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A daily weather generator for use in climate change studies

C.G. Kilsby [a,*], P.D. Jones [b], A. Burton [a], A.C. Ford [a], H.J. Fowler [a], C. Harpham [b], P. James [a], A. Smith [a], R.L. Wilby [c]

[a] *School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Claremont Road, Newcastle upon Tyne NE1 7RU, UK*
[b] *Climatic Research Unit (CRU), School of Environmental Sciences, University of East Anglia, Norwich, UK*
[c] *Environment Agency of England and Wales, Nottingham, UK*

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Abstract

This paper describes the development of a weather generator for use in climate impact assessments of agricultural and water system management. The generator produces internally consistent series of meteorological variables including: rainfall, temperature, humidity, wind, sunshine, as well as derivation of potential evapotranspiration. The system produces series at a daily time resolution, using two stochastic models in series: first, for rainfall which produces an output series which is then used for a second model generating the other variables dependent on rainfall. The series are intended for single sites defined nationally across the UK at a 5 km resolution, but can be generated to be representative across small catchments (<1000 km^2). Scenarios can be generated for the control period (1961–1990) based on observed data, as well as for the UK Climate Impacts Programme (UKCIP02) scenarios for three time slices (2020s, 2050s and 2080s). Future scenarios are generated by fitting the models to observations which have been perturbed by application of change factors derived from the UKCIP02 mean projected changes in that variable. These change factors are readily updated, as new scenarios become available, and with suitable calibration data the approach could be extended to any geographical region.

Keywords: Weather generator; Stochastic; Rainfall model; Climate change; Climate scenario

Software availability

Name of software: EARWIG (Environment Agency Rainfall and Weather Impacts Generator).
Developer: School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, UK.
Contact: Chris Kilsby, School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU, UK. E-mail address: c.g.kilsby@ncl.ac.uk
Year first available: 2006.
Hardware required: PC.
Software required: Windows 2000 or XP.
Program language: Fortran numerics: interface developed under MS Visual Studio.
Program size: 30 Mb of disk space required: runs within 60 Mb of memory.
Availability: Can be made available to researchers on request to the authors.
Cost: N/A.

1. Introduction

Impact assessments of climate change on hydrology and related fields such as agricultural and water management practice require time series of weather variables for specific catchments or locations at daily or higher resolution. Data are needed for both the current climate and a range of future possible scenarios. These series must be consistent, both between variables, and with a range of observed and projected

* Corresponding author. Tel.: +44 191 222 5614; fax: +44 191 222 6669.
E-mail address: c.g.kilsby@ncl.ac.uk (C.G. Kilsby).

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statistics of the variables in order to account for extremes (floods and droughts) and seasonality. Such series are not directly available from climate models, and this paper describes an alternative approach using a "weather generator" to provide series of rainfall, temperature, humidity, wind and potential evapotranspiration at river catchment scales.

The proposed methodology uses stochastic models of rainfall and weather. Previous weather generators have used simple rainfall models based on either Markov chains (Richardson, 1981) or empirical distributions of wet/dry spells (Semenov and Brooks, 1999). The approach described here uses a more sophisticated Neyman-Scott point process model (Cowpertwait, 1991) capable of more accurately reproducing higher order rainfall statistics. The general approach taken is as follows:

- Observed data of rainfall and other weather variables used to define current climate.
- Regional Climate Model (RCM) rainfall and temperature data used to derive factors of change from current climate state to define climate change scenarios.
- Stochastic model of daily rainfall fitted to current climate, and then re-fitted for possible future climates using future, factored daily rainfall statistics.
- Weather Generator (WG) model based on regression relations between daily climatic variables and daily rainfall: parameterised using current climate data, and then applied for possible future climates, using future factored daily climate variable statistics.
- Software implementation using a map viewer linked to a spatial database allowing the flexible selection of areas for generation of series.

The essentials of this methodology have been previously applied within the BETWIXT project at 17 UK sites (for rainfall) and 5 sites for all variables (see BETWIXT Project website). This paper describes how the method can be extended to continuous UK coverage, providing a capability of generating rainfall and other weather variables representative of any location and a range of possible future climates and time-periods. In principle, and with suitable observed and RCM data, the approach can be extended to any geographical region. The elements of the methodology are described in more detail in the following sections.

2. Climate data

2.1. Observed data

UKMO/UKCIP (UK Meteorological Office/UK Climate Impacts Programme) 5-km gridded weather data were used in this project (Perry and Hollis, 2005a,b). These consist of two 5 km × 5 km gridded datasets covering the UK for the period 1961–2000. The first is of monthly values of mean temperature, daily temperature range, rainfall, sunshine, cloud, and wind speed. The second is daily rainfall for the period 1958–2002. These data were generated in a geographical information system combining multiple regression with inverse distance-weighted interpolation taking account of geographic and topographic factors (Perry and Hollis, 2005a,b). Daily series from 115 sites, with a reasonable national coverage, were used to provide additional information on climatic variables at the daily level. These sites are the same as those used by Osborn et al. (2000).

The 1961–1990 period is taken as a climatological normal for rainfall. However, it is possible to use other periods for this purpose, or even to set the model up for separate decades to explore issues of climatic variability and stationarity of model relationships.

Grids of rainfall statistics derived from this data set are shown in Fig. 1.

Variables apart from rainfall are available only at the daily level for 1995–2000 so an approach combining monthly data (available 1958–2002) with site data has been followed (see Section 5).

2.2. Climate scenarios

The methodology is illustrated using UKCIP02 change factors, but the approach is applicable using change factors taken from any global or regional climate model. The model future scenarios are based on the UKCIP02 scenarios (Hulme et al., 2002) for four emissions scenarios (SRES A1, A2, B1 and B2) and three future time-slices (2020s, 2050s and 2080s as defined below) derived from the HadRM3H integrations. A control scenario simulating the 1961–1990 period is also available. The approach relies on deriving factors of change for various statistics from control to future scenarios and applying these to observed statistics, rather than using the RCM's rainfall climatology directly as it does not reproduce the spatial patterns of mean rainfall or seasonality accurately (Fowler and Kilsby, 2004) and, more importantly, does not accurately represent extreme dry spells or extreme rainfall events (Fowler et al., 2005).

Change factors are derived using multiplicative factors for rainfall statistics and additive ones for other climate variables on a calendar month basis. These are taken directly as ratios for the mean (M), variance (Var) and skewness (S) of daily rainfall, and a logit transformation of proportion of dry days (PDry) to ensure linearity across the range of values.

The following equations are used to apply the calculated change fields (α) for a general variable P (using the suffix GCM to indicate climate model values):

$$\frac{P^{\mathrm{Fut}}}{P^{\mathrm{Obs}}} = \frac{P^{\mathrm{GCMFut}}}{P^{\mathrm{GCMCon}}} \tag{1}$$

where $\alpha = P^{\mathrm{GCMFut}}/P^{\mathrm{GCMCon}}$ and therefore,

$$P^{\mathrm{Fut}} = \alpha P^{\mathrm{Obs}} \tag{2}$$

For PDry however, the following equation is used:

$$\frac{X(\mathrm{PDry}^{\mathrm{Fut}})}{X(\mathrm{PDry}^{\mathrm{Obs}})} = \frac{X(\mathrm{PDry}^{\mathrm{GCMFut}})}{X(\mathrm{PDry}^{\mathrm{GCMCon}})} \tag{3}$$