Interpretation for use of surface wind speed projections from the 11-member Met Office Regional Climate Model ensemble

Post-launch technical documentation for UKCP09
1. Summary

1.1 Probabilistic projections of future changes in surface wind speed (interpreted throughout this report as wind speed at a standard observing height of 10 metres above the surface) were not provided in UKCP09, due to lack of suitable multi-model climate data.

1.2. However, daily values of surface wind speed (and also of westerly and southerly wind components) are available at 25 km resolution from the ensemble of 11 Met Office regional climate model (RCM) variants run for UKCP09. This ensemble was run from 1950-2099, driven by the UKCP09 Medium scenario of future emissions of greenhouse gases and aerosols. There are no corresponding RCM projections for the High or Low emissions scenarios. Data are available from the Climate Impacts LINK website (see http://badc.nerc.ac.uk/data/link), and provide an important resource for users who require time series of wind speed or direction at high spatial resolution for impact assessments and adaptation planning. This document assesses this information, focusing primarily on wind speed. Users should be clear that these data are not probabilistic in nature but provide a sample of 11 possible futures which do not encompass the full range of possible future changes in wind speed, and cannot be used to estimate the relative likelihood of different changes.

1.3. The RCM surface wind speeds show biases when compared to long-term climatological means derived directly from observations, or from atmospheric reanalysis datasets. The biases vary with location and season, but are characterised by lower than observed speeds over mountainous regions of Scotland and Wales, and higher than observed speeds over low-lying regions of England. These biases can be attributed to aspects of the parameterisation of unresolved orography and surface roughness.

1.4. Despite biases in the time-averaged values, the RCM simulation provide time series and distributions of daily wind speed which replicate observed characteristics more realistically than is achieved in their driving global climate model simulations (run at 300 km resolution).

1.5. Furthermore, it is found that projected patterns of future change in surface winds are similar in the regional and global model projections, and are also similar to wind changes above the atmospheric boundary layer. This implies that the surface wind changes are determined mainly by large scale physical processes affecting the circulation of the free atmosphere, and are therefore unlikely to have been significantly influenced by biases in the

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detailed representation of boundary layer mixing in the models over the UK or Europe.

1.6. Therefore, it is recommended that users requiring detailed wind speed information exploit the RCM data, provided that the consequences of the above-mentioned climatological biases are carefully assessed in their applications. Specifically, it is recommended that users apply the fractional changes in RCM wind speeds to observed climatological values of their metric of interest (e.g., 30-year averaged values of wind speed, or some relevant percentile of the climatological distribution of daily values). If users require plausible time series of future wind speeds, rather than projections of a few specific climatological metrics, then a range of bias correction strategies may need to be considered. Examples could include simply correcting RCM-projected future time series to remove biases in the long term average value estimated by comparing simulated and observed historical climatologies, or adjusting observed historical time series according to correction factors which vary with wind speed, deduced by comparing simulated and observed distributions of daily values. These and other potential strategies will have alternative strengths and limitations, which will need to be assessed dependent on the application in question. Any bias correction strategy will involve the assumption that the sign and magnitude of the climate change signal is not affected by the biases in the present day RCM climatology, based on the assessment at (1.5) above.

1.7. If observed wind speed data is not available it is suggested users obtain expert advice to discuss alternative bias correction strategies.

1.8. Projected future changes in 30-year averages of surface wind speed are relatively small within the RCM ensemble, with seasonal changes at individual locations across the mainland UK lying within the range +10% to –15%.
2. Introduction

2.1. As discussed in the UKCP09 climate projections science report (Murphy et al. 2009), it was not possible to provide probabilistic projections of future changes for certain variables (soil moisture, latent heat flux, snowfall rate and wind speed). The probabilistic projection methodology involves sampling climate modelling uncertainties by combining results from perturbed variants of the HadCM3 configuration of the Met Office global climate model with projections from alternative international climate models. In the case of wind speed the required data (which requires values based on accumulated values of wind speed at individual model timesteps) was not available from the other global climate models. In the absence of a UKCP09 probabilistic projection for wind speed, there are four possible alternative sources of projections of transient changes during the 21st century:

