Meteorological Data and Dispersion Modelling

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Summary.
There are two main sources of meteorological data for dispersion modelling in the UK. These are the UK Meteorological Office and Trinity Consultants Inc. No particular distinction is made between the use of data from these two sources, though they are not identical. This note discusses these differences and the effects they may have on dispersion calculations.

1. Introduction.

Dispersion modelling for regulatory purposes in the UK usually requires estimates of pollutant ambient concentrations and deposition covering a variety of criteria, for example human exposure, ecosystem damage and nuisance (DOE(1996), Review Group on Acid Rain(1997)). Emissions and discharge stack heights have to be controlled to remain within these limits. Most of these criteria are based on annual statistics of some sort, both annual averages and a variety of upper bound statistical limits, such as 98%ile and maximum hourly values for nitrogen dioxide and a 99.9%ile 15-minute hourly maximum for sulphur dioxide. Obtaining these statistics requires dispersion calculations on an hourly basis, using hourly weather data, over a whole year, 8760 calculations in total. There may also be a need to carry out calculations for several individual years in order to account for year-to-year variations in pollution statistics.

The dispersion models that are most commonly used for these calculations in the UK are the USEPA ISC model, its UK equivalent the R91 model, the newly arrived (and technically more advanced) USEPA AERMOD model and the UK ADMS model (which is similar in character to the AERMOD model and has been in use in the UK for some years). They all require hourly meteorological data in special formats (different in each case) which has to be processed from the raw data obtained from the meteorological site of interest. This is then processed further within the models in order to provide the parameters specifically required for dispersion calculations. The most important of these meteorological parameters are wind speed, wind direction, boundary layer height and an atmospheric stability criterion (a Pasquill/Gifford stability criterion for the ISC and R91 models and the Monin/Obukhov length scale for the USEPA AERMOD and UK ADMS models). Wind speed and direction are measured directly at meteorological sites, the boundary layer height and stability criteria are derived from other data, including time of day, solar radiation and cloud cover. The derivation of these modelling parameters, especially the boundary layer height and Monin/Obukhov length scale, is a matter of much study and discussion (See, for example the published papers in the two modelling Harmonisation Workshops(Cosemans and Maes(1995), Kretschsmar and Cosemans (1997))) and subject to significant variation between different methods.

There are two sources of UK meteorological data processed for dispersion modelling. These are the UK Meteorological Office, which collates data from all the sites, and Trinity Consultants Inc. The latter provide their own versions of the ISC and AERMOD models (amongst others) and have a world wide provision of meteorological data for modelling purposes (as does the UK Meteorological Office). Trinity Consultants data is probably the most commonly used dispersion data in the USA. Trinity Consultants also supply a CD-ROM of UK meteorological data, which contains data for the years 1993-97. This covers about 240UK sites, including the 75 sites whose data is most suitable for dispersion modelling. Data from the remaining sites, though deficient in some way for modelling purposes, is nonetheless useful for other reasons and the CD-ROM represents the most comprehensive set of UK meteorological data readily available. There is no equivalent data set available from the UK Meteorological Office, who will supply only specific data on request on a fee-paying basis.

The requirements for adequate meteorological data for dispersion modelling are fairly stringent and all essential parameters must be available. Trinity Consultants recommend that there should be at least 90% availability of data over the year and short gaps in data may be filled in by proscribed procedures. There are about 75 UK meteorological sites that can provide data to this standard over long periods. This may seem sufficient, but there is in fact quite sparse coverage over some parts of the country. It is common for these and other sites to be short of data at weekends or of cloud cover information generally.

In the UK there is no proscription on the source of meteorological data for regulatory modelling and there is a division of modelling data users between the two suppliers. Both claim to apply high standards of quality control to their data. Data from Trinity Consultants is significantly cheaper than from the UK Meteorological Office and the constraints on its use are less onerous, so that it is quite popular. We know of at least two respectable practitioners (who will remain nameless) who use only Trinity Consultants data. The authors use data from both sources and have been interested to note that no consideration has been given to whether their data is in fact identical. It is this, and its effect on dispersion modelling studies that is considered here.

2. Comparison of Meteorological Data.

Figure 1 shows plots of four basic meteorological parameters, wind speed and direction, temperature and cloud cover, between the Meteorological Office and Trinity Datasets for identical hours in the year for the site at Finningley (near Doncaster) during 1994. Similar results were obtained from single year data at three other sites. Values from the Meteorological Office data are along the abscissa, for the Trinity data along the ordinate. The solid line is the 1:1 line. It can be seen that there are differences between the two data sources, though in fact most of the data lies close to the 1:1 line. It has to be remembered that there are 8760 points plotted on each graph and in fact most of the data points overlay one another close to the 1:1 line. Some statistics of the comparison are given in Table 1, below. The resolution given for the measurements is the worst value from either data source. The final two columns give the number of samples within twice the resolution.

It can be seen that, except for cloud cover, the frequency of equal values of the parameters is relatively low. However, most of the hourly data values agree to within twice the resolution of the data. This is the minimum difference required to remove the effects of 'digitising' the data within the limits of resolution. Figure 1 also has broken lines either side of the 1:1 line corresponding to plus and minus twice the resolution of the data.

