Numerical Weather Prediction

Improvement to the Nimrod Wind Nowcasting Scheme over High Ground.

Forecasting Research Technical Report No. 406

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Abstract

The Met Office mesoscale model typically forecasts unrealistically low windspeeds over high ground due to the sub-grid orographic roughness parameterisation.
A scheme to correct the unrealistically low wind speeds has been proposed by Pete Clark at the Joint Centre for Mesoscale Meteorology, University of Reading. This scheme also includes an adjustment for the difference in height between the observing station and the mesoscale model smoothed orographic height.
Several versions of the scheme have been implemented for the Nimrod wind nowcasting system and a trial has been conducted. This report outlines the adjustment scheme and presents some results. Further modifications are described and the results of trials presented. The overall picture is that of a clear improvement under the new scheme. Finally, suggestions for further work to improve the Nimrod wind forecast are presented.

Acknowledgements

Thanks to Rod Brown and Phil Hopwood for many useful discussions.

Contents

1 Introduction

The Nimrod wind nowcasting scheme uses current synoptic observations to adjust the mesoscale model wind forecast. A difference field is formed by spreading the (model - observation) differences in both speed and direction using a recursive filter. The difference field is added to the model forecast to produce the analysis. It was intended to advect the difference field with the gradient wind and add to the appropriate mesoscale model forecast to produce the Nimrod forecast speed and direction. Unfortunately, the mesoscale model typically forecasts unrealistically low windspeeds over high ground due to the sub-grid orographic roughness parameterisation. This effect dominated the difference field, which when advected over the sea led to unrealistically high windspeeds. It was necessary to make the difference field stationary in order to produce the best forecast. It was also necessary to limit the spread of information by the recursive filter to stop large differences spreading from high ground to low ground.

A scheme to correct the unrealistically low wind speeds has been proposed by Pete Clark at the Joint Centre for Mesoscale Meteorology, University of Reading. This scheme also includes an adjustment for the difference in height between the observing station and the mesoscale model smoothed orographic height. Several versions of the scheme have been implemented and a trial conducted. This report outlines the adjustment scheme and presents some results. Further modifications are described and the results of trials presented. Finally, suggestions for further work to improve the wind forecast are presented.

2 Outline of scheme.

To aid interpretation of the results a very brief description of the scheme is given here. Further details are in Clark (2002) (henceforth referred to as PC02). The scheme consists of two stages:

2.1 Roughness Adjustment to the model windspeed

A suitable reference height (see below) is chosen and below this height, instead of the UM windspeed profile, which can be thought of as approximately logarithmic with a roughness length based on the sub-gridscale *orographic* roughness, a logarithmic profile with a *vegetative* roughness is fitted (see ***Figure 1***). This generally gives greater shear below 10m and consequently a higher model windspeed at 10m. This adjustment to the model windspeed will be referred to in this report as ‘roughness adjustment’ (R.A.).

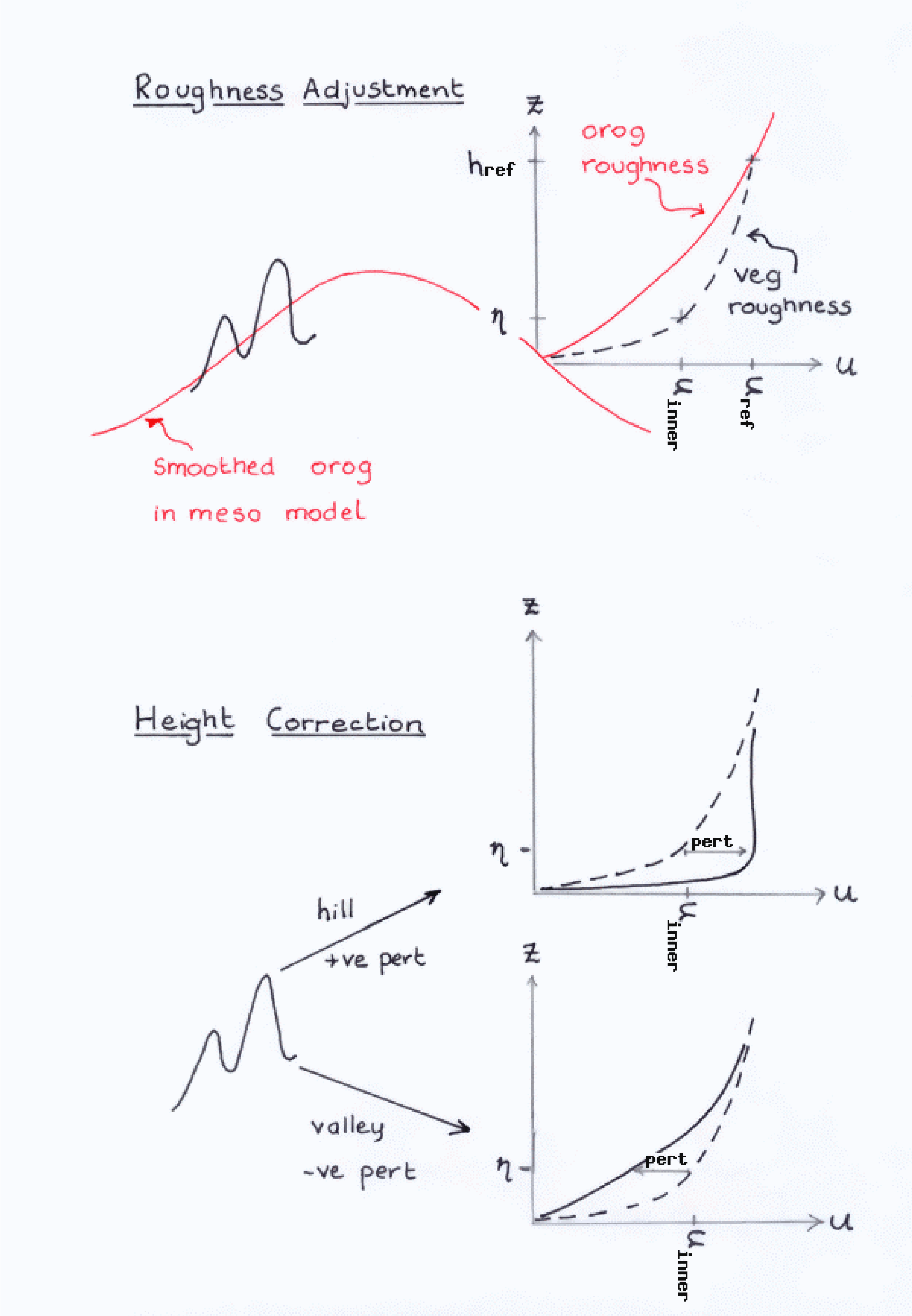

Figure 1 Schematic diagram showing the roughness adjustment and the height correction.

2.2 Height Correction to the observations

A perturbation is subtracted from the observation (see again ***Figure 1***). This perturbation depends on the height of the observation station (h_s) relative to the mesoscale model orographic height (h_m), and is an increasing function of ($h_s - h_m$). This can be thought of as correcting the observed windspeed 10m above the real orography to an anticipated windspeed 10m above the mesoscale orography, which is not the same as the real orography due to orographic smoothing. The practice of making an adjustment to the observed windspeed will be referred to in this report as 'height correction' (H.C.). However, for consistency with the nomenclature of PC02 and with the nomenclature of linear theory in general, this adjustment is also referred to as a perturbation: the amount by which the vegetative-roughness windspeed profile (the broken black line on the u vs. z graphs in ***Figure 1***) is perturbed by the sub-gridscale orography (the small-scale wiggly hills shown in black in ***Figure 1***), giving the local windspeed profile (the solid black line on the u vs. z graphs in ***Figure 1***).

3 Implementation

3.1 Roughness Adjustment

Following PC02, we take the reference height to be:

$$h_{ref} = k^{-1}, \tag{1}$$

where the local wavenumber, k, is given by

$$k = \pi \frac{A/S}{h/2}. \tag{2}$$

The fields of silhouette orography, A/S, and the half peak-to-trough height, $h/2$, are stored in Nimrod constant ancillary files which in turn are derived from the file `qrparm.orog.pp` Note that these fields vary between UM4 and UM5. We take the outer layer windspeed to be the unified model windspeed at the reference height:

$$u_{\text{outer}} = u_{ref} = u_{\text{UMFC}}(h_{ref}). \tag{3}$$

The adjusted model wind is assumed to be equal to the inner layer windspeed which is given by

$$u_{\text{inner}} = u_{ref} \frac{\ln(\eta / z_0)}{\ln(h_{ref} / z_0)} \quad , \tag{4}$$

where η is the height above local orography at which the windspeed is to be calculated (always 10 metres in this work) and z_0 is the *vegetative* roughness, which is stored in a Nimrod constant ancillary file derived from qrparm.veg.z0.pp The use, over significant orography, of this inner layer windspeed in place of the unified model 10 metre windspeed constitutes the roughness adjustment.

3.2 Height Correction

Turning now to the height-correction part of the scheme, the perturbation that we subtract from the observation to 'correct it down' to 10m above the mesoscale model orography we obtain from (c/f PC02 equation 4.37)

$$u_{pert} = u_{\text{outer}} \, \text{Re}\left\{ \left(1 - \frac{K_0(\xi(\eta))}{K_0(\xi(z_0))} \right) \right\} k(h_s - h_m) e^{-k\eta} \quad , \tag{5}$$

where

$$\xi(\eta) = 2\left(\frac{i \ln(\eta / z_0)}{2\kappa^2} k\eta \right)^{\frac{1}{2}} \quad \text{and} \quad \xi(z_0) = 2\left(\frac{i \ln(\eta / z_0)}{2\kappa^2} k z_0 \right)^{\frac{1}{2}} \tag{6}$$

in which κ is Von Karman's constant, taken to be 0.4, and $i = \sqrt{-1}$. K_0 is a modified Bessel function of the second kind and is evaluated using the NAG routine S18DCF.

