A High-Resolution Numerical Weather Prediction Model for Nowcasting Precipitation in the Grand-Duchy of Luxembourg (NWPLux)

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Abstract

Compared to alluvial floods, flash or pluvial floods are difficult to predict because they result from intense and brief periods of extreme precipitation. The project NWPLux aims to develop, a high-resolution numerical weather prediction (NWP) model for effective local heavy rainfall prediction in a nowcasting scenario and provide real time for flood simulation. Modelling is based on the Weather Research and Forecasting (WRF) model, with a large-eddy simulation (LES) type 3-dimensional cloud model to simulate small-scale, high-intensity convective precipitation. It is the first such dedicated NWP model for Luxembourg and the Greater Region. As part of this project, we will also test run the LISFlood flood model in an operational inundation forecast mode, meaning that the flood model will be run with the WRF precipitation forecasts as inputs.

As an initial run the WRF model was setup with two distinct domains, specifically the Greater Region and Luxembourg with respective horizontal grid spacing of 16 km and 4 km, leveraging high resolution static data. Met data from the NCAR RDA dataset ds083.2 was utilized, spanning from July 08, 2021 to July 15, 2021, and was subjected to the "Conus" physics suit. The output interval was one hour.

Preliminary results from NWP runs indicated that the higher resolution simulations (4 km) exhibited superior performance when compared to the lower resolution simulations (16 km). The model outputs were integrated with the LISFlood flood model yielding first preliminary flood predictions.

Keywords: NWP, WRF, Flash flood, LISFlood, cloud modelling

Introduction

Flash floods differ from alluvial floods in terms of their rapid onset and little warning, making them challenging to predict [1]. Flash floods are often caused by intense and brief periods of heavy rainfall, commonly associated with severe weather events like thunderstorms or hurricanes [2]. These floods are particularly common in areas with poor drainage systems or urban environments with limited water absorption due to concrete and asphalt surfaces [2]. Predicting flash floods requires accurate forecasts of extreme precipitation events and a precise understanding of local hydrological conditions [3]. Improvements in short-term weather forecasting and knowledge of hydrological conditions are crucial for better prediction and management of flash flood risks [4].

On the other hand, alluvial floods are typically easier to predict as they result from gradual water accumulation in established water channels over time [5]. The water level rises gradually, allowing for better estimation and planning [6].

Enhancing weather forecasting relies on numerical weather prediction (NWP) models that use data from various sources to predict current and future weather patterns [7].

Figure 1: Rasport (Commune in Luxembourg) under flood July 2021

These models are crucial for forecasting and managing weather-related risks, including floods [8]. By combining NWP with flood models, accurate rainfall forecasts can improve flood predictions, enhance understanding of climate-hydrological interactions, and enable better flood risk management and mitigation strategies [9].

Flood modeling is an essential component of comprehensive flood risk management, providing valuable information on flood probability and impact [10]. It helps understand water system behavior and supports proactive planning and informed decision-making [11].

Acknowledgements

This work is funded through the University of Luxembourg (UL) Research Projects GSCG and SGSL, and used the UL High Performance Computing (ULHPC) facility. Colleagues from the University of Memphis are funded through the NRF Grant (PLR-1245660). The authors would like to thank numerous colleagues from the University of Luxembourg, National Oceanography Centre, British Antarctic Survey and the Government of South Georgia and the South Sandwich Islands for their continued support of our work in South Georgia. Furthermore, data and products provided by the IGS and its ACs, and UNAVCO Inc. are highly appreciated [Dow et al., 2009].

Study Area

The study area for this research includes Luxembourg and the Greater Region, a transnational area in Western Europe that includes parts of Belgium, France, and Germany, in addition to Luxembourg. The Greater Region has diverse landscapes, such as the densely forested Ardennes massif, the rolling hills of the Oesling in northern Luxembourg, and the fertile lowlands of the Gutland in southern Luxembourg. The area's climatic conditions are characterized by a warm oceanic maritime climate with moderate to heavy rainfall throughout the year.

