Preparing ICON for heterogeneous architectures - Experiences and the way forward

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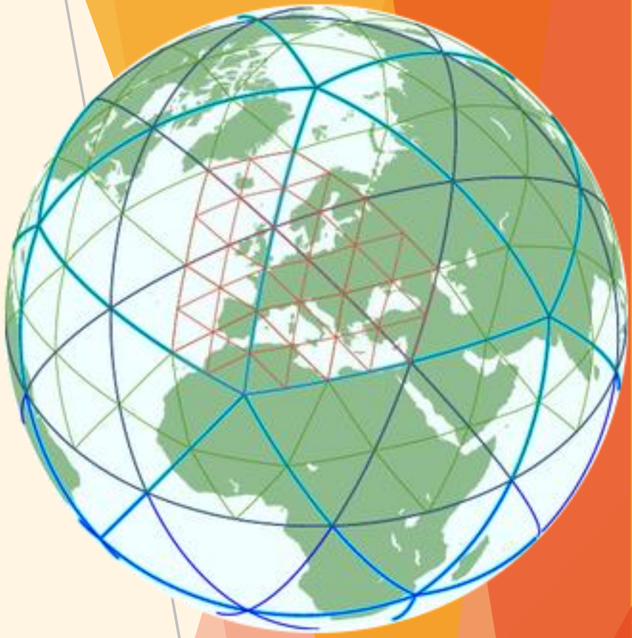
7th ENES HPC Workshop, May 9-11, 2022

ICON (ICOsahedral Nonhydrostatic model)

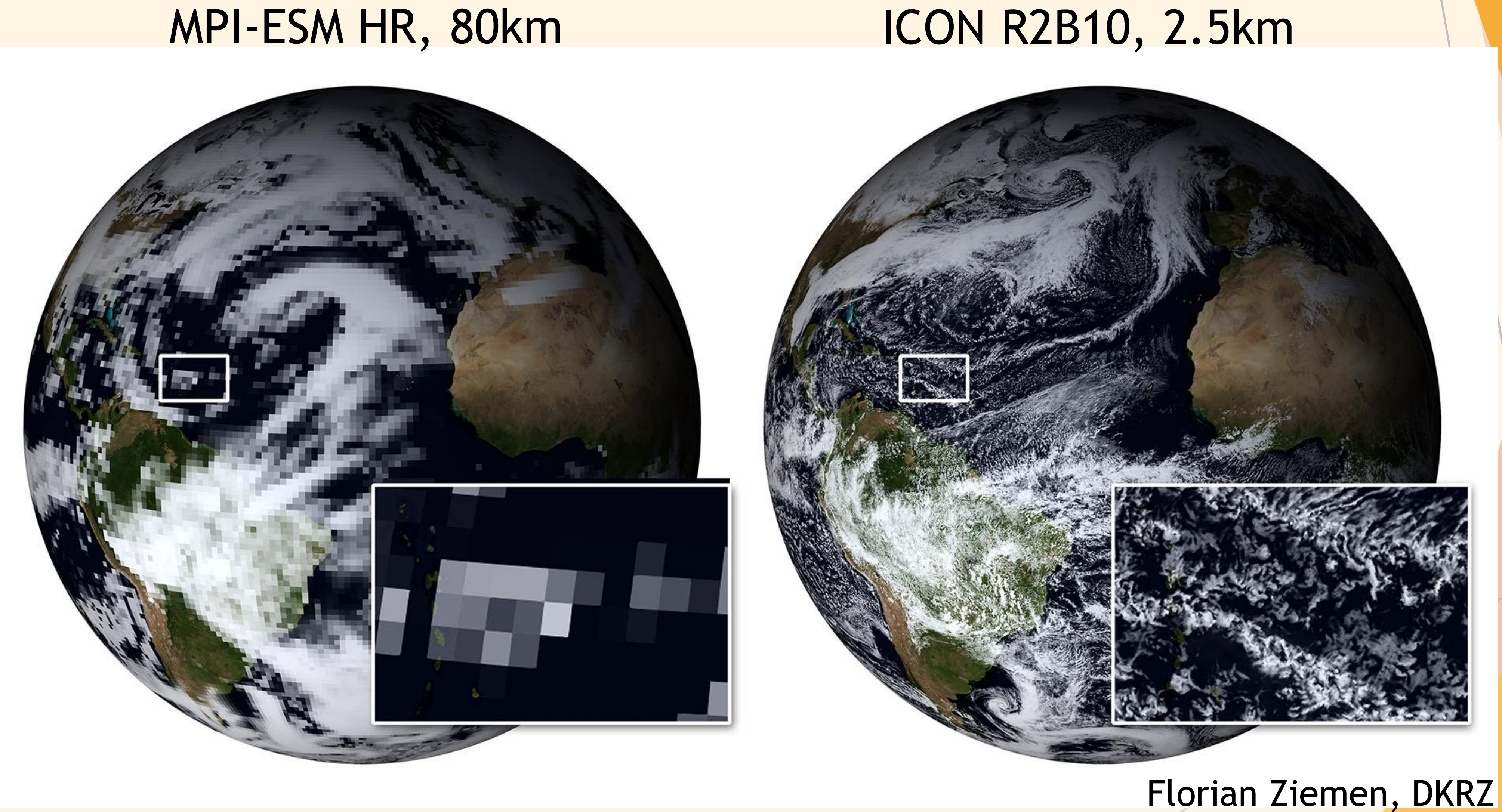
- ICON is a weather and climate model with atmosphere, ocean and land components
- Almost 2 decades development; initially by DWD and MPI-M, later also KIT and DKRZ and now also in collaboration with C2SM
- Mostly written in Fortran using MPI/OpenMP for parallelisation
- ~ 2 Million lines of code



