Improvement and calibration of clouds in models

April 12-16, 2021, Météo-France, Toulouse, France

Résumés/Abstracts

Lundi/Monday 12 après-midi

Introduction: Frédéric Hourdin & Fleur Couvreux: Results of the High-Tune project

Toward Lagrangian simulations of EUREC4A/ATOMIC cloud regimes

Steven Boeing1, Peter Blossey2, Leif Denby1, Roel Neggers3, Jan Kazil4, Pornampai Narenpitak4, Lorenzo Tomassini5, Romain Roehrig6, Stephan De Roode7, Leo Saffin1, Zhiqiang Cui1, Ralph Burton1, Alan Blyth1, the EUREC4A and ATOMIC teams _8

We discuss the design of Lagrangian simulations based on the EUREC4A and ATOMIC field campaigns. The simulations are informed by both the extensive campaign observations and reanalysis data (using an ensemble of trajectories), with modifications to improve the upstream boundary layer state. The aim is to provide a realistic representation of the atmosphere to study the evolution of cloud regimes, and explore the requirements for and limits of idealised models.

New tools are developed to produce simulation input based on conventions developed in the DEPHY and HIGH-TUNE projects. The case studies are coordinated with a concurrent grey-zone modelling study and target mesoscale regimes with different modes of organisation (e.g. cloud size, cloud spacing, cold pools and detrainment regions). We will discuss sensitivity experiments and possibilities for further extensions of the case design, like including SST heterogeneities, and aim to show a few initial results from large-eddy simulation.

Toward realistic cloud transitions during cold air outbreaks in ModelE

Florian Tornow1,2, Andrew Ackerman2, Ann Fridlind2, Brian Cairns2, George Tselioudis2

Cold air outbreaks (CAOs) often transition from near-overcast cloud streets into broken, open-cellular clouds downwind. NASA's ACTIVATE campaign collects in-situ and remote sensing observations of atmospheric constituents during CAOs in the NW Atlantic. We simulate CAOs in DHARMA LES and ModelE SCM, each using a domain following the marine boundary layer (MBL) flow and provided with MERRA-2 boundary conditions and in-situ observed aerosol profiles.

Using LES, we show that transitions are initiated by substantial rain, acting to stratify the MBL and deplete cloud condensation nuclei (CCN). We investigate the role of frozen hydrometeors to accelerate cloud transitions and further show several meteorological drivers of transitions that can vary both across and within CAO cases. Lastly, we show a first evaluation of SCM's ability to capture transition-initiating rain and CCN depletion and note outstanding uncertainties in warm and cold precipitation formation.

Organization development in shallow cumulus precipitating convection

Oumaima Lamaakel, Georgios Matheou

The development of precipitation in trade-wind shallow cumulus boundary layers is an important process because it affects the boundary layer energy balance and has the potential to strongly modulate the convective environment. The development of convective organization is studied using large-eddy simulations of the boundary layer observed during the RICO campaign. The LESs employ extensive horizontal domains, up to 160 x 160 km in the horizontal directions, and fine resolution (40 m). The analysis focuses on the rate of energy transfer to the large-scale and quantifies the time scale of convection organization. Even though horizontal integral length scales

are about 15 km, clouds form organized structures of about 100 km. Boundary layer flow statistics depend on the LES domain size and change when the domain is increased from 80 km to 160 km.

The strong impact of weak horizontal convergence on continental shallow convection

Marcin Kurowski1, Wojciech W. Grabowski2, Kay Suselj1, Joao Teixeira1

Large-scale horizontal convergence/divergence perturbations are omnipresent in the atmosphere. However, they are often too subtle to detect them by state of the art remote and in situ measurements. We examine their impact on continental shallow convection using large-eddy simulation (LES). The results show a strong sensitivity of liquid water path and cloud-top height to the perturbations. In contrast, cloud-base area coverage and mass flux are weakly affected. Those impacts are comparable to microphysical sensitivity from cloud droplet number concentration perturbations. The simulation results provide a stringent test for convection parameterizations, especially important for large-scale models progressing toward resolving some nonhydrostatic effects. One such test is performed using the multi-plume Eddy-Diffusivity/Mass-Flux parameterization. Its results show a general agreement with the LES, although some discrepancy for deceasing convection is also documented.

On the role of aerosol characteristics and parameterization schemes on Arctic mixed-phase clouds

Luisa Ickes1, Hannah Imhof1, Annica M. L. Ekman2

Arctic low-level clouds are highly sensitive to microphysical processes, which can either sustain or break down the mixed-phase state and thereby determine the longevity of the clouds and their radiative impact. They are influenced by aerosol particles, which can act as ice nuclei (IN) or cloud condensation nuclei (CCN) and the parameterization schemes used for the aerosol-cloud interactions and the microphysical processes in the cloud. In this study we investigate:

1.) the influence of the chemical composition of CCN and IN

2.) the influence of different freezing parameterization schemes

on the cloud microphysics and the evolution of a mixed-phase Arctic cloud using the large-eddy simulation model MIMICA (Savre et al., 2014).

We show that in terms of CCN activation the aerosol size is more important than chemical composition. For INP the chemical composition has a strong influence on the cloud characteristics, but these results are highly dependent on the freezing parameterization.

Interactions between the Amazonian rainforest and cumuli clouds: A large-eddy simulation, high-resolution ECMWF-IFS and observational intercomparison study

Jordi Vila, Xumei Wang, Xabier Pedruzo-Bagazgoitia, Martin Sikma, Anna Agusti-Panareda, Souhail Boussetta, Gianpolo Balsamo, Luiz Machado, Thiago Biscaro, Pierre Gentine, Scot Martin, Jose Luis Fuentes, Tobias Gerken

The explicit coupling at metre and second scales of the vegetation responses to the atmospheric-boundary layer dynamics drives a dynamic heterogeneity that influences surface fluxes and cloud formation. Focusing on a representative day during the Amazonian dry season characterized by a transition from a clear boundary layer to shallow cumuli, we investigated the diurnal cycle of the energy, moisture and carbon dioxide at the surface, and the coupling during this transition. Three different methodologies are applied: a large-eddy simulation technique (DALES), a high-resolution global weather model (ECMWF-IFS) and a complete observational data set collected during the GoAmazon campaign.

The overall model-observation process comparisons of radiation and surface fluxes, turbulence and cloud dynamics are very satisfactory with all the modelled variables within the standard deviation of the monthly aggregated observations.

Constraining Stochastic Parametrisation Schemes using High-Resolution Model Simulations

Hannah Christensen

Stochastic parametrisation is used in weather and climate models to represent model error. We present a technique for systematically deriving new stochastic parametrisations or for constraining existing stochastic approaches. A high-resolution simulation is coarse-grained to the desired forecast model resolution. This provides the initial conditions and forcing data needed to drive a Single Column Model (SCM). By comparing the SCM parametrised tendencies with the evolution of the high-resolution model, we measure the 'error' in the SCM tendencies. As a case study, we use this approach to assess the physical basis of the Stochastically Perturbed Parametrisation Tendencies (SPPT) scheme. We provide justification for the multiplicative nature of SPPT, and for the large temporal and spatial scales used in the stochastic perturbations. However, we also identify issues with SPPT. In particular we find that an alternative approach is needed to represent uncertainty in the convection scheme.

Continental shallow cumulus clouds in E3SM parameterizations against ARM observations and LES

Yunyan Zhang

Fair-weather shallow cumulus (FWSC) clouds are important but still remain a challenge for climate models to simulate. FWSC clouds are tightly coupled with the underlying land surface and strongly respond to diurnal varying surface heat fluxes. In this study, we use a set of golden FWSC days to improve our understanding on sub-cloud layer turbulence and cloud morphologies based on advanced measurements in most recent years at Southern Great Plains (SGP) site by US Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program. The performance of the single column model of US DOE Energy Exascale Earth System Model (E3SM) is assessed against both ARM data and large eddy simulation results. With this approach, we hope to identify parameterization deficiencies for potential model improvement.

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A physically-based bimodal diagnostic cloud scheme: description and evaluation

Kwinten Van Weverberg, Cyril Morcrette, Ian Boutle

The UK Met Office uses a diagnostic CFP for its operational regional forecasts (~1km grid spacing) over the UK. This scheme assumes a uni-modal, symmetric pdf of the sub-grid saturation departure variability. However, a long-standing systematic lack of cloud necessitates an empirical bias-adjustment in operational forecasts. This paper explores the origin of this bias and proposes a new physically-based, diagnostic CFP. The proposed CFP first identifies entrainment zones (EZ) near sharp inversions. In the EZ it is then assumed that air parcels from above the inversion penetrate into the mixed layer, leading to two modes of variability residing within a single grid box. Weights are assigned to each mode so as to conserve the grid-box mean saturation departure. An extensive process-based and multi-year statistical evaluation shows that the new scheme significantly improves cloud forecasts, for the right reasons, over the US Great Plains ARM site and over the UK.