- At the global climate model scale, a 17-member “perturbed physics ensemble” (hereafter referred to as PPE_GCM) of HadCM3 variants sampling uncertainties in surface and atmospheric model parameters (see section 3.2.4 of Murphy et al. 2009*), and driven by the SRES A1B emissions scenario, also identified as the UKCP09 Medium scenario;

- A multi-model ensemble (MME) of projections of 21st century climate from 15 alternative global climate models (also using SRES A1B emissions), these being a subset of 23 coupled ocean-atmosphere models contributing to the IPCC Fourth Assessment Report (see Meehl et al. 2007) from which wind information was available**;

- An 11-member ensemble of perturbed variants of the Met Office regional climate model (PPE_RCM), driven from 1950-2099 by global projections from 11 members of the PPE_GCM ensemble;

- A multi-model ensemble of regional climate model projections from the European Union ENSEMBLES project.

* Noting that the PPE_GCM ensemble was referred to as PPE_A1B in section 3.2.4 of Murphy et al (2009).

** Note that this multi-model ensemble of transient climate change projections is different from the multi-model ensemble of projections of equilibrium climate change (response to doubled CO2) used in the construction of the UKCP09 probabilistic projections (for reasons described in section 3.2.8 of Murphy et al., 2009). Wind speed data is not available from either of these multi-model ensembles, although daily average values of westerly and southerly wind components was available for a subset of members in either case.
Data from the PPE_GCM and PPE_RCM ensembles is available from the Climate Impacts LINK project, operated by the British Atmospheric Data Centre (BADC); see http://badc.nerc.ac.uk/data/link, with access conditions described at http://badc.nerc.ac.uk/conditions/ukmo_agreement.html. Data from the global multi-model ensemble can be accessed from the Program for Climate Model Diagnosis and Intercomparison (PCMDI), based in California, which has collected model output from simulations contributed by modelling centres around the world, as part of the Coupled Model Intercomparison Project (CMIP3) of the World Climate Research Programme. The CMIP3 multi-model dataset can be freely accessed for non-commercial purposes via http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php.

2.2. The eleven member PPE_RCM ensemble provides an opportunity to access wind projections expressed at a finer spatial scale (25 km resolution) compared to the global model projections discussed above, and is therefore potentially a more attractive option for use in impact and adaptation studies for the UK. Here we assess the strengths and limitations of the data from this ensemble.

2.3. As noted above, the RCM projections from the ENSEMBLES project (available from http://ensemblesr3.dmi.dk/) provide an additional source of fine scale projections of wind. These projections use the same emissions scenario as PPE_RCM (the UKCP09 Medium scenario), and consists of a partly-filled matrix of simulations in which a number of global models developed in Europe are used to drive a number of European regional models. Data is freely available, subject to conditions at http://ensembles-eu.metoffice.com/docs/Ensembles_Data_Policy_261108.pdf. The regional models in these experiments are configured at either 25 km or 50 km horizontal resolution, the simulations running from 1951 to either 2050 or (in some cases) 2100. We do not evaluate the ENSEMBLES projections in this note (although we note that that three of the global model projections providing driving data are taken from the PPE_GCM ensemble run for UKCP09, and one of the regional models is taken from the PPE_RCM ensemble). Users wishing to assess these projections will need to perform their own evaluation, for example along similar lines to the evaluation of PPE_RCM projections provided below.

2.4. Each of the eleven RCM variants in the PPE_RCM ensemble run for UKCP09 was configured from the corresponding variant of the PPE_GCM ensemble, using the same representations of atmospheric dynamical and physical processes, including perturbations to model parameters matching those implemented in the relevant driving global projection. The RCM projections were run at 25 km horizontal resolution, using the European domain shown in Figure 3.8 of Murphy et al. (2009), driven at the lateral boundaries by time series of variables (such as temperature and winds) saved from the corresponding global projection. Sea surface temperatures and sea-ice extents were also prescribed using values saved from the relevant global projection, since the regional model used in UKCP09 (like most RCMs) does not include an interactive ocean component. The purpose of RCMs is to provide high resolution climate projections consistent with their driving global model projection at spatial scales skilfully resolved by the latter, but adding realistic detail at finer scales. This is commonly referred to as downscaling. Further details of the RCM projections can be found in section 3.2.11 of Murphy et al (2009). The potential advantages of projections from RCMs over those from global models are that they can capture detailed spatial contrasts not resolved in the global models, particularly those arising from mountains and
coastlines, and that they can capture climate variability and extreme events more faithfully, particularly aspects arising from regional-scale processes. Their main limitation is that they inherit larger scale biases from their driving global simulations, so cannot correct these. See also Chapter 5 of Murphy et al. (2009).
3. Evaluation of RCM winds in present-day climate