If we multiply equation (5) by $u_{\text{outer}} / u_{\text{inner}}$ we obtain the expression given in PC02, equation 4.37. Our reason for omitting this factor is that we originally anticipated that u_{outer} and u_{inner} might be derived from different heights in the unified model. We wished therefore to avoid the possibility of absurd perturbations arising when $u_{\text{inner}} << u_{\text{outer}}$. (In the event we based both u_{outer} and u_{inner} on the unified model windspeed at a single reference height as described above, so this hazard was avoided.) Whilst the omission of the factor is not justified on physical grounds, in a refinement of the model (described below) we introduce a tuning parameter which may be regarded as subsuming a generic $u_{\text{outer}} / u_{\text{inner}}$ factor, constant for all sites.

4 Initial trial

Data from the initial trial, which followed closely the method suggested in PC02, were gathered throughout July 2002. Data for the 4-week period 1st – 28th July are considered in the initial trial.

Two observation stations, Cairngorm (1245m) and Aviemore (226m), lie within 20 km of each other and are thus suited to a detailed study of the effects of the scheme.

Cairngorm is approx. 640 metres above the mesoscale orography, Aviemore approx. 220 metres below[1]. The Nimrod windspeed analysis merges observations with a background field which is a mesoscale model forecast, unadjusted in the operational case but with the roughness adjustment applied in the trial case. ***Figure 2*** shows the observation-background anomalies at Cairngorm and Aviemore for both the operational and initial trial schemes. Trials where run at midnight and midday. Bars show the anomaly between observed windspeed (circled) and the background field used for analysis. Brown bars show data for Cairngorm and are offset slightly to the left for clarity. Pink bars show data for Aviemore and are offset slightly to the right for clarity. In the modified case both of the modifications described above (i.e. roughness adjustment and height correction) have been applied (so, for example, at Cairngorm the modified observation is smaller and the modified background is usually larger). It can be seen that the anomalies have on the whole decreased, but note in particular the effect of the modification on cases where the observed windspeed at Cairngorm is high. For clarity some such cases are shown in isolation in ***Figure 3***. It can be seen that the anomalies at Cairngorm have dramatically decreased in these cases.

[1] The discrepancy between these figures and the point heights is, of course, accounted for by the fact that the mesoscale orographic height is different at the two stations. Also note that these values vary according to the version of the mesoscale model.

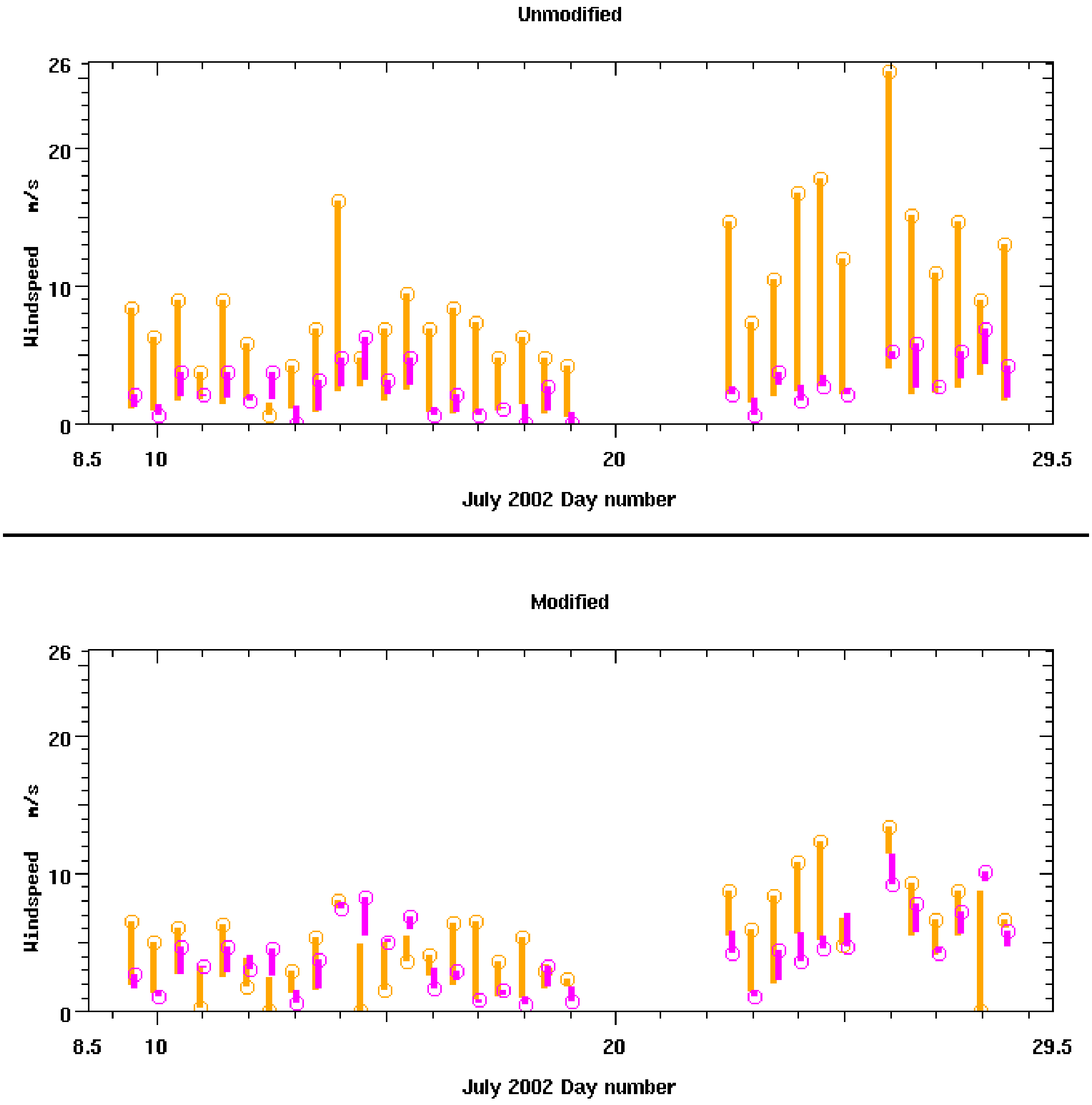

Figure 2 Observation/background anomalies at Cairngorm (brown) and Aviemore (pink).For full details see main text.

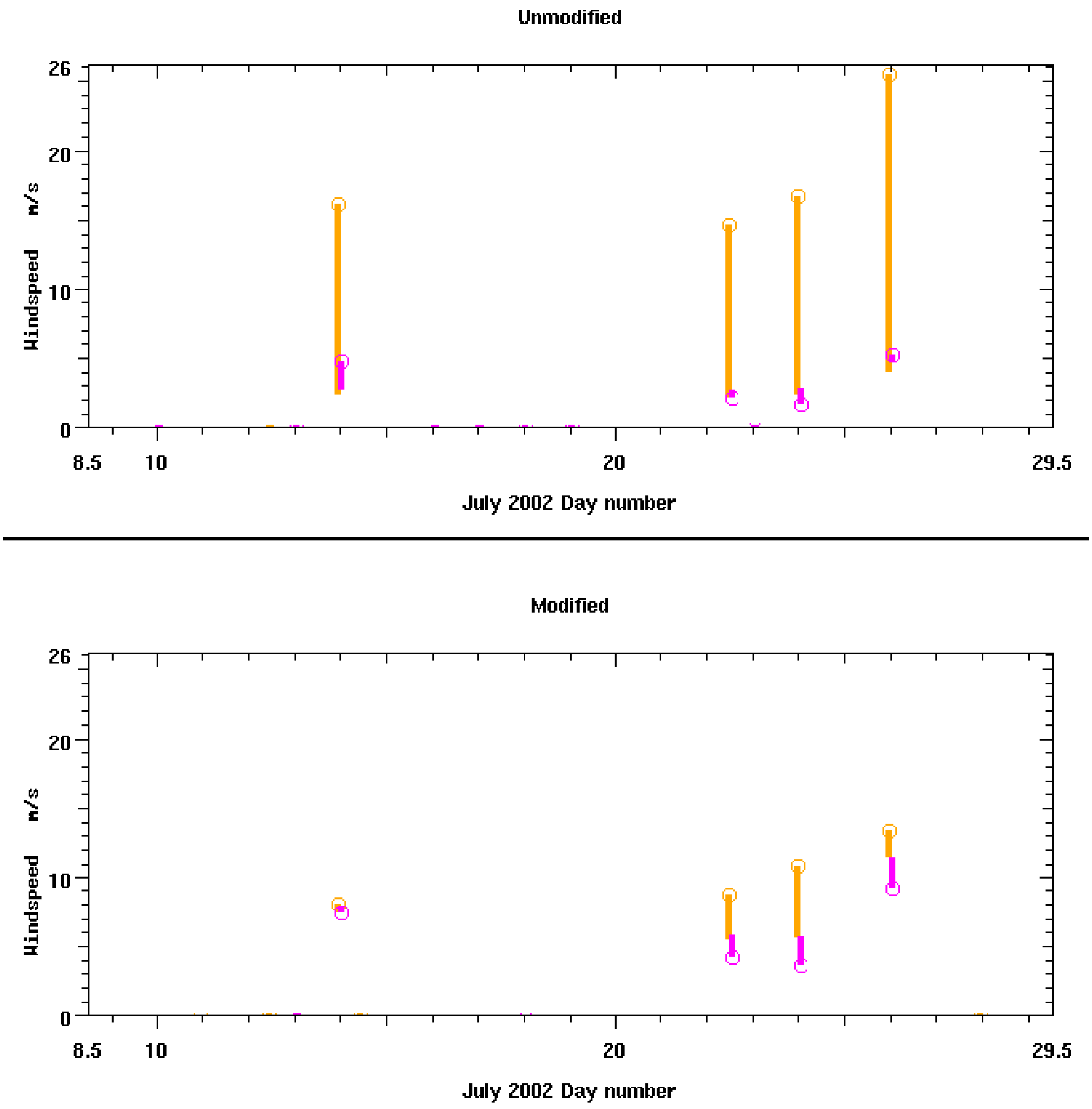

Figure 3. As figure 1 but high windspeed cases selected.

In order to put the assessment on a quantitative footing data were also gathered for more than one hundred high-ground stations throughout the period. The modification was only applied to stations in areas of high ground meeting particular criteria (for example, the local value of A/S must exceed some tolerance since it appears as denominator in equation 4.54 of PC02). Data from stations where the mesoscale orographic height at the nearest gridpoint is greater than 100 m were considered in the initial trial. For each station the anomaly between the observation and the background field was calculated with and without the modification. Overall statistics for the period are presented in ***Table 1***.

