BACCHUS

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

Collaborative Project

SEVENTH FRAMEWORK PROGRAMME
ENV.2013.6.1-2

Atmospheric processes, eco-systems and climate change

Grant agreement no: 603445

Deliverable number:	**D3.1**
Deliverable name:	Description of joint framework and case study protocols to investigate the key factors controlling clouds in contrasting environments
WP number:	3
Delivery date:	Project month 18 (30/11/2014)
Actual date of submission:	01/12/2014
Dissemination level:	PU
Lead beneficiary:	UOXF
Responsible scientist/administrator:	Philip Stier
Estimated effort (PM):	4
Contributor(s):	Paul Field (UNIVLEEDS), Louise Nuijens (MPG Hamburg), Hang Su (MPG Mainz), Ari Laaksonen (FMI), Paul Connolly (UMAN)
Estimated effort contributor(s) (PM):	
Internal reviewer:	Ulrike Lohmann

Summary of results

We developed a joint framework and case study protocols to investigate the role of aerosol vs. dynamics in contrasting regime for three contrasting environments: Arctic, Amazon, Barbados

1. Arctic Case Study

Participants:
University of Leeds (p.field@leeds.ac.uk): UM-UKCA
University of Manchester (p.connolly@manchester.ac.uk): WRF
Finnish Meteorological Institute (Ari.Laaksonen@fmi.fi): UCLA-LES-SALSA

Objectives: i) to understand how aerosol and cloud properties will change in a future climate with reduced sea ice coverage; ii) identify processes controlling the behaviour of aerosols and clouds in the present-day summertime Arctic boundary layer; iii) assess how aerosols and clouds respond to reductions in sea ice and the climate response of boreal forests; iv) identify the roles of biogenic sources, advected anthropogenic aerosol and local shipping emissions for Arctic clouds and climate;

1.1. Models

Large Eddy Simulations

Essential requirements	Desirable
dx=50m, dz=10 (near cloud top), domain size 10km square. Run length 24h Initialisation profiles (ecmwf, aircraft, sonde, Surface fluxes, subsidence rate.	Increased resolution dx=20m, dz=5m or finer. Run length 48h

Limited Area Models

Essential requirements	Desirable
dx=500m, dz=20m (near cloud top), domain size 500km. Run length 36h	Domain size 1000+ km square, dx<500m, dz=10m, run length 48h. Consider possibility of doing ensemble runs.

Global reanalysis data will be used to drive limited area model integrations, which in turn will be used to provide forcing for higher resolution (LES) simulations.

1.2. Simulated Periods / Campaigns

Candidate measurement campaigns are ACCACIA, ISDAC and MPACE with a final decision to be taken in January 2015.

Essential requirements	Desirable
Droplet and ice particle size (1-1000microns) distribution characterisation Above- and below-cloud aerosol size distribution (0.1-10microns) Temperature, pressure, humidity, bulk liquid water	Microwave radiometer, satellite overpasses (e.g. Calipso, Cloudsat, MODIS), Lidar (aircraft and ground). Vertical velocity (insitu and remotely sensed)

and ice water content profiles from near surface to above cloud. Broadband SW and LW radiation measurements	Ice nuclei concentration measurements Sonde profiles

1.3. Control Setup

Control	Fixed background droplet and ice crystal concentration (mediated through ice production nudging e.g. MPACE). Values to be determined from case observations

1.4. Sensitivity Studies

LoINDiag	0.1x control IN representation
INProg	Droplet activation and ice nucleation/droplet freezing will be mediated by aerosol. This will grow in complexity depending on the level of aerosol-cloud coupling and in-domain source terms that the participating models possess. We will consider both nudging aerosol fields to match observations and attempt the use of aerosol sources from 0.1°x0.1° HTAP v2.2 emissions. Aerosol production via precursors is more complex and may be pursued if model development is sufficiently advanced.
PHYSproc	Microphysical process sensitivity tests e.g. role and importance of Hallett Mossop

