Th

Improvement and calibration of clouds in models

Future of Clouds in Models Session

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

* * *

Feel free to ask your questions through this document during or after the different talks. The objective is to be able to extend discussion as there is no real coffee break.

1- 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.

* * *

Question 1 <Tobias Göcke>: How did you couple your predator prey scheme to the different convection parametrizations? Does this mean to change the closure?

Maxime Colin: Thanks for the question and suggestion. We haven't coupled the predator-prey model yet. It's just been running by itself. But in the future, we could probably try to use the predator-prey model (or an improved version of it) instead of the convection scheme in a SCM or in a GCM. I'm not sure if the predator-prey model could be coupled with a convection scheme or how to do it.

Question 2 <Chimene Daleu>: very nice talk! I am currently assessing CoMorph (the new Met Office NERC convective parameterization scheme) in depth across a wide range of physical processes and your presentation gave me some ideas. From your talk you are testing several convective schemes and I will like to know if you are looking for any collaboration? if yes, I will be happy to deliver and analyse results from the SCM version of the Met Office Unified Model using three different convection schemes (6A Mass-Flux scheme, the Simple Betts-Miller scheme and CoMorph). Thanks for your nice talk

Maxime Colin: Thank you Chimene. Yes, it sounds exciting if you want to collaborate and include the MetOffice model! I remember that CoMorph is a very nice scheme so I would be keen to see how it behaves for the tests we have in mind. If anyone else wishes t

Question <name>:

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

Chimene 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−Δt 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.

* * *

Question 1 <Nicolas Rochetin>: Does the 2nd phase correspond (suppression of deep convection at the place where rainfall already happened) to divergent mesoscale circulations ? e.g studies by Chris Taylor, Guichard, etc ? Ha ok then the answer is no if there is no heterogeneities at the surface … If so, then the memory you are talking about only lies in the atmosphere. And thanks for this nice talk !

Answer(Chimene Daleu): You are welcome!
We have repeated the control simulation with prescribed heterogeneous surface conditions (wet and dry patches) and we haven't yet analysed the memory properties in the new runs. I will come back to you once I have an answer to your question.
Please could you give the reference of Chis Taylor and Guichard ?

NR : I don't know if these studies are fully related to "memory" per se, but they deal with soil-moisture heterogeneity deep convection initiation, which is, somehow, memory.

Taylor and Lebel 1998
https://doi.org/10.1175/1520-0493(1998)126<1597:OEOPCS>2.0.CO;2

Taylor et al, 2011
http://nora.nerc.ac.uk/id/eprint/14104/1/N014104PP.pdf

Taylor et al, 2010
https://agupubs.pericles-prod.literatumonline.com/doi/pdfdirect/10.1029/2009GL041652

And mine :-) (among others) Rochetin et al, 2017
http://doi.wiley.com/10.1002/qj.2935

Question 2 <Fleur Couvreux>: How do you interpret the fact that you have the maximum of persistence between 4-10 km (what link with the average size of your precipitation events?) How is the possible advection of rainfall events by mean wind taken into account in your persistence computation?
Answer (Chimene Daleu): Please refer to the answer if question 4 (2nd paragraph)
Question 3 <Yunyan Zhang>: how land surface coupling is handled? did you allow soil moisture carry memory or did you assume any heterogeneity in surface fluxes too? maybe you just answered this..
Answer (Chimene Daleu): Our study has been limited to idealized settings with prescribed homogeneous surface conditions and we recognised that the results obtained may be modified by the presence of interactive land-surface.
The simulations described in my presentations have been repeated with prescribed heterogeneous surface conditions (wet and dry patches) and we already have differences on the time of triggering of convection and the onset of precipitation. We also have differences on the spatial distribution of rainfall events. We will continue the analysis by looking at the impact of heterogeneous surface conditions on convective memory

Question 4<Catherine Rio>: do you suggest there is no need for memory for local convection in models with resolution coarser than 25km?
Answer (Chimene Daleu): Our study reveals that there is no need for memory for convection in models with resolution coarser than 50 km. For spatial scales coarser than 25 km (but finer than 50km) convective memory is weaker compared to that at grey-zone scales of 4-10km for disorganised convection. However, our study has some limitations and we recognise that we may have different memory properties for organised convection.
In our study, the majority of rainfall events have areas smaller than 10 km2 and the memory properties are stronger around the same spatial scale. Simulations generating rainfall events larger than those obtained in our study may have different memory properties.

