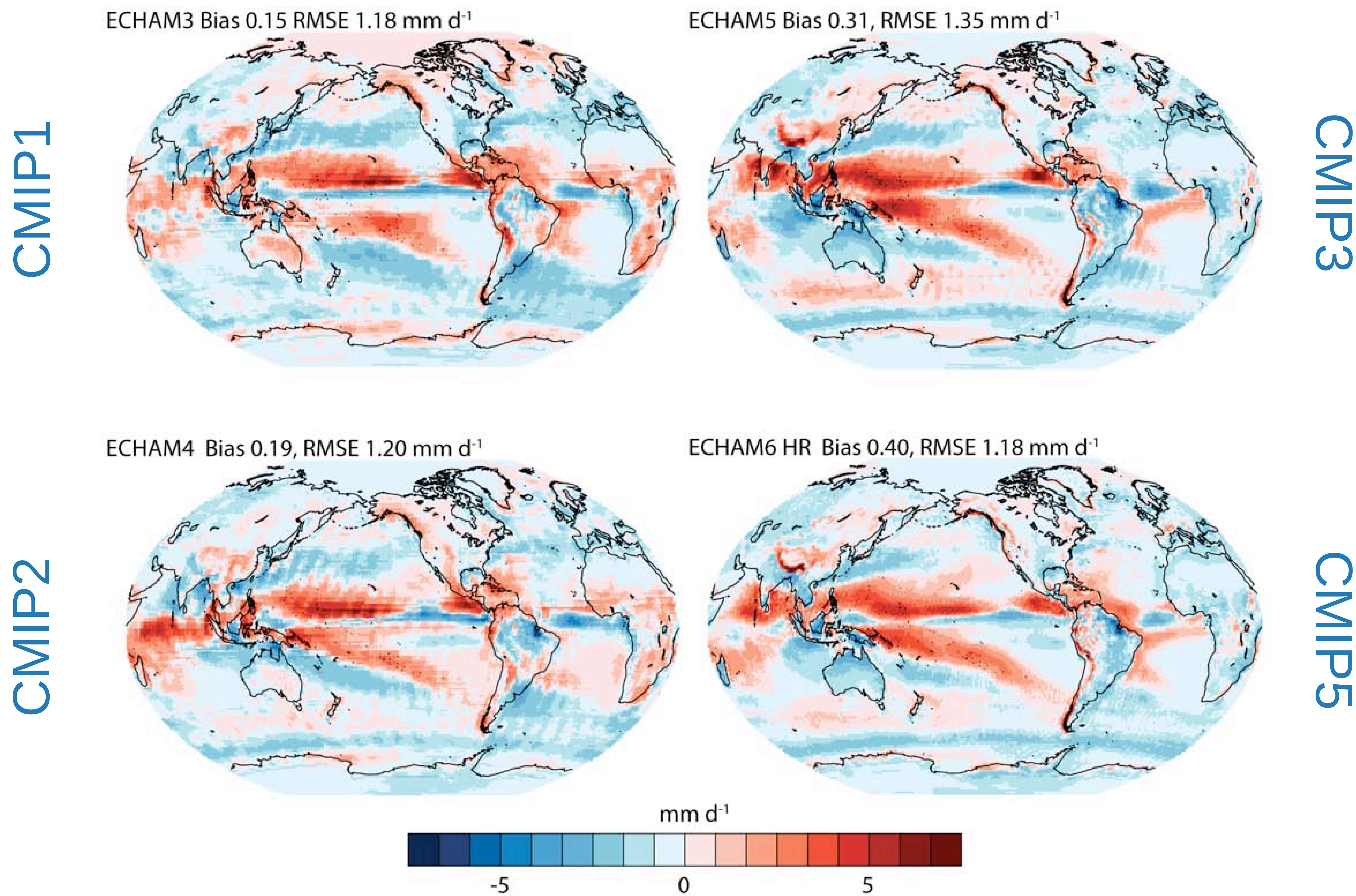
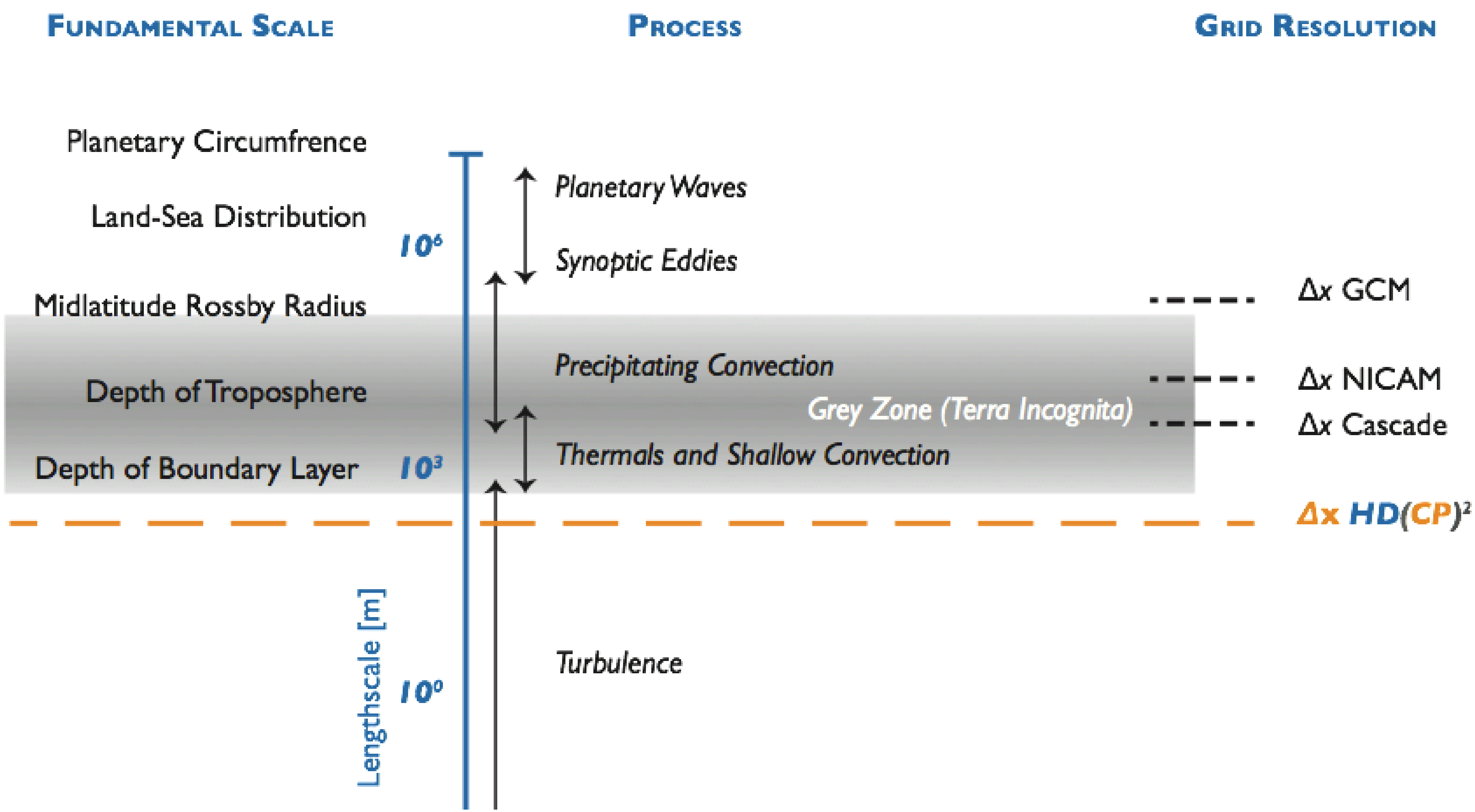
High Definition Clouds and Precipitation for Climate Prediction

