Usage Report of DKRZ Resources

Project: bb1152 ClimXtreme (subproject bm1159)

Project title: ClimXtreme: Climate Change and Extremes (ClimXtreme)

Project leader: P. Friederichs, J Pinto, U. Ulbrich, F. Kaspar

Project Funding: BMBF

Reporting period: 05/2024 – 10/2024

Table 1: Used resources at DKRZ (by end of October 2024) in project bb1152 (and subproject bm1159).

Resource bb152	Granted	Utilization	Remaining
Levante CPU nodes (Node hours)	49080	39255	9825
Levante GPU nodes (Node hours)	20200	12634	7566
Levante Storage (TiB)	404	214	190
Archive project (TiB)	80	535	-455
Archive long term (TiB)	2	221	-219
Resource bm1159	Granted	Utilization	Remaining
Levante CPU nodes (Node hours)	7690	6037	1653
Levante GPU nodes (Node hours)	10000	7625	2375
Levante Storage (TiB)	447	417	30
Archive project (TiB)	38	-	38
Archive long term (TiB)		-	

Scientific activities conducted during the report time

1. Module A – A1 SEVERE

Subproject: A1: Scale Dependent Process Representation and Sensitivity Analysis for Most Extreme Events

Subproject leader: Hendrik Feldmann, Joaquim G. Pinto, Armenia Franco-Diaz, Marie Hundhausen, Christoph Braun, Ali Serkan Bayar, Institute of Meteorology and Climate Research (IMK-TRO), Karlsruhe Institute for Technology (KIT), Karlsruhe

1.1 Usage report May 2024 – October 2024

The aim of SEVERE is to derive improved estimates for precipitation events in present and future climate, considering high-resolution spatial and temporal scales. For high return-period events the changes and variability of the relevant small-scale (e.g. convection conditions, heat and moisture fluxes, etc.) and large-scale processes (weather- and teleconnection pattern, as well as large-scale moisture advection) are analysed. In the reporting period a special focus was put on the climate change effect for high temporal resolutions using kilometre-scale climate ensembles. Hundhausen et al. (2024a) showed that the increase of extreme precipitation intensities per degree of warming is highest for short duration events (event durations < 3 hours) and long return period. For long events with a duration from one to several days, the increase is less pronounced and more uncertain, because of the differences in the representation of the changes in large-scale dynamics in the different forcing GCM simulations. Further topics where the representation of sub-hourly extremes (Hundhausen et al, 2024b). For the evaluation of the characteristics of sub-hourly events convection permitting simulations were performed with COSMO-CLM driven by the ERA5 reanalysis.

A paper on the identification of extreme precipitation events over a range of day to multiday duration from coarse-scale GCM results compared to kilometre-scale simulations is in preparation (Pinto et al., 2024).

Some parts of the planned event-based simulations have to be postponed, since a colleague is on temporary leave.

The transfer of the regional MiKlip data to the WDCC is still going on. All Metadata have been provided to DKRZ. About half are already uploaded by DKRZ (example: Feldmann, Hendrik; Panitz, Hans-Jürgen; Brand, Sascha; Kottmeier, Christoph **(2021)**. *MiKlip EUR-22 20C dec26o1914-r1i1p1-LR CCLM-5-0-9 19150101-19241231 6hr ModelLevel*. DOKU at DKRZ. https://hdl.handle.net/21.14106/f286ecafebadef8a626037ba345c50ba7ac2164a). Until the transfer is complete the existing archive space, which contain this data, is still required.

1.2 Project related publications:

Hundhausen, M., Feldmann, H. Kohlhepp, R., Pinto, J.G., 2024a: Climate change signals of extreme precipitation return levels for Germany in a transient convection-permitting simulation ensemble. International Journal of Climatology, 44(5), 1454–1471. https://doi.org/10.1002/joc.8393

Hundhausen, M. Fowler, H.J., Feldmann, H. Pinto, J.G. 2024b: Sub-hourly precipitation and storm event profiles in a convection permitting multi-GCM ensemble. Weather and Climate Extremes, submitted

Pinto, J.G., Franco- Díaz, A. Feldmann, H., 2024: Scale dependency of heavy precipitation events between GCM simulations and kilometre-scale regional downscaling. In preparation

2. Module A – A5 DesAttHeat

Subproject:	A5: Towards an improved description and attribution of the most extreme Central European Heat Waves
Subproject leader:	Alexander Lemburg, Andreas Fink, Joaquim G. Pinto, Institute of Meteorology and Climate Research (IMK-TRO), Karlsruhe Institute for Technology (KIT), Karlsruhe

2.1 Usage report May 2024 – October 2024

As mentioned in the previous report, in WP1 of module A5 we investigate differences between heatwaves that are associated with an omega blocking and those linked to subtropical ridges, which are projected to play a greater role in a future climate. During the reporting period, the focus was on investigating the Lagrangian characteristics of heatwave-related air masses and whether they substantially differ between ridge- and omega-type heatwaves. For this, we select the purest 20 cases of each type and compute backward trajectories with Lagranto using highly-resolved ERA5 data. We start trajectories from different pressure levels throughout the troposphere to understand both 1) which processes lead to anomalous heat near the surface and 2) what are the sources of low potential vorticity air in heat wave-related upper-level blockings. In this report we focus on the first question. Preliminary results suggest that ridge-type HWs tend to be characterized by a slightly higher advective contribution to the overall temperature anomaly. Moreover, particularly two or three days after HW onset, anomalous subsidence and associated adiabatic heating contributes more to warming in ridge-type HWs than in omega-type HW. In turn, omega-type HWs are characterized by a stronger contribution of diabatic