Table 1. Statistics of Meteorological Data Comparison. Finningley 1994

Parameter	Measurement Resolution	No of Hours Values Equal	% of Total	No of Hours Values Within	% of Total
Temperature	±0.5°C	1572	18	±1°C	99.6
Wind Speed	±0.5m s^{-1}	3090	35	±1m s^{-1}	87
Wind Direction	±10°	3511	40	±20°	90
Cloud Cover	±1 Okta	7255	83	±2 Oktas	96

The largest differences between the two data sets are of wind speed and direction and there is a reason for this. The data provided by Trinity Consultants is obtained from the US National Climatic Data Centre (NCDC), which collates meteorological data world-wide. They have also, in co-operation with the USEPA, developed procedures for supplying data suitable for dispersion modelling (Beychok(1994) p.153). NCDC-based data is thus the standard source of meteorological data for dispersion modelling in the USA. Their format for wind speed and direction data is to take the average values over the first ten minutes of each hour. In comparison, wind speed and direction from Meteorological Office data is averaged over the full hour. The NCDC's choice of data format seems to be mainly related to maintaining continuity of data with earlier (and, in many cases, still current) methods of collecting meteorological data by hand. The usual method of doing this is to record the meteorological parameters at the start of each hour, during which task a measurement of wind speed and direction is recorded over the first ten minutes of the hour.

It must be appreciated that this latter method of recording wind speed is not necessarily inferior to taking a full average over the hour. Indeed, it is probably advantageous in assessing some wind speed parameters, such as the frequency of occurrence of extreme wind speeds. Nor is it statistically significant that some of the sample is lost, as long as there are sufficient numbers of sampled data points to determine any required parameter. In the present case there are nominally 8760 samples in both data sets, which is adequate for determining most air pollution parameters. The main meteorological distinction between the two data sets is the averaging time used. A 10-minute averaged wind speed can be expected to show a greater variability than an hourly average since the wind is more unsteady in speed and direction in the shorter term. This should not affect a calculation of the annual mean wind speed, but might show a higher value of, say, the 98%ile. The additional variability can be predicted approximately by a number of methods and depends on several meteorological factors including wind speed, height above the ground and atmospheric stability. However, a rough order of the standard deviation of the additional variability in six 10 minute means within a given hour would be of the order of 1-8% in wind speed and 0.3°-3° in wind direction against values of the hourly mean.

Some statistics of variation in temperature and wind speed between data sets from the two sources are shown in Table 2, below. There are no differences between any statistics of temperature. The wind speeds show some differences. The annual mean wind speed from the Trinity data set is about 3% higher than from the Meteorological Office data set and the standard deviation of the wind speed from the Trinity data set is 5% higher than from the Meteorological Office data set. These differences are consistent with the arguments over averaging times above, but are small compared with the year-to-year differences that often occur. The small differences between the higher order statistics, the skewness and kurtosis, are not significant.

Table 2. Statistics of Temperature and Wind Speed Between Meteorological Office and Trinity Consultants Data Sets. Finningley, 1994.

Statistic	Temperature °C		Wind Speed m s^{-1}	
	Met Office	**Trinity**	**Met Office**	**Trinity**
Annual Mean	9.95	9.95	4.33	4.48
Standard Deviation	5.71	5.71	2.59	2.72
Skewness	2.03	2.04	2.26	2.27
Kurtosis	3.49	3.49	4.35	4.38

Figure 2 shows bar charts of wind speed in five categories for 30° wind sectors, for the two data sources, again for Finningley 1994, together with data for one additional year, 1993 for Meteorological Office data. It can be seen that there are slight differences between the two data sources in this example, but that differences between Meteorological Office data for 1993 and 1994 for the site are significantly greater than between the two data sets for 1993. Closer inspection of the 1993 data from the two sources shows that in the lowest wind speed band, Trinity Consultants data shows overall slightly lower wind speeds than does that of the Meteorological Office. In the highest wind speed band, the opposite occurs, the Trinity Consultants data shows slightly higher wind speeds overall. This is consistent with the greater variability in wind speed that might be expected with a 10-minute averaging period against one hour.

3. Dispersion Calculations from the Two Meteorological Data Sets.

In view of the possible uncertainties in dispersion calculations due to these differences, we have carried out some sample dispersion calculations, using emission data consistent with a large power station with a stack of 200m height and a heat release from the stack of about 300MW. Dispersion calculations from larger, higher discharges of this sort tend to show greater effects from changes in the boundary layer characteristics (derived from the meteorological data) than from sources at lower heights. The dispersion model used was UK ADMS, versions 2.2 and 3. The meteorological data was for Finningley, 1994, as in the meteorological data comparison above.

Figures 3, 4 and 5 show calculated concentration contour maps of, in turn, annual average, 99.9%ile and 100%ile concentrations. Each Figure shows a plot from using each combination of UK ADMS Version 2.2 or 3 with Meteorological Office or Trinity data for Finningley, 1994, as discussed above.

