BACCHUS

Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding

Collaborative Project

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1. Summary of results

This deliverable aims at investigating the key processes controlling cloud systems in contrasting environments. It builds on D3.1 outlining the protocol for the individual case studies including model configurations and available measurements.

1.1. Arctic Case study

In order to investigate the key processes controlling cloud systems in an Arctic environment, we have selected a case study based on the observations available during the 2008 ASCOS campaign. Simulations of this case have been performed using three large-eddy simulation (LES) models: UCLALES-SALSA, operated at FMI; MIMICA, operated at Stockholm University; and COSMO-LES, operated at KIT. Simulations have also been performed using three numerical weather prediction (NWP) models: COSMO-NWP, operated at ETH; WRF, operated at the University of Manchester; and UM-CASIM, operated at the University of Leeds.

Each of the three NWP models was initialized with output from the ECMWF global reanalysis. The models were run with 0.009° x 0.009° horizontal resolution rotated grid (approximately 1x1 km throughout the domain) spanning a 600 km x 600 km domain, centred at 87.3° N, 6.0° W. The simulated duration was 48 hours starting at noon UTC, Aug. 30th, 2008.

The three LES models were initialized with a set of potential temperature and humidity profiles based on preliminary output from UM-CASIM. No flux of heat and moisture from or to the surface was permitted, as fluxes of heat and moisture from sea ice would be negligibly small.

We have chosen to perform a set of simulations with prescribed the cloud droplet number concentration (CDNC) of 30 cm^{-3} and 3 cm^{-3} as well as simulations with prognostic CDNC based on prognostic aerosol with initial concentrations of 80 cm^{-3} and 30 cm^{-3}. We prescribe ice crystal number concentrations (ICNC) in each case as either 1 L^{-1}, 0.2 L^{-1}, or 0.02 L^{-1}, as well as performing a case without cloud ice.

Results from the case with prescribed CDNC of 30 cm^{-3} and prescribed ICNC of 0.2 L^{-1} are shown in Fig. 1.

The MIMICA, COSMO-LES, and COSMO-NWP models all produce a mixed-phase cloud at a similar altitude of ~1 km from the surface. However, cloud depth, cloud liquid water content and cloud ice water content all differ between the models. If the habit of the precipitating ice crystals in WRF is changed from dendrites to spheres, then WRF also produce a mixed-phase cloud at approximately 1 km from the surface (not shown).

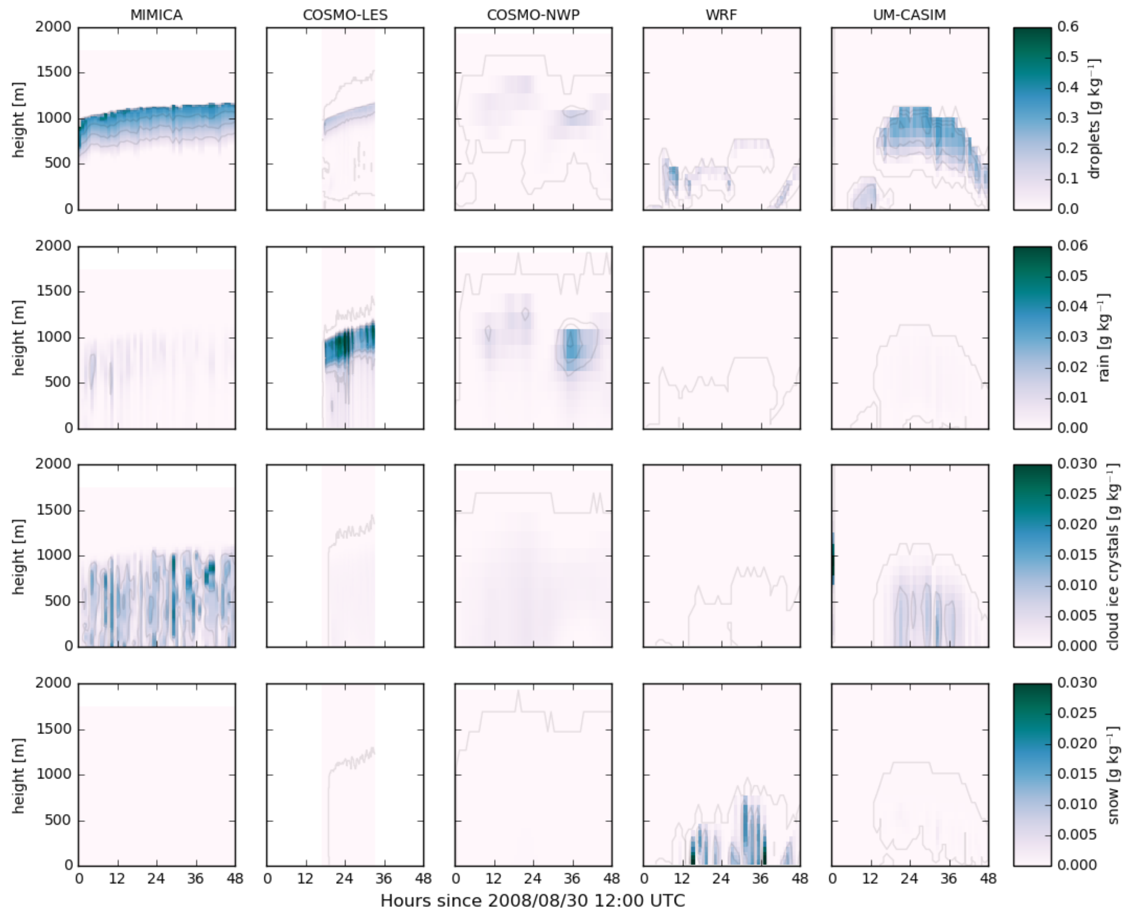

Figure 1: Mass mixing ratios of cloud species at the centre of the domain for each model for the case with prescribed CDNC of 30 cm^{-3} and prescribed ICNC of 0.2 L^{-1}. From top to bottom: cloud droplets, rain, cloud ice crystals, and snow. Note that the colour bar limits differ between rows.

Our preliminary analysis therefore indicates that there is much diversity even when CDNC and ICNC are prescribed, and that the model results are sensitive to the habit assumed for precipitating ice crystals.

In order to explain the differences between the models, we use the tendencies in modelled cloud species mass mixing ratios due to diverse model processes. For example, we show in Fig. 2 the loss rate of cloud droplet mass due to autoconversion to rain plotted against the cloud droplet mass simulated by each of the models. Rates of autoconversion to rain are clearly greater for low cloud droplet mass mixing ratios within the MIMICA and COSMO-LES models compared to the three NWP models, which is the most likely cause of the greater mass fractions of rain simulated by MIMICA and COSMO-LES compared to the three NWP models (Fig. 1).

