Interim UKCIP98 Daily Weather Scenarios
(prepared for MAFF under contract to DETR)

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1 Introduction

The daily weather scenarios described in this document represent an interim product generated for use in a MAFF project evaluating the impact of climate change and extreme events on agriculture in England and Wales. The scenarios are interim in so far as they are an extension of the UKCIP98 climate scenarios produced in October 1998 (Hulme and Jenkins, 1998), yet only a forerunner of the new set of UKCIP climate scenarios scheduled for the end of 2001 (the UKCIP2001 scenarios).

The four UKCIP98 scenarios were termed Low, Medium-low, Medium-high and High and were associated with a range of possible future greenhouse gas emissions trajectories and a plausible range of global climate sensitivities. The UKCIP98 report described changes in annual and seasonal-mean climate for three future 30-year periods centred on the 2020s, the 2050s, and the 2080s. The UKCIP98 scenarios were constructed using results from a series of climate model experiments completed using the Hadley Centre HadCM2 global climate model (GCM). This model has a spatial resolution of 3.75° in longitude by 2.5° in latitude, thus the UK was represented by six GCM grid boxes. Results were presented for a number of climate variables and changes in interannual and inter-daily variability were summarised for mean temperature and precipitation. As well as information being presented at the GCM resolution, the UKCIP98 CD-ROM also contained seasonal and annual scenarios at a resolution of 10km, derived by interpolating the GCM changes onto an observed 10km 1961-90 mean monthly climatology. This approach was termed ‘unintelligent downscaling’ in that no additional meteorological information was used in the interpolation procedure.

The interim scenario product described here has been created in response to a request for higher spatial and temporal resolution climate scenarios for the UK, so that changes in higher order moments - such as interannual and inter-daily variability - as well as probabilities of daily weather extremes to be analysed for a wider range of climate variables than presented in the UKCIP98 report.

2 Scenario Construction

These interim weather scenarios have been constructed using results from an experiment performed using the Hadley Centre regional climate model (RCM) HadRM2 (Jones *et al*., 1997; Noguer *et al*., 1998). RCMs are driven by boundary conditions extracted from GCM experiments, in this case extracted from an experiment completed using the same HadCM2 model from which the UKCIP98 scenarios were derived. The resolution of this RCM is ~50 km and the model grid is centred over Europe. We use results from two experiments performed with the HadRM2 model: a control experiment (driven by results from the HadCM2 control or unforced experiment) and a future greenhouse-gas forcing experiment (driven by results from the HadCM2 GGa2 experiment in which equivalent-CO_2 concentration increases from 1990 onwards by 1% per annum). The HadRM2 control experiment simulates a 30-year period nominally representing ‘current’ climate conditions, while the HadRM2 greenhouse-gas forced experiment simulates a 20-year period, 2080-2100. We have used these model results in order to derive daily weather series for a baseline “1961-1990” 30-year period, and for two future periods, the “2020s” and the “2050s” (to be consistent with the UKCIP98 report). Our interim weather scenarios, however, encompass only the 20-year periods 2015-2034 and 2045-2064, respectively, since we are constrained by the 20 years of data from the HadRM2 greenhouse-gas forced experiment. We use the HadRM2 unforced experiment to construct the nominal “1961-90” baseline weather series and the HadRM2 greenhouse gas 2080-2100 experiment to construct the future “2020s” and “2050s” series. The construction of these latter series relies on scaling the HadRM2 results for 2080-2100 on the basis of the global warming values (or the regional precipitation changes for the precipitation variable) predicted for the 2020s and 2050s under the four UKCIP98 scenarios. Such scaling methods generally make the assumption that the response of regional mean climate to greenhouse gas forcing is linearly related to global-mean temperature. These methods have been widely used in scenario construction for several years when applied to monthly and seasonal data (Santer *et al*., 1990; Rotmans *et al*., 1994; Jones, 2000), although we are not aware of applications of such scaling methods to daily data from RCM experiments.

