Clouds, circulation and climate simulations

Marco Giorgetta[1], Anurag Dipankar[1]
Panos Adamidis[2]

(1) Max Planck Institute for Meteorology, Hamburg
(2) German Climate Computing Center (DKRZ), Hamburg

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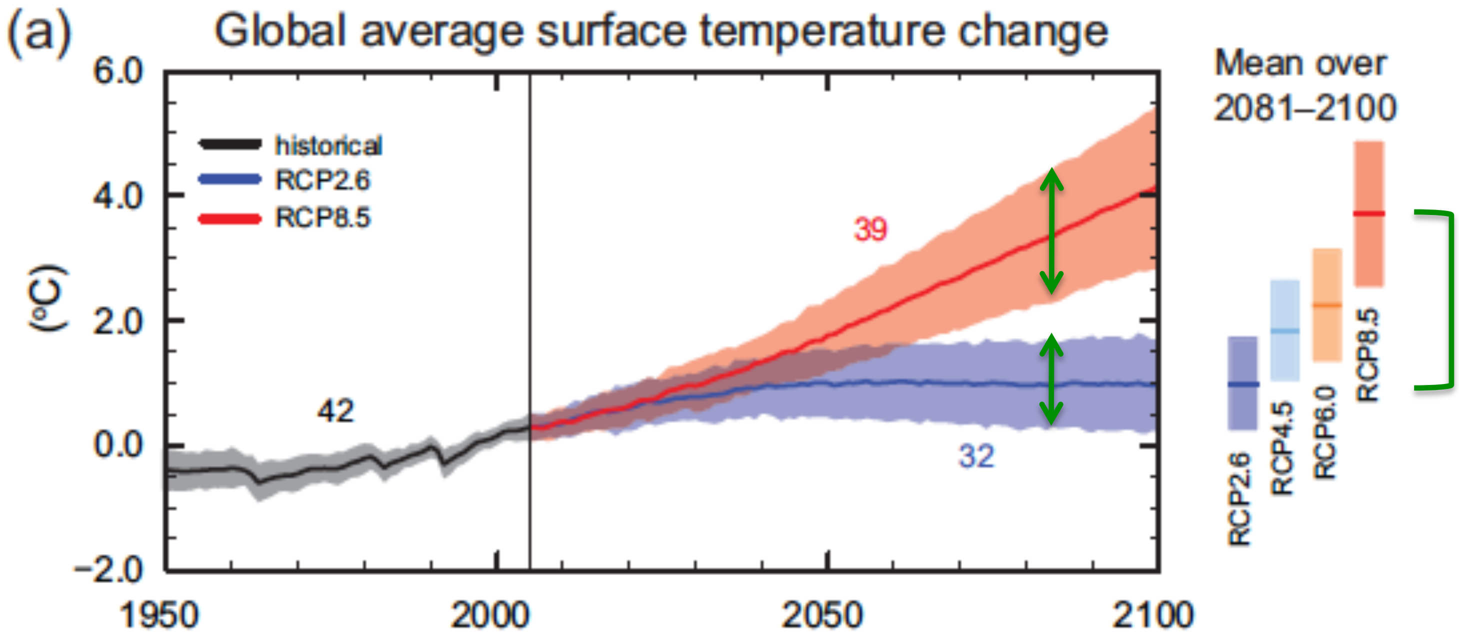
Outline

- Clouds, climate and circulation – a grand challenge
- HD(CP)^2 – a German project with a focus on clouds
- ICON – the model to be used for HD(CP)^2
- Computational challenges for the ICON model
- Summary

