HD(CP)^2

High definition clouds and precipitation
for advancing climate prediction

Report on DKRZ resources in 2018

Consortium project HD(CP)^2

Executive Summary

Document structure

This report summarizes the individual reports of projects associated to the project HD(CP)^2 (High-definition clouds and precipitation for advancing climate prediction). The reporting will cover the time period from 2018-01-01 to 2018-12-31. The individual project numbers are

- bm0834
- bm0838
- bm0852
- bm0982
- bm0974 (includes former project bm0992)
- bm0994
- bm1018
- bm1027
- bm1032
- bb1041

The numbers for used computation time and used storage resources are taken as on 30 September 2018 unless stated otherwise.

Contents

1 Project bm0834

Project title: HD(CP)^2 Module M (Modelling)
Principal investigators: Bjorn Stevens, Rieke Heinze,Panos Adamidis, Joachim Biercamp, Kerstin Fieg

Granted computation time for 2018: 1.228.353 node*h
Used computation time for 2018: 1.144.660 node*h
Granted storage on Lustre (/work): 2.178.742 GiB
Granted storage on HPSS (/arch): 2.236.294 GB
Granted storage on HPSS (/doku): 260.599 GB

For the year 2018 DKRZ's steering committee granted nearly 1.9 million node*h to the consortium project HD(CP)^2 , which is about 25% of the total amount of computing time available for BMBF projects on Mistral. This reflects the ambition of the HD(CP)^2 project of being one of the "lighthouse projects" for the German Climate Research Community.
From this share, 65% of the computing time was assigned to subproject bm0834 (Modul M) and used to perform model simulations of interest for the HD(CP)^2 community of the domains DE (over Germany), TA (over the Tropical Atlantic) and NA (over the Northern Atlantic). The remaining 35% (approx. 665.000 node*h) were distributed to the 10 other subprojects of the consortium.
According to DKRZ policy, the project management is allowed to shift resources between the projects of the joint project, when necessary and agreed by the principal investigators of the subprojects. This led to multiple relocations of compute and storage resources from and to subproject bm0834.
In total, DKRZ's steering committee granted about 2.6 Mio GiB for Lustre /work, 2.6 Mio GB for HPSS /arch and 32000 GB HPSS for /doku to the HD(CP)^2 project. The bm0834 share accounts for 2.17 Mio GiB on Lustre /work, 2.23 Mio GB HPSS on /arch and 26000 GB HPSS on /doku.

1.1 Usage of requested computation time

1.1.1 DE domain

The HD(CP)^2 consortium agreed on the following 13 days that were (re-)simulated and finalized between January and October 2018 on Mistral. The full-day DE simulations are the core element of the consortium, as all modules within HD(CP)^2 use these simulations for their scientific questions. Therefore it is necessary that these simulations are re-simulated, once model errors are detected. This happened through the course of the year, leading to two re-simulations.

Dates:

2013-05-02

2015-07-05-redone

2015-07-04-redone

2016-08-01 to 2016-08-02

2017-06-22

2016-05-29

2016-06-06

2014-06-17

2015-06-17

2016-05-26 to 2016-06-30 (long-term simulation at 600m resolution)

2013-05-05

2013-06-20

For one full-day simulation, a total of 65.000 node*h is used. This is in detail 60.000 node*h (actual simulation of the day), 2500 node*h (reading input/restart files) and 2500 node*h (writing output). Approximately 3% of overhead is calculated for bug-fixing, model evaluation and the preparation of the model setup and output data. The used computing resources (status of 04 Oct 2018) for the DE simulations are 845.000 node*h (production, pre- and postprocessing, 3% overhead).

1.1.2 NA domain

The simulations that were done over the domain of the Northern Atlantic were twofold. First there were simulations over a wide area done with the ICON-NWP (using 31.000 node*h). Second there were simulations over a much smaller area with the ICON-LEM (using 1.335.000 node*h).
The ICON-NWP simulations extended from 78W-40E and from 23N-80N, resulting in a coverage of complete Europe and parts of North Africa. Simulations were performed with grid resolutions ranging from 80 km to 2.5 km, with 1-moment and 2-moment cloud microphysics, and with and without a convection parameterization. About 26.000 node*h were used in total for these experiments. The detailed time periods that have been simulated are found in Table 1.

Starting date	End date	Simulated days
2016-09-20, 0 UTC	2016-09-23, 0 UTC	3
2016-09-22, 0 UTC	2016-09-26, 0 UTC	4
2016-09-29, 0 UTC	2016-10-03, 0 UTC	4
2016-10-02, 0 UTC	2016-10-06, 0 UTC	4
2016-10-13, 0 UTC	2016-10-17, 0 UTC	4

Table 1: NA simulations

The setup for the ICON-LEM simulation was finished and first runs were tested. The computing time that was used for this is 5.000 node*h. In total 1.366.000 node*h were used to perform the NA simulation up to September 2018.
For the remaining quarter in 2018, first ICON-LEM simulations for the NAWDEX campaign will be performed. The focus will be on the ascent region of the warm conveyor belt of cyclone Vladiana, which was measured in the NAWDEX IOP3 by the HALO and FAAM aircrafts on Sep 23, 2016. Two ICON-LEM simulations are planned, one using the 2-moment cloud microphysics that is applied in the ICON-LEM setup for the DE domain, and one using the 1-moment cloud microphysics that is applied in the operational ICON-NWP model. For the two runs, the computational budget will be totaling to 33.243 node*h.

1.1.3 TA domain

The full-day simulations that were done over the domain of the Tropical Atlantic used about 22.000 node*h each, which includes a 10% overhead for the pre- and post processing. There were in total eight full day simulations (see Table 2).

These allow a better understanding of cloud formation and precipitation processes over subtropical marine regions that are often a substantial factor of climate uncertainty. The simulations are in synergy with the two NARVAL field campaigns in December of 2013 and August of 2016.

Date	Flight number of NARVAL experiment
2013-12-11	N1 RF02
2013-12-12	N1 RF03
2016-08-12	N2 RF03
2016-08-19	N2 RF06
2013-12-20	N1 RF08
2013-12-15	N1 RF05
2016-08-24	N2 RF08
2016-08-10	N2 RF02

Table 2: List of TA simulations

The simulations reveal shallow cumulus in the trades with embedded shallow mesoscale organization fueled by evaporating precipitation and associated cold pools. Further into the tropics the northerly rims of the edge intensified ITCZ emerges, connected to even stronger convective organization.

The resources that were used for the TA simulation are about 176.250 node*h (production, pre- and post-processing, 10% overhead). The used storage space on /work is 390 TB.

1.1.4 Storing resources

For the utilization of DKRZ's storing resources, a data management plan has been established. It describes in detail the amount of data that is stored for the individual experiments on the /work and /archive directories.The relevant numbers for the report of 2018's usage are as follows:

- /work: DKRZ's steering committee granted 2.17 PB for /work and 2.00 PB are currently in use, which is 94%. This is due to the fact that analyses on the data are still performed and project scientists rely on the fast access to all HD(CP)^2 experiments. This is also true for post-processing activities.
- /archive: DKRZ's steering committee granted 2.24 PB of which 1.25 PB are currently in use. This is 55% and consists of restart, output, grid and log data of the DE domain experiments. This set of information enables the reproduction of every individual experiment. The data from the TA and NA experiments are still under evaluation, subsequent archiving should follow until end of 2018.
- /doku: It was agreed that the model output for the DE simulations will be stored in a temporal resolution of 10 min at the /doku archive, as these are the core products of HD(CP)^2 . This 10 min data (with metadata attached) is available for all project members for the time of ten years.

1.2 Resulting publications in 2018

The above simulations are used throughout the entire HD(CP)^2 community, leading to a number of publications in 2018:

Baumgartner, M. and Spichtinger, P. (2018): Towards a bulk approach to local interactions of hydrometeors, Atmos. Chem. Phys., 18, 2525-2546, doi.org/10.5194/acp-18-2525-2018.