Daily weather series have been constructed for maximum, minimum and mean temperature, precipitation, relative humidity, total downward or incident short-wave radiation and 10m wind speed, variables chosen with the calculation of potential evapotranspiration (PET) in mind. Mean temperature was included primarily for the purpose of calculating specific humidity from relative humidity, and is a direct model variable rather than the mean of maximum and minimum temperature (note: in other contexts mean temperature is often derived as the average of maximum and minimum temperature). Although net downward surface radiation is required for the calculation of PET, only total downward surface radiation was available from HadRM2 at daily time-steps.

3 Scaling Methods

The HadRM2 model grid is comprised of 113 longitude by 103 latitude grid points on a rotated polar grid (pole=160,30). Data were selected only for UK land areas, which amounted to 125 land 50km grid boxes in HadRM2 (compared to the six land boxes in the HadCM2 model). The HadRM2 land grid boxes are shown in Figure 1, with the HadCM2 GCM land grid boxes overlain for reference. The co-ordinates of these HadRM2 grid boxes, both in rotated pole and absolute longitude/latitudes, are contained in the text file ‘regco.dat’.

1. Baseline weather scenarios:

For the baseline weather scenarios we used results from the HadRM2 control experiment directly. We nominate this baseline or reference series to be representative of the nominal period “1961-1990” (i.e., ‘current’ climate according to convention in climate scenario construction exercises) in which there is no climate forcing relative to the future climate scenarios. These weather series are **not** simulations of the actual series of years from 1961 to 1990 and should be seen as the attempt of the HadRM2 model to represent current climate over the UK. It is also important to realise that these baseline scenarios represent weather on a 50km grid and **not** weather for individual point locations (as measured by observational station data). The statistical characteristics of the weather scenarios presented here are therefore **different** from those obtained from observational data.

To be consistent with the future weather scenarios described below a few changes were imposed on these baseline series taken from HadRM2. Precipitation is a highly localised climate variable and GCMs often simulate too much continuous “drizzle” because of their coarse resolution. Even RCMs at a 50km resolution cannot capture localised precipitation events. For precipitation, therefore, if the model simulated values below 0.2 mm/day we set these values to be zero in order to obtain more realistic wet-day and dry-day sequences in the weather scenarios. To be consistent with the future weather scenarios (see below), for short-wave surface radiation and 10m wind speeds respective minimum thresholds of 0.5 W/m2 and 0.1 m/s were set.

2. Future weather scenarios:

The main consideration in the construction of the future weather scenarios was how to apply scaling methods to different climate variables, some being continuous such as temperature and some being discrete such as precipitation, in order to ‘preserve’ the inter-daily variability from the HadRM2 model. We first examined the annual cycle for a random year in the HadRM2 control experiment for each of these climate variables. We classed all the variables except precipitation as broadly continuous. We then used two scaling methods: one to construct the scenarios for temperature, relative humidity, short-wave radiation and wind, and the other to construct the precipitation scenarios. For both methods anomalies between the HadRM2 future greenhouse-gas scenario experiment and the HadRM2 control experiment were scaled to produce the future “2020s” and “2050s” series for the four UKCIP98 scenarios (these four scenarios are described in detail in the UKCIP98 report).

Method A for continuous variables.

We used the following equation to construct the scaled daily weather series for maximum temperature, minumum temperature, mean temperature, shortwave radiation, relative humidity, and wind speed:

$$V_{scen,d} = (Vbar_{fut,m} - Vbar_{ctl,m}) \times (scalar) + Vbar_{ctl,d} + (V_{fut,d} - Vbar_{fut,d}) \quad [Eq. 1]$$

Where: scalar = $\Delta T_{UKCIP98} / \Delta T_{HadCM2}$
and: $\Delta T_{UKCIP98}$ = global warming for the respective UKCIP98 scenario and time-slice
ΔT_{HadCM2} = global warming from the pair of HadCM2 experiments that provided the boundary conditions for the HadRM2 experiments.