3 - 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 pursuing 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.

* * * * *

Question 1 <Martin Köhler>: Wonderful! For cumulus, is the sub-cloud downdraft maybe related to the cumulus induced subsidence? OK, thanks, just to make sure.
Answer (Florent) => Ok I didn’t fully understand the question. Yes it may be related to cumulus induced subsidence (on the relatively large scale). But it is not fully certain because the well-mixed downdraft are also seen in clear-sky boundary layers, named as dry tongues in Fleur’s work. So I think it remains an open question.

Question 2 <Robert Pincus>: Very nice work. How do you reconcile your result that most transport is realized through coherent structures with the good results from eddy-diffusion mass-flux schemes we saw on Monday(?) ? Is it related to the scale of the structures - that they are small enough to be represented as eddies?
Answer (Florent) => I wasn’t available on Monday but I know that recent EDMF schemes are doing a great job in reproducing the low-cloud transition for instance This work mostly aims to understand structures, but it might help building new EDMF schemes which may include mass-flux downdrafts.
The scale will be really important indeed. If the sub-cloud layer is thin, large eddies represented by the eddy-diffusivity theory might be enough to represent the sub-cloud transport. But it also needs to represent relevant entrainement processes.

Question 3 <Fabian Senf>: Nice talk! How do you define coherence? In time, in space, or both?
Answer (Fleur) => only coherence in space

Fabian: Did you think about tracking the objects in time? This could give information about lifetime of the plumes / w-structures. If you have no tool at the hand you could try out
https://github.com/climate-processes/tobac
(Najda): Hi :) our tool can also do time but just treating the 4th dimension as any dimension eg no special treatment of merging and splitting => 3D structures that share one cell in two contiguous time steps will be labeled the same throughout their whole life time. Do you do something with time? Are you able to manage large cloud fields with python? Our tool is based on the scipy ndimage library and we have trouble with very large 4D fields (we usually cut them in time, label

them and then stitch them back together). I remember reading your work and I liked it (but then I forgot sorry)
(Florent) Thank Najda for the detailed answer. I saw the toback software. It looks like a nice tool !
(Fabian): Hi, great to hear! I have also had a positive experience with time as extra dimension if the objects only cover a very small area - otherwise you could easily get a single domain filling object ;-). Very fields is an issue - we planned `dask`support for out-of-memory computation, but we are not there now …
(Najda) interesting! have you coded the whole thing or does it also rely on python libraries? Have you thought switching to other languages? I’ve been reflecting on going to C… where I better control memory allocations (I’m not very good at python)

4-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.

* * *

Question 1 <**Vishal Dixit**>: Did you test the sensitivity to the LES domain size? I wonder if the vertical force balance in clouds is sensitive to the circulations pressure gradients are able to trigger.

(Jian-Feng) We haven’t tested the sensitivity to the domain size. I think the domain size may be relevant when the organization comes in. In our case, the organization is very weak. I guess the dominance of dynamical pressure gradient force may still be there because they also work at the scales of thermals. But I need to do more tests. For triggering, I think the pressure gradient force near cloud base should have impact. I also see positive pressure gradient force at cloud base if we just focus on single cloud during its early development stage. Thanks for your question. Hope these answer your question. **Vishal:** Thanks Jian-Feng, excellent talk!

Question 2 <George Matheou>: Most LES models for shallow Cu are either Boussinesq or Anelastic, thus the baroclinic torque is not included in the resolved equations. Should I start worrying about my anelastic LES model missing the baroclinic term?

(Jian-Feng) Thanks a lot for your question. I think the impact of vorticity on pressure perturbation should still be there as the diagnostic relationship between pressure perturbation and deformation/vorticity does not depend on the baroclinic torque. The small scale overturning circulations should still have impact on local pressure perturbation within clouds. While the density variations are neglected in Boussinesq or Anelastic approximation, its impact is still considered in the buoyancy term, though the continuity equation has been simplified. So the circulations can still arise through the inhomogeneous distribution of buoyancy within clouds, and thus the pressure field can be affected.

