Hydrological modelling of the extreme flooding event of July 2021 in Belgium

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Introduction

The flooding event of July 2021 is a natural disaster that resulted in fatalities and extensive damage to infrastructure. The flood was triggered by the extreme precipitation event of 13-14 July 2021. Return periods for precipitation accumulations from 1 to 3 days significantly exceeded 200 years at several places. We investigate this unprecedented rainfall event for a selection of catchments of the Meuse River in Belgium using hydrological modelling and forecasting. We make use of a high resolution radar-based quantitative precipitation estimation of the event (RADFLOOD21, Journée et al. 2023), generated at the Royal Meteorological Institute of Belgium. This dataset is used to perform simulations with the hydrological model SCHEME in order to analyze the hydrometeorological conditions responsible for the flooding. Hydrological reforecasts are also performed, using the RADFLOOD21 data for initialization and precipitation hindcasts as input to a hydrological ensemble prediction system (HEPS) based on the model SCHEME. The precipitation hindcasts used here are provided by the ECMWF ENS ensemble predictions. The main goal of the study is to evaluate the model and forecasting system performance in terms of river discharge for this exceptional precipitation event, and to investigate the impact of the new input data.

The hydrological model SCHEME

The hydrological model SCHEME is the distributed version of the IRMB conceptual model (Bultot and Dupriez 1976). This model is also used in mid-range streamflow forecasts (Roulin and Vannitsem 2005) and hydrological validation of satellite precipitation products (EUMETSAT H-SAF project). Its structure can be summarised as follows:

- daily time step, resolution of 7 km, 9 land covers;
- snow accumulation and melting, interception by the vegetation for each cover, two soil layers, two underground water reservoirs;
- potential evapotranspiration (PET) based on Penman formula;
- routing based on the network width function (number of channels along the river network as a function of distance from the outlet);
- model parameters optimised in a variety of sub-catchments based on observed streamflow, then regionalised over the domain of the two river basins in Belgium (Meuse and Scheldt).

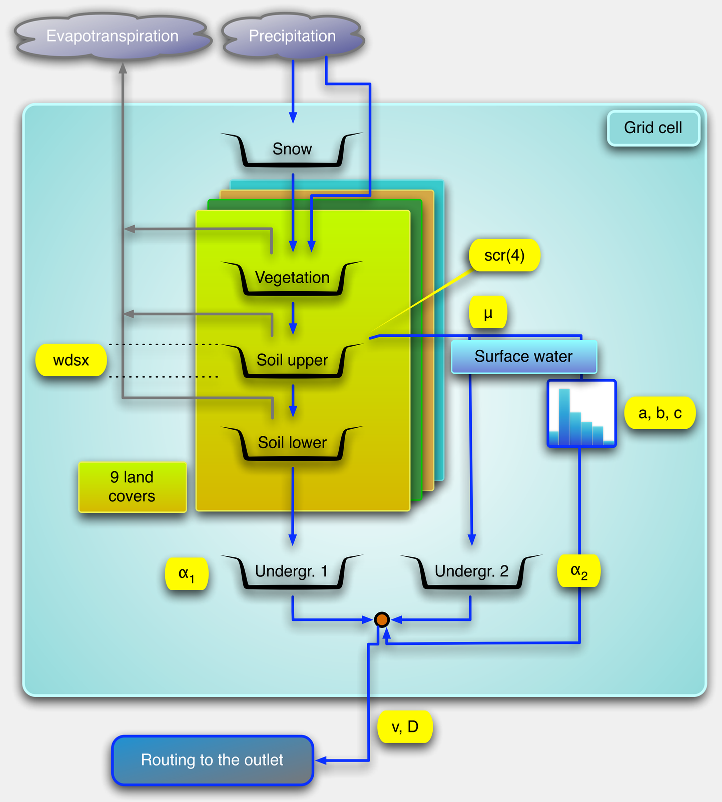

Fig. 1 The SCHEME model structure (Van den Bergh and Roulin 2010)

