Usage Report of DKRZ Resources

Project: bb1152 ClimXtreme

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

Project leader: A. Hense, C. Kottmeier, J Pinto, U. Ulbrich, F. Kaspar

Project Funding: BMBF

Reporting period: 06/2021 – 04/2022

Scientific activities conducted during the report time

1. Module A – Subproject A1 SEVERE

Project:	bb1152 ClimXtreme – A1 SEVERE
Subproject:	Scale Dependent Process Representation and Sensitivity Analysis for Most Extreme Events (A1 SEVERE)
Subproject leader:	Hendrik Feldmann, Alberto Caldas-Alvarez, Joaquim G. Pinto, Christoph Kottmeier
Reporting period:	11/2021 – 04/2022

1.1 Usage report November 2021 – April 2022

The aim of SEVERE is to derive robust estimates for precipitation events in present and future climate with return periods beyond the range, which can be derived from observations (e.g. < 100 years). For these event set 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.

To derive robust estimates and classifications, a sufficient number of events is needed. Within MiKlip a unique large ensemble of consistent regional climate simulations with COSMO-CLM have been calculated. They cover about 13.000 simulation years for the period 1900 – 2030 (called LAERTES-EU, Ehmele et al., 2020) with a horizontal resolution of 25 km. For the core period, 1960 – 2019, each calendar year is sampled up to 200 times by the ensemble simulations, allowing for a robust estimation of the trends and variability of high-return-period events.

However, for a sufficient representation of the regional and local scale processes, simulations on the convection permitting scale (~3km resolution) are required, to adequately represent the local-scale processes.

For the reporting period 2022, the following tasks had been announced.

1. Bringing the data from the regional MiKlip ensembles required for a further (episodic) downscaling the LTA
2. The episodic downscaling of extreme precipitation events to convection permitting scales.

The first task was severely delayed by the technical difficulties with the new HSM system. Nevertheless, the meta-data and file formats have been prepared for a block of 300 simulations. The rest could be prepared in relatively short term, given the necessary archive space for the transformation is available. Currently, the data are owned by the expired project bb0849 “MiKlip regional”. For the LTA archiving a renaming a reordering is required. Since writing is no longer enabled for the old project, the adapted files now have to be accounted for under bb1152 “ClimXtreme”. This adaptation of filenames and paths

does not caused additional data amounts, but just a renaming and moving. As of April, four of these simulations have been put to LTA by DKRZ.

Task 2

The MiKlip regional large RCM ensemble (LAERTES-EU, Ehmele et al., 2020) has been used to force a hydrological model for several major European river catchments. It could be shown, the LAERTES-EU data allow for a statistical robust estimation of runoff return values for gauges of the Rhine catchment up to 1000 years (Ehmele et al., 2022). For smaller catchments in complex terrain, a higher resolution is needed as the 25 km grid spacing of the regional MiKlip simulations. Therefore, several extreme precipitation events have been simulated over a large Central European domain in convection permitting resolution of 3 km. The identification and comparison of such events in observations, reanalysis and simulations is done using the PSI index, for which a FREVA plug-in has been developed and implemented. The method has been evaluated and applied to analyse the scale dependent representation of precipitation extremes submitted by Caldas-Alvarez et al. (2022a). This paper will be part of cross-journal ClimXtreme special issue (SI).

Several past extreme events are past extremes have been downscaled from the ERA5 reanalysis data. Among others, the Ahr/Erft flooding in July 2021 event has been simulated. Currently, the members of SEVERE contribute to the finalization of a two-part publication for the SI of the meteorological and hydrological aspects, the impact, and the placement of the event in relation to past and expected future changes.

In addition, episodical downscaling was performed for an extreme event in the Berlin area in June 2017. This episode is the focus of a joint ClimXtreme publication submitted to the ClimXtreme special issue (Caldas-Alvarez et al., 2022b).