1.5. Diagnostics and Output

Suggested Diagnostics from WGNE GreyZone study:
http://appconv.metoffice.com/cold_air_outbreak/constrain_case/home.html

2. Barbados Case Study

Participants:
Max Planck Institute for Meteorology (Louise Nuijens, Bjorn Stevens): UCLA-LES
Finnish Meteorological Institute (Ari Laaksonen): UCLA-LES-SALSA
University of Oxford (Philip Stier, Laurent Labbouz, Max Heikenfeld): MPI-ESM-CCFM

Objectives: To study aerosol cloud interactions in a highly climate-relevant environment. LES/CRM/GCM/SCM modeling case study representative for the trades. The frequent occurrence of shallow cumulus cloud potentially susceptible to aerosol perturbations make this an ideal site.

2.1. Simulated Periods / Campaigns

To study the relative importance of large-scale meteorology versus the aerosol on the characteristics of cloud systems in the trades we propose to use a simplified framework that brings us closer to a regime where equilibrium responses are found. This framework is modified after Bellon and Stevens (2011) to study equilibrium states for cloudy boundary layers.

2.2. Control Setup

It prescribes large-scale forcings and initial profiles that are not uncommon for Barbados or the broader trades, but that are further idealized relative to observations, excluding a couple of mechanisms, such as wind shear or horizontal temperature and moisture advection, which would introduce additional influences on the dynamics of the trade-wind cumulus layer that we wish to exclude. The idealized set up is constrained as to more easily reach a stationary state, *e.g.,* the boundary layer will stop deepening during the simulation, which excludes the influence of a deepening layer on precipitation and cloudiness, and allows us to collect statistics from the simulations over a longer period.

The idealized set-up supports an Eulerian reference frame with large-scale forcings that are constant in space and time, that is, we do not simulate an increase in SST or decrease in subsidence such as used in Lagrangian frameworks. The large-scale forcings include a profile of the large-scale vertical velocity (in this case, mean subsidence), a profile of the wind speed that is constant with height, and a prescribed radiative cooling rate (Table 1). The subsidence profile w takes an exponential form:

$$w(z) = w_0[1 - e^{-z/H}] \qquad (1)$$

and is coupled to the temperature lapse rate in the free troposphere, which follows from the assumption that subsidence warming equals radiative cooling Q_r:

$$d\theta/dz(z) = Q_r/w(z) \qquad (2)$$

H, the scale height, equals 1 km. The relative large subsidence rate (compared to observations), w_0 = 7.5 mm s^{-1} helps compensate for the lack of large-scale advective tendencies, it mimics the effect of advecting a sloped inversion, and accommodates a stronger cooling rate which helps offset the lack of a separate term representing the advective cooling within the sub-cloud layer.

The initial profiles of temperature and humidity in the idealized case are well-mixed and constant with height up to 1 km, with θ = 298 K and q = 13 gkg^{-1}, topped by an inversion layer that extends up to 1.6 km. Above that height, θ follows from Equation 2, and to ensure a zero drying tendency in the free troposphere the humidity gradient is set to zero with q equal to 4 gkg^{-1}. The initial wind profile equals the geostrophic wind that is constant with height, with a zonal component of 10 ms^{-1} and a meridional component that is 0 ms^{-1}. The domain is 12.8 x 12.8 x 5 km with a grid-spacing of 50 m in the horizontal and 25 m in the vertical, stretching by a factor 1.02 in the region where z > 4 km. This is a relatively small domain, which does not allow for mesoscale organization, but can only support one significant rain event at a time. This makes the precipitation statistics intermittent - hence the need for stationary solutions that allow for longer simulation periods over which to average statistics - but excludes the uncertainties related to the treatment of microphysics, and hence processes that are known to be crucial for further development of precipitation and cloudiness (including cold pool dynamics). Not unimportantly, it is computationally less expensive.