ICON at km-scales

- HD(CP)^2 project enabled efficient km and hectometre (hm) scale applications over large regional domains
- These efforts enabled the use of ICON to perform the first global storm-resolving (SR) simulations in Europe
- ICON is one of only four models worldwide to have been run as an SR-ESM, i.e., coupled with km-scale resolution in the atmosphere and ocean

Simulation of clouds



MPI-ESM HR, 80km

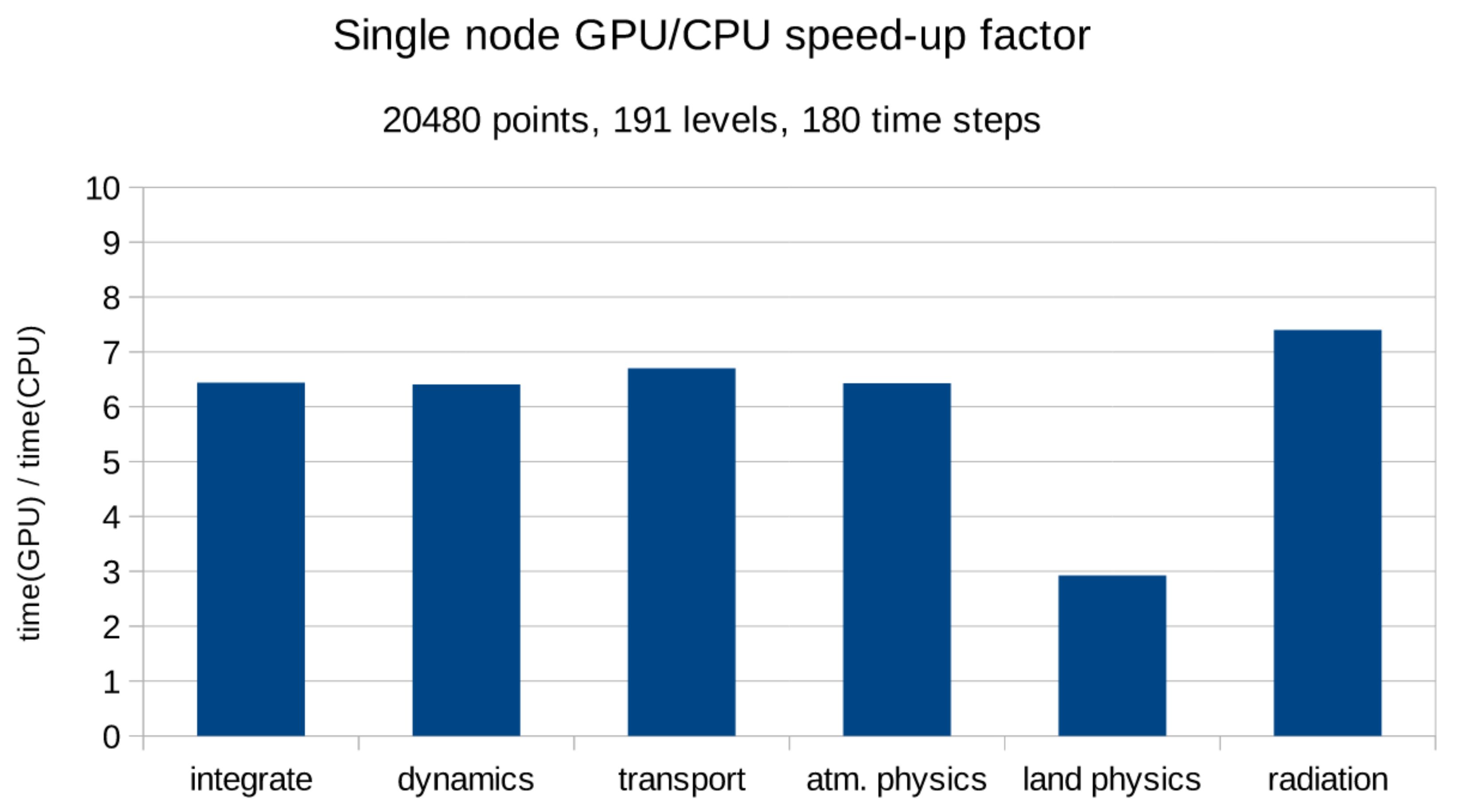
ICON R2B10, 2.5km

Florian Ziemen, DKRZ

ICON on GPUs

- GPU port of ICON-A motivated by the QUBICC project (Quasi-biennial oscillation in a changing climate) (Giorgetta et al., 2022)
- Decision to stay with ICON Fortran code base and add OpenACC directives for portability
- Need to replace the radiation scheme PSRAD with RTE-RRTMGP, which works efficiently on GPUs
- CLAW source-to-source translator used for the GPU port of the land component JSBACH