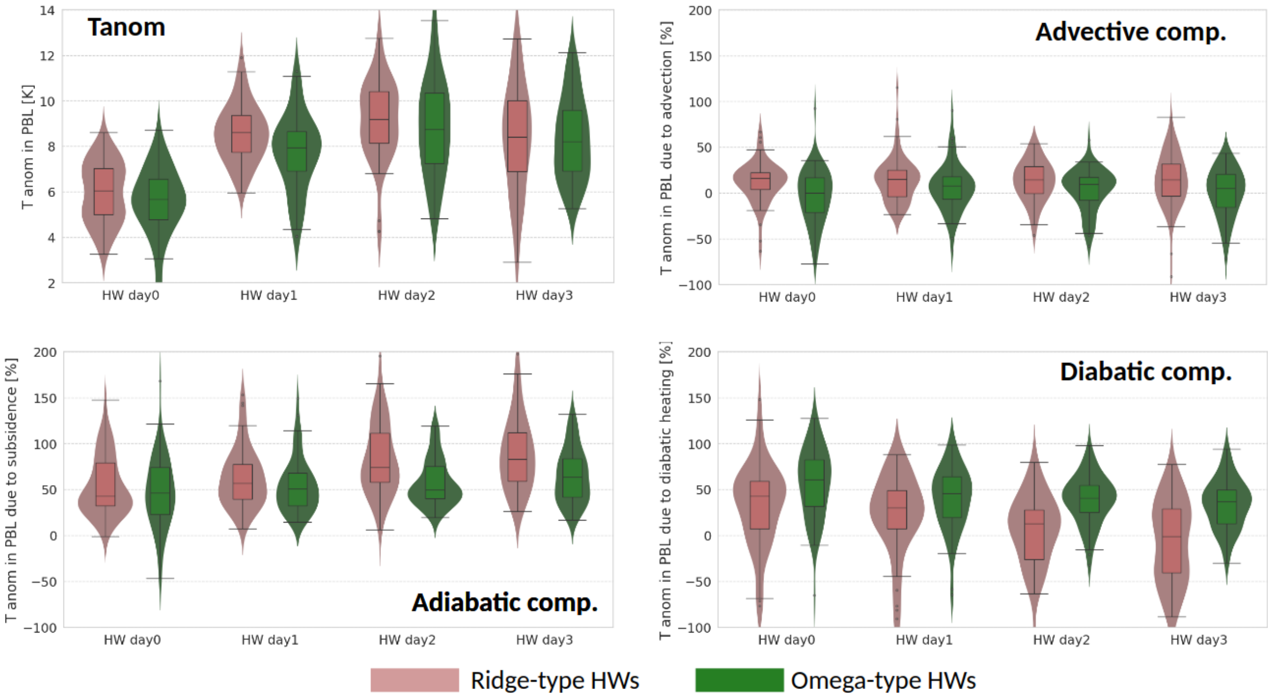

Figure 1: Composite-averaged near-surface temperature anomalies of 20 selected ridge-type and omega-type heatwaves (top left) and the respective contributions due to advection (top right), adiabatic warming due to subsidence (bottom left) and diabatic heating (bottom right). Shown are results for the respective onset day and the following 3 days of the respective heatwaves.

heating, which is mainly attributable to a higher insolation due to stronger negative anomalies in cloud cover.

Results are based on the application of an algorithm of Roethlisberger & Papritz (2023) applied to a large number of backward trajectories initiated near the surface over Germany (6-14°E, 48-54°N).

3. Module A – A6 CyclEx

Subproject:	A6: Intensity and structural changes of extreme mid-latitude cyclones change in a warming climate
Subproject leader:	Svenja Christ, Pinto Joaquim G. Pinto, Julian Quinting Institute of Meteorology and Climate Research (IMK-TRO), Karlsruhe Institute for Technology (KIT), Karlsruhe

3.1 Usage report May 2024 – October 2024

CyclEx investigates the changes in the intensities and frequencies of extreme mid-latitude cyclones in a warming climate and uncertainties related with the representation of diabatic processes. Followed up on the work of idealized baroclinic life cycles in the ClimXtreme A6 project Phase 1, for Phase 2, we plan first to (1) identify the most extreme observed windstorms in ERA5 and high resolution MPI-GE global climate model simulations using the ZYKPAK plug-in on the FREVA analysis platform and to (2) carry out pseudo-climate warming simulations with ICON-CLM. In addition to the pressure tendency equation (PTE) analysis (Fink et al., 2012), we will use the EuLerian Identification of ascending Air Streams (ELIAS) approach (Quinting et al. 2022, Quinting and Grams 2022) for the quantification of diabatic processes to study the possible scale dependency of the relevant physical processes on extreme cyclones.

Dr. Ting-Chen Chen, who has left the project end of 2023, published a paper in on the results of Phase 1 in the report period on the idealized ICON simulations.