UCLA-LES simulations are performed with the two-moment warm rain scheme of Seifert and Beheng (2001), which assumes a constant cloud droplet number concentration Nc, *i.e.*, the two-moment approach is only applied for rain, not for cloud droplets. It is set to a lower limit of 50 cm^{-3}, representing a clean maritime environment.
At the surface, a prescribed sea surface temperature (SST) and a slip/no-penetration condition are used, with surface thermodynamic and momentum fluxes parametrized with bulk aerodynamic formulae. A

Galilean transform (that is commonly used to reduce numerical dissipation and to lower the CFL number in LES) is set to the mean wind speed.

The simulations are run for 7 days.

Table 1: Initial and boundary conditions, forcings and other specifications for the baseline simulation. * At z > 4 km vertical grid is stretched uniformly by a factor of 1.02.

2.3. Sensitivity Studies

The following deviations from the below base line simulations are proposed: a doubling and quadrupling of the droplet number concentration N_c,. These simulate the change from periods with relatively pristine conditions measured on Barbados, to periods that are influenced by Saharan dust events and biomass burning over South America, during which peak values of N_c as high as 500 cm^{-3} have been measured (Siebert et al, 2013). A 2 and 4 gkg^{-2} increase in the free tropospheric humidity q above 1.6 km, and an increase in the geostrophic wind speed u_g by ±5 ms^{-1} (u_g remains unchanged).

The former two will simulate the relative effect of changes in the aerosol and changes in the environmental humidity that are thought to control precipitation in shallow cumuli. Observations indicate, however, that the effect of humidity is much larger than the effect of the aerosol (Lonitz et al., 2014). The wind speed experiment will simulate the effect of an additional external forcing that works predominantly on the surface fluxes, and which in observations is found to have the strongest predictive skill for cloudiness and precipitation (Brueck et al., 2014). An additional experiment on a domain of 50 x 50 x 5 km will be conducted to study the role of mesoscale organization.

Forcings		**Perturbations**
w_0 (ms^{-1})	7.5 10^{-3}	
H (m)	1000	
Q_r (Kd^{-1})	2.5	
u_g (ms^{-1})	10	+ / - 5 ms^{-1}
v_g (ms^{-1})	0	
Initial and boundary conditions		
SST (K)	300	
q (g kg^{-1})	z < 1 km: 13 z≥1.6km: 4	z≥1.6km: + 2 / + 4 gkg^{-1}
θ (K)	z < 1 km: 298 z≥1.6km: dθ =Qr/w dz	
Domain and resolution		
Δt (s)	1	
Δx,Δy,Δz (m)	50 x 50 x 25*	
nx, ny, nz (-)	256 x 256 x 190	
domain size (km)	12.8 x 12.8 x 5	25 x 25 x 5
Microphysics		
N_c	50 cm¯3	100cm^{-3}, 200cm^{-3}

2.4. Diagnostics and Output

Beyond the standard output, including profiles of humidity, temperature and winds, cloud fraction and precipitation fluxes, and time series of the boundary layer depth, total cloud cover, surface fluxes and surface precipitation rate, we request output the 3D fields of humidity, temperature, liquid water, rain water and the three velocity components at the end of the simulation (single time step) to evaluate ESM's cloud scheme(s) and microphysics.

Suggested diagnostics include time statistics of scalars and averaged profiles over the last hours of the simulations, following the protocol of the RICO intercomparison case, http://www.knmi.nl/samenw/rico/output3d.html

References

Bellon, G., and Stevens, B. (2012). Using the Sensitivity of Large-Eddy Simulations to Evaluate Atmospheric Boundary Layer Models. Journal of the Atmospheric Sciences, 69(5), 15821601. doi:10.1175/JAS-D-11- 0160.1

Seifert, A. and Beheng, K. D.: A double-moment parameterization for simulating autoconversion, accretion and selfcollection, Atmos. Res., 5960, 265281, 2001

Brueck, H. M., L. Nuijens, and B. Stevens, 2014: Mechanisms controlling seasonal and synoptic time scale variability in low-level cloudiness in the North Atlantic trades. Journal of the Atmospheric Sciences, accepted.