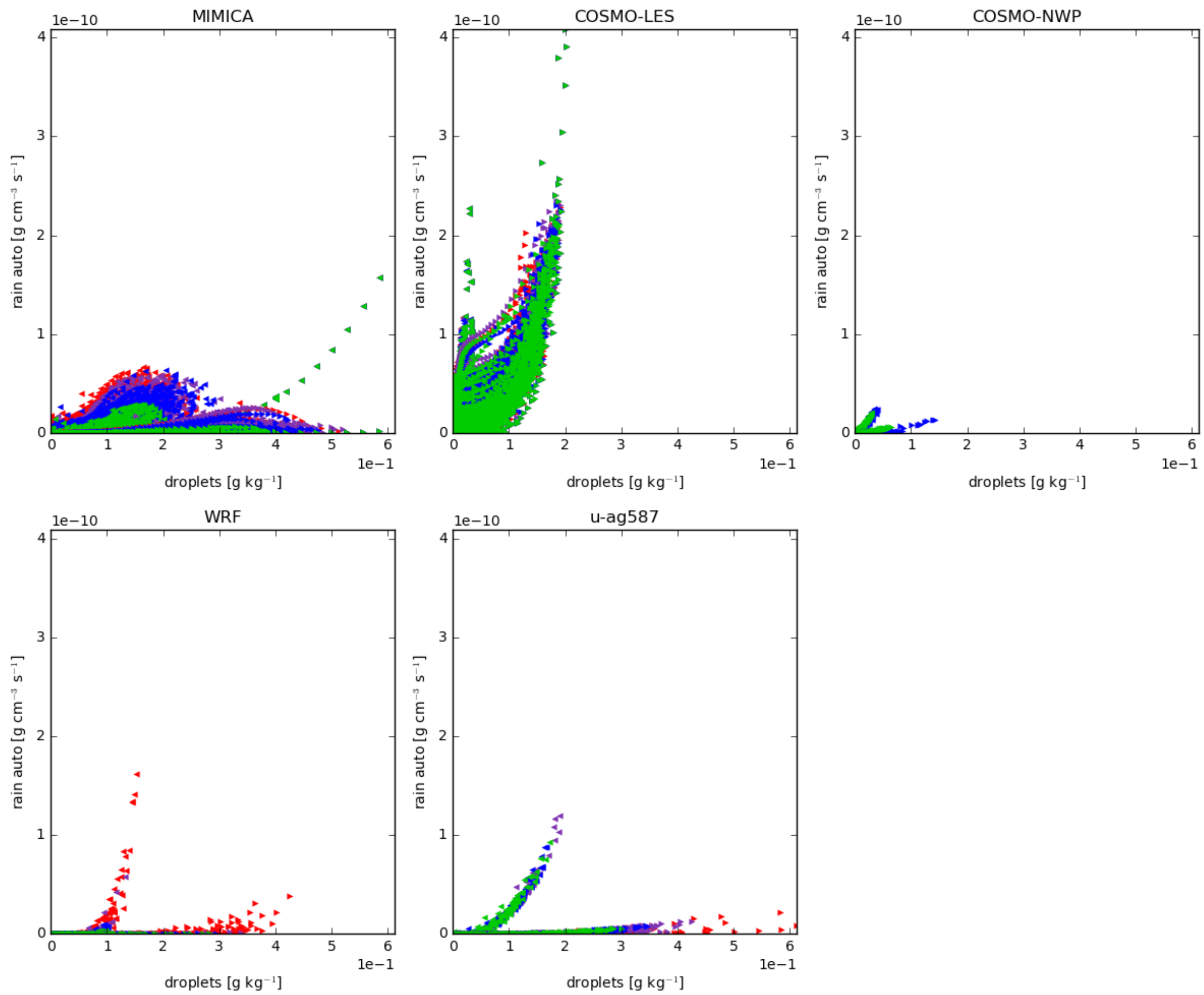

Figure 2: Scatter plots of loss rates of cloud droplet mass due to autoconversion to rain vs. cloud droplet mass mixing ratio, for the MIMICA, COSMO-LES, COSMO-NWP, WRF, and UM-CASIM models. Results are shown for all prescribed CDNC cases. Marker style denotes prescribed CDNC (leftward arrow: 3 cm^{-3}, rightward arrow: 30 cm^{-3}) and colour denotes prescribed ICNC (red: no ice, purple: 0.02 L^{-1}, blue: 0.2 L^{-1}, green: 1 L^{-1}).

Results from the UCLALES-SALSA model using prognostic CCN are shown in Fig. 3. When the initial aerosol concentration is set to 80 cm^{-3} (right column), a cloud is produced that lasts throughout the duration of the simulation. When the initial aerosol concentration is set to 30 cm^{-3} (left column), available CCN within the cloud are depleted and the cloud dissipates after about 12 hours of simulated time. These results suggest that the UCLALES-SALSA model is able to represent the important processes for the CCN-limited cloud regime.

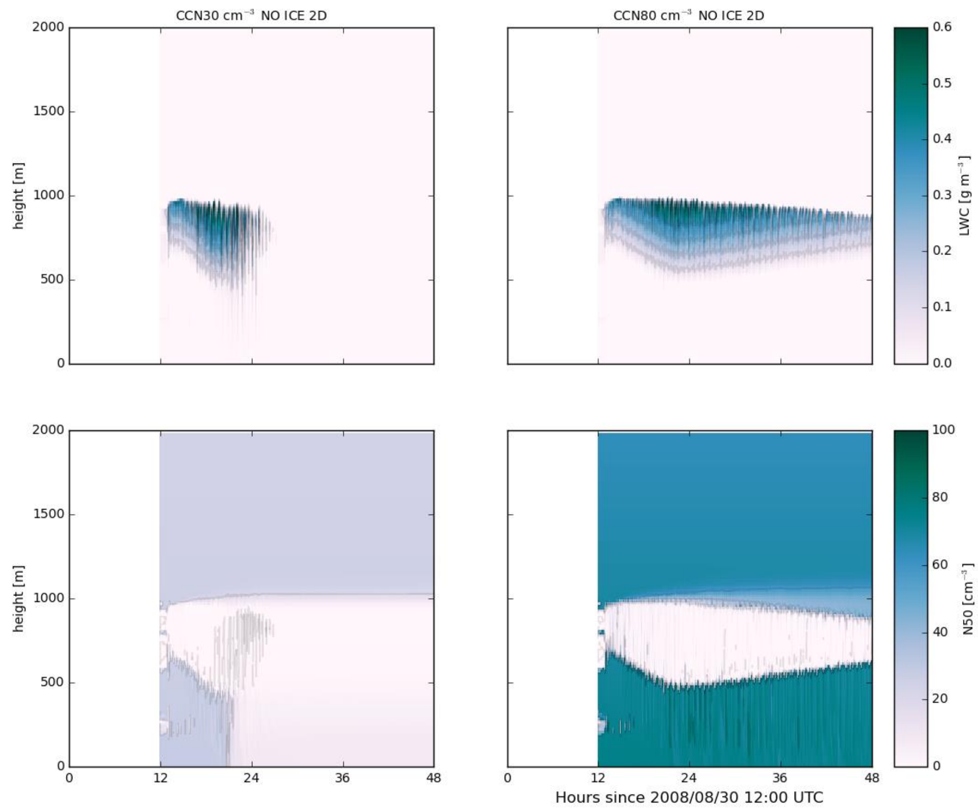

Figure 2: Liquid water content (top row) and number concentration of aerosol greater than 50 nm in diameter (N50, bottom row) as simulated by UCLALES-SALSA for the CCN 30 cm^{-3} case (left column) and the CCN 80 cm^{-3} case (right column) with no ice.

1.2. Amazon Case Study

Multiple modelling tools have been used to investigate the cloud formation and evolution in the Amazon areas. We select the Green Ocean Amazon (GOAMAZON) and ACRIDICON campaign period for the case study for better model validation and comparison. To better understand the underlying cloud microphysics, detailed microphysical pathway analysis/process analysis modules for different models were developed.