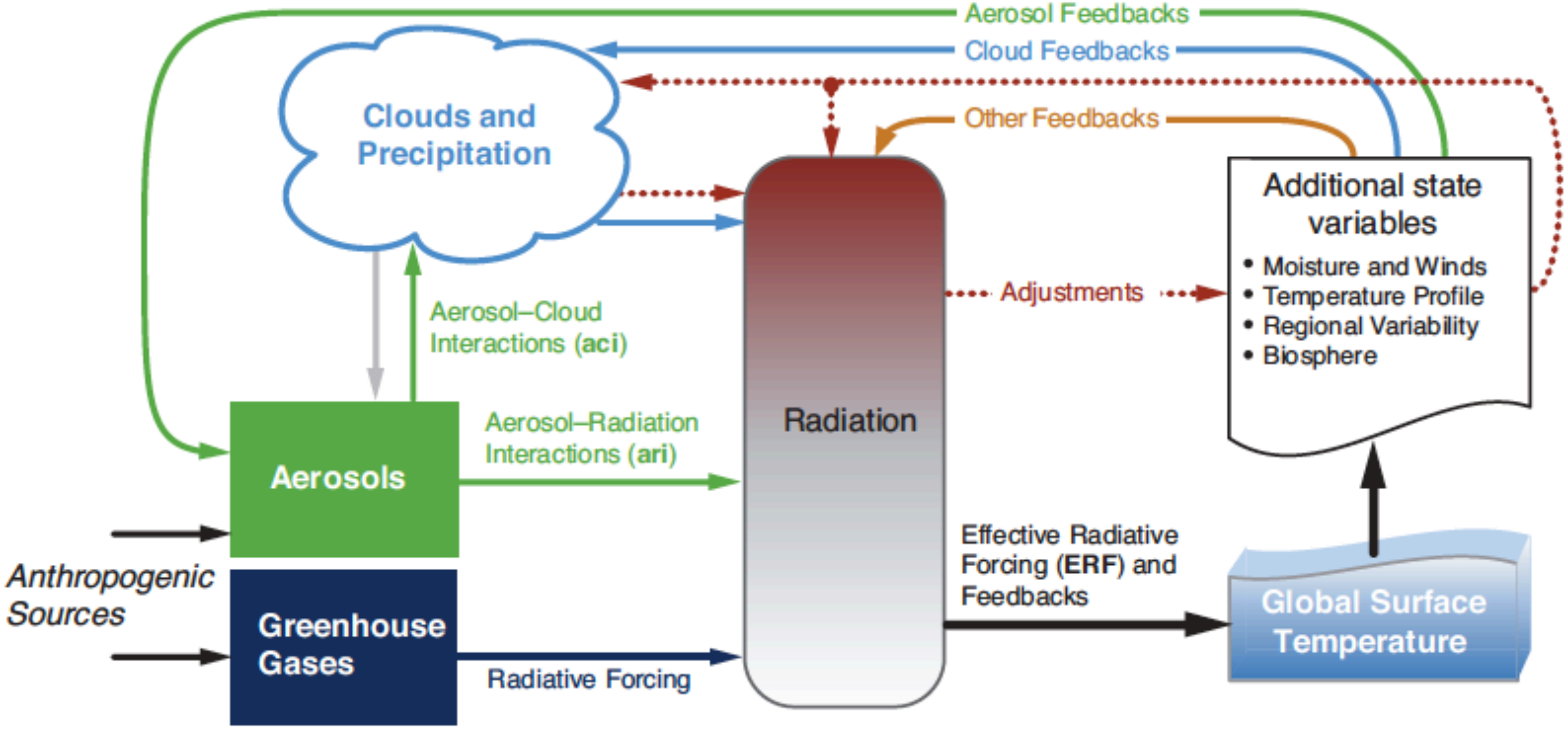
Climate change uncertainties



IPCC AR5, Summary for policy makers, Figure SPM.7a

- **Different scenarios of futures of economies, populations and policies: RCP2.6, RCP4.5, …RCP8.5**
- **Different models predict different warming rates for the same scenario**

Forcing and Feedback pathways

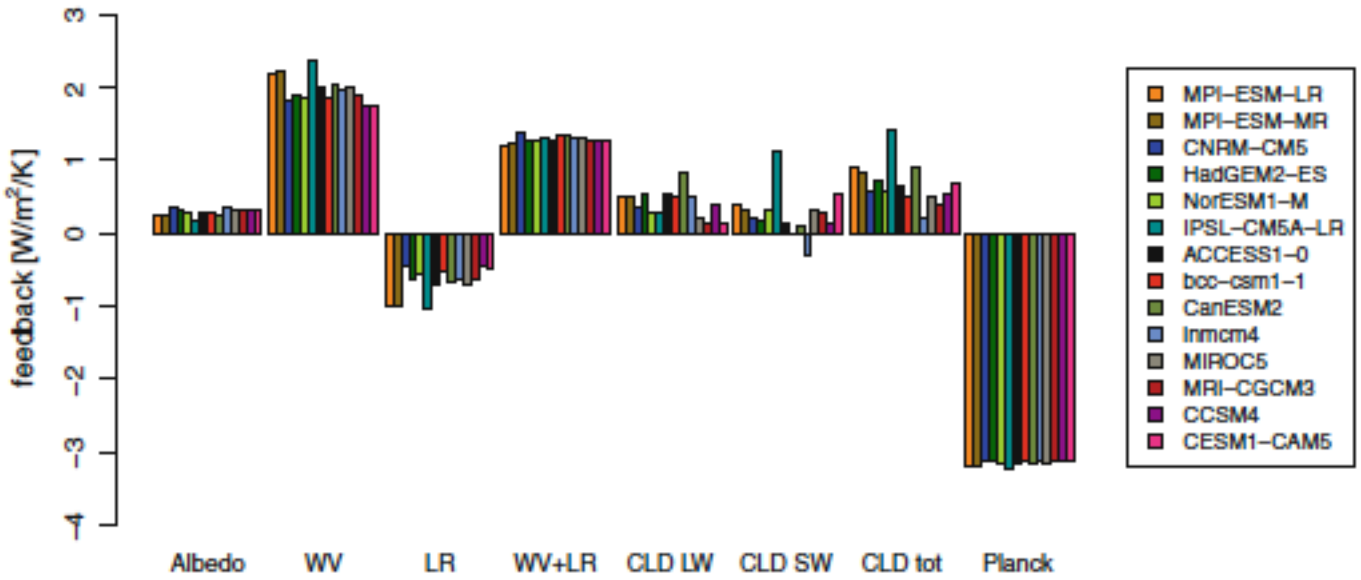


IPCC, AR5, Chapter 7, Clouds and aerosol, Figure 7.1

- **The global surface warming depends on the forcing and feedbacks**
- **If different models predict different warmings for the same forcing, the feedbacks must differ.**

Which feedbacks are uncertain?