Bjorn Stevens, Joachim Biercamp, Ulrike Burkhardt, Susanne Crewell, Sarah Jones**, Andreas Macke, Axel Seifert, Clemens Simmer** and Johannes Quaas

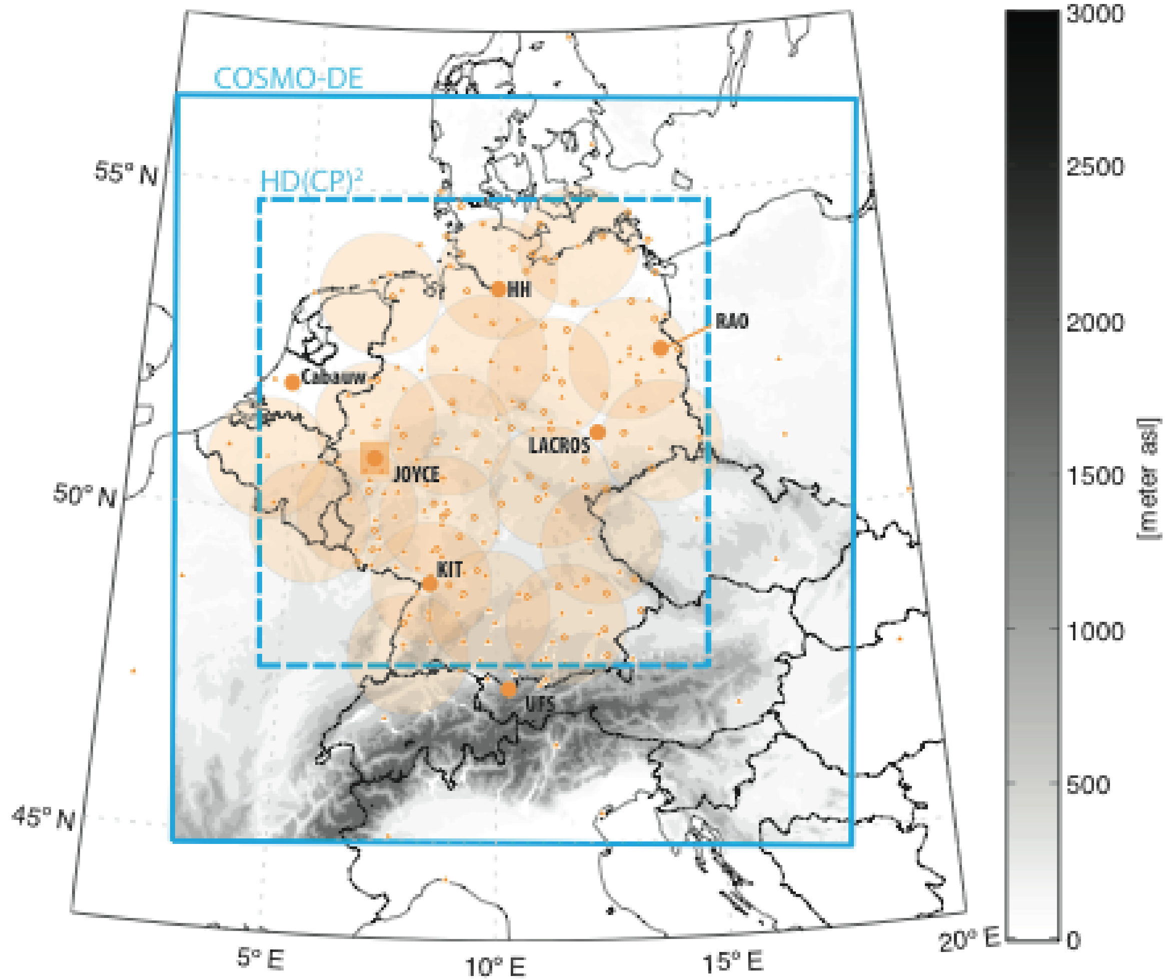
Precipitation (circulation) biases from 20 years of ECHAM



The Grey Zone



ICON and a Mature Observational Network

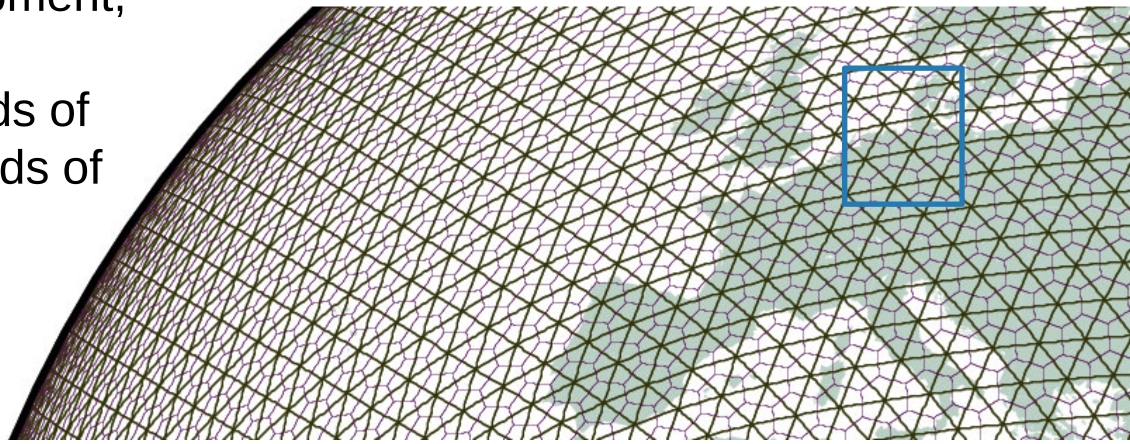


Across Germany, and Europe more broadly, is an unprecedented observational network, with supersites at CABAUW, RAO (Lindenberg) and other locations that are comparable to the best instrumented sites anywhere in the world.