Therefore, the episodic downscaling has been shown to be useful to analyse the meteorological evolution including their pre-conditions of extreme events. The 1000 most extreme events from the 13.000-year LAERTES-EU ensemble (return period > 10 years) have been identified and characterized. For several events with return periods of 500 years and more, an episodic downscaling has been performed. It could be shown that events with a similar evolution of the Ahr/Erft flooding event could occur, with even higher peak intensity, larger extension and higher persistence under current climate conditions.

This shows the suitability and effectivity of the approach and the necessity to store the LAERTES-EU data required for downscaling in the DKRZ LTA. Even with a large domain and very high resolution, it is possible to downscale a large number of such events with a reasonable amount of computing time, which would be impossible for the whole 13.000-year ensemble. Currently, applications for other extremes (windstorms, heat waves, compound events) are developed, based on the episodic downscaling of the large ensembles.

References:

Ehmele, F.; Kautz, L.-A.; **Feldmann, H.; Pinto, J. G.,** 2020: Long-term variance of heavy precipitation across central Europe using a large ensemble of regional climate model simulations. Earth System Dynamics, 11 (2), 469–490. doi: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., **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 Natural Hazards and Earth System Sciences, 22 (2), 677–692. doi:10.5194/nhess-22-677-2022.

Caldas-Alvarez, A., Feldmann, H., Lucio-Eceiza, E., and **Pinto, J.G.**, 2022a: Scale-dependency of extreme precipitation processes in regional climate simulations of the greater Alpine region. Weather and Climate Dynamics Discussions, https://doi.org/10.5194/wcd-2022-11, in review.

Caldas-Alvarez, A., Augenstein, M., Ayzel, G., Barfus, K., Cherian, R., Dillenardt, L., Fauer, F., **Feldmann, H.**, Heistermann, M., Karwat, A., Kaspar, F., Kreibich, H., Lucio-Eceiza, E., Meredith, E.P., Mohr, S., Niermann, D., Pfahl, S., Ruff, F., Rust, H.W., Schoppa, L., Schwitalla. T., Steidl, S., Thieken, A.H., Tradowsky, J.S., Wulfmeyer,

V., and Quaas, J., 2022b: Meteorological, Impact and Climate perspectives of the 29 June 2017 Heavy Precipitation Event in the Berlin Metropolitan Area.NHESS Discussion, https://doi.org/10.5194/nhess-2022-96, in review.

2. Module D – Subproject D1/D2 CoSoDaX

Project: bb1159/bb1152 ClimXtreme

Subproject: Coordination of software and data management for ClimXtreme (D1/D2 CoSoDaX)

Subproject leader: Etor Lucio-Eceiza, Deborah Niermann

Reporting period: 0 6/2021 – 04/2022

2.1 Usage report 06/2021 – 04/2022

2.1.1 Planned work, performed simulations, summary of (preliminary) results

Module D is a supporting module of ClimXtreme, in charge of the Coordination of software and data management for ClimXtreme (CoSoDaX). In addition to the general coordination activities, this includes three main contributions: (a) the development 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 operation of an infrastructure for the ClimXtreme project partners.

XCES is based on Freva [2], a scientific software framework for high performance computing. equipped with a standardized model database, a programming interface and a history of evaluations. XCES has been hosted at the ClimXtreme/MiKlip server linked to DKRZ's HLRE3 (Mistral) but is currently being migrated to HLRE4 (Levante). Originally developed at the Freie Universität Berlin (FUB) [3], Freva is maintained and updated by the Climate Informatics and Technologies (CLINT [4]) group at DKRZ. Freva is used by other sisterprojects within DKRZ (Regiklim [5] and ESGF [6]) as well as by other institutions (e.g., Mavis [7] at the DWD).