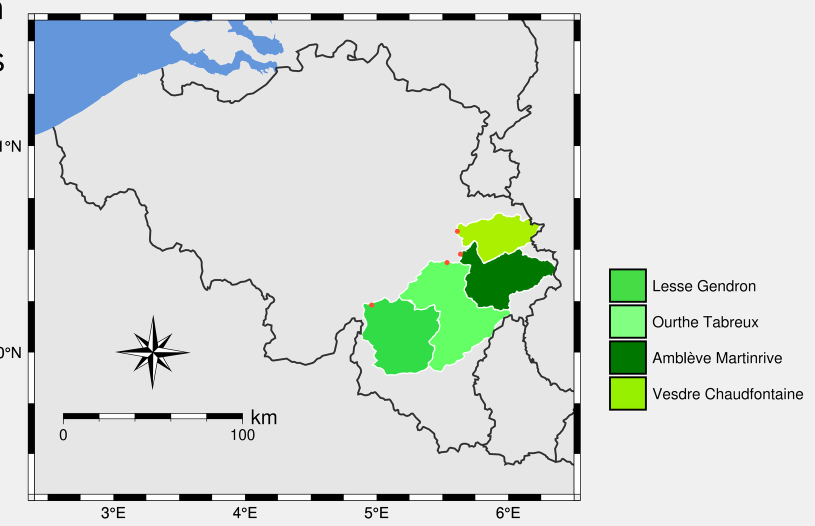

Fig. 2 The catchments of the study and their outlets (from southwest to northeast: Lesse, Ourthe, Amblève, Vesdre)

References

(1) Journée, M. et al.: Hydrol. Earth Syst. Sc. **27**, 3169-3189, 2023.
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(3) Van den Bergh, J. and Roulin, E.: *Atmos. Sci. Lett.* **11**, 64-71, 2010.
(4) Roulin, E. and Vannitsem, S.: *J. Hydrometeorol.* **6**, 729-744, 2005.
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Data and study area

1. Precipitation from rain gauges (RG) and other meteorological variables used as input to the SCHEME model (spatially interpolated station data and ECMWF ensemble forecasts).
2. Quantitative Precipitation Estimation (QPE) and RADFLOOD21 (RFL21) data as alternative precipitation forcing for the SCHEME model.
   - QPE: ground rainfall estimation based on 3D weather radar reflectivity measurements processing, including beam blockage correction, mitigation of non-meteorological echoes, precipitation classification (Goudenhoofdt et Delobbe 2016); available from September 2016.
   - RADFLOOD21: dedicated dataset covering the period from 11 to 17 July 2021; obtained from revised processing and optimization of weather radar measurements as in QPE and merging with rain gauge data (Journée et al. 2023).
3. Discharge observations (from Service public de Wallonie).

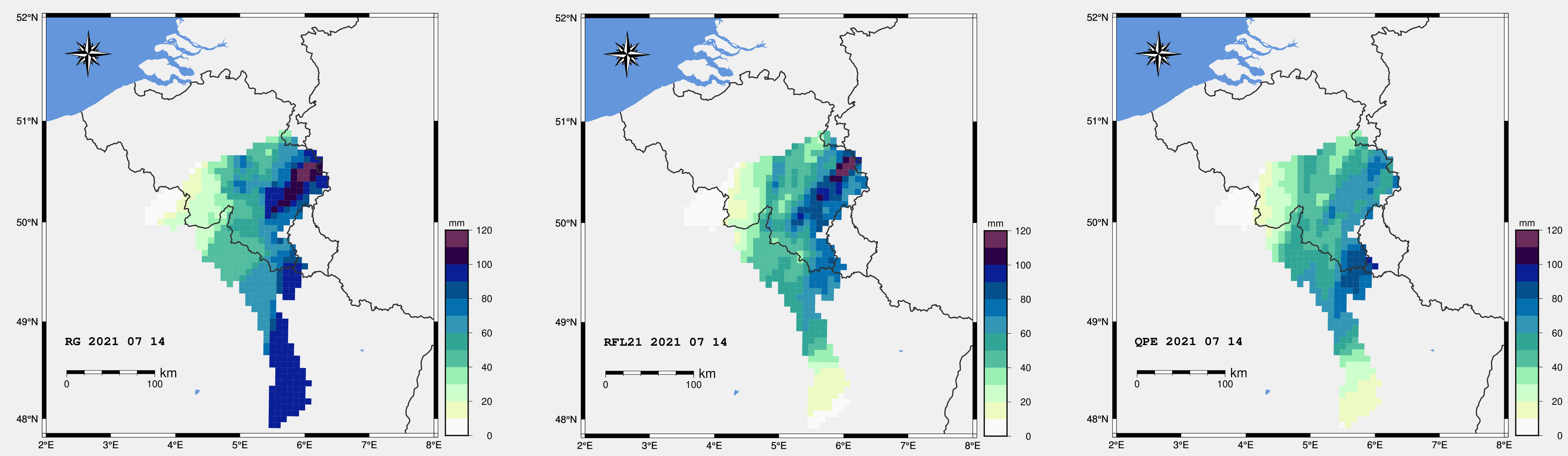

Fig. 3 Daily precipitation from RG, RFL21 and QPE in the Meuse River basin, July 14. (best match between RG and RFL21 in Belgium)

The area of interest is defined by the following catchments in the **Meuse** River basin: (1) the **Vesdre** catchment - outlet: Chaudfontaine, (2) the **Amblève** catchment - outlet: Martinrive, (3) the **Ourthe** catchment - outlet: Tabreux and (4) the **Lesse** catchment - outlet: Gendron (Fig. 2).