Missing: coordination and standardization.

DWD and MPI have embarked on an ambitious new model development, ICON. The ICON1 release is scheduled for 2012 and will become operational at DWD in 2013. ICON is designed around the demands of High Performance Computing, and the stricter conservation demands of Climate Modeling.

Missing: a basis for broader community involvement and an extension to finer scales.



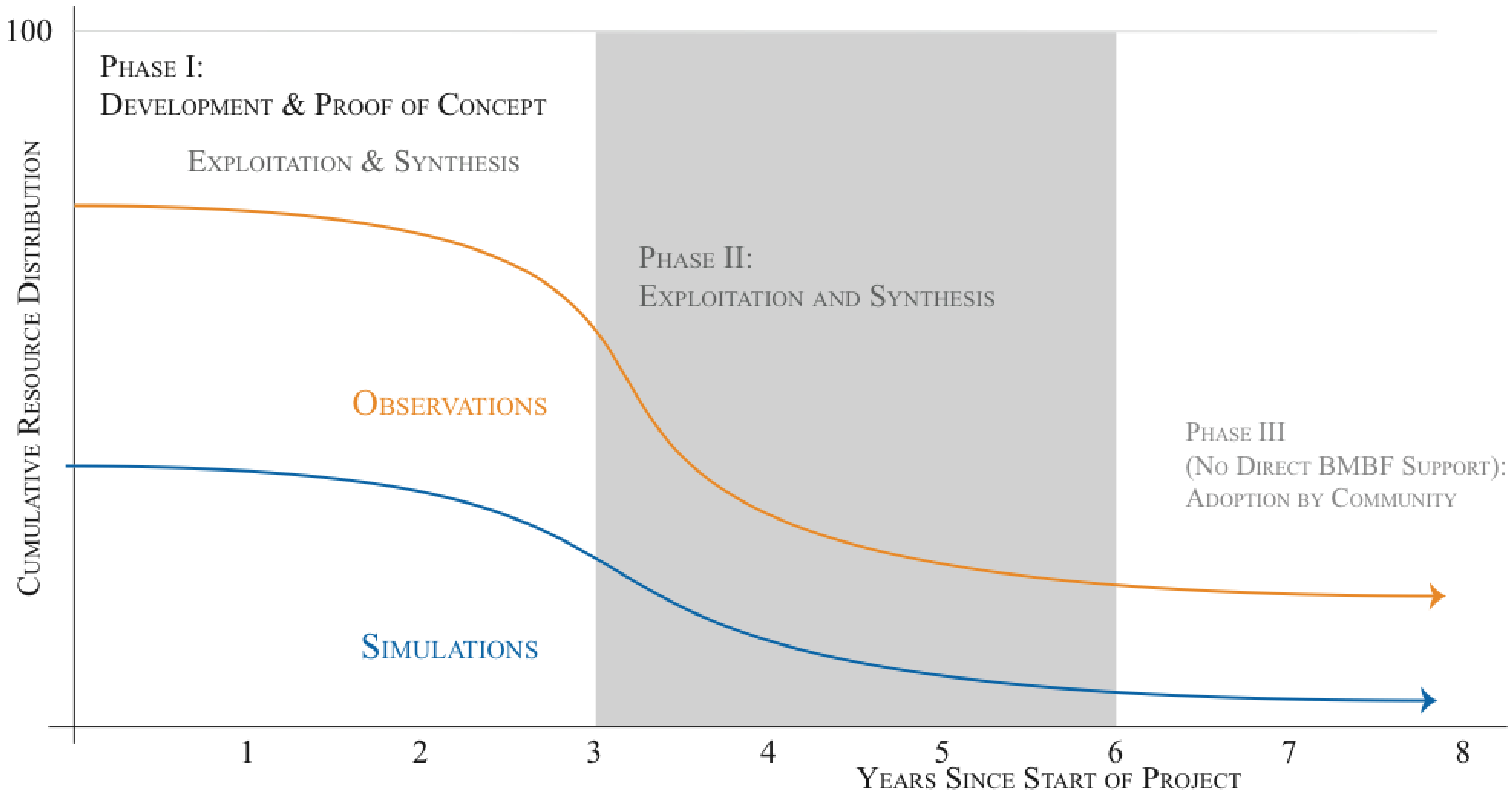
The HD(CP)^2 Initiative

A ***coordinated two phase project*** that will develop high definition modeling and observations to improve the representation and understanding of clouds and precipitation (CP) for climate prediction.

- ➡ ***Improved Climate Prediction:*** to significantly improve the CP representation in climate models
- ➡ ***Quantification of Uncertainty:*** to quantify how much of the imprecision in current climate projections one can expect to eliminate through an improved CP representation.
- ➡ ***A Great Leap:*** to place national research efforts at the forefront of international efforts to harness new breakthroughs in computing and sensing.

… today we are presenting the proposal for the first phase, roughly 11 M€ for three years, to develop the proof of concept

HD(CP)² Overview



*… a **coordinated two phase** project where the first phase concentrates resources in the development of infrastructure and a demonstration of the proof of concept.*

HD(CP)² Overview (three essential figures)

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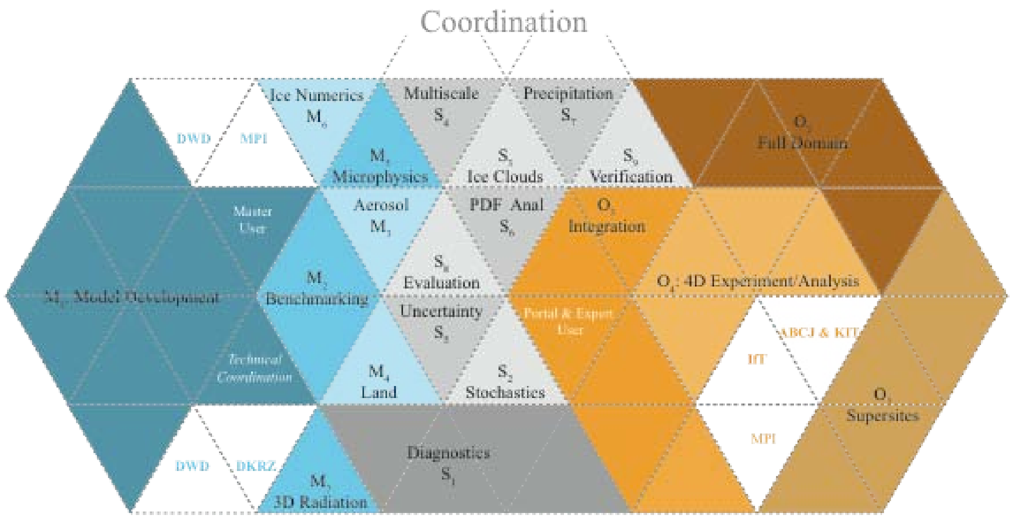

