Project: 983
Title: Decadal variability of extreme events over Europe
Report for period 01.01.2024-31.12.2024

In recent years, our project has focused on several extreme events (single cases) and their (decadal) variability across Europe. Besides new high-resolution model simulations (with WRF/WRF-Hydro and ICON-CLM), our primary data source is the LAERTES-EU dataset (Ehmele et al., 2020, 2022), containing an unprecedented 12,000 years of regional climate model data. In 2025, we conducted hydrological modelling using WRF-Hydro to estimate low flow events on the Rhine River and performed high-resolution calibration/ tuning simulations of extreme windstorm events across Europe with the ICON model.

Severe Drought / Low Water Events

In a PhD project funded by CEDIM[1], the interdisciplinary research center for disaster management and risk reduction technology at KIT, we are simulating drought and low-water events in the Rhine River to study their impact on the transport of goods during such extreme events. We use the WRF-Hydro model to achieve this goal. The initial step was to calibrate the WRF-Hydro hydrological model using the ERA5 dataset as input meteorological forcing data, focusing on recent drought incidents like the 2018 drought. This entire procedure was completed in 2024. In 2025, we focused on scanning the LAERTES-EU data, which contains more than 12.000 years of meteorological data to extract extreme drought events. The task involves using drought indices and statistical analysis of precipitation and temperature variables, such as the Standard Precipitation and Evapotranspiration Index (SPEI). We were able to determine the 10 most extreme cases based on a combined cumulative SPEI value of three, six, and twelve months. The selected events were run with the calibrated WRF-Hydro model and compared to the navigation threshold (GlQ20), which indicates the severity of the drought event concerning navigation. A paper showing this results in currently available in NHESS in open discussion:
Campoverde, A. L., Ehret, U., Ludwig, P., and Pinto, J. G.: Drought propagation in the Rhine River basin and its impact on navigation using LAERTES-EU regional climate model dataset, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-3988, 2025.

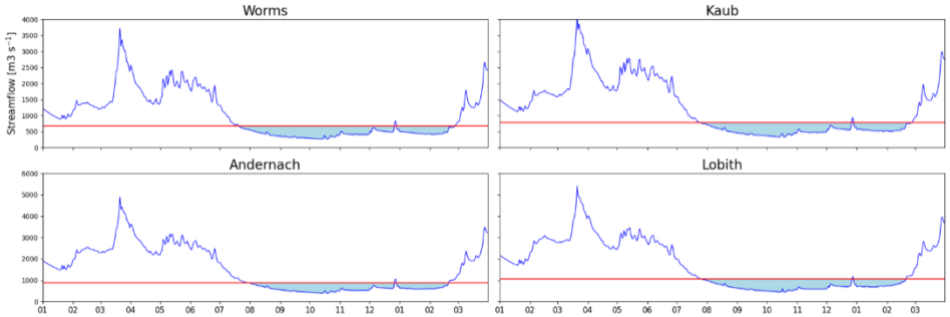

Fig 1: Daily hydrographs simulated by WRF-Hydro for a severe LAERTES-EU event at the gauges in the waterway of the Rhine River of the EV2 (blue line), in comparison with the navigation threshold GlQ20 (red).

Severe European Windstorm Events

In this project, we produce a storm catalog consisting of high-resolution simulations of strong winter windstorm events in Europe. We cover storms during the period from 1960 to 2023 and use the model

[1] https://www.cedim.kit.edu/index.php

ICON-CLM with ERA5 forcing data from the data pool at DKRZ. The horizontal resolution of the simulations is 0.028° and each simulation has a duration of 3-5 days to capture the storms as they propagate through Europe. The production of this catalog has been started in 2024 and by the end of 2025, it will comprise more than 300 individual events. Last year, we focused on storms affecting the full European domain. During 2025, we added storms of particular importance for various sub-regions in Europe, such as Iberia or the Baltics, so that the catalog is also representative for these areas. For the convective permitting summer storms, we made some test and calibration runs; the production of this dataset will be conducted in 2026 (see request document for 2026).