Biasutti, M., Voigt, A., Boos, W. R., Braconnot, P., Hargreaves, J. C., Harrison, S. P., Kang, S. M, Mapes, B.E., Scheff, J., Schumacher, C., Sobel, A. H., and Xie, S. (2018): Global energetics and local physics as drivers of past, present and future monsoons. Nature Geoscience, 11(6), 392, https://doi.org/10.1038/s41561-018-0137-1

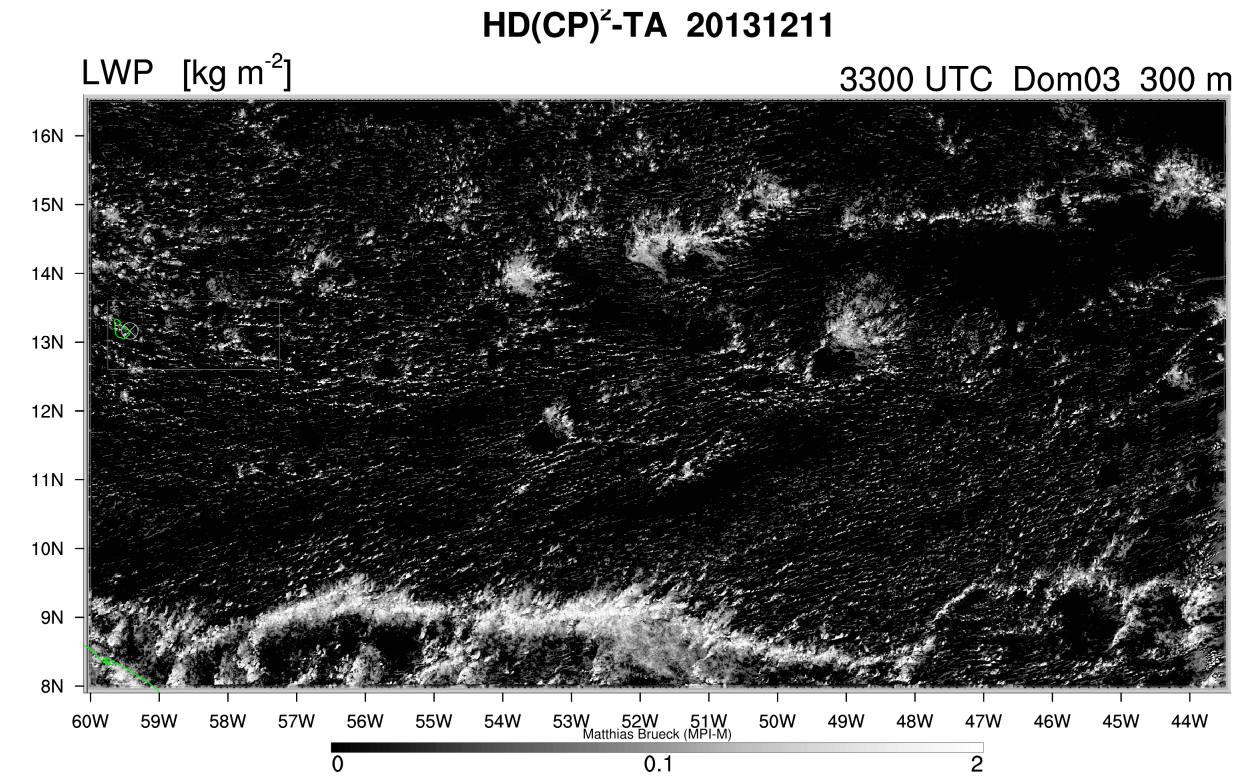


Figure 1: ICON-LEM large-eddy simulation of liquid water path of the the 300 m resolution domain highlights a range of cumulus phenomena.

Brdar, S. and Seifert, A. (2018): McSnow: A Monte-Carlo particle model for riming and aggregations of ice particles in a multidimensional microphysical phase space. Journal of Advances in Modeling Earth Systems, 10, doi:10.1002/2017MS001167

Brune, S., F. Kapp and P. Friederichs (2018): Convective organization in ICON large-eddy simulations, submitted to QJRMS

Düsing, S., Wehner, B., Seifert, P., Ansmann, A., Baars, H., Ditas, F., Henning, S., Ma, N., Poulain, L., Siebert, H., Wiedensohler, A., and Macke, A. (2018): Helicopter-borne observations of the continental background aerosol in combination with remote sensing and ground-based measurements, Atmos. Chem. Phys., 18, 1263-1290, doi.org/10.5194/acp-18-1263-2018.

Gryspeerdt, E., Quaas, J., Goren, T., Klocke, D., and M. Brueck (2018): An automated cirrus classification, Atmos. Chem. Phys., 18, 6157-6169, doi.org/10.5194/acp-18-6157-2018.

Moseley, C., Henneberg, O., and Haerter, J. (2018): Amplified convective precipitation from multi-merging, submitted to Journal of Advances in Modeling Earth Systems

S.K. Muppa, A. Behrendt, H.-S. Bauer, K. Warrach-Sagi, F. Späth, N. Kalthoff, V. Maurer, A. Wieser, R. Heinze, C. Moseley, R.A.J. Neggers, P. Siligam, and V. Wulfmeyer (2018): Characterizing turbulent processes in the convective boundary layer:Evaluation of large eddy simulations with high-resolution lidar observations. submitted to QJRMS.

Schäfer, S.A.K., and A. Voigt (2018): Radiation weakens idealized mid-latitude cyclones, Geophys. Res. Lett., 45, doi:10.1002/2017GL076726.

Senf, F., D. Klocke, and M. Brueck (2018): Size-resolved evaluation of simulated deep tropical convection. Mon. Wea. Rev., 0, https://doi.org/10.1175/MWR-D-17-0378.1

2 Project: bm0838

Project title: HD(CP)^2 Module S1 (Fast cloud adjustments to aerosols)
Principal investigators: Johannes Quaas

Granted computation time for 2018: 120 node*h
Used computation time for 2018: 246 node*h
Granted storage on Lustre (/work): 11240 GiB
Granted storage on HPSS (/arch): 0 GB
Granted storage on HPSS (/doku): 10 GB

The module S1 is concerned with the influence of aerosols on cloud formation and precipitation. The module made extensive use of the HD(CP)^2 consortia runs that simulated a change in CO_2 concentration.

2.1 Usage of requested computation time

The work resulting from the simulations conducted in the project bm0838 led in the reporting period to two publications:

- Nam et al. (2018) finalized the key output from the contribution to the module S2 in HD(CP)^2 , where it was shown that the HD(CP)^2 consortia simulations with the ICON-LEM can be used to constrain the rapid adjustments of clouds to CO_2 perturbations (and thus, the effective radiative forcing by CO_2). In the reporting period, in the course of the final revisions, additional full-day simulations were of essential importance.
- Gryspeerdt et al. (2018) made use of the HD(CP)^2 modelling output to define cirrus cloud regimes. This is a key point in the HD(CP)^2 S1 module on cloud adjustments to aerosol, in order to be able to compare them to satellite observations in a meaningful manner. Fig. 2 shows exemplarily the PDF of the vertical wind classified for three different cirrus cloud regimes.

2.2 Resulting publications in 2018

Gryspeerdt, E., Quaas, J., Goren, T., Klocke, D., and Brueck, M. (2018). An automated cirrus classification. Atmospheric Chemistry and Physics, 18(9), 6157-6169.

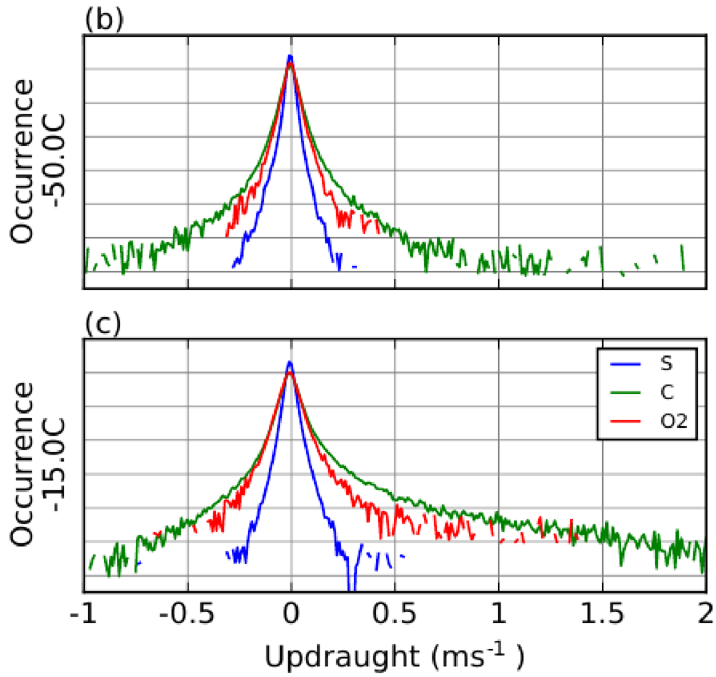


Figure 2: PDFs (panel b and c) of vertical wind in the HD(CP)^2 ICON-LEM simulations at two isothermal surfaces at cirrus levels (top: $-50°\mathrm{C}$, bottom: $-15°\mathrm{C}$) for three cirrus regimes: blue ("S") - synoptic regime, green ("C") convective, and red ("O2") orographic. From Gryspeerdt et al. (2018).