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Institution	Module	Overview	PI	Main Links	PM	k€
MPI	Coordination	Project Management	Stevens/Crewell/Burkhardt	M, O , S	36	285
DKRZ	M1	Optimization, Parallelization, Workflow, Technical Coord.	Biercamp/Adamidis/Ronneberger	M2, S1	144	823
DWD	M1	Numerics, Initialization	Zängl	M2, M4, S1	72	405
FZJ	M1	Parallelization	Hoffmann	S1, M2	36	214
KIT	M1	Optimization	Heuveline	S1, M2	36	214
MPI	M1	Physics, Master User	Giorgetta	M2, M5, S1	72	403
IMuK	M2	Benchmarking, Land Surface	Raasch	M1, M4, O4	36	213
MPI	M2	Benchmarking, Microphysics	Stevens	M1, M3, O4	36	203
IfT	M3	Aerosol Initialization	Tegen	M2, M5, S5	18	111
KIT	M3	Aerosol Initialization	Hoose	M2, M5, O4	18	142
KIT	M4	Land Surface	Kalthoff	M2, M7, O4	36	214
MPI	M5	Next Generation Microphysics	Seifert	M3, S2, S8	36	204
Mainz	M6	Microphysics and Numerics	Spichtinger	M1, M2, S4	24	143
LMU	M7	3D Radiation	Mayer	M1, M2, O3	36	220
DWD	O1	Contribution to data flow and case studies	Lehmann/Görsdorf	M2, M4,O3	36	215
IfT	O1	Ice Clouds and Aerosols	Ansmann/Wandinger	M3, O4, S3	36	215
FZJ	O1	Contribution to data flow and case studies	Bohn	M2, O3,O4	24	208
IGMK	O1	IDVAR (Thermodynamic Retrievals)	Löhnert	M2, O2,O4	60	356
LIM	O1	Water Vapor and Entrainment	Pospichal	O2, O4	24	141
MIUB	O2	Precipitation	Simmer/Trömel	O4, S7	36	215
FUB	O2	Irradiances (albedo, OLR)	Fischer	M7, O3, O4	36	215
IfT	O2	Integration and Synthesis	Deneke	O3, S1	24	109
IGMK	O2	Water Vapor and Clouds	Crewell	M2, O3, S1	36	215
LIM	O2	Integaration and Synthesis	Quaas	S3, S6, S8	60	356
Köln-CS	O3	Database for LES Scales	Lang	M2, O1, S1	36	215
IGMK	O3	Database for LES Scales	Crewell	M2, O1, S1	18	109
LMU	O3	Forward operators	Mayer	M7, O2, O4	24	141
UHH	O3	Expert User, Perfect Model, Precip Verification	Ament	M2, O4, S7	72	356
MIUB	O4	Precipitation	Simmer	S1, O2, O4	18	109
IfT	O4	Microphysics and Closure	Siebert/Macke	M2, M5, O1	72	427
IPM	O4	Moisture (remote sensing)	Wulfmeyer	O1, O2, O3	36	282
KIT	O4	Surface measurements	Kalthoff	M4, O2	36	211
MPI	O4	Clouds (remote sensing)	Kinne	M7, O2, S8	18	109
DLR	S1	Diagnostics (Feature Tracking)	Jöckel	M1, S2, O4	56	599
FUB	S1	Diagnostics (Feature Identification)	Klein/Hege/Horenko/Spichtinger	M2, S1	36	194
Köln	S1	Diagnostics (Turbulent Budgets)	Shao	M2, M4, O4	24	141
LIM	S1	Diagnostics (PDF Schemes)	Quaas	S2, S3, S6	18	107
LMU	S2	Stochastic Convection	Craig/Dörnbrack	M5, O2, S1	36	214
DLR	S3	Ice Cloud Parameterization	Burkhardt/Kärcher	M2, M5, O2	28	300
Mainz	S4	Multiscales and Microphysics	Spichtinger/Klein	O4, S6, M6	36	214
DWD	S5	Ensembles	Köhler/Jones	M2, S3, S1	36	205
LIM	S6	PDF Cloud Schemes	Quaas	S1,O1,O2	18	107
MIUB	S7	Precipitation Features	Trömel/Simmer	M2, O2, O4	36	214
DWD	S8	Evaluation	Wapler/Jones	M2, O2, O3	36	205
MIUB	S9	Verification	Friederich	M2, O3	36	214
Sum					1734	10712

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Institute	Model (PM)	Obs (PM)	Synth (PM)	Total (PM)	Principle investigators
IMuK	36			36	Raasch (36)
IPM		36		36	Wulfmeyer (36)
Mainz	24		36	60	Spichtinger (60)
FZJ	36	24		60	Hoffmann (36); Bohn (24)
FUB/ZIB		36	36	72	Fischer (36); Hege/Klein (36)
UHH		72		72	Ament (72);
DLR			84	84	Burkhardt (28); Jöckel (56)
LMU	36	24	36	96	Mayer (60); Craig (36)
LIM		84	36	120	Pospichal (24), Quaas (96)
KIT	90	36		126	Heuveline (36); Hoose (18); Kalthoff (72)
MIUB		54	72	126	Trömel (45), Simmer (36; 18), Friederichs (36)
DKRZ	144			144	Biercamp (72); Adamidis (36), Ronneberger (36)
IfT	18	132		150	Tegen (18), Siebert/Macke (72), Deneke (24), Ansmann (36)
IGM/CS		150	24	174	Löhnert (60); Crewell (54); Lang (36); Shao (24)
DWD	72	36	72	180	Zängl (72); Jones,Köhler (36), Wapler (36); Lehmann (36)
MPI	144	18	36	198	Stevens (72); Seifert (36); Giorgetta (72); Kinne (18)
Total	600	702	432	1734	828 to Universities (excluding KIT/Kalthoff)

… the project is broken down into three modules which provide the framework for 45 projects led by 42 investigators, with roughly 11 M€ requested to support 1734 person months (roughly 50 postdocs over the course of the project).