Decadal variability of European Windstorms

Using the LAERTES-EU regional climate model ensemble, we investigate the long-term climatology of near-surfaced wind speeds and gust over Europe related to windstorms. Overall, LAERTES-EU shows no significant trend for both the mean wind and the gusts over various regions in Europe (mainly the Prudence regions). The statistical distributions agree well with those of reanalysis data such as ERA5 or COSMO-REA6. Deviations are found only for the very high percentiles or extremes. The data also show internal variability on multiple scales from annual to multi-decadal which can be related to a certain degree to the NAO. We also investigate the representation of the large-scale weather regimes in LAERTES-EU in comparison with the reanalysis. In can be shown that the frequency, the intensity, and the spatial pattern of theses weather regimes are well represented in LAERTES-EU. The results will be published in a study whose submission is planned for late 2025. The results are the base knowledge for transferring the LAERTES-EU data into a stochastic windstorm event set for Europe including the relationship to specific weather regimes and a further downscaling to a higher resolution (see proposal for 2026).

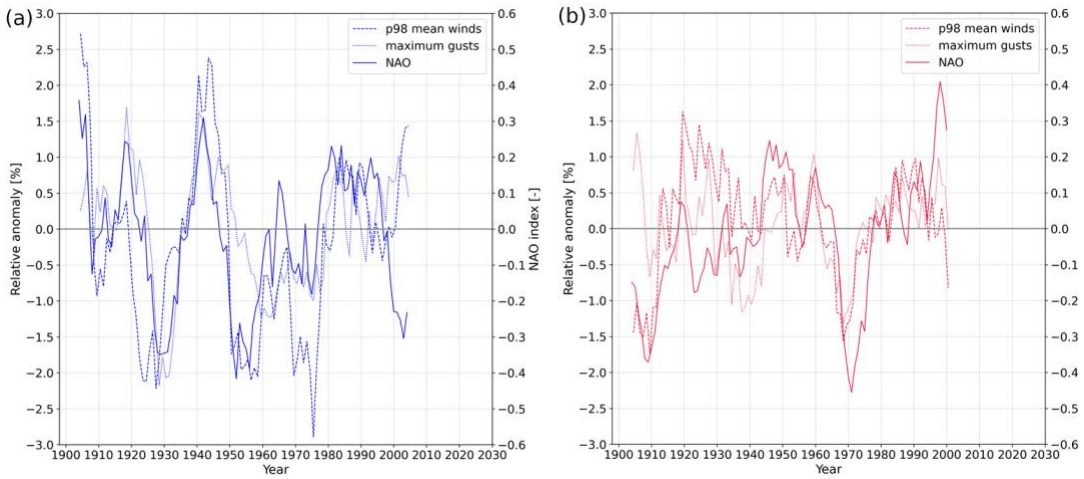

Fig. 2: Comparing the time series of the winter NAO index (solid line) with the anomaly of the annual 98th percentile of daily mean wind speeds and maximum gusts, spatially averaged over Central Europe. (a) shows the result for LAERTES-EU data block 1, while (b) shows the result for block 3..

References:

Ehmele, F., Kautz, L.-A., Feldmann, H., and Pinto, J. G. (2020): Long-term variance of heavy precipitation across central Europe using a large ensemble of regional climate model simulations, Earth Syst. Dynam., 11, 469–490, https://doi.org/10.5194/esd-11-469-2020.

Ehmele, F., Kautz, L.-A., Feldmann, H., He, Y., Kadlec, M., Kelemen, F. D., Lentink, H. S., Ludwig, P., Manful, D., and Pinto, J. G. (2022): Adaptation and application of the large LAERTES-EU regional climate model ensemble for modeling hydrological extremes: a pilot study for the Rhine basin, Nat. Hazards Earth Syst. Sci., 22, 677–692, https://doi.org/10.5194/nhess-22-677-2022.