Prediction of the bulk liquid fraction of mixed-phase particles in the Predicted Particle Properties (P3) microphysics scheme

Mélissa Cholette1, Julie Mireille Thériault2, Jason Milbrandt1, Hugh Morrison3

The accurate prediction of freezing rain, ice pellets and wet snow, is a principal source of uncertainty in weather forecasting because mixed-phase particles involved in their formations are neglected in microphysics parameterizations. A new approach to predict the liquid fraction of mixed-phase particles in the Predicted Particle Properties (P3) microphysics scheme is described.

The objective is to show the impacts of the predicted liquid fraction on the precipitation types produced during the extreme North American 1998 Ice Storm simulated with the Weather Research and Forecasting model (WRF). A decrease in freezing rain and an increase in solid accumulations are obtained when the liquid fraction is predicted because of smaller raindrop sizes from partial melting and larger ice particle sizes from refreezing. The predicted liquid fraction impacts the simulated precipitation properties and atmospheric conditions while permitting the realistic representation of new precipitation types.

CLUBB+MF in CAM6: implementation and evaluation of shallow convection cases

Mikael K. Witte1,2,3, Adam Herrington4, Marcin Kurowski2, Joao Teixeira2, Maria Chinita2,3, Kay Suselj2, Julio Bacmeister4

An eddy diffusivity/mass flux (EDMF) type combination of the Cloud Layers Unified By Binormals (CLUBB) and JPL stochastic multi-plume mass flux schemes has been implemented in the National Center for Atmospheric Research Community Atmosphere Model version 6 (CAM6). In this implementation, termed CLUBB+MF, CLUBB uses a double-Gaussian representation of the sub-grid thermodynamic probability density functions (PDFs) while the MF plumes represent extremely skewed events associated with the convective tail of the PDFs. Using archetypal single column model case studies of non-precipitating shallow convection, we demonstrate the improved performance of CAM6 CLUBB+MF with respect to reference LES solutions in terms of vertical fluxes, boundary layer depth and cloud macrophysical properties. Specifically, the MF component increases vertical transport, thus accelerating boundary layer growth and cloud penetration.

Towards operational implementation: A stochastic shallow convection scheme

Maike Ahlgrimm1, Alberto De Lozar1, Daniel Klocke2, Mirjana Sakradzija1

Even at storm-resolving resolutions, shallow boundary layer clouds cannot be explicitly resolved. However, traditional convection parameterisations typically rely on assumptions that are no longer valid at these scales either. To address this problem, a stochastic convection scheme for shallow clouds was developed in cooperation between the Max-Planck-Institute (Hamburg) and the German Weather Service (DWD).

After initial tests and case studies during the development process, the scheme has undergone further development with a view towards operational implementation in the ICON limited area model. A version of the scheme using stochastic differential equations was developed as an alternative, computationally more efficient option. Tests in hindcast-mode over Germany and the Atlantic during the EUREC4A campaign show promising results, reducing systematic errors related to low cloud properties while rendering a number of resolution-dependent tuning parameters and limiters unnecessary.

Improved parametrization of the boundary layer in Harmonie-Arome with a focus on low clouds

Wim de Rooy

The turbulence, convection and cloud scheme form the core of the HARMONIE-AROME boundary layer parametrization. These schemes are tightly coupled. Hence, an integral approach is needed to develop and optimize these parametrizations together. Substantial modifications are based on a wide variety of argumentations ranging from theoretical considerations, in-depth comparison of 1D model results with LES, and optimizations of uncertain parameters by evaluation of 3D model results.

Several results are shown with the updated set of parameterizations. Most striking is the improvement on the most important deficiency of the current Harmonie-Arome model, namely the underestimation of low stratus clouds and the overestimation of the cloud base height. Other improvements concern the triggering of rain and the representation of the stable boundary layer.

As illustrated, most improvements can be related to a better preservation of atmospheric inversions.

Local impact of stochastic shallow convection on clouds and precipitation in the tropical Atlantic

Mirjana Sakradzija1,2, Fabian Senf3, Leonhard Scheck2,4, Maike Ahlgrimm5, Daniel Klocke5,2

The local impact of stochastic shallow convection on resolved convection, clouds and precipitation, isolated from its remote impact through the large-scale circulation, is tested in a case study over the tropical Atlantic on 20th December 2013. A stochastic shallow convection scheme is compared to the operational shallow convection and a case with no representation of shallow convection in ICON at a convection-permitting resolution. In the stochastic case, convective heating is substantially increased in the subcloud layer, the boundary layer is deeper, while evaporation is enhanced at the expense of sensible heat flux at the ocean's surface. As a result, the stochastic case proves to be superior in reproducing low-level cloud cover, deep convection and its organization, as well as the distribution of precipitation in the Atlantic ITCZ. The local stochastic convection invigorates the resolved convection and is crucial for a better representation of resolved deep clouds.

Impacts of a change in deep convection scheme on the ARPEGE data assimilation system

Antoine Hubans, Yves Bouteloup, Cécile Loo, Pascal Marquet

In this work, we focus on the evaluation of the physical parametrization of deep convection in the French model ARPEGE. We evaluate the direct impact of this parametrization in a forecast only study as well as the indirect impact with a 4D-Var and the study of the analysis. We have replaced the previous parametrization by the one used in the Integrated Forecast System (IFS) developed at the ECMWF. We seize the opportunity of using an other model parametrization to rearrange physical tendencies in the same way as in the IFS. This diagnostic is new for the ARPEGE environment and it leads to an intecomparison between the two model physics. To evaluate the coupling, we use several ARPEGE 4D-Var to compare the change in analysis with an estimate of the analysis error. Those studies show a significant impact of the new scheme both in the tendencies and in the analysis.

A Unified Eddy-Diffusivity/Mass-Flux Approach for Modeling Atmospheric Convection

Kay Suselj, Marcin Kurowski, Joao Teixeira

We describe a fully unified parameterization of boundary layer and moist convection. The new parameterization is based on the stochastic multi-plume eddy-diffusivity/mass-flux approach. The convective plumes represent both surface-forced updrafts and evaporatively driven downdrafts. The type of convection (i.e., dry, shallow, or deep) represented by the updrafts is not defined a priori, but depends on the near-surface updraft properties and the stochastic interactions between the plumes and the environment through lateral entrainment. Such a formulation is void of trigger functions and additional closures typical of traditional parameterizations. The updrafts are coupled to relatively simple warm-, mixed-, and ice-phase microphysics. The downdrafts control the development of cold pools near the surface that can invigorate convection. The new parameterization is validated against large-eddy simulations for precipitating marine and continental cases.

Mardi/Tuesday 13 matin

A machine learning assisted stochastic cloud population model as a parameterization of cumulus convection

Samson Hagos1, Jingyi Chen1, Katelyn Barber1, Koichi Sakaguchi1, Zhe Feng1, Heng Xiao1, Bob Plant2

A machine learning assisted cloud population model is coupled with the Advanced Research Weather Research and Forecasting (WRF) to represent fluctuations in cloud base mass flux associated with the life cycles of cumulus convection cells. In this model, the size distribution and associated cloud base mass flux of the convective cells are related to their previous state and the change in the convective area via a transition function. The convective area tendency in turn is assumed to depend on cloud base mass flux resolved by the host model (WRF). The transition function is represented by neural network trained by a 1 km grid spacing WRF simulation. The cloud population model continuously predicts the cell size and cloud base mass flux distributions which are then fed to an entraining plume model. It is shown that such approach to parameterization can lead to realistic precipitation statistics and diurnal cycle over various regions as well as MJO related propagation of precipitation.

Development of a physically-based parameterization of the raindrop formation processes through machine-learning

Azusa Takeishi, Chien Wang

While quick transformations of cloud droplets into raindrops are frequently observed, reproducing such fast conversions in atmospheric models has been one of the major challenges. Recently some studies showed the importance of turbulences in expediting the cloud-droplets-to-raindrop process. In addition, it has long been argued that aerosol size distributions and chemical compositions may be critical to the collision-coalescence process. In this study, we utilize a parcel model that calculates the processes of aerosol activation, condensational growth, and collision-coalescence, all based on physical equations. We apply machine-learning algorithms to model-simulated raindrop mass alongside ten dynamical and microphysical variables as input features. Differences between the machine-learned results and those predicted by empirical parameterizations, as well as the applicability of the machine-learning-based parameterization in a regional model, will be discussed.