3.1. A validation of surface RCM wind speeds was performed using observations at meteorological observing stations from 1971–2000. These were initially interpolated to a 1 km resolution grid of the UK and then aggregated to the 25 km wind grid* of the RCMs to provide 30-year averages of surface wind speed values for each season. Results for winter (December, January, February – DJF) are shown in Figure 1a and b as an example of the two grids. The 1km interpolation used values from neighbouring points and a correction for height (Perry and Hollis, 2005). The period of data used differs from the UKCP09 baseline due to the sparsity of available observations in the 1960-1970 period, which makes the interpolation used in gridding much more difficult due to the local characteristics of the observation site, such as local terrain (Dan Hollis – personal communication). Figure 2 shows the mean surface wind speed values for each season on the 25 km grid, defining spring as (March, April, May – MAM), summer (June, July, August – JJA), and autumn (September, October, November – SON).
3.2. Model surface wind speed diagnostics from the thirty year period 1971-2000 were used to calculate an ensemble mean of 30-year average seasonal values from the eleven regional model simulations. The results (Figure 3) show that the PPE_RCM ensemble simulates spatially-averaged values (over the whole UK) similar to observations, and also reproduces the main broad-scale feature of the observed seasonal cycle (lower speeds in summer compared to other seasons). However, values over regions of relatively high orography (particularly the Scottish and Welsh mountains) are generally lower than observed, whereas values over low-lying regions (particularly the Midlands and South-East England) are too high. This is confirmed by Figure 4, which shows that the patterns of model bias are quite consistent across the seasons. Absolute biases are shown in the top row of Figure 4, and are typically 1 to 3 ms$^{-1}$ below observed data in mountainous regions, the largest negative biases occurring over the Scottish Highlands. In relative terms (bottom row of Figure 4) these negative biases are typically in the range 10-40%, whereas positive biases in the range 10-30% occur across much of the Midlands and the South East. The patterns of bias are broadly consistent across all members of the PPE_RCM ensemble (Figure 5 shows this for the winter season, as an example). This demonstrates that the pattern of bias is robust to the perturbations to physical processes applied in the ensemble, as afgcx (Figure 5a), the ensemble member employing parameter settings consistent with the standard published version of HadCM3 (Pope et al. 2000), shows a similar pattern of errors to the 10 ensemble members containing parameter perturbations relative to the standard settings.

Figure 2: Observed surface wind speeds (ms$^{-1}$) on the 25 km RCM grid, averaged over 1971-2000 for a) DJF b) March to May (MAM) c) June to August (JJA) d) September to November (SON).

Figure 3: Ensemble averages of surface wind speed simulated by the eleven RCM variants for 1971-2000 (ms$^{-1}$), for a) DJF b) MAM c) JJA d) SON.
3.3. Like most global climate models, members of the PPE_GCM ensemble simulate the main characteristics of the observed atmospheric circulation with considerable skill, however there are inevitably also biases at regional scales. For example, these simulations exhibit a slight southward displacement in the location of the North Atlantic winter storm track at the longitudes of the UK, accompanied by a slight underestimation of the mean intensity of the storms, although the biases are smaller than those exhibited in many of the global climate models submitted to IPCC AR4 (see Figure A3.6 of Murphy et al. 2009). The southward shift in the winter storm track is consistent with the ensemble mean bias pattern of 850 hPa winds (Figure 6e), which shows slightly stronger westerly winds than observed to the south of the UK, with an easterly bias to the north. However, in general the seasonal biases in the mean westerly and southerly wind components are modest (Figure 6e-g and 7e-g), and the regional climate model simulations (Figures 6a-d and 7a-d) essentially replicate the synoptic-scale patterns of error found in the driving global simulations, with the addition (as expected) of some regional detail.

