Performance Analysis and Simulations for the Project "High Definition Clouds and Precipitation for advancing Climate Prediction (HD(CP)²)"

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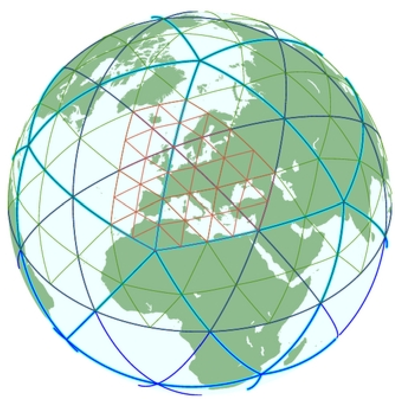
HD(CP)²

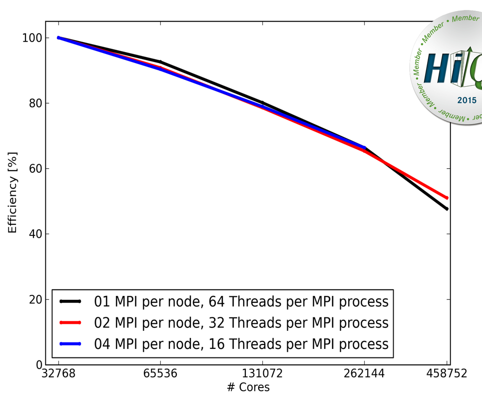
German-wide initiative funded by BMBF since September 2012

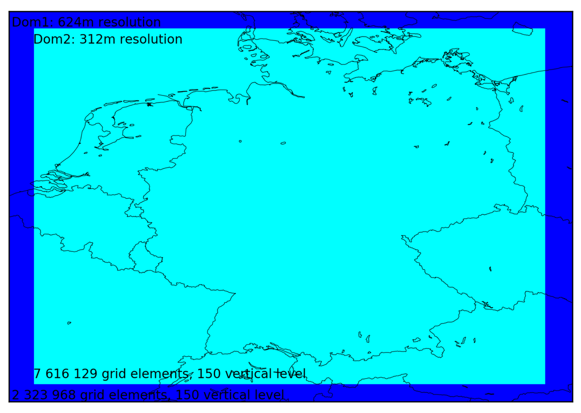
- Aim:
  - Improve understanding of cloud and precipitation events
  - Increase quality and number of available observations
  - Evaluate and improve modeling capabilities
- Synthesize observational and modeling approach:
  - Advance basic understanding of clouds and precipitation processes in climate
  - Better representation of clouds and precipitation in lower resolution global circulation models



ICON

ICON as a unified modeling framework offers three basic physics packages, which are dedicated to numerical weather prediction (NWP), climate modeling (GCM) and large eddy modeling (LEM). In the first phase of HD(CP)² the LEM component of ICON was developed, to run on very high resolutions to overcome a suite of parameterization challenges.