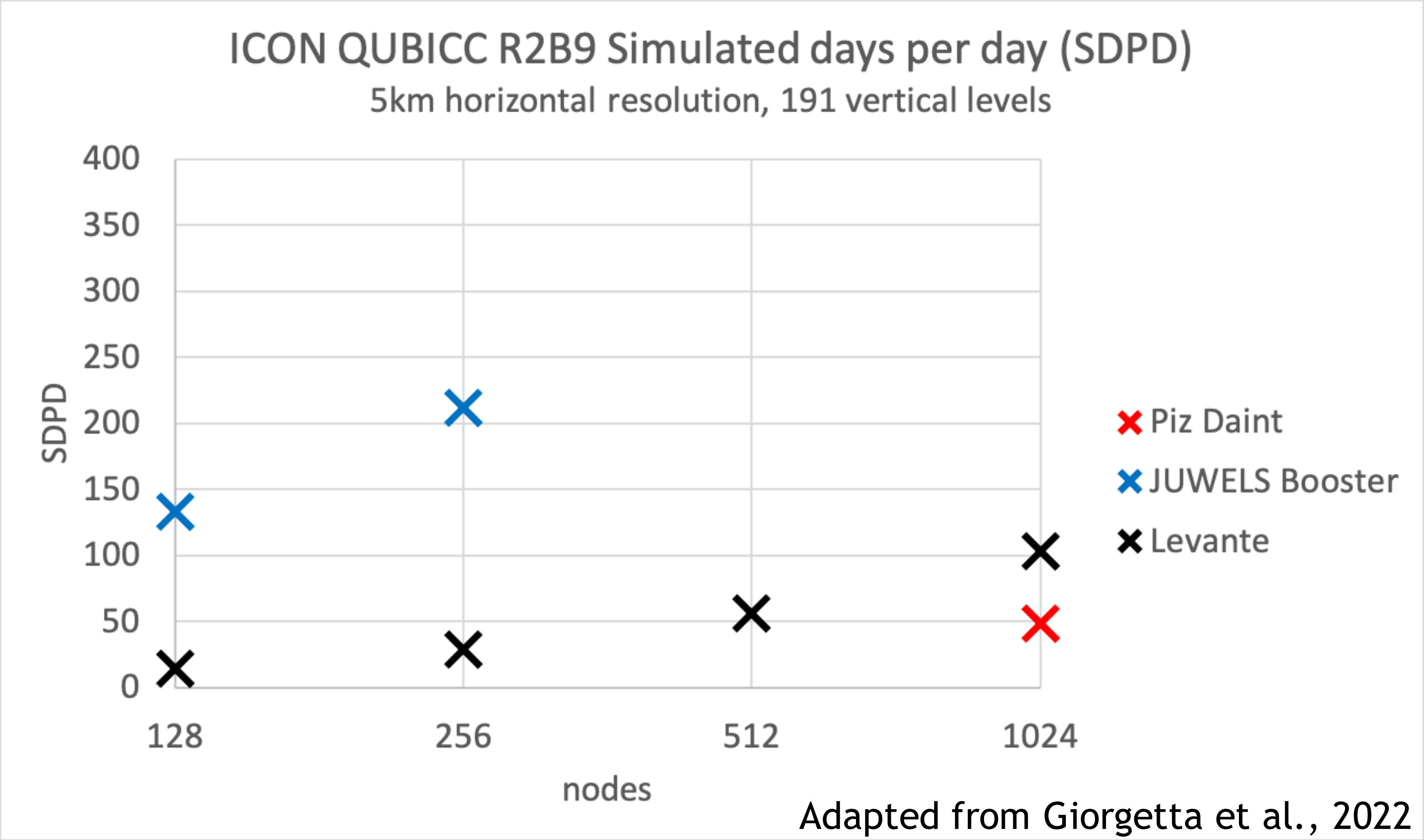
ICON on GPUs



On Piz Daint: Intel Xeon E5-2690 v3 CP and NVIDIA Tesla P100 GPU

Giorgetta et al., 2022

ICON on GPUs



Adapted from Giorgetta et al., 2022

ICON on GPUs - summary

- ICON-A successfully ported to NVIDIA GPUs using OpenACC directives, but…
  - CLAW tool for JSBACH no longer supported -> alternative needed
  - ICON-O not yet ported to GPUS -> work ongoing to run the coupled model hybridly on JUWELS with the atmosphere on the GPU partition and the ocean on the CPU partition
  - What about LUMI? Will the Cray compiler support sufficient OpenACC for the current ICON version to run on LUMI? Alternative: Source-to-source translation to OpenMP

Moving forward: (pre)WarmWorld and ICON-C

- **WarmWorld**: German national project initiative proposed to the BMBF hopefully starting in September 2022. Project partners: DKRZ, DWD, KIT, MPI-M, AWI, ECMWF, FZJ, JSC, Uni Köln, Uni Hamburg, Uni Leipzig
- **ICON-C**: Coordinated effort involving all ICON partners (C2SM, DKRZ, DWD, KIT, MPI-M) to rewrite ICON for scalable development on emerging architectures
- **preWarmWorld**: Preparatory project for WarmWorld; separately funded by BMBF; started in 2021; project partners: DKRZ, JSC, MPI-M