Figure 4: Differences in seasonal surface wind speed between the PPE_RCM ensemble mean and observations, averaged over 1971-2000, expressed as absolute values in (ms$^{-1}$) (a-d), and as a percentage of the observed value (e-h).
Figure 5: Biases in the simulations of surface mean wind speed (ms$^{-1}$) averaged over 1971-2000 for individual PPE_RCM ensemble members relative to the observations of Figure 2, for winter (DJF). Each ensemble member (panels a-k) is referred to by its run identifier on the Met Office supercomputer (afgcx, afixa, etc). Panel l shows the bias for the ensemble mean of the eleven members.
3.4. Figures 6 and 7 illustrate biases found in winds simulated in the free atmosphere, where the effects of friction are relatively small and winds at middle latitudes are typically close to geostrophic values implied by a balance between the pressure gradient force and the Coriolis effect of the Earth’s rotation. Winds at the surface are strongly influenced by those in the free atmosphere, but are also modified by the effects of drag in the atmospheric boundary layer, which slows the wind speeds relative to geostrophic values and also alters the wind direction by creating a cross-isobaric component away from centres of high pressure and towards centres of low pressure. In general, therefore, errors in the climatology of surface winds can arise either from the effects of biases in the large scale circulation in the free atmosphere, or from the detailed regional processes determining the turbulent mixing affecting winds in the boundary layer. An obvious question, therefore, is whether the patterns of surface wind speed bias seen in the RCM simulations are simply a consequence of biases in the free atmospheric winds inherited from the driving global model simulations in the PPE_GCM ensemble. Figure 8 shows surface wind speed values and biases found in a simulation using one of the PPE_RCM ensemble members (that using standard unperturbed parameter settings), driven at its lateral boundaries by a time series of winds specified from the ERA40 reanalyses of observations (Uppala et al. 2005). The seasonal patterns of bias are very similar to those found in the corresponding ensemble member (afgxc) driven by winds from the global climate model, and also to biases found in the other members of the PPE_RCM ensemble (Figure 8 cf Figure 5). Similar bias patterns are also obtained when the model wind speeds are compared with ERA40 near-surface values (not shown), as an alternative to the observational dataset of Figure 1 (with the caveat that the ERA40 winds are generally slightly higher than those in the observational dataset, so biases relative to ERA40 are shifted slightly lower). These results show that the patterns of wind speed bias found in the RCMs cannot be attributed to biases in the large scale circulation inherited
from the driving global model simulations, and must therefore arise from issues in the simulation of regional boundary layer effects.

3.5. This is supported by analyses of the performance of the model representation of boundary layer processes when used in a version of the Met Office Unified Model configured for numerical weather prediction over the UK (Howard and Clark, 2007). Near-surface wind speeds are found to exhibit similar low biases over high land, which are attributed to the parameterisation of the effects of unresolved orography in the model. These effects are represented as an additional drag, included by increasing the basic surface roughness length in the model (due to the effects of vegetation) to include a component due to the effects of hills and valleys not represented through the use of a grid-box average orographic height in the model. The aim of this orographic roughness parameterisation is to achieve a realistic representation of the effects of orographic drag on the synoptic scale flow at heights above the lower part of the atmospheric boundary layer, well above the orography. However, this is achieved at the cost of an unrealistic wind profile near the surface in mountainous regions, as the artificially enhanced drag is applied at the surface, and hence reduces the near-surface winds excessively. In contrast, the other characteristic bias found in the RCM simulations (excessively high speeds over low-lying regions of the Midlands and South-East) is likely to arise from the use of values for the basic (vegetative) component of roughness length which are too small.