This equation is comprised of three components:

- the scaled mean monthly anomalies between the future 2080-2100 HadRM2 and the HadRM2 control series: $(Vbar_{fut,m} - Vbar_{ctl,m}) \times scalar$
- the daily mean climatology for the HadRM2 control: $Vbar_{ctl,d}$
- the daily anomaly series for the HadRM2 2080-2100 greenhouse-gas forcing experiment: $V_{fut,d} - Vbar_{fut,d}$

We explain these components as follows.

Mean monthly climatologies were calculated for the two experiments with the difference being $Vbar_{fut,m} - Vbar_{ctl,m}$. This defines the change in the annual cycle due to greenhouse gas forcing for the period 2080-2100.

The global warming value (ΔT_{HadCM2}) between the HadCM2 GGa2 experiment for the 2080-2100 period and the HadCM2 control experiment for the 30-year period used as the boundary conditions to the HadRM2 control was then calculated. The monthly mean anomalies from the HadRM2 experiments were normalised by this global warming value ($\Delta T_{HadCM2} = 4.06^oC$) and then multiplied by the global warming value for the appropriate UKCIP98 scenario and time-slice (*e.g.* for the UKCIP98 Low scenario for the 2020s ($\Delta T_{UKCIP98} = 0.57^oC$).

The control or baseline daily-mean climatology from HadRM2 ($Vbar_{ctl,d}$) was then added back to the scaled monthly anomalies. The daily climatology was used as oppose to the monthly climatology to avoid discontinuities or step jumps between each month in the resultant scaled climatology.

Finally, the daily anomaly series ($V_{fut,d} – Vbar_{fut,d}$) for each year from the HadRM2 greenhouse gas experiment were added to this scaled daily-mean climatology.

This approach produces a scenario daily weather series which preserves the day-to-day changes in variability simulated in the HadRM2 greenhouse gas forced experiment, but in which the mean monthly changes in temperature were consistent with the magnitude of global warming associated with the UKCIP98 scenarios and time-slices.

<u>Method B for precipitation</u>

There are a number of reasons why the above scaling methodology does not work well for precipitation. Precipitation has discrete wet and dry "spells" of the order of several days to weeks and does not have a pronounced annual cycle like the other variables. Scaling monthly mean values may not capture so well the precipitation changes due to different forcings. More significantly, the daily anomaly series calculated from the HadRM2 greenhouse gas forced experiment may also contain large negative values which would be retained as smaller negative values in the final scenario daily weather series.

For this variable we therefore needed to apply an alternative scaling method. We chose to constrain (on a seasonal time-step) the precipitation weather scenarios to the UKCIP98 precipitation scenarios and used the following equation:

$$P_{ngrid,scen,d} = P_{fut,d} \times (P_{ctl,s}/P_{fut,s}) \times \Delta P\_UKCIP98_{ngrid,scen,s} \qquad \text{[Eq. 2]}$$

First, seasonal-mean climatologies were constructed for the HadRM2 control and greenhouse gas experiments (seasonal values were used since the UKCIP98 report contains seasonal rather than monthly changes). The percentage changes in seasonal-mean precipitation for the four UKCIP98 scenarios and two time-slices were taken from the UKCIP98 report and mapped onto the appropriate HadRM2 50km grid box. The future HadRM2 daily precipitation series ($P_{fut,d}$) was then multiplied by the respective seasonal-mean precipitation ratio of HadRM2 control:future climatologies ($P_{ctl,s}/P_{fut,s}$), itself scaled by the percentage change in the respective seasonal-mean precipitation for the appropriate UKIP98 grid box, scenario and time-slice ($\Delta P\_UKCIP98_{ngrid,scen,s}$). This approach preserves the inter-daily precipitation structure from the HadRM2 greenhouse gas forced experiment (i.e., the wet-day/dry-day sequence is the same for each of the eight interim MAFF weather scenarios), but scales the daily magnitudes by an amount that ensures that the pattern of seasonal-mean precipitation changes across the UK in the UKCIP98 scenarios is also preserved. The HadRM2 cross-correlations between precipitation and the other variables is also maintained (see Appendix).