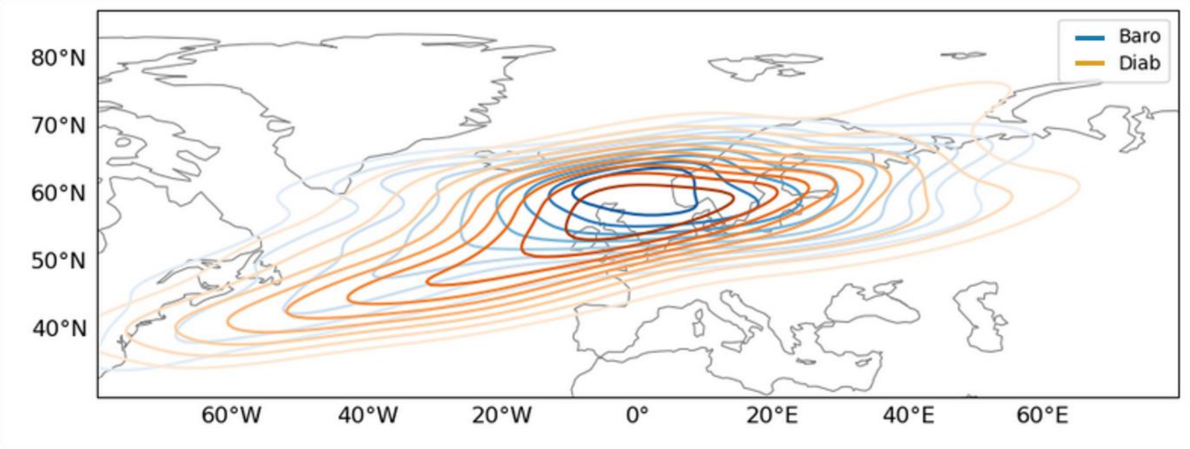

Figure 2: Cyclone Density of extreme ERA5 extended winter windstorms impacting central Europe, orange diabatically and blue baroclinically driven cyclones.

Since the start of Svenja Christ in the project in February 2024 the first part of the planed project was started and cyclone tracks of ERA5 were selected and further analyzed with the PTE and the ELIAS approach. Additionally, cyclone composites were generated and analyzed. The main preliminary result is that the separation with the help of the PTE approach into diabatically and baroclinically driven cyclones shows structural differences of their position (Figure 2Figure 2) and features, like surface wind, precipitation, and warm conveyor belts (WCBs). Diabatically driven cyclones are associated with more precipitation, stronger surface winds and more WCBs.

The analysis descripted above used the Plugin ZYKPAK for the cyclone tracks, which is implemented in the XCES (see chapter 8). Storage and computing resources on Levante were used additionally from the use of ZYKPAK.

Due to a change in project members, with Dr. Ting-Chen Chen being replaced by Svenja Christ as a new PhD student, the planned ICON-CLM simulations have been postponed to next year. As a result, the requested resources for 2024 have not been fully utilized, as the simulations have not yet been conducted.

3.2 Project related publications:

Fink, A.H., Pohle, S., Pinto, J.G., Knippertz, P., 2012. Diagnosing the influence of diabatic processes on the explosive deepening of extratropical cyclones. Geophysical Research Letters 39. https://doi.org/10.1029/2012GL051025

Quinting, J.F., Grams, C.M., 2022. EuLerian Identification of ascending AirStreams (ELIAS 2.0) in numerical weather prediction and climate models – Part 1: Development of deep learning model. Geoscientific Model Development 15, 715–730. https://doi.org/10.5194/gmd-15-715-2022

Quinting, J.F., Grams, C.M., Oertel, A., Pickl, M., 2022. EuLerian Identification of ascending AirStreams (ELIAS 2.0) in numerical weather prediction and climate models – Part 2: Model application to different datasets. Geoscientific Model Development 15, 731–744. https://doi.org/10.5194/gmd-15-731-2022

4. Module B – B1.3 Patteta

Subproject: B1.3: Process-based attribution of extreme temperatures to anthropogenic drivers
Subproject leader: Sebastian Sippel (Uni Leipzig)

4.1 Usage report May 2024 – October 2024

The project "Process-based attribution of extreme temperatures to anthropogenic drivers (PATTETA)" is carried out at Leipzig University's Institute for Meteorology within climXtreme II (Module B, "Statistics"). The core objective is to deepen our understanding of future weather extremes, particularly focusing on the climatic drivers behind heat wave changes in Central Europe, including greenhouse gases, aerosols, and atmospheric circulation. Structured into three work packages (WPs), PATTETA aims to:

- Assess the impact of greenhouse gases and aerosols on historical to present heat waves (WP1),
- Determine the role of atmospheric circulation in the frequency of extreme heat events and project these findings into future scenarios (WP2),
- Facilitate the transfer of this knowledge to address practical, application-relevant questions, such as envisioning historical heat waves in future climates (WP3).

To achieve these goals, PATTETA utilizes advanced climate modeling techniques, particularly leveraging DAMIP simulations within CMIP6 for WP1 and CESM2 model simulations for WP2 and WP3.

We have started to use resources from early 2024 onwards. Specifically, we prepared and downloaded single forcing large ensemble climate model data for WP1, and we ported and installed the climate model CESM2 on Levante for WP2 and WP3. Because we have mainly focused on model setup and testing, we have not yet used a very large share of our granted resources. However, we are now ready to conduct larger simulations, and hence we anticipate that we will use up our current resources in the next reporting period. Total Resource use: ca. 27000 node hours and 50 TB of storage. We describe the state of the simulations in more detail below:

Download and preparation of single forcing large ensemble data:

After downloading the large ensemble single forcing model simulations from CESM2 to DKRZ, we have also begun using other single forcing model simulations from CMIP6. In single forcing simulations, only one forcing (e.g., anthropogenic aerosols or greenhouse gases) is changed, while all others remain unchanged or all but one are changed (e.g. all but anthropogenic aerosols). We plan to use these simulations to determine the different contributions to global and regional heatwave trends. An initial result is shown in Figure 3.

Setting up the Community Earth System Model Version 2 (CESM2) on Levante:

To use CESM2 for various research questions regarding the attribution of extreme events (WP2 and WP3 in PATTETA), we ported CESM2 to Levante. This was achieved with the help of the DKRZ staff and Module D. The CIME environment which is used to set up and perform CESM simulations was configured to run with the compilers which are used on Levante. We carried out some first test simulations. Specifically, we checked the bit-by-bit reproducibility of the model on Levante which is important for our planned experiment design. Besides we did benchmarking tests and tested different options to branch from existing runs with and without perturbations. We also tested how we can branch from simulations that were computed on different computing clusters.