1.2.1. Methodology

WRF and ECHAM-HAM (Oxford)

Simulations for the second intensive observation period (IOP) of the GOAMAZON campaign are performed, focusing on a case study around the satellite overpass/aircraft flight on the 6th September 2014 that has been used in the analysis of WP3.2. These simulations include the WRF model with the Morrison microphysics scheme and the single column model setup of ECHAM-HAM with the Convective Cloud Field Model CCFM (Wagner and Graf 2010; Kipling et al. 2016; Labbouz et al. 2016).

The aerosol model HAM used in ECHAM-HAM has been implemented in WRF and is currently undergoing final testing (Heikenfeld et al., 2017b). The simulations are performed with a setup consisting of three nested domains (d01: Δx=9km, 252x252, parametrized convection; d02: Δx=3km, 420x420, resolved convection; d03: Δx=1km, 480x480, resolved convection) centred around the ARM measurement facility at Manacpuru. The simulations are forced with boundary conditions from the ERA Interim Reanalysis at the outside of the outermost model domain (d01) available at 6h frequency. The innermost domain (d03) is used as a target domain for all analyses presented here. We have added a detailed cloud microphysical pathway analysis for the Thompson and Morrison microphysics schemes in the WRF model. The inclusion of a cell tracking algorithm will allow to extend this to a statistical analysis in the near future (Heikenfeld et al., 2017a).

The global circulation model ECHAM-HAM is used in Single Column Mode (SCM) in order to compare the results with the domain-average high resolution WRF simulations. ECHAM-HAM has 31 sigma-hybrid vertical levels, and a 12-minute timestep. Convection is parametrised using the standard bulk mass-flux scheme or the latest version of CCFM, simulating a population of convective clouds instead of a single average cloud. The SCM is driven by advective tendencies of specific humidity and temperature derived from variational analysis (provided by ARM in the framework of GOAMAON), and humidity and temperature are also relaxed to the temperature and humidity profiles with a 6-h relaxation time scale.

To isolate the effect of cloud microphysics, microphysical aerosol effects are represented by two different values for CDNC in the simulations with both WRF and ECHAM-HAM-CCFM. The two values of CDNC represent cloud droplet numbers for relatively clean background conditions (250 cm^{-3}) and a moderately polluted case (500 cm^{-3}). The simulations for the SCM are also performed with CCN activation (Abdul-Razzak and Ghan, 2000).

WRF-Chem (MPIC)

The impacts of emissions/aerosol concentration on the cloud microphysics, dynamics and precipitation over the Amazon areas were investigated using the WRF-Chem model. Ensemble sensitivity studies were conducted for different emission scenarios (emissions scaled by different factors, EMISS*0.01, EMISS*0.1, EMISS, EMISS*2, EMISS*5, EMISS*10). The simulations over the Amazon areas start were conducted from 30 August till 10 September 2014, covering a case study around the satellite overpass/aircraft flight on the 6 September 2014 that has been used in the analysis of WP3.2, and the Lin parameterization scheme (Lin et al., 1983) is used to describe the cloud microphysics. There are 40 vertical layers. The comprehensive measurements of aerosol and cloud properties from the campaign and the ATTO (Amazonian Tall Tower Observatory) site will help to validate the model simulations and ensure the representativeness of the selected cases.

In order to unravel the complicated interactions, MPIC employed the process analysis (PA) module in WRF to quantify the causation of changes in the concentrations of individual hydrometeor classes. The PA calculates the rate of change in the mass or number concentration of each hydrometeor type caused by a particular process, thereby enabling the determination of the relative importance of relevant microphysical processes under different fire forcing and aerosol conditions.

UCLALES-SALSA (FMI)

The UCLALES-SALSA model is a LES model with detailed spectral aerosol and cloud microphysics. A model version suitable for warm clouds is near completion (Tonttila et al., 2016). The Amazon case study is based on the GOAmazon campaign from 1 Sep to 10 Oct, 2014. Atmospheric and surface boundary conditions and large scale forcing (negligible) for UCLALES-SALSA were obtained from ECMWF analyses. Aerosol in the initial simulations was assumed to be composed of organics (90%) and ammonium sulphate (10%) and the total number concentration was set to 1000 cm^{-3}, however, further simulations can be based on in-situ observations.

Satellite observations (FMI)

The ATSR dual view (ADV) and single view (ASV) algorithm have been developed at the FMI to derive aerosol properties from the AATSR radiances over land and over ocean respectively, while the cloud module SACURA in the ADV/ASV algorithm retrieves cloud properties.

We collected Level 2 MODIS as well as ADV/ASV-retrieved aerosol and cloud properties over an extended area of the Amazon that includes also the Caribbean. As ENVISAT was lost in 2012, ADV/ASV algorithm is constrained by this temporal limit.

With the aim of associating parameters from different satellite dataset, cloud optical properties at 1km x 1km resolution from MODIS and ADV algorithm are directly compared. The focus is on liquid clouds. The standard MODIS aerosol Level 2 product, MxD04, has 10x10km resolution but MODIS Collection 6 has introduced a new one with a 3x3 km spatial resolution, which will be soon included in our results. The ADV/ASV algorithm retrieves aerosol properties at 1x1km. These aerosol parameters are collocated in time and space to derive spatial distribution over the case study area as well as compared, locally, with the AERONET station of Manaus EMRAPA.

These observations, with the additional modelling data provided by Harri Kokkola, are used in WP3 D3.4 for satellite and ESM evaluation over the year of 2008. The evaluation is done primarily over the case study regions over the Amazon and Barbados. We hope to expand the analysis to other ESM data as well.

1.2.2. Results

Model comparison: WRF vs ECHAM-HAM-CCFM in SCM mode

The SCM performs well in reproducing precipitation over the domain, and WRF also gives satisfactory results until 21 UTC but does not simulate any precipitation afterwards (Figure 4).

The WRF simulation also has larger liquid water path and ice water path than the SCM simulations, while having an on average a drier atmosphere (Figure 5).

Increasing CDNC leads to a delay in both the onset and the peak of precipitation simulated by WRF (Figure 4), however the delay is small and it is hence difficult to conclude on a microphysical effect from asimulation with a duration of only one day. Moreover, there is no significant impact on the hydrometeor profile to support a

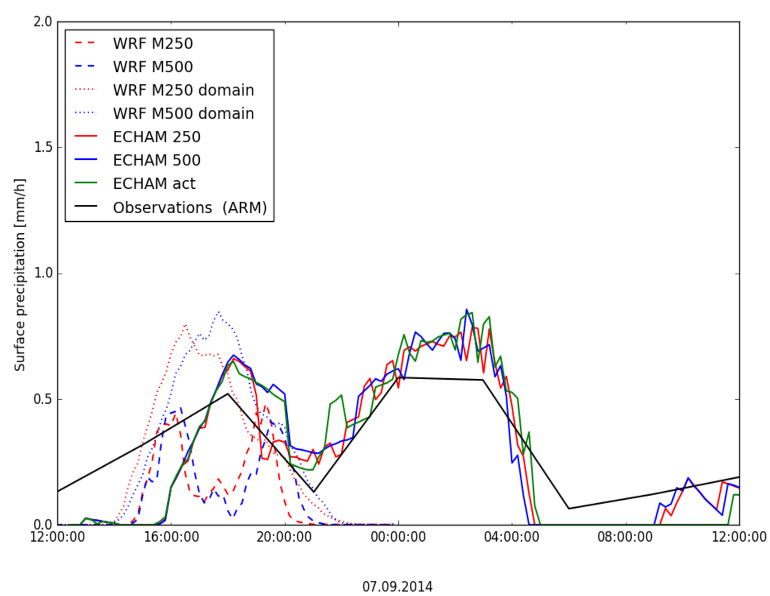

Figure 4: Surface precipitation for the simulations with WRF (dashed/dotted) and with the ECHAM-HAM_CCFM SCM (solid). Colours denote the choice of cloud droplet number concentration, "act" meaning that it is calculated from CCN activation. For WRF both the average over the domain of the SCM (dashed) and over the entire inner domain of the simulation d03 (dotted) are shown. 3-hourly observed surface precipitation from the ARM Radar measurements are shown in black.