Total 8465 cases	Mean anomaly	RMS anomaly
Unmodified	-1.43	2.71
Modified	0.36	2.44

Table 1. Mean and RMS of anomalies throughout the period for all cases.

A histogram of these data is presented in ***Figure 4***. The underestimation bias of the unmodified approach can be seen. The same plot is redrawn with a non-linear scale on the abscissa in ***Figure 5*** – this highlights the large number of cases of underestimation of strong winds by the unmodified approach which gives two cases of underestimation by more than 20 m/s.

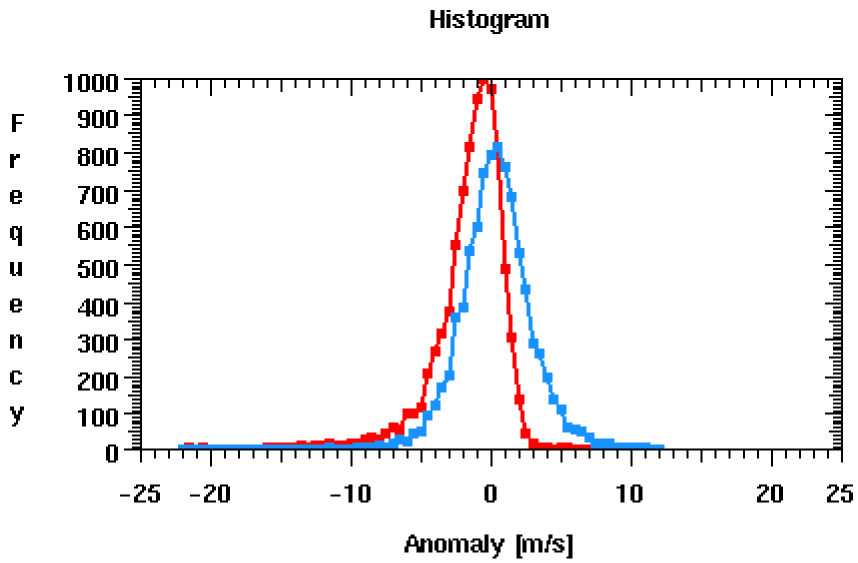

Figure 4. Histogram of anomalies (all cases). Red shows the unmodified approach and blue shows the modified scheme.

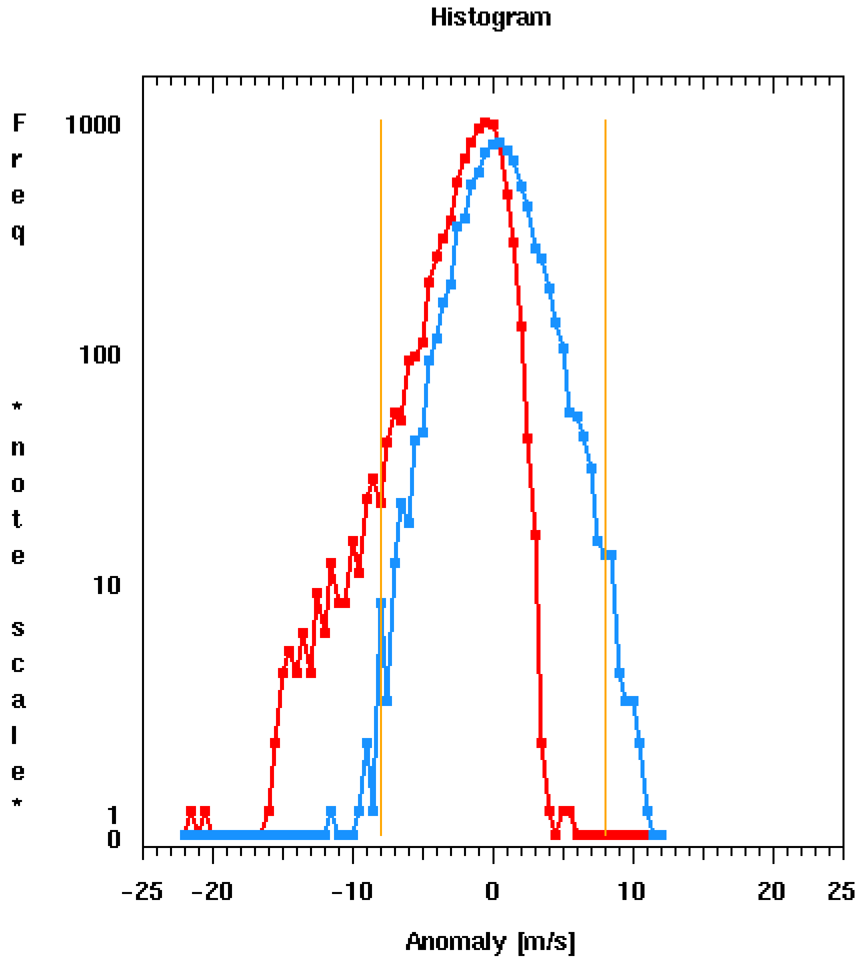

Figure 5. As Figure 4, but a non-linear scale has been applied to the abscissa to highlight the frequencies of anomalies of magnitude greater than 8 m/s.

In ***Table 2*** statistics for cases where the observed windspeed exceeded 10 m/s are shown. The corresponding histogram is shown in ***Figure 6***.

134 cases	Mean anomaly	RMS anomaly
Unmodified	-10.86	11.17
Modified	0.88	4.38

Table 2. Mean and RMS of anomalies throughout the period for cases where the observed windspeed exceeded 10 m/s.

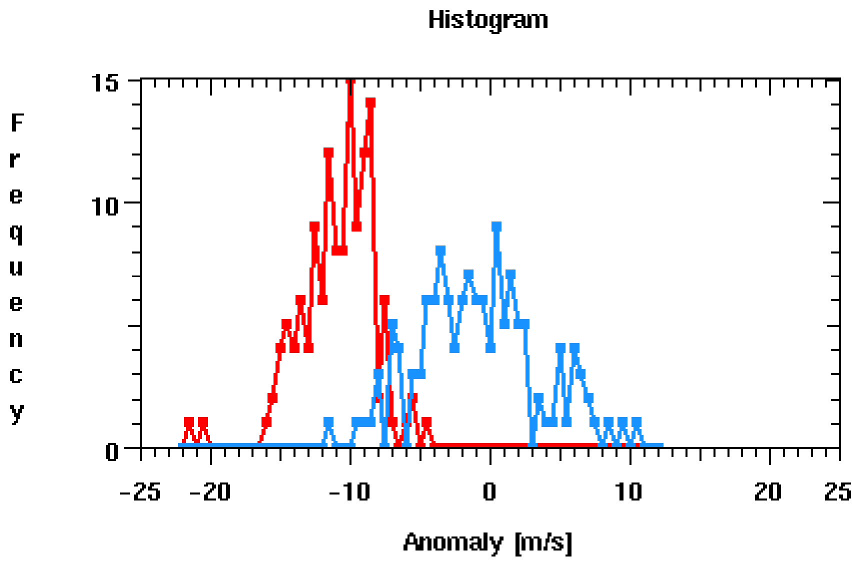

Figure 6. As figure 3 but for cases where the observed windspeed exceeded 10 m/s.

Both ***Table 1*** (all cases) and ***Table 2***(observations exceeding 10 m/s cases) show an improvement in both the mean and RMS anomalies; this improvement is much more significant at high windspeeds. ***Figure 6*** shows that the unmodified approach under-predicted the wind in all cases where the observed windspeed was greater than 10 m/s.

4.1 Wind direction.

The scheme described has no explicit effect on the Nimrod wind forecast direction except in the rare case where the roughness adjustment is applied in a location where the unified model 10m wind is so light as to have no meaningful direction (recall that the wind is stored as horizontal components in integer units of decimetres per second). In such cases the direction is taken from the next model level to have a meaningful direction.

A small implicit effect may also arise due to the relatively low-resolution discretisation of the components.

A further possible source of apparent direction anomalies between this scheme and the existing one is the verification algorithm, which only compares directions if the model windspeed is greater than 5 m/s. Thus any change in the forecast windspeed can lead to apparent differences between the direction statistics from the original and from the modified scheme.

5 Minor Modifications and Tuning.

Some variations on the method described by PC02 have been developed and analysed. First it seems counter-intuitive to base the height correction on the *model* windspeed – which may be in error – why not base the correction on the observation? Taking $u_{\text{outer}} = u_{ref}$ as described and using equation (5) for our perturbation we can write

$$u_{\text{pert}} = C_4 u_{\text{inner}}$$

where C_4 can be regarded as a fixed value for a given observation station, being a function of the orographic roughness parameter in the mesoscale model at that location, the vegetative roughness at that location, the difference between the station height and the mesoscale model orographic height at that location, and the value of η (the height at which we wish to calculate the windspeed, here 10 metres), but *not* a function of the windspeed itself. This is possible because of the linearisation approximation used in the scheme. So, if our existing perturbation calculation is expressed

$$u_{\text{pert}}^{\text{m}} = C_4 u_{\text{inner}}^{\text{m}} \quad ,$$

where the superscript "m" denotes model, and

$$u_{\text{pert}} = u_{\text{station}} - u_{\text{inner}}$$

then our alternative perturbation calculation can be written

$$u_{\text{pert}}^{\text{ob}} = C_4 u_{\text{inner}}^{\text{ob}} \tag{7}$$

where the superscript "ob" denotes observation, so that our corrected observation, instead of being

$$u_{\text{station}}^{\text{ob}} - u_{\text{pert}}^{\text{m}}$$

becomes

$$u_{\text{inner}}^{\text{ob}} = u_{\text{station}}^{\text{ob}} - u_{\text{pert}}^{\text{ob}}$$

which, using equation (7), becomes

$$u_{\text{inner}}^{\text{ob}} = \frac{u_{\text{station}}^{\text{ob}}}{(1 + C_4)}$$

This is our alternative corrected observation (denoted 2b below). Note that in the method described previously (denoted 2a below) the model windspeed is adjusted to the height of the observation; in method 2b the observation is adjusted to the model orographic height. In addition to this, two different tuning methods were tested.