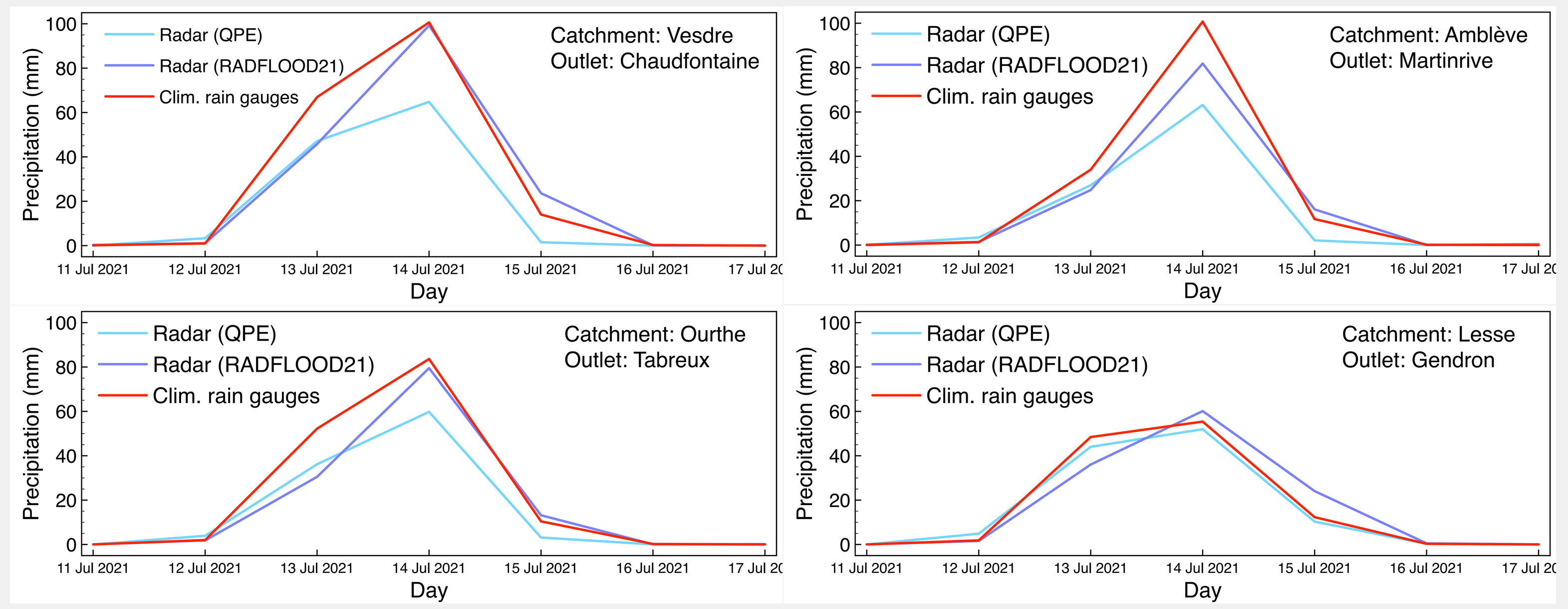

Fig. 4 Areal averages of daily precipitation from RG, RFL21 and QPE, July 2021

Modelling approach

1. Simulations with the model SCHEME using three different sources of precipitation forcing (QPE, RADFLOOD21 and climatological rain gauges with 24h accumulation) for July 2021.
2. Hydrological reforecasts using meteorological forecast from ECMWF as forcing in the model SCHEME (Van den Bergh and Roulin, 2010) for the precipitation event of July 14, 2021.
   - Model water content (soil moisture and river network) at forecast start initialized using two different precipitation forcing sources (QPE and RADFLOOD21).