Table 3, below, gives the maximum values of the annual mean and 100, 99.9, 99, 98 and 95 percentiles for these cases. Table 4 gives the position of these maxima in each case. The ratios between values using different models and between different versions of the model shown in Table 3 are given in Table 5. A bar chart of the data in Table 5 is shown in Figure 6.

Table 3. Maximum Concentrations from the Plots in Figures 3, 4 and 5. Hourly averaged concentrations in µg m^{-3} for a release of 1 kg s^{-1}.

Model/ Met data	Annual Mean	100 %ile	99.9 %ile	99 %ile	98 %ile	95 %ile
ADMS v2.2						
Met Office	0.53	291	49.5	20.4	7.07	1.01
Trinity	0.62	234	64	24.9	9.22	1.33
ADMS v3						
Met Office	0.50	64.6	46.6	19.3	8.97	0.80
Trinity	0.59	66.2	48.1	22.4	12.0	1.29

Table 4. Position of Maximum Concentrations Given in Table 3.

Model/ Met data	Coords (km)	Annual Mean	100 %	99.9 %	99 %	98 %	95 %
ADMS v2.2							
Met Office	X	462	460	462	462	468	474
	Y	424	423	424	424	433	440
Trinity	X	462	454	458	462	464	480
	Y	424	427	429	424	423	422
ADMS v3s							
Met Office	X	462	464	462	462	466	474
	Y	424	418	424	424	424	440
Trinity	X	462	462	462	462	468	480
	Y	424	431	424	424	423	422

The contour maps in Figures 3-5 mostly show broadly similar distributions of the concentration contours though, as these and Tables 3-5 show, there are differences due both to the meteorological data and the version of ADMS used. Table 5 shows that most of the values calculated using the four combinations of model and meteorological data are within 25% of one another. It is also clear that variations between the two different versions of the dispersion models are as great as those between the two different sets of meteorological data. The greatest differences between both models and meteorological data are in estimating the 100%ile concentration between ADMS versions 2.2 and 3 and (for no reason that is clear) the 95%ile concentrations. Overall the Trinity Consultants meteorological data and ADMS v 2.2 produced the highest concentrations, but not consistently.

Table 5. Ratios of Concentrations from Table 3 for Different Model Versions and Meteorological Data.

Model/ Met data	Annual Mean	100%ile	99.9%ile	99 %ile	98 %ile	95 %ile
Met Office /Trinity						
ADMS v2.2	0.85	1.24	0.77	0.82	0.77	0.76
ADMS v3s	0.85	0.98	0.97	0.86	0.75	0.62
ADMS v3s/v2.2						
Met Office	0.94	0.22	0.94	0.95	1.27	0.79
Trinity	0.95	0.28	0.75	0.90	1.30	0.97

Figure 6 also shows a bar chart of ratios of concentrations calculated for 15 minute and hourly averages in the dispersion model. This difference is mainly of interest due to the 15 minute averaging time required for the EPAQS 99.9%ile short term sulphur dioxide limit. The effect of the shorter averaging time has to be calculated within the dispersion model from the dispersion calculation based on hourly data. There are again differences between the variations in model and meteorological data, though with different patterns to those of the hourly data. The 99.9%ile, the parameter of greatest interest, shows a relatively small variation between different models and meteorological data.

Figure 7 shows a plot of the percentile concentrations at the point of maximum annual mean concentration for the four combinations of data and model. All the curves follow the same trend, with the greatest differences at the 100%ile and 95%ile values. There is a marked rise in concentration at the 100%ile value using ADMS v.2.2, which is greatest with Meteorological Office data.

It must be noted that some of the differences between the calculations noted above are related not to the dispersion calculation directly, but to the model's interpretation of the meteorological data, which in turn affects the dispersion calculation. Figure 8 shows a plot of the differences in boundary layer height calculated by versions 2.2 and 3 of the ADMS model. About 9% of the values exceed a difference of $\pm$ 50m.

4. Discussion and Conclusions.

The two sources of meteorological data investigated here show differences, partly due to the definitions of wind speed and direction used, though both claim to apply high standards of quality control. However, the comparison also shows that a high proportion of the differences are within the limits of resolution of the data and of the 'digitisation' that causes a measurement to be placed within a specific range band, of wind speed and direction for example. It must also be noted that year-to-year differences in meteorological data are significant and will generally be greater than between the two data sets for the same single year.

These differences between the two sources of meteorological data are large enough to affect dispersion calculations with the dispersion model used here, UK ADMS, differences in the upper bound percentiles of interest in air pollution studies being significantly greater than the annual means. However, the differences in calculated concentrations between the two most recent versions of UK ADMS , versions 2.2 and 3, are of the same order and in some cases greater than those generated between the two different meteorological data sets.   It must be noted in this context that the recent transfer from version 2.2 to version 3 of ADMS seems to be largely passing without any major interest being shown in any differences of calculation that may exist between them. This particular model is not alone in this matter and it may be regarded as surprising that such matters are not take more seriously.

