Comparison of the potential skill of raw and downscaled GCM output for river flow forecasting: a UK case study

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1.Introduction

Forecasting of river flows at seasonal time scales, defined as lead times of 1 to 6 months, is an area of growing research interest. This is because seasonal forecasts of river flows are of practical use in informing water management decisions and preparing to mitigate hydrological extremes (floods or droughts), which may have major societal and economic impacts. The fundamental aim of our work is to improve the accuracy achieved of the seasonal forecasts of river flows.

The aim of this research is to compare the potential skill of river flow forecasting using (1) Global Climate Model (GCM) output in the form of reanalysis data and (2) downscaled precipitation data from GCMs.

This poster research focuses upon the River Dyfi catchment in West Wales, UK (see section 3). The work undertaken includes the calibration of the Probability Distributed rainfall-runoff Model (PDM), and the input of GCM reanalysis data and downscaled reanalysis data into the PDM rainfall-runoff model.

2. The PDM Rainfall-Runoff model

The Probability Distributed Model (PDM) is a lumped rainfall-runoff model (based on probability distributed moisture stores) that transforms rainfall and potential evaporation to river flow at the basin outlet. A schematic of the PDM structure is shown in figure 1 (PDM User Guide, 2005).

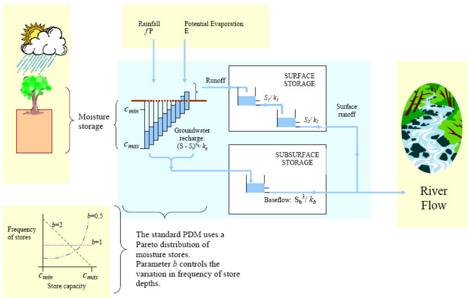


Figure 1: The Probability Distributed Model (PDM)

3. Data

The River Dyfi basin was chosen as a test case as it has limited anthropogenic influence, hence the climate-flow signal should be stronger than a basin with greater human impact. It is a temperate basin, and relatively small with an area of 471.3 km². In figure 2 the rain gauges used to calculate the catchment-averaged rainfall are in red, and the dark brown colour show elevations higher than 600 metres. Daily catchment-averaged rainfall, monthly catchment-averaged potential evaporation (PE) and daily river flow data were used to calibrate the PDM. PDM was calibrated for 01/05/1980 – 30/04/1990, and evaluated for 01/05/1991 – 30/04/2001.

ERA-40 data were used as input in the PDM, which is a 45 year reanalysis of meteorological observations produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA-40 data was available at 2.5˚ x 2.5˚, and at a reduced 1.5˚ x 1.5˚ grid resolution.

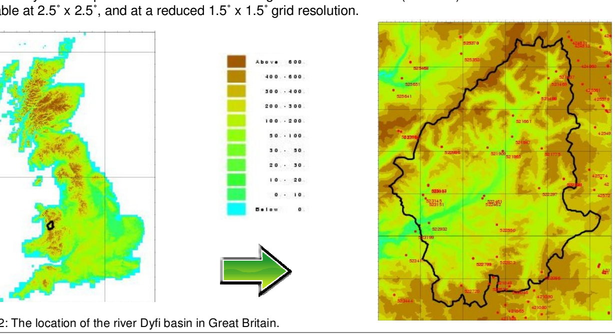


Figure 2: The location of the river Dyfi basin in Great Britain.

4. Methods

1. ERA-40 data

The stratiform and convective precipitation and snowfall were summed daily for the two grid points nearest the Dyfi catchment (52.5˚N 5˚W and 52.5˚N 2.5˚W for 2.5˚ resolution; 52.5˚N 4.5˚W and 52.5˚N 3˚W for 1.5˚ resolution). These rainfall time series were then run directly through the PDM model, whilst the PE data was left unchanged from the model calibration. The grid point from which the precipitation explained the highest proportion of river flow in the PDM was the westernmost point (52.5˚N 5˚W and 52.5˚N 4.5˚W for 2.5˚ and 1.5˚ resolution respectively), and these two grid points were used for the downscaling procedure.

2. Downscaling technique

Owing to the coarser resolution of the ERA-40 data in comparison with the spatial scale of the river basin, the Statistical Downscaling Model (SDSM) Version 4.1 was utilised to produce rainfall data at the catchment scale. The key process when using SDSM is the identification of empirical relationships between the local scale predictand (rainfall) and regional scale predictors. A Calibrate Model operation fitted the best multiple regression equation for the whole year between the predictand and set of predictors, and a stochastic Weather Generator produced an ensemble of 20 synthetic daily rainfall series. Three predictor variables explained best the rainfall and they were the Mean Sea-level Pressure (MSLP), 850hPa Specific Humidity (q) and 850hPa zonal velocity (u). These variables could be considered as independent, as shown in figure 3.

The ability of GCM and downscaled GCM rainfall time series to reproduce river flow was assessed through the percent exceedance flow (QN). For example the Q5 value is the river flow which is equalled or exceeded 5% of the time (high flow index), and the Q95 value is the river flow which is equalled or exceeded 95% of the time (low flow index).

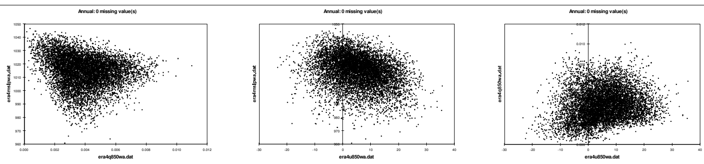


Figure 3: Correlation between the variables used in the regression model.