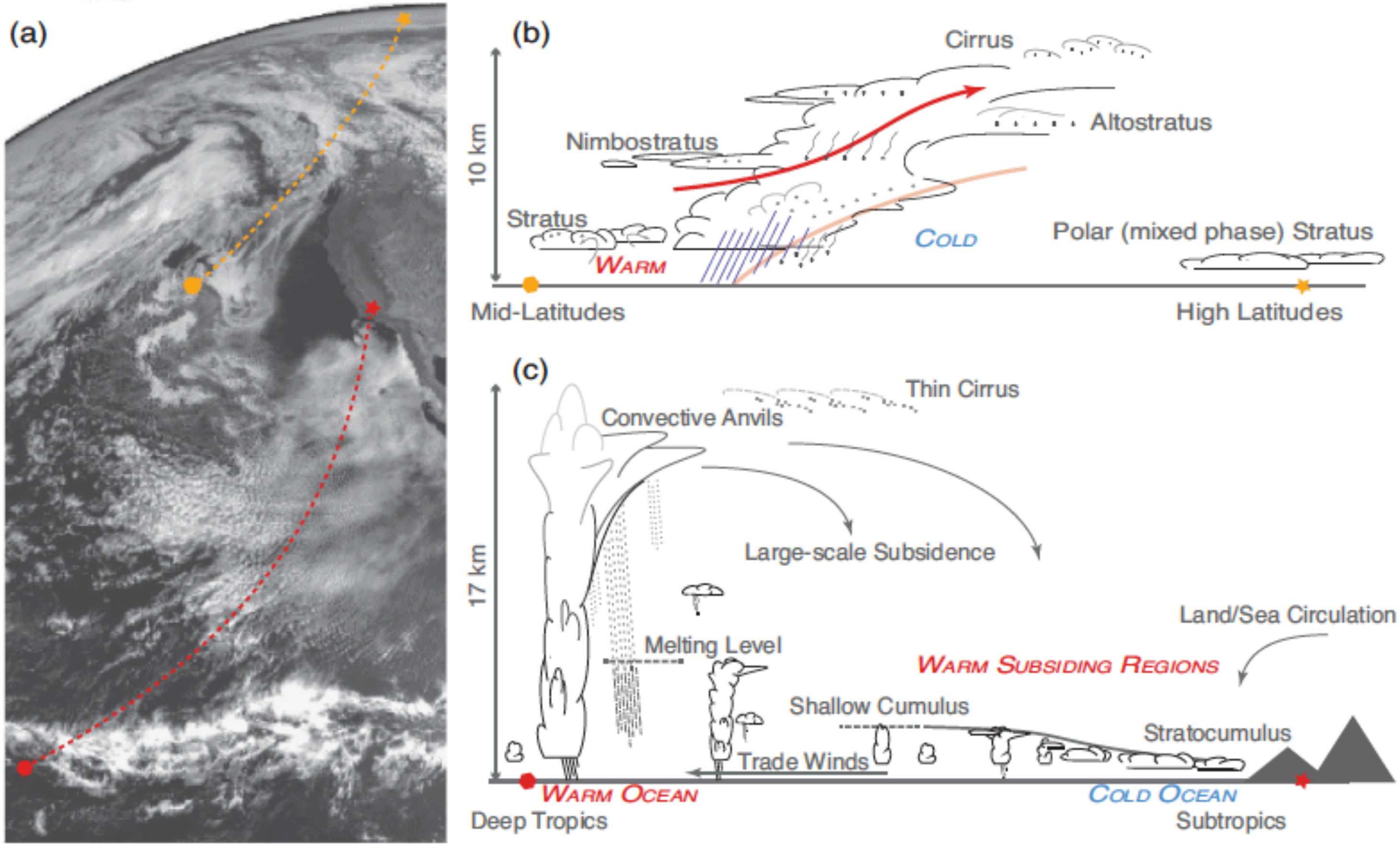
- A feedback explains how much the forcing that causes the warming is modified once a warming of 1K has happened.
- Positive → more warming; Negative → less warming.



Tomassini et al., 2013

- **The cloud feedback is most uncertain, especially CLD SW.**

Why are clouds difficult for climate models?



IPCC, AR5, Ch. 7: Clouds and aerosol, Figure 7.4

- **Clouds occur on many scales, and heights**
- **Clouds contain liquid water, or ice particles, or a mix.**

Modelling alternatives

- **”General circulation models”**
  - Resolution of ~100km for climate to ~10km for weather forecasting
  - Parameterize turbulence, cloud microphysics and cloud dynamics.
- **“Cloud resolving models”, e.g. NICAM@Earthsimulator**
  - Resolutions of ~5km to 1km
  - Resolve deep convective clouds
  - Parameterize turbulence, cloud microphysics and the smaller clouds
  - Unclear separation between resolved and unresolved clouds → “Grey Zone”
- **“Large eddy simulation (LES) models”**
  - Resolution of ~100m
  - **Resolve cloud dynamics** (smallest cloud = 1 cell volume)
  - Parameterize turbulence and cloud microphyiscs

→ LES models could be a valuable tool to learn about cloud dynamics
If LES models can be run on large enough domains → computational challenge

→ HD(CP)2 project (Stevens et al.)