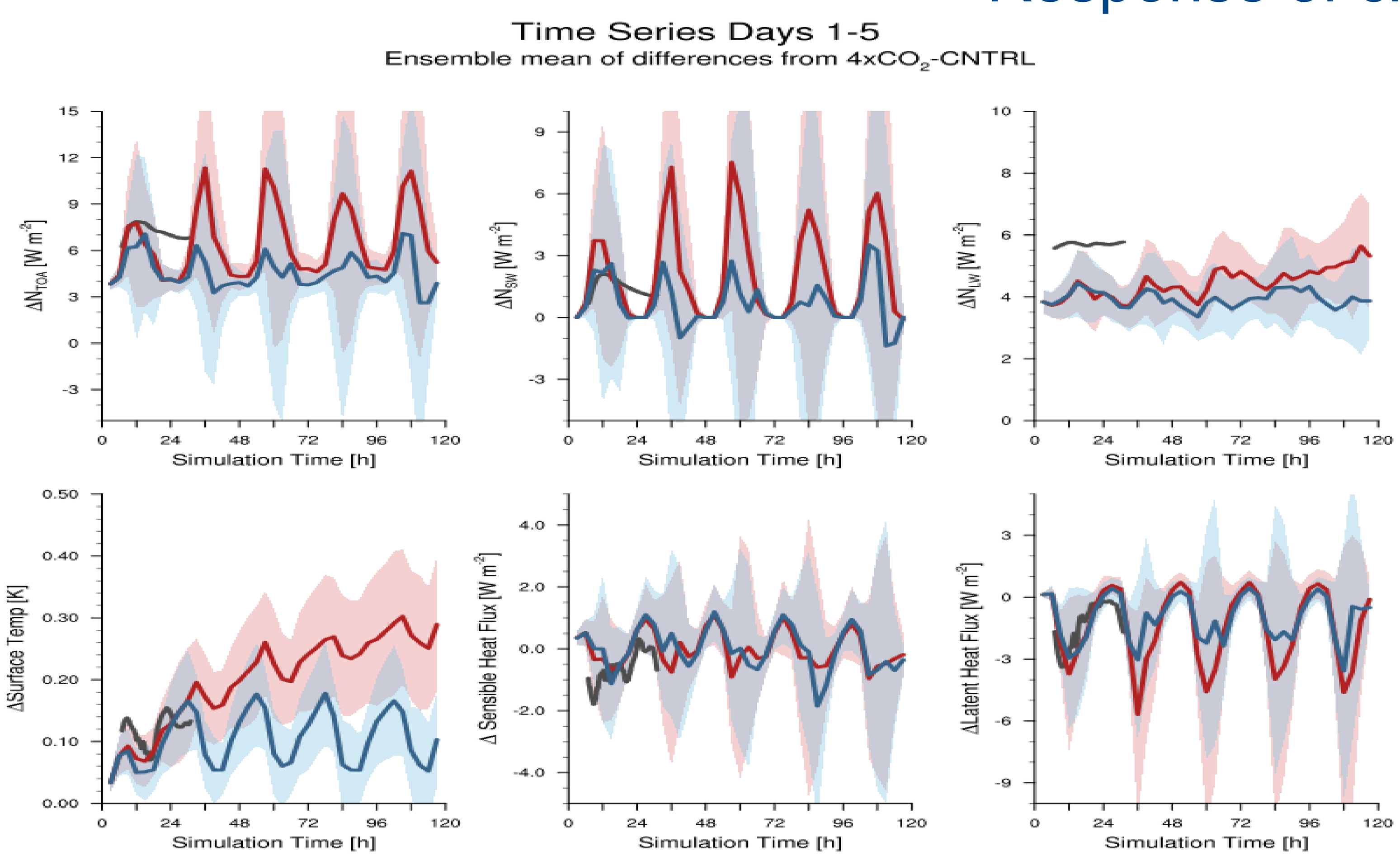




Simulation setup:
- Two nested grids: 624m – 312m
- 150 vertical levels
- 3s time step

A typical simulation of 24 hour
- Generates 4 TB model output
- Produces 10 TB restart files
- Needs 3 Mio core-h on JUQUEEN
- Runs for 7.8 days on 1024 cores

Response of clouds to anthropogenic forcings



The figure presents time series of changes over the first 5 days after a perturbation in CO2 concentrations for both the ICON-GCM and ICON-LEM. The top row show the mean change in net top-of-atmosphere radiation budget, as well as its shortwave and longwave components, of a 92-member ensemble of the ICON-GCM and the ICON-LEM. On the bottom, the differences in surface temperature, surface sensible heat flux, as well as latent heat flux are shown.