5. Results

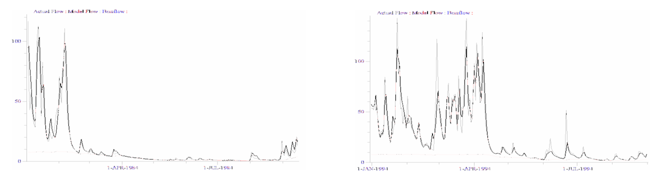
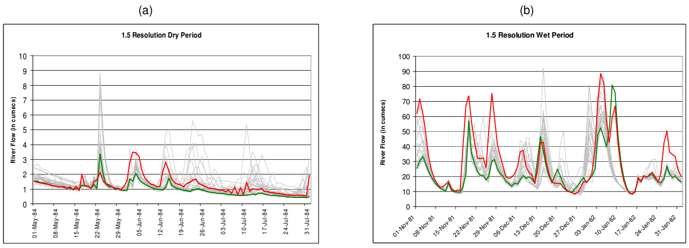
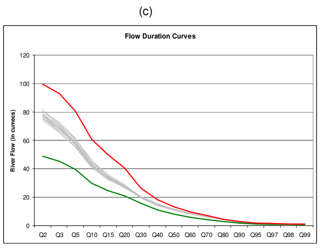


Figure 4: A portion of the PDM calibration period (left), and evaluation period (right).





(d)

	R^2 value	Wet day Total	Wet Day rain intensity (in mm)	Mean Flow Bias	Q5 Bias	Q95 Bias	Q98 Bias
Evaluated Model	0.856	2847	6.93	-0.901	-1.09	7.58	7.29
ERA40 RES 1.5	0.372	2811	3.06	-91.6	-96.98	-38.03	-42.2
RES 1.5 downscaled Ensemble Mean	0.526	2066	6.65	-34.78	-33.43	2.96	0.72
RES 1.5 downscaled Ensemble Range	0.501 to 0.561	2025 to 2104	6.39 to 6.87	-38.20 to -30.51	-40.52 to -25.9	-12.52 to 11.9	-14.16 to 12.81
ERA40 RES 2.5	0.375	2806	3.08	-90.23	-95.14	-40.6	-43.17
RES 2.5 downscaled Ensemble Mean	0.405	1214	8.23	-69.81	-64.46	-33.17	-29.46
RES 2.5 downscaled Ensemble Range	0.082 to 0.465	1175 to 1248	8.09 to 8.38	-73.37 to -66.34	-73.15 to -57.56	-45.47 to -22.37	-38.08 to -23.88

Figure 5: PDM simulated river flows for the calibrated flow (red line), ERA40 1.5˚ resolution input (green line) and the 20 ensembles generated by the downscaling process (grey lines) for (a) a dry period and (b) a wet period. The flow duration curves for 1.5˚ resolution is shown in (c), and table (d) displays statistics on the different data input.

Precipitation from both the ERA-40 resolutions result in underestimated modelled flows compared to the observed; and this is highlighted by the very large negative biases in the Q5, Q95 and Q98 in table 1.5 (d).

When the ERA-40 rainfall time series is run through the PDM, the simulated flow (green line) is lower than when the observed series is input (red line). The ERA-40 data does represent the number of wet days (wet day is defined here as > 0 mm) accurately. However, the average rainfall intensity from ERA-40 on the wet days is under half of what the observations suggest. This implies that the bias in the ERA-40 rainfall maybe due to the underestimation of the rain amount which falls in the events, rather than the rainfall occurrence.

The downscaling process generated different daily rainfall time series, and this on average increases the R^2 value by 0.15 and 0.03 for 1.5˚ and 2.5˚ resolution respectively. Figure 1.5 (c) shows the improvement in using downscaled series versus 1.5˚ resolution ERA-40 data in the flow duration curves. The biases between the percent exceedance flows are reduced substantially for the downscaled ensemble mean in comparison with the direct use of ERA-40 data in the PDM.

6. Conclusions and Future Work

The background to this work was to compare the potential skill of raw versus downscaled GCM output for simulating river flow. The results at both tested resolutions highlighted that by using ERA-40 precipitation data as direct input to the PDM rainfall-runoff model, the simulated river flow substantially underestimated the observed river flow in the Dyfi basin. This is likely to be due to the reanalysis data's inability to resolve catchment-scale (or GCM sub-grid scale) atmospheric processes such as orographic enhancement of rainfall over the Welsh Mountains. The direct use of GCM output as input to a rainfall-runoff model is thus not recommended due to its poor ability in reproducing observed river flows.

To address the relatively poor performance of the GCM data, a statistical downscaling technique (SDSM) was used. The downscaling process added skill to the river flow simulations for ERA-40, and more particularly for ERA-40 1.5˚ resolution. This improvement is significant for all parts of the river regime (from high flows such as Q5 to low flows such as Q95).

This research suggests that much improvement is added to GCM output when combining them with statistical methods. In the future we intend to test the downscaling method used here on seasonal forecasts from GCMs to assess how combining dynamical with statistical techniques could forecast river flow in the UK.

7. References

1. ERA-40 data set. http://www.ecmwf.int/products/data/archive/descriptions/e4/index.html
2. The PDM Rainfall-Runoff Model Version 2.2. Centre for Ecology and Hydrology, September 2005

Acknowledgements

We would like to thank Dr Alberto Troccoli for his kind help in obtaining the ERA-40 dataset. Additionally, we would like to thank Dr Steven Cole for his assistance with the PDM Rainfall-Runoff model.