River Routing Models to Support NWP Evaluation

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1. Introduction

An integral part of many numerical weather prediction (NWP) systems is the calculation of land surface hydrology as noted in Pappenberger et al (in press). Such schemes produce predictions of runoff at the global or continental scale, with the main aim of closing the terrestrial water budget to feed back to the atmosphere and ocean. A number of published studies have attempted global hydrological modelling and runoff routing (Alcamo et al., 2003; Arora and Boer, 2003; Balsamo et al., 2008b; Bosilovich et al., 1999; Decharme et al., 2008; Dezetter et al., 2008; Ducharne et al., 2003; Fekete et al., 2004; Guo and Dirmeyer, 2006; Lucas-Picher et al., 2003; Nijssen et al., 2001; Oki et al., 2003; Olivera and Raina, 2003). However, this remains a very difficult task, demanding high computational resources whilst suffering from necessarily low resolution predictions and poor observed comparison data. Indeed, Widen-Nilsson (2007) points to three main sources of errors in such global hydrological modelling studies: (i) geographical location and bounding of river catchments; (ii) river runoff- and precipitation data quality, especially mismatches in time and location and (iii) unknown, or unavailable data on, anthropogenic influences on river runoff. Moreover, Dezetter et al. (2008) show that it is difficult to define a single model implementation that is acceptable for all locations across the globe. We would add that uncertainties in model parameterisation can have a major effect on global runoff predictions. The complexity of the river routing algorithm will definitely depend on the type of application, for example climate modelling prediction systems may be able to use very simplistic schemes as only monthly average predictions are necessary (van de Hurk, personal communication). In contrast, NWP models should apply more complex approaches (Pappenberger et al., in press). This conference contribution highlights how river routing can contribute to improve NWP and support their evaluation.

2. Properties of River 'Discharge'

It would be wrong to assume that river discharge is a variable which is 'separated' from other components of the system. It is directly influenced by surface and sub-surface runoff and influences fresh water influxes into the ocean. Balsamo et al. (2009) demonstrated that river discharge must be considered as part of a global daily hydrometerlogical chain. River discharge has properties, which are distinct from many other variables:

- **Spatial integrator**
River discharge integrates precipitation over a river catchment. It can be more or less sensitive to the precipitation distribution in such a catchment. Integration over a catchment is not physically arbitrary, as it would be for integration over politically bounded regions, such as nation states. Instead the integration region is defined by topography i.e. the catchment outline, thus it provides a very meaningful integration.

- **Temporal integration**
River discharge integrates precipitation over several lead times. For example, a river forecast of 7 days also includes antecedent moisture in the catchment, i.e. precipitation fallen before those 7 days, the memory of which depends on the catchment characteristics. This allows the assessment of the properties of NWP models which are beyond simple 24 hours integrations

- **Process integration**
Any land surface scheme has a large number of different hydrological processes, starting from infiltration to vertical and lateral transport processes including finally of river recharge processes. Discharge integrates over all of these hydrological processes.

- **Holistic**
River discharge is influenced by an interplay of various meteorological variables including evaporation, precipitation, temperature amongst others. It is a measure of the quality not only of the singular meteorological variables but also their cross-correlations

- **End user focused**
Discharge is a very important variable used by a large number of end-users such as national agencies, civil protection authorities, transport (shipping), insurance, energy, stock market companies and so on. Most prominently it is essential to many flood and drought forecasting systems (for a review see Cloke and Pappenberger, 2009)

Under normal flow conditions river discharge is comparably easy to measure in contrast to many other surface variables, such as ground water flow. Although it should be remembered that discharge is rarely measured directly; instead river level (stage) is measured and discharge is then derived over stage-discharge curves. This can be the cause of very large uncertainties in the discharge values, particularly in low flow and flood conditions (Pappenberger et al., 2006).

3. Diagnostics

One prominent use of river routing models can be in the diagnostics of NWP model errors and how the hydrological model can be improved. In figure 1 an example is shown of the European Flood Alert System, which is a flood forecasting system driven by different NWPs for the station Hofkirchen (Danube) published in Bogner and Pappenberger (submitted). The analysis of the predictive uncertainty allowed an understanding of the weaknesses of different NWP systems and a comparison of their performance. Such an analysis can then be fed back into the design process of these models and help to improve predictions.