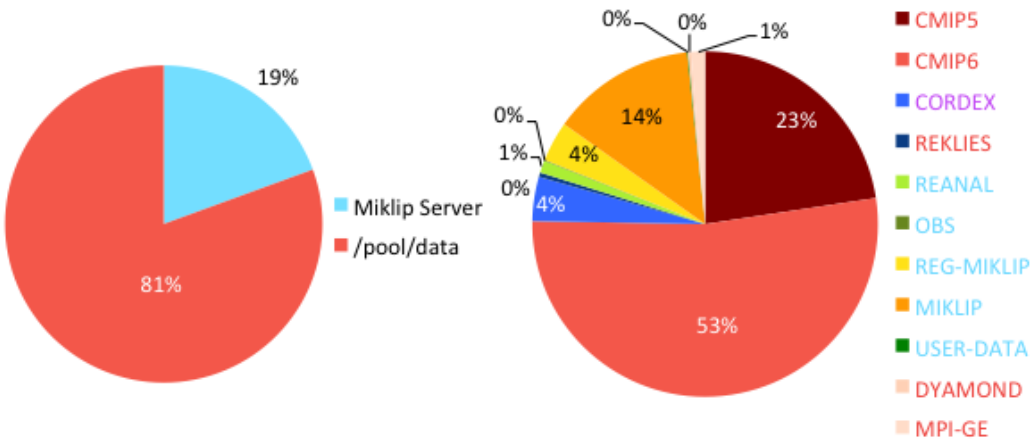

Figure 1: *Insight of the 6.6 PB of data accessible through XCES in Mistral. Left, percentage of the data hosted in the ClimXtreme/MiKlip server (blue) and linked from Mistral (red). Right, percentage of data according to their type and whether they are hosted in MiKlip (names in blue) or in the /pool/data/ at Mistral (names in red), CORDEX is a special case as is partially hosted by both*

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 [8], this data collection has been progressively expanded with relevant datasets that include reanalyses such as ERA5, ERA-Interim, ERA20C, COSMO-REA6 and COSMO-REA2, observational data sets such as RADOLAN, RADKLIM, HYRAS, EOBS and DWD station observations, and also climate projection data from REKLIES, CORDEX, CMIP5, CMIP6 and MPI-GE. Currently more than 15 million files totalling more than 6.6 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 has been hosted at the ClimXtreme/MiKlip server (more than 1.3 PB). An overview of the data types integrated in the system is given in Figure 1. Due to the HPC migration and the shutdown of the MiKlip server at the end of May, a complete restructuring of the data has been conducted to accommodate the allocated resources of Module D under bm1159/bb1152. This effort has included the removal and archival of several datasets. 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. Currently more than 10 plugins are in different stages of development, in addition to 14 inherited from the former MiKlip project. The goals of the plugins are very diverse, from the quality assessment of the data sets (e.g. Figure 2), to identification of extreme events via specific climate indices (e.g. Figure 3) or the calculation of co-occurrence probabilities for extreme events of different nature (e.g. Figure 4).

Figure 2: *Evaluation of ERA5 2m-temperature against hourly DWD-station observation at location Potsdam with REALISTIC, a plugin developed by Module D at Mavis (DWD), that is in being adapted to XCES.*