G.M: Thanks! very nice, insightful talk!

5- - Some challenges for the future representation of clouds in global models

Richard M 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.

* * * * *

Question 1 <Frédéric Hourdin>: LESS SCIENTIFIC. COULD BE KEPT FOR THE CHAT I like the way all the talks (including yours) are discussing the arrival of global km resolution models as a great opportunity to understand/answer questions, but underlying the fact that coarser grid modes are here for a while. I am a bit afraid of the destinE, which by taking a lot of place in the programs, and giving the impression that future climate projections will be done with km resolution models, may be a problem for the research on parameterized physics in the future. I am always a bit frightened by those big names which start to occupy our environment of work. And thanks for the presentation !

***RF**: Thanks Frederic. I understand the concerns about DestinE but I think there remain many uncertainties how far this will go at least in the near-term. There will still be a need for lower resolutions for a long time yet!*

Yes. Your talk was particularly clear. But it means that it is important to make the point strongly and explain around, and to Europe and so, that not everything should be put in the high resolutions.

***RF**: As a community we've talked about longer simulations of O(1km) global modelling for a long time, but now it has potential to become a reality through a large collaborative initiative (which is where DestinE comes in). There will be a lot of research and opportunities for the community (for all sorts of applications) that can feed off this initiative.*

...I think a longer conversation for the bar - if only we were all in Toulouse!

Question 2 <Sophia Schäfer>: Great overview, thank you. Do you have any plans for considering cloud shapes and inhomogeneity in the microphysics?

***RF**: Thanks Sophia, we have been doing research to improve cloud edge parametrization (with Mark Fielding) and to represent in-cloud liquid and ice inhomogeneity (with Maike Ahlgrimm), still to implement operationally, but they are both areas that are important to represent as physically and realistically as possible.*

Question 3 <Najda Villefranque> about perturbated ensembles, do you think we could use the high-tune tool to keep a small region of parameter space and sample configurations from it to run

ensembles? or more generally, how do you plan to chose your parameter changes? Also, do you already have SCM cases representative of the southern ocean and russian cases you have shown? (I totally agree we need more cases to better constrain the parameterisations)
Continuity (Fleur): I really think that high-tune tool can provide some range of parameter values for the ensemble to choose the range for SPP. But let's wait for Richard answer on that. Thanks Richard by the way for this nice talk.
***RF**: Thanks Najda, Fleur, Yes, that was one of my questions earlier in the week. It is perhaps something to explore - there certainly looks to be information from HighTune that could be used to inform the choice and magnitude of parameter perturbations. We have used "expert knowledge" so far for parameter choices but we have also looked at other global parameter tuning methodologies as well - e.g. the ensemble methodology (EPPES Ollinaho et al 2013, QJRMS) and we are currently also looking at techniques utilising the IFS data assimilation scheme that leverages all the information in the system globally.*

Frédéric (and to add on) : Richard you are probably right that HighTune tools can not answer. But the problem is not the tool but the observations :) Or the well defined case. HighTune tools will just do the best of it once you have it :) So the answer is coming below : Etienne will prepare the case and you will just have to run HighTune on it then :)
Etienne: I am sure Frédéric would be happy to join us for this work ;)
***RF**: Thanks Frederic, Etienne*
Yes, I agree absolutely - HighTune is a great tool to have and agree the success relies on the observational input, via a representative and wide range of case studies with accurate and realistic LES. So adding Southern Ocean and other case studies around the globe will be important. HighTune is great for finding parameter values but does have some limitations and perhaps could be seen as a "necessary but not sufficient constraint" for global model development. For the supercooled liquid water example I showed, the problem was a combination of a "structural" problem (related to the subgrid mixed-phase saturation function that should be used) and a parameter calibration (in-cloud liquid-ice condensate overlap), so could certainly have been used for the latter part of the problem with the right case studies.