Lonitz, K., Stevens, B., Nuijens, L., Sant, V. and Hirsch, L. (2014): Signatures of aerosols and meteorology in long-term radar observations of trade-wind cumuli. Journal of the Atmospheric Sciences, submitted.

Siebert, H. and co-authors (2013): The fine-scale structure of the trade wind cumuli over Barbados – an introduction to the CARRIBA project. ACP, 13, 10061-10077.

3. Amazon Case Study

Participants:

Max Planck Institute for Chemistry (Hang Su, Stephan Nordmann, Yafang Cheng, Ulrich Pöschl): WRF-Chem, ATHAM

Max Planck Institute for Meteorology (Louise Nouijens, Bjorn Stevens): UCLA-LES

Finnish Meteorological Institute (Ari Laaksonen): UCLA-LES-SALSA

University of Oxford (Philip Stier, Laurent Labbouz, Max Heikenfeld), WRF-Chem-HAM, MPI-ESM-CCFM

Objectives: (i) to develop representative cases for the study of Amazon rain forest. The cases will reproduce ground and aircraft measurements of aerosol and clouds in the Amazon region; (ii) to improve the understanding of aerosol-cloud interactions by quantifying the contribution of individual microphysical processes in the cloud formation and development; (iii) to perform ensemble sensitivity studies of aerosol perturbations for a range of emissions/aerosols concentrations.

3.1. Simulated Periods / Campaigns

We focus on the periods of the ACRIDICON-CHUVA campaign in Amazon. The comprehensive measurements of aerosol and cloud properties from the campaign and the ATTO site will help to validate the model simulations and ensure the representativeness of the selected cases.

3.2. Control Setup

To simulate the Amazon case, we will configure WRF-Chem model as follows:

Essential requirements	Desirable
• 2 nested domains with resolution of dx= 12 km and 4 km, 40 layers • Initialization data (FNL, MOZART chemical boundary conditions) • 0.5°x0.5° ECLIPSE emissions • QFED2 fire emissions	• Increased resolution dx= 1 km in the inner domain with additional nesting • 0.1°x0.1° HTAP v2.2 emissions

The measurement data include meteorological parameters, aerosol size distribution and chemical composition, droplet distribution, primary biological particles, CCN and IN along with satellite remote sensing data.

Cloud properties are subject to multiple microphysical processes, e.g., CCN activation, autoconversion, freezing, condensation, evaporation, etc. In order to unravel the complicated interactions, we employed the process analysis (PA) method to quantify the causation of changes in the concentrations of individual hydrometeor classes. The PA calculates the time-integrated 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. The PA module has been developed and imbedded into the model.

3.3. Sensitivity Studies

Cloud formation can be a highly non-linear process which puts a serious constraint on individual sensitivity studies. One of the critical issues is how representative an individual case study is in elucidating aerosol-cloud interactions. To address this question, high-resolution ensemble sensitivity studies are designed over a wide range of aerosol concentrations. In practice, the change of aerosol concentrations is done by varying the emissions from 1/10 to 10 times of the base case.

3.4. Diagnostics and Output

The output would be 3-D fields of meteorological parameters, aerosol properties and all cloud hydrometeors, and 2-D fields of precipitation at 60 minute time intervals.

4. Changes with respect to the DoW

Due to delays in the recruitment of research staff for some partners, some elements of this protocol, such as the harmonisation among the setup of different models contributing to each of the case studies, are still under discussion. We anticipate finalising the protocol at the first BACCHUS science meeting in January 2015.

5. Dissemination and uptake

This case study protocol serves as input to Task 3.2 in Work Package 3 and provides important information to coordinate the work in all other work packages.