CDNC impact (Figure 5). The SCM appears to be insensitive to changes in convective cloud-base CDNC. Additional analysis exploring a larger range of CDNC values will be performed to understand the low sensitivity to CDNC observed in these simulations and possible limitations due to the current microphysics parameterisations.

The SCM uses forcing data based on observations around the central facility of the ground based measurements, while the cloud-resolving model (CRM) simulation with the WRF model is more freely evolving with a more distant forcing from the reanalysis product at the boundary of the outer domain. This can be overcome by a more statistically based comparison over the entire campaign period (39 days). The lack of liquid water in the SCM also shows deficiencies in the microphysics (Labbouz et al., 2017). Ongoing work with CCFM will improve the microphysics parametrisation and comparisons of the process rates between WRF and CCFM will help understanding current CCFM deficiencies (Labbouz et al., 2017; Heikenfeld et al., 2017a). It should also lead to a better assessment of CDNC impact (or lack of impact) on the microphysics.

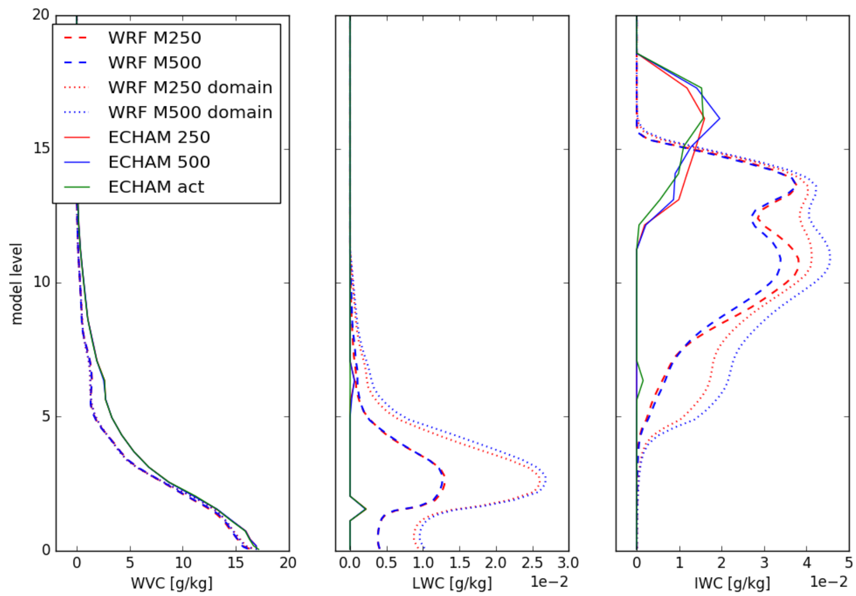

Figure 5: Water vapour content, liquid water content and ice water content as mass mixing ratios for the simulations with WRF (dashed/dotted) and the ECHAM-HAM CCFM single column model (SCM) (solid). For the WRF simulation, both the average over the target area, equivalent to the area of the SCM (dashed), and the average over the entire inner domain d03 (dotted) are shown.

1.2.3. Aerosol effects on cloud formation and evolution

Figures 6 and 7 show the modelling results on a regional and a single cloud scale by WRF-Chem. The liquid hydrometeors are more sensitive to the perturbation of aerosols than the frozen hydrometeors at both scales, confirming the result of Chang et al. (2015). CDNC is more sensitive to aerosol perturbation than the cloud mass concentration (Fig. 7e). According to our modelling results, increasing aerosol concentrations will enhance the formation of cloud droplets, suppress the formation of rain drops and have little impact on the frozen hydrometeors.

The accumulated precipitation is only reduced by ~10% when emissions are increased by one order of magnitude. This is similar to the small effects of the modest changes in CDNC (250 cm^{-3} and 500 cm^{-3}) on precipitation and the water content profiles from the CRM and SCM simulations (Figure 4 and 5). The suppression of precipitation by elevated aerosol concentrations can be attributed to the reduction in droplet size and the increased precipitation path. Such effect is less prominent at lower aerosol concentrations and becomes stronger as aerosol loading increases. Unlike Chang et al. (2015) (a single cloud scale study), we see very smooth changes of cloud hydrometers against aerosol perturbation at a regional scale. Moreover, the aerosol perturbation-induced processes can also change the dynamics (e.g., updraft/downdraft distributions in Fig. 7f) and further influence the cloud evolution (ice cloud in Fig. 7b).

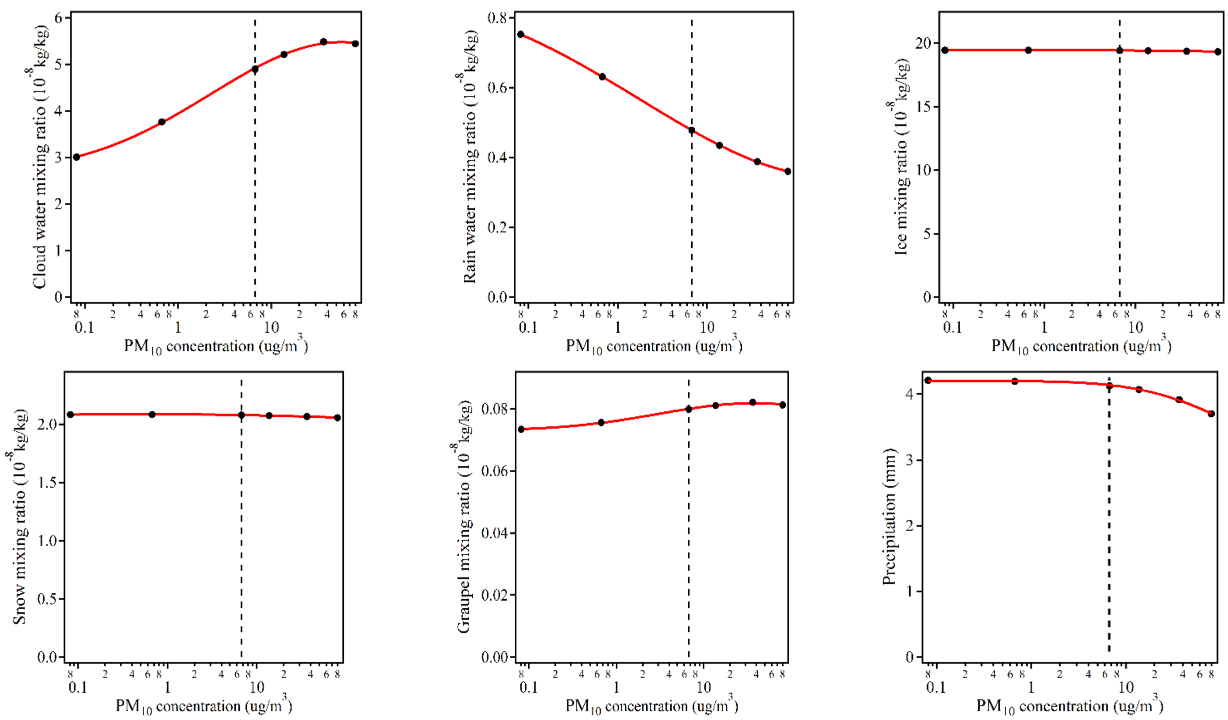

Figure 6: Averaged mixing rate of cloud water, rain water, ice, snow, and graupel as well as accumulated precipitation rates under different surface PM10. The dashed line indicates the base scenario EMISS.