Question 4 <Etienne Vignon> Very great talk Richard. I just wanted to mention that recent campaigns recently gave new observational constraints/information on the microphysical processes (CAPRICORN, SOCRATES, MARCUS). We (modelers) now have some new elements (such as the order of magnitude of INP concentrations) to adapt or develop parameterizations to this specific environment.
***RF**: Thanks Etienne. Yes it would be great to use more of the data from the recent Southern Ocean observational campaigns to constrain the models. There are lots of cloud-related questions and it is a sensitive region. I am involved in some of this work, currently using the MICRE data.*

Question 5 <Sophia Schäfer>: What data is most helpful for constraining particle shape and size?
***RF**: Different radiation frequencies are sensitive to different particle sizes and even shape. Using different radar frequencies and lidar (e.g. CloudSat and CALIPSO or EarthCARE are an example), but there are also sensitivities in other frequency ranges e.g. microwave/sub-mm. There is much more to do in this area but using different frequencies simultaneously will be of key importance.*

INVITED TALK:
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.

Question 1 <Frédéric Hourdin>: Why minimize the number of adjustable parameters as a principle ? We have hundreds of processes coupled. And at the smallest scale, the closest to the individual process, very difficult to avoid parameters. Probably the more physical the model the larger the number of parameters ?
Parameters scarcity concerning the physics of the XIX century. But we put hundreds of processes, for which will never describe everything. We are doing a science off the XXI century (with computers) based on physics of the XIX. Not sure rules of the past are applicable to what we are doing. Vegetation, trees, grass, structure of the soil for water transfer, geometry of clouds at all scales.

TS: Yes, you will need many [O(100)] parameters. But you still want to minimize the number to avoid overfitting, for example. Sparsely parameterized models tend to generalize better (out of sample prediction). Of course, you want "correct" models, and that will require more parameters than, say, in the Law of Universal Gravitation. The contrast here is deep-learning approaches to convection, which require >1M parameters even in aquaplanet settings. We do not have enough observational degrees of freedom to constrain so many parameters.

I agree of avoiding overfitting. But not sure to see the link with the number of parameters. OK if you are thinking to 1M parameters. I may agree that it is too much. I think I see your point there. Very specific of the new machine learning approaches and what they call overfitting; Which is fitting everything because you have more neurones than data or something like that. Ok. Quite far from saying that you should have 5 rather than 20 parameters in a convective scheme. Thanks

Question 2 <Romain Roehrig>: For deep convection, you mentioned that the memory terms are key to get the smooth transition from shallow to deep convection. Did you identify which terms are key for that (in particular which variable(s), or which variance/flux term(s) - eg, if I remember correctly, Colin et al. 2019 JAS showed that the boundary-layer humidity field is important for deep convection)?
(follow-up, Najda Villefranque) I didn't get if you just hadn't had time to look at this or more generally if you hadn't access to the detailed processes in your parameterization? Are you able to learn from your model once it's calibrated, do you know why it works when it works?

TS: Yes, our models are based on processes, so they are relatively easy to analyze and interpret. We are in the process of doing more analysis, to try to understand, for example, what is crucial for the cloud response to climate change. It would also be interesting to look at the question of which memory terms are most important.

Question 3 <Daniel Williamson> It seems obvious that the calibration error cannot be Gaussian in the presence of structural error. I buy error in observations being Gaussian. But I don’t see why a missing process can’t mean essentially perfectly correlated error (space/time correlation will be more complicated than that). Ignoring this will mean overfitting to the training sample, or, more informally, getting things that look right for the wrong reasons and so perform poorly when we extrapolate. You mention incorporating structural error. Does this get incorporated into the “calibrate” stage?

TS: Keep in mind that the error is on **statistics** (time aggregates). So central limit theorem applies.

I don’t see this. Yes CLT applies to time, but not space. So consider a model where a current, for reasons of low resolution, is in a different place compared to the data. When you average over time, the error becomes more constant (and non-Gaussian). So it seems like there is a time-error that is Gaussian, but there is a structural error there too, and to ignore it means the EKF will try to push the model towards data it shouldnt match exactly (spatially).

TS: It’s important to distinguish different sources of error: (1) The error term connecting the model-simulated statistics to observed (or LES-simulated) statistics comes from CLT; it is plausibly Gaussian. (2) There are various sources of structural error, e.g., in parameterizations. Source (2) needs to be modeled separately. Our strategy for structural error modeling is to include models for structural error where that error actually occurs, rather than in the model-data connection (e.g., where Kennedy & O’Hagan put it in their classical paper). For example, we are working on including structural model error terms in the entrainment/detrainment formulation, which is a place where in fact we are likely making structural errors. Because this structural error is mapped to observations through a highly nonlinear map (the model with parameterizations), their effect on observations is not Gaussian, even if the underlying structural model error is Gaussian.