The red and blue lines denote the mean changes of the Global_4xCO2 (global CO2 quadrupled) and Local_4xCO2 (CO2 only quadrupled in the inner nest) experiments with the ICON-GCM, respectively, relative to a control simulation with the ICON-GCM. These simulations show that (i) a clear signal in net top-of-atmosphere radiative balance emerges within a few days after a 4xCO2 perturbation, and (ii) the use of present-day CO2 concentrations in the global simulation providing the boundary conditions is not an issue for short lead times, up to ~36 hours. We also found that the atmospheric processes of rapid adjustments over Central Europe are largely a local-to-regional atmospheric phenomenon and are rather independent of larger-scale dynamical effects. These results imply that high-resolved large-eddy simulations over a limited area can be instructive for assessing and constraining global rapid cloud adjustments. Thus, we can compare these properties with changes simulated by the ICON-LEM in black. Originally, it was proposed that the two ICON-LEM simulations be run for May 2, 2013 for a period of 24 hours because a large variety of cloud regimes occurred over Germany that day. Building upon the results of the ICON-GCM experiments, we have now extended the ICON-LEM simulations for an additional 14 hours.

The changes modelled by the ICON-LEM are within the standard deviation of the differences found in the ICON-GCM for most variables. The results suggest that high-resolved large-eddy simulations, such as the ICON-LEM, over a limited area can be instructive for assessing and constraining global rapid cloud adjustments thanks to their ability to resolve cloud dynamics and thermodynamics. This has been an open question since large-eddy models can only be run on over limited domains, run for a short period of time, and are influenced by boundary conditions. Thus, it was proposed to perform two ICON-LEM simulations, a control and a 4xCO2 sensitivity experiment on JUQUEEN. Through the combination of these two ICON-GCM and ICON-LEM studies, we hope to learn how rapid adjustments manifest and ultimately help constrain rapid adjustments in general circulation models.

Model versus observations

In a simulation for November 24, 2015, a widespread Atlantic frontal system can be seen which passed Germany from the North-West caused by a low pressure system over Island. The descending ice clouds associated with the warm front showed sublimating ice and snow on the cloud bottom which transformed over the day into light drizzle. During the second half of the day the precipitation on the ground transformed from rain to snowfall. Overall, this winter case includes a multitude of relevant cold cloud microphysical processes. Intensive observations at the Jülich Observatory for Cloud Evolution (JOYCE) and the first german triple frequency radar experiment (TRIPEX) (Bonn, Karlsruhe, Köln) exist for this day which makes it a "golden case" to evaluate the ICON performance for cold cloud processes and winter precipitation.

ICON captures the main timing and structure of the event quite well!

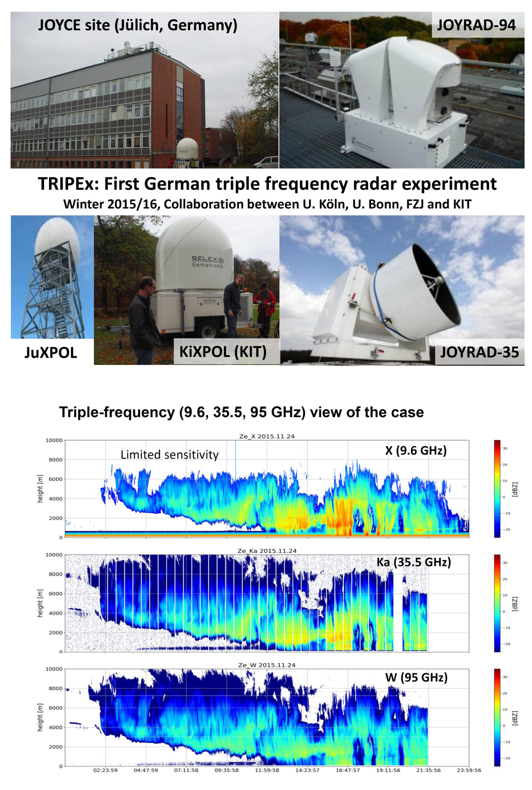
Also the transition from a rather stratiform event in the warm front to a more convective event in the cold front sector is nicely captured.

