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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

A0270 Seasonal River Flow Forecasting Using Multi-model Ensemble Climate Data

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1. Aim and Introduction

The objective of this research is to assess the relative skill of predictions of river flow using: (1) a multi-Global Climate Model (GCM) ensemble dataset and (2) downscaled multi-GCM data as input to a hydrological model. Our overarching aim is to advance the seasonal forecasting of river flows in the UK. This research focuses upon the River Dyfi basin in West Wales, UK, which is a test catchment for the wider project.

The basis for seasonal atmospheric predictability resides on an anomalous lower boundary forcing. Such anomalies include sea-surface temperature (SST) (Brankovic et al., 1994). Seasonal predictability has been more evident in the tropics owing to the weaker internal chaotic variability. Although extratropical predictability is restricted by the nonlinearities and instabilities of the atmospheric flow, certain areas have shown predictability (Shukla, 1998). Defined here as lead times of 1 to 6 months, seasonal river flow forecasting although in its infancy, has potential to aid water management decision making and preparation for human response to hydrological extremes.

2. Data

The River Dyfi basin (Figure 1) was chosen for the study as it is near natural, hence the climate-flow signal should be clearer. It is a temperate catchment, and relatively small with an area of 471.3 km^2. Daily catchment-averaged rainfall, monthly catchment-averaged potential evaporation (PE) and daily river flow data were used to calibrate the Probability Distributed Model (PDM) rainfall-runoff model.

The DEMETER project is the source of the multi-model climate data, and this consists of 7 GCMs (see Table 2) each with 9 ensemble members. The GCMs are from different institutions throughout Europe. This approach takes into account the uncertainty in the initial conditions, and the inaccuracy introduced when the GCM equations are truncated for integration on a supercomputer (Palmer et al., 2004). The DEMETER models are available on a 2.5˚ x 2.5˚ grid. The closest land-based grid point to the River Dyfi basin (52.5˚N 357.5˚E) was used in the study. Hindcasts (retrospective forecasts) with lead times of up to 6 months are available from 1st Feb, 1st May, 1st Aug and 1st Nov initial conditions. The period 1980–2001 is considered, as it is common to all models.

3. Methods

The PDM is a lumped rainfall-runoff model (based on probability distributed moisture stores) that transforms rainfall and PE to river flow at the basin outlet (Moore, 2007). PDM was calibrated for 01/05/1980–30/04/1990, and evaluated for 01/05/1991–30/04/2001.

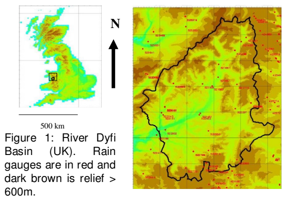


Figure 1: River Dyfi Basin (UK). Rain gauges are in red and dark brown is relief > 600m.

Each hindcast from the 4 start dates was split into the first 3 and last 3 months, and the subsequent concatenation of the split hindcasts produced 2 time series (0–3 and 4–6 month lead series respectively) (Figure 2). The total forecasted precipitation and the observed PE were inputted into the PDM.

The Statistical Downscaling Model (SDSM) (Wilby et al., 2002) Version 4.1 was used to produce data at the basin scale, as previous studies have shown the improvement this process discloses (Lavers et al., 2007). SDSM was calibrated on the ERA-40 reanalysis dataset (over 01/05/1976–30/04/1991), as it provides one of the best estimates of the real atmosphere. SDSM uses multiple linear regression models (in this case one per month) to link large-scale DEMETER predictors with basin scale rainfall, and a stochastic weather generator produces daily rainfall time series. Three predictors were used: 500 hPa geopotential and zonal wind, and the 850 hPa meridional wind.

For each DEMETER ensemble member 10 forecast series were produced over the period 01/05/1980–30/04/2001 (total of 630 members). All of these 630 downscaled members were inputted to the PDM. Overall forecasting skill was assessed using 2 versions of the R^2 statistic: an original and a modified version (left and right equations below respectively). The R^2 values were calculated on the 31 day moving average river flows. The modified version compares the median DEMETER forecasted flow to the historical median flow on that day (green curve on figure 4), instead of the mean river flow (grey line on figure 4).

$$R^2_{orig} = 1 - \frac{\sum_i \left(Observed(i) - ForecastEnsembleMean(i)\right)^2}{\sum_i \left(Observed(i) - \overline{ObservedFlows}\right)^2} \qquad R^2_{mod} = 1 - \frac{\sum_i \left(Observed(i) - ForecastEnsembleMedian(i)\right)^2}{\sum_i \left(Observed(i) - HistoricalMedian(i)\right)^2}$$

Two extreme events (one low (01/07/1984–31/08/1984) and one high flow (01/10/2000–30/11/2000)) were analysed to assess how the forecasted river flow driven by the downscaled rainfall series compares to the observed flow. Contingency tables (tables 2 and 3) were established to count the number of flows observed and forecasted above and below the median flow of the analysed period. The percent correct forecast (red boxes in tables) is defined as:

$$percent\ \ correct = \left(\frac{correct\ \ diagonal\ \ elements\ \ sum}{total\ \ elements}\right) \times 100$$

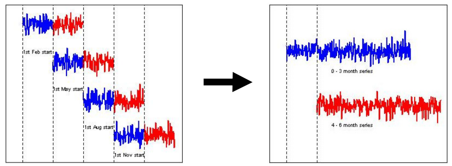


Figure 2: Schematic of the production of the 0–3 and 4–6 month lead series.

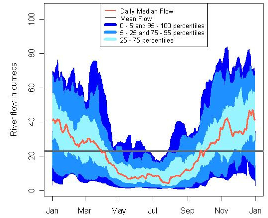


Figure 3: The Historical 31 day Moving Average (1976–2001) River Dyfi Flow.

