

EGU24-3245, updated on 30 Apr 2024

<https://doi.org/10.5194/egusphere-egu24-3245>

EGU General Assembly 2024

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Sensitivity of simulated rain intensity and kinetic energy to aerosols and warm-rain microphysics during the extreme event of July 2021 in Belgium

Kwinten Van Weverberg^{1,2,3}, Nicolas Ghilain^{2,4}, Edouard Goudenhoofd², Matthias Barbier¹, Ester Kostinen¹, Sébastien Doutreloup⁴, Bert Van Schaeybroeck², Amaury Frankl¹, and Paul Field⁵

¹Department of Geography, Ghent University, Ghent, Belgium

²Royal Meteorological Institute of Belgium, Brussels, Belgium

³Atmospheric Processes and Parametrizations, Met Office, Exeter, United Kingdom

⁴Department of Geography, University of Liège, Liège, Belgium

⁵Institute for Climate and Atmospheric Science, University of Leeds, Leeds, United Kingdom

This paper presents an evaluation and sensitivity analysis of km-scale simulations of the unprecedented extreme rainfall event of July 2021 over Belgium and Germany, with a specific focus on sub-hourly extremes, size distributions and kinetic energy (KE) of rain. These variables are critical for hydrological applications, such as flood forecasting or soil loss monitoring, but are rarely directly obtained from Numerical Weather Prediction (NWP) or climate models. We present an extensive set of simulations exploring sensitivities to realistic variations in a newly implemented double-moment microphysics parameterization in the UK Met Office Unified Model. Most simulations reproduce the overall characteristics of the event, but overestimate the extreme rain rates. The rain rate - KE relation is captured well, despite too large volume-mean drop diameters. Amongst the sensitivities investigated, the representation of the raindrop self-collection - breakup equilibrium and the raindrop size-distribution shape have the most profound impact on the rainfall characteristics. While extreme rain rates vary within 30 %, the rain KE varies by a factor of four between the realistic perturbations to the microphysical assumptions. Changes to the aerosol concentration and the rain terminal velocity have a relatively smaller impact on the extreme rainfall characteristics. However, larger aerosol loading produces slightly smaller domain total rainfall, for which we propose a mechanism involving dynamical impacts of warm-rain suppression. Given the large uncertainties, a continued effort to improve the model physics will be indispensable to reliably estimate sub-hourly rain intensities and KE for direct hydrological applications.