HD(CP)^2 Phase 1 Objectives: Model | Observations | Synthesis

- Proof of concept, which we define to be the provision of a series of high-resolution summer-season hind-casts over Germany (and some part of NW Europe) **with a highly scalable model over a grid whose element spacing is approximately 100 m and whose outer dimension is 1000-1500 km.**
- To evaluate and develop encapsulations of relevant data, including statistical properties, over different spatio-temporal scales in order to enable the critical assessment of the HD(CP)^2 simulations, as well as tools to enable model-data intercomparison
- To develop frameworks for the parameterization of CP in climate models, with the help of both the HD(CP)^2 simulations and observations; to devel methods for the evaluation of both the parameterizations and the simulations; and to prepare and implement the necessary diagnostics as well as data processing and analysis methods relevant for the parameterization development and evaluation.

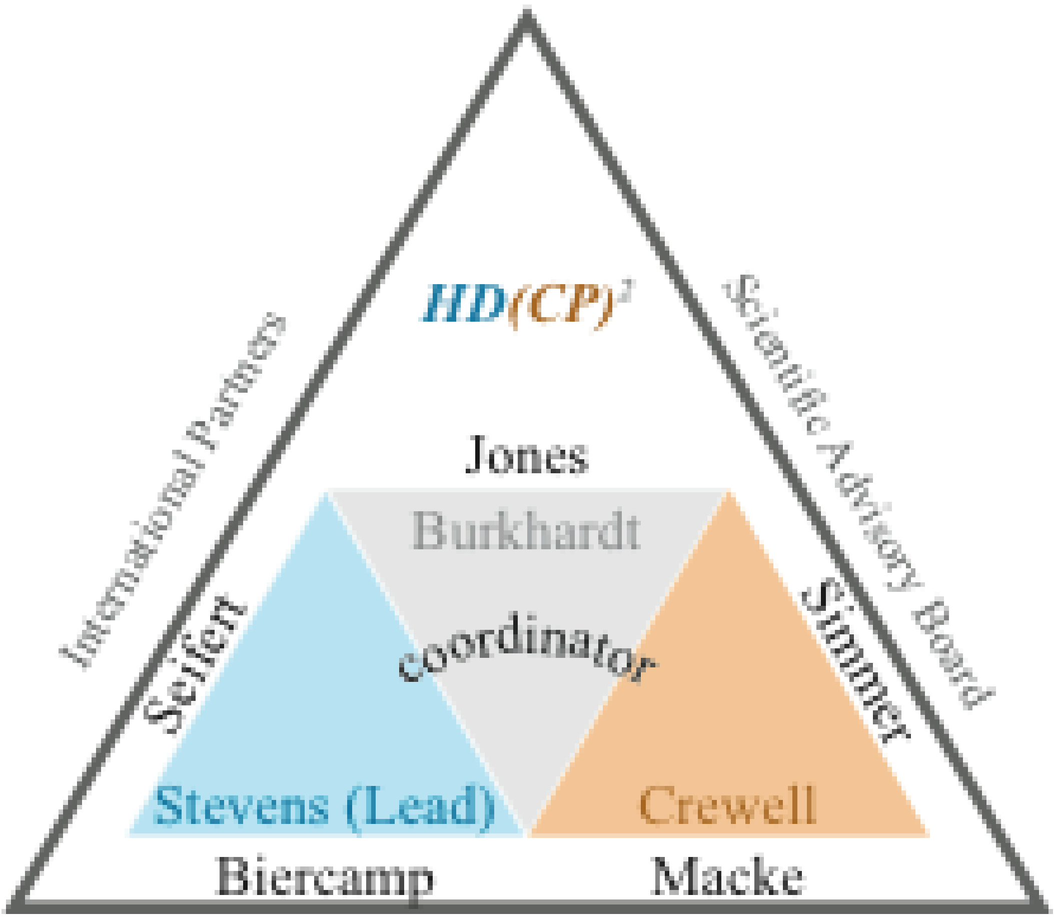
… during Phase I roughly 40% of the resources go to modeling, 40% to observations, and 20% to Synthesis

HD(CP)^2 Overview (notes on project selection)

- Excellence was the first criterion
- Sixteen institutions are involved, throughout Germany
- Roughly half of the resources are distributed over slightly more than one third of the institutions.
- Modules are associated with geographic centers of gravity: **modeling is concentrated in Hamburg/Offenbach;** Observations in Köln/Leipzig; and Synthesis in Munich/Bonn.

  However this concentration is not exclusive: projects were also selected so as to involve the model development with the observations, the observations with the synthesis and so on. … our Ying Yang principal.
- **The project leverages significant resources of participating institutions, particularly investments in modeling (ICON at DWD/MPI)** and observations (IfT/Köln/Jülich) by the respective centers.
- A small number of exploratory projects were initiated to begin involving the community in the HDCP development … priming the pump for phase II.
- A mix of young and experienced investigators

HD(CP)^2 Project Management



Scientific Coordinator (negotiating)

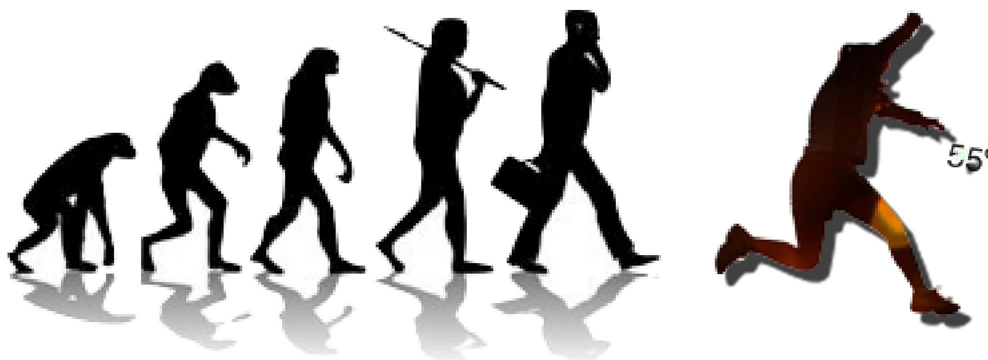
Scientific Advisory Board:
- •Tom Ackerman (U Washington)
- •Sandrine Bony (CNRS-LMD)
- •Christoph Schär (ETH)
- •Thomas Schulthess (ETH/CSCS)
- •Pier Siebesma (KNMI/Delft)

External Partners (in discussion)