WarmWorld Goals

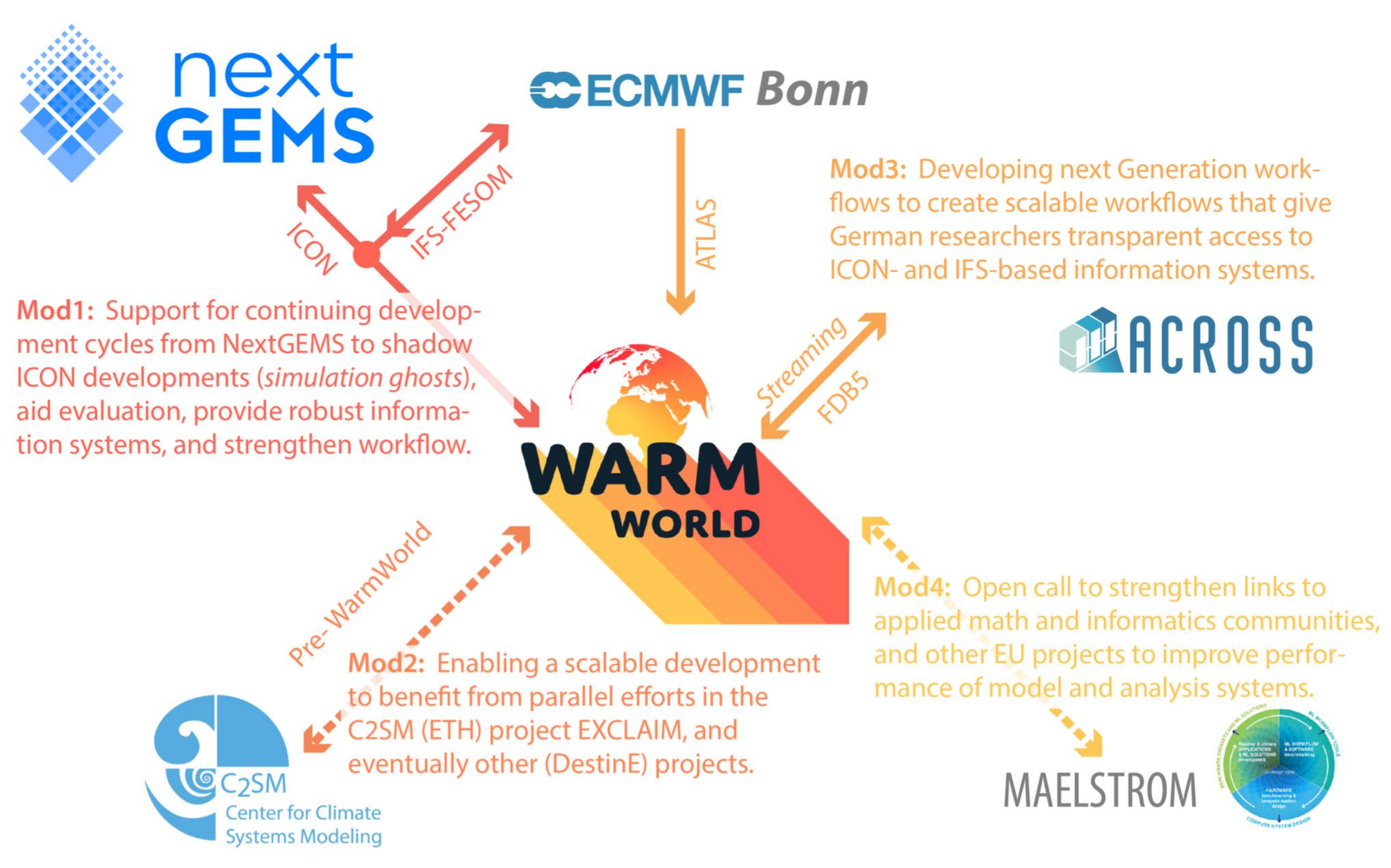
Assess the detailed trajectory of global warming and the quantitative implications of this warming for human and natural systems

- Coupled ICON running with an acceptable simulation quality on km scale > 0.5 SYPD by 2026
- **ICON-C**: A free and open source software implementation of the fully (land, ocean, atmosphere) coupled ICON to enable scalable development
- Integrated workflow to expose information of ICON alongside IFS-based solutions and observational data

WarmWorld Modules

- **Better**: Responsible for defining and testing the model configurations
- **Faster**: Responsible for transforming the ICON code base into an open, scalable, modularized and flexible code
- **Easier**: Responsible for developing novel methods to make information visible, accessible, and interoperable
- **Smarter**: Aims to involve the applied maths and informatics communities, to improve the workflow and the model performance

WarmWorld collaborations



Mod1: Support for continuing development cycles from NextGEMS to shadow ICON developments (*simulation ghosts*), aid evaluation, provide robust information systems, and strengthen workflow.