3.6. The existence of biases in the simulated long-term historical averages of wind speed demonstrates the need to adjust the RCM wind speeds using a postprocessing strategy (see section 5), but does not necessarily preclude the generation of credible future time series of wind speeds, provided that the RCMs provide reasonable simulations of variability about the long-term average. This aspect is assessed in Figure 9, which shows frequency
distributions of daily-averaged wind speed values simulated by the PPE_RCM ensemble member with standard parameter settings (blue curves) in winter, for grid points nearest to seven observing stations* (whose values are shown in red). Here, the advantages of using RCM wind speeds, rather than values from the driving coarse-resolution global model (black curves), are more clearly demonstrated. For example, at Lerwick, Ringway, Aldergrove and Turnhouse the RCM distributions avoid the excessive occurrence of high values found in the GCM distributions. At St Mawgan the RCM matches observations better at low speeds, whereas the GCM matches better at high speeds. At the other two stations the GCM and RCM biases relative to observations are similar. Overall, it is clear that the RCM distributions verify better against observations than their GCM counterparts. The detailed reasons for the improvements are not investigated here, however they are likely to arise from better representation of the regional influences of mountains and coastlines in the RCM, coupled with improved resolution of features of synoptic storm systems such as fronts and troughs.

Figure 8: Seasonal biases in the simulation of surface wind speed (ms⁻¹) averaged over 1971-2000 relative to the observations of Figure 2, in an integration of the PPE_RCM ensemble member with standard parameter settings driven with time series of boundary conditions obtained from ERA40 re-analyses. Top row (a-d): Absolute biases in ms⁻¹. Bottom row (e-h): biases as a percentage of the observed value.

* When using information from nearby points on the RCM or GCM wind grids to predict observed winds at specific stations, it is important to ensure that the model points selected are representative of the (land or marine) climatic characteristics of the target location, because surface winds over sea tend to be greater due to reduced surface roughness lengths compared to land. For the six mainland observing stations in Figure 9, a simple strategy of selecting the nearest point results (as required) in the identification of model points characteristic of land conditions, whereas for Lerwick the nearest points are representative of sea conditions. This is reasonable for comparison against a coastal station on a small island.
Figure 9: Relative frequencies of daily average values of surface wind speed observed during December to February over the period 1961-1990 (red curves), for seven observing stations. Blue and black curves show corresponding distributions of values simulated at the nearest grid points in the variants of the regional and global climate model with standard parameter settings. The histograms use a bin width of 0.5 ms⁻¹.
4. Assessment of projected future changes

4.1 Figure 10 shows the percentage change in the long term average of surface wind speed for each member of the PPE_RCM ensemble in winter (December to February), for 2070–2099 relative to 1961–1990*. The ensemble mean of the changes (Figure 10(l)) shows a small reduction in wind speed for all but a handful of grid boxes, however there are variations between individual ensemble members with some (afixa, afixj, afixm) showing predominately positive changes, excepting parts of northern Scotland. The range of changes found across the ensemble is shown in Figure 11. Despite the variations in responses across the different members, the winter changes (top row of Figure 11) show a modest range, as do changes in the other seasons. All changes lie within the range +10% to −15%.

4.2 An important caveat is that the 11 member PPE_RCM ensemble represents only a subset of the range of modelling uncertainties included in the UKCP09 probabilistic projections. The projections account for a wider range of uncertainty by sampling fully the expert-specified parameter space of surface and atmospheric processes in HadCM3, and also by estimating the effects of uncertainties arising from structural modelling errors in these processes by including results from other climate models, plus further uncertainties arising from carbon cycle, sulphur cycle and ocean transport processes (see also Chapter 5 of Murphy et al. 2009). Consequently, it should not be assumed that the spread of outcomes simulated by the eleven RCM variants can be taken as the full range of changes consistent with current understanding. This is illustrated in Figure 12 where, for selected UK grid points, the PPE_RCM ensemble of changes in December to February is compared against results simulated by the 17 member PPE_GCM ensemble (where the eleven PPE_GCM members used to drive the RCM projections are shown as black crosses), and also against projections from a multi-model ensemble of 15 global coupled ocean-atmosphere models contributed to the IPCC AR4 (Meehl et al. 2007). The RCM changes conform fairly closely to the changes in their driving models, noting that some differences would be expected due to the effects of downscaling. However, the envelope of RCM changes is somewhat narrower than the wider spread of changes found in either the full PPE_GCM ensemble or (in particular) the multi-model ensemble. The envelope of changes in the latter is also shifted towards larger values in the examples shown. Therefore, users of RCM wind speeds should be aware that multi-year averages of future wind speed could increase or decrease by