4 Important Notes About Applying these Scenarios

- The baseline weather series supplied here are **not** simulations of the actual series of years from 1961 to 1990. They represent the result of the HadRM2 model to simulate current climate over the UK - the stated years are purely nominal.

- It is also important to realise that all the data presented here represent 'weather' on a 50km grid and **not** weather for individual point locations (as conventionally measured by observational station data). The statistical characteristics of the weather scenarios presented here are therefore **different** from those obtained from observational data.

- The above two points mean that if these data are used in any impacts/adaptation work (e.g. crop modelling), the impact of the future weather scenarios on an exposure unit (e.g. crop yield) **must** be compared against the simulation of that same exposure unit under current conditions that **uses the baseline climate data supplied here, rather than conventional point observational data from climate stations**. If this requirement is not adhered to then any assessment of climate change impact on the exposure unit is invalid.

- Since the weather sequences supplied here are relatively short (20 or 30 years), the most extreme weather conditions experienced within the UK - whether under current or future climate - will **not** be represented. This is a limitation of the duration of the HadRM2 simulations that can only be overcome by using much longer RCM simulations or else stochastic weather generators.

5 Data Files

See Appendix 1 for some graphical and tabular diagnostics of the resulting scenarios.

The data files are provided in ASCII format. There is one data file containing all the variables for the baseline period and one file for each of the four scenarios and each of the two future time periods. For example, there is a data file for the UKCIP Low scenario for the 2020s and a separate file for the 2050s. There are a total of nine data files in all, and are named:

‘maff2000_**Scenario_Time period**.dat’

where:

Scenario: ‘baseline’ = baseline, ‘low’ = UKCIP98 Low, ‘mlow’ = Medium-low, ‘mhigh’ = Medium-high and ‘high’ = High
Time period: ‘2020s’ or ‘2050s’

[Note: the baseline file has no time period in its name: maff2000_baseline.dat]

Each file is organised grid box by grid box and contains daily weather series for 30 years for the baseline and for 20 years for the future scenarios. A separate data file ‘regco.dat’ gives the co-ordinates of each of 125 grid boxes in rotated pole and absolute lat./long. co-ordinates. The former are recommended for plotting maps, as in this co-ordinate system the data can be represented on a regular grid. The 125 land grid boxes are arranged from north to south, starting from northern Scotland and ending in Cornwall. See Figure 1 for a location map. The first line of the data file header contains the grid box number and the absolute longitude (°W or °E centre of grid-box; negative is west) and latitude (°N centre of grid box) as well as the elevation in metres. The format statement for this header is: (11x,i3,13x,f6.3,12x,f6.3,16x,f6.2).

For each data file there are then two further header lines which give the layout of the data and the appropriate units. These lines are:

File	Grid	Year	Month	Day	Tmax	Tmin	Tmean	Prec	Rhum	Dswf	Wind
					degC	degC	degC	mm/d	%	W/m2	m/s

The explanation of these columns is as follows:

File: scenario and time period: ‘BASE’ = baseline, ‘LL20’ = Low 2020s, ‘LL50’ = Low 2050s, ‘ML20’ and ‘ML50’ = Medium-low 2020s and 2050s respectively, ‘MH20’ and ‘MH50’ = Medium-high 2020s and 2050s, ‘HH20’ and ‘HH50’ = High 2020s and 2050s.

Grid: grid box number

Year: the nominal model year, 1961 to 1990 for the baseline, 2015 to 2034 for the 2020s and 2045 to 2064 for the 2050s. Note: years ‘1961’ to ‘1990’ are model simulated years and are not simulations of actual years 1961 to 1990.

Month: 1 = January to 12 = December.