Question 4 <Romain Roehrig>: You mentioned that you would like to implement all this approach “online” (learning from observations and LES). Why do you think it is needed to do that in climate modeling?

TS: It may not be necessary. But it’s helpful to have such an “active learning” strategy to interactively, e.g., guard against overfitting. In the end, and maybe this is what you are getting at, once a model is calibrated and has quantified uncertainties, you can run it like we run climate models usually, without any LES spun out etc.

Question 5 <Nicolas Rochetin> : When saying “reducing the number of parameters” , are you implicitly saying, getting closer to a “theory” ? In which, of course, we intent to describe the system with the less possible number of equations and parameters,, under the form of an “elegant” formulation.

TS: Yes, another way of saying what I meant is to say we want to advance theory and then use data where theory reaches its limit. Because we cannot easily verify climate predictions (the signal is only emerging slowly), we need trust in models, and that will come from the interpretability that comes from good theory. -- More pragmatically, I continue to be impressed how models/parameterizations improve when you focus on careful theory. I did not emphasize this in the talk, but the key to get stable BL right, for example, was to have careful theory for mixing lengths. And we have seen similar success in biophysics (land plant) models too.

6-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 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.

* * * * *

Question 1 <George Matheou>: Very nice talk! (I think I missed this point) how do the atmospheric conditions (SST, subsidence, etc) vary in the simulations in the LWP-N space? There is a quite large LWP range, that suggests pretty diverse ABL conditions.

GF:George, the SST, theta, q, BL depth and aerosol are initial conditions. Sfc fluxes evolve. The subsidence is fixed. The ICs map to LWP and N in non-unique ways (equifinality).
We wanted to cover a large range of precipitating and non-precipitating systems.

GM: Thanks, it’s very fascinating that there is such a strong trend in the LWP-N space.

Question 2 <Fleur Couvreux>: I found very interesting your analysis in variable-space such as LWP/N; Albedo/cf: did you also look at link between other variables that are informative? Can the parameterizations capture the different relationship seen in LES you showed?

GF: Fleur, another state space of interest is the radar reflectivity/optical depth space. It has been shown to isolate condensation vs coalescence growth in liquid clouds. There’s no reason to limit to 3 variables. On the second part of your question, we have built simple cloud ‘models’ that have a few free parameters. This allows us to relate those parameters to the shape of (in that case) Albedo/cloud fraction.

Question 3 <Fabian Senf>: Very impressive results! I wonder how adjustments of a time scale of 20 h (for adjustment of ship track perturbation) interfere with changes of the environment that happen on the same scale, e.g. advection of different air masses or the diurnal cycle. In reality, this might change the adjustment quite drastically. Am I wrong?

GF: Fabian, you are right, 20 h approaches the point where inversion adjustment time scales become important. The microphysical process timescales are usually thought to be short, and the fast manifolds tend to slave to the slow (inversion) manifold. But I think we need to think about multiple timescales, as you point out.

Question 4 <Azusa Takeishi>: Thank you for the talk. I'm very curious about the scale of the LES simulations: do they include parameterizations for microphysical processes (like a microphysics scheme in cloud-resolving models), or are they more explicit like a bin model? I'm wondering because some microphysics schemes could sometimes have some "tendencies" (e.g., produce too much rain, saturation adjustment, etc.), depending on the equations used for calculating the processes. Is there a possibility that the use of such parameterizations in LES could skew the machine-learned results too? Or it doesn't matter too much?

GF: In order to run large numbers of LES we have to make some compromises on resolution and microphysics. This is described in Glassmeier et al. 2019. While our LES has bin microphysics, we chose to use a bin-bulk scheme that also solves for supersaturation, activation, and all warm processes. I'm sure that if we used our bin scheme it would affect the results. But I'm pretty sure that the basic result of a slower (20 h) LWP adjustment timescale relative to the fast albedo adjustment timescale wouldn't change significantly.

-7-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 Giangrande[1], Thijs Heus[2], **Chongai Kuang[1]**, Shawn Serbin[1]

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.