Results

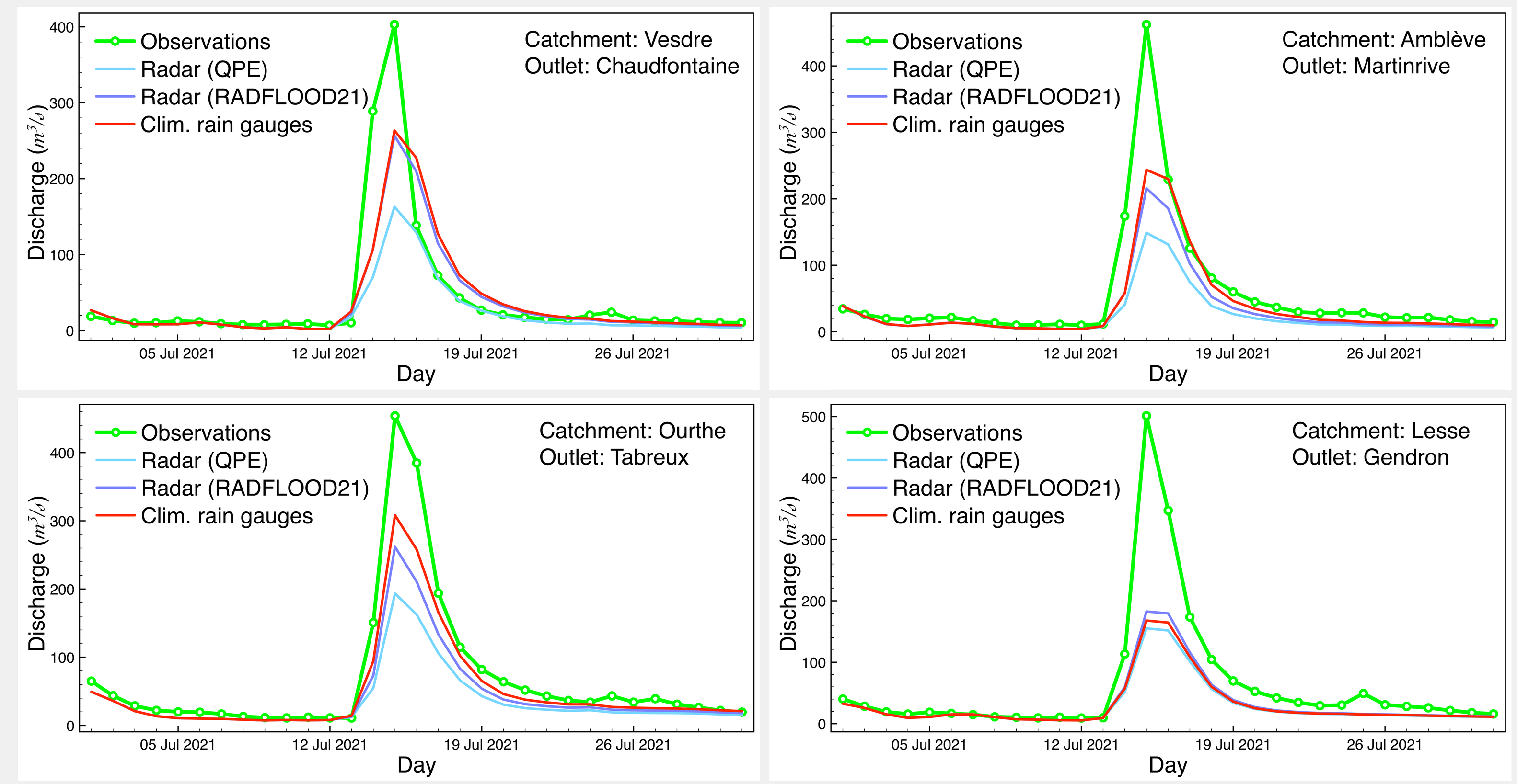

Fig. 5 Daily discharge using as model forcing RG, RFL21 and QPE precipitation data, July 2021