- HD(CP)2: High Definition Clouds and Precipitation for
  advancing Climate Prediction

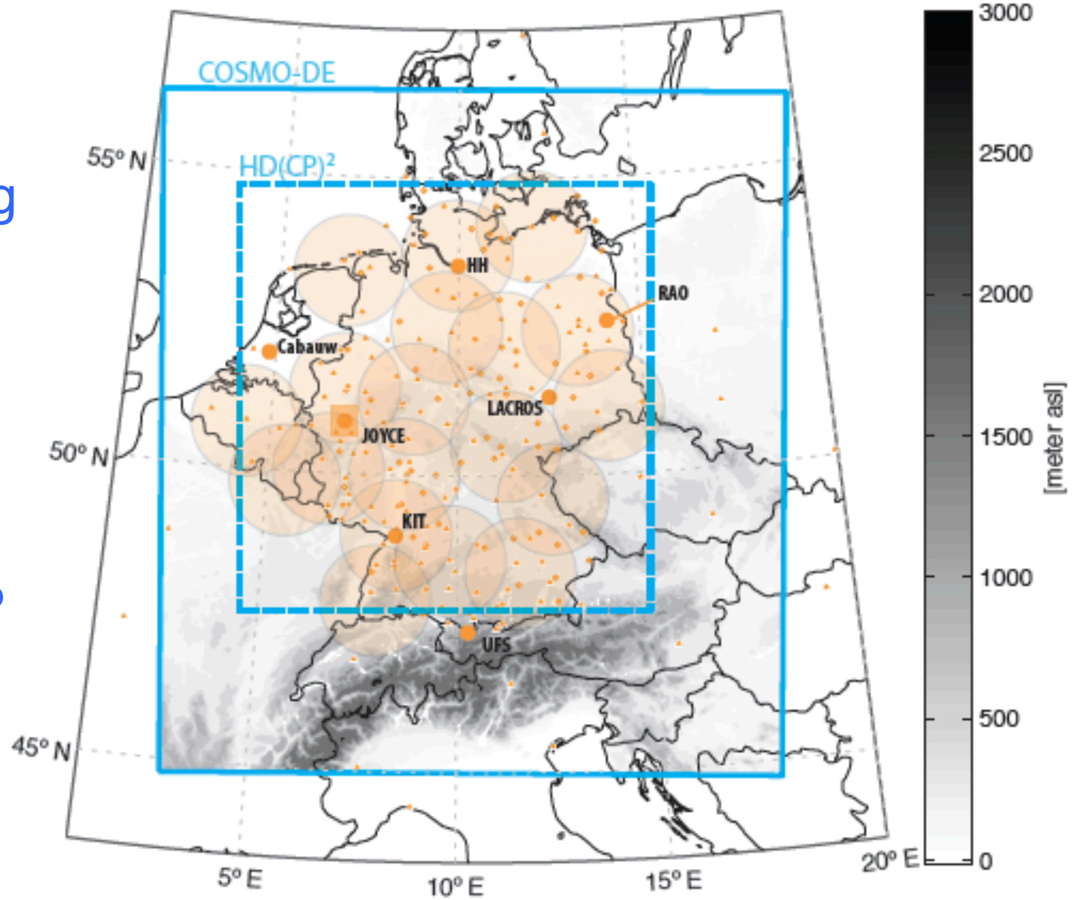
- A large German project to investigate the dynamics and properties of summer time convective clouds over Germany.
- Intensive observations campaigns
- Modeling at scales of ~100m on domains from
  ~20km x 20km to ~800km x 800km
- Investigate the dynamic interaction between the clouds, their cloud-free environment and the surface.
- Contribute to the development of better cloud parameterizations for non-cloud-resolving models

The HD(CP)² domain

- HD(CP)² marks the largest domain proposed for a LES simulation using the ICON model. Will receive boundary data from COSMO-DE.

- COSMO-DE is the regional operational NWP model of DWD

- Orange areas and dots indicate observational sites



The ICON atmosphere model

- Developed jointly by DWD and MPI-M to obtain a unified model system for research and operational forecasting.

- The ICON-atmosphere model solves the non-hydrostatic equations of motion on a triangular unstructured grid (Zängl et al., 2014).

- Can be configured at resolutions from ~100km (climate) to ~10km (NWP) to 100 m (LES), using different sets of parameterizations.

Estimates of computing resources for HD(CP)^2

- 30 simulated days
- 100 m horizontal resolution and 200 levels
- Done in ~1 week

Resolution	625m (50 level)	625m (50 level)	100m (200 level)
Model time (days)	1	30	30
CPU time (hours)	6	180	180
Number of cores	448	448	70000 if scaling 100%

→ ICON-LES needs to scale to 100k core!!