Mod2: Enabling a scalable development to benefit from parallel efforts in the C2SM (ETH) project EXCLAIM, and eventually other (DestinE) projects.

Mod3: Developing next Generation workflows to create scalable workflows that give German researchers transparent access to ICON- and IFS-based information systems.

Mod4: Open call to strengthen links to applied math and informatics communities, and other EU projects to improve performance of model and analysis systems.

Faster objectives

- Transform the ICON code base into an open, scalable, modularized and flexible code named **ICON-C** (“ICON-consolidated”).
- Refactor ICON with the goal of scalable development to enable portable performance improvements – ultimately making ICON faster
- Initiate target performance ports to meet throughput (>0.5SYPD on a 2.5km or finer grid) goals
- Progressively redefine the ICON code structure to expose areas of performance improvement for targeted exploration of new programming concepts

ICON redesign

- WarmWorld is just one piece of the puzzle towards ICON-C; larger coordinated effort involving all ICON partners
  - Balancing between different needs: Operational numerical weather forecast and cutting-edge climate modelling
- EXCLAIM (ETH Zürich): **Ex**treme scale **c**omputing and data p**la**tform for cloud-resolving we**a**ther and cl**i**mate **m**odelling
  - Approach: Re-write ICON code into a descriptive user code based on Python, which is then translated into standard imperative language (e.g. C++) for specific architectures using a toolchain based on GT4Py (GridTools for Python)

ICON realities

- ICON is largely monolithic:
  - Huge code base is compiled in
  - Namelists are used to (de-)activate large tracts of code
  - Minimal unit testing
- Git submodules are used, but only few can be decoupled from compilation
- Components are not cleanly separated
- Uses complex derived types
- Contains unused code

ICON-C first development steps

- Refining the Development Process
- Implementation of a disable functionality, initially via #ifdef, and clean-up
- Modularisation of components: Proposal and prototypes
- Prototype Data Management
- Infrastructure Measures
- Testing Hierarchy and Tools

preWarmWorld

- Funded by the BMBF as a separate project to prepare for **WarmWorld** and to facilitate timely coordination with external projects such as EXCLAIM
- Provide a technical blueprint in terms of modularization and programming paradigms
- Overlap between the latter phase of **preWarmWorld** and the start of **WarmWorld** allows these plans to be coordinated before delivering the development environment (repository, test structure, licenses) for use in **WarmWorld**

Planned assessment of programming paradigms in preWarmWorld

- Evaluation, comparison and prototypical implementation of selected modules using modern programming paradigms targeting heterogeneous hardware
- Implement granule using GridTools framework
- Implement granule using a *generic DSL*, like AnyDSL
- Implement granule using a *domain independent generic library*, like Kokkos and/or DPC++ / SYCL
- Implement granule using the concept of an *embedded DSL*
- Analyse the applicability and, if suitable, implement the interfacing of the above concepts to the front-end developed in the ESCAPE2 project

Summary and Conclusion

- ICON-A successfully ported to (NVIDIA) GPUs using OpenACC
- Significant rewriting and refactoring of ICON is needed for scalable development on emerging architectures => **ICON-C**
- **preWarmWorld**: Assessment of programming paradigms and modular software blueprint
- Steps are underway in **preWarmWorld** together with partners in **ICON-C** and EXCLAIM to
  - rewrite the memory management in C++ with a C-Fortran interface
  - prepare a stand-alone version of the atmospheric tracer advection as a playground, on which to try out different programming paradigms

References

- Giorgetta, M. A., Sawyer, W., Lapillonne, X., Adamidis, P., Alexeev, D., Clément, V., Dietlicher, R., Engels, J. F., Esch, M., Franke, H., Frauen, C., Hannah, W. M., Hillman, B. R., Kornblueh, L., Marti, P., Norman, M. R., Pincus, R., Rast, S., Reinert, D., Schnur, R., Schulzweida, U., and Stevens, B.: The ICON-A model for direct QBO simulations on GPUs (version icon-cscs:baf28a514), EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-152, 2022.

Thank you for your attention!