Assessing calibration issues and intrinsic limits of a convection parameterization using machine learning

Romain Roehrig1, Daniel Williamson2,3, Fleur Couvreux1, Frederic Hourdin4

Over the past ten years, the CNRM climate model development team has developed and implemented a convective scheme that aims at representing dry, shallow and deep convection in a unified and continuous way. During its integration, the question of its effective ability to capture the various convective regimes arose. The present work investigates this latter question in a rigorous manner: does a set of tuning parameters exist for this parameterization? Or are we facing its intrinsic limits? This investigation is made possible thanks to (i) the recent availability in our SCM of a wide range of single-column model convective cases, each of them being associated with relevant references (the new input standards for SCM forcing shared within the French community were instrumental for this achievement), and (ii) the development of machine-learning tools that provide an objective framework for process-based model tuning, and which ultimately illuminate the issue of parameterization tuning.

Machine-learned atmospheric optical properties for radiative transfer computations

Menno Veerman1, Robert Pincus2,3, Caspar van Leeuwen4, Damian Podareanu4, Robin Stoffer1, Chiel van Heerwaarden1

A fast and accurate treatment of radiation is essential for high quality atmospheric simulations, but radiative transfer solvers are computationally very expensive. In this study, we use machine learning to determine the optical properties of the atmosphere, which control the absorption, scattering and emission of radiation. We train multiple neural networks to predict all optical properties calculated by the RRTM for General circulation model applications - Parallel (RRTMGP) from the pressure, temperature, water vapour content and ozone mixing ratio of each grid cell. The predicted optical properties are highly accurate and resulting downward longwave and shortwave radiative fluxes have errors within 0.5 W/m2 at the surface. Depending on the size of the neural networks, our implementation is up to 4 times faster than RRTMGP. We thus conclude that neural networks are very suitable to emulate the calculation of optical properties.

Parameterization and tuning of cloud and precipitation overlap in LMDz

Ludovic Touzé-Peiffer, Frédéric Hourdin, Catherine Rio

We will present the effect of a new parameterization, inspired by Jakob & Klein (2000), to take into account cloud overlap in the formation and evaporation of precipitation in the atmospheric model LMDz. In this parameterization, at each level, the precipitation flux is divided into clear-sky and cloudy precipitation fluxes, with corresponding precipitation fractions. Newly formed precipitation falls within the clouds, thereby increasing the cloudy precipitation flux. By definition, the cloudy precipitation falls in saturated air, so only the clear-sky precipitation flux evaporates. This simple treatment corrects some inconsistencies found in the standard version of LMDz and leads to a better representation of cloud and precipitation overlap.

The version of LMDz containing this new parameterization is tested and tuned using the HighTune tools over various 1D case studies and in 3D simulations. The results illustrate the potential of machine learning techniques to guide the development of new parameterizations.

Characterising Convection Schemes Using Their Linearised Responses to Convective Tendency Perturbations

Yi-Ling Hwong1, Siwon Song1, Steven Sherwood1, Alison Stirling2, Catherine Rio3, Romain Roehrig3, Chimene Daleu4, Robert Plant4, David Fuchs1, Penelope Maher5, Ludovic Touzé-Peiffer6

We study the behaviour of convection schemes by probing their responses to small perturbations in temperature and moisture tendencies following the linear response function method of Kuang (2010). We compare 12 physical packages in 5 atmospheric models using single-column model (SCM) simulations under RCE conditions. Results are also compared to that of a cloud-resolving model (CRM). We show that the procedure is able to isolate the behaviour of a convection scheme from other physics schemes. We identify similarities but also substantial differences among the SCMs and between the SCMs and the CRM, some of which can be explained by scheme physics. All SCMs display kinks in their responses, which are absent from the CRM, suggesting that they might be related to switches or thresholds embedded in convective parameterisation. The models' moisture responses are related to their RCE profile, while their temperature responses do not and therefore can be regarded as independent diagnostics.

Sensitivity of observable output of modeled microphysics to stochastically perturbed parameters

Tomislava Vukicevic1, Derek Posselt2, Aleksa Stankovic1

This study investigates sensitivity of cloud and precipitation parameterized microphysics to stochastic representation of parameter uncertainty to evaluate a potential to use satellite remote sensing to estimate properties of such uncertainty representation for the purpose of ensemble modeling. A stochastically perturbed parameterization scheme (SPP) is applied to multiple microphysical parameters within a lagrangian column model. The experiments based on ensemble simulations indicate a high sensitivity of simulated microphysics-sensitive satellite observables to the SPP properties. The analyses suggest a strong potential to use the satellite observations to estimate the modeled stochastic uncertainty of the parameterizations. Further analyses will be presented at the conference.

A Hybrid Deep Learning CNN-LSTM Model for Predicting Monthly Rainfall Over Japan

Paul Adigun

Predicting rainfall is an important task due to the high reliance on it, especially in the agriculture sector. Prediction is difficult and even more complex due to the dynamic nature of rainfall. In this study, we carry out monthly rainfall prediction over some selected locations in Japan. The rainfall data were obtained from the Japan Meteorology Agency (JMA). We study the predictive capability of a hybrid Convolution Neural Network (CNN) integrated with Long Short Term Memory (LSTM) model on the parameters recorded by the automatic weather station in the selected regions. The developed hybrid model is applied to four different locations in different climatic regimes in terms of monthly precipitation characteristics. Overall, this study was able to establish the skill performance of hybrid CNN-LSTM model in capturing complex relationship between the causal variables and monthly variation of rainfall in the study region.

Tropical free-tropospheric humidity differences in global storm-resolving models

Theresa Lang1, Ann Kristin Naumann2, Bjorn Stevens2, Stefan Alexander Buehler1

Tropical free-tropospheric humidity (FTH) plays a key role in controlling the Earth's outgoing longwave radiation (OLR), but it is poorly simulated by conventional climate models. We investigate whether global storm-resolving models (GSRMs) simulate FTH more accurately, by quantifying inter-model differences in the multi-model ensemble DYAMOND. We find that the model spread in FTH is approximately halved compared to conventional climate models. However, the differences still cause a considerable spread of 1.2 Wm2 in tropical mean clear-sky OLR. To reduce this spread a reduction of humidity biases would be most beneficial in the lower and mid free troposphere. In the horizontal, FTH biases in two moisture regimes have a particularly strong impact: Dry subsidence regimes and moist regions adjacent to deep convection. In the most critical regions FTH biases are related to parameterized processes (e.g. microphysics, turbulence), so a better understanding of how they affect FTH is needed.

Microphysical sensitivities in global storm-resolving simulations (SRMs)

Ann Kristin Naumann

In global SRMs that resolve convection explicitly instead of parameterizing it, microphysical processes are now fundamentally linked to their controlling factors, i.e., the circulation. While in conventional climate models the convective parameterization is one of the main sources of uncertainties (and a popular tuning parameter), this role might be passed on to the microphysical parameterization in global SRMs. In this study, we use a global SRM with a one-moment microphysics parameterization and do several sensitivity runs, where in each run we vary one parameter of the microphysics scheme in its range of uncertainty. First results indicate that microphysical sensitivities in global SRMs are substantial and resemble inter-model differences such as in the DYAMOND ensemble. Among the parameters tested, the scheme is particularly sensitive to the ice fall speed and the width of the raindrop size distribution, which both cause several 10s W/m2 variation in radiative fluxes.

Impact of middle atmospheric humidity on boundary layer turbulence and clouds

Neelam Namadev Malap1,2, Thara Prabhakaran1, Anandakumar Karipot2

We investigated the moisture present above the boundary layer and its association with the cloud development and boundary layer(BL) turbulence using Large Eddy Simulation (LES). The dry boundary layer with shallow clouds observed during Cloud-Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) over the arid Indian peninsula is studied here. LES derived fluxes and variances are compared with the constant altitude aircraft observations at different elevations. LES simulations with the drier conditions above the BL resulted in deeper, warmer and drier BL with an enhanced boundary layer turbulence. Drying has resulted in energetic BL eddies and a doubling of moisture exchange coefficients. LES sensitivity indicates that the middle atmospheric water vapor alone could influence the shallow to deep cumulus cloud transitions in the monsoon regime in a dramatic way. A 30% drying above the BL could drastically reduce the liquid water path and cloud albedo by 10-15%.