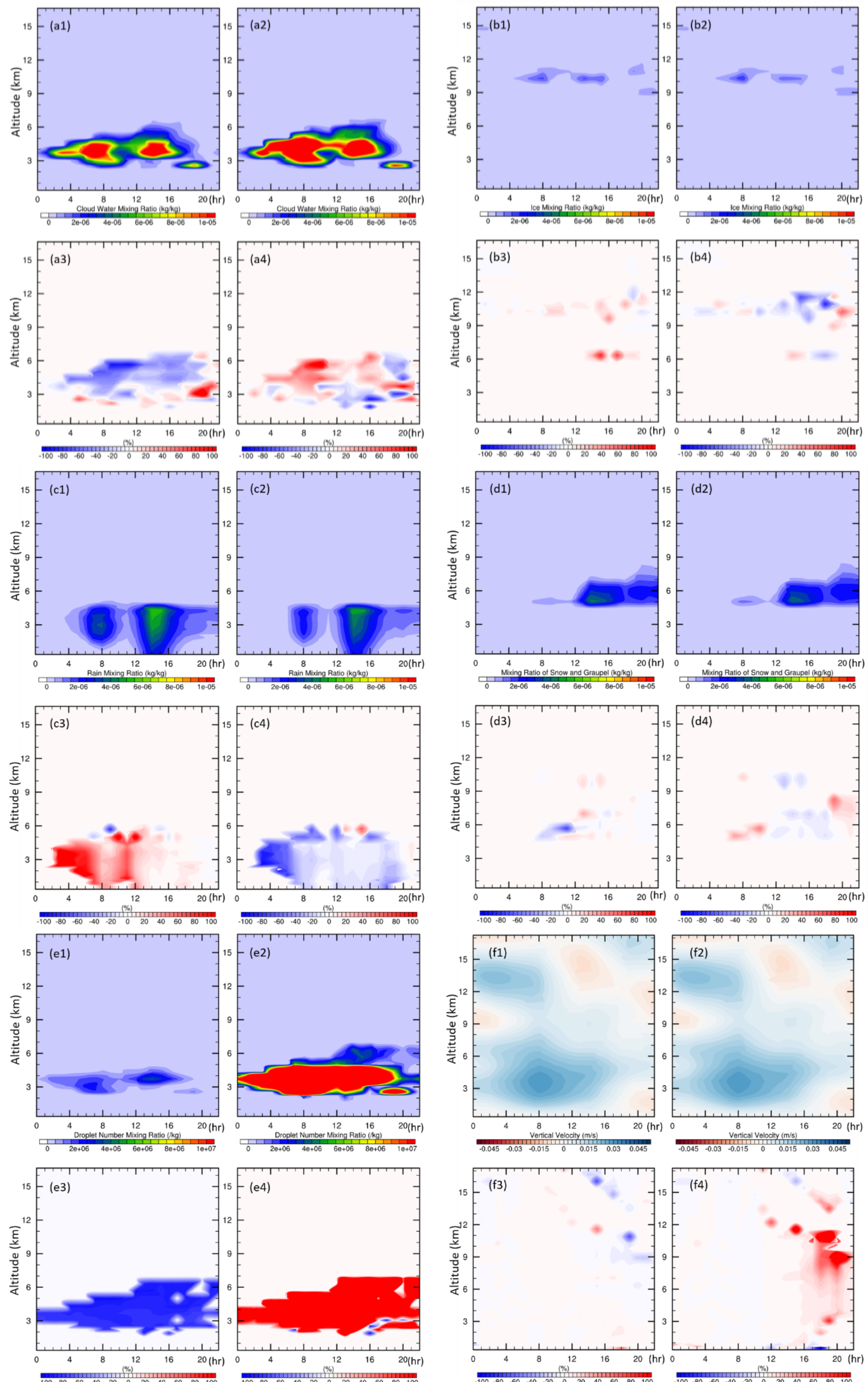

Figure 7: Evolution of cloud hydrometeors (a-e) and dynamics (f) for a single cloud under different emission scenarios and the percentage change with respect to the base case. EMISS*0.1 (sub-panel 1 and sub-panel 3) and EMISS*10 (sub-panel 2 and sub-panel 4).

Cloud formation and surface heat/humidity flux

The first simulations with the LES model UCLALES-SALSA show that surface heat and humidity fluxes are important for cloud formation. Low resolution fluxes were obtained from ECMWF analyses and these were interpolated to a finer temporal resolution. Using these boundary conditions the model was able to simulate realistic cloud formation and evolution including precipitation. Figure 8 shows an example of a 24-hour 2D simulation. The simulation showed the development of the cloud layer including the formation of an afternoon rain shower. The finalized model will be used in further 3D simulations where we will quantify the effects of aerosol on cloud evolution.

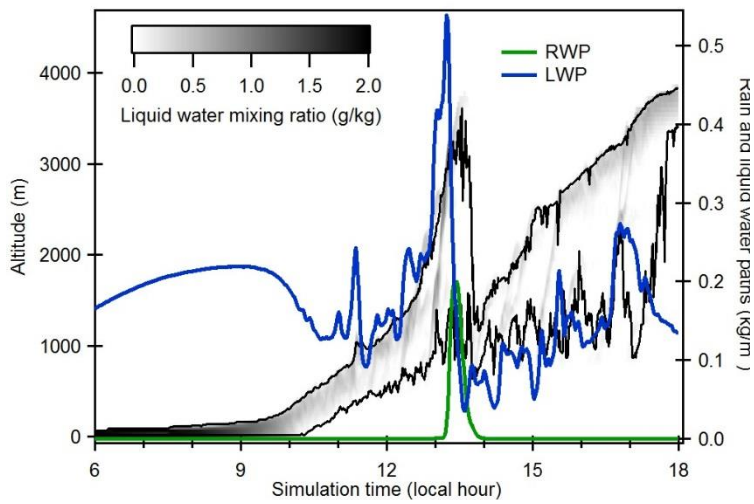

Figure 8: Profile of the liquid water mixing ratio and time series of rain (RWP) and liquid (LWP) water paths for one day (from 06:00 to 18:00) as simulated by UCLALES-SALSA.