5.1 Tuning.

A simple two-pronged approach to tuning was adopted:

(1) Tune u_{inner} : $u_{\text{inner}}^{\text{m,tuned}} = k_1 u_{\text{inner}}^{\text{m}}$, where k_1 is a constant for the scheme, and
(2) tune the perturbations : $u_{\text{pert}}^{\text{ob, tuned}} = k_2 u_{\text{pert}}^{\text{ob}}$ where k_2 is a constant for the scheme.

This approach is simpler than tuning the reference height and it is anticipated that it will have a similar effect, since the reference windspeed is closely related to the reference height owing to the low shear induced by the orographic roughness scheme.

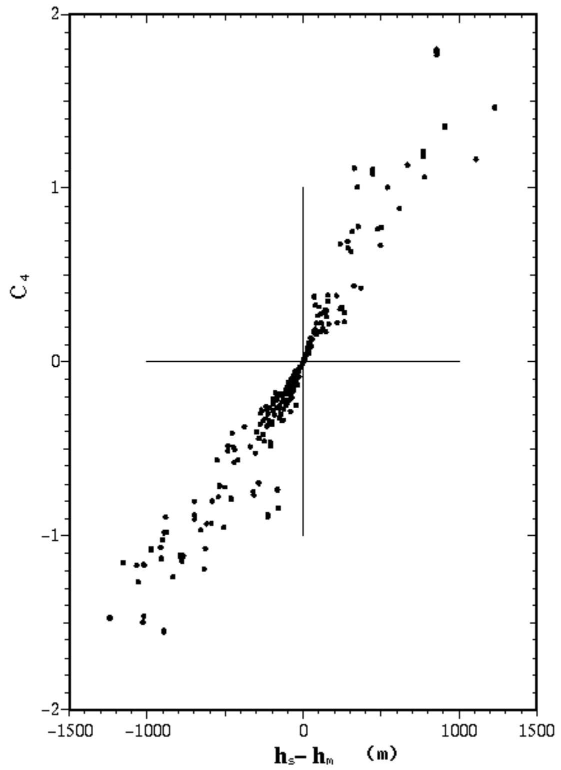

Figure 7: Relationship between C_4 and ($h_s - h_m$) for stations in the Nimrod area.

Furthermore, since $u_{\text{pert}} = C_4 u_{\text{inner}}$ and C_4 is closely related to $(h_s - h_m)$, the height of the station (h_s) above the mesoscale orographic height (h_m)(see ***Figure 7***), this two-pronged approach effectively allows us to independently reduce the magnitudes of the intercept (by tuning k_1) and the gradient (by tuning k_2) of the fit lines in Figure 8 and **Figure 9**. A modification of this approach is to use two different values of k_2 : $k_{2\text{hi}}$ for 'hill' sites ($h_s - h_m > 0$) and $k_{2\text{lo}}$ for 'valley' sites ($h_s - h_m \le 0$). The motivation for this will become apparent in the discussion of the results below.

Tuning is effected by selecting stations for which C_4 is small (so that the value of k_2 has little effect on the anomaly) and adjusting k_1 until a minimum in the RMS anomaly is achieved. Then, using this tuned value of k_1, all stations are considered and k_2 is similarly adjusted until a minimum in the RMS anomaly is achieved (or in the case of method 3b, two separate adjustments of $k_{2\text{hi}}$ and $k_{2\text{lo}}$ giving two separate minima).

Table 3 summarises all of the methods presented and introduces a convenient shorthand notation for each one.

Method	Summary
0	No adjustment
1	Model inner-layer windspeed used instead of level 1 windspeed
2a	Height-dependent perturbation calculated, based on model windspeed
2b	Height-dependent perturbation calculated, based on observed windspeed
3a	As 2b but with tuning: k_1 and one value of k_2
3b	As 2b but with tuning: k_1, k_{2hi} and k_{2lo}

Table 3 : Summary of methods.

5.2 Results of minor modifications and tuning.

Figure 8 shows scatter plots of anomaly (model – ob) vs. height difference ($h_s - h_m$) for each of the six methods applied to data from four cases in which strong winds were observed. Linear least-regression lines have been fitted to all data in the plots of methods 0 to 3a; two separate lines for 'hills' and 'valleys' have been fitted for method 3b.
The four datetimes considered were:

199809301500
199812270000
199911260900
200208150400

The tuning parameters obtained from this data by minimisation of the RMS anomaly as described above were:

Method 3a: k_1=0.74 , k_2=0.6
Method 3b: k_1=0.68 , k_{2hi}=1.4 , k_{2lo}=0.0

At first sight it appears that method 2a is better for $h_s - h_m < 0$ and method 2b is better for $h_s - h_m > 0$. This is because using method 2a we are effectively scaling the anomaly to the station height: 'hill' anomalies ($h_s - h_m > 0$) are scaled up, 'valley' anomalies ($h_s - h_m < 0$) are scaled down. Using method 2b we have all anomalies represented consistently, i.e. scaled to a height of η (10 metres) above h_m.

Close inspection of the plot for method 3a, Figure 8 reveals the motivation for independent tuning of the hill and valley perturbations: the underestimates for hill stations have increased compared to method 2b. Note in particular the –12 m/s anomaly (i.e. underestimate) at $h_s - h_m \approx 640$ m. The corresponding worst underestimate for this station (Cairngorm) using method 3b is about –5 m/s.

Whilst tuning, a lower limit of zero was set for k_{2lo} , implying that the valley observations (for which C_4 is negative) can be scaled up but not down. It was this lower limit which produced the smallest RMS anomaly. Setting $k_{2\mathrm{lo}} = 0$ is equivalent to replacing the lower limit of $0.5\,u_{\mathrm{inner}}$ suggested in PC02 by a lower limit of u_{inner}.

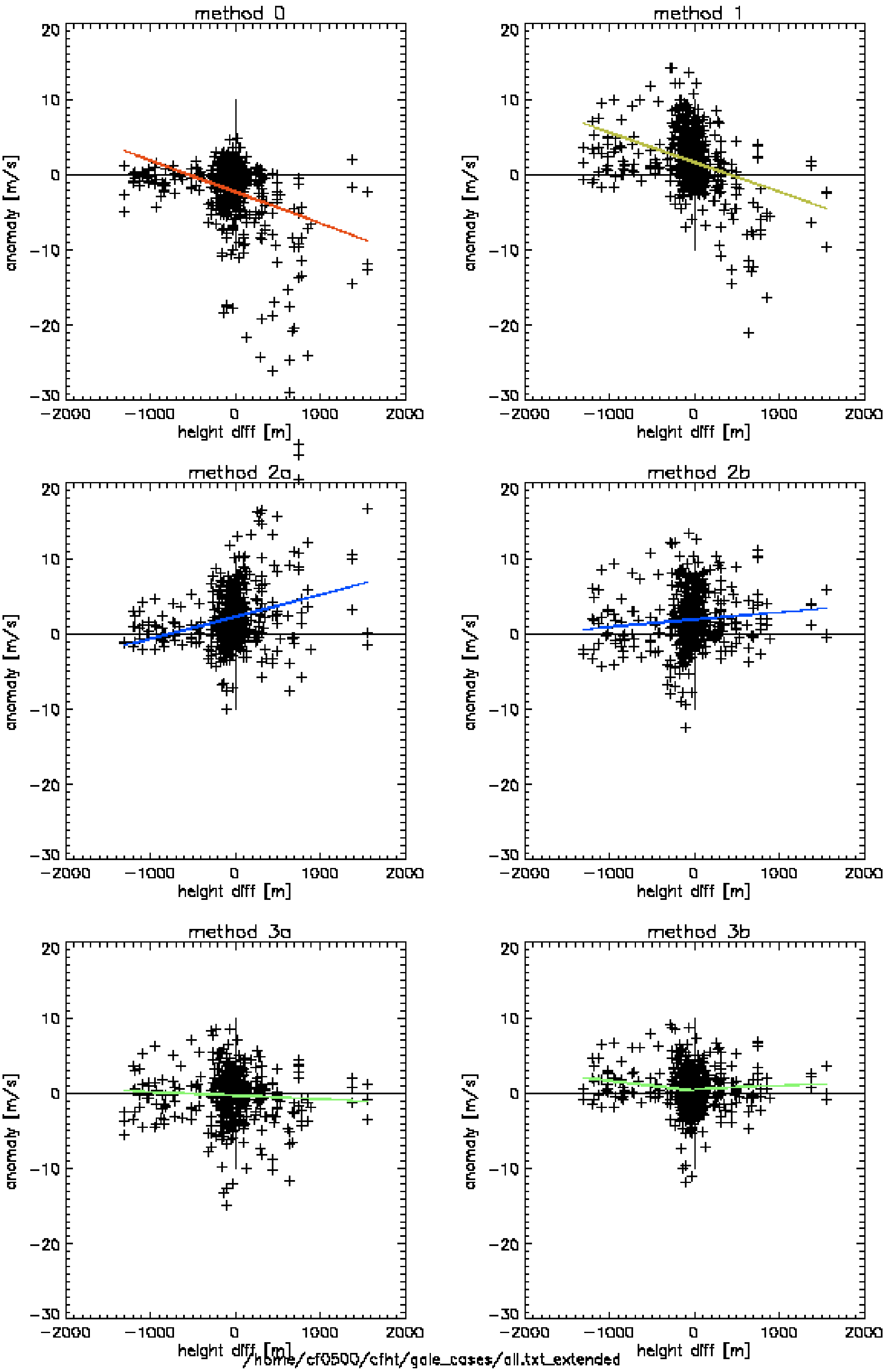

Figure 8. Scatter plots of anomaly vs. height difference for each of the six different methods applied to four cases in which strong winds were observed.

Statistics for the six different methods applied to the strong wind cases are shown in ***Table 4*** .

Method	Mean anomaly	RMS anomaly
0	-2.05	4.88
1	1.87	4.53
2a	1.84	4.56
2b	1.91	3.95
3a	0.05	3.01
3b	0.68	2.66

Table 4

As a test, the tuning approach described above was applied to a different set of data, taken from September 2002. The nine datetimes considered were:

200209031200
200209041200
200209051200
200209061200
200209071200
200209081200
200209091200
200209101200
200209111200

The maximum observed windspeed in this data set was ~17m/s as opposed to ~38 m/s for the four strong wind cases. The resulting tuning parameters were:

Method 3a: k_1=0.87 , k_2=0.6
Method 3b: k_1=0.78 , k_{2hi}=1.8 , k_{2lo}=0.0

The value of k_{2hi} is noticeably larger than that obtained with the strong wind data. It is suggested that the value obtained from the strong wind data be initially adopted for operational use. This should give smaller anomalies on occasions of strong winds (assuming that the appropriate value of k_{2hi} depends in some systematic way on the overall wind strength).
Figure 9 shows the results of applying the *strong-wind-derived* tuning parameters to the September 2002 cases listed above.