Interpretable Machine Learning and Remote Sensing for Cloud Detection and Classification

Thomas Chen

The detection and classification of atmospheric clouds, in both ground-based and satellite-based domains, is crucial to the understanding of Earth's energy balance, climate, and weather. Utilizing the latest deep learning methodologies, we train a convolutional neural network, of the ResNet50 architecture, on cloud imagery data from the ground. Building off of previous work, we explore the interpretability of models, i.e. how and why the models are coming to their decisions. This requires ablation studies concerning different input modalities and the fine-tuning of particular features like the learning rate and loss functions. We also propose the generation of gradient class-activation maps for the visual representation of the inner workings of our machine learning models. These figures, which act as saliency maps, allow us to break open any black box models and understand why they are making their decisions. Interpretability is key to be aware of biases within the models.

Invited Talk: Daniel Williamson: Title to be defined

Climate model development and the role of machine learning

Daniel Williamson, Wenzhe Xu, Bertrand Nortier

Machine learning and AI, thanks to a number of high-profile successes, are often touted as potentially holding the keys to solutions to some of science's greatest challenges. Indeed Google's DeepMind, having achieved some of the aforementioned successes, turned their attention to weather and climate prediction. But what is machine learning and can it replace climate modelling (my view is no)? In this talk I will introduce some key ideas in machine learning, and argue how it can assist in climate model development, for example through tuning and falsification of parameterisations.

In the last half of my talk I will focus on recent innovations with Gaussian processes and their implications for tuning. In particular I will introduce 2 ideas: Kernel History Matching (KHM) and Integrating Gaussian Processes (IGPs). KHM is a new tuning method capable of searching parameter space for climate models with important emergent features without requiring that these features occur in exactly the same place or at the same times as they do in reference data sets (knowing that in general they can't due to limited resolution). IGPs use (deep) Gaussian processes to couple components of a network (e.g. a climate model). I will demonstrate the technology and look ahead to its implications for tuning.

Mercredi 14 après-midi

Representing 3D effects in atmospheric radiation schemes.

Robin Hogan

In this talk I will discuss the representation of 3D cloud radiative effects in the radiation schemes of large-scale atmospheric models, and hence the prospects for estimating the global impact of 3D radiation on the Earth system. I will start by outlining the principle of the "SPARTACUS" solver for accounting for 3D effects in an approximate but affordable way, which is available as an option in the open-source ecRad radiation scheme used at ECMWF. An improvement following from comparison to benchmark shortwave Monte-Carlo calculations is the careful inclusion of the mechanism of "entrapment", which tends to make scenes darker compared to equivalent calculations in which 3D effects are neglected. Observational evaluation of shortwave SPARTACUS will also be presented from a long-term analysis of the ratio of direct-to-total fluxes at the surface. More recent comparisons to longwave Monte-Carlo calculations imply that SPARTACUS tends to overestimate 3D radiative effects in the longwave. A mechanism to explain this is currently under investigation, and relates to the limitations of the two-stream approximation underpinning SPARTACUS, but could be improved by adding more streams. Lastly, I will summarize a new approach to using machine learning for atmospheric radiative transfer: rather than trying to emulate the entire radiation problem, which is very difficult with sufficient accuracy for NWP, we run a fast 1D radiation scheme and the emulate the "3D correction" training on the difference between SPARTACUS and the 1D scheme. This achieves close to the accuracy of SPARTACUS without incurring the 4-5 times greater computational cost.

Addressing radiation and cloud uncertainties with the new radiation scheme ecRad in ICON

Sophia Schäfer1, Martin Köhler1, Robin Hogan2,3, Carolin Klinger4, Daniel Rieger1, Maike Ahlgrimm1, Alberto de Lozar1

Cloud-radiation interactions strongly impact atmospheric energy and water balance, but are challenging to capture for radiation schemes in global weather and climate models, due to cloud complexity on sub-grid scales. Simplifying assumptions are used to parametrise cloud geometry and cloud particle size, shape and scattering functions. These assumptions introduce uncertainties in cloud-radiation interaction and the climatic role of clouds.

The new modular radiation scheme ecRad significantly improves global radiation, clouds and energy balance in ICON, and also allows us to vary the parametrisations, providing a choice of solver, cloud ice and water optical properties, vertical overlap and horizontal inhomogeneity treatment. We analyse the uncertainty and impact of these radiation parametrisations and cloud parametrisations in ICON and evaluate against exact radiation models and various satellite observations, guiding improvement in the representation of clouds and radiation.

Process-based climate model development harnessing machine learning: III. The Representation of Cumulus Geometry and their 3D Radiative Effects

Najda Villefranque1,2,5, Stephane Blanco2, Fleur Couvreux1, Richard Fournier2, Jacques Gautrais3, Robin J. Hogan4, Frédéric Hourdin5, Victoria Volodina6, Daniel Williamson6,7

We analyze the role of cloud geometry parameters (vertical overlap, horizontal heterogeneity and cloud size) that appear in the parameterization of radiation. The solar component of a radiative transfer scheme that includes a parameterization for 3D radiative effects of clouds (SPARTACUS) is run on an ensemble of input cloud profiles synthesized from LES outputs. The space of cloud geometry parameter values is efficiently explored using the High-Tune:Explorer tool. SPARTACUS is evaluated by comparing radiative metrics to reference values provided by a 3D radiative transfer Monte Carlo model. The best calibrated configurations yield better predictions of TOA and surface fluxes than the one that uses parameter values computed from the 3D cloud fields: the root-mean-square errors averaged over cumulus cloud fields and solar angles are reduced from ~ 10

W/m² with LES-derived parameters to ~ 5 W/m² with adjusted parameters. However, the errors on absorption remain around 2 to 4 W/m².

A LES-benchmark case for surface solar irradiance variability under shallow cumulus

Chiel van Heerwaarden, Menno Veerman, Bart van Stratum, Wouter Mol, Jordi Vilà-Guerau de Arellano

Shallow cumulus clouds drive strong variability in space and time in surface solar irradiance, with shadows and bright spots due to reflection of light off cloud edges. Due to the tight coupling of the land surface, boundary-layer turbulence, cloud processes, and cloud-radiation interactions, our understanding of surface irradiance variability is still incomplete. Hence, our capacity to forecast it is limited. With large-eddy simulations we can very well simulate shallow cumulus convection, but producing realistic patterns of surface solar irradiance remains a challenge. We present here a LES-benchmark case for irradiance variability based on observations of a shallow cumulus day in August 2018 in Cabauw, The Netherlands. We compare the ability of the MicroHH model with the new 1D RTE+RRTMGP radiation code and the DALES model with the 3D TenStream solver in reproducing 1 Hz-observations of direct and diffuse radiation, near-surface meteorology, and cloud macrophysical properties.

To what extent does the radiative effect of low-level clouds depend on an accurate description of their vertical structure?

Raphaël Lebrun1,2,3, Jean-Louis Dufresne1,2,3, Najda Villefranque1,2,3

In this work we quantify the impact on the radiative flux of two approximations used in atmospheric models to parameterize clouds : homogeneity of cloud properties in each cell and exponential random overlap of clouds.

For this, we perform plan-parallel Monte-Carlo radiative computations with classical low-level cloud LES cases.

To test the homogeneity hypothesis, we mapped the variables of the LES onto a coarser vertical grid (GCM/RCM), while preserving the total cloud cover. Radiative transfer computations show that this idealized coarsening leads to a relative difference in cloud albedo up to 20% (5-7% of albedo) for vertical layers of 100m thickness.

As we investigate the ERO approximation, we show it can be considered as a Markovian process and we compute the optimal overlap parameter for which the total cloud cover is conserved. We obtain that the ERO approximation introduces only small errors.

Finally, we use ERO to represent the LWC heterogeneity within a coarse cell.

Introducing cloud horizontal overlap at NWP scales (1-10 km) in a fast 3D radiative transfer model

Mihail Manev1, Bernhard Mayer1, Claudia Emde1, Aiko Voigt2

Interactions between radiation and clouds are a source of significant uncertainty in both numerical weather prediction (NWP) and climate models. Here we present a hybrid radiative transfer model that combines a traditional twostream maximum random overlap (twomaxrnd) radiative solver (Črnivec and Mayer, 2019) with a Neighbouring Column Approximation (NCA) model (Klinger and Mayer, 2019), which parametrizes horizontal photon transport between adjacent grid-cells. Thereby the hybrid includes both subgrid-scale effects and grid-scale horizontal transport. In addition we introduced a horizontal cloud overlap scheme to the hybrid model. Further we assess the performance of the model at the NWP scale (1-10 km) for various realistic cloud configurations using results from the benchmark Monte-Carlo model MYSTIC (Mayer, 2009).