The final question that must be asked therefore is whether there is any reason why either source of meteorological data should not be used for dispersion modelling studies. There would seem to be two arguments. Firstly that present UK preferred standard practice is to use Meteorological Office hourly data. If so this is not promulgated anywhere and amounts to a form of proscription, which the regulatory authorities are keen to avoid. Secondly, that the nature of the Trinity Consultants data, using a 10-minute average at the start of each hour, is statistically less satisfactory than full hourly averages as supplied by the Meteorological Office. The statistical differences between the two meteorological data sets, discussed above, in fact seem relatively small compared with other sources of error in the dispersion modelling chain.   In practice these differences between the data sets should have little effect on annual average dispersion calculations, as seems to be the case here. Calculations of upper bound percentiles show more variability, but this is in any case a problem associated with this type of estimate, which is more uncertain than an overall mean.   Meteorological data based on ten minute averages should in principle provide a more accurate way of estimating the 99.9%ile 15 minute mean EPAQS SO_2 limit, as its 10-minute averaging time is closer to the 15 minute mean required than an hourly average. However, the other upper bound concentrations of interest, for NO_2, are hourly averages for the 100%ile and 98%ile.

This brief investigation shows clearly enough that all sources of meteorological data are not the same and that both the choice of dispersion model and of meteorological data affect the resultant dispersion calculation. Whether these differences should be regarded as critical is arguable and the authors' view is that they mostly lie within what might be called the 'noise' of modelling. That is, we are here approaching the limits of accuracy of present modelling methods. Part of the problem may be that advanced dispersion models such as UK ADMS or AERMOD are more sensitive to meteorological data than the older simpler models. Given the uncertainty in all collected meteorological data and the relatively large year to year differences that occur in the UK, differences due to the choice of meteorological data do not seem particularly critical.

There would, however, seem to be a good case for expecting that modelling studies should quote the source of their meteorological data, along with the type and version of the dispersion model used. At present the latter is nearly always given , the former hardly ever.

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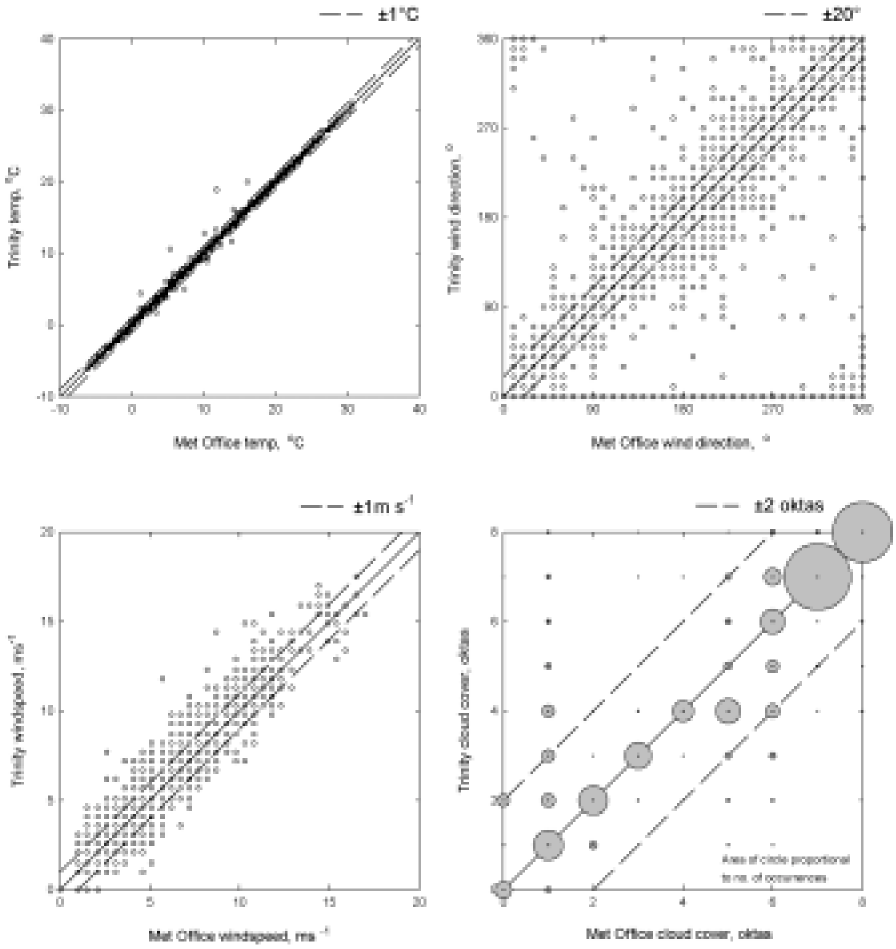
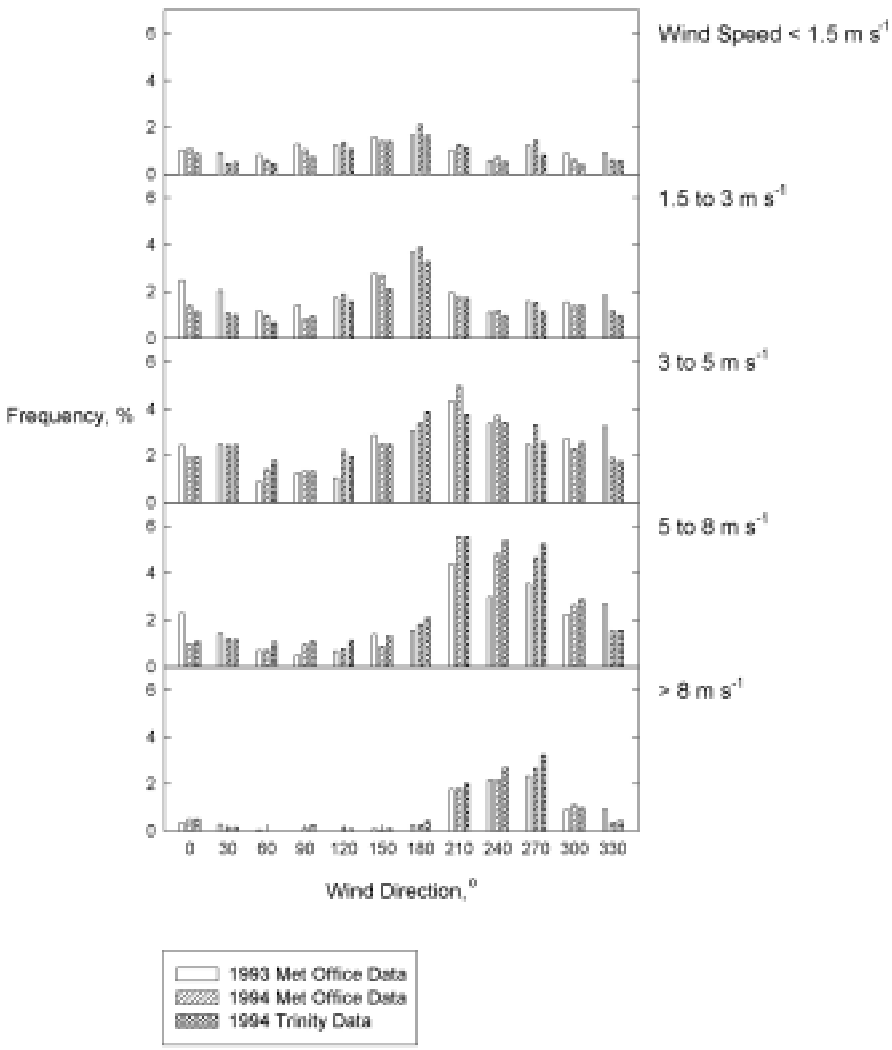