The Greater Region includes several important river systems, including the Moselle, Sauer, and Our rivers, which serve as crucial sources of water for the surrounding areas. moreover, these rivers have historically been subject to seasonal flooding with heavy rainfall. The diversity of soils and climate over a large area provides excellent opportunities to study the complex interactions between climatic events, hydrological processes and flood risk in many countries.

The climatic conditions prevailing in the Greater Region can be characterized as a warm oceanic maritime climate. This climate is influenced by maritime air masses, resulting in mild temperatures and relatively high levels of precipitation throughout the year. The temperature ranges from mild to moderate, with average annual temperatures typically ranging from 8 to 12 degrees Celsius. Precipitation is evenly distributed throughout the year, with annual rainfall ranging from 700 to 1,200 millimeters. The region experiences moderate to heavy rainfall, which contributes to the fertility of the soils and the growth of lush forests and vegetation[12]

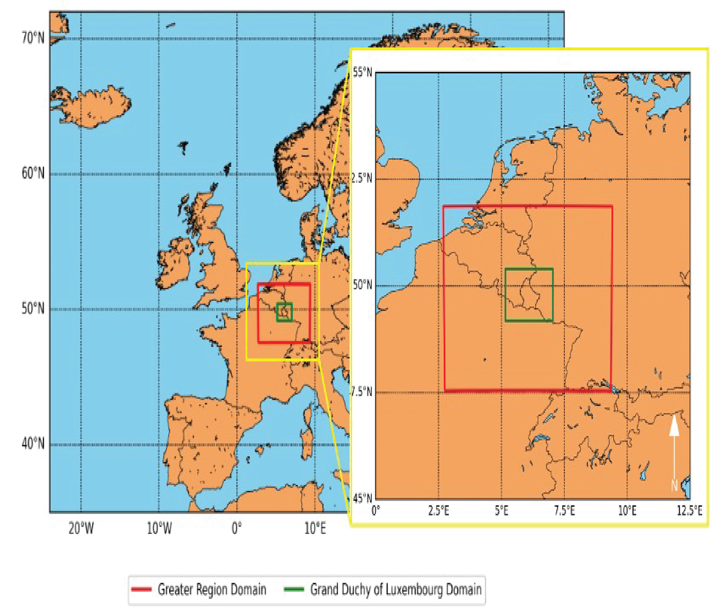

Figure 2: domain for Greater Region (in red) and for Luxembourg (in green)

Methodology

A first test run on the 14 July 2021 event in Luxembourg was conducted using a developed NWP model based on the WRF model. The model utilized a range of data sources, including high-resolution static data and meteorological data, to inform the simulations. Two domains were selected: the Greater Region (encompassing parts of Belgium, France, Germany, and Luxembourg) and a localized domain within Luxembourg. The NWP model was configured with a resolution of 16 km for the Greater Region and 4 km for Luxembourg, enhancing the representation of local geographical features. Meteorological data from the National Center for Atmospheric Research (NCAR) Research Data Archive, covering the specific period from July 8 to July 15, 2021, was incorporated. The model generated hourly output, and graphics were produced using Python.

Table 1: WRF Model Configuration: Physics and

Parameter	Setting	Remarks
Physics		
Microphysics	mp_physics = 8	Thompson graupel scheme: Simulates cloud and precipitation processes using the Thompson graupel microphysics scheme.
Cumulus parameterization	cu_physics = 6	Tiedtke scheme: Represents vertical transport and cloud processes associated with convective systems.
Longwave radiation	ra_lw_physics = 4	RRTMG scheme: Simulates longwave radiation using the RRTMG radiation scheme.
Shortwave radiation	ra_sw_physics = 4	RRTMG scheme: Simulates shortwave radiation using the RRTMG radiation scheme.
Planetary boundary layer	bl_pbl_physics = 2	Mellor-Yamada-Janjic (Eta) TKE scheme: Simulates heat, momentum, and moisture exchange in the planetary boundary layer.
Surface layer	sf_sfclay_physics = 2	Monin-Obukhov (Janjic Eta) scheme: Simulates heat, momentum, and moisture exchange in the surface layer.
Surface physics	sf_surface_physics = 2	Unified Noah land-surface model: Models land-atmosphere interactions, soil moisture, and evaporation.
Dynamics		
Hybrid_opt	hybrid_opt = 2	Enabled: Uses a hybrid vertical coordinate system.
W_damping	w_damping = 0	No damping applied to the vertical velocity at the model top.
Diff_opt	diff_opt = 2	Mixing terms evaluated in physical space using stress form.
Km_opt	km_opt = 4	Horizontal Smagorinsky first-order closure for turbulence parameterization.
Diff_6th_opt	diff_6th_opt = 0	No 6th-order diffusion.
Diff_6th_factor	diff_6th_factor = 0.12	Sixth-order damping factor.
Base_temp	base_temp = 290.0	Base state temperature in the model.