3 Project: bm0852

Project title: HD(CP)^2 Module S3, subproject 4 and HD(CP)^2 Module S1, subproject 2; Diagnostics and ice clouds in ICON
Principal investigator: Ulrike Burkhart

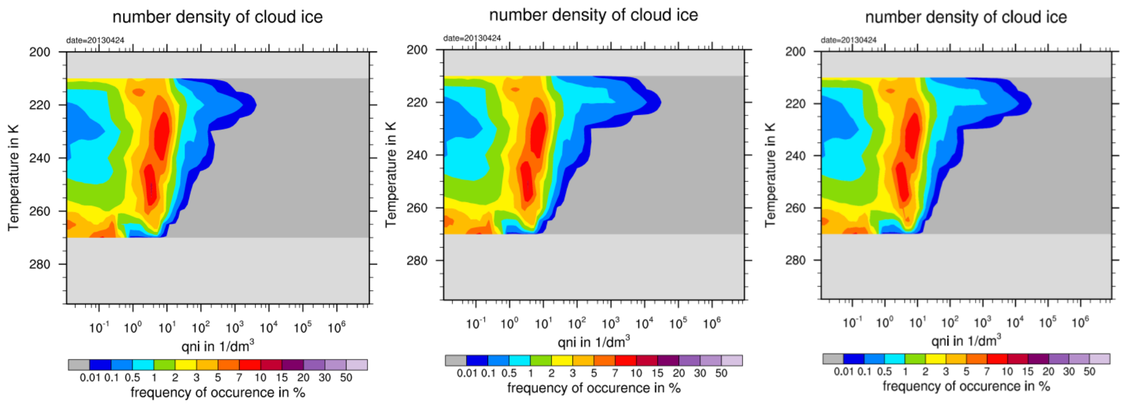
Granted computation time for 2018: 24.003 node*h
Used computation time for 2018: 18.365 node*h
Granted storage on Lustre (/work): 40.789 GiB
Granted storage on HPSS (/arch): 1.312 GB
Granted storage on HPSS (/doku): 0 GB

The project bm0852 provided computation time and storage resources to two suproject of the HD(CP)^2 project. The above numbers of the used resources are as of October 22, 2018. Computation time was used for studies on contrail induced cirrus clouds as well as on convection and its influence on the water budget.

3.1 Usage of requested computation time

3.1.1 HD(CP)^2 moduel S1, subproject 2 (Contrail cirrus clouds)

We implemented a parameterization for contrail cirrus within ICON-LEM. The parameterization includes ice crystals nucleation in contrails (Kärcher et al. 2015)) and the loss of ice crystals in the vortex phase (Unterstrasser 2016). As expected many small ice crystals are formed during contrail formation at aviation levels (210 - 230 K) as seen in Figure 3. But due to the definition of a minimum mass threshold for ice



(a) (b) (c)

Figure 3: CFAD analysis showing frequency of occurrence of ice crystal number density at different temperatures for (a) the simulation with contrail nucleation parameterization without changing minimum mass threshold, (b) simulation with a change in minimum mass. (c) Same as (b) with monotonic flux limiter. Simulations were 1 hour long.

(10^{-12} kg) within the model, the number of ice crystals was corrected down. Therefore, the threshold was lowered by 2 orders of magnitude (10^{-14} kg) without any visible effect on the hydrometeor statistics except the increase in number concentration of small ice crystals at flight levels (see Figures 3a and 3b).

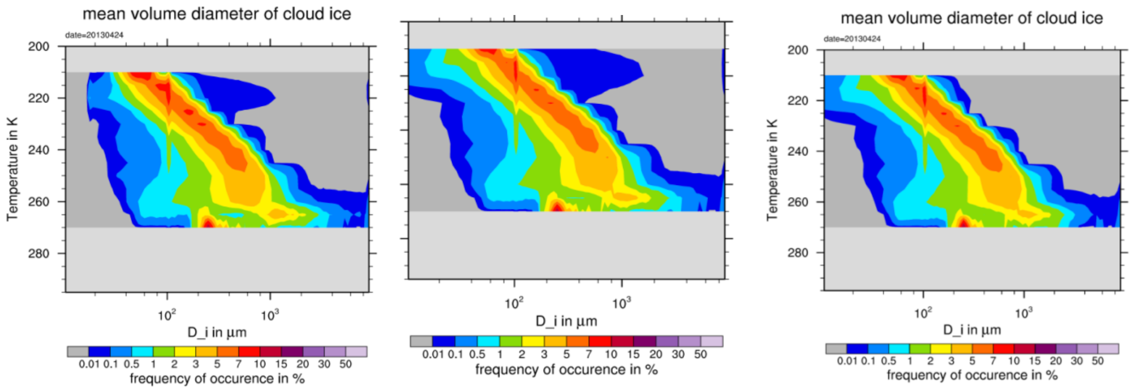
After changing the minimum mass threshold the frequency of high ice crystal number concentrations ($>$100 N/dm^3) is significantly increased. Those high number concentrations together with a high frequency of small mean volume diameter ($<$30 μm, see figure 4) is a typical sign for contrails. The frequency of large ice crystals (bigger than 1000 microns in diameter) is also increased at flight levels in the perturbed simulations (simulation with contrail parameterization) relative to simulations without contrail parameterization. This problem is enhanced when the contrail parameterization is applied using the reduced minimum mass threshold (see Figure 4b hanging to a monotonic flux limiter removed the big ice crystals in the simulations (see Figure 4c) and preserves sharp gradients in concentration fields.

We have calculated the fraction of ice crystals surviving after the vortex phase (survival fraction) and the final contrail vertical depth after the vortex phase. Many ice crystals survive when contrails form in high ice supersaturated air, since ice crystals are larger in high ice supersaturated regions, resulting in smaller sublimation loss of ice crystals and a high survival fraction (Fig. 3). The survival fraction of contrail ice crystals is affected by natural clouds when contrails form within natural clouds, because some ice crystals of natural clouds are entrained into the contrail plume during mixing and sublimate during the vortex descent which will increase relative humidity locally in the vortex (figure 5a). Therefore, more ice crystals may survive the vortex descent (figure 5b).

The next steps will be to merge our contrail parameterization scheme into the main ICON-LEM main branch in order to perform large simulations. Those simulations will enable an evaluation of our contrail parameterization with observations.

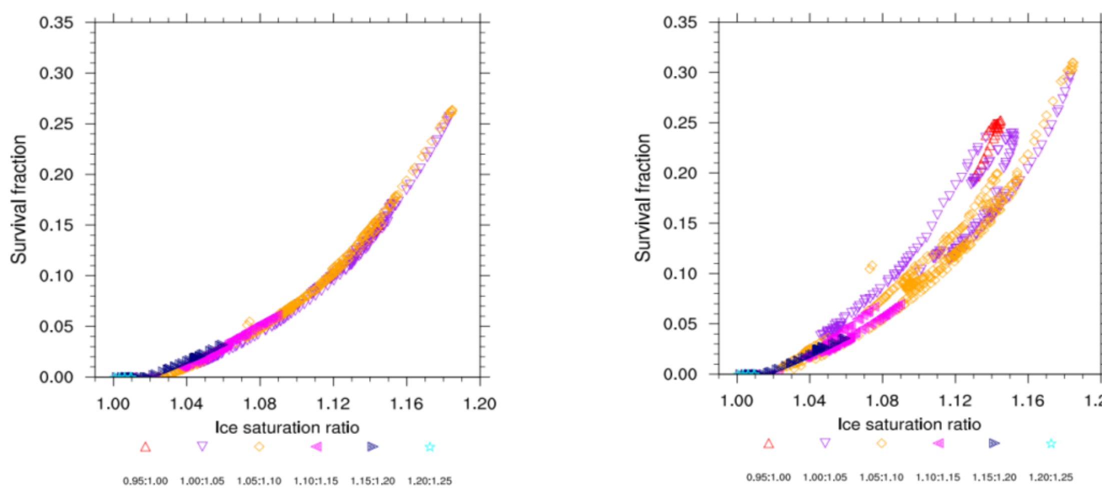
3.1.2 HD(CP)^2 module S3, subproject 4 (Influence of convection on cirrus clouds and the water budget of the upper troposphere)