Day: 1 to 30. Note: model months are always 30 days, one model year is 360 days.

These are followed by the variable name and its units:

Tmax: 1.5m screen maximum daily temperature in degrees C
Tmin: 1.5m screen minimum daily temperature in degrees C
Tmean: 1.5 screen mean temperature in degrees C. Note: this is the model mean and may be different from the average of Tmax and Tmin. We include this variable for the calculation of specific humidity from relative humidity (both are 24-hour model means averaged over same time-step). For other purposes we recommend calculating the mean temperature using the average of Tmax and Tmin.
Prec: total daily precipitation in mm/day
Rhum: 1.5m daily mean relative humdity in %
Dswf: total daily downward surface shortwave flux in W/m^2
Wind: 10m daily mean wind speed in m/s

The format for these data is: (a4,2x,i3,2x,i4,3x,i2,4x,i2,1x,7f8.2).

Missing data in the files are shown as ‘9999.99’.

Sample layout:

```
Grid box =   1 longitude = -3.747 latitude = 58.517 elevation(m) =  96.54
File Grid  Year  Month Day     Tmax    Tmin   Tmean    Prec    Rhum    Dswf    Wind
                               degC    degC    degC    mm/d     %      W/m2     m/s
BASE    1 '1961'   1     1     4.59    1.87    3.33    2.05   94.63    9.91    5.66
BASE    1 '1961'   1     2     1.80   -2.02   -1.01    5.69   96.13    2.79    8.47
BASE    1 '1961'   1     3    -0.43   -1.01   -0.67    2.09   91.50    5.66    7.44
BASE    1 '1961'   1     4     0.03   -3.33   -1.48    0.33   86.00    8.11    5.44
BASE    1 '1961'   1     5     1.50   -2.90   -1.27    7.16   92.50   12.34   10.19
BASE    1 '1961'   1     6     0.79   -2.42   -0.77    9.93   98.63    1.83    4.72
BASE    1 '1961'   1     7     2.13    0.19    1.21    0.57   86.38   16.77    3.85
BASE    1 '1961'   1     8     4.93    2.03    3.34    1.49   82.50    5.24   11.32
BASE    1 '1961'   1     9     3.49    1.16    2.17    0.59   85.25   25.20    7.66
```

BASE	1	'1961'	1	10	6.66	3.54	6.16	1.44	93.50	3.67	6.60
BASE	1	'1961'	1	11	7.70	5.97	6.65	0.00	95.00	15.69	7.66
BASE	1	'1961'	1	12	6.81	3.86	5.53	0.00	92.75	29.56	7.57
BASE	1	'1961'	1	13	6.98	3.87	5.03	1.34	94.50	19.55	4.22
BASE	1	'1961'	1	14	4.47	1.34	2.99	0.00	87.38	22.77	4.78
BASE	1	'1961'	1	15	2.99	1.00	2.05	0.20	94.50	10.53	4.78
BASE	1	'1961'	1	16	3.91	2.53	3.31	1.40	96.13	1.14	5.63
BASE	1	'1961'	1	17	5.29	3.37	4.09	0.64	92.75	18.77	6.35
BASE	1	'1961'	1	18	4.65	2.77	3.44	0.00	90.13	32.68	10.04

6 References

Hulme,M. and Jenkins,G.J. (1998) **Climate change scenarios for the United Kingdom** UKCIP Technical Note No.1, Climatic Research Unit, Norwich, UK, 80pp.

Jones,R.G., Murphy,J.M., Noguer,M. and Keen,A.B. (1997) Simulation of climate change over Europe using a nested Regional Climate Model. II: Comparison of driving and regional model responses to to a doubling of carbon dioxide **Quart. J. Royal Meteorol. Soc**., 123, 265-292.