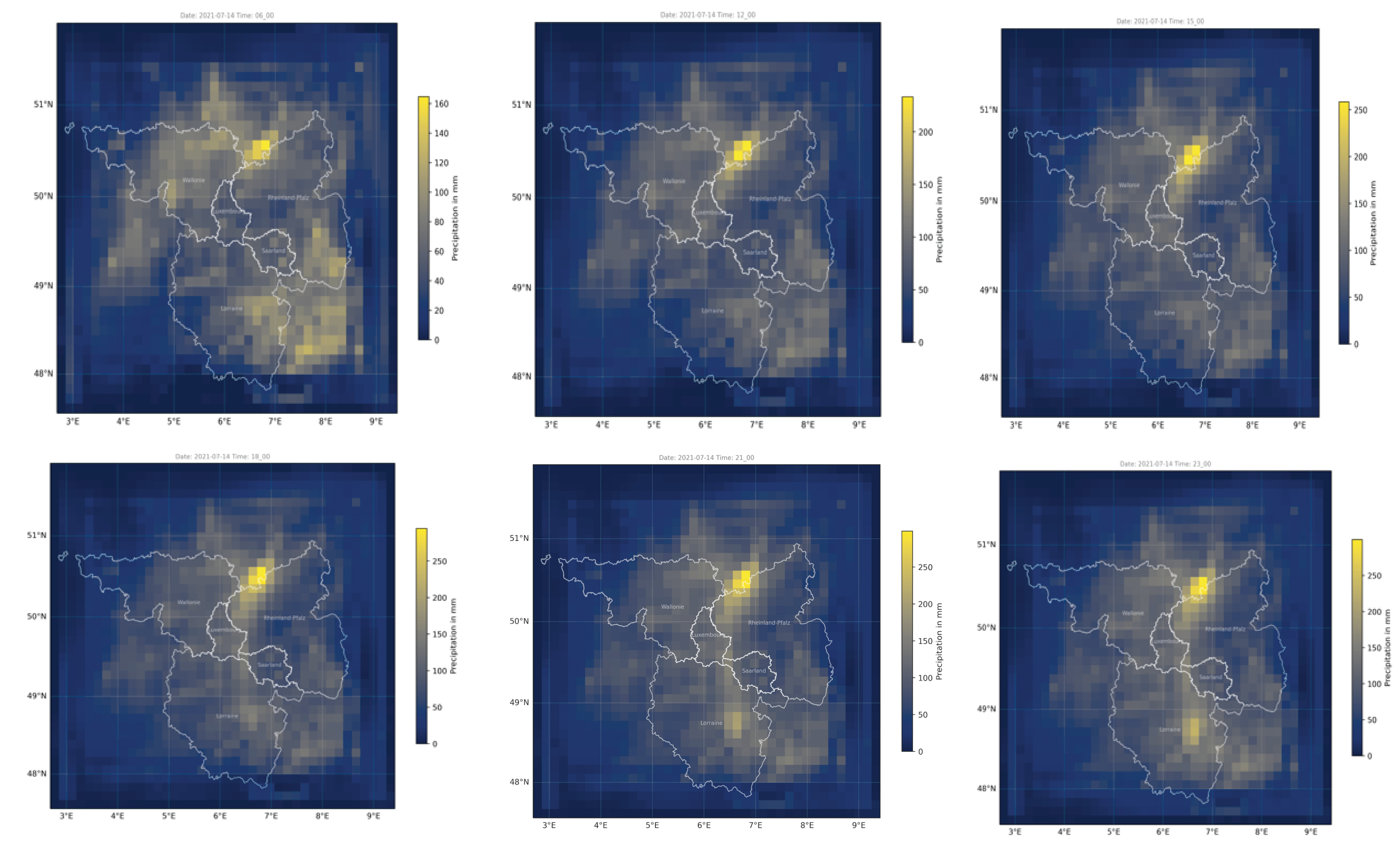

Figure 3:Precipitation for Greater Region on July 14, 2021.