ICON-LES on the road to Petascale Systems

- Limited Area Experiments on a domain covering Germany:
  - resolution 416m with 3,514,000 grid cells
  - resolution 240m with 10,567,680 grid cells
  - resolution 104m with 56,229,888 grid cells

- Supercomputing Systems
  - Blizzard@DKRZ : 8448 cores - 158 TeraFlop/s
  - SuperMUC@LRZ : 147456 cores - 2.8 PetaFlop/s
  - JUQUEEN@Jülich : 458752 cores - 5 PetaFlop/s

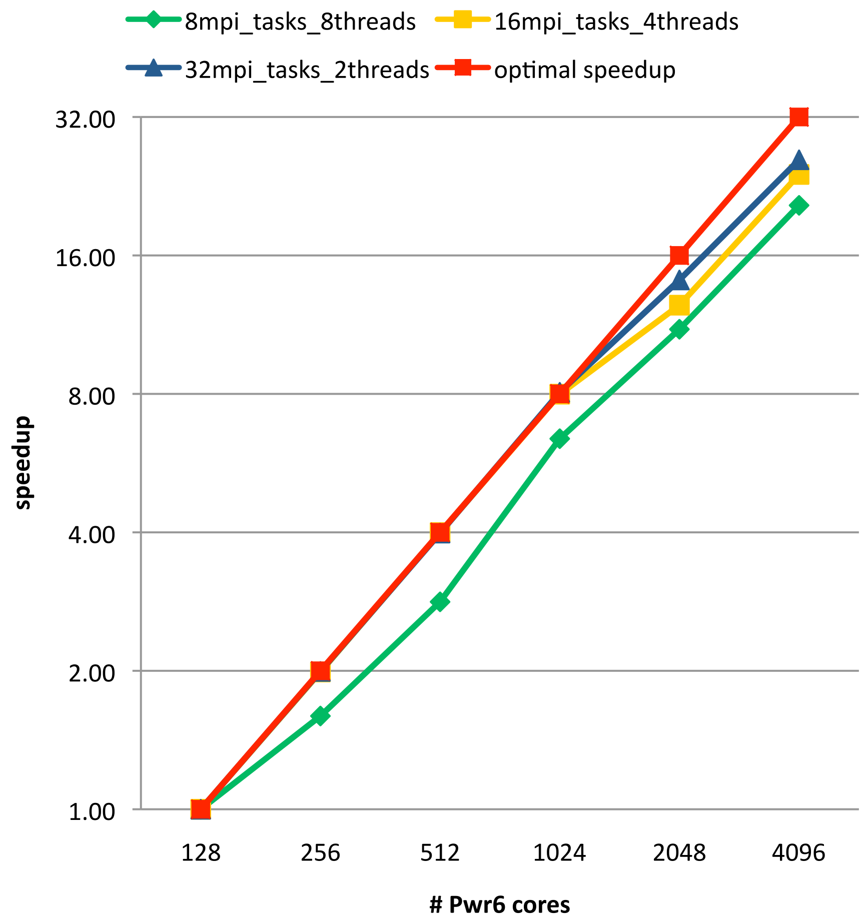
ICON-LES on the road to Petascale Systems

- Limited Area Experiments on a domain covering Germany:
  - resolution 416m with 3,514,000 grid cells
  - resolution 240m with 10,567,680 grid cells
  - resolution 104m with 56,229,888 grid cells

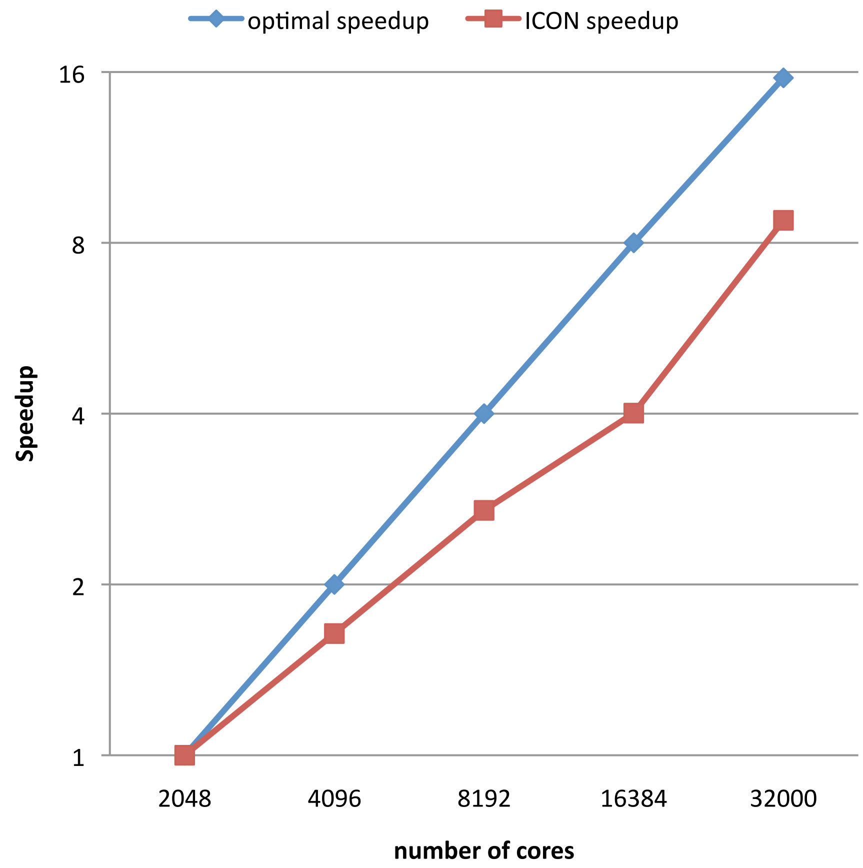
- Supercomputing Systems
  - Blizzard@DKRZ : 8448 cores → 7872 cores
  - SuperMUC@LRZ : 147456 cores → 32k cores
  - JUQUEEN@Jülich : 458752 cores → 65k cores