$HD(CP)^2$ *Organizational Elements*

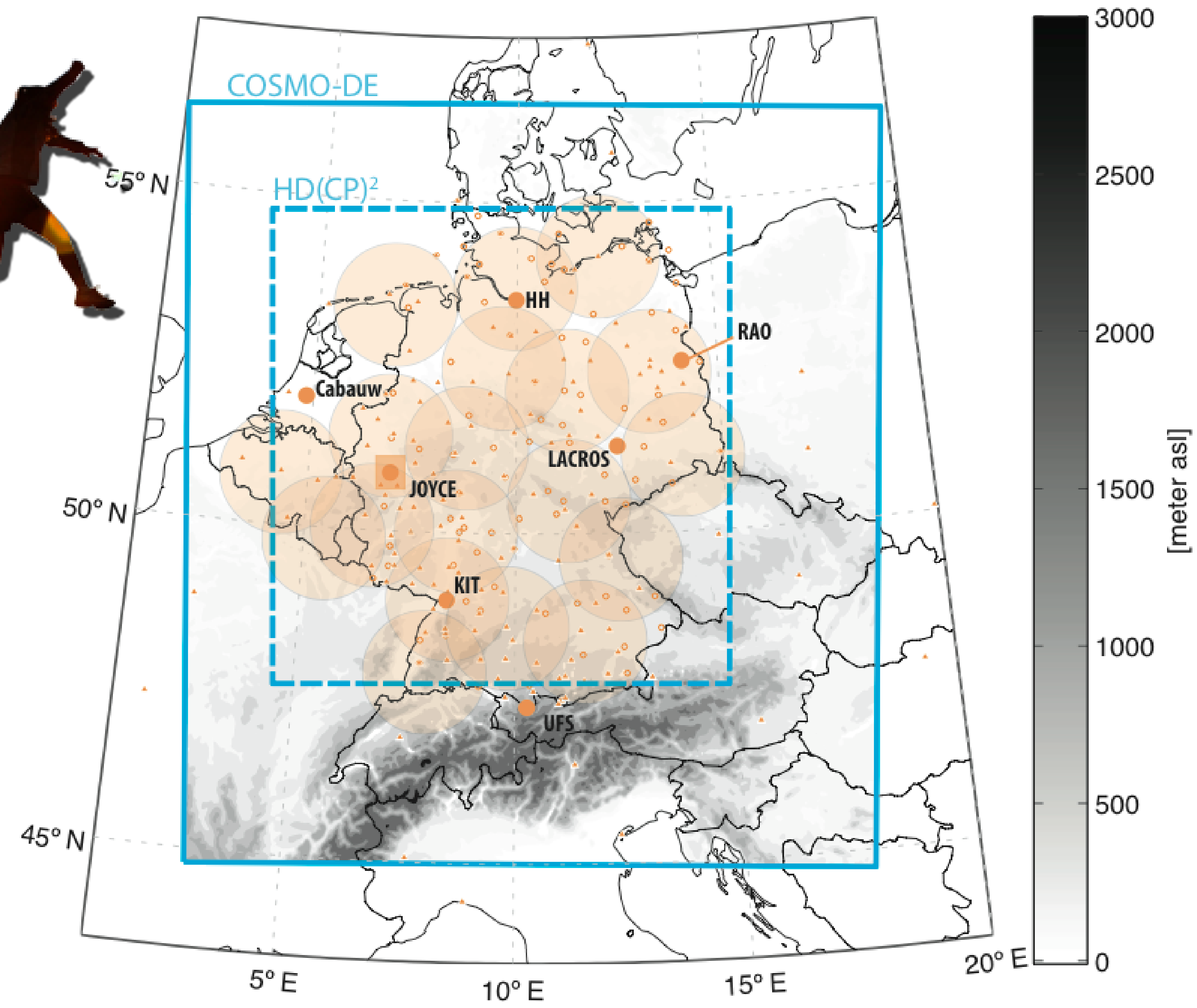
- **Coordinator** reports to lead-PI and works closely with expert users and technical coordinator.
- The introduction of **expert users and technical coordinator** is an innovation designed to aid project management.
- Centers of gravity give some organic cohesion, but project identity and broader cohesion to be introduced through **twice yearly project meetings** (all hands).
- Funding for smaller cross work-package meetings and work exchange. Several of the projects propose **small focused workshops** to initiate their activities and aid in critical decision making (for instance what target computational architectures to work toward).
- Pre-conference (no cost) Ringberg workshop (**Toward Global LES**) being organized by MPI to "hopefully" kick-off the workshop.
- An international project conference entitled: **High-definition modelling and observations of clouds and precipitation for climate prediction** to be organized at the end of the first phase to help disseminate the fruits of the project.

HD(CP)² Model Module



The Great Leap:

A Community Model for Exascale Computing



P. Adamidis, J. Biercamp, M. Giorgetta, C. Hoose, N. Kalthoff, M. Lukácová, B. Mayer, K. Ronneberger, S. Raasch, A. Seifert, P. Spichtinger, **B. Stevens,** I. Tegen, G. Zängl

HD(CP)^2 Model Module

Most of the effort is in a coordinated model development project. But this is purposely isolated from the broader community, and some of the experimental issues related to model configuration.