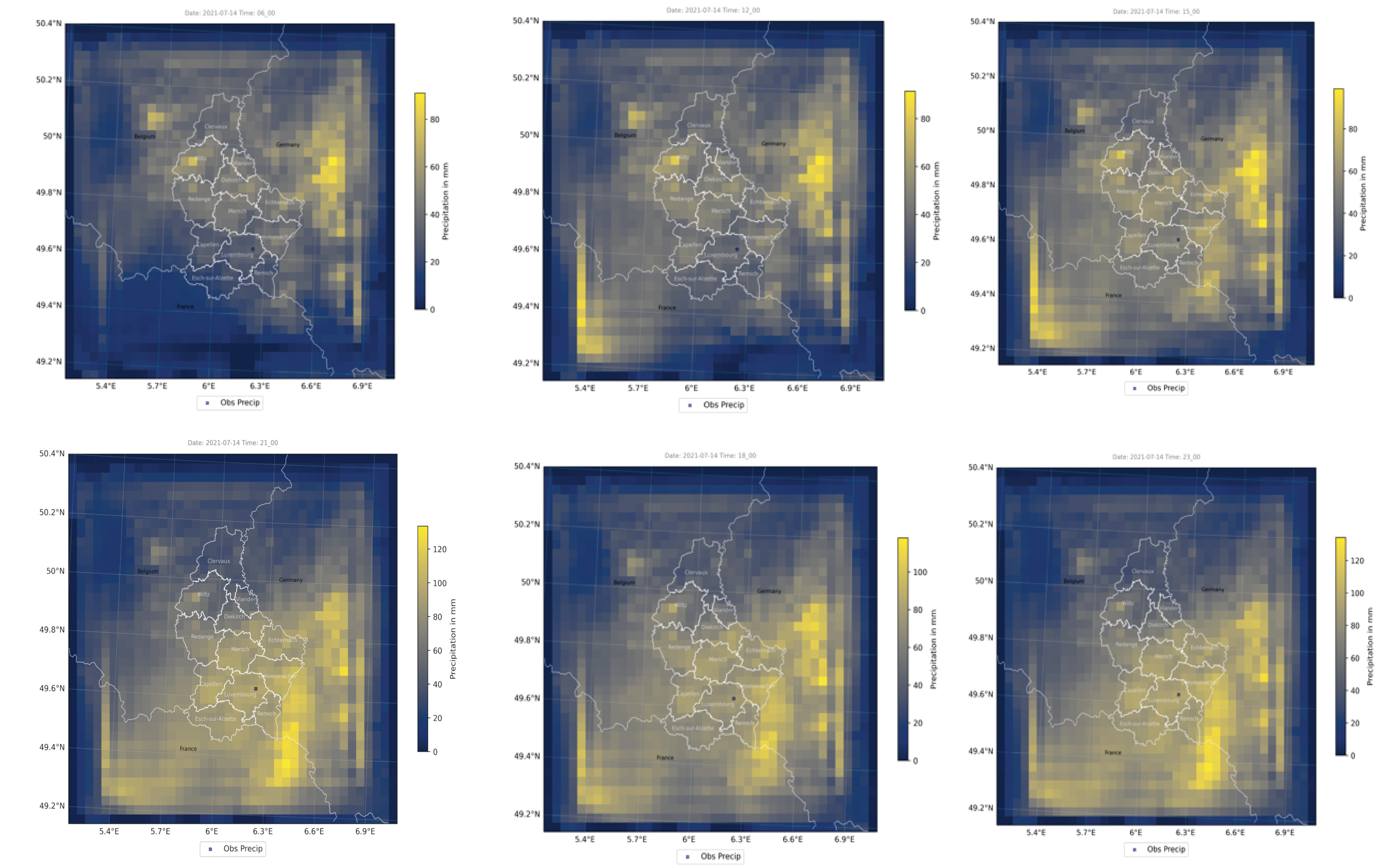

Figure 4:Precipitation for Luxembourg July 14, 2021

Conclusions

- The study's conclusions reveal a strong correlation between NWP simulation resolution and result accuracy, with higher resolution (4 km) simulations outperforming lower resolution (16 km) ones, owing to improved granularity and detail in representing localized weather events.
- Future work includes developing a cloud model and integrating it with the WRF NWP model, followed by integration with LISFlood for enhanced flood forecasting capabilities.

References

[1] L. Kuksina and V. Golosov, "Flash floods: Formation, study and distribution," E3S Web of Conferences, vol. 163, Apr. 2020, doi: 10.1051/E3SCONF/202016302005.

[2] R. Williams and J. M. Keifer, "Coastal Flooding Mitigation Presentation, February 16, 2012," pp. 115–121, 2012.

[3] C. G. Collier, "Flash flood forecasting: What are the limits of predictability?," Quarterly Journal of the Royal Meteorological Society, vol. 133, no. 622, pp. 3–23, Jan. 2007, doi: 10.1002/QJ.29.

[4] K. Ali, R. M. Bajracharyar, and N. Raut, "Advances and challenges in flash flood risk assessment: a review," J Geogr Nat Disasters, vol. 07, no. 02, 2017, doi: 10.4172/2167-0587.1000195.

[5] B. Wisner, J. C. Gaillard, and I. Kelman, "Handbook of hazards and disaster risk reduction," Handbook of Hazards and Disaster Risk Reduction, pp. 1–875, Mar. 2012, doi: 10.4324/9780203844236.

[6] G. C. Nanson and M. R. Gibling, "Rivers and alluvial fans," Sedimentology, pp. 925–952, Mar. 1978, doi: 10.1007/3-540-31079-7_173.