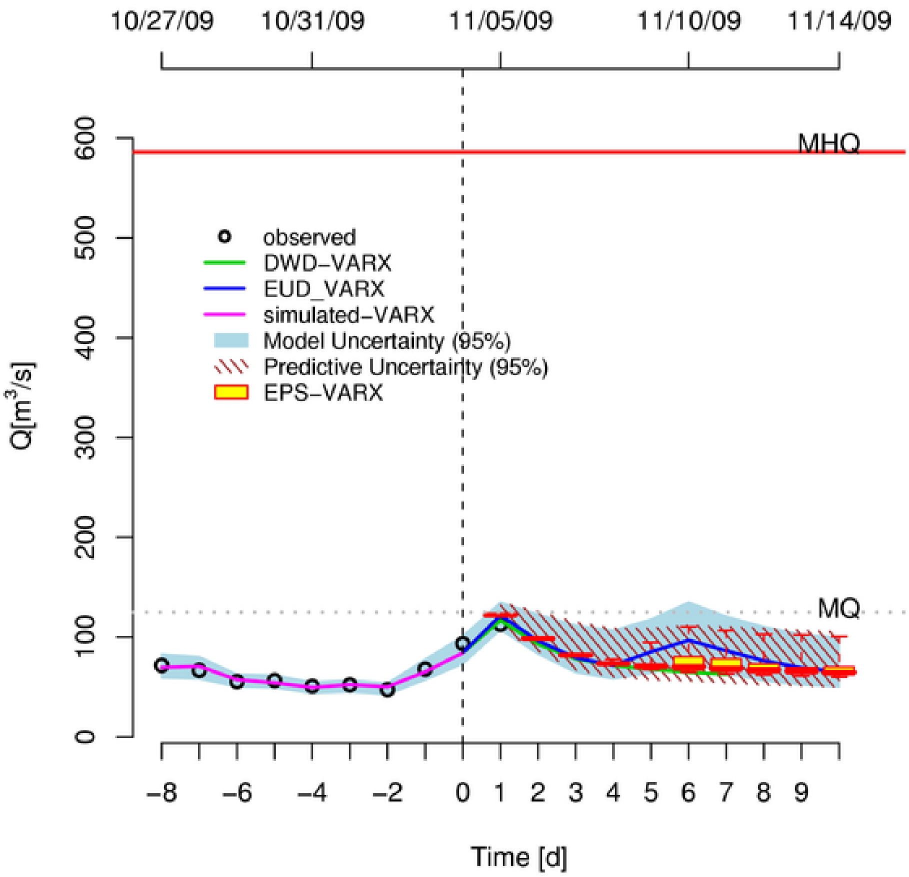

Figure 1: Model and predictive uncertainty of a hydrological model driven by several NWP systems. The green line is the forecast of the German Weather Service (DWD-VARX). The blue line symbolises the deterministic forecast of ECMWF and the yellow box plots the EPS of ECMWF. The figure is taken from Bogner and Pappenberger (submitted).

Another example, of the use of diagnostics is given in Pappenberger et al. (in press), where a in depth analysis of a routing scheme coupled to HTESSEL using the SOBOL Sensitivity analysis (Cloke et al., 2008) indicated that the most sensitivity to the river routing comes from the Groundwater delay parameter (GTM). This demonstrated that further research is needed on the split between the modelled surface-groundwater flow (e.g. adding a third outflow) and/or the free outflow (e.g. adding a groundwater boundary). River discharge can also be used to compare several NWP forecast systems (He et al., 2009) (Pappenberger et al., 2008a), which allows an exposure of the strength and weaknesses of individual systems and thus allows for an improvement of individual forecast systems.