During the last computing period the Sundqvist cloud scheme including a prognostic cirrus cover in ICON-GCM was used to conduct an ensemble of transpose AMIP simulations of different days with increased convective activity over Germany. Nucleation thresholds of 110% and 120% relative humidity over ice were used to simulate heterogeneous nucleation in the convective clouds consistent with LEM and NWP simulations. The results were evaluated regarding high cloud cover and cloud top height and compared to



(a) (b) (c)

Figure 4: CFAD analysis showing frequency of occurrence of ice crystals sizes at different temperatures (a) simulation with contrail nucleation parameterization without changing minimum mass threshold. (b) Simulation with a change in minimum mass, (c) same as (b) with monotonic flux limiter. Simulations were 1 hour long.



(a) (b)

Figure 5: The figures show the survival fractions, the Brunt-Väisälä frequencies are indicated with colors. (a) Survival fraction of contrail ice crystals in vortex phase without including impact of cirrus ice crystals sublimation. (b) Same as (a) with impact of cirrus ice crystal sublimation.

observational data from the CiPS algorithm, as well as results from the ICON-LEM and ICON-NWP models (6).

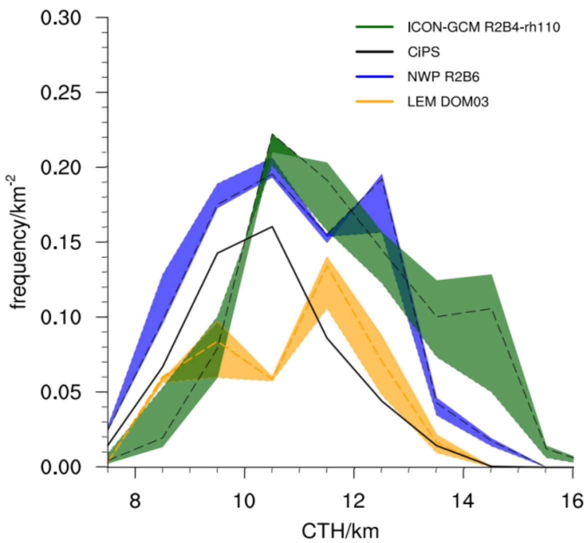


Figure 6: Probability distribution of cloud top height (CTH) for an ensemble of 5 convective days simulated with the ICON models. In black are observational results from CiPS

We also evaluated the skewness parameterization of the total water PDF in the Tompkins cloud scheme including a prognostic cirrus cover in ICON-GCM using high-resolution ICON-LEM data. The insights from this study will help to improve the parameterization and therefore the representation of cirrus clouds in the GCM model.

3.2 References

Kärcher, B., U. Burkhardt, A. Bier, L. Bock, and I. J. Ford (2015), The microphysical pathway to contrail formation. J. Geophys. Res. Atmos., 120, 7893-7927. doi: 10.1002/2015JD023491.

Unterstrasser, S.: Properties of young contrails - a parametrisation based on large-eddy simulations, Atmos. Chem. Phys., 16, 2059-2082, https://doi.org/10.5194/acp-16-2059-2016, 2016.

4 Project bm0974

Project title: HD(CP)^2 Module S5 (Clouds and convective organization)
Principal investigator: Rieke Heinze

Granted computation time for 2018: 329.925 node*h
Used computation time for 2018: 295.781 node*h
Granted storage on Lustre (/work): 204.800 GiB
Granted storage on HPSS (/arch): 250.000 GB
Granted storage on HPSS (/doku): 10.000 GB

4.1 Usage of requested computation time

3D radiative effects were shown to have an impact on cloud development in high resolution (large eddy) simulations. Temporal interaction of high resolved clouds and realistic (3D) heating and cooling rates in the solar and thermal spectral range can cause differences in cloud field organization, e.g. promoting the formation of cloud streets (Jakub and Mayer, 2017), or leading to cell-structures and clustering (Klinger et al., 2017). Apart from the heating and cooling rates, the neglect of horizontal transport of radiation leads to a bias in the radiative flux. One example is shown in Figure 7. Here we calculated solar upwelling radiation based on liquid and ice water of the ICON-LEM DOM3 (2014-07-29 12:02:30Z) domain with a 3D radiative transfer model (MYSTIC; Mayer 2009) and compared it to a 1D approximation (Delta-Eddington Two stream) simulation using the Independent Column Approximation (ICA). The simulations were performed with a constant surface albedo ($A = 0.2$) and the sun is positioned directly in the south at a zenith angle of $60°$. 3D solar radiation is much smoother than the 1D approximation, due to the fact that a 1D approximation neglects horizontal transport of radiation. The domain averaged mean difference (bias) for the 1D approximation totals in an underestimation of net-reflected sunlight of $-17.5\mathrm{Wm}^{-2}$ (6.4%) compared to the 3D simulation.

Complex 3D interaction between clouds and radiation exist in nature, however, radiative effects are, due to their computational cost in general treated as plane-parallel, one-dimensional problem (1D approximation) in current climate, weather and also large-eddy-simulation models. Therefore, detailed studies of the interactions between clouds and radiation on long temporal scales are necessary to characterize these subgrid effects and to develop accurate parameterizations for lower resolution models. For this purpose, high resolution models (such as ICON-LEM) are an important tool to study these cloud-radiative effects. Due to the enormous computational cost of accurate 3D radiative transfer codes (e.g. Monte Carlo Methods), parallelizable 3D radiative transfer parameterizations (e.g. Jakub and Mayer 2015) are required in these high resolution models. The result of these simulations will be published in a project wide publication that is planned for early 2019.
The organization characteristics of shallow precipitating convection and its impact on the boundary layer turbulence for the Rain in Cumulus (RICO) case were addressed using MicroHH-LES. During the reporting period, a detailed analysis of the water vapour variance in a precipitating cloud-topped boundary-layer was performed and thereby investigated the complex interplay between precipitation, cloud organization, and moisture variance. In order to understand the spatial distribution of variance generation associated with the convective activity, the LES data was analyzed using conditional averaging. For this purpose, we implemented an online conditional sampling code in MicroHH-LES, which could define cloud active and non active areas. After implementing the scalar second and third order budgets (already done in the last reporting period) and conditional sampling in MicroHH-LES, three idealized LES experiments of RICO were repeated using Mistral computing facility. We also performed different test simulations to examine the robustness of the budget analysis of the second and third order moments and to understand the usefulness of the budget during different regimes of cloud organization for RICO.