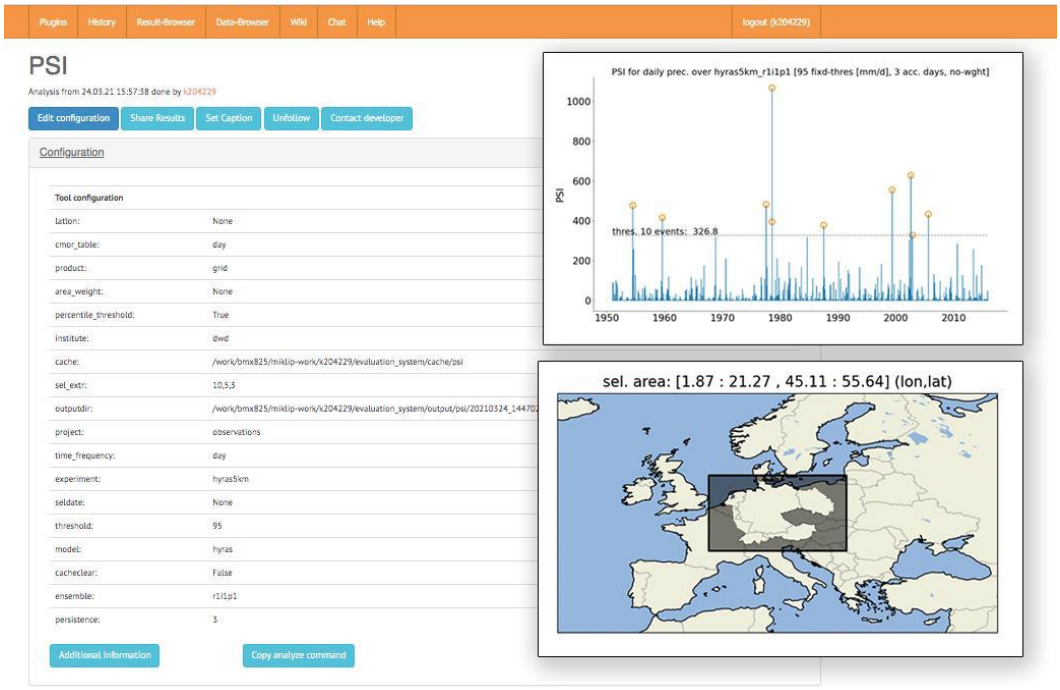

Figure 3: *Evaluation of the Precipitation Severity Index (PSI) for a selected region, time period and gridded precipitation dataset via PSI plugin, already running in XCES. It was developed by Module A1 with the assistance of Module D.*