Strong Scaling on Tera/Petascale Systems

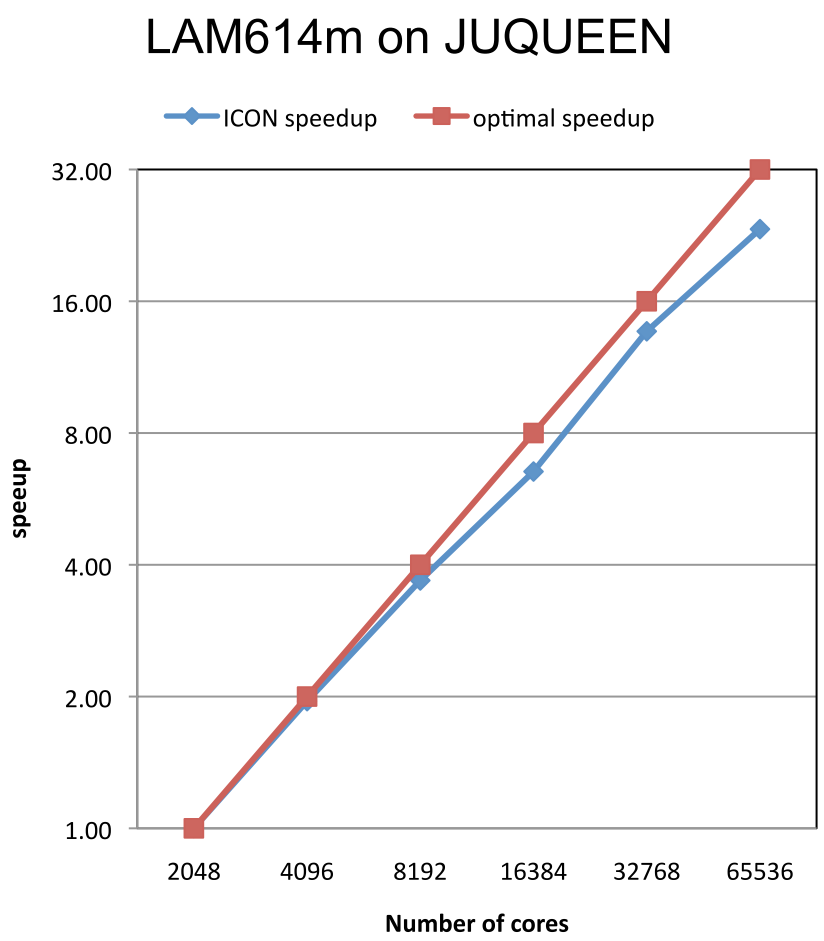
LAM416m on BLIZZARD

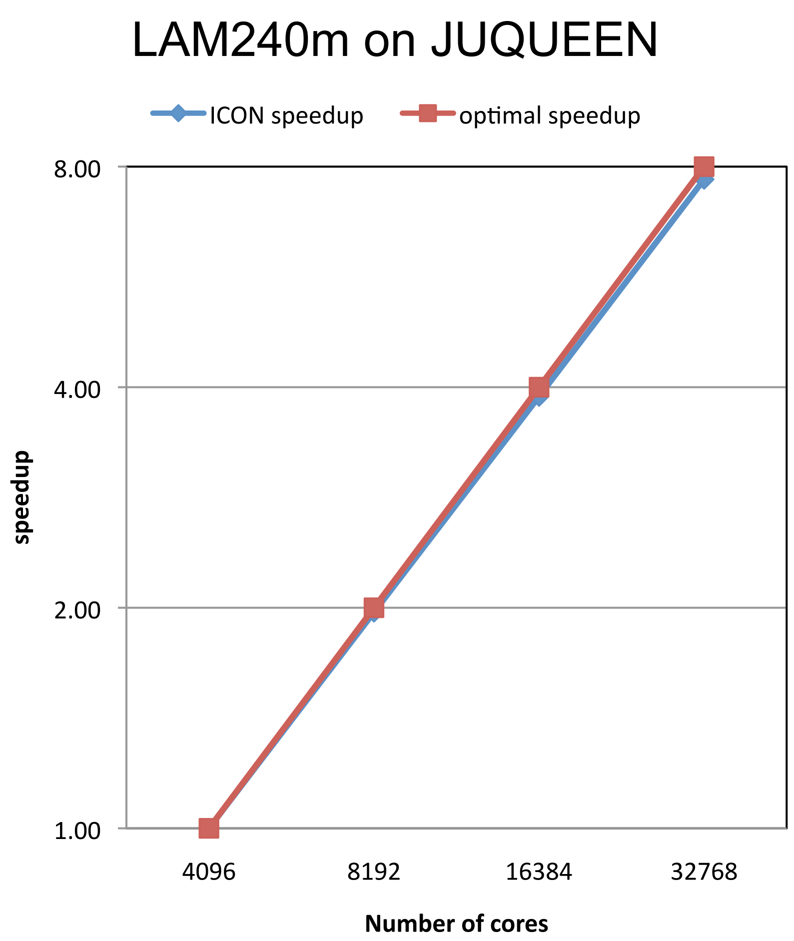


LAM416m on SuperMUC



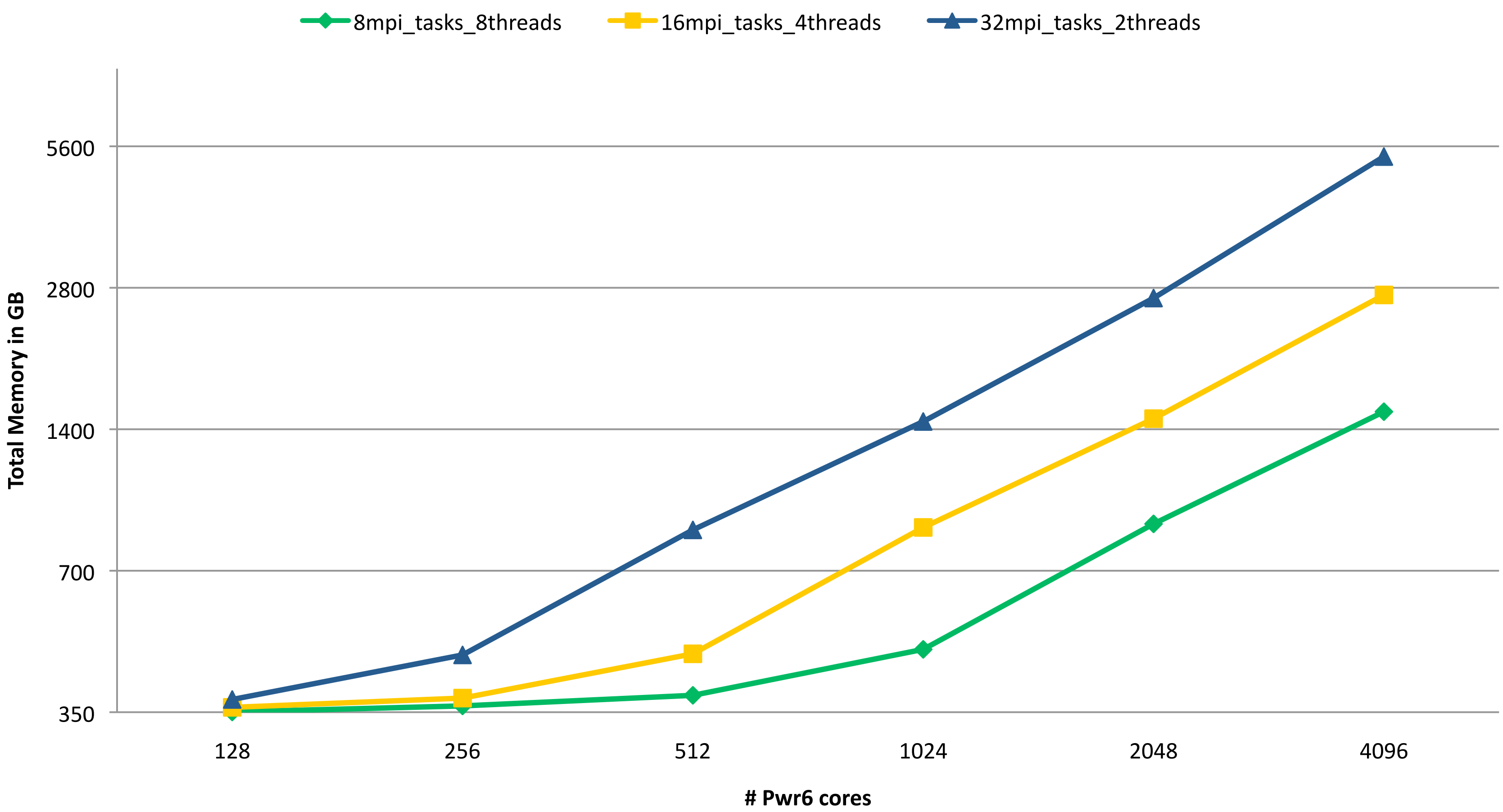
Strong scaling with two resolution





Challenges for Petascale Systems

Memory scaling for LAM416m on BLIZZARD



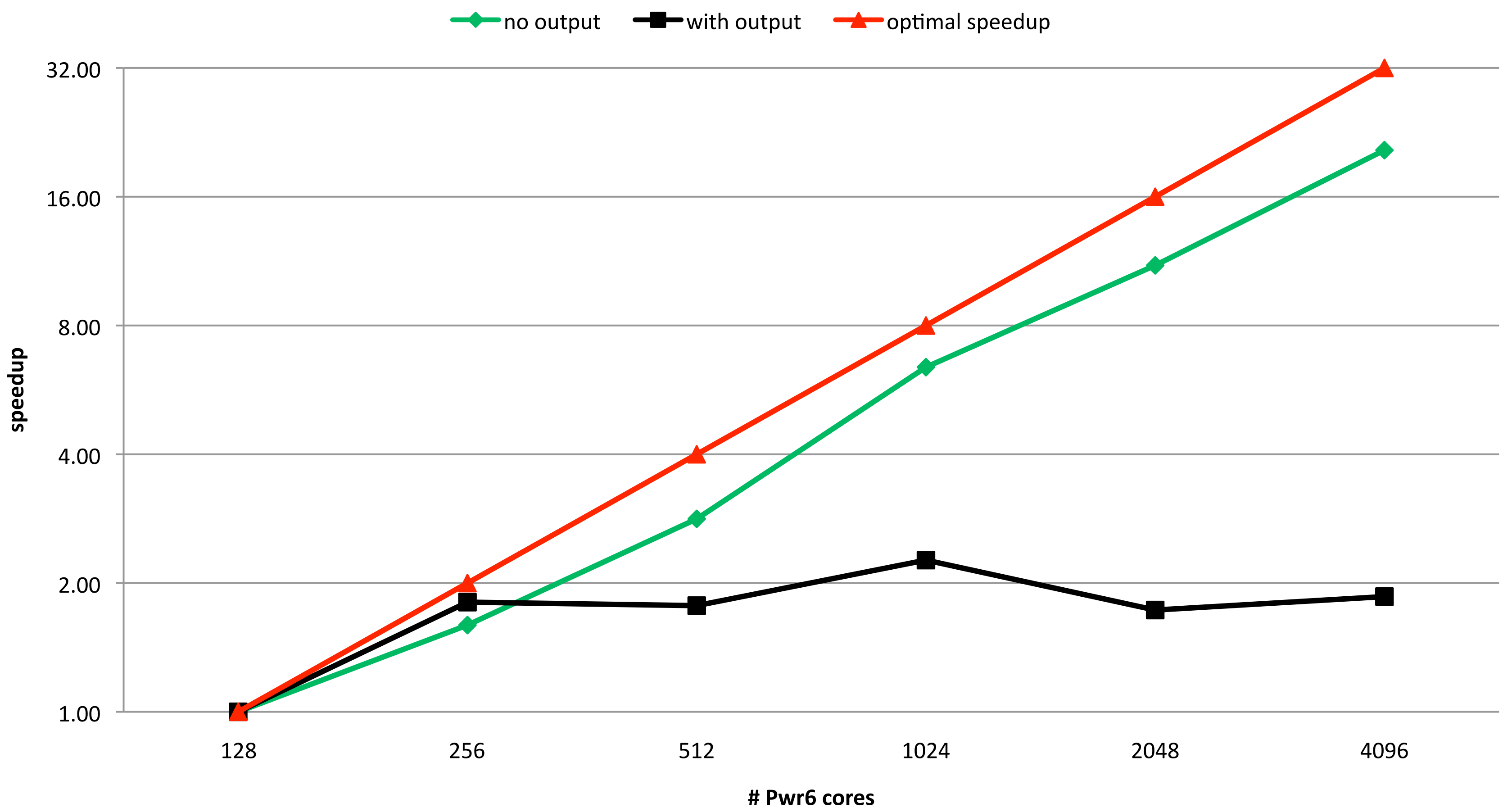
Memory issue of ICON

- Global-size data structures still used for:
  - Input of grid related data
  - Domain decomposition
  - Communication patterns
  - Memory grows with number of tasks and grid size

- Prototype solutions under development:
  - Parallel and distributed reading of grid related data
  - Parallel domain decomposition
  - Communication patterns without global size arrays