The simplest river flow forecast possible is based on the historical (1976–2001) time series, where for each day, the median and the percentiles of the observation on that day are calculated on a 31 day window (15 days before and after the observation) (Figure 3). For a given day, the corresponding historical median could be a forecast. This is the equivalent to the climatology for rainfall.

4. Results

	0-3 month rainfall series	0-3 month downscaled series	4-6 month downscaled series
R^2_{orig}	-0.568	0.253	0.221
R^2_{mod}	-1.827	-0.414	-0.492

Table 1: R^2_{orig} and R^2_{mod} for the 1980–2001 period.

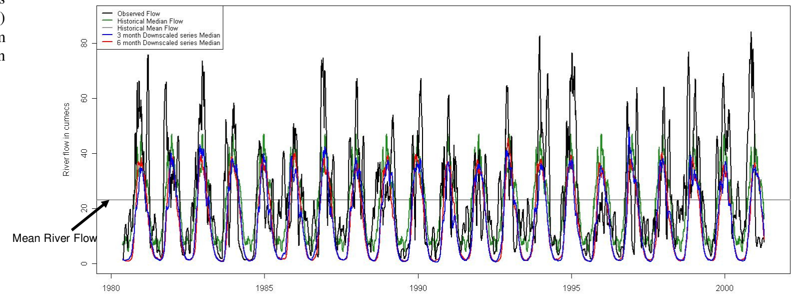


Figure 4: 31 day Moving Average Downscaled Driven Flows over 1980–2001.

The forecasted river flow driven by the 0–3 and 4–6 month DEMETER rainfall series significantly underestimates the observed river flow (poor R^2, table 1). The median flow time series of the multi-model ensemble (630 simulated flows) for the downscaled 0–3 and 4–6 month rainfall series from 1980–2001 are better than using the mean river flow as a forecast over the period, but not as accurate as using the daily historical median flow (table 1). There is no large degradation in hindcast skill when using the 4–6 month series.

Table 2 (a) – (i): Contingency tables for July and August 1984 (Low flow period). Correct forecasts in red boxes (blue boxes for DEMETER median).

(a) observed / Forecasts

CERFACS	> median	< median
> median	0	31
< median	0	31

(b) observed / Forecasts

ECMWF	> median	< median
> median	26	5
< median	15	16

(c) observed / Forecasts

INGV	> median	< median
> median	31	0
< median	31	0

(d) observed / Forecasts

LODYC	> median	< median
> median	2	29
< median	0	31

(e) observed / Forecasts

METEO FRANCE	> median	< median
> median	0	31
< median	0	31

(f) observed / Forecasts

MPI	> median	< median
> median	19	12
< median	28	3

(g) observed / Forecasts

UKMO	> median	< median
> median	31	0
< median	31	0

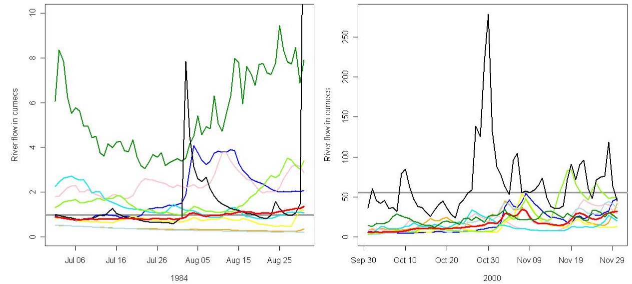
(h) observed / Forecasts

DEMETER MEDIAN	> median	< median
> median	20	11
< median	4	27

(i) observed / Forecasts

HISTORICAL MEDIAN	> median	<median
> median	31	0
< median	31	0

Figure 5: Hydrographs of the daily median flows. Observed (black) and DEMETER (coloured).



Hydrographs (Figure 5) for the 2 extreme events show the time series of the daily ensemble median flow (DEMF). Only the 0–3 month contingency tables are shown here. For Summer 1984 (Table 2) the DEMETER DEMF time series produced the best forecasts and the MPI DEMF time series had the worst forecasts (75.8 and 35.5 % correct respectively). For Autumn 2000 (high flow period) the historical median and UKMO DEMF have 50 and 56.7 % correct respectively (Table 3). The other DEMETER model forecasts had 50 % correct.

(a) observed / Forecasts

HISTORICAL MEDIAN	> median	<median
> median	0	31
< median	0	31

Table 3 (a) and (b): The historical median (a) and UKMO (b) forecast contingency tables.

(b) observed / Forecasts

UKMO	> median	< median
> median	6	24
< median	2	28

5. Conclusions & Further Work

It is not possible to directly use multi-GCM precipitation to generate runoff in temperate basins like the River Dyfi. The SDSM downscaling process significantly improved the forecasted river flow. A promising result was only the small degradation in skill when using the 4–6 month lead downscaled rainfall series compared to the 0–3 month lead time. Potentially this type of forecast could be utilised at this longer lead time.

Over the whole 1980–2001 period, the downscaled DEMETER multi-model ensemble median flows are currently not as accurate as using the daily historical median flow (as shown in the R^2_{mod} values). However, specific extreme events can be forecasted more skilfully with some DEMETER models than by using the historical daily median flow, and this was shown for the low flows of Summer 1984. Further work will assess whether it is systematic to produce more skilful low flow forecasts compared to historical flows, and whether skilful forecasts can be linked to specific atmospheric conditions.

Other future work will (1) test different downscaling techniques to determine whether an ensemble of downscaling techniques yields improved forecasts, and (2) assess the skill of the techniques under different flow regimes. This research has not yet exploited the probabilistic aspect of the multi-model ensemble river flow forecasts. Further work will investigate the likelihood or confidence levels associated with the ensemble forecasts, and extend the research to other river basins in the UK and Western Europe.

6. References

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