The Contributions of Shear and Turbulence to Cloud Overlap for Cumulus Clouds

Anthony Sulak2,1, **Thijs Heus2**, William Calabrase2,3, Shawn Ryan2

Vertical cloud overlap, the ratio of cloud fraction by area and by volume, for cumulus clouds are studied using large-eddy simulations (LES) due to the inefficient, wide-range values of cloud overlap. We can obtain information about the cloud cover of a cloud field by inspecting the individual clouds in that cloud field. We start with the maximum-random assumption and adjust this assumption for individual clouds. From this there is an underprediction which leads to the conclusion that something can be added. We extend this by considering physical factors of cloud overlap: area variability, vertical wind shear, and turbulence. We use numerical schemes to calculate the effect of each contributor based on cloud height. The resulting model shows good accuracy in modeling the cloud overlap.

Uncertainty of shortwave cloud radiative impact due to the parameterization of liquid cloud optical properties.

Erfan Jahangir, Quentin Libois, Fleur Couvreux, Benoit Vie

In general circulation models (GCMs) the shortwave (SW) cloud radiative effect (CRE) largely depends on the bulk radiative properties of clouds. These properties rely on the amount of condensed water, and the single scattering properties (SSP) of cloud particles. The SSPs, which quantify the interactions between radiation and individual cloud particles, are governed by the size and shape of the particles.In GCMs, the liquid clouds prognostic variables are generally liquid water content and total droplet concentration, but no information is provided regarding particle size. As a consequence, an assumption is required on the droplet size distribution (DSD) to diagnose the cloud particle effective radius (reff). SSPs are then parameterized in terms of reff.

To this end, new SSPs parameterizations, covering various DSD assumptions, are developed and implemented in the radiative scheme of ecRad to assess the uncertainties in CRE, resulting from the hypotheses on parameterization of SSPs.

Evaluation of low-level marine tropical clouds in CMIP6 models: the 'too few too bright' bias

Dimitra Konsta1, Jean-Louis Dufresne2, Helene Chepfer2

Climate models tend to underestimate the cloud cover and overestimate the cloud albedo, a default referred to as the 'too few too bright bias'. In this study we examine whether this bias is still present in the current generation of CMIP6 models for low level tropical marine clouds.

The characteristics of low-level clouds simulated by six climate models participating in CMIP6 are analyzed using the COSP simulator. Key cloud variables are evaluated against different satellite datasets: cloud cover and cloud vertical distribution from CALIPSO lidar observations and cloud optical depth from PARASOL mono-directional reflectance.

It is found that the "too few too bright bias" is still present for low level clouds of the CMIP6 models under study. Common biases are found regarding the co-variation of the cloud properties, their dependence on cloud environmental conditions and in the vertical profile of CMIP6 models, the latest being attributed to the mistreatment of the cloud heterogeneity.

Increasing resolution and resolving convection improves the simulation of cloud-radiative effects over the North Atlantic

Fabian Senf1, Aiko Voigt2,3, Nicolas Clerbaux4, Hartwig Deneke1, Anja Hünerbein1

Numerical experiments were carried out using the ICON model with varying grid spacings between 2.5 and 80 km and with different subgrid-scale parameterization approaches. Simulations have been performed over the North Atlantic with either one-moment or two-moment microphysics and with convection being parameterized or explicitly resolved by grid-scale dynamics. Simulated cloud-radiative effects are compared to products derived from Meteosat measurements. Furthermore, a sophisticated cloud classification algorithm is applied for a decomposition of cloud-radiative effects. It is found that flux biases originate equally from clearsky and cloudy parts of the radiation field. Simulated cloud amounts and cloud-radiative effects are dominated by marine, shallow clouds, and their behaviour is highly resolution dependent. Bias compensation between shortwave and longwave flux biases, seen in the coarser simulations, is significantly diminished for higher resolutions.

Development of a Fast Three-Dimensional Dynamic Radiative Transfer Solver for Numerical Weather Prediction Models

Richard Maier, Bernhard Mayer, Claudia Emde, Fabian Jakub

The increasing resolution of NWP models makes 3D radiative effects more and more important. These effects are usually neglected by the 1D independent column approximations used in most of the current models.

To address these issues, we present a new „dynamic“ approach of solving 3D radiative transfer. Building upon the existing TenStream solver (Jakub and Mayer, 2015), radiation in this 3D model is not solved completely in each radiation time step, but is rather only transported to adjacent grid boxes. For every grid box, outgoing fluxes are then calculated from the incoming fluxes from the neighboring grid cells of the previous time step. This allows to reduce the computational cost of 3D radiative transfer models to that of current 1D solvers.

Here, we show first results obtained with this new solver with a special emphasis on heating rates. Furthermore, we demonstrate issues related to the dynamical treatment of radiation as well as possible solutions to these problems.

Emergent Constraints on Regional Cloud Feedbacks

Nicholas James Lutsko1, Max Popp2, Robert Nazarian3

Low-cloud based emergent constraints have the potential to substantially reduce uncertainty in Earth's Equilibrium Climate sensitivity, but recent work has shown that previously-developed constraints fail in the latest generation of climate models, suggesting that new approaches are needed. Here, we investigate the potential of emergent constraints to reduce uncertainty in regional cloud feedbacks, rather than in the global-mean cloud feedback. Strong relationships are found between the monthly/interannual variability of tropical clouds and the tropical net cloud feedback. When combined with observations, these relationships substantially narrow the uncertainty in the tropical cloud feedback, and show that the tropical cloud feedback is likely > 0. Promising relationships are also found in the 90°-60°S and 30°-60°N regions, though these relationships are not robust across model generations and we have not identified the associated physical mechanisms.

Effects of different cloud overlapping parameters on simulated total cloud fraction over the globe and East Asian region

Haibo Wang

The cloud overlapping parameter (vertical decorrelation length, Lcf) from CloudSat/CALIPSO is implemented in BCC_AGCM2.0 to reduce the uncertainly in radiation field. Comparing the results obtained by using the constant Lcf of 2 km with those using the above retrieved Lcf, it is found that the total cloud fraction simulation has been obviously improved by using the satellite-based Lcf. The error of global mean total cloud fraction between simulations and CERES is decreased by 1.6% in both the winter and summer, of which the positive deviation of total cloud amount at tropical convection area and the negative deviation in subtropical region both are significantly reduced. In East Asia, using the satellite-based Lcf can decrease the error of average total cloud fraction by 1.8% (1.4%) in the winter (summer). Overall, using Lcf from CloudSat/CALIPSO satellite data can improve the simulation of total cloud fraction and thus obtain more accurate simulation of radiation field.

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Convective momentum transport through the subtropical shallow convection in LES simulations

Vishal Dixit, Louise Nuijens, Kevin Helfer

Does atmospheric moist convection transport horizontal momentum upwards to significantly impact surrounding flows? This has remained an enigma in spite of considerable efforts. We utilize unique multi-day large eddy simulations run over the tropical Atlantic under German HDCP2 project to evaluate the convective momentum transport (CMT) effects by shallow convection.For typical trade wind profiles during boreal winter, the convection acts as an effective "cumulus friction" to decelerate the north-easterlies. This effect is maximum near the cloud base while in the cloud layer, the effects are weak but are distributed over relatively a deeper layer. In the cloud layer, the zonal component of the momentum flux is counter-gradient and penetrates deeper than reported previously. The transport through convective updrafts and downdrafts captures the right sign of the counter-gradient momentum transport but underestimates it severely.

Turbulent effects and dynamics of the cloud-environment interface in a LES of a growing cumulus congestus

Clément Strauss, Didier Ricard, Christine Lac

A Large-Eddy Simulation (LES) of a cumulus congestus has been performed using the Méso-NHmodel with a 5-m resolution in order to study the fine-scale dynamics and mixing on its edges. Toroïdal circulation eddies have a strong signature on the resolved turbulent fluxes.

A partition of the cloud and its environment is used to characterize the dynamics, buoyancy and turbulence near the cloud edges. At the vicinity of the cloud-environment interface, downdrafts caused by eddies coexist with a buoyancy inversion while the cloud interior is mostly rising with positive buoyancy. Turbulence on the edges is finer scale than inside the cloud.

An alternative simulation, where evaporative cooling effects are suppressed, indicates that those effects are mainly present near the edges and contribute to attenuate the convective circulation. Evaporative cooling has also an impact on the buoyancy inversion and on the path of the entrained air.

Improved Ice Aggregation Formulation in a Two-Moment Microphysics Scheme

Markus Karrer1, Axel Seifert2, Davide Ori1, Vera Schemann1, Stefan Kneifel1

Accurate simulation of ice aggregation is important for precise precipitation prediction, especially when sophisticated models are used, e.g. two-moment bulk microphysics schemes. We simulated 43 days with ICON-LEM and applied a radar forward operator to perform a statistical comparison between synthetic and observed multifrequency radar measurements. The analysis reveals an overestimation of the Doppler velocity and snow particle sizes at higher temperatures.