Figure 1. Comparative Plots of Wind Speed, Wind Direction, Temperature and Cloud Cover for Trinity Consultants and Meteorological Office Data. Finningley, 1994



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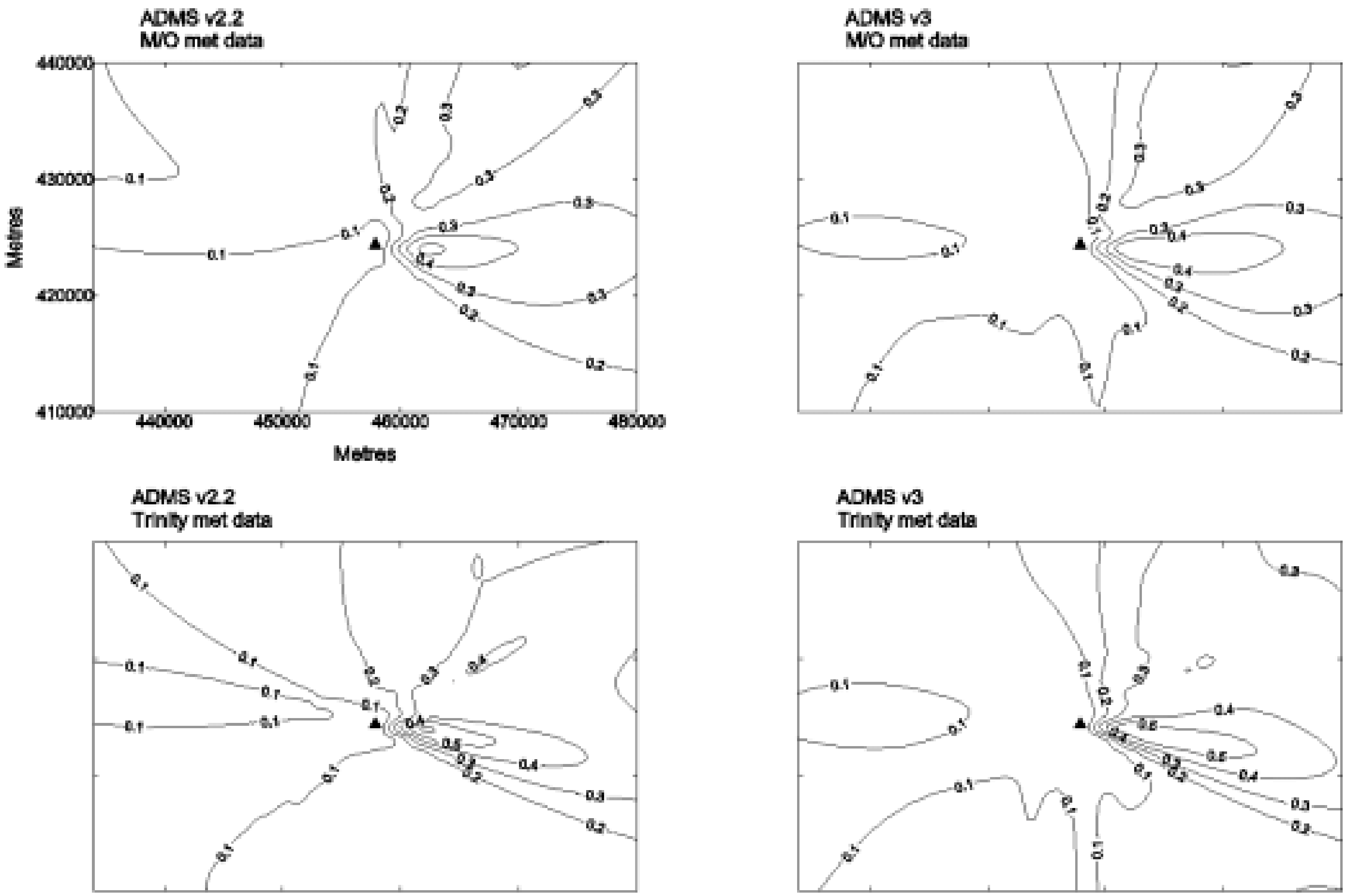