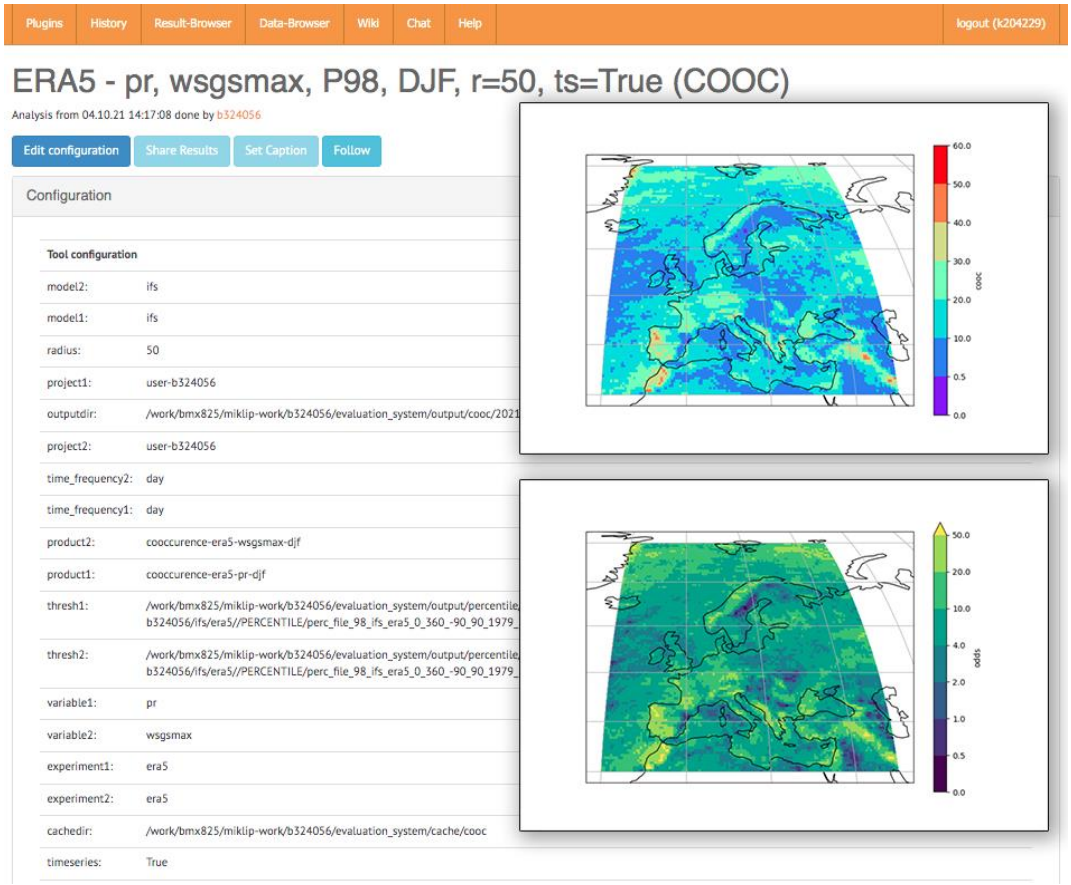

Figure 4: *Co-occurrence probabilities for precipitation and wind gust extreme events for a selected region, time period and gridded precipitation dataset via COOC plugin, in development at XCES by Module C1.*

These plugins are hosted and run through XCES and are available to the whole ClimXtreme community. Up until now the evaluation runs have been conducted using MiKlip's computational and storage resources. During the last period, more than 11000 plugin calls have been done, and the storage preserved to outputs has grown continuously. The output storage is currently being migrated to HLRE4 along with the XCES framework itself, and the plugins within.

Both plugins developed within and databases included in ClimXtreme have been used for several event studies and publications:

- Meteorological, Impact and Climate perspectives of the 29 June 2017 Heavy Precipitation Event in the Berlin Metropolitan Area, Preprint: https://doi.org/10.5194/nhess-2022-96
- Scale-dependency of extreme precipitation processes in regional climate simulations of the greater Alpine region, Preprint: https://doi.org/10.5194/wcd-2022-11 (under review)
- A comprehensive study of the extreme heat and drought of the 2018 European summer (under preparation)
- Wind and storm damage: From meteorology to impact (under preparation)

An adjacent line of research of CLINT is focused on the application of AI/ML methods [9] 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 3's GPU cores.

2.1.2 Used Resources at DKRZ in 06/2021 – 04/2022

In January of 2022, project bm1159 (ClimXtreme - CoSoDax Data and Software Management on ClimXtreme Server, former joint project under bmx825 of MiKlip) was joined under project bb1152, transferring to it some computing and storage resources for the exclusive use of Module D.

Up to now, Module D has barely used any resources of the bm1159/bb1152 project because it mainly relied on its own resources at the ClimXtreme/MiKlip server. The HPC migration, originally planned for August 2021 [10] has been subsequently postponing this usage until April-May 2022, with entry of Levante on its operative phase. This explains the discrepancies between requested and used resources (see Table 2). Once the aforementioned restructuring of the data was completed, all of it has already been migrated to Levante under bm1159. On the other hand, some user workspace and plugin output related data are still in the migration process and, hence, they have not been reflected in the table yet. Once the migration phase is completed at the end of May, Module D will considerably increase the usage of the requested resources for the next period. Finally, it is noteworthy that to our latest consultation of the LUV, the used storage resources of bm1159 for Levante have not been yet updated.

Table 1: *granted (second column) and used (third column) resources per type (first column) for project bm1159/bb1152.*

	Granted resources	Used resources
Computing time [Node h]	18097	4524
Work space [TB]	420	327
Archive [TB]	274.5	0

References

[1] https://www.xces.dkrz.de/

[2] Kadow, Christopher, et al. "Introduction to Freva–A Free Evaluation System Framework for Earth System Modeling." *Journal of Open Research Software* 9.1 (2021).

[3] freva.met.fu-berlin.de

[4] https://www.dkrz.de/de/kommunikation/aktuelles/ki-gruppe_dkrz

[5] https://www-regiklim.dkrz.de

[6] https://cmip-esmvaltool.dkrz.de

[7] mavis.dwd.de (behind firewall)

[8] https://www.fona-miklip.de/

[9] Kadow, C., Hall, D. M., Ulbrich, U., 2020: Artificial intelligence reconstructs missing climate information. *Nature Geoscience*, 1-6

[10] https://www.dkrz.de/de/kommunikation/pub/mitteilungen/ausgabe-42-11-2020