We implemented new particle property relations inferred from aggregation modeling and updated other microphysical parameters that affect aggregation rates (e.g. formulation of the aggregation kernel, sticking efficiency). This allowed us to evaluate the sensitivity of aggregation to these parameters. The particle properties and the aggregation kernel have the largest impact and their improvement in the scheme leads to smaller biases in the simulated Doppler velocity and snow particle size.

Process-oriented Evaluation of cloud parameterizations using a Cloud System Concept

Claudia J. Stubenrauch1, Marine Bonazzola1, Graeme L. Stephens2

Recently GEWEX initiated working groups on Process Evaluation Studies (PROES) to provide observational based metrics for a better understanding of physical processes. Within the framework of UTCC (Upper Tropospheric Clouds and Convection) PROES we are creating a synergetic data base of UT cloud systems. Convective cores, cirrus anvils and surrounding thin

cirrus are identified using cloud emissivity derived from IR Sounder observations. Lidar - radar observations of CALIPSO-CloudSat and TRMM provide information on the vertical structure and precipitation of these systems, essential to determine their heating rates. This cloud system concept allows to relate the anvil properties to processes shaping them.
We present the utility of this process-oriented observational metrics (relations between cloud system properties and proxies mimicking their life stage and convective depth) for the development of a more coherent bulk ice cloud scheme in the LMDZ climate model.

Improving convection in LES through detailed land-surface modelling

Bart J.H. van Stratum, Chiel C. van Heerwaarden, Jordi Vilà Guerau de Arellano

LES is skilful in forecasting convection because of its explicit representation of turbulence and convection. However, this skill strongly depends on a correct partitioning of the available energy over the surface heat and moisture fluxes. Our goal is to improve the representation of the land-surface in LES, through a detailed representation of the (plant) physiological processes, and spatial properties of the surface. First, we setup a new testbed for performing LES of realistic weather, forcing LES with the dynamic tendencies obtained from the dynamic core of HARMONIE-AROME. Validation of a multi-week LES experiment shows that this setup manages to capture the wide variety of weather phenomena observed in reality. Second, we are developing a new land-surface model, including a high-resolution database of the surface properties of the Netherlands. We demonstrate the land-surface model in offline mode (forced by ERA5), running in high resolution over a central part of the Netherlands.

Application of Remote Sensing to Study Dynamical and Morphological Characteristics of Meso-Scale Convective Systems to Develop ‘Thunderstorms Numerical Prediction Model (TNPM)’Over Tropics’.

Virendra Kumar Goswami

The large scale kinematic and thermodynamic behavior, evolutionary features & 3D structure of selected mesoscale Convective Systems, e.g. intense Cloud Clusters, and Severe Thunderstorms, NHCZ & SHCZ, SSTs would be investigated by using Aircraft, Doppler Weather Radar, conventional, and Satellite data fitted with Lightning sensors & CubeSats carrying high-frequency passive microwave sensors, over the domain.
The values of characteristics, e.g. lifetime, distribution, trajectories, size, &3Dstructure, i.e., the vertical extent of these systems would be computed in order to develop a ‘Thunderstorms Numerical Prediction Model‘ for Asian, Tropical, Mid-latitude.
Based on Goswami’s ‘Cluster Coalescence Theory’ & ‘Giant Cluster Theory’; regional/sub-regional tropical Cyclone Forecasting Model (TCFM)’ would be developed using satellite imageries & computation of deep convective mass transport inside the thunderstorm-cell through Cloud Tracer Analysis.

Evaluation and improvement of cloud and precipitation processes of NICAM with ULTIMATE

Masaki Satoh1, Woosub Roh1, Shuhei Matsugishi1, Yasutaka Ikuta2, Naomi Kuba1, Hajime Okamoto3

We propose a collaboration study between numerical models and ground remote-sensing observation data over the metropolitan area of Tokyo. The initiative is called ULTIMATE (ULTra-sIte for Measuring Atmosphere of Tokyo metropolitan Environment), in which using an intensive observation data in the Tokyo area together with satellite observations, cloud microphysics schemes of numerical models are evaluated and improved.
We will consider the use of observation data planned for ground validation of the EarhCARE satellite and the dual-polarization Doppler weather radar, which is now in operation at the Japan Meteorological Agency. We particularly focus on the evaluation and improvement of the Non-

hydrostatic Icosahedral Atmospheric Model (NICAM), which can be used seamlessly on both global and regional domains, allowing us to quickly test the improved scheme on a global scale, compare it with satellite observations, and estimate climate sensitivity.

Aerosol-cloud-turbulence interactions in well-coupled Arctic boundary layers over open water

Jan Chylik, Roel Neggers

Recent field campaigns in the Arctic have successfully collected state-of-the-art datasets on low level mixed-phase clouds, however key aspects still prove hard to measure. We present complementary high-resolution simulations to serve as a virtual laboratory, being properly constrained by relevant measurements. The focus lies on gaining insight into interactions between aerosol, hydrometeors and turbulence.

A composite LES case is constructed based on dropsonde profiles collected by collocated airborne measurements in a cloudy boundary layer over open water in the Fram Strait as observed during the ACLOUD campaign on 18 June 2017.

The results highlight the impact of ice hydrometeors on the thermodynamic state and turbulence of the Arctic boundary layer. Furthermore, we find that the variation in aerosol concentrations also modifies the structure of the turbulence. Opportunities created for the evaluation of parameterizations for Earth System Models will be highlighted.

Realities of developing and improving parameterizations related to clouds in global climate models

Hideaki Kawai, Seiji Yukimoto, Tsuyoshi Koshiro, Naga Oshima, Taichu Tanaka, Hiromasa Yoshimura, Ryoji Nagasawa

The aim of the presentation is to introduce realities of developing and improving schemes related to clouds in global climate models. The representations of clouds in climate model MRI-ESM2 used in CMIP6 simulations are significantly improved from the previous version MRI-CGCM3 used in CMIP5 simulations. The score of the spatial pattern of radiative fluxes at the top of the atmosphere for MRI-ESM2 is better than any of the 48 CMIP5 models. We will show comprehensively various modifications related to clouds, which contribute to the improved cloud representation, and their main impacts. The modifications cover various schemes and processes including the cloud scheme, turbulence scheme, cloud microphysics processes, the interaction between cloud and convection schemes, resolution issues, cloud radiation processes, the aerosol properties, and numerics. We would like to emphasize that the improvement of performance in climate models is ordinarily contributed by many minor modifications.

Sensitivity of ice formation processes in the ice modes scheme

Tim Lüttmer, Peter Spichtinger

Common microphysics bulk schemes only consider a single ice class which includes sources from multiple formation mechanisms. We developed and implemented a two-moment microphysics scheme in the atmosphere model ICON that distinguishes between different ice modes of origin including homogeneous nucleation, deposition freezing, immersion freezing, homogeneous freezing of water droplets and secondary ice production from rime splintering, frozen droplet shattering and collisional break-up, respectively.

Model assumptions, e.g. choice of nucleation parameterizations and representation of ice nucleating particles, affect crucially the time evolution of clouds in the simulations. Using our newly developed bulk scheme we can determine the contribution of the various ice formation mechanisms to the total ice content. We will present idealized studies of convective cases with a focus on the sensitivity of secondary ice mechanisms.

A new diagnostic cloud scheme for heterogeneous moist parameterisations

Martin Köhler

In the ICON model parameterisations of microphysics, turbulence and convection provide a heterogeneous set of information acting on moisture and cloud that is then fed to radiation through a filter called the cloud cover parameterisation.

We are presenting a concept for a new cloud cover parameterisation that is based on a total water PDF with at least three moments - mean, variance and skewness - such as provided by a double-Gaussian or beta function. These three moments are then determined as follows: the mean uses grid mean water quantities from the dynamical core, the variance comes from the TKE turbulence scheme and the skewness is based on statistics from the convection scheme.

First SCM model results evaluated against LES will be presented as well as impacts on radiative fluxes in a set of global ICON simulations.

Improvement of a representation of mixed-phase clouds, and its impact on a global cloud-system-resolving simulation

Akira T. Noda1, Tatsuya Seiki1, Woosub Roh2, Masaki Satoh2,1, Tomoki Ohno1

Many GCMs have suffered from an underestimation of low-level mixed-phase clouds in mid-to-high latitudes, leading to an underestimation of solar albedo. Reducing this bias is thus important for improved projection of a future climate. Roh et al. (2020, JAS) and Seiki and Roh (2020, JAS) recently revealed major sources of the underestimated mixed-phase clouds in a one-moment bulk cloud microphysics scheme: overestimations of the Bergeron-Findeisen and riming processes and a growth rate from cloud water to rain. This presentation applies their scheme to a global atmospheric model, NICAM, to investigate its impacts on clouds over the global domain. A 14-km mesh NICAM experiment shows improved reflection of solar incident not only higher latitudes but lower latitudes due to a reduction of rain formation, showing that revised warm microphysics processes also play an important role to improve a global radiative energy budget. Impacts on cloud feedback processes will be also discussed.