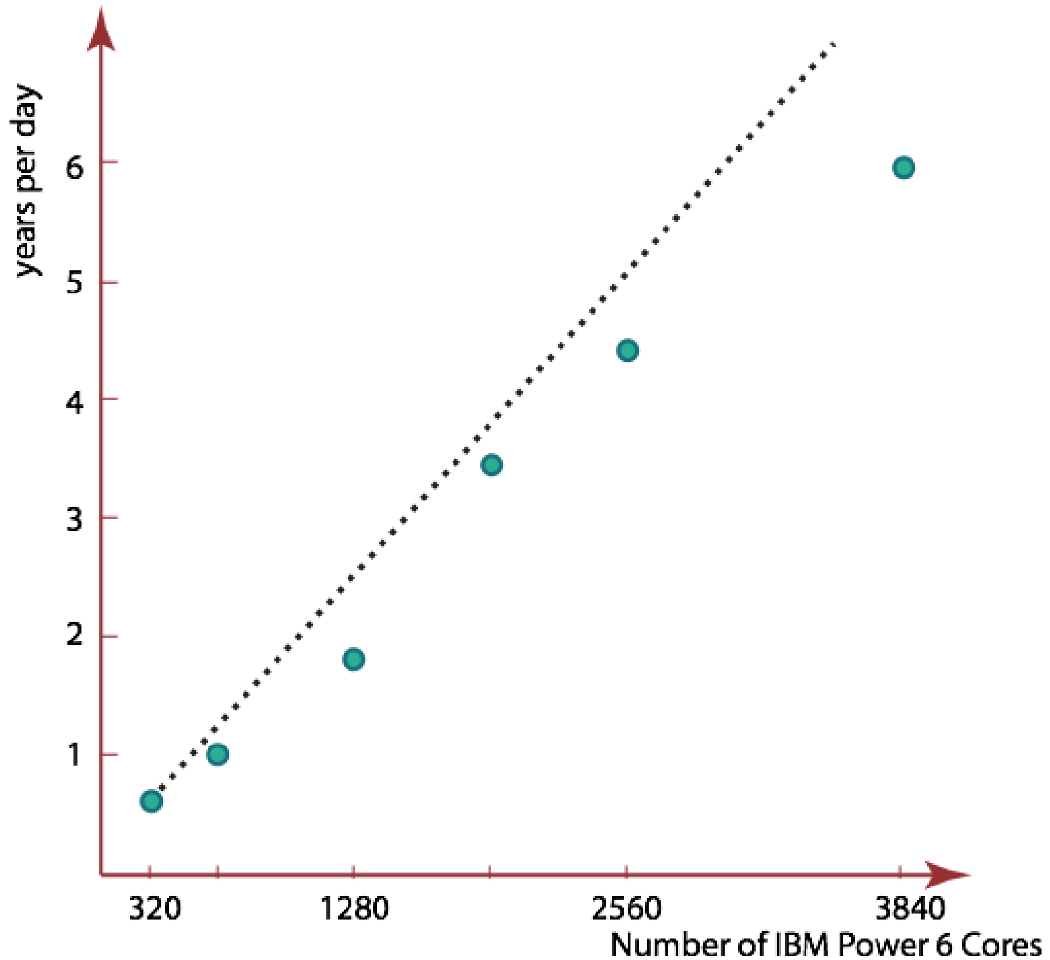
HD(CP)^2 Key Model Module Concepts

- Main Issues that must be solved are incorporated in M1, main model module, which is kept somewhat isolated from the rest of the project.
- External data and best practice issues addressed in smaller PI lead projects (M3-M7).
- **Benchmarking project** M2 is a central component of the module, it is introduced to resolve the purposeful isolation of the model builders, and provide working data for the rest of the project as the model is being constructed.
- The **master user** and **technical coordinator** have been introduced to help keep the project focused and on track. They will manage most of the communication through the project.

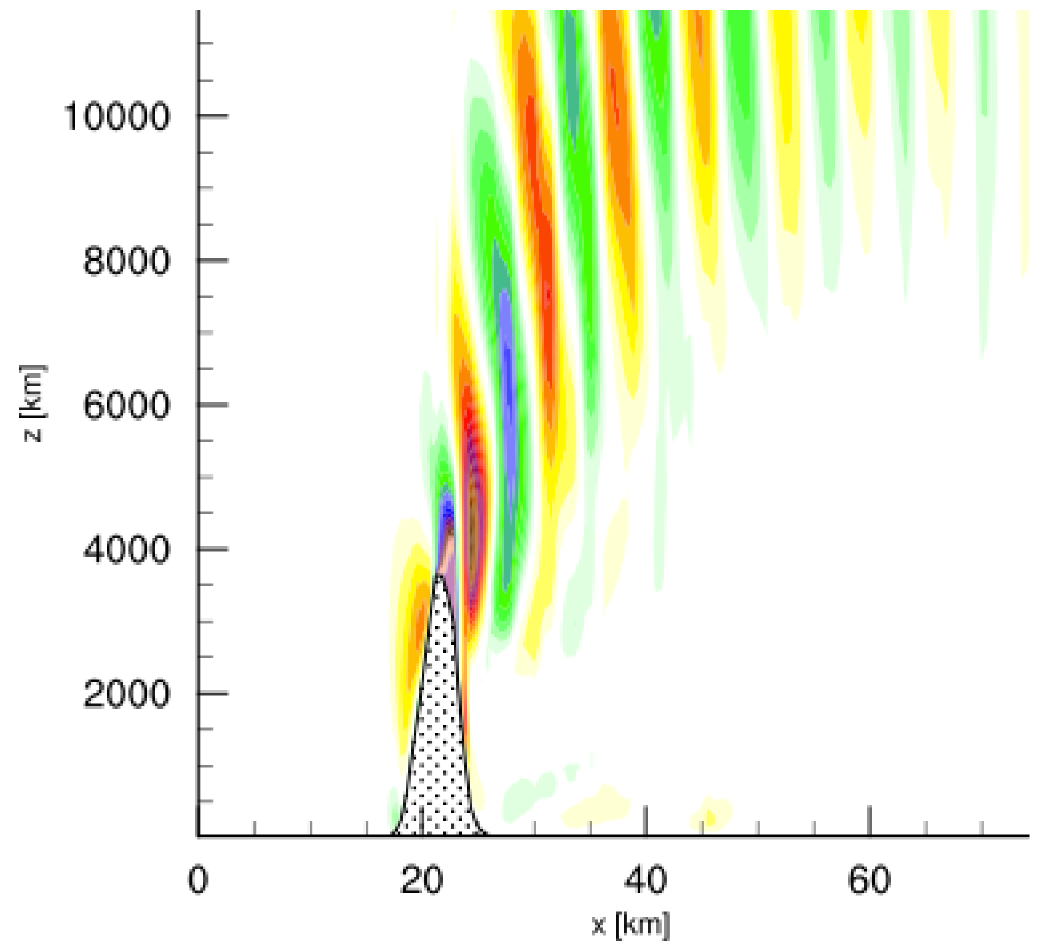
Forward Momentum

The ICON development at DWD & MPI is coming into maturation; the project will benefit from basic research conducted as part of ScaLES (BMBF), and ongoing work as part of ICOMEX (G8)

Preliminary Versions of ICON hold promise



Scaling of model is already quite reasonable. Here we show tests with R2B7 (35 km) out to 4000 cores, tests at higher resolution at DWD show scaling out to 8000 cores.



ICON already out performs COSMO-DE over steep terrain, it is stable for slopes as large as 60º, roughly twice the stability limit of COSMO-DE

Project M1: HD(CP)^2 Model Development (Workpackages)

WP 1: Dynamics Implementation (G. Zängl, DWD) 2FTE at DWD

-Adjust core (subgrid turbulence model) to the needs arising from very high resolution

-Initial and boundary data provision (housekeeping)

WP 2: Physics implementation and testing (B. Stevens and M. Giorgetta, MPI) 2FTE

-Implement LES scale (standard) physical parameterizations.

-**Master (Expert) User**

WP 3: Software integration, parallelization and optimization (J. Biercamp and P. Adamidis, DKRZ) 2 FTE at DKRZ, 1 FTE at FZJ, 1 FTE at KIT

-Parallel I/O

-Optimization of communication

-Hybrid/Multilevel Parallelization

-**Technical Coordinator**

This is actually a relatively small project that leverages investments in ICON by MPI-M (Hamburg) and DWD

WP 4: Framework and Workflow (J. Biercamp and K. Ronneberger, DKRZ) 2 FTE

-Scripting

-Building on tools developed in METAFOR (EU) and C2-INAD (BMBF)

Project M2: Benchmarking

To develop a suite of benchmarks for use by the HD(CP)^2 community, and explore uncertainties associated with incomplete input data (land surface, aerosol, and remaining parameterizations)

Two groups with established experiences in different aspects of LES modelling

-The PALM group led by S. Raasch (Univ Hannover) has expertise in land surface interactions

-The UCLA-LES group led by B. Stevens (MPI-M) has experience with clouds, convection and precipitation

Will deliver high-resolution, large-domain output to project partners in the first year

-Idealized CBL

-***HD(CP)^2*** **prototype simulations, HPS (semi-idealized diurnal cycle) and Workshops**

-Stable boundary layer effects

-Microphysics and Convection (Leveraging activities at Clouds and Convection HeRZ at MPI-M)

-Land surface and heterogeneity (Leveraging experiences at Univ Hannover)

Overlap and cooperation with PI lead projects in Model Module

-Land surface modeling (Kalthoff)

-Aerosol (Tegen & Hoose)

-**Contributing to the quantification of uncertainty**.