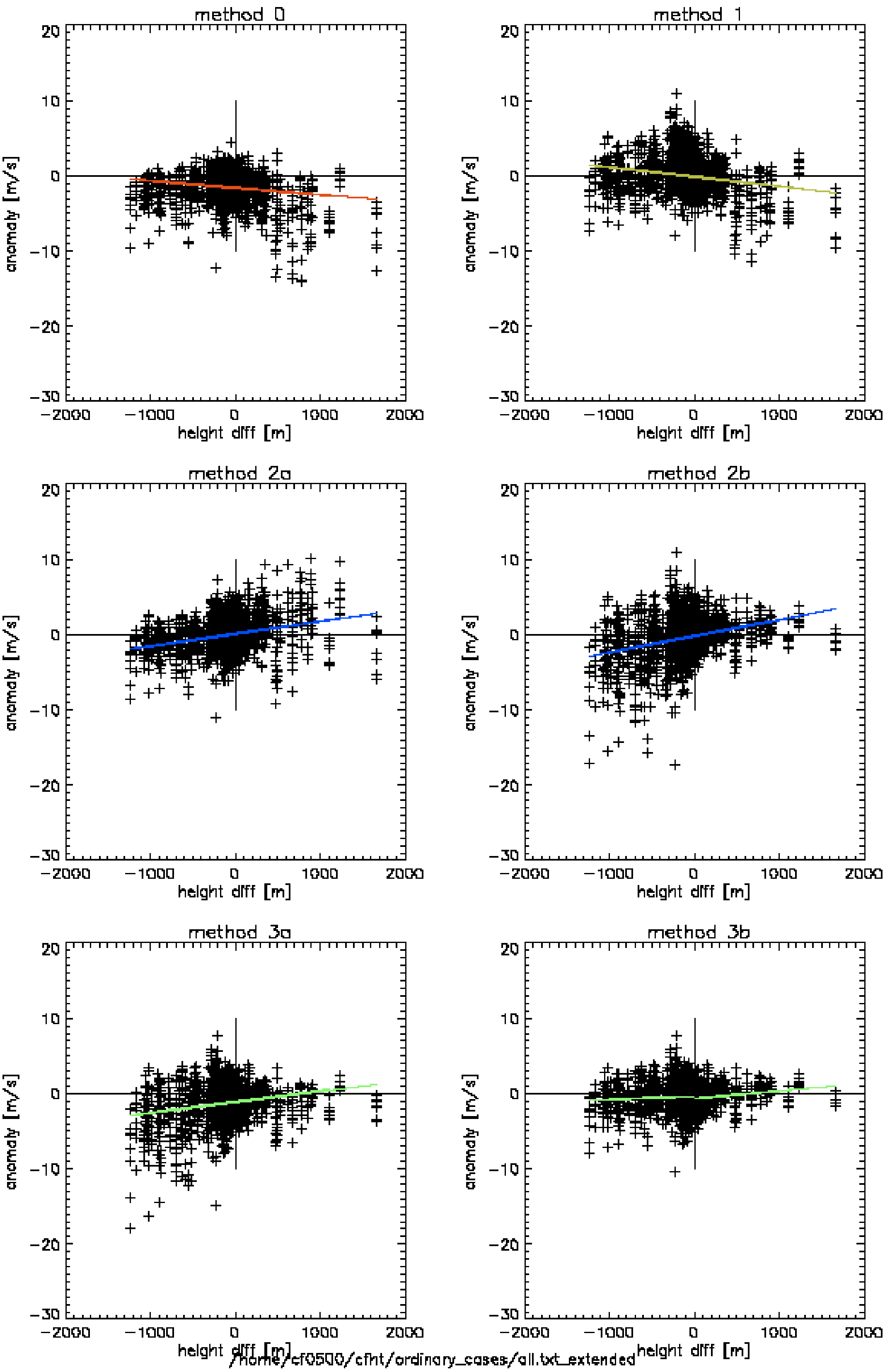

Figure 9. Scatter plots of anomaly vs. height difference for each of the six different methods applied to nine cases from September 2002.

Statistics for the six methods applied to the 9 lighter wind cases are shown in ***Table 5***.

Method	Mean anomaly	RMS anomaly
0	-1.50	2.63
1	0.05	2.34
2a	-0.22	2.39
2b	-0.34	2.78
3a	-1.09	2.66
3b	-0.47	1.82

Table 5

Histograms for the anomalies are shown in ***Figure 10*** (strong wind cases) and ***Figure 11*** (lighter wind cases). Again a non-linear scale has been used for the frequencies to emphasise the occasional serious errors. The scale used is $\log_2$ (frequency + 1); this is a convenient logarithmic scale as it maps zero to zero and one to one.

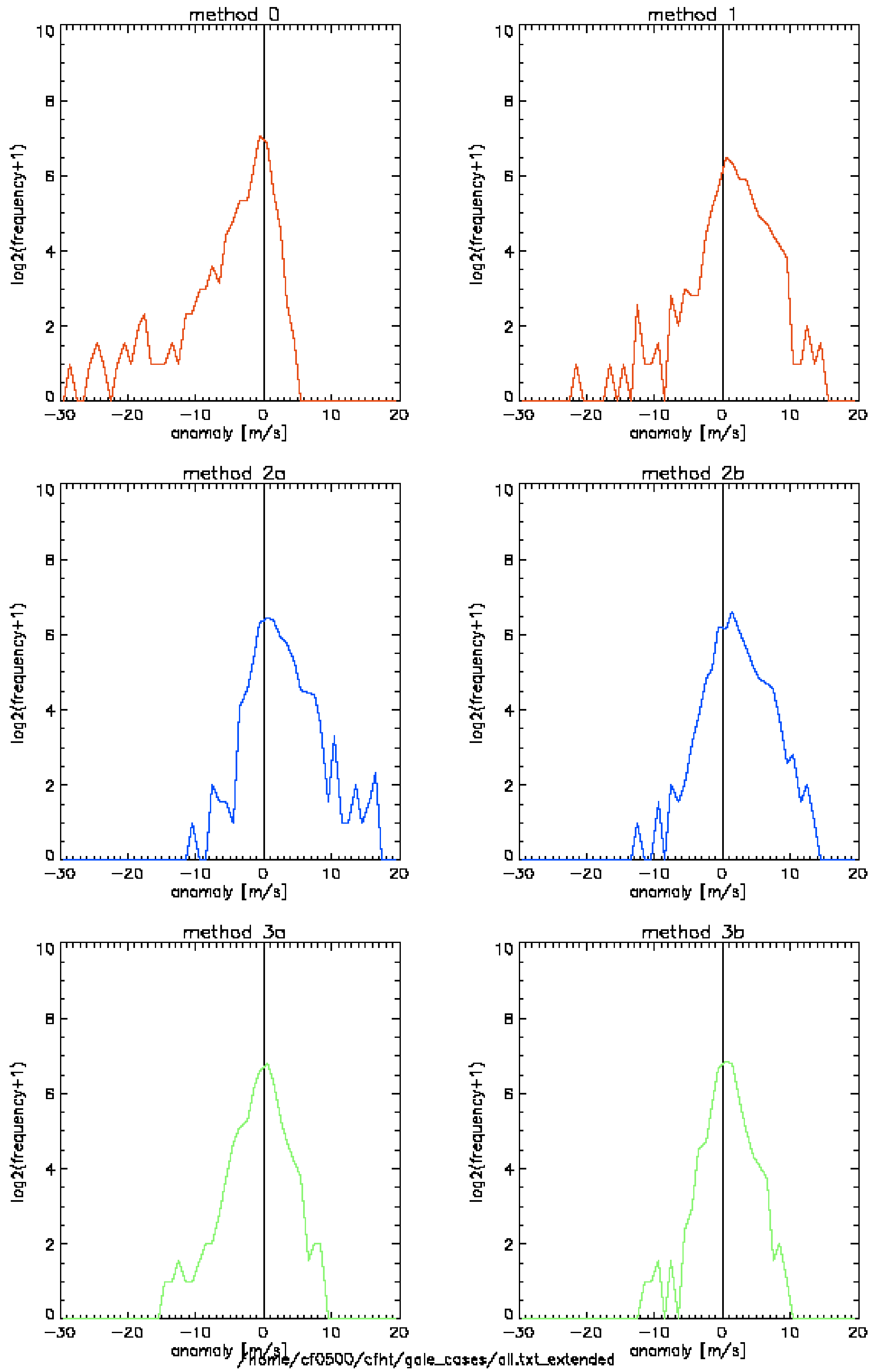

Figure 10. Histograms showing frequency of anomalies for each of the six different methods applied to four cases in which strong winds were observed.