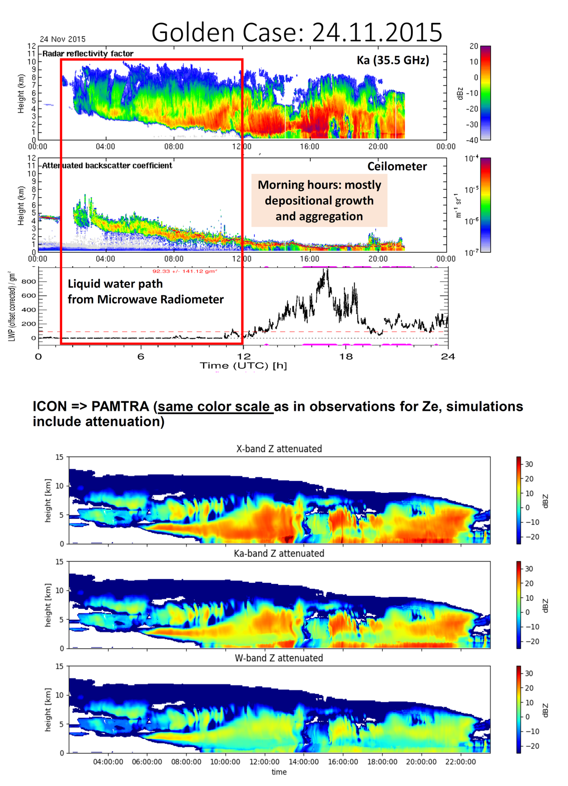
The radar reflectivities at all 3 frequencies are much larger in the ICON simulations compared to the observations. More detailed tests with the Passive and Active Microwave TRAnsfer model (PAMTRA) revealed, that mainly the snow component is driving the reflectivities high. Uncertainties in the scattering properties are smaller than the differences observed.

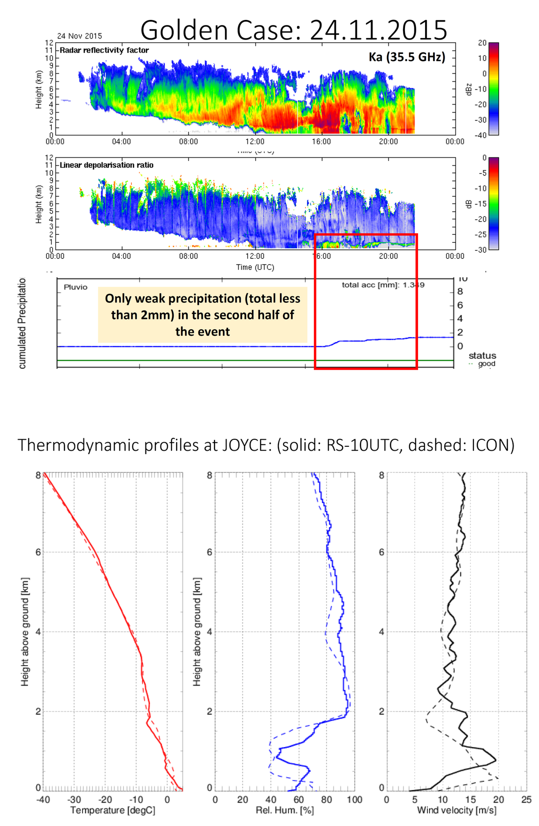
Overall, the issue of too much and large snow is quite well known for the Consortium for Small-scale Modelling (Cosmo) and since the microphysical scheme (Seifert&Beheng, 2006) is also used in ICON this issue seems to be also present here. Also the cloud ice reaches too far up in the atmosphere which is not confirmed by the observations.

Triple-frequencies provide a larger constraint to such comparisons because the refelctivities represent different weights to certain parts of the particle size distribution (PSD) (lowest frequency most affected by the large particle tail of the PSD). Hence they are different in the parts where particles are not Rayleigh scatterers at all frequencies.