Using CESM2 for circulation nudging experiments:

Several large-scale simulations with the earth system model CESM2 have been carried within our storyline attribution framework during the last reporting period. These include a 200 year spin-up simulation to bring the model to an equilibrium, and a factual and a counterfactual simulation from 1850 to 2024 for a historical and a pre-industrial scenario. We evaluated the reproduction of climatic anomalies by our circulation nudging method, and performed some preliminary analysis with the attribution framework.

Small CESM2 ensemble for boosting and/or importance sampling:

We simulated a 42 member CESM2 (fully coupled) ensemble for the period 2021-2031 representing current climatic conditions. The initial conditions for the ensemble are taken from another similar ensemble simulated at ETH-Zürich. Additionally, we simulated a 450-year piControl simulation with CESM2. This current climate ensemble and the piControl run will be used for dedicated ensemble boosting and importance sampling experiments allowing for a comparison between current and pre-industrial climate. Note that, although similar ensembles already exist, we had to re-simulate these ensembles to allow bit-by-bit reproducibility on Levante which is required for ensemble boosting.

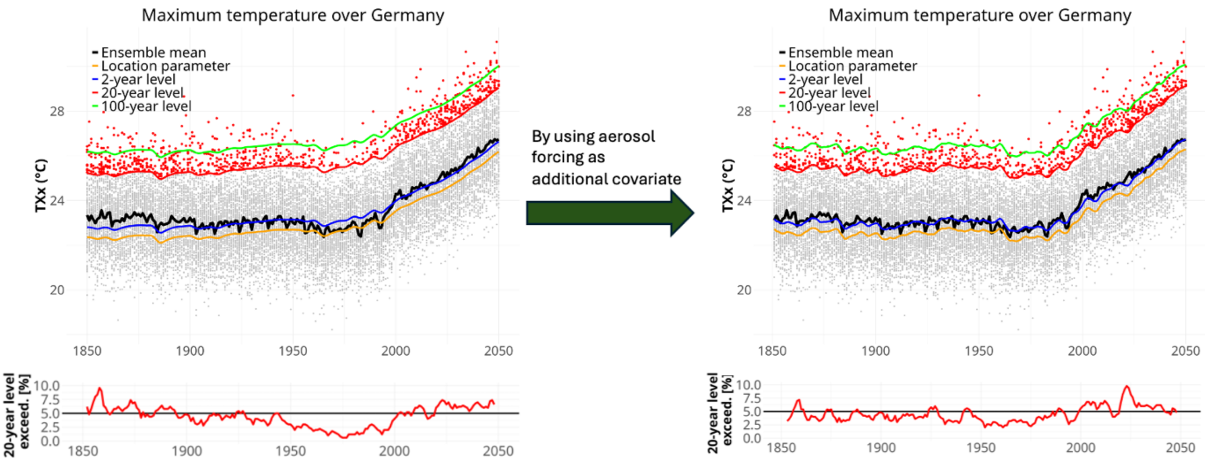

Figure 3: Temporal evolution of the CESM2 LE yearly maximum temperature (TXx) over Germany and corresponding return levels of the non-stationary GEV with GMST as a covariate. Dots show the individual values of the ensemble simulations. TXx above the 20-year level are highlighted in red and shown as the 5-year running mean of the number of exceedances. Over Germany, the 20-year level is exceeded less frequently from 1950 to 2000, the period of high aerosol levels. However, when adding the local smoothed aerosol forcing from the CESM2 SFLE as an additional covariate in the GEV, the attribution results improve significantly.

5. Module B – B2.4 XPreCCC

Subproject:	B2.4: Characterizing EXtreme Precipitation Events under Climate Change Conditions
Subproject leader:	Edmund Meredith, Henning Rust, Uwe Ulbrich (FU Berlin)

5.1 Usage report May 2024 – October 2024

The work proposed for 2024, as in 2023, centred around performing Lagrangean analysis of precipitation in convection-permitting COSMO-CLM simulations, both from an event-based perspective and at multidecadal timescales. XPreCCC applied the tracking algorithm of Meredith et al. (2023) to the continuous climate simulations of Haller et al. (2022a,b) in order to examine uncertainties in precipitation projections conditional on the large-scale circulation. This analysis is ongoing.

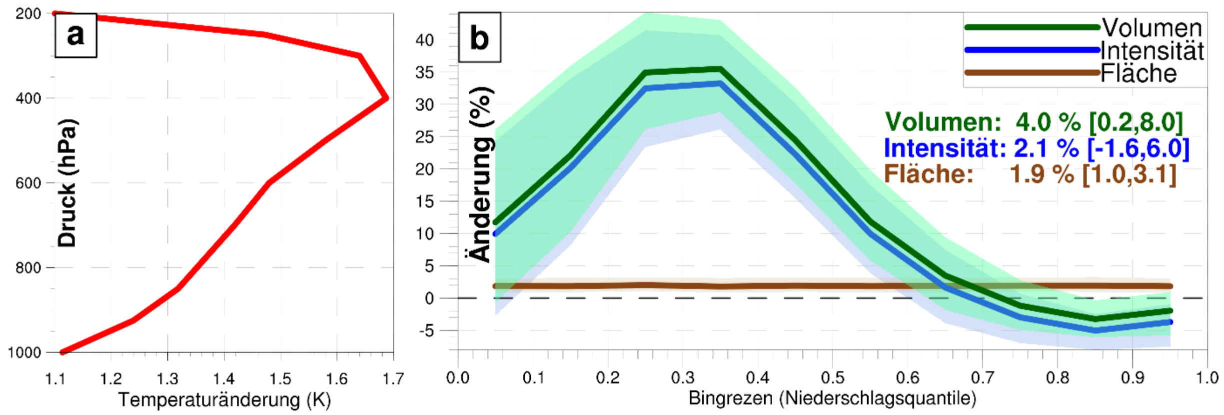

Figure 3: (a) Vertical warming profile since the preindustrial climate, (b) Change of the precipitation distribution due to past warming. The bin edges represent quantiles of the precipitation (intensity) distribution, and the change is the difference of these bin means between the climates (blue curve). The change in volume (green curve) is based on the total precipitation volume accounted attributable to each bin, taking into account that the total precipitation area changes between climates. See Friedrich et al. (2024) for further details.