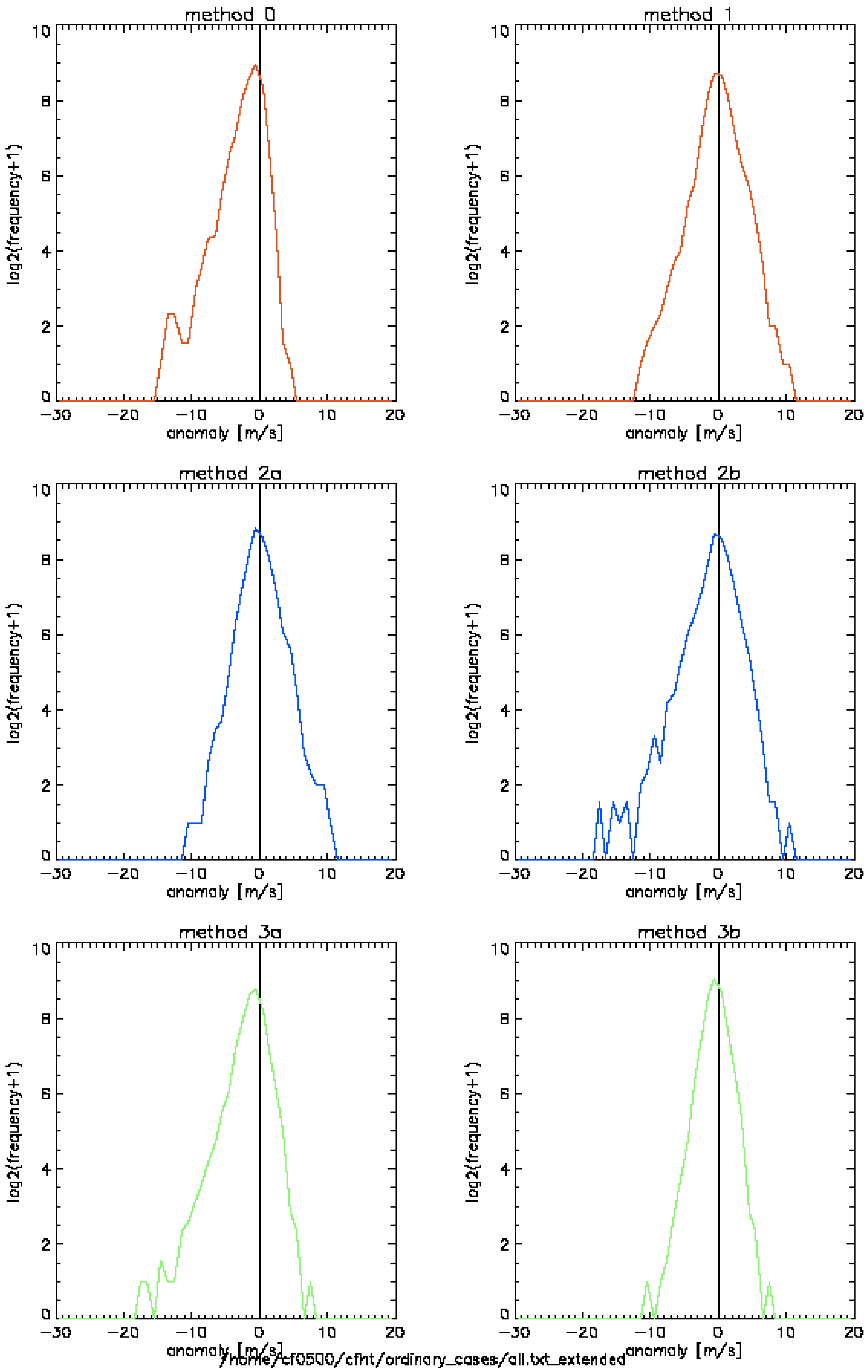

Figure 11. Histograms showing frequency of anomalies for each of the six different methods applied to nine cases from September 2002.

5.3 Rejection of observations in the operational scheme

The operational scheme rejects windspeed observations from stations at a station height of more than 500 m if the observed windspeed is more than 10 m/s different to the background. In one of our test cases (199812262100) eighteen observations were rejected on this criterion. No observations are rejected on this criterion by the trial scheme.

5.4 Verification statistics for two months

The impact of the tuned scheme on various forecast windspeed statistics for Dec 2002 and Jan 2003 is shown in Figure 12. Strong winds were encountered in the Nimrod area during January for a period of about 3 days; hence the impact is more noticeable in that month. The Appendix shows details of an example case.

5.4.1 Calculation of the verification statistics.

It would be possible to verify the new method by comparing height-corrected observations at the forecast time with the forecast, which works with height-corrected observations. However this would show the new scheme in an artificially good light compared to the old since the correction is always an attenuation (recall that for valley sites we do not amplify the windspeed) and thus the errors would be attenuated too. So to make a fair comparison the forecast to be verified is instead ‘corrected back up’ to a predicted value at the station height. To accomplish this, the value of k_2C_4 for each site is stored as an extra field in the file yyyymmddhhmm_text_windanl_obs and this file is used as the source of the observations when verifying, in distinction to the existing verification algorithm, which accesses the Horace database as a source of the observations.

Two further modifications have been made to the verification software:

- The criterion for making a direction comparison is now that both observed and forecast windspeeds exceed 5 m/s.
- Bilinear interpolation is now used to establish the forecast windspeed at a station, in place of north-west neighbour.

Also an error in the software, which caused the unified model direction errors and under/over-prediction statistics to be added to the Nimrod statistics for T >3 has been corrected.

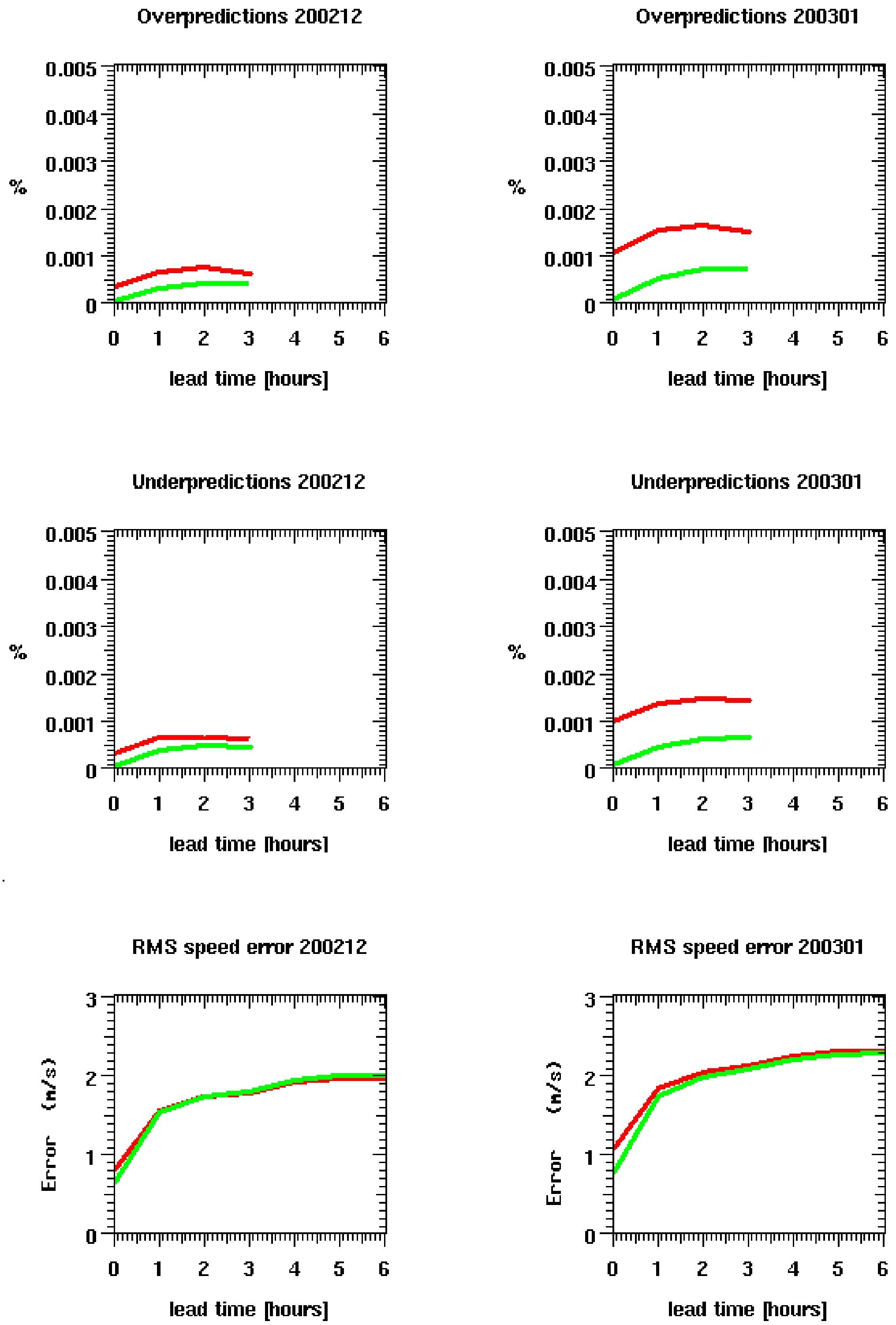

Figure 12. Impact of tuned scheme on RMS windspeed errors for December 2002 and January 2003. The operational forecast is shown in red and the trial in green. Under/overprediction refers to errors of more than 5 m/s. (Under/over-prediction statistics for lead times greater than three hours are not available.)

6 Conclusions

Results of a trial to test a scheme designed to compensate for the unrealistically low windspeeds forecast over high ground by the mesoscale model due to the sub-gridscale orographic roughness parameterisation have been presented, along with suggestions for some minor modifications and tuning. Our recommended scheme is that denoted "3b" above, with k_1=0.7 , $k_{2\text{hi}}$=1.4 , $k_{2\text{lo}}$=0.0 Note that the analysed windspeed field may, in general, appear to agree *less well* with the *raw* windspeed observations under the recommended scheme, because the recommended scheme analyses a *corrected* observation.

7 Suggestions for further work

7.1 More refined tuning.

The tuning method presented applies a universal tuning parameter to the perturbations; this does not vary between individual stations. An obvious extension of this is to tune the perturbation at each station independently, perhaps using different parameters for different observed wind directions to take some statistical account of the influence of direction. An incidental advantage of this could be the obviation of the need to calculate C_4: it could be subsumed into the tuning parameter for that station. In the event of the introduction of a new station, a default value of C_4 could be provided as described in suggestion 2, and a default value of k_2 taken from the existing scheme.

7.2 Approximate C_4.

Figure 7 reveals a fairly close relationship between C_4 and $(h_s - h_m)$ for all the stations in the Nimrod area: this could be exploited to avoid a great deal of calculation in the height-correction stage of the scheme. Approximating the relationship by $C_4 = \min[2.1, \max[0, (h_s - h_m)/454\text{metres}]]$ produces a maximum (i.e. worst-case-station) change in the height-corrected observation equal to 13% of the raw observation. The principal advantage of this is a large improvement in the simplicity, and thus maintainability, of the software.