1.2.4. Conclusions

- Increasing aerosol concentrations in the Amazon will enhance the formation of cloud droplets, suppress the formation of rain drops and have little impact on the frozen hydrometeors. CDNC is more sensitive to aerosol perturbation than the cloud mass concentration. During the simulated period, aerosol perturbations in the Amazon have a modest effect on precipitation and the water content profiles from the WRF CRM, WRF-Chem and ECHAM-HAM-CCFM (SCM) simulations.
- The SCM performs well in reproducing precipitation over the domain, while WRF gives satisfactory results for part of precipitation events (Figure 1). The lack of liquid water in the SCM shows deficiencies in the microphysics. Ongoing work within CCFM will improve the microphysics parametrization and comparisons of the process rates between WRF and CCFM will help understanding CCFM current deficiencies.
- Correct surface heat and humidity fluxes are important for modelling cloud formation. Using these boundary conditions the LES model is able to simulate realistic cloud formation and evolution including precipitation.

1.3. Barbados Case Study

1.3.1. Methodology

Field measurements of shallow convection in the tropical North Atlantic, near Barbados, from both ground-based and airborne platforms in the vicinity of the Atlantic ITCZ were collected as part of NARVAL-II campaign. These measurements complement a similar suite of measurements made in the winter North-Atlantic trades as part of NARVAL-I, in December 2013. The two studies provide an opportunity to compare the development of shallow clouds in very different dynamic, thermodynamic and aerosol environments. Including the trans-Atlantic ferry flights, nine flights were flown during NARVAL-II, comprising 95 flight hours. During NARVAL-I eight flights were flown, four of which were trans-Atlantic. The in situ measurements comprised the instrument payload described by Stevens et al. (2016) with a high-resolution scanning spectral imager replacing the mini-differential optical absorption spectrometer thereby enabling more advance measurements of cloud coverage and microphysical retrievals. In addition, during NARVAL-II ground based measurements from the Barbados Cloud Observatory were augmented by extensive aerosol measurements, including supersaturation resolved CCN and bio-aerosol, made by the MPI-Chemistry.

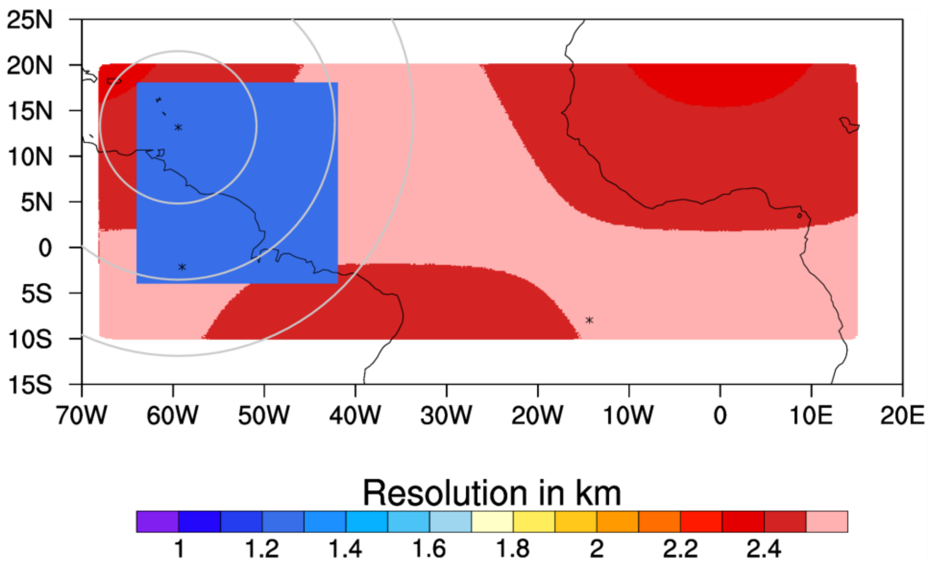

Figure 9: Simulation grid, with mesh spacing coloured for NARVAL-II. The non-uniformity of the outer (2.4 km) grid is because of its icosahedral form. The inner grid was constructed to cover measurement sites near the Amazon Tall Tower (ATTO) and Barbados. The outer grid was extended sufficiently far south to overlap with ground based measurements being conducted on Ascension Island (also indicated) near 8◦S.

To support these studies high-resolution modelling studies were also performed using the ICON model and in cooperation with the German Weather Service. The simulations were unprecedented in terms of the fineness of their horizontal grid and the expansiveness of their domain. 36 hour simulations were performed starting at 0Z on each of the days in December 2013, when NARVAL-I took place, and on each of the days in August 2016, when NARVAL-II took place. The simulation domains spanned the entire tropical Atlantic, with a 2.4 km grid mesh spanning the region from 15 °E to 68 °W and from 10 °S to 20 °N. A finer, 1.2 km grid mesh, was nested between 42 °W and 64 °W in longitude and 4 °S and 18 °N in latitude (Fig. 9). The simulations were forced by ECMWF analysis data that was available with a roughly 16 km resolution. The timestep of the outer grid and inner grid was 24 s and 12 s respectively. Volume output was saved hourly and selected two-dimensional fields were saved every 30 minutes.

Airborne measurements have been analysed to define case studies for exploring the interplay between clouds, aerosols, water vapour, radiation and circulation. Initially three flights from each of the campaigns have been selected wherein LES studies are being performed. The LES model has a grid-spacing of between 150 and 300 m and cover the area of flight operations. ICON offers the capability to force these simulations with open boundary conditions, but to use their mean large-scale forcings to drive more idealized simulations using cyclic boundary conditions. For NARVAL-I the period between 12 and 15 December during which there were three flights and the boundary layer was capped by exceptionally dry air has been selected for study. For the NARVAL-II period three flights, RF03 (Aug 12), RF05 (Aug 17) and RF06 (Aug 19) have been chosen for study.

During NARVAL-II new methods for measuring vertical velocity were developed and tested, in partnership with Sandrine Bony who was funded to develop and test these methods through an ERC grant. These methods involved the heavy deployment of dropsondes, with more than 50 dropsondes launched on each of RF03 and RF06. Sounding data was uploaded to and integrated into the meteorological analyses. The heavy deployment of sondes and the remote sensing from the aircraft provides a very detailed view of the vertical structure and meteorological/aerosol environment of the atmosphere.

1.3.2. Results

Flights sampled a wide range of conditions for testing aerosol-cloud interactions. Meteorological conditions for the intense study periods differ in ways that appear typical for differences between the winter trades and the suppressed regime near the summer ITCZ. For the NARVAL-I flights the free troposphere is exceptionally dry above the marine boundary layer, which terminates near 2.5 km, there is considerable wind-shear with winds switching between easterlies and westerlies near 4 km and strong winds near the surface. During the NARVAL II, even in suppressed conditions, the free troposphere is moister, winds are lighter with easterlies extending through the troposphere. During the summer mission layers of Saharan Dust were also mixed within the study area.

The inter-leaving of water vapour, dust in different dynamical environments within close proximity was a hallmark of the summer NARVAL-II measurements. For instance, during RF06 of NARVAL-II longitudinally extended layers with sharp boundaries differed in their dust and water vapour distributions, cloud patterns and low-level divergence. The ability to measure the dynamic environment, through good spatial coverage of the vertical profile of horizontal winds from the dropsondes, showed that cloud patterns coincided with large-differences in low-level divergence, but that this coincided with large differences in the water vapour and aerosol (Saharan dust) above the boundary layer, between 2 km and 4 km. This is illustrated with the help of lidar data (courtesy of Martin Wirth of DLR) shown in Fig. 10.