[7] B. Wisner, J. C. Gaillard, and I. Kelman, "Handbook of hazards and disaster risk reduction," Handbook of Hazards and Disaster Risk Reduction, pp. 1–875, Mar. 2012, doi: 10.4324/9780203844236.

[8] Cloke H. L. and Pappenberger F, "Ensemble flood forecasting: A review," J Hydrol (Amst), vol. 375, no. 3–4, pp. 613–626, 2009, doi: 10.1016/j.jhydrol.2009.06.005.

[9] Bauer P., Thorpe A, and Brunet G, "The quiet revolution of numerical weather prediction," Nature, vol. 525, no. 7567, pp. 47–55, 2015, doi: 10.1038/nature14956.

[10] F. S. Awol, P. Coulibaly, and I. Tsanis, "Identification of Combined Hydrological Models and Numerical Weather Predictions for Enhanced Flood Forecasting in a Semiurban Watershed," J Hydrol Eng, vol. 26, no. 1, p. 04020057, Nov. 2020, doi: 10.1061/(ASCE)HE.1943-5584.0002018.

[11] R. O. Tom, K. O. George, A. O. Joanes, and A. Haron, "Review of flood modelling and models in developing cities and informal settlements: A case of Nairobi city," J Hydrol Reg Stud, vol. 43, p. 101188, Oct. 2022, doi: 10.1016/J.EJRH.2022.101188.

[12] E. Commission, J. R. Centre, C. Cammalleri, J. Vogt, F. Micale, and P. Barbosa, Climate change impacts and adaptation in Europe, focusing on extremes and adaptation until the 2030s : PESETA III : Task 9, Droughts : final sector report. Publications Office, 2018. doi: doi/10.2760/282880.

Presented at: *International Precipitation Conference (IPC) 14 at Norman , Ok, USA, June 05-09, 2023*