7.3 Spread the anomalies more widely.

Historically the range over which the windspeed anomalies were spread by the recursive filter was limited in order to prevent the large anomalies over the Scottish mountains being spread over the North Sea, giving unrealistically large windspeeds there. Now that the anomalies are smaller there is the possibility of spreading them more widely, or possibly even advecting them with the unified model forecast geostrophic winds.

7.4 Give less weight to valley observations.

Sheltered observations are generally less useful than exposed ones in building a picture of the wind field, so it seems reasonable to give more weight to exposed sites and less to sheltered ones. The recursive filter has provision for weighting – the observations could perhaps be weighted according to h_s / h_m, for example. In a more sophisticated model the weight could also depend on wind direction.

7.5 Analysis at the top of the boundary layer

The scheme presented here adjusts the 10 metre UM windspeed and corrects the observed windspeed. Then in Nimrod we create a10 m windspeed analysis using the UM field as background and a recursive filter to spread the observations around. However it could be argued that we're still not comparing like-with-like because the observations, though corrected for the influence of the station height, are still going to be influenced by things like the local roughness, so that an observation from a station in an urban area will be smaller than one in open country, or over the sea. Would it be more consistent to use the linear theory to interpret observed windspeeds as an implied windspeed above the (vegetative) boundary layer (say 1000 m windspeed) and then use the UM 1000 m windspeed as background to form an analysis of this? It would then be necessary to model the behaviour of the boundary layer below in order to form the surface analysis. One possible problem (Clark, 2002, pers. comm.) is that of compounding errors by correcting observations 'up' to the broader scale.

8 Bibliography

PC02 Clark, Pete, 2002. 'Linear perturbations to flow'.
See http://vulcan/~appc/documents/Documents.html under 'Documentation and working documents' Linear flow theory parts A and B.

9 Appendix: Example Cases.

9.1 Impact of roughness adjustment on a typical wind field.

Figure 13 (left) shows a typical unified model windspeed field over the Nimrod area. The impact of the untuned roughness adjustment (method 1) is shown (right). The replacement of the unified model level one windspeed by the inner layer windspeed over high ground can be seen to result in an increased windspeed over most of the high ground in the British Isles, over parts of Norway and over some of the Alps.

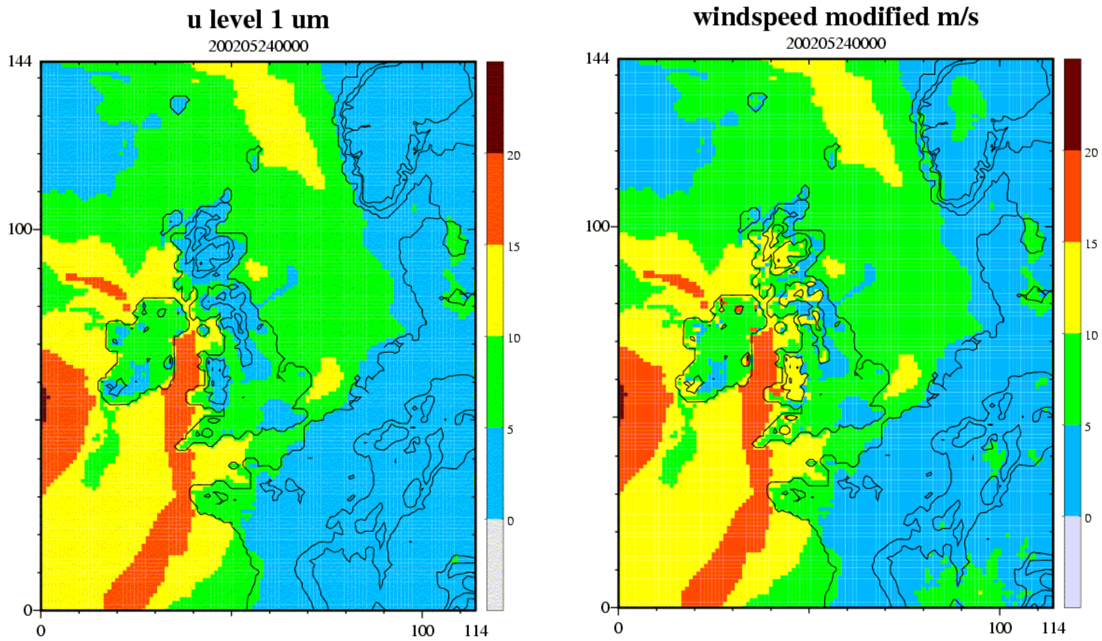

Figure 13 Comparison of unadjusted unified model 10-metre (level one) windspeed field (left) with adjusted 10-metre windspeed field (right) for 200205240000. Over high ground the unified model level one windspeed has been replaced by the inner layer windspeed.

9.2 Impact of the height correction

Here we present charts showing the distribution of observation-background field anomalies for both the unmodified and modified (method 3b) approach. In ***Figure 14*** and ***Figure 15*** the anomaly at each station location is indicated by colour. Notice in particular that there are some large anomalies over the mountainous regions; these are much reduced over the Scottish highlands by the modified scheme. ***Figure 16*** shows the raw observations used in the analysis.

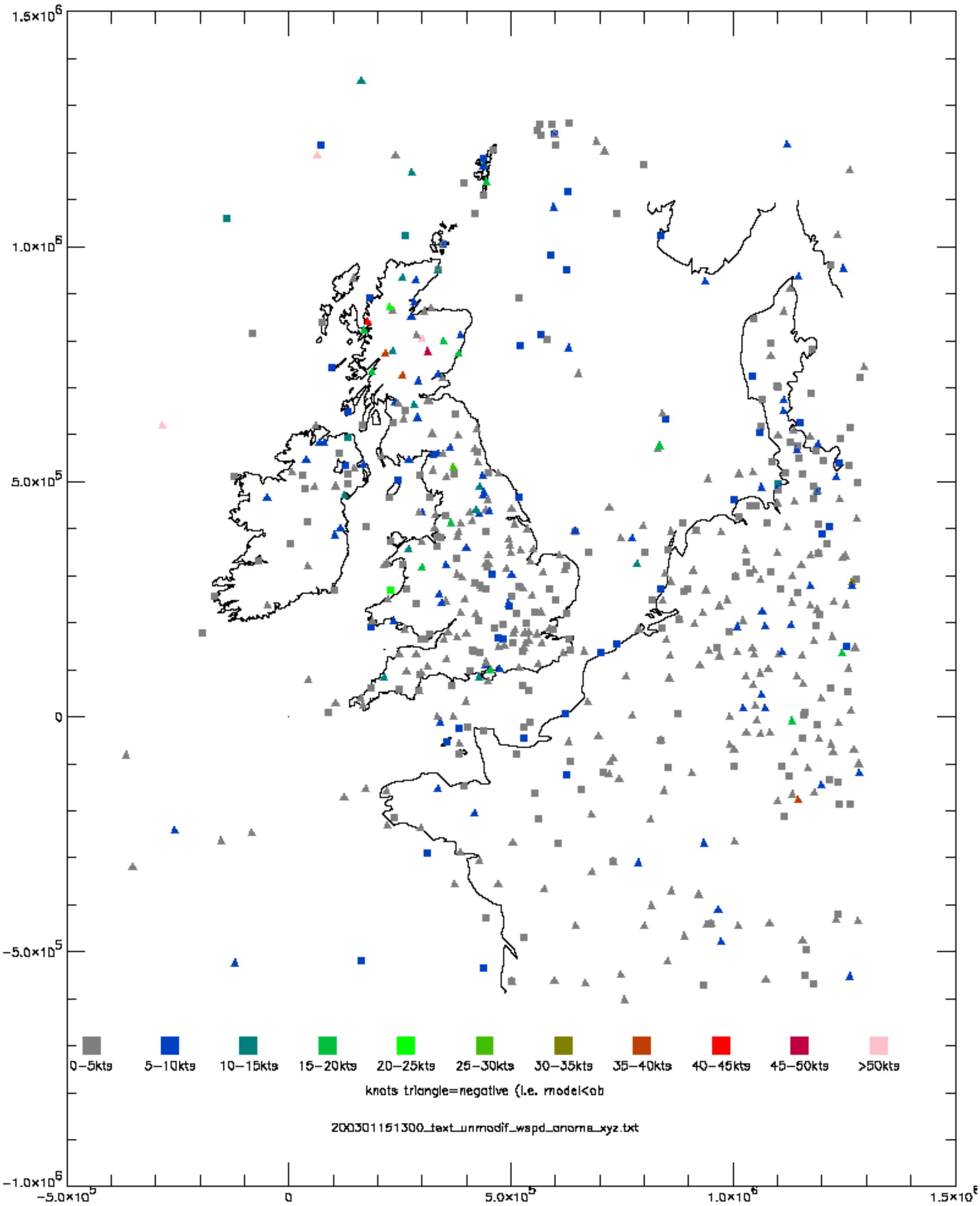

Figure 14: Anomalies at station locations, unmodified approach.

