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Interactive comment on "A robust and parsimonious regional disaggregation method for deriving hourly rainfall intensities for the UK" *by* D. Maréchal and I. P. Holman

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We would like to thank the reviewers for their helpful comments, in particular to Drs. Onof and Koutsoyannis for their eponymous reviews. The comments of the reviewers of our paper focussed on three key areas which we address below:

1. The purpose of our proposed methodology for rainfall disaggregation
2. The selection of days with rainfall $>$15 mm
3. The use of a log-Normal distribution to represent the largest hourly rainfall

The purpose of our proposed methodology for rainfall disaggregation

Within Europe, the policy schism between agriculture and the environment is gradually being broached, principally through the reform of the Common Agricultural Pol-

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icy (CAP) and the implementation of the Water Framework Directive (Chave 2001). Both these policies are also encouraging a standardization of approaches intra- and inter- nationally in many areas e.g. national ‘cross-compliance’ requirements of maintaining land in Good Agricultural and Environmental Condition for receiving payments under CAP, and the Common Implementation Strategy (CIS) to allow the coherent implementation of the Water Framework Directive, which focuses on methodological questions relating to achieving a common understanding of the technical and scientific implications of the Directive. To support the implementation of the Water Framework Directive, the European Commission has established a research ‘cluster’ on Integrated Catchment Water Modelling (CatchMod) (http://www.harmonica.info/Catchment_Modelling_projects/The_EC_CatchMod_Cluster.php) whose objective is the development of common harmonised modelling tools and methodologies for the integrated management of water at river basin or sub-basin scales.

Hydrological and water quality models have two important roles to play in supporting the integration and national standardization of these two policy areas. Firstly they can inform the development of cost-effective sampling regimes, helping to spatially and temporally target sampling towards high risk areas and times. Example of such models are Holman et al. (2004), which simulates the spatial distribution of compound-specific pesticide leaching risk to groundwater and Brown et al. (2002) which simulates the temporal distribution of compound-specific surface water concentrations of pesticides at the catchment outlet. Both these model are applied to the whole of England and Wales.

Secondly, they can be used for ex ante evaluation of the effectiveness and consequences of environmental and agricultural policy measures. Examples of models which are applied nationally at a gridded or catchment resolution to assess the consequences of changes to agricultural land management practices on surface water are Lord and Anthony (2000- nitrate concentrations), Brazier et al. (2001- erosion) and Hutchins et al. (2002- phosphorus delivery to rivers). Soil erosion by overland flow, resulting from infiltration-excess (Hortonian) runoff, generates rill networks on hillslope areas (Favis-Mortlock et al., 2000), and is an important process in generating sediment and the transport of pollutants which have a significant loss pathway sorbed to sediment, in particular phosphorous and pesticides. However, all of the aforementioned national models combine the mechanisms of infiltration-excess and saturation-excess runoff generation into a single runoff process. In doing so, they implicitly assume that soil properties, which dictate the division of the two processes, are temporally invariant. Although infiltration excess surface runoff is generally accepted as being of lesser importance in humid and temperate regions, it is becoming increasingly apparent that it can be an important process in a wide range of soils (Evans 1996, Holman et al., 2003) due to land use changes or to farming practices which impact on the infiltration characteristics of the soil (e.g. Arvidsson, 2001; Chambers and Garwood, 2000; Harrod, 1994, Haynes, 1981; Kwaad, 1994).

The lack of incorporation of infiltration-excess runoff in national models partly reflects the availability and accessibility of hourly rainfall data. Hourly rainfall data are collected by the UK Meteorological Office at only a few hundred stations, yet there are 930 sub-catchment and catchments in England and Wales which are individually simulated by Brown et al. (2002), whilst individual simulations are carried out for over 39,000 2km x 2km grids in the national pesticide leaching model of Holman et al. (2004).

If simulation of infiltration-excess runoff is to be explicitly included in future developments of these national fine grid or catchment scale water quality models, the large number of model cells necessitates a operational, robust, computationally efficient, regionalised rainfall disaggregation methodology that can be used nationally. Such a method needs to generate, without the need for hourly rainfall data, time series of hourly rainfall that aggregate up to the observed daily totals, although the temporal structure of the individual rainfall events is not necessary (unlike in flood estimation or urban hydrology). The aim of this study was therefore to develop and validate a rainfall disaggregation method from daily to hourly intensities that can be operationally, as

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opposed to theoretically, applied throughout the United Kingdom.

The selection of days with rainfall >15 mm

As described above, the purpose of the methodology is to support national simulation of diffuse source pollution, in particular those in which infiltration-excess runoff constitutes an important loss pathway. A threshold was therefore chosen to represent a minimum daily rainfall total below which infiltration excess runoff was unlikely to be generated.

In selecting a threshold for use in flood estimation, Boughton (2000) used 15mm/day as the basis for the larger daily rainfalls that are important in flood studies. The choice of 15 mm as the threshold value in Boughton (2000) was influenced by the daily rainfall generation model used in which rainfalls >15 mm form the upper class for generation purposes (Boughton 1999). Osborne and Hulme (2002) also used 15mm/day as the heavy-event definition for UK rainfall.