Figure 3. Contour Concentration Maps of Annual Average Concentration for the Two Meteorological Data Sets, Calculated using UKADMS Versions 2.2 and 3.
Concentrations in ug/m3 for an Emission of 1kg/s.

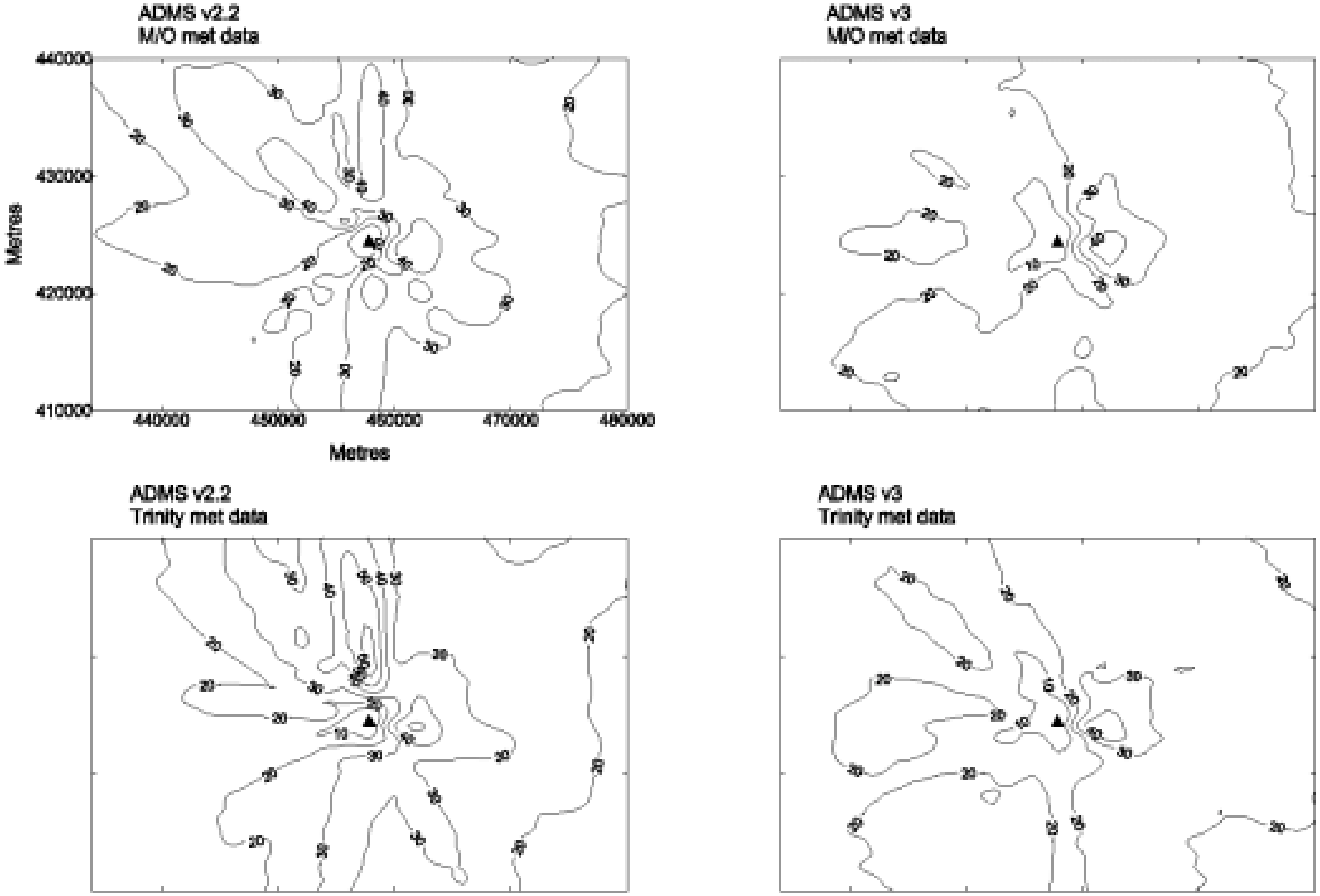