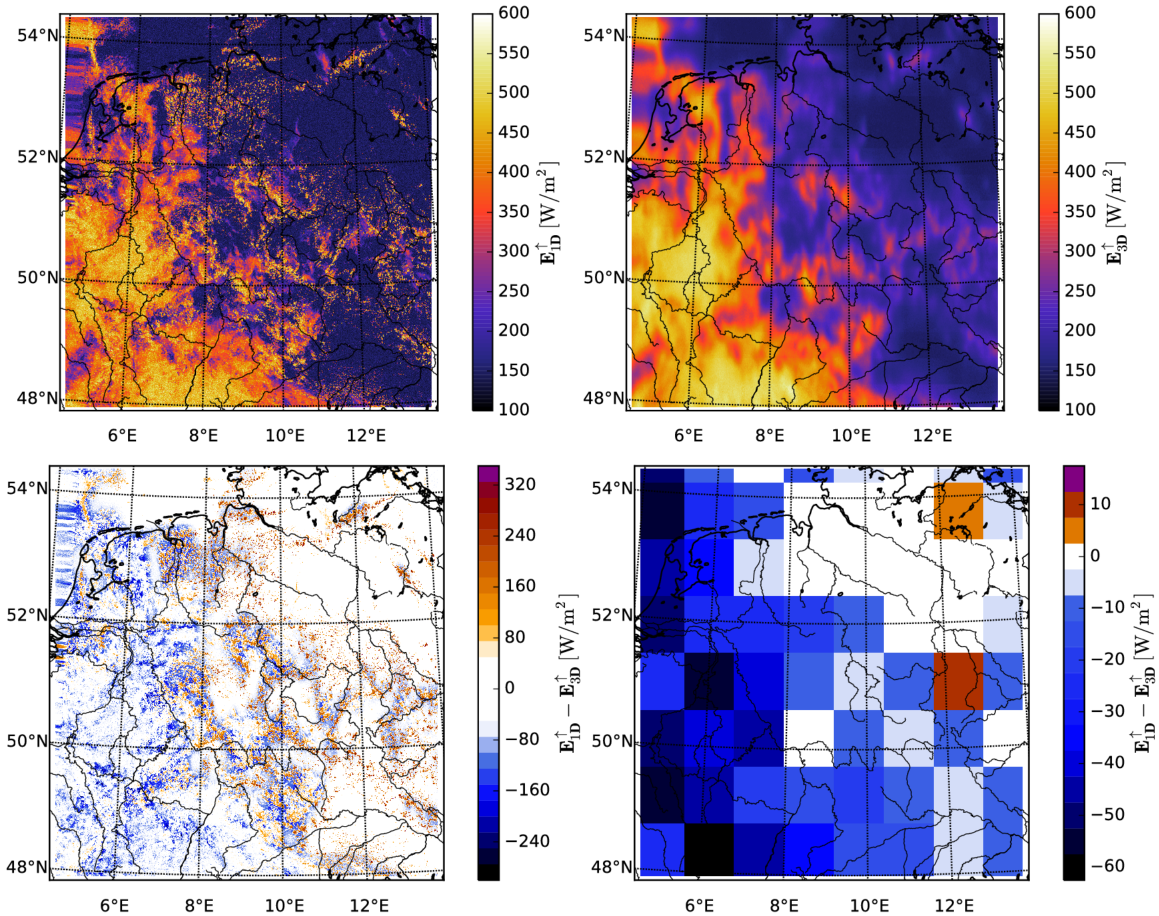


Figure 7: 3D, 1D schemes (upper row) and the difference (lower left) between the two radiative transfer simulations for the upwelling (reflected) solar irradiance at the top of the model domain (at 15km). The lower right panel shows the same plot averaged over about 80km by 80km tiles.

The study focused on the physical mechanisms behind the generation of the moisture variance, the relative role of precipitation dynamics versus cloud microphysics, and the interaction among the sub-cloud, the cloud, and the cloud inversion layers. Moisture variance increase was associated with the presence of dry air downdrafts within the sub-cloud layer (Figure 8) and with moist updrafts in the cloud layer (not shown here). The budget of the third order moment of moisture showed the importance of microphysics as an important sink term in the cloud layer. Currently a manuscript on this is under preparation.

Convection presents one of the major uncertainties in current weather and climate models (Bony et al. 2015, Sherwood et al. 2014). In particular, the spatial distribution of convective zones over the globe (Oueslati and Bellon, 2015), and the diurnal cycle of convection (Bechtold et al., 2004) produced by current convection parametrisations deviate from observations. Cold pools and gust fronts that form from precipitation and downdraughts at the site of previous convection constitute an important feedback between convection, the boundary layer and the surface. These effects both modify local thermodynamic properties and dynamically trigger new convection in adjoining areas (e.g. Torri et al., 2015), tending to increase convective organization and prolong convective activity, but are not represented in convection parametrisations. Our aim is to capture the increased probability of triggering close to previous convection, depending on cold pool properties and time delay, and use this information to improve the probability of triggering convection in models, both in the Plant-Craig stochastic convection parametrisation (Plant and Craig, 2008) for weather

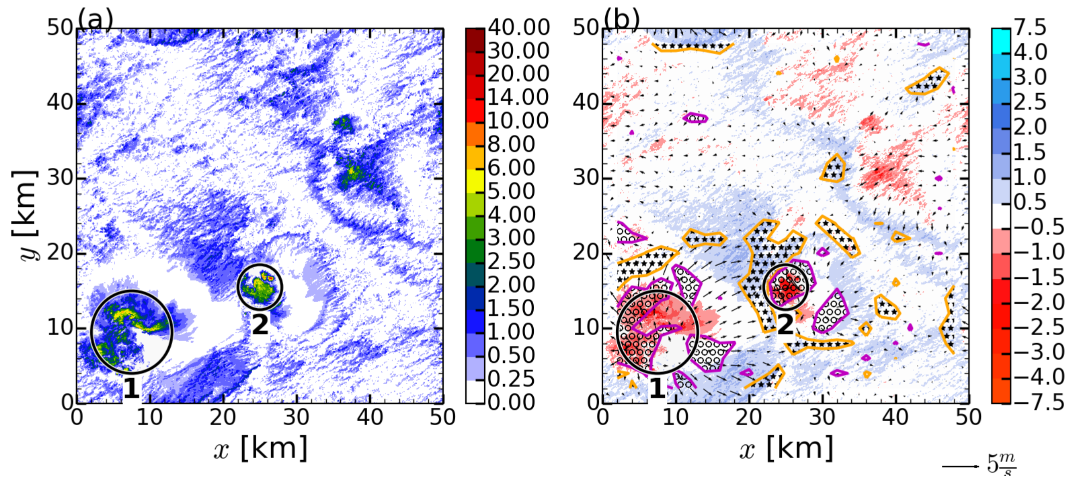


Figure 8: Horizontal cross section of (a) moisture variance in $(gkg^{1-})^2$ (b) moisture perturbation in gkg^{-1} and wind vectors for 35h at 50m. Region 1 and 2 represent the main area of interest. The stars surrounded by orange contours represent convergence region and magenta contours filled with open circles show the divergence regions.

and climate models and in km-scale models that partly resolve deep convection.

We identify and track individual cold pools and convective cells, using a cold pool identification method by Rieke Heinze that combines virtual potential temperature and precipitation criteria, labelling code by Fabian Senf (Heinze 2018, personal communication), and the Iterative Raincell Tracking Tool of Moseley et al. (2018). This allows us to determine the intensity and properties of individual cold pools. Comparing this information with the initiation of new convection at later time steps allows us to estimate the amount of convective triggering associated with the cold pools.

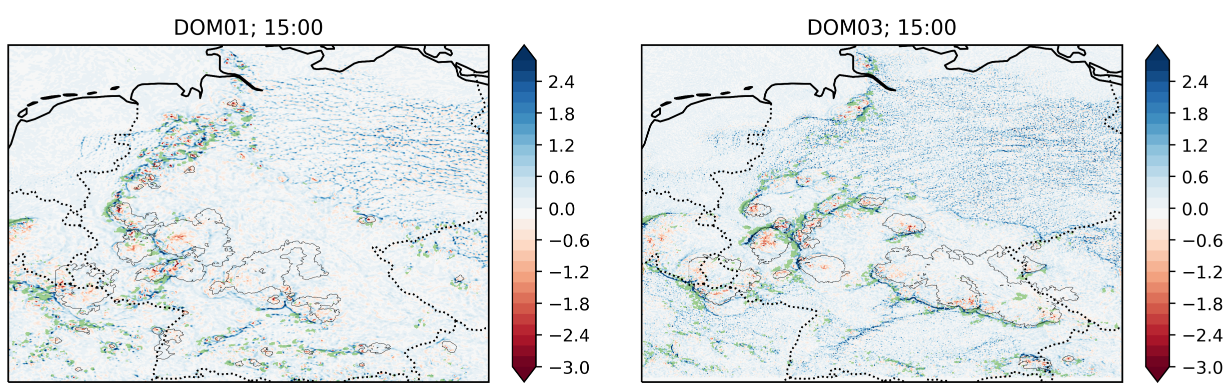


Figure 9: Vertical velocity at 1 km (shaded), cold pools (thin black contours) and time-delayed precipitation initiation (green contours), as seen in ICON-LEM-DE simulations for 6 June 2016 15 UTC, with grid resolution about 600 m (DOM01, left) and 150 m (DOM03, right). Model output has been interpolated to a common 1.5 km rectangular grid. Green contours show precipitation above 0.1 mm at any time between 15:20 UTC and 15:40 UTC, with no previous precipitation. Gust fronts are marked by strong updraughts. Figure by Mirjam Hirt.