XPreCCC conducted further event-based ensemble simulations with the COSMO-CLM at convection-permitting resolution. As planned in the previous proposal, the vast majority of expended computing resources were consumed by this work. One such experiment was a conditional attribution study of the extreme flooding in southern Germany during May and June 2024, which compared the event under present conditions and in a counter-factual preindustrial climate. It was found that under preindustrial conditions, the event would have had a smaller spatial extent, a lower total precipitation volume and lower local intensities, see Figure 4. The more extreme nature of the present-day event could be attributed to a strong intensification of the moderate intensities in the present climate; there was little difference between the highest intensities in the two climates. This experiment was included in the publication Friedrichs et al. (2024).

The work performed in 2024 was in accordance with that envisaged in the preceding proposal.

5.2 Project related publications:

Friederichs, P., et al. (2024). Ergiebige Dauerniederschläge und Hochwasser in Süddeutschland im Mai und Juni 2024. Bericht des Forschungsnetzwerkes ClimXtreme. doi:10.17169/refubium-44009

Meredith, E. P., Ulbrich, U., and Rust, H. W. (2023). Cell tracking of convective rainfall: sensitivity of climate-change signal to tracking algorithm and cell definition (Cell-TAO v1.0), Geosci. Model Dev., 16, 851–867, https://doi.org/10.5194/gmd-16-851-2023.

6. Module C – C2 CARLOFFF

Subproject: C2: Convective Atmospheres: Linking Radar-based Event Descriptors and Losses From Flash Floods

Subproject leader: Gerd Bürger, Maik Heistermann (Uni Potsdam)

6.1 Usage report May 2024 – October 2024

CARLOFFF addresses the classification of convective environments over Germany with respect to their potential to excite extreme convective rainfall events, as represented by CatRaRE[1]. Model calibration with the coarser (CMIP6-) field resolution was completed. We have extended the predictor set to include circulation parameters of divergence and vorticity, hoping that especially the deep learning methods

[1]catalogue of heavy precipitation events (Version 2022.01 exceeding DWD warning level 3 for severe weather

would profit from using a pattern-based predictor set. All relevant calibration runs were completed successfully, and so were most of the CMIP6 applications. This includes the original DE (all Germany) runs, the 2R (North/South Germany) runs, and the 4R (NW, NE, SE, SW Germany) runs. Besides for the CatRaRE database, this setting has been applied to the two alternative index sets WEI and xWEI. All calculations required the employment of GPUs from Levante.
Calibration results for 4R are shown in Figure 5. They are altogether quite similar, with slightly better skills for CatRaRE. For CatRaRE, the deep learning network *LeNet-5* performs best now, followed by the classical method of random forests (TREE) which is best for the other indices. We have still not been able to resolve the issue of the large skill spread for the deep learning methods. For example, some of the DenseNet realizations clearly outperform all other methods.

For 4R and CatRaRE, we have started to conduct the full ANOVA for all simulation runs (*historical, ssp125, ssp585*), along with trend analyses for the obtained annual probabilities for the CatRaRE-type events.

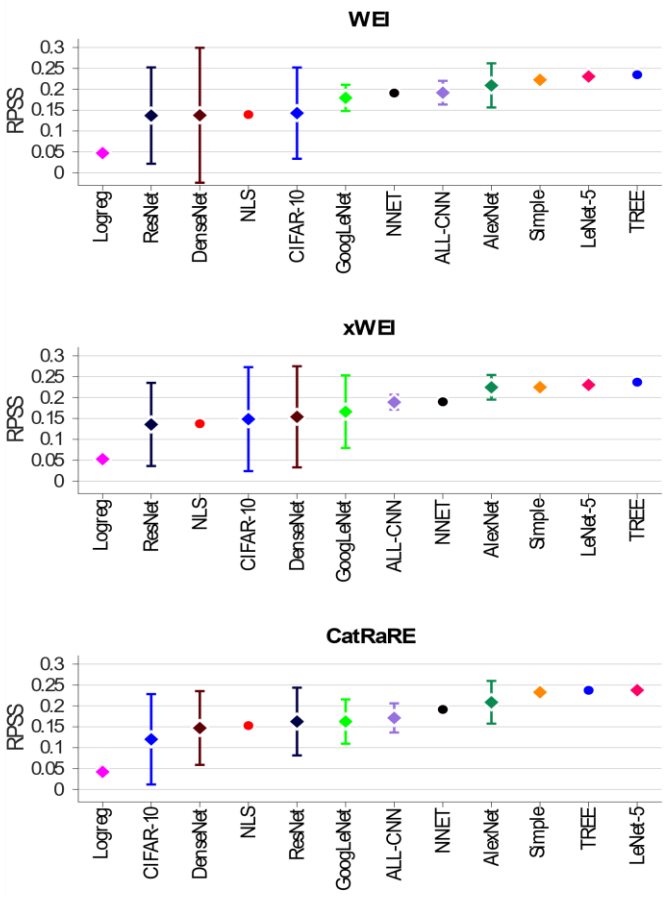

Figure 5: Ranked probability score of the 4R (NW, NE, SE, SW) classifications of ERA5 with coarser CMIP6 resolution, using extended predictor set.