Cloud microphysical parameterization and Orography influence on extreme rainfall event of Kerala (2018)

Sandeep Pattnaik

The goal is evaluate the ability of these sophisticated CMPs in replicating the event. In addition, efforts are made to provide a new evidence of support from remote synoptic scale events facilitated by orography causing this extreme rainfall event over Kerala (2018). It is found that the choice of CMP has considerable impact on the rainfall forecast characteristics and associated processes. Horizontal moisture flux convergence (MFC) was the major (minor) driver of convection for higher (weaker) threshold of rainfall with WDM6 predicting the most consistent peaks of MFC in comparison with the TRMM rain rate peaks.Hydrometeor analysis suggests that the Milbrandt and Thompson Aerosol Aware schemes (WDM6 and WSM6) were unable (able) to capture the cloud ice realistically which led to large (less) error in the rainfall prediction.

A cold pool perturbation scheme to improve convective initiation in convection-permitting models

Mirjam Hirt, George C. Craig

Cold pools are essential for organizing and initiating convection. In a recent investigation, we identified several sensitivities of cold pool driven convective initiation to model resolution within hectometer simulations. In particular, a causal graph analysis has revealed that the dominant impact of model resolution on convective initiation is a direct consequence of weak vertical velocities at the gust fronts, rather than being related to changes in the buoyancy or other properties of the cold pools.

To address this deficiency, we develop a parameterization for convection-permitting models to improve the representation of cold pool gust fronts. We enhance vertical wind tendencies within these gust fronts towards a target vertical velocity based on similarity theory. This parameterization strengthens gust front circulations and thereby enhances cold pool driven convective initiation. Consequently, precipitation is amplified and becomes more organized in the afternoon and evening.

Recent developments in prognostic physics in ARPEGE-Climate: Turbulence in the presence of convection and discretization of convective vertical velocity in PCMT

Jean-François Guérémy

This talk presents 2 recent developments in prognostic physics included during 2018 in ARPEGE-Climat and implemented in 2019 in the coupled operational seasonal forecasting system of Météo-France. The first and most important one concerns the consideration of convective PCMT transport flows in turbulence; this is done by including thermal and dynamic convective productions, in addition to their pre-existing turbulent contributions, in the temporal evolution equation of the turbulence. The second development deals with a better discretization of the convective vertical velocity equation in PCMT. Results will be illustrated using 1D simulations on case studies and 3D global simulations in mean climate and seasonal forecast mode.

Persistence behaviour of heat and momentum fluxes in convective surface layer turbulence

Subharthi Chowdhuri1, Thara Prabhakaran1, Tirtha Banerjee2

The characterization of heat and momentum fluxes is of paramount importance for a plethora of applications, ranging from engineering to Earth sciences. Nevertheless, how the turbulent structures associated with velocity and temperature fluctuations interact to produce the emergent flux signatures, is not evident till date. We investigate this by studying the switching patterns of intermittently occurring turbulent fluctuations from one state to another, a phenomenon called persistence. We discover that the persistence patterns for heat and momentum fluxes are widely different. Moreover, we uncover power-law scaling and length scales of turbulent motions that cause this behavior. Furthermore, by separating the phases and amplitudes of flux events, we explain the origin and differences between heat and momentum transport in convective turbulence. Our findings provide new understanding on the connection between flow organization and flux transport, two cornerstones of turbulence research.

Using LES and observations to inform the representation of convective organization and memory in next-generation Earth System Models.

Roel Neggers

The genesis and maintenance of spatial patterns in cumulus cloud populations have become intensely studied in recent years. This effort is motivated by the important role that organization plays in the coupling between convective clouds and the general circulation, in climate sensitivity, as well as in the grey zone problem in convective parameterization. Guided by this research, new conceptual modeling frameworks for capturing both organization and memory effects have been proposed, many of which take population dynamics into account. The nature of these new approaches creates unique data requirements for their calibration, training and evaluation. Where most previous model evaluation initiatives have focused on reproducing bulk statistical moments such as the mean and (co)variances, new schemes are required to also reproduce metrics reflecting spatial organization and convective memory. In this presentation we will briefly review the consequences of this development on how Large-Eddy Simulations (LES) and observations can be used for this purpose. As a practical example we will consider BiOMi (Binomials on Microgrids, https://doi.org/10.1029/2020MS002229), a newly formulated model to describe populations of interacting convective thermals as distributed over a two-dimensional Eulerian grid. Key elements include i) a fully discrete formulation based on a spatially-aware Bernoulli process, ii) object age-dependence for representing life-cycle effects, and iii) a prognostic number budget allowing for object interactions and movement. These features introduce convective memory and organization, but also optimize the computational efficiency of the framework. The BiOMi thermal population model is coupled to an EDMF parameterization and implemented in a primitive circulation model. First experiments for subtropical marine Trade wind conditions as observed during the RICO and EUREC4A field campaigns are discussed, including an evaluation against associated LES and observational datasets.Train a new convective population model against observations and LES to reproduce spatial patterns in convection.

Vendredi 16

Comparing convective memory in different schemes with imposed fixed RCE state

Maxime Colin, Steven Sherwood, Yi-Ling Hwong

Convective parameterizations necessarily reduce the number of degrees of freedom. Recent studies advocate for introducing an additional prognostic variables for unresolved atmospheric structures ("microstate memory"), adding on the more traditional large-scale influences on convection.

To test if convective schemes can capture such memory, we analyse various convective schemes in a single-column situation, with LMDZ and WRF as convective playgrounds. We compare the scheme responses in a setup similar to radiative-convective equilibrium but with an imposed fixed large-scale state. We use analogous cloud-resolving simulations (which showed exponential convective evolution) as a reference.

More fundamentally, this fixed large-scale state setup aims to identify to what extent the behaviour of convection is determined by the thermodynamic state variables, by fixing them to see how convection varies. Results show that one must add some other predictor to predict convective activity.

Memory properties in cloud-resolving simulations of the diurnal cycle of deep convection

chimène laure Daleu

A series of high-resolution three-dimensional simulations of the diurnal cycle of deep convection over land are performed using the new Met Office NERC cloud-resolving model. This study features scattered convection. A memory function is defined to identify the effects of previous convection in modifying current convection. It is based on the probability of finding rain at time $t0$ and at an earlier time $t0-\Delta t$ compared to the expected probability given no memory. The memory is examined as a function of the lag time Δt. It is strongest at grey-zone scales of 4–10 km, there is a change of behavior for spatial scales between 10 and 15 km, and it is reduced substantially for spatial scales larger than 25 km. At grey-zone scales, there is a first phase of the memory function which represents the persistence of convection and it is maintained for about an hour. There is a second phase which represents the suppression of convection in regions which were raining 1 to 3 hr previously, and subsequently a third phase which represents a secondary enhancement of precipitation. The second and third phases of the memory function develop earlier for weaker forcing. When thermodynamic fluctuations resulting from the previous day are allowed to influence the development of convection on the next day, there are fewer rainfall events with relatively large sizes, which are more intense, and thus decay and recover more slowly, in comparison to the simulations where feedback from previous days is removed. Further sensitivity experiments reveal that convective memory attributed to these thermodynamic fluctuations resides in the lower troposphere.

Object-oriented analysis of coherent boundary-layer structures in high-resolution simulations

Florent Brient1, Fleur Couvreux2, Rachel Honnert2, Catherine Rio2

In this study, we will characterize coherent ascending and descending structures in large-eddy simulations. In that aim, a methodology has recently been developed based on passive tracers emitted respectively at the surface, at cloud base and at cloud top. Applied to a simulation of marine stratocumulus boundary layer, it has shown that these coherent structures cover only a small domain fraction but contribute significantly to turbulent transports of heat and moisture, with a significant contribution of subsiding coherent plumes.

We are pursing this study by applying this method to various boundary layer simulations: clear sky, marine cumulus, continental cumulus and St-to-Cu transitions. We investigate the importance of subsiding structures and the relative importance of the physical processes controlling the triggering of these structures. Further work on the spatial organizations of clouds and the development of boundary-layer parameterizations will be discussed.