We find that in an environment with weak large-scale forcing, the majority of convective precipitation is associated with cold pools. The passage of cold pool gust fronts correlates strongly with precipitation at a time delay of 30 min, confirming that the gust fronts play an important part in new triggering, and that 30 min is the time needed for new convective cells to develop to the point of precipitation initiation. We are preparing a publication detailing our analysis methods and findings. We are planning to extend the analysis to cases with stronger large-scale forcing and background winds by more exactly tracking convection associated with cold pools, and to analyse the lifecycles of convective cells and cold pools in more detail.

To support the evaluation of the ICON-LEM simulations synthetic satellite images in the visible spectral range were computed on Mistral. The fast forward operator for visible and near-infrared satellite images (VISOP) developed at LMU Munich was used to process the model output on full-resolution unstructured ICON grids. Due to the large amounts of data involved in this process and the computational effort caused by taking 3D effects into account, a parallel version of the operator was applied and the parallelization was further improved. Synthetic MODIS images with 250m resolution proved very useful for the model evaluation, as they allowed for a direct comparison of model clouds and real clouds at scales down to the effective model resolution. In addition, synthetic SEVIRI images, which provide information on the evolution of the cloud distribution, were generated and made available via the DKRZ swiftbrowser.

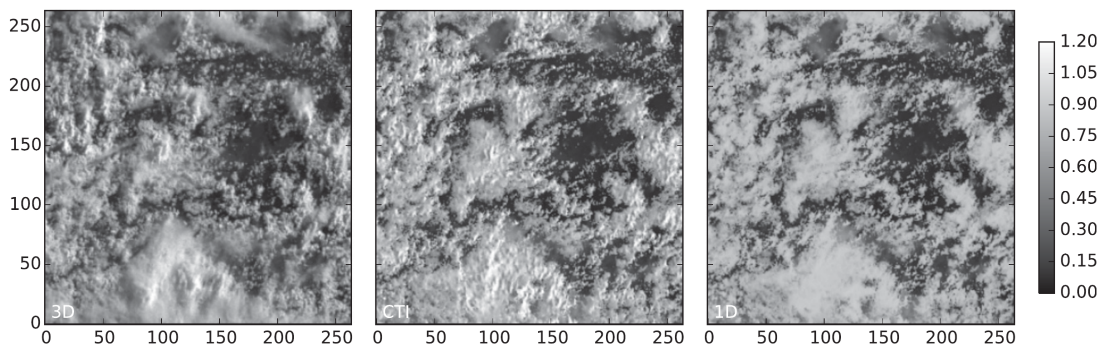


Figure 10: Synthetic visible satellite images (based on ICON-LEM model output) computed with a 3D radiative transfer (RT) solver (left), a 1D RT solver with 3D correction (middle) and pure 1D RT solver (right).

Moreover, 3D-Monte-Carlo radiative transfer calculations based on ICON-LEM model output were carried out to generate reference results (see Figure 10) which we used to improve the fast 3D approximations we developed for the forward operator (Scheck et al. 2018).

4.2 References

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5 Project bm0982

Project title: HD(CP)^2 Module S4 (Land Surface Heterogeneity)
Principal investigator: Christopher Moseley

Granted computation time for 2018: 274010 node*h
Granted storage on Lustre (/work): 69632 GiB
Granted storage on HPSS (/arch): 75000 GB
Granted storage on HPSS (/doku): 5000 GB

In September 2017, a major error has been detected in the calculation of the momentum flux in the ICON-LEM model ("wind bug") as well as in March 2018 a major bug in the roughness length systematic underestimating the surface momentum. S4 is particularly strongly affected by this error, since it directly impacts the feedback between the land surface and the PBL via momentum, energy and water vapor fluxes, and thus also affects the state and stability of the boundary layer including the occurrence and distribution at least of the of boundary layer clouds. An analysis of the impact of the error has shown, that the strong non-linear reaction of the PBL state to the wrong momentum flux makes the exploitation of results, even for sensitivity analyses very cumbersome and most probably ill-fated.

5.1 Usage of requested computation time

For 2018, an amount of 274010 node*h was granted to the project bm0982 for the use in S4. In the reporting period, the following simulations have been performed on this computing account:

1. Several runs with ICON-LEM covering a horizontal grid spacing from 5km down to 150m were performed. We are now able to use COSMO, IFS and ICON-EU data as boundary forcing. Development and test work was successfully performed so that ICON-LEM data on model levels can be used to drive the backward trajectory model LAGRANTO. Calculation and output of budget terms for temperature and humidity was implemented in ICON-LEM and is already used by us and other groups within HD(CP)^2 .
2. ICON-NWP and ICON-LEM Simulations were forced with COSMO data using the same land cover data independent of the resolution. The development of the boundary layer in dependency of the boundary layer scheme and grid resolution was investigated.
3. ICON NWP and LEM simulations during the HOPE campaign are done in cooperation of subproject 2 and 6. These simulations were used for a publication of higher moments in the planetary boundary layer. A publication for the higher moments in the boundary layer is in review.
4. Idealised ICON simulation with realistic radiosonde profile including the land surface model TERRA for different types of convection and different shapes and sizes of land heterogeneities induced by land cover are successfully implemented and performed.
5. Idealised simulations with the model PALM were performed to study fundamental exchange processes between atmosphere and soil on the turbulent scale. We achieved new results for the interaction of land-surface models with large-eddy simulations. Furthermore, we started to quantify the error of Monin-Obukhov Similarity-Theory (MOST) over heterogeneous terrain.
6. For TP2: 4 simulations of single days on three domains DOM1, DOM2, DOM3 (156 m target resolution), in a small domain setup covering the South West of Germany, for the SABLE measurement campaign in Baden-Württemberg (ca. 10000 node hours per model day)
7. Simulation of 3 single test days on the large DE domain DOM1 (600 m grid spacing) with modified land cover:

  - A control simulation "CT" with unmodified EXTPAR input
  - A simulation "FOREST" with modified EXTPAR input where the entire domain is covered by mixed forest.
  - A simulation "FOREST-LOWZ0" with modified EXTPAR field where the entire domain is covered by mixed forest, but with reduced surface roughness length

8. Performed on the M contingent: 3 simulations of a 6-day period, in the CTR, FOREST, and FOREST-LOWZ0 setup as described in point 7, respectively.
9. In work package 3, eight idealized setups with "river-like" soil moisture pattern with heterogeneity scale ranging from 0.6 to about 80 km were performed using ICON-LEM. The study provides insight into the influence of spatial scale of soil moisture heterogeneity on catchment-scale circulations and the ensuing growth of the convective boundary-layer. This work has been submitted to Quarterly Journal of the Royal Meteorological Society as a research paper.

5.2 Justification of shifted computing time

- 1 node hour expired in March 2018. In the second and third quarter of 2018 no computing time expired.
- Computing time is shifted from project 0982 to 0834 as the afforestation experiments were done on the M contingent (see [8] above).

6 Project bm0994

Project title: HD(CP)^2 Module S3 (Anvil Cirrus and stratiform outflow), subproject 2
Principal investigator: Peter Spichtinger

Granted computation time for 2018: 11130 node*h
Used computation time for 2018: 5761 node*h
Granted storage on Lustre (/work): 5620 GiB
Granted storage on HPSS (/arch): 5000 GB
Granted storage on HPSS (/doku): 0 GB

In this project cirrus clouds as driven by the outflow of warm conveyor belts (WCBs) are investigated. For this purpose, special cases of WCBs are analyzed, using the ICON model in a coarser resolution (i.e. in the NWP mode with horizontal a resolution of $\Delta x \sim 1 - 10\mathrm{km}$).

6.1 Usage of requested computation time

6.1.1 Development and extension of ice microphysics scheme

For addressing the issue of dominant pathways of ice nucleation, the microphysics scheme was extended. In the existing scheme there is only one class for cloud ice, which can be formed via different pathways; once ice crystals are formed, number and mass concentrations stemming from different sources are just added. We extended the cloud ice class to five classes. Each of them consists of a number concentration $\mathrm{nc}_{\mathrm{class}}$ and a mass concentration $\mathrm{qc}_{\mathrm{class}}$. The classes represent different ice formation pathways, i.e. homogeneous freezing of solution droplets, deposition nucleation, immersion freezing, homogeneous freezing of preexisting cloud droplets and secondary ice production due to Hallett-Mossop process (driven by riming), respectively. For all classes, also the collision between ice crystals and water droplets must be taken into account. These processes were also included into the extended scheme. The scheme was tested using the implemented Weisman-Klemp test case.