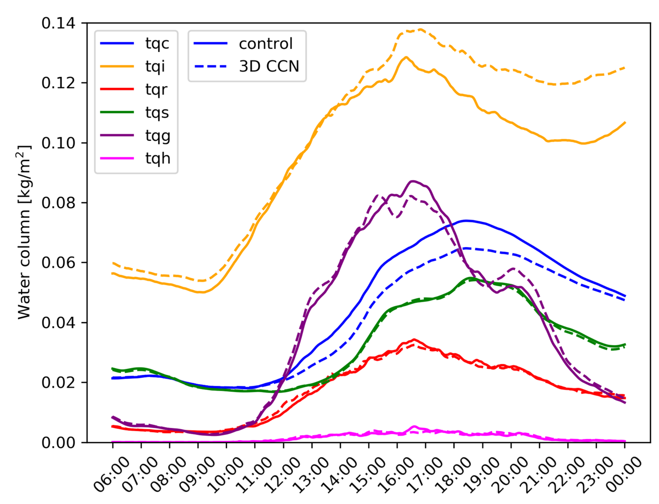
Future plans: Add also mean Doppler velocity to the comparison which adds constraints to the sedimentation velocity. Apply different microphysical schemes in ICON and repeat the comparison

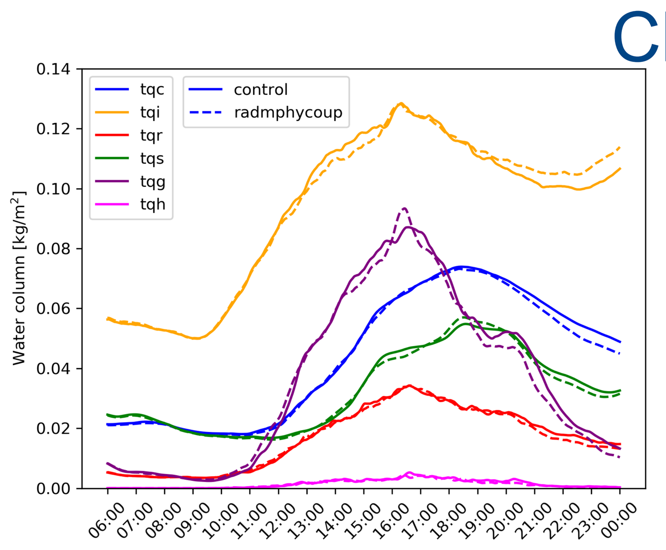




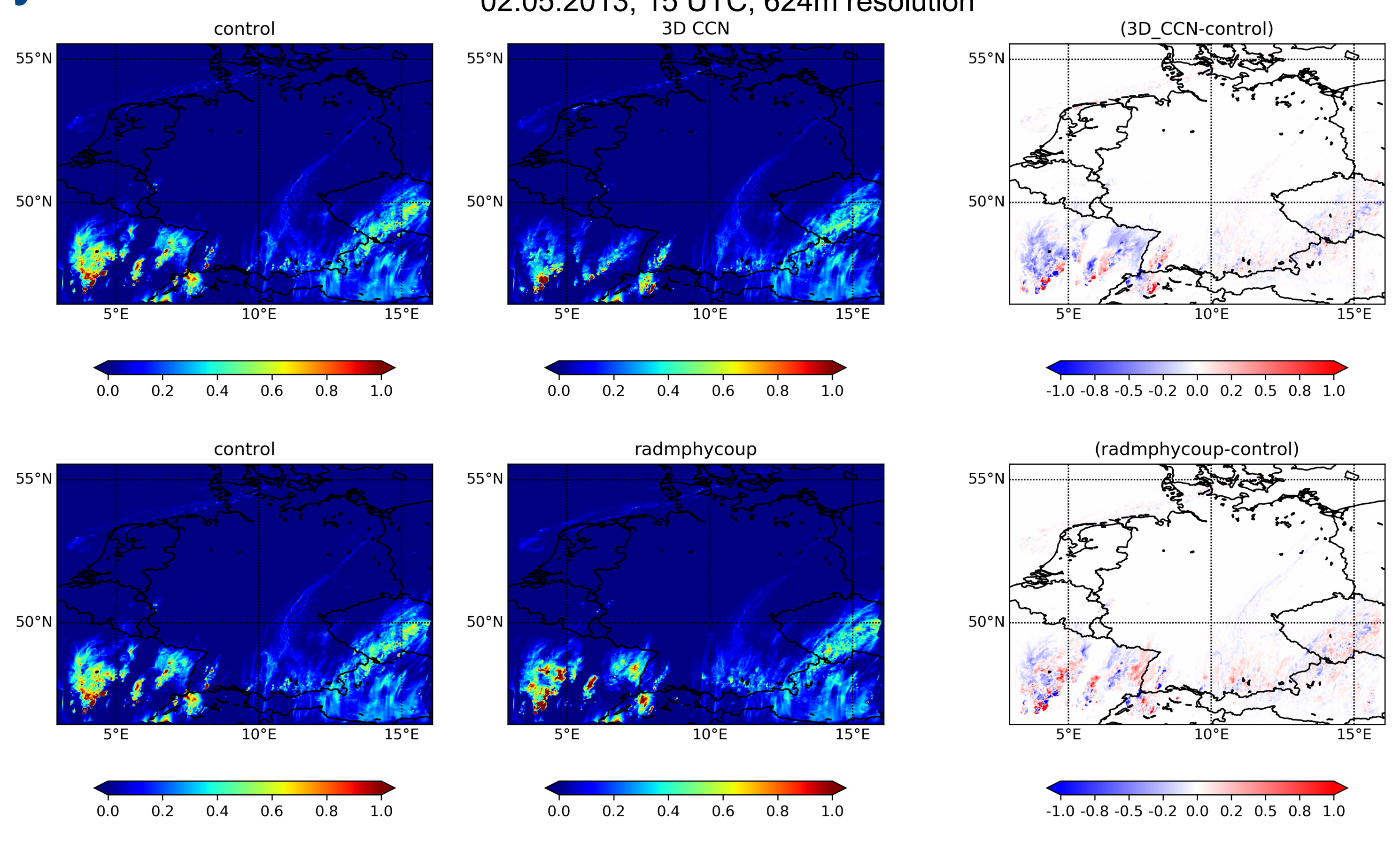


Cloud microphysics





Total column integrated cloud ice [kg/m²]
02.05.2013, 15 UTC, 624m resolution



The cloud response to aerosol is highly uncertain, yet a very important climate forcing mechanism. It is in particular unclear how cloud microphysical processes and cloud dynamics respond to perturbations in cloud condensation nuclei (CCN) perturbations. The response strongly depends on the way cloud and precipitation microphysical processes are implemented in the model. This subproject uses high-resolved ICON-LEM simulations to investigate the response of clouds and radiation. The level of detail of the representation of aerosol-cloud interactions in the ICON-LEM is, however, not yet sufficient in the standard version to realistically represent the relevant effects. Therefore modifications have been done, which are tested in sensitivity studies. The first one is, that instead of a horizontally and temporally constant CCN profile, a spatially and temporally varying climatology, derived from a model with interactive aerosols is to be read in (3D CCN). The second aspect is, that in the standard version the cloud radiative effects currently are only computed on the basis of specific cloud liquid- and ice water. Instead, the information the model computes about cloud droplet- and ice crystal number concentrations should be taken into account properly when computing cloud optical thickness. This is done in the simulation labeld with radmphycoup. Both sensitivity studies show a response compared to the control run and further analyses will be done to assess the relevance of the process and improve the ICON-LEM model in terms of the cloud representation.