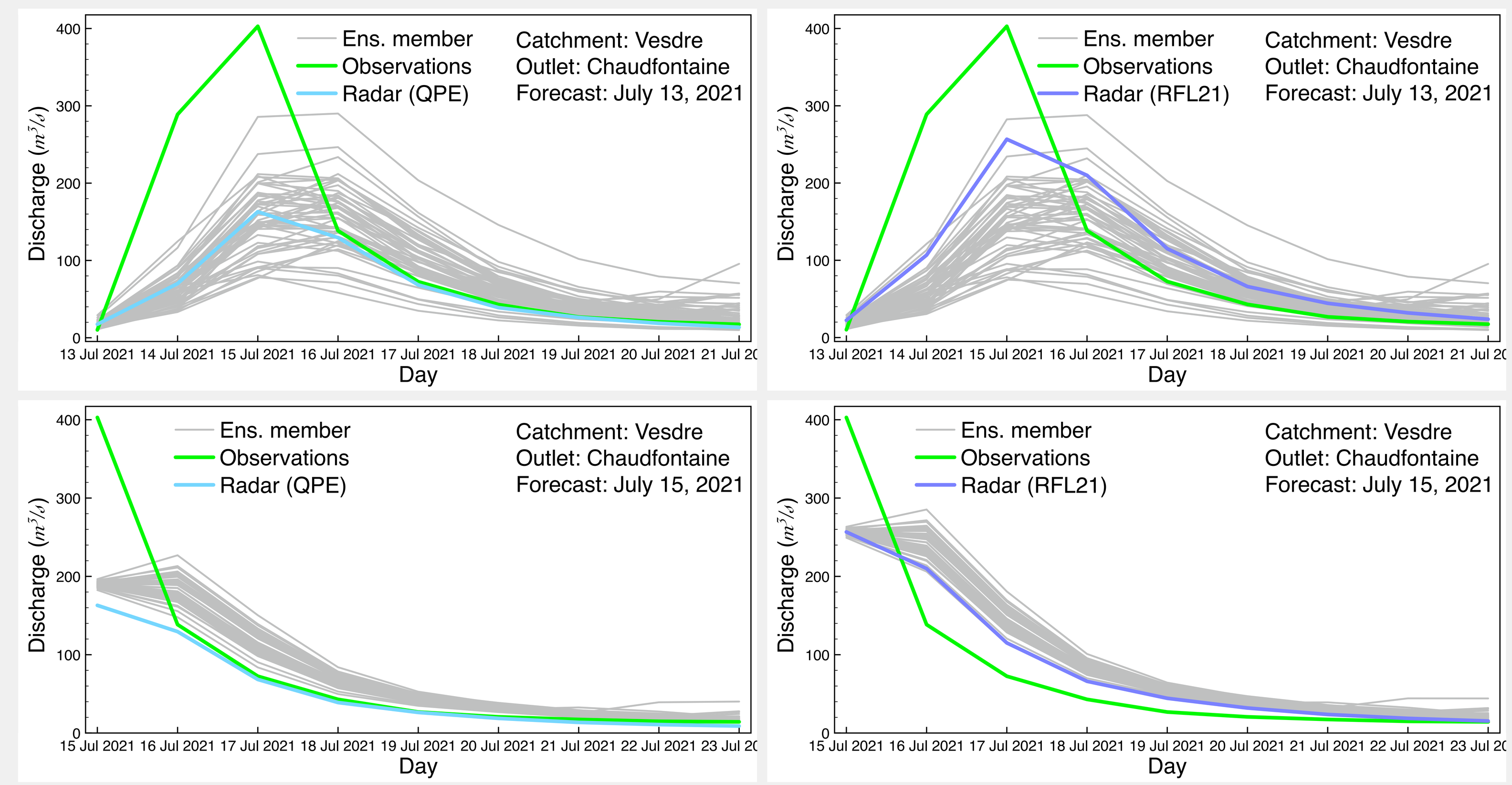

Fig. 6 Daily discharge in reforecast experiments with QPE and RFL21 model initialization, reforecasts of July 13 and 15, 2021, Vesdre catchment

Conclusions - Outlook

- In all cases the SCHEME model discharge simulations cannot reach the highest observed peak but otherwise they have good overall performance (Nash-Sutcliffe efficiency up to 0.863 and Pearson correlation up to 0.994 in July 2021). The RADFLOOD21 simulations are consistently better than the QPE simulations.
- In the reforecast experiments, the RADFLOOD21-initialized forecast starting on July 15 shows increased discharge due to improved precipitation estimation compared to the QPE estimations. Yet, despite this improvement the observed peak discharge is beyond range, underlining the extreme nature of the event and the current strengths and limitations of the forecasting system. Only the Vesdre catchment is shown here but the conclusion holds for all catchments considered in the analysis.
- An in-depth analysis of the discharge and precipitation ensembles, statistical post-processing using hydrological reforecasts and use of alternative sources of meteorological forcing, e.g. from high-resolution deterministic NWP model, could be considered in future work.

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SPW Service public de Wallonie