6.1.2 First investigations of WCBs using the new ice scheme

We selected some cases of WCBs, which will be investigated in ensemble simulations. In a first step, we carried out some simulations for a WCB case as already described in literature (see Joos and Wernli,2012). The scheme worked very well and produced realistic results, see figure 11. However, it seems that heterogeneous nucleation is too dominant, i.e. too many ice crystals are produced. This is probably due to the fact that we used a nucleation scheme, which was mostly developed for simulating clouds in an environment, which is dominated by dust emissions. We carried out several sensitivity studies for determining the impact of different parameters in the nucleation scheme. However, it seems that we have to include another scheme for heterogeneous ice nucleation, which is able to represent also standard environmental background of aerosols. Once this scheme is implemented, we will carry out ensemble simulations of the WCB case in order to determine the impact of environmental conditions as well as model parameters on the formation of ice clouds via different pathways of formation. Thus, we will try to investigate the issue of in situ vs. liquid origin ice clouds, as described in Krämer et al. (2016).

6.2 Deviations from the planned schedule

Unfortunately, there were delays in the project progress, as already stated in the last report in 2017. The project was interrupted between 31/10/2016 and 30/04/2017, until Tim Lüttmer started to work on the project. In addition, some some additional ice microphysics parameterizations (see above) had to be developed in order to address the research questions adequately. This task required only marginal computing time.

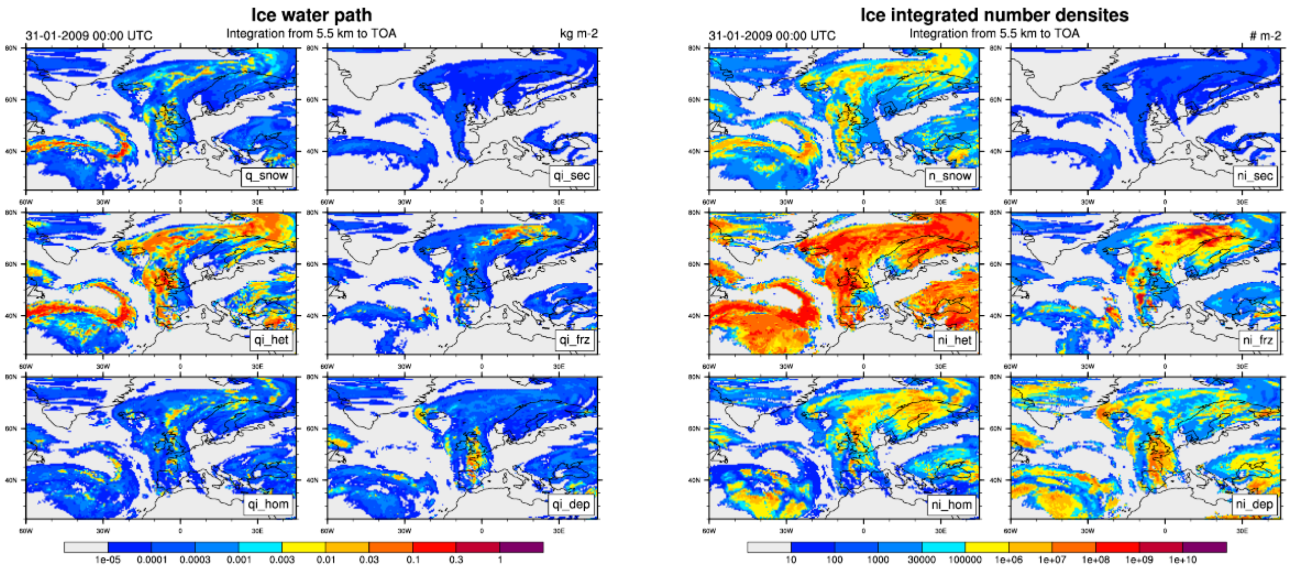

Figure 11: Ice water path (left) and ice crystal number burden (right) for a developing warm conveyor belt. The six different ice modes, as discriminated by formation mechanism are shown in the different panels (snow, secondary formation, immersion freezing, homogeneous freezing of cloud droplets, freezing of solution droplets and deposition nucleation).

6.3 References

Krämer, Martina, et al. (2016): A microphysics guide to cirrus clouds-Part 1: Cirrus types. Atmospheric Chemistry and Physics 16 (2016): 3463-3483.

Joos, H. and Wernli, H. (2012), Influence of microphysical processes on the potential vorticity development in a warm conveyor belt: a case-study with the limited-area model COSMO. Q.J.R. Meteorol. Soc., 138: 407- 418. doi:10.1002/qj.934

7 Project bm1018

Project title: HD(CP)^2 Module S6 (Storm tracks in the context of climate)
Principal investigators: Aiko Voigt

Granted computation time for 2018: 10.000 node*h
Used computation time for 2018: 7.800node*h
Granted storage on Lustre (/work): 32768 GiB
Granted storage on HPSS (/arch): 16000 GB
Granted storage on HPSS (/doku): 0 GB

7.1 Usage of requested computation time

The computing time was used to perform global ICON-NWP simulations of climate change in a prescribed-SST setup. For this, the model version icon-2.1.00 in resolution R2B4 with 47 levels was used. These simulations applied the cloud and water-vapor locking technique. Moreover, the technique to lock either only clouds or both clouds and water vapor was applied.
A full set of prescribed-SST simulations that at the same time lock clouds and water vapor have been calculated. This set complements earlier simulations that were performed in 2017, in which only clouds were locked. Global warming in this setup is mimicked by a uniform 4K SST increase. This set comprises 10 simulations in total, each with a length of 30 years. These simulations have contributed to a paper that is currently under review, see below (Voigt, Albern, Papavasilieuo, 2018, submitted). The consumption for this set was 4500 node*h.
Moreover, a full set of simulations with locked clouds and with global warming mimicked by a patterned SST increase (as in the CMIP5 AMIPFuture runs) was simulated. This set comprised 6 simulations, each with a length of 30 years. The total consumption for this set was 2700 node*h.
Besides the locking techniques, the partial-radiative-perturbation technique was implemented in ICON-NWP and teste. This the technique was used to diagnose the cloud-radiative forcing in the global warming simulations. The consumption for these simulations was 300 node*h.
Furthermore some computing time was used to perform COOKIE aquaplanet simulations with ICON-NWP and ICON-MPI. These simulations contributed to a paper that is now published in Geophysical Research Letters (Albern et al., 2018; see below). The consumption for these simulations was again 300 node*h.

In the last quarter of 2018, the remaining computing time will be used to implement and test a slab ocean setup in the global ICON-NWP model, and it is planned to start first production simulations with the slab ocean. In these simulations, cloud-radiative changes will be allowed to impact SST, so that these simulations will complement the existing prescribed-SST simulations. The estimated consumption in for the fourth quarter of 2018 is 2500 node*h.

The number for the usage of the resources up to now are

- /work storage: 16.000 GB
- /arch storage: 550 GB

7.2 Resulting publications in 2018

The performed simulations led to three publications that are submitted and in review.:

N. Albern, A. Voigt, S.A. Buehler, and V. Grützun, 2018: Robust and non-robust impacts of atmospheric cloud-radiative interactions on the tropical circulation and its response to surface warming, Geophysical Research Letters, doi: 10.1029/2018GL079599.

N. Albern, Voigt, A., and J. Pinto, Cloud-radiative impact on the global warming responses of the midlatitude jet streams and storm tracks, to be submitted to JAMES.

A. Voigt, N. Albern, and G. Papavasileiou, 2018: Poleward circulation expansion amplified by rising high-level clouds, submitted.

