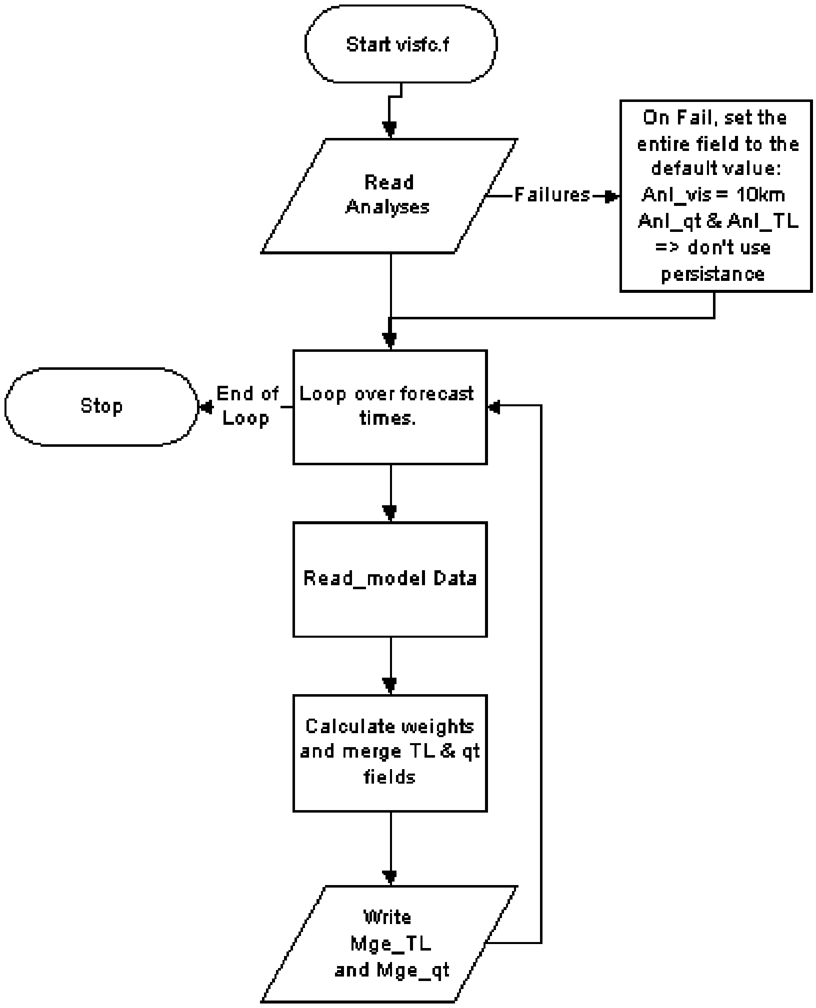
Visanl.x



Visdiag.x


Start of Visdiag.x
Read in Required Data
Calculate Temperature, Humidity Mixing Ratio and Liquid Water Mixing Ratio using T_q_qL_from_TL_qt
Calculate the Dewpoint and Relative Humidity using Td_RH_from_T_q
Read in Cloud Data
Calculate total water using qt_from_cloud and merge total water data
Calculate Visibility using Vis_from_qt_T
Adjust Visibility to allow for Precipitation using Precip_adjust if data available (checks Rain Rate and Snow Prob Flags)
Calculate Fog Probabilities using FogProb_from_qt_T
Calculate Worst Visibility using WorstVis_from_qt_T
Adjust Worst Visibility to allow for Precipitation using Precip_adjust if data available (checks Rain Rate and Snow Prob Flags)
Write Temperature, Dew Point Temperature, Visibility, Worst Visibility, Relative Humidity, Humidity Mixing Ratio, Liquid Water Mixing Ratio and 5000, 1000 and 200m Fog Probability Files
Stop

Visfc.x



The weights for merging the T_L and q_t data are detailed in the section on the Outline of Program Logic.