6.2 Project related publications:

Bürger, G. and M. Heistermann. "Shallow and deep learning of extreme rainfall events from convective atmospheres." *Natural Hazards and Earth System Sciences* 23.9 (2023): 3065-3077.

7. Module C – C3 CROP4EUROPE

Subproject: C3: Impacts of compound weather extremes on cops in Germany: present and future
Subproject leader: Elena Xoplaki (Uni Giessen)

7.1 Usage report May 2024 – October 2024

During the reporting period we initiated essential pre-calculations and preprocessing steps before starting our main analysis. These preparatory tasks were necessary to ensure that our data was in the right format, clean, and aligned with the analytical methods we intended to use.

Since these steps are often computationally demanding and time-consuming, we decided to leverage resources from our teams' other relevant projects (e.g. Regiklim) to optimize the process. By combining efforts, we were able to share computational power, tools and datasets, which allowed us to streamline this part of the workflow. This collaboration was not only efficient in terms of final computation burden for the DKRZ infrastructure but also provided us with better-prepared data, saving time for the core analysis to follow.

As a first pipeline for bias correction we tailored to our models a convolutional neural networks (CNN)-based methodology for the variables we are interested in for the current work in progress, the AI-based crop growth emulator. An example architecture tested is shown in Figure 6.

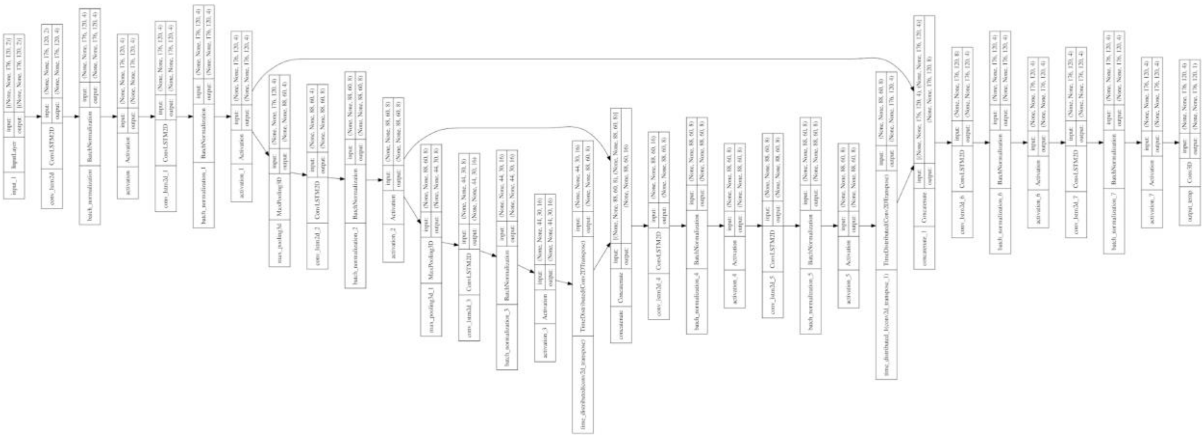

Figure 6: Bias adjustment CNN architecture.

For the compound extremes detection pipelines we have implemented two crop-related indices, the Heat Magnitude Day (HMD) and the Standardized Precipitation Evapotranspiration Index (SPEI) for the European domain, utilizing statistical methodologies for both extreme events detection and listing and benchmarking datasets for the future steps in the frame of the project. Sample results for 2003 are presented in Figure 7, both HMD and SPEI are generated with a reference period of 1993-2016.

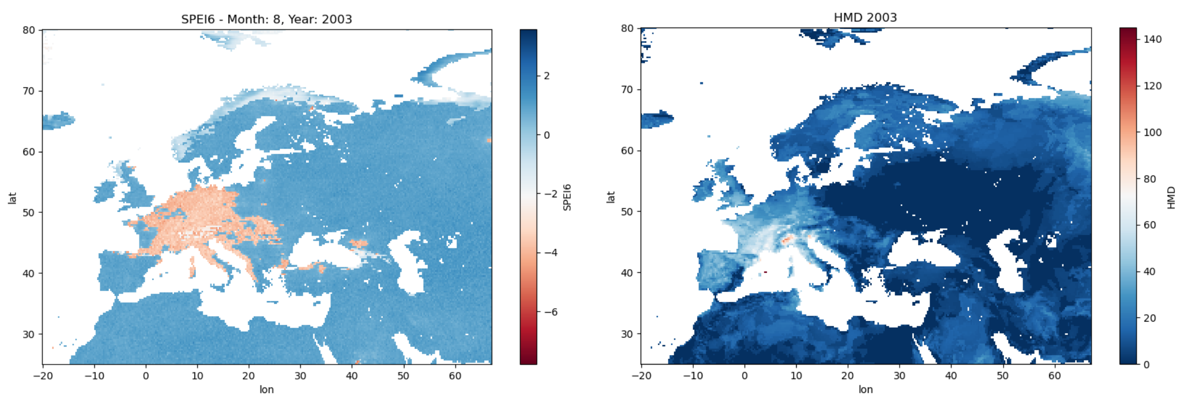

Figure 7: Year 2003 SPEI and HMD indices for the greater European domain.

These preliminary efforts are critical to building a solid foundation for the work that follows, especially the sound formulation of the AI-based surrogate crop growth model and derivative impact related products.

8. Module D – CoSoDaX

Subproject: bb1159 (D1/D2): Coordination of software and data management for ClimXtreme
Subproject leader: Etor Lucio-Eceiza, Deborah Niermann

8.1 Usage report May 2024 – October 2024

Module D is a supporting module of the ClimXtreme research project and is responsible for the coordination of software and data management (CoSoDaX). In addition to the general coordination activities, this includes the following main contributions: (a) the development and operation of a central evaluation system for climate extremes (XCES [1]), (b) the provision and analysis of basic data sets for the evaluation of climate extremes, (c) the support of software developments for the investigation of extreme events and the maintenance of existing software.