7.3 Deviations from the planned schedule

During the course of the year it was decided to focus only on the ICON-NWP version (originally, it was also planned to perform simulations with the ICON climate version). The reason for this was twofold: first, the NWP simulations turned out to be very interesting on their own, leading to a publication in preparation for JAMES (Albern, Voigt and Pinto). Second, the ICON climate version was only released during the course of the year 2018.
For 2018 it was originally also planned to perform locked cloud simulations to study the NAO variability. Yet, before starting this work, there was the need to finish the observational analysis using CloudSat/Calipso and ERA-Interim reanalysis data. This has proven more challenging than expected, therefore these simulations had to be postponed. It is planned to perform these simulation in 2019 (see the request for allocation from the HD(CP)^2 consortium).
Despite these slight necessary changes, it is planned to fully use the allocated resources until the end of 2018. For Q42018, it is planned to archive those simulations currently stored on work, so that also the allocated archive space will be used before the end of 2018.

8 Project bm1032

Project title: HD(CP)^2 Module S1 (Anvil Cirrus and stratiform outflow), subproject 4
Principal investigator: Corinna Hoose

Granted computation time for 2018: 100 node*h
Used computation time for 2018: 76 node*h
Granted storage on Lustre (/work): 1000 GiB
Granted storage on HPSS (/arch): 0 GB
Granted storage on HPSS (/doku): 0 GB

8.1 Usage of requested computation time

The requested computation time was used for test simulations and for postprocessing and visualization of the data from the HD(CP)^2 consortia simulations. A particular an analysis was of the microphysical process rates via a newly developed recalculation method.

8.2 Deviations from the planned schedule

The postprocessing methods have undergone intensive testing, which was done offline (with data from idealized ICON-LEM simulations run locally at KIT). Therefore, fewer node*h than planned have been consumed.

8.3 Resulting publications in 2018

This work was done in the course of a master thesis and is currently prepared for a peer-review publication. It can be downloaded at `http://www.imk-tro.kit.edu/download/Masterarbeit_Markus_Karrer.pdf` (Ice growth processes in two bulk microphysics schemes compared to radar observations. Master thesis of Markus Karrer, Karlsruhe Institute of Technology, 2018.)

9 Project bm1032

Project title: HD(CP)^2 Module S3 (Anvil Cirrus and stratiform outflow), subproject 4
Principal investigator: Martin Köhler, Harald Rybka, Axel Seifert

Granted computation time for 2018: 21730 node*h
Used computation time for 2018: 28004 node*h
Granted storage on Lustre (/work): 32768 GiB
Granted storage on HPSS (/arch): 3200 GB
Granted storage on HPSS (/doku): 0 GB

9.1 Usage of requested computation time

The granted node hours have been used for sensitivity simulations of ICON-LEM starting with different initial and lateral boundary conditions. Data from IFS and operational ICON weather forecasts (DWD) have been applied to start ICON-LEM simulations with slightly different atmospheric fields as opposed to the original COSMO initial conditions. The origins of IFS and ICON initial and lateral boundary conditions underlie a coarser horizontal grid, hence include minor information of small scale features. The influence of using coarser initial data and lateral boundary conditions has been investigated.

9.2 Deviations from the planned schedule

Only minor changes from the planned work have been taken into account. Instead of using individual members from the IFS ensemble runs to initialize further ICON-LEM simulations separate runs have been performed with interchanges of IFS and DWD initial and lateral boundary conditions. This intercomparison allows to separately identify the direct impact of the initial atmospheric fields or lateral boundary conditions onto the model forecast.

10 Project bb1041

Project title: HD(CP)^2 Module S2 (Boundary layer clouds), workpackages 1,4 and 7
Principal investigators: Vera Schemann

Granted computation time for 2018: 10.000 node*h
Used computation time for 2018: 9607 node*h
Granted storage on Lustre (/work): 10.240 GiB
Granted storage on HPSS (/arch): 3.000 GB
Granted storage on HPSS (/doku): 1.000 GB

10.1 Usage of granted computation time

The computation time was mainly used for the proposed high-resolution simulations around the supersite JOYCE (Jülich ObservatorY for Cloud Evolution). After establishing the test bed setup during the last period in 2017, we now used the computation time to perform simulations necessary for a detailed evaluation. The main focus is on 9 days during the HOPE (HD(CP)^2 observational prototype experiment) period ($24.4. - -2.5.2013$). This period offered a wide range of different synoptic situations, which made it very valuable for model evaluation and testing. Additionally we performed simulations for the study of the nocturnal boundary layer (as proposed) and for different days with specific weather conditions (e.g., the 24.11.2015 for a winter front or the 17.6.2014 for a drizzling cloud). We also performed some simulations around other supersites (Barbados and Ny-Ålesund) for testing purposes.

10.2 Deviations from the planned schedule

We did not perform the proposed global simulations due to delays and problems with the implementation of our improved parameterization. We also performed less simulations around Barbados than were originally planned, as we rather focused our research effort on the supersite JOYCE. The spare simulation time was used for additional high-resolution simulations around JOYCE, e.g. with a semi-idealized model version, which is beneficial to compare different model setups.

Publications from the allocation period 01.01.2018 – 31.12.2018

N. Albern, A. Voigt, S.A. Buehler, and V. Grützun, 2018: Robust and non-robust impacts of atmospheric cloud-radiative interactions on the tropical circulation and its response to surface warming, Geophysical Research Letters, doi: 10.1029/2018GL079599.

N. Albern, Voigt, A., and J. Pinto, Cloud-radiative impact on the global warming responses of the midlatitude jet streams and storm tracks, to be submitted to JAMES.

Baumgartner, M. and Spichtinger, P. (2018): Towards a bulk approach to local interactions of hydrometeors, Atmos. Chem. Phys., 18, 2525-2546, doi.org/10.5194/acp-18-2525-2018.

Biasutti, M., Voigt, A., Boos, W. R., Braconnot, P., Hargreaves, J. C., Harrison, S. P., Kang, S. M, Mapes, B.E., Scheff, J., Schumacher, C., Sobel, A. H., and Xie, S. (2018): Global energetics and local physics as drivers of past, present and future monsoons. Nature Geoscience, 11(6), 392, https://doi.org/10.1038/s41561-018-0137-1

Brdar, S. and Seifert, A. (2018): McSnow: A Monte-Carlo particle model for riming and aggregations of ice particles in a multidimensional microphysical phase space. Journal of Advances in Modeling Earth Systems, 10, doi:10.1002/2017MS001167

Brune, S., F. Kapp and P. Friederichs (2018): Convective organization in ICON large-eddy simulations, submitted to QJRMS

Düsing, S., Wehner, B., Seifert, P., Ansmann, A., Baars, H., Ditas, F., Henning, S., Ma, N., Poulain, L., Siebert, H., Wiedensohler, A., and Macke, A. (2018): Helicopter-borne observations of the continental background aerosol in combination with remote sensing and ground-based measurements, Atmos. Chem. Phys., 18, 1263-1290, doi.org/10.5194/acp-18-1263-2018.

Gryspeerdt, E., Quaas, J., Goren, T., Klocke, D., and M. Brueck (2018): An automated cirrus classification, Atmos. Chem. Phys., 18, 6157-6169, doi.org/10.5194/acp-18-6157-2018.

Master thesis of Markus Karrer, KIT: Ice growth processes in two bulk microphysics schemes compared to radar observations, `http://www.imk-tro.kit.edu/download/Masterarbeit_Markus_Karrer.pdf`

Moseley, C., Henneberg, O., and Haerter, J. (2018): Amplified convective precipitation from multi-merging, submitted to Journal of Advances in Modeling Earth Systems

S.K. Muppa, A. Behrendt, H.-S. Bauer, K. Warrach-Sagi, F. Späth, N. Kalthoff, V. Maurer, A. Wieser, R. Heinze, C. Moseley, R.A.J. Neggers, P. Siligam, and V. Wulfmeyer (2018): Characterizing turbulent processes in the convective boundary layer:Evaluation of large eddy simulations with high-resolution lidar observations. submitted to QJRMS.

Schäfer, S.A.K., and A. Voigt (2018): Radiation weakens idealized mid-latitude cyclones, Geophys. Res. Lett., 45, doi:10.1002/2017GL076726.

Senf, F., D. Klocke, and M. Brueck (2018): Size-resolved evaluation of simulated deep tropical convection. Mon. Wea. Rev., 0, https://doi.org/10.1175/MWR-D-17-0378.1

A. Voigt, N. Albern, and G. Papavasileiou, 2018: Poleward circulation expansion amplified by rising high-level clouds, submitted.