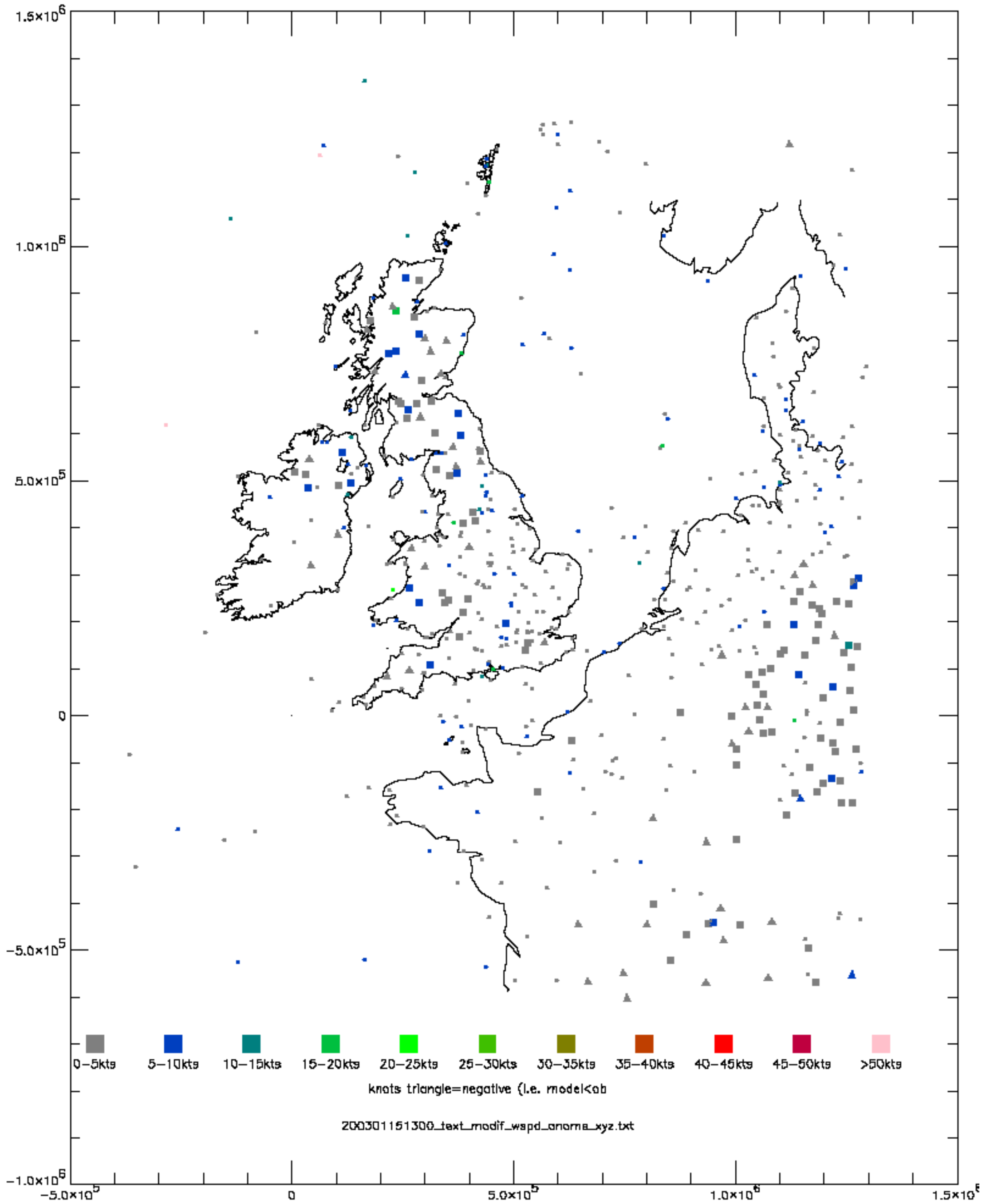

Figure 15: Anomalies at station locations, modified approach. The smaller dots indicate stations that do not meet the criteria for modification.

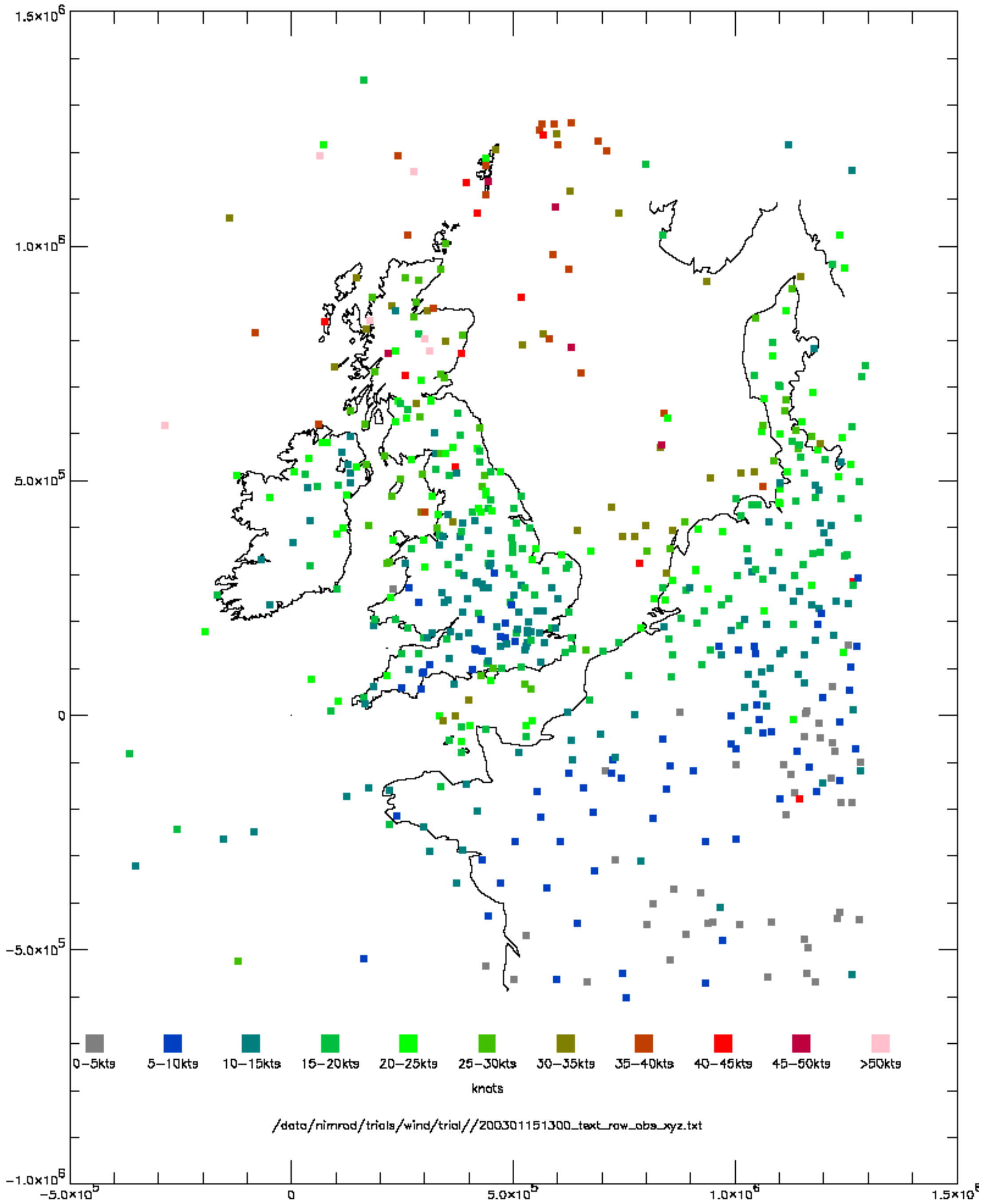

Figure 16. Raw windspeed observations used in the analysis for 1300Z 15 Jan 2003

9.3 Impact of modified scheme on a typical Nimrod analysis.

Figure 17 shows a comparison of the unified model six-hour forecast for 12:00 on 15th Jan 2003 with the corresponding Nimrod analysis produced using the modified scheme (method 3b).

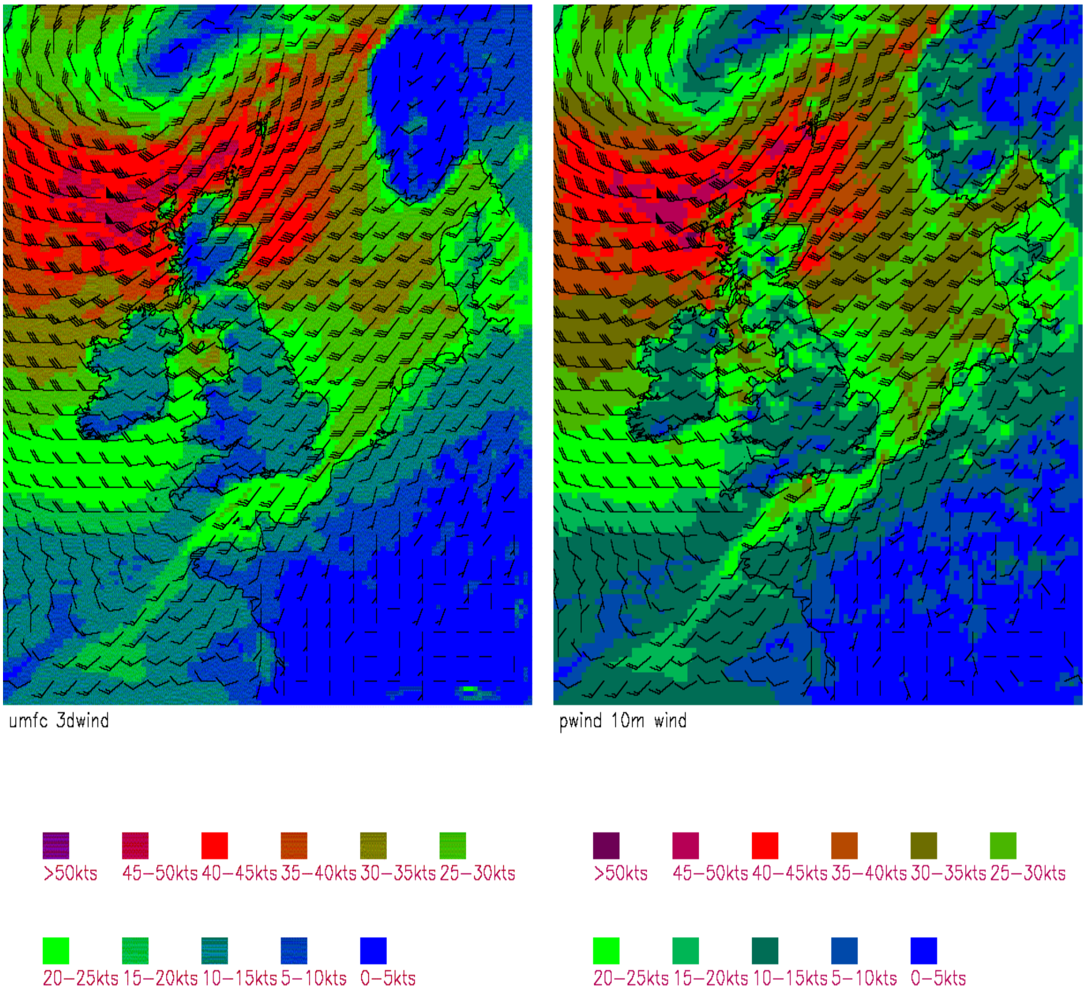

Figure 17 Left: Unified model wind forecast for 200301151200 (six-hour lead time). Right: Nimrod windspeed analysis for 200301151200 using method 3b.