Figure 4. Contour Concentration Maps of 99.9%ile Concentrations for the Two Meteorological Data Sets, Calculated using UKADMS Versions 2.2 and 3. Concentrations in ug/m3 for an Emission of 1kg/s.

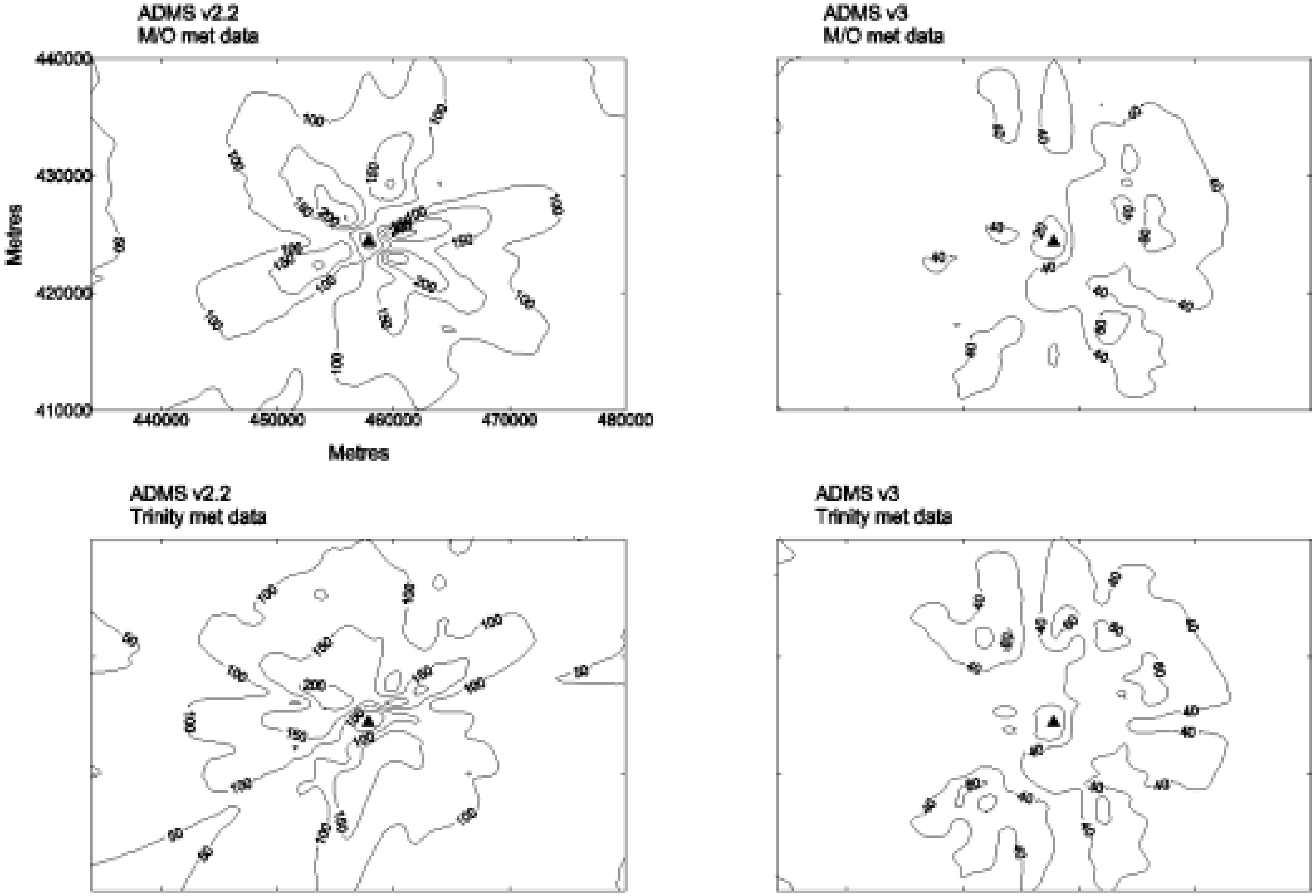
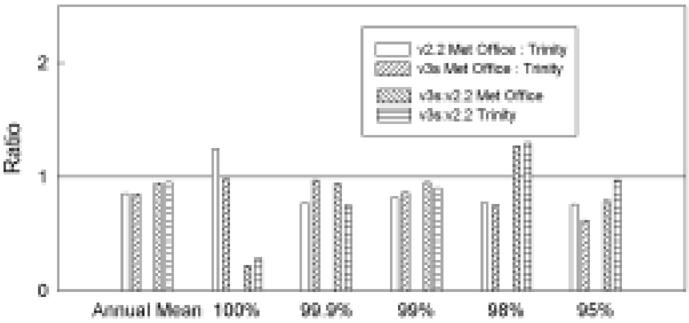