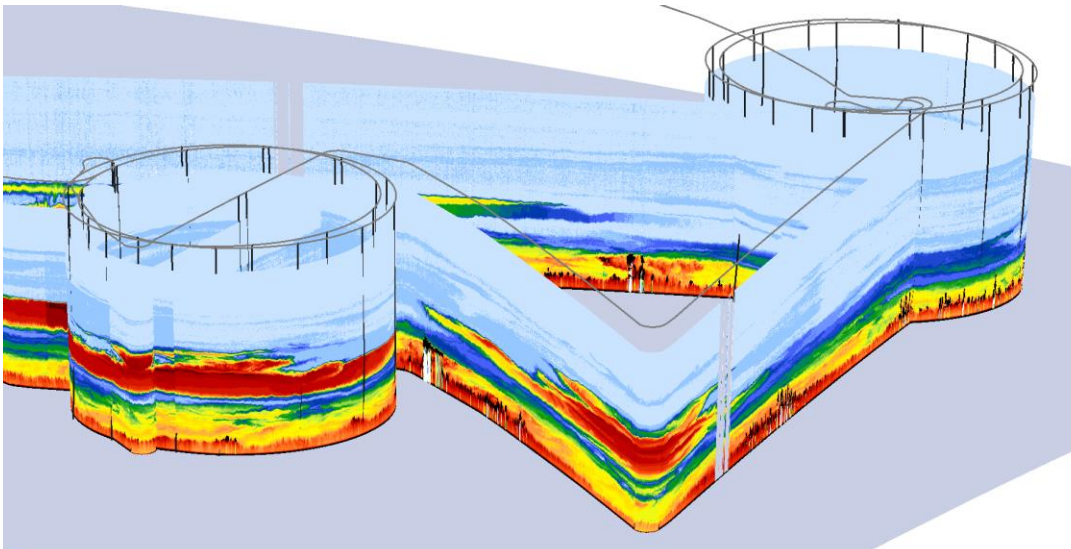

Figure 10: Aerosol backscatter from downward looking lidar during RF06 of NARVAL-II. Warmer colours imply more backscatter. Extinction of signal is associated with clouds. Flight level was roughly 9km and the lidar roughly measures the region of the atmosphere from 8 km to the surface. Thin vertical lines extending downward from flight level indicated dropsonde launches. Black lines and extinction of signal is indicative of clouds.

The lidar data (Fig. 10) shows the flight track, consisting of an eastbound leg initiating the two circular patterns in the Southeast (foreground) of the plot. These are followed by a track to the southeast, which then turns toward the north-northeast to fly under the passing A-train constellation of satellites, and concludes with a second set of circles in the northeast, before returning in a westward direction toward Barbados. To give an indication of scale the circles are roughly 200 km in diameter. Comparing the southern with the northern circles it is apparent that the southern circles are over a strong scattering (dust) layer near 3 km, separated by an aerosol-free layer from the underlying moist boundary layer. During this flight segment there were very few clouds. In the northern segment the elevated aerosol layer is absent and there are many more clouds. Indeed enhanced cloudiness is apparent immediately after leaving the aerosol layer shortly after turning to the northeast along the A-train underpass. Analysis of sounding data show that the northern circles are characterized by a dynamic environment of low level convergence, the opposite of what is found in the southern environment.

In addition to the identification of specific case studies, and initial simulations with ICON, analysis of the ICON data has been performed for the purposes of comparing with the airborne (dropsonde) data. From the high-resolution ICON data dropsonde profiles have been constructed to mimic the measurements performed by the aircraft and these are being compared to the analysis of the actual dropsonde data. Profiles from the sondes and the ICON simulations have been analyzed to help define the cases for LES and SCM studies. They are also being compared to transpose AMIP simulations of the full climate model initialized by analyses. Examples of this analysis is shown in Fig. 11 for the period of analysis in NARVAL1 and NARVAL2. In particular, this analysis highlights the very different humidity and vertical velocity structure.

The NARVAL-II cases, also the contrast to the winter cases from NARVAL-I are being used to test the generality of the winter versus summer cases constructed based on measurements at the Barbados Cloud Observatory (Stevens et al., 2016) as well as earlier studies of the effects of aerosol-cloud interactions on the development of fields of cumulus clouds (Seifert et al., 2015; Vogel et al., 2016; Sandu and Stevens, 2011). The ability to link these simulation studies to the airborne measurements, and constrain them by aerosol CCN and bio-aerosol measurements, is helping advance our understanding of the relative role of aerosol versus dynamic influences on cloud development.

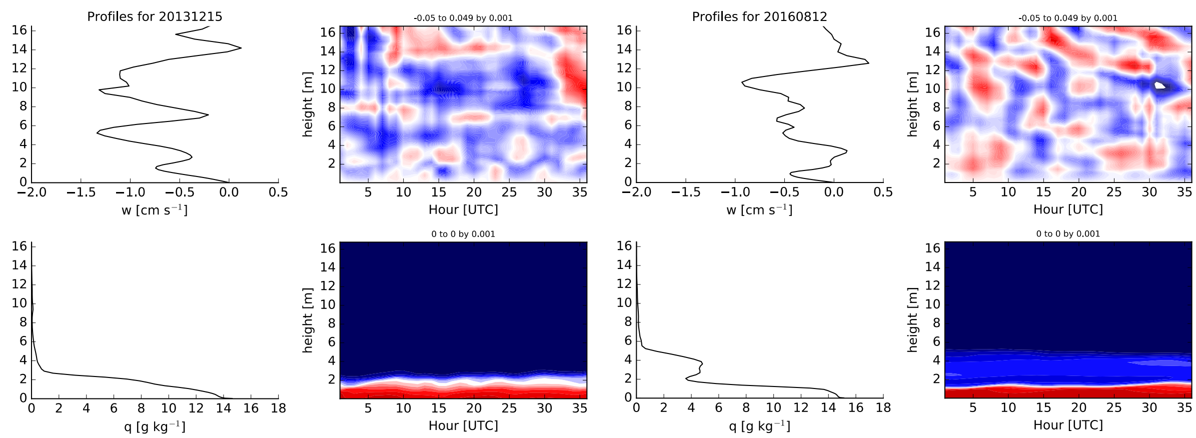

Figure 11: Mean vertical velocity (upper left) and its time evolution (upper right), humidity (lower left) and its time evolution (lower right) as derived from high-resolution ICON simulations for NARVAL1 campaign (15 Dec 2013, left) and for RF03 during NARVAL-II (8 Dec 2016, right).

1.3.3. Conclusions

Field measurements and high-resolution simulations have been performed to analyze the interplay of clouds, their meteorological and aerosol environment in regions of shallow convection in the winter trades and near the summer ITCZ. The measurements include state-of-the-art remote sensing from ground based and airborne platforms, and the August 2016 measurements are partly supported by BACCHUS including ground-based CCN measurements and extensive atmospheric soundings.

The measurements and simulations have been used to define case studies for exploring the role of the aerosol in modulating the cloud environment. Initial focus is on the differences between the summer and winter trades, wherein the role of the aerosol is much more pronounced in the former. Also different aerosol environments within close vicinity of one another are being used to explore the role of the aerosol, also in modulating radiative fluxes, on their environment.

1.4. Overall conclusions

This task investigated key process controlling cloud systems in contrasting environments.