Projects M3-M7

To develop appropriate input data sets and explore possible improvements to the HD(CP)^2 model.

- Aerosol
- Land Surface
- Microphysical Processes
- Numerical Methods (Microphysics)
- Radiation

The base HD(CP)^2 model is being developed around standard and simple approaches to physical parameterization, as have developed within the LES community over the past years. But it is not clear that this is the best approach. These projects are, for the most part, designed to help us address this issue.

HD(CP)² Model Module Summary (and Milestones)

- **<u>The model project will deliver a model.</u>**
  (highly scalable model over a grid whose element spacing is approximately 100 m and whose outer dimension is 1000-1500 km.)
- The benchmarking will help us evaluate it against established codes.
- The benchmarking will provide previews of HD(CP)² like data, for evaluation and synthesis activities, as well as for comparison with observations (4D Experiment)
- Small single PI projects will, together with the benchmarking, explore uncertain aspects of the HD(CP)² model and its configuration (input).
- The project will tell us if 3D radiative effects, or further refinement in the microphysics, or the scale at which land surface data is provided, substantially affect the statistics of the HD(CP)² model.
- The project will provide the first high-resolution simulations of the diurnal cycle, and with them an understanding of the role of the nocturnal boundary layer on the daytime development.

HD(CP)² Model Module Summary (and Milestones)

- Positively reviewed
- 10+ Mio € for total project (first phase = 3 years)
- 40% of which for Model Development

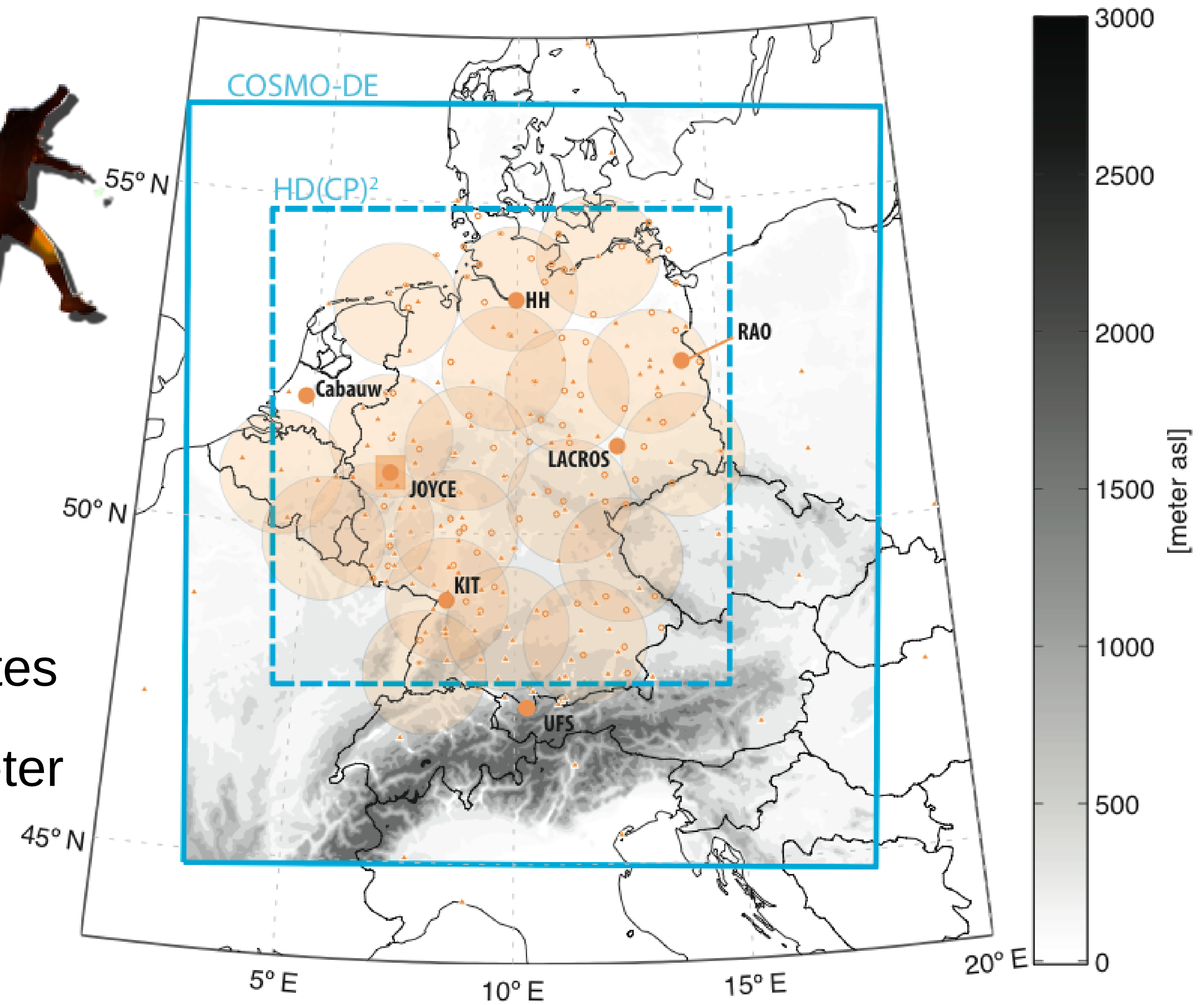
- Start in summer 2012 with a small stakeholder workshop
- Start hiring process in July 2012

- Start working in Autumn 2012

$HD(CP)^2$ Observations Module

The Great Leap:

Data integration over germany for clouds and precipitation



- Supersites
- Ceilometer
- GPS

Ament, F., A. Ansmann, B. Bohn, **S. Crewell**, H. Deneke, J. Fischer, N. Kalthoff, S. Kinne, U. Lang, V. Lehmann, *U. Löhnert*, *A. Macke*, B. Mayer, B. Pospichal, *J. Quaas*, H. Siebert, C. Simmer, S. Trömel, U. Wandinger, V. Wulfmeyer