Figure 5. Contour Concentration Maps of 100%ile Concentrations for the Two Meteorological Data Sets, Calculated using UKADMS Versions 2.2 and 3. Concentrations in ug/m3 for an Emission of 1kg/s.

Variation in Hourly Average Concentrations
with Type of Meteorological Data and Version of UKADMS.



Ratio of 15 minute to 1 hour averages

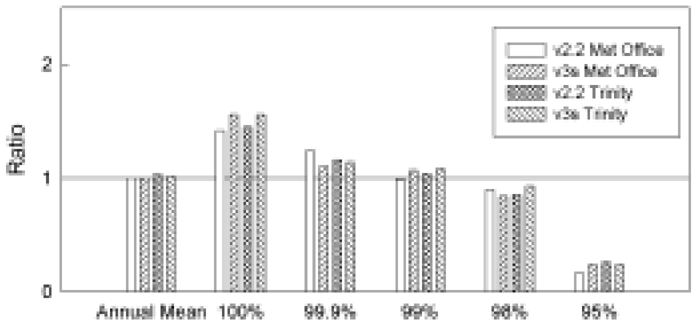


Figure 6. Bar Charts of the Concentration Ratios in Table 5 for Maximum Concentrations using Different Combinations of Model and Meteorological Data.

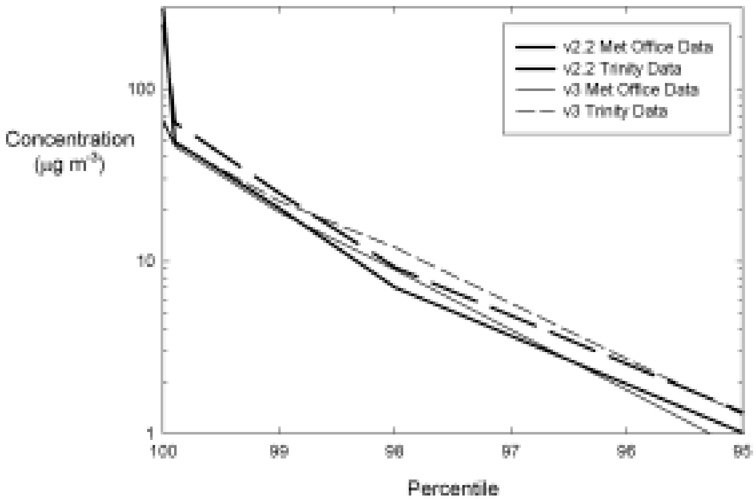


Figure 7. Percentile Plots of Concentration at the Point of Maximum Annual Mean Concentration in Figure 3 using Different Combinations of Model and Meteorological Data.

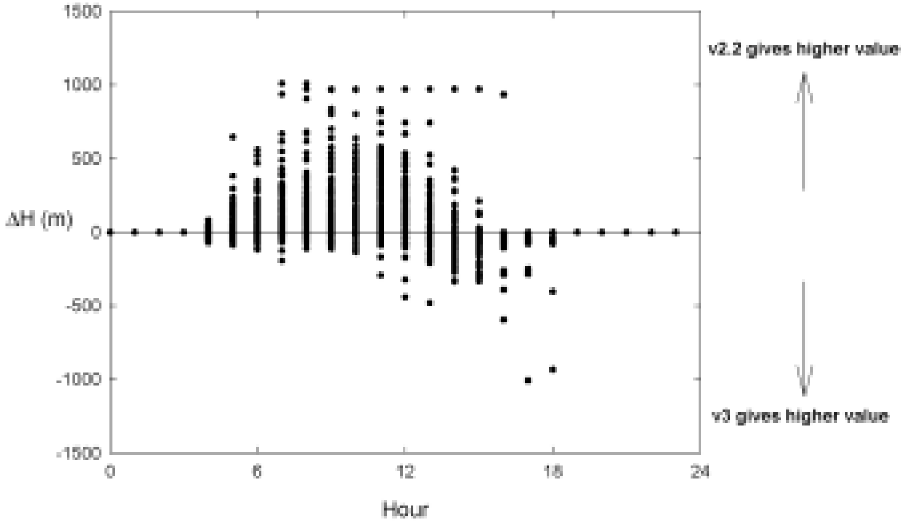


Figure 8. Differences in Calculation of Boundary Layer Height Between UK ADMS Versions 2.2 and 3. From Finningley 1994 Meteorological Office Data.