  - New gather algorithm

Challenges for Petascale Systems

Impact of serial I/O for LAM416m on BLIZZARD



I/O issue of ICON

- Serial I/O
  - ICON-output is gathering global data on output task, writes global files

- Prototype solution under development:
  - Asynchronous parallel I/O with global files
  - Develop online post-processing
    - Instrument simulators
    - Cloud feature tracking
    - Cloud statistics
  - Reduce 3d output fields

From Petascale to Exascale Systems

- Taking the challenges for Petascale HPC systems as chance to prepare for Exascale HPC-Systems
- Necessary changes of ICON are in progress
  - Parallelizing, Parallelizing,…….,Parallelizing
  - Change habits in planning of experiments and output
- Future Exascale architectures with accelerators ?
  - Collaboration with CSCS/ETH (Will Sawyer, Thomas Schulthess) towards tuning of ICON for Supercomputers with accelerators in discussion

Summary

- Instruments for observations and supercomputers are the most important technical tools for climate research
- To exploit supercomputers means to design models which scale in all components: computational and data
- A close collaboration of climate scientists and computing scientists is needed to develop scaling models for the largest supercomputers
- Planning of experiments and evaluation need to evolve
- The ICON development profits strongly from the collaboration with DKRZ and CSCS to bring ICON to their largest machines.