XCES is based on Freva (Kadow et al., 2020), a scientific software framework for high performance computing, equipped with a standardized model database, a programming interface and a history of evaluations, maintained and updated by the Climate Informatics and Technologies (CLINT [2]) group at DKRZ.

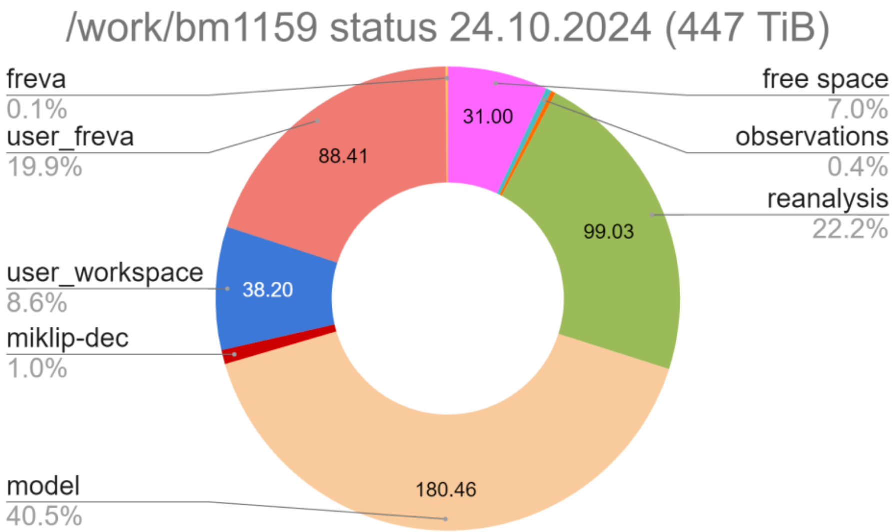

Figure 8: Storage demand (TiB) of different data types under /work/bm1159/XCES/, hosted in the ClimXtreme project bm1159 and percentage of data according to their type.

One of the primary goals of Module D is to build up a reasonable database for the joint project, accessible through XCES. Based on the data from the former MiKlip project [3], this data collection has been progressively expanded during the first phase of ClimXtreme by the following relevant datasets: RADKLIM, EOBS, HYRAS-DE, ERA5. Currently more than 10 million files totaling more than 5 PB of data can be accessed through XCES. Although the vast majority of the data is linked from the /pool/data, a significant amount of it is hosted under the joint project bm1159 (around 280 TB). An overview of the data types integrated in the system and hosted with resources of bm1159 (joint project of main bb1152) is given in Figure 8.

XCES grants a flexible incorporation of verification routines (plugins). These analysis tools are being developed by Modules A-C with the assistance of Module D, or by Module D itself to fulfill the needs of the project and be used by any member of the Consortium. Within the second phase of the project 2 plugins are fully available to the project, another 10 are functionally run but still not made open to all, and 3 more are in development stages (for an overview see Table 2Table 2). Additionally, 22 plugins were inherited from ClimXtreme Phase1, former MiKlip project and other Freva-instances (e.g. related to RegIKlim-Nukleus project).

*Table 2: Overview of plugins developed during ClimXtreme2 (in * those not fully available yet) project and a short description of their functionality.*

plugin	topic	project
pca	principal component analysis based on xeofs	B1.1/B3.7

trendtest	linear trends with t-test for significance	B1.1/B3.7
analogues*	analysis of circulation analogues	B1.1/B3.7
dacollector*	data preparation for detection and attribution studies	B1.1/B3.7
dsmetrics*	dynamical systems metrics computation	B1.1/B3.7
dualtrees2d*	maps of dominant spatial scales via 2D wavelet transforms	B1.1/B3.7
regional_hwmid*	Regional evaluation with Heat Wave Magnitude Index daily	B3.7
returnmaps*	maps of precipitation sums and return periods	C
sousa_blocking*	atmospheric blocking with Sousa detection method	A
spei*	computes drought indices SPI and SPEI	B3.7
tlsw*	trend and time-depended autocovariance via wavelets	B3.7

The goals of the plugins are very diverse, from the calculation of linear trends with significance level (e.g. Figure 9 left), to principal component analysis (e.g. Figure 9 right) or precipitation aggregation and return levels (e.g. Figure 10).

These plugins are hosted and run through XCES and are available to the entire ClimXtreme community. During the period 2024.04-2024.10, more than 3,900 plugin calls have been made (more than 6,400 since January) , so the amount of storage allocated to outputs has grown steadily. XCES users currently use close to 130 TiB between plugin outputs, data indexed back to XCES, and their own workspace. Both plugins developed within and databases accessible through XCES are being used for several event studies and publications within the project, including technical flooding reports of recent events, see chapter 8.2.