* The 1961-90 baseline was used for consistency with the UKCP09 projections, but the percentage future changes are found to be very similar when a 1971-2000 baseline is used (not shown)
Figure 10: Changes in surface wind speed (%) in winter (DJF) for 2070-2099 relative to 1961–1990, for the eleven individual RCM projections (a-k). Panel l shows the ensemble-mean changes.
Figure 11: Envelope of changes in surface wind speed (%), for 2070-2099 minus 1961–1990, for (a) DJF, (b) MAM, (c) JJA, (d) SON. At each grid point in a given season the envelope is defined as the minimum change found across the eleven PPE_RCM ensemble members (left panel), and the maximum response (right panel). The central panel shows the ensemble-mean change. Note that different ensemble members provide the minimum or maximum changes at different grid points, so the maps do not represent the change simulated by any particular ensemble member.
4.3 Another issue is whether the biases in the historical simulation of surface wind speeds discussed in section 3 affect the credibility of the future changes projected by the RCMs. In general, changes in the atmospheric circulation in response to anthropogenic forcing can arise from a combination of remote and local influences. Remote influences could include, for example, changes in horizontal and vertical thermal gradients and moisture availability which influence the genesis and development of synoptic storms and anticyclones over the North Atlantic, or the effects of changes in tropical or extratropical sea surface temperature anomalies in altering the statistics of more persistent circulation anomalies over the UK through changes in the generation of quasi-stationary planetary waves. On the other hand, regional influences can potentially also have an influence, for example through changes in the frequency of occurrence of stable, neutral or convective boundary layer profiles, which would affect the relationship between changes in surface winds and changes at higher levels in the free atmosphere.
Figure 13: Ensemble mean future changes in surface wind speed for 2070–2099 relative to 1961–1990 from the RCM projections (top row) and their driving global model projections (bottom row), for DJF (a and e), MAM (b and f), JJA (c and g), and SON (d and h).

Figure 14: Ensemble mean future changes in the westerly component of wind at 850 hPa for 2070–2099 relative to 1961–1990 from the RCM projections (top row) and their driving global model projections (bottom row), for DJF (a and e), MAM (b and f), JJA (c and g), and SON (d and h).
4.4 In practice, patterns and magnitudes of future changes in surface wind speed are similar between the PPE_RCM ensemble and the driving global model ensemble (see Figure 13, which shows ensemble mean changes for 2070-99 relative to 1961-90 across Europe). Figures 14 and 15 show ensemble-mean changes in the westerly and southerly components of wind at the 850hPa level (representative of changes in the free atmosphere just above the boundary layer). The ensemble mean changes are modest, reflecting the lack of a strong, consistent signal across the different ensemble members (e.g. Figures 10 and 11). However, the ensemble-mean patterns do show some large scale structure, with (for example) a reduction in westerly flow over the southern half of the UK in summer (with stronger westerlies to the north), and an increase in southerly flow over the UK in winter. The change patterns for 850 hPa wind components are also very similar between the RCM and driving global model ensembles, and do not reflect the bias patterns found in the RCM surface wind speeds for the UK (cf Figure 4). These results indicate that the projected changes in surface wind over the UK and Europe in the RCMs are determined mainly by the effects of the large scale climate change feedback processes on changes in winds in the free atmosphere, which are inherited from the driving global model projections. The future changes do not appear to be significantly affected by the issues in the parameterisation of the drag due to surface roughness and orography which give rise to the historical simulation biases discussed in section 3. Figure 12 supplies further support for this conclusion, given that the ensemble mean and spread of the global and regional model changes is similar for grid points affected by both positive biases in the historical simulations (several low-lying locations in England) and negative biases (several Scottish locations at higher elevations).

Figure 15: As Figure 14 for changes in the southerly component of wind at 850hPa.
5. Recommendations

5.1 The results of sections 3 and 4 indicate that the projections of future change in near-surface wind speed from the 11-member ensemble of RCM projections produced for UKCP09 are credible, but that users needing future projections of absolute values need to account for the effects of historical simulation biases in the RCMs. This can be done by deriving seasonally based change factors from the eleven member RCM ensemble for the specific metrics of interest (e.g. mean wind speed, 90th percentile of daily wind speed), which should then be applied to observed values of the desired metric to provide eleven possible future projections.