Pressure Drag for Shallow Cumulus Clouds: From Thermals to the Cloud Ensemble

Jian-Feng Gu1, Robert Stephen Plant1, Christopher Earl Holloway1, Mark Muetzelfeldt2

This study takes the first step to bridge the gap between the pressure drag of a shallow cloud ensemble and that of an individual cloud composed of rising thermals. It is found that the pressure drag for a cloud ensemble is primarily controlled by the dynamical component. The dominance of dynamical pressure drag and its increased magnitude with height are independent of cloud lifetime and are common features of individual clouds except that the total drag of a single cloud over life cycle presents vertical oscillations. These oscillations are associated with successive rising thermals but are further complicated by the evaporation-driven downdrafts outside the cloud. The horizontal vorticity associated with the vortical structure is amplified as the thermals rise to higher altitudes due to continuous baroclinic vorticity generation. This leads to the increased magnitude of local minima of dynamical pressure perturbation with height and consequently to increased dynamical pressure drag.

Some challenges for the future representation of clouds in global models

Richard Michael Forbes

The representation of clouds, precipitation and their impacts are fundamental for weather forecasting and climate models, yet many regime-dependent systematic errors continue to be present. This presentation considers a number of challenges for global models in the future to utilise: i) the increasing amounts of data from passive and active satellite instruments that can help to constrain properties of modelled cloud and precipitation across the globe; ii) the increasing computational power and advances in computational science allowing higher resolution and the potential for more complex physical parametrizations; iii) improved understanding of physical processes translating into more accurate representations of cloud and precipitation and their interactions with turbulence, radiation and other processes. Examples from the ECMWF global forecast model will be used to highlight potential directions for the future in each of these areas.

CliMA's Approach Toward Data-Informed Climate Models With Quantified Uncertainties .

Tapio Schneider

While climate change is certain, precisely how climate will change is less clear. But breakthroughs in the accuracy of climate projections and in the quantification of their uncertainties are now within reach, thanks to advances in the computational and data sciences and in the availability of Earth observations from space and from the ground. I will survey the design of a new Earth system model (ESM), under development by the Climate Modeling Alliance (CliMA). The talk will cover key new concepts in the ESM, including turbulence, convection, and cloud parameterizations and fast and efficient algorithms for assimilating data and quantifying uncertainties through a three-step process involving calibration, emulation, and sampling.

On the use of Emulators, built from Ensembles of Large Eddy Simulations, to study Clouds and Aerosol-Cloud Interactions

Franziska Glassmeier1, Fabian Hoffmann2, **Graham Feingold3**

In this presentation we will discuss efforts to train emulators to mimic the the behavior of stratocumulus cloud systems. We specifically employ Gaussian-process regression, an established machine-learning technique. Our emulators are built using an ensemble dataset of hundreds of simulations of aerosol-cloud interactions (Glassmeier et al. 2019). First we will show that emulators successfully reproduce key cloud field properties such as cloud fraction, cloud albedo, and cloud radiative effect. Second we will show how valuable emulation is for interpreting physical processes, and how it connects to our broad knowledge-base acquired through LES case studies, mixed layer models, and single column models. Third, we will discuss how emulators might be used to enhance our understanding of cloud systems observed at supersites in naturally covarying conditions.

Science and Deployment Plan for the Department of Energy (DOE) 3rd Atmospheric Radiation Measurement (ARM) Mobile Facility: Coupled Observational-Modeling Studies of Land-Aerosol-Cloud Interactions in the Southeastern United States

Scott Giangrande1, Thijs Heus2, **Chongai Kuang1**, Shawn Serbin1

The DOE 3rd ARM Mobile Facility will be relocating to the Southeastern United States (SEUS) for a five year deployment starting in the Spring of 2023. The SEUS features ubiquitous shallow-to-deep convection, with strong seasonal variability in environmental and aerosol forcings that promote isolated and organized convection to different levels of intensity. SEUS science drivers that target the onset of convective clouds include: (i) the role of large-scale vs. meso-scale thermodynamic perturbations in the onset of shallow convection; (ii) the role of the surface and prior convection on subsequent convection; (iii) identifying the key atmospheric processes in the transition from shallow-to-deep convection; and (iv) the role of moist thermals and the middle tropospheric relative humidity on shallow-to-deep convective cloud transitions. We will present our latest planning and solicit feedback on SEUS science drivers, preferred siting criteria, and instrument configurations.

How semi-automatic tuning tools can help parameterization improvement : Application to the sub-grid water distribution of a statistical cloud scheme

Louis d'Alençon, Frédéric Hourdin, Catherine Rio

The semi-automatic tuning or calibration tools developed in the High-Tune project led to a proposal for an adjustment of global models with a pre-calibration performed on 1D cases in comparison with LES (Couvreux et al., 2020, Hourdin et al., 2020). Applied to the LMDZ model, using the ARM-cumulus, RICO and SANDU transition test cases, the procedure confirmed the relevance of the thermal plume model coupled with a bi-gaussian cloud scheme to represent shallow cumulus.

However, in trying to extend the parametric exploration to the cases of deep convection (CINDYNAMO and TOGA), a systematic flaw was identified with an excess of cloud cover and relative humidity (both close to 100\%), attributed to an "all-or-nothing" behaviour of the statistical scheme indicating a missing source of variability from deep convection. We show how the tuning tools helped us to propose and adjust a new parameterization to solve this particular problem, without degrading the results for shallow cumulus cases.

Characterising the shape, size and orientation of cloud-feeding coherent boundary layer structures

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Convective clouds interact with their immediate environment, both at cloud level and below-cloud in the boundary layer, and through this may affect their own development and organisation. One of the aims of the GENESIS project is to quantify this by making a systematic study of coherent boundary layer structures and their interaction with moist convection, based on analysis of Large-Eddy Simulations.

The aim is to provide new insight into the two-way interaction between clouds and their environment, and through this aid the development of convection schemes with better

representation of sub-grid variability, specifically by producing a statistical description of the forcing from below cloud base.
Using tools developed to identify and track cloud-triggering coherent structures we will present results on how ambient characteristics affects their length-scales, orientation and magnitude of coherent structures feeding convective clouds. Specific focus will be given to the effects of changing surface Bowen ratio and strength of ambient wind shear.

A new terrain-following vertical coordinate formulation to improve the simulation of fog and low stratus in atmospheric models

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Fog and low stratus over complex terrain are challenging for LES and numerical weather prediction models, even at horizontal resolutions of ~1 km or below. In order to run over topography, numerical models typically employ a terrain-following vertical coordinate formulation. As a consequence, models have strongly sloping coordinate surfaces above hilly or mountainous terrain at altitudes where fog and low stratus typically occur. We illustrate how horizontal advection across sloping coordinate surfaces is associated with spurious numerical diffusion that promotes premature dissipation of fog and low stratus. We present a locally smoothed vertical coordinate formulation to partially alleviate this issue. We demonstrate the attained improvements based on a case study calculated with a numerical weather prediction model, but results are of relevance to a wide range of atmospheric models.

Higher Vertical Resolution for Select Physical Processes in the Energy Exascale Earth System Model (E3SM)

Hsiang-He Lee1, Peter bogenschutz1, Takanobu Yamaguchi2,3

Coarse vertical resolution in the current global climate models may be a significant cause of low cloud bias because planetary boundary layer parameterizations, including higher-order turbulence closure (HOC), cannot resolve sharp temperature and moisture gradients often found at the top of subtropical stratocumulus layers. The aim of this work is to implement a new computational method, the Framework for Improvement by Vertical Enhancement (FIVE) into the Energy Exascale Earth System Model (E3SM). Three physics schemes are interfaced to vertically enhanced physics (VEP), which allows for these schemes to be computed on a higher vertical resolution grid compared to rest of the E3SM model. In this study, we use VEP for turbulence, microphysics, and radiation parameterizations and demonstrate better representation of subtropical boundary layer clouds while limiting additional computational cost from the increased number of levels.

Vertical grid-refinement for stratocumulus clouds in ECHAM-HAM

Paolo Pelucchi, **David Neubauer**, Ulrike Lohmann

n global climate models (GCMs), the cloud cover of marine stratocumulus clouds is commonly underestimated. The coarse vertical resolution of GCMs does not allow to resolve important aspects of cloud-topped marine boundary layers well, like sharp temperature inversions, cloud top cooling or entrainment. To alleviate this problem in a numerical safe approach, a vertical-grid refinement is applied only in the radiation scheme of the ECHAM-HAM GCM. To this end the inversion height is reconstructed based on Grenier and Bretherton (2001) and used to redefine model levels and hence the vertical extent of stratocumulus clouds. Global simulations show that this makes the cloud cover and the thickness of stratocumulus clouds used in the radiation scheme more realistic. However, the method cannot be applied to its full potential since there is a frequent mismatch between the model level of the inversion and the cloud top.