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Simulation and downscaling models for potential evaporation

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Abstract

As hydrologists begin to explore the potential of modern computers to simulate hydrological systems over long periods of time, there is an increasing need for high-quality tools that can generate appropriate inputs to these systems. This paper presents some statistical models for generating sequences of potential evaporation (PE), possibly conditioned on rainfall, applied to data from southern England. There have been significant trends in PE in this area over the period 1961–1993; moreover, the variance of the series shows strong seasonal structure. The methodology presented here provides an intuitively simple means of reproducing such features. Moreover, as well as allowing the generation of simulated sequences, it can be used to produce sequences at a fine timescale from coarse-resolution data.

Keywords: Evapotranspiration; Continuous simulation; Heteroscedasticity; Kalman filter

1. Overview

In simple terms, many hydrological systems can be reduced conceptually to a water balance equation:

$$\text{Precipitation} - \text{Evapotranspiration} = \text{Runoff} + \text{Change in storage}. \quad (1)$$

Most hydrological rainfall-runoff models are designed to solve this equation, for a given precipitation sequence (and possibly the associated evapotranspiration).

There is currently a substantial amount of research interest in the use of rainfall-runoff models to simulate hydrological systems over long periods of time. The hope is that this use of 'continuous simulation' will yield more insight into the behaviour of a system than simpler approaches based, for example, on analysis of individual historical events. Continuous simulation does, however, require an ability to simulate realistic input sequences at an appropriate timescale. Consequently, there is a substantial body of literature devoted to the development of precipitation models for this purpose. In comparison, attempts to simulate evapotranspiration sequences, which may also be required by rainfall-runoff models, are in their infancy.

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The processes governing evapotranspiration are complex, and it can usually be measured only indirectly (Shuttleworth, 1993). For this reason, many runoff models work with potential evaporation (PE) rather than actual evapotranspiration. In the UK, since 1978 the primary source of PE data for hydrological applications has been the Meteorological Office Rainfall and Evaporation Calculation System (MORECS). This uses a modified version of the Penman–Monteith equation (Monteith, 1965) to estimate PE on a $40\times40\ km^2$ grid covering the whole of the UK. For details, see Thompson et al. (1981). The calculations are based on daily values of meteorological variables, along with information on land usage. However, the published output is at a weekly timescale, which is unsatisfactory in those applications for which daily or subdaily values are required. To deal with this problem, the pragmatic approach of assuming PE to be constant throughout the week is widespread in current practice (E. Stewart, personal communication). As a zeroth order approximation this is probably reasonable, since evaporation varies much more smoothly in time than does precipitation, for example. However, the effects of ignoring fine-scale variability in PE sequences are not known.

In the work reported here, models have been developed for both weekly and daily PE sequences. These models are effectively heteroscedastic autoregressions. They have been constructed in such a way as to allow simulation of weekly or daily sequences, and also to simulate realistic daily sequences that are consistent with a given weekly sequence. They are therefore suitable both for use in continuous simulation studies, and for the derivation of realistic daily historical sequences from weekly data.

The methodology is illustrated using data from the south of England. Section 2 provides a summary of these data. Sections 3 and 4 describe the development of models for weekly and daily PE, as well as analyses of the relationship between precipitation and PE. In Section 5, these models are used to develop a downscaling procedure that is appropriate for generating daily sequences subject to fixed weekly totals; and the work is summarised in Section 6.

2. Data and preliminary analysis

Three separate sources of data have been used in this study:

1. Weekly MORECS PE data (in mm) from a single $40\times40\ m^2$ grid-square in Surrey, in southern England. The data span the period from January 1961 to March 1993, and are a subset of the Thames catchment data used in Jolley and Wheater (1996). The MORECS output includes PE calculations for a homogeneous grass surface, and for the estimated real land usage. For current purposes, the choice of PE measure is immaterial; the modelling methodology below can be applied in any situation, and we anticipate that the conclusions are unlikely to be sensitive to land use changes. Here, we focus on the 'grass' data since these are routinely used as a reference land use (Penman, 1948).
2. Daily rainfall and evaporation data (both in mm) from an experimental station at Silwood Park in Berkshire, which is located just outside the MORECS grid square. These run from July 1989 to August 1994. The data were collected as part of a set of lysimeter experiments carried out by Imperial College (Burne et al., 1994). The rainfall data were gathered using a 0.2 mm tipping-bucket gauge; the PE calculations used the MORECS form of the Penman-Monteith equation, with a winter wheat crop.
3. Daily rainfall data (in mm) from a gauge located at Rotherfield Park in Surrey, near the centre of the MORECS grid square. The record spans the period 1923–2000; 1557 of the daily values (around 0.5%) are missing. These data are used to investigate the relationship between PE and rainfall.

The data have been checked for possible errors and outliers; their quality appears reasonable.

Preliminary analyses of the PE sequences revealed that evapotranspiration is higher, and substantially more variable, in summer than in winter. Also, the weekly MORECS sequence shows apparent increasing trends in almost all months of the year (Fig. 1). There is, as expected, a relationship between rainfall and PE, although this relationship is weak: the largest