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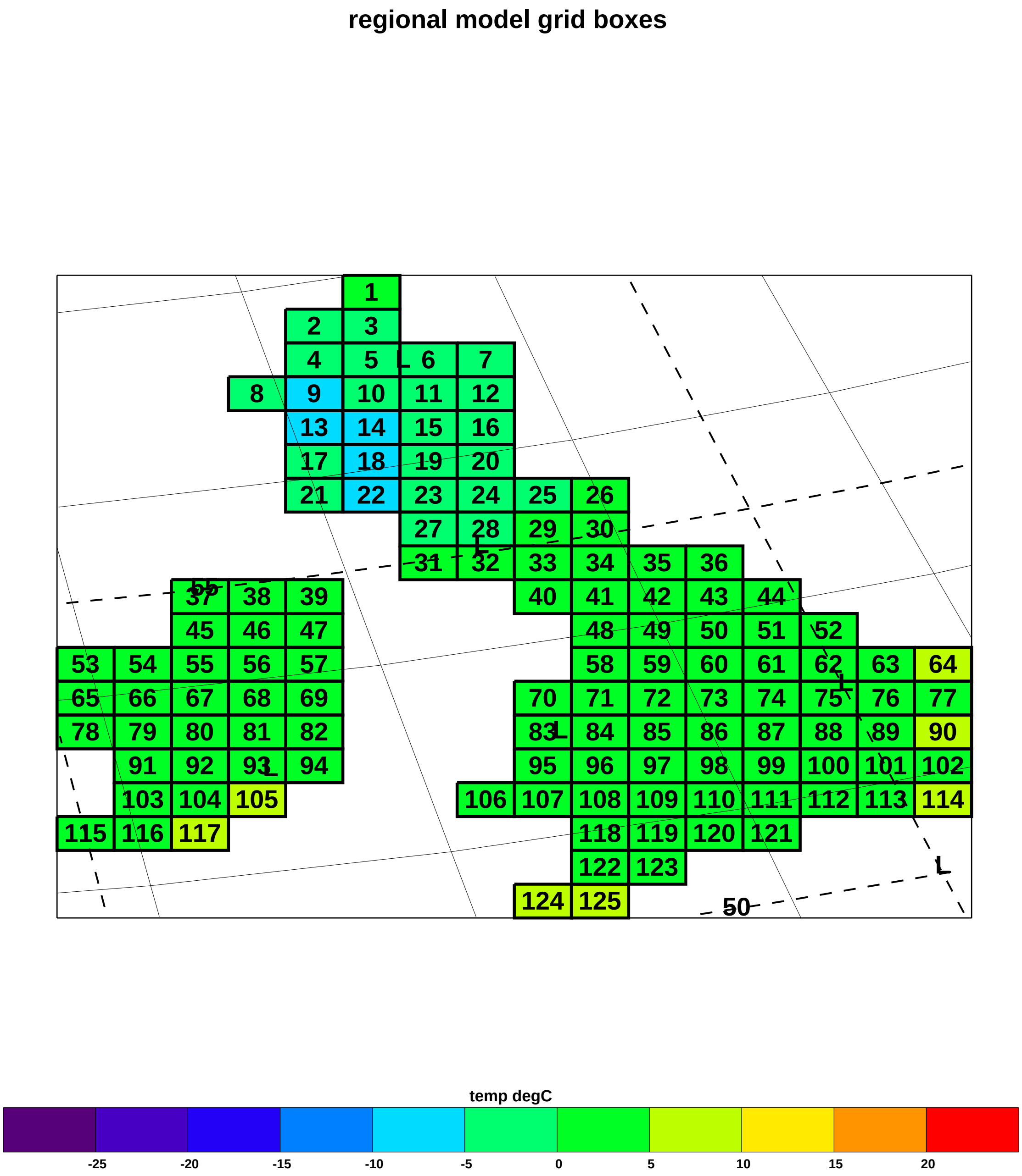

Figure 1: The 125 grid boxes for which the daily weather scenarios are presented. Grid box numbers correspond to the coding scheme used in the data files. Each grid box is a 50km land cell in the HadRM2 model.