4. Evaluation

The coupling of river routing models, hydrological models and meteorological models is a valuable method to evaluate application specific performance of meteorological predictions (for an example of such an evaluation see Balsamo et al., 2008a). It also allows the indirect evaluation of the predictions of several variables which are otherwise difficult to measure. Ahrens et al. (2007) argue that such an integrated approach overcomes scale issues and allows evaluation of high resolution precipitation forecasts by utilizing for example discharge predictions and discharge observations (rather than precipitation forecasts and observations). The methodology respects the importance of dominant hydrological processes (see discussion inPappenberger et al., 2008b) and the non-linear error transformation by the hydrological model (for an example of this see Gurtz et al., 2003; Verbunt et al., 2006). As runoff integrates the precipitation and the land surface model errors (on snow/evaporation) it becomes really interesting at high spatial resolutions where precipitation is more difficult to be scored. It is in this context very important to respect the cascade of uncertainties and acknowledge the uncertainties in the hydrological as well as routing model (Pappenberger and Beven, 2006; Pappenberger et al., 2004; Pappenberger et al., 2005). For example, the European Flood Forecasting System (Bartholmes et al., 2007; de Roo et al., 2003; Ramos et al., 2007; Thielen et al., 2007) successfully provided 7 day forecasts for the July and August 2002 flood in the Danube (as reported in Pappenberger, 2008). This suggests that the meteorological forecast has been adequate in timing and precipitation quantities for this forecast period.

Other examples in which river discharge was used successfully to understand the performance of NWP systems are for example, the analysis of Pappenberger et al (submitted) in which an assessment of flood forecasting system based on ECMWF weather forecasts over a period of 10 years is presented. The simulations clearly show that the skill of the river discharge forecasts have undergone an evolution linked to the quality of the operational meteorological forecast. Overall, over the period of 10 years, the skill of the flood forecasts has steadily increased which is higher than the increase in skill derived from precipitation forecasts alone.

5. Severe Weather

Predicting severe weather is one of the core activities in many NWP centres. Many of the highest impact extreme weathers are linked to discharge for example flooding and droughts (see figure 2).

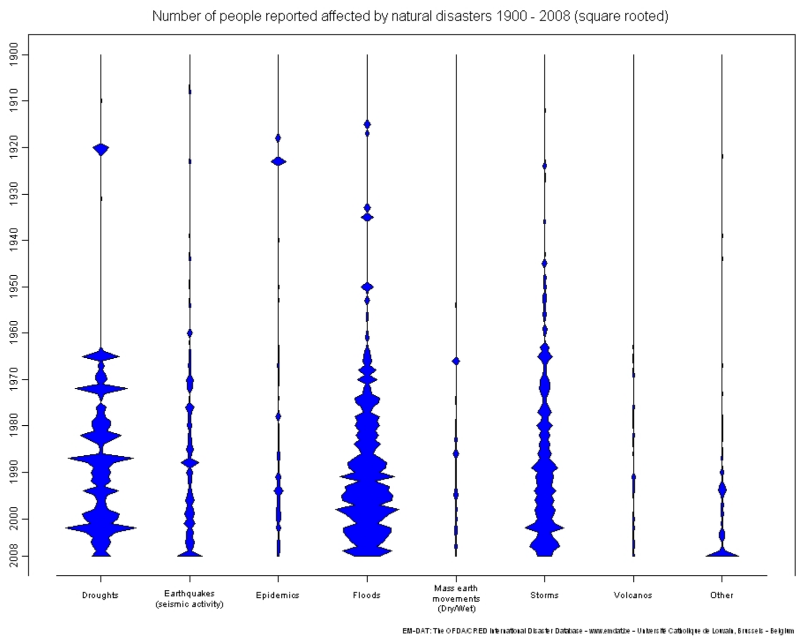

Figure 2: Number of people reported affected by natural disasters 1900-2008 (Square rooted) Source: EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.net – Université catholique de Louvain – Brussels – Belgium.

Moreover, the ability to predict extreme weather is often directly linked to the quality and performance of the land surface which in turn is evaluated over discharge predictions.

6. Summary

We have demonstrated in this short report the importance of river discharge to Numerical weather prediction systems. It can be stated that River Routing can:

1. help to identify where to improve your model, in particular the Land Surface Scheme, and benchmark various land surface schemes and NWP systems
2. evaluate performance integrated over multiple forecast fields (e.g. temperature, precipitation, evaporation) taking account of co-variances and spatio-temporal correlations in an end user value oriented framework
3. support the goal of improving extreme weather predictions

Future research needs to integrate river routing models and land surface schemes of NWP in a more coupled framework and allow for a fully integrative evaluation.

7. References

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