In this study, a dataset from the National Soil Resources Institute (the former Soil Survey of England the Wales) (Hallet et al, 1995) of topsoil saturated hydraulic conductivity for all soil series (soil types) shown on the National Soil Map of England and Wales was examined. This soil parameter was used by Evans et al. (1999) and Maréchal and Holman (2005 In Press) within the simulation of hortonian runoff within the catchment scale SWBCM and CRASH models, respectively. The dataset, based on a pedotransfer function (Hollis and Woods, 1989) which derives saturated hydraulic conductivity from sand, clay and organic carbon contents and bulk density provides indicative saturated hydraulic conductivities for 351 different soil types under arable cultivation and 381 under permanent grassland. Taking the 15 mm threshold volume used by Boughton (2000) as a starting point and assuming a ‘worst case’ rainfall intensity of 15mm/hr, this data showed that 99% of soils under arable cultivation and 100% of soils under permanent grassland are likely to have representative topsoil saturated hydraulic conductivities which exceed this threshold and are thus unlikely to generate hortonian runoff from rainfall below 15 mm/hr.

Based on this analysis of representative soil properties, it could be argued that the 15 mm threshold is too low. However, a field assessment of soil conditions under autumn-sown crops, late-harvested crops, field vegetables, orchards and sheep fattening and livestock rearing systems within four UK catchments that experienced serious flooding in the autumn of 2000 showed that soil structural degradation of the soil surface, within the topsoil or at the base of the topsoil was widespread in all five cropping systems, under a wide range of soil types and in all four catchments (Holman et al. (2003). It was likely therefore that the topsoil structural degradation observed would significantly reduce their actual infiltration rate and lead to more common hortonian runoff than anticipated from the representative soil data of Hallet et al (1995). In addition, Chamber and Garwood (2000) in a monitoring study of soil water erosion in 12 erosion-susceptible arable catchments in England and Wales between 1990 and 1994, found that rainfall events causing erosion were greater than 15 mm/day in about 80% of cases.

Therefore the 15 mm/day threshold, supported by Boughton (2000), Osborne and Hulme (2002), Holman et al. (2004) and Chamber and Garwood (2000), was used as a compromise between the magnitude of rainfall events likely to lead to infiltration-excess runoff and the bias that would be introduced from using the much more abundant small daily rainfalls (Boughton (2000).

The use of a log-Normal distribution to represent the largest hourly rainfall

The log-Normal distribution of most intense observed hourly rainfall gave a better overall fit than the other distributions (including power distributions) tested. The comparison of predicted vs observed maximum hourly intensities for all climatic regions shown in our paper (Figure 6) demonstrates that the log-Normal distribution has no apparent tendency to under-predict rainfall intensities below 50mm/hr. Although the three rainfall events between 50-60 mm/hr are underpredicted, this is insufficient number to identify a systematic problem in the fitted distribution.

There is evidence in Koutsoyiannis (2004a, 2004b, 2005) that fat-tailed distributions such as a power distribution can better fit extreme rainfall intensities better than the log-Normal distribution used in this study. However, we defend our use of the log-Normal distribution for the UK data on the following basis:

1. we are looking for an empirical, data-dependent, fit to the observational data which we assume contains a better implicit representation of rainfall generation processes in the UK than distributions derived empirically or theoretically from more global datasets (e.g. Koutsoyiannis 2004b). As we describe in our paper, the seasonal changes in the regional parameter values derived from our empirical approach are consistent with the observed regional climatologies of the British Isles (Wheeler and Mayes, 1997). This also supports the use of the climatic regions of Gregory et al (1991), which are similar to the standard areas (districts) used by the UK Meteorological Office when generating climatologies;

2. Koutsoyiannis (2004b) states that the choice of distribution is less important for short period events than for those with longer (more than 10 year) return periods. Since our disaggregation method is not intended for flood studies, the ability to accurately disaggregate the most extreme rainfall events is not so vital;

3. Koutsoyiannis (2004b) analysed long ($>$100 year) time series of daily rainfall data from regions in Europe and North America. However, closer examination of the UK data shows it to be the least variable and extreme of the data used within the analysis. This is perhaps unsurprising given that the other regions had predominantly Mediterranean or continental climates or are affected by tropical storms, compared to the maritime-influenced climate of the UK. The sample maxima of the UK annual maximum daily rainfall series in Koutsoyiannis (2004b) have the smallest range and the lowest maximum; the sample mean also had the smallest range and lowest maximum, and the coefficient of variation has the lowest minimum, mean and maximum values;

4. A global relationship is derived by Koutsoyiannis (2004b) between the sample mean

and maximum of the annual maximum daily rainfall series for the six different geographical zones which is approximated by a power law with exponent slightly higher than one (1.08). However, because of the small range in sample mean of the UK data, the UK data do not appear (Koutsoyiannis 2004b- Fig 2) to fit well along this distribution;

5. A non-exponential type (pareto) distribution is advocated by Koutsoyiannis (2005) for samples with high coefficient of variation, and this is demonstrated using hourly rainfall data from a single rainfall station in Athens, Greece. However, the coefficient of variations for the daily data series used for the Mediterranean zone (which includes data from Athens) in Koutsoyiannis (2004b) is almost 25% higher than for the UK data;

6. Gregory et al. (1993) fitted the gamma distribution to daily precipitation amounts from UK regions. Variations in beta, the scale parameter, explain most of the seasonal and spatial variability in precipitation (Osborne and Hulme, 2002). The scale parameter (beta) simply stretches the distribution while maintaining the skew given by the shape parameter (alpha), so that increasing beta stretches the distribution out so that the probability of exceeding any threshold is increased (Osborne and Hulme, 2002). van der Voet et al (1996) parametised the Richardson weather generator across the Europe Union. Their values of the gamma distribution scale parameter for rainfall for the UK have a very low seasonal range and for winter (January) rainfall are low compared to most of the Europe Union, and significantly lower than the Mediterranean region. This also supports the relatively unextreme nature of UK rainfall.

Remaining comments

We agree with the remaining comments made by the reviewers and will incorporate their suggestions into the amended manuscript.

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