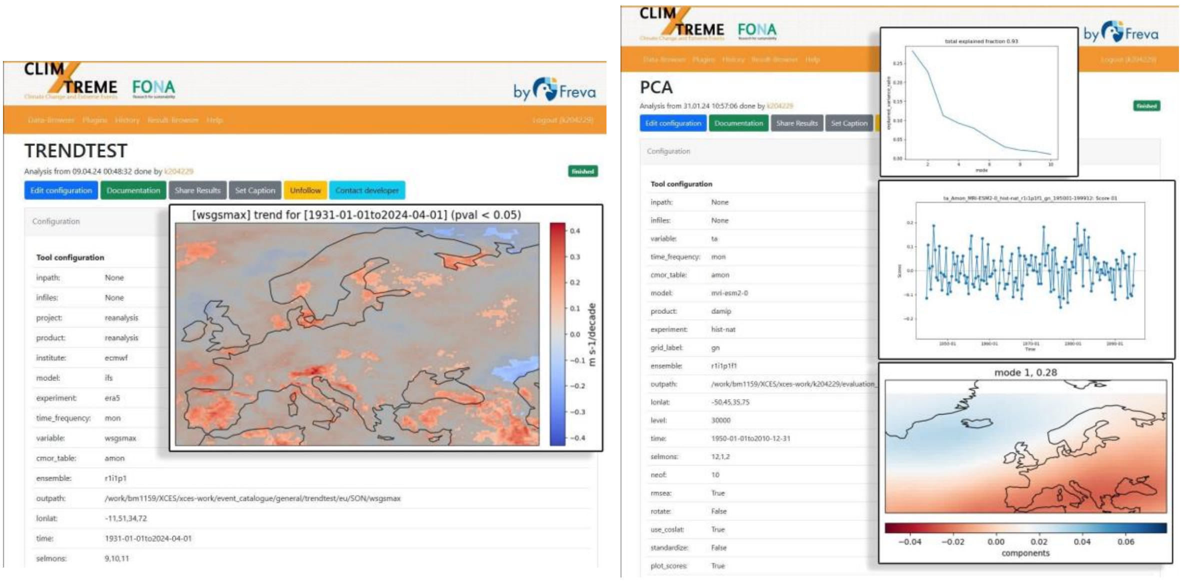

***Figure 9**: (left) Significant linear trends for maximum surface wind speed for a certain time period via TRENDTEST plugin, developed at XCES by Module B3.7. (right) Explained variance, score and EOF of first PCA for temperature via PCA plugin, developed at XCES by Module B3.7.*

An adjacent line of research of CLINT is focused on the application of AI/ML methods (Kadow et al., 2020) to tackle a variety of climate science related topics, with a direct usability through XCES (i.e., data and plugins) in mind. The research group has been further developing that methodology under HLRE 4's GPU cores.

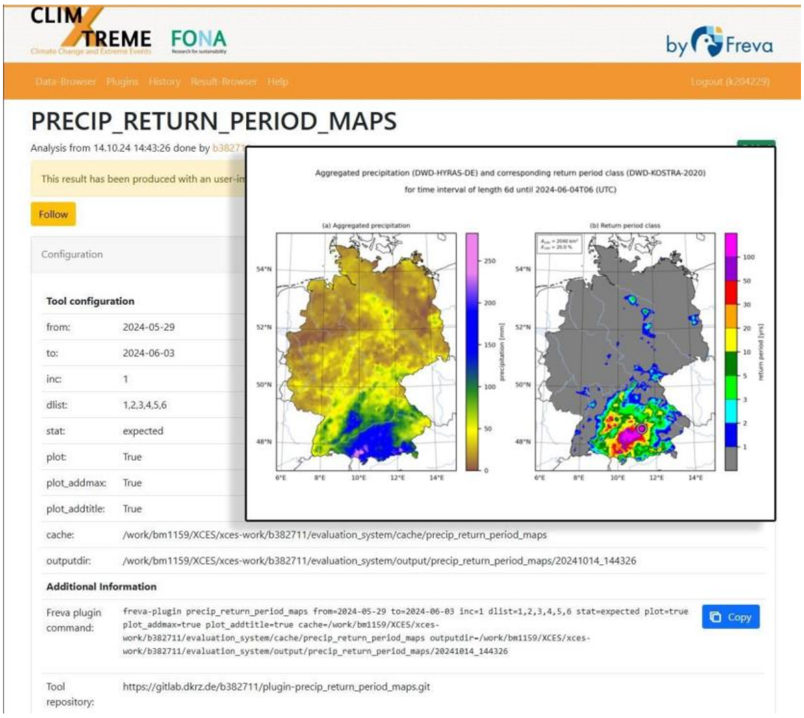

Figure 10: Aggregated precipitation and return period map for 6 day time interval for Hyras dataset via RETURNMAPS, developed at XCES by Module C (not yet fully available).

Used Resources at DKRZ in 04/2024 – 10/2024

In December 2023, the official Kick-Off for ClimXtreme phase 2 took place. Since then, an active community of XCES users and developers has thrived, as reflected by the CPU hour usage and numbers of plugin runs, which justified the additional resources request. During next year a consolidation of existing plugins is expected, along an increasing amount of new ones. On top of that, workflows involving usage of multiple plugins for the evaluation of past and current events will be tested, with an expected comparable usage of CPU hours. On the other hand, the ML line of research has been actively using the allocated GPU resources (Table 1), whose trend is expected to be maintained for next year, including the technology transfer to plugins run under XCES. Furthermore, as mentioned above, most of the available workspace storage is being used (416 out of 447 TiB, see Figure 8 and Table 1), and it will grow in order to accommodate for new datasets and plugin results. As far as archive resources are concerned, contrary to what was originally thought, XCES users need their plugin outputs available and therefore no archiving has been done. We have therefore requested fewer archive resources for the next period to reflect actual needs.

8.2 Project related publications:

Grieger, J., Kunz, T., Buschow, S., Daniell, J., Lucio Eceiza, E. E., Fauer, F. S., ... & Vorogushyn, S. (2024). Dauerniederschläge und Weihnachtshochwasser im Winter 2023/24. http://dx.doi.org/10.17169/refubium-43523 (technical report)

Friederichs, P., Grieger, J., Kunz, T., Ulbrich, U., Bürger, G., Buschow, S., ... & Vorogushyn, S. (2024). Ergiebige Dauerniederschläge und Hochwasser in Süddeutschland im Mai und Juni 2024 (DOI still not available). (technical report)

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