For the Artic case study, three LES models were used to study of cloud formation in an idealised setup combining idealised and realistic setups using prescribed and prognostic cloud droplet and ice crystal number concentrations. While the models produce clouds at a similar altitude, key cloud parameters differ between the model simulations, even for the case of prescribed droplet and ice crystal numbers. A simulation with explicit aerosols shows that depletion of CCN can lead to the observed suppression of clouds in this CCN limited environment.

The Amazon case study exploited recent measurement campaigns conducted in this area, the GOAMAZON and ACRIDICON campaigns. The results show that increasing aerosol concentrations in the Amazon areas will enhance the formation of cloud droplets, and can suppress the formation of rain drops but has little impact on the frozen hydrometeors. During the simulated period, aerosol perturbations have a modest effect on precipitation and the water content in the Amazon area. A comparison of a global climate model in single column mode with cloud-resolving models provides the basis for further efforts on improving model performance. The results also highlight the importance of surface heat and humidity fluxes for cloud formation and evolution, including precipitation.

The Barbados case study exploited the opportunities provided by the NARVAL-II campaign conducted in summer of 2016. These measurements include ground-based aerosol and CCN measurements for the first time and enable comparisons between shallow clouds in different meteorological and aerosol environments in the winter and summer trades. High-resolution simulations have been performed and are being analysed. These simulations, driven by meteorological analyses are being further refined to accommodate more idealised, or process studies using LES as well as General Circulation Models in Single Column and Transpose AMIP mode.

1.5. References

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2. Changes with respect to the DoW

The work presented in this deliverable made extensive use of field campaign data not available at the drafting of the DoW. In particular, the Barbados case study exploited opportunities provided by the NARVAL-II campaign conducted in summer of 2016. The scientific exploitation of the work in all case studies is ongoing and expected to result in a set of strong publications to be submitted in 2017.

3. Dissemination and uptake

Invited conference presentations

- Stevens, R. G.*, Carslaw, K. S., Field, P. R., Hill A. A., Shipway ,B. J., Wilkinson, J. M., Connolly, P. J., Dearden, C., Laaksonen, A., Leeuw, G., Saponaro, G., Raatikainen, T. E., Possner, A., Hoose, C., Weixler, K., Ekman, A. M. L., Dimitrelos, A., “Model intercomparison of CCN-limited Arctic clouds during ASCOS”, Invited talk at Dalhousie University, Halifax, NS, Canada, 10/2016 (oral presentation)

Conference presentations

- Heikenfeld, M.*, White, B., Weigum,N., Labbouz, L., Stier,P., “High-resolution WRF/chem simulations to understand the impact of aerosols on ice microphysics in convective clouds”, HDCP2 - Understanding clouds and precipitation conference, Berlin, Germany, 02/ 2016 (poster presentation)
- Heikenfeld, M.*, White, B., Labbouz, L., Weigum,N., Stier,P., “High-resolution simulations of aerosol impacts and ice-phase microphysics in convective clouds over the Amazon”, International Conference on Clouds and Precipitation, Manchester, UK, 07/2016 (poster presentation)
- Labbouz, L.*, Kipling, Z., Stier ,P., Protat, A., Morrison H., Milbrandt, J, “How well can we represent the subgrid distribution of convective clouds in a climate model?”, 17th International Conference on Clouds & Precipitation, Manchester, UK, 07/2016 (oral presentation)
- Labbouz, L.*, Kipling, Z., Stier ,P., Morrison H., Milbrandt, J, “New development in convection and convective microphysics parameterisation in ECHAM-HAM”, HDCP2 - Understanding Clouds and Precipitation conference, Berlin, Germany, 02/2016 (poster presentation)
- Labbouz, L.*, Kipling, Z., Stier ,P., Morrison H., Milbrandt, J, “Cloud microphysics in the Convective Cloud Field Model in ECHAM-HAM”, BACCHUS 2nd Annual Meeting, Zurich, Switzerland, 01/2016, 02/2007 (oral presentation)
- Labbouz, L.*, Kipling, Z., Stier ,P., Morrison H., “Parameterization of convection and convective microphysics in ECHAM-HAM”, Gordon Research Conference on Radiation and Climate, 07/2015, Lewiston, ME, USA (poster presentation)

- Stevens, R. G.*, Carslaw, K. S., Field, P. R., Hill A. A., Shipway ,B. J., Wilkinson, J. M., Connolly, P. J., Dearden, C., Laaksonen, A., Leeuw, G., Saponaro, G., Raatikainen, T. E., Possner, A., Hoose, C., Weixler, K., Ekman, A. M. L., Dimitrelos, A., "Model intercomparison of CCN-limited Arctic clouds during ASCOS", CASIM Users' Meeting, Leeds, UK 11/2016 (oral presentation)
- Stevens, R. G.*, Carslaw, K. S., Field, P. R., Hill A. A., Shipway ,B. J., Wilkinson, J. M., Connolly, P. J., Dearden, C., Laaksonen, A., Leeuw, G., Saponaro, G., Raatikainen, T. E., Possner, A., Hoose, C., Weixler, K., Ekman, A. M. L., Dimitrelos, A., "Model intercomparison of CCN-limited Arctic clouds during ASCOS", Institute for Climate and Atmospheric Science Annual Science Meeting, Leeds, UK 11/2016 (poster presentation)
- Stevens, R. G.*, Field, P. R., Shipway ,B. J., Hill A. A., Carslaw, K. S., "Arctic Aerosol-Cloud Interactions During ASCOS", 17th International Conference on Clouds & Precipitation, Manchester, UK, 07/2016 (oral presentation)
- Stevens, R. G.*, Field, P. R., Shipway ,B. J., Hill A. A., Wilkinson, J. M., Carslaw, K. S., "Arctic Aerosol-Cloud Interactions During ASCOS", Aerosols, Clouds, Precipitation & Climate Workshop, Oxford, UK, 04/2016 (oral presentation)
- Stevens, R. G.*, Carslaw, K. S., Field, P. R., Hill A. A., Shipway ,B. J., Wilkinson, J. M., Connolly, P. J., Dearden, C., Laaksonen, A., Leeuw, G. Saponaro, G., Raatikainen, T. E., Possner, A., Hoose, C., Weixler, K., Ekman, A. M. L., Dimitrelos, A., "Model Intercomparison of an Arctic Stratus Case Study", BACCHUS 2nd Annual Meeting, Zurich, Switzerland, 01/2016 (oral presentation)
- Stevens, R. G.*, Hill A. A., Shipway ,B. J., Field, P. R., and Carlsaw, K .S., "Arctic Aerosol-Cloud Interactions during ASCOS", American Geophysical Union Fall Meeting, San Francisco, CA, USA, 12/2015 (oral presentation)
- Stevens, R. G.*, Hill A. A., Shipway ,B. J., Field, P. R., and Carlsaw, K .S., "Arctic Aerosol-Cloud Interactions during ASCOS", Institute for Climate and Atmospheric Science Annual Science Meeting, Leeds, UK 11/2015 (poster presentation)
- Stevens, R. G.*, Hill A. A., Shipway ,B. J., Field, P. R., and Carlsaw, K .S., "Arctic Aerosol-Cloud Interactions during ASCOS", European Aerosol Conference, Milan, Italy, 09/2015 (poster presentation)

A special session exploring the NARVAL measurements at the EGU General Assembly 2017 has been organized and links to the ongoing cloud modelling community have been established.