5.2 For users who require time series of surface wind speeds, as opposed to a single metric such as the time average, it is recommended that users consider the strengths and weaknesses of alternative bias correction methodologies. A simple approach, for example, would be to express the simulated future daily values as fractional anomalies relative to the simulated long term historical average, and then apply those to the observed long term historical average to provide time series of absolute future values. This would have the advantage of preserving changes in the variability of wind speed projected by the RCMs, but would not account for variations in the historical simulation bias as a function of wind speed (compare blue and red curves in Figure 9, for example). A more sophisticated bias correction strategy would be to derive a set of change factors from the RCM projections for corresponding percentiles of the wind speed distribution. These factors could then be applied to observed historical time series of wind speed to provide possible future time series. This would have the advantage of accounting for historical simulation biases more comprehensively, but would generate future time series which fail to account for potential changes in the characteristics of climate variability simulated by the RCMs, and in which the autocorrelation characteristics between consecutive wind events may be distorted by the application of time-varying change factors. In practice, the optimal bias correction strategy is likely to be application-dependent, and it is recommended that users assess carefully the consequences of different approaches.

5.3 The bias correction strategies suggested above assume the availability of suitable observations, such as the gridded climatological values shown in Figure 1. If suitable observations are not available (for example if it is desired to generate site-specific projections for locations at which there is no observing station), then alternative bias correction methodologies will need to be considered. The approach of Howard and Clark (2007), based on
boundary layer theory, is one example. If wind speed observations are not available, it is recommended that users obtain expert advice to discuss their application and assess potential methods to account for biases in RCM wind speed.

5.4 Users should be aware that projections derived from the ensemble of RCM projections have the advantage of accounting for local climatic influences not resolved in coarser resolution global model projections (section 3.6), yet do not sample the full spread of possible outcomes consistent with current understanding of uncertainties in climate modelling. Consequently, users who wish to assess more fully the modelling uncertainty should compare the spread of RCM derived results with those from other modelling data. Sources would include the 17-member PPE_GCM ensemble of perturbed physics variants of HadCM3 global model carried out for UKCP09 (see section 2.1 above), which samples a somewhat wider range of process uncertainties than those sampled in the eleven RCM projections, or the multi-model ensemble of projections from alternative climate models shown in Figure 12. Note, however, that only values of daily-averaged westerly and southerly wind components are available from the multi-model projections, whereas daily values of wind speed (in addition to wind components) are available from the PPE_GCM ensemble. Users wishing to estimate changes in wind speed from multi-model projections can potentially do so using relationships between wind speed and the daily average component values.

5.5 While the set of eleven RCM projections do not provide a sufficiently comprehensive dataset to support robust estimates of the relative likelihood of different levels of change in future wind speeds, users may wish to combine results from the eleven members, for example to obtain an ensemble-average change (as in section 4.8 of Murphy et al. 2009). However, there is no guarantee that the ensemble average will then represent either a “most likely outcome”, or an outcome that can be guaranteed more credible than all of the individual projections. In principle, the UKCP09 methodology could allow a weight to be assigned to each of the RCM projections (by inheriting the weight assigned to the corresponding variant of the global model through the process of constraining the projections using observations – see section 3.2.9 of Murphy et al. (2009)). In theory, these weights could be used to provide refined estimates of the ensemble mean or spread of the RCM projections. In practice, however, the global and regional variants of HadCM3 used to provide the wind projections described in this report were selected to sample parts of the model parameter space of roughly equal credibility (section 3.2.4 of Murphy et al. 2009), therefore we would advise users that attempting to weight the individual model projections would not necessarily lead to a significantly refined set of projections, especially when considered in the light of the generic limitations of the ensemble. As discussed, the issue is that when there is only a relatively small number of ensemble members, weighting members can effectively reduce the ensemble size still further (e.g., if one or two of the model ensembles are given a much higher weight that the others. This limitation would outweigh any beneficial effect from increased precision that weighting may provide, especially considering that the wind is a variable with a small signal compared to the associated noise.
References


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