* * * * *

Question 1 <Maxime Colin>: What kind of observations of spatial heterogeneity are you interested in? Can you measure horizontal heterogeneity of low-level thermodynamic variables?

Question 2 <Yunyan Zhang>: maybe it is still too early to ask, do you have any specific component targeting on modeling activities?

CK: It is not too early to ask - our team is planning targeted modeling activities that examine coupled aerosol, convection, and land-atmosphere science drivers that will be informed by where we eventually site the AMF3. We are very much interested in secondary organic aerosol, its connections to biogenic VOC emissions, coupled-feedbacks with surface radiation,

Question 3 <Kwinten Van Weverberg>: maybe I missed it, but for how long will the AMF3 be at the location in the southeast US?

CK: We have an expectation for an initial deployment length of 5 years.
5 years for the first deployment

8-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.

* * *

Question 1 <Najda>: Nice! Sorry that was a bit fast for me, can you explain again what you added to the parameterization and the physics behind? -- yes!! thanks

Question 2 <Zhihong Tan>: Nice talk! After tuning the cloud bottom seems to be much lower and there is no discernable LCL. Is it anything to be concerned about? -- Thanks Frédéric!

Frédéric : I agree. II noticed that too. We should check. If it is the case it will be a problem.

Louis : Thank you to show me this problem. I will check with Frédéric.

I didn’t focus a lot on that part, I just launched a few tests, it’s very sensitive to the value of a, with a = 2 (instead of 1,85), the LCL is much better. It would be interesting to dig into it.

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

Leif Denby (1), Steven Boeing (1), Douglas Parker (1), and Mike Whitall (2)

(1) University of Leeds, Institute for Climate and Atmospheric Science, School of Earth and Environment, Leeds, United Kingdom (l.c.denby@leeds.ac.uk), (2) Met Office, Exeter, United Kingdom

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.

* * * * *

Question 1 <name>:

Question 2 <Jan Chylik>: Thank you for interesting talk. Does your toolkit also capture turbulent structures that are decoupled from the surface, such as seeder-feeder induced turbubulence in stratified clouds? LD: It could absolutely. All that is needed is to add a mask function that works on the scalar fields that are relevant to finding these structures. You can see examples of the mask functions I've added so far (for clouds, cold-pools, boundary layer structures from a bottom-up decaying tracer for example) here:
https://github.com/leifdenby/genesis/blob/master/genesis/utils/mask_functions.py
I recently taught a course using the toolkit too, there are some jupyter notebooks from that here: https://github.com/leifdenby/genesis-complete-workshop-2019, but feel free to email me (l.c.denby@leeds.ac.uk)/raise a issue on the repository if you have any questions :)

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

Stephanie Westerhuis[1], Oliver Fuhrer[2]

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.

* * * * *

Question 1 <Cyril Morcrette>: Are you not smoothing the orog, just the vertical levels

SW: No, we only smooth the vertical coordinate surfaces.
We have seen that smoothing the orography would also be beneficial for fog and low stratus on the Swiss Plateau, but obviously other phenomena would be degraded by this measure.

CM: thanks. Nice that you are able to get the benefit for clouds, without messing up valley flows etc.

SW: The difficulty lies in finding a good compromise between smoothing the levels enough to make them flat-tish at low altitudes and not only at ~10km amsl and not running into problems with e.g. unsmooth derivatives of the metric terms. But so far we seem to be lucky…

Question 2 <Jan Chylik>: Thank you for interesting talk. How does your terrain-following coordinates formulation interact with the parameterization of local effect? Does the parameterization of nocturnal BL and drainage become an issue?

SW: We have not yet had the time to have a closer look at other phenomena. Our focus so far was on fog and low stratus. We have simulated a full month (December 2016), and see a neutral or positive impact on FLS extent as well as profiles of temperature and humidity. But other periods and a focus on other phenomena such as e.g. thunderstorms is on the TODO-list for the next months.
Regarding nocturnal BL: If it is stably stratified, smoother vertical coordinate surfaces should help. At least in the COSMO model the usual problem is that inversions become weakened too quickly.

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

Hsiang-He Lee[1], Peter bogenschutz[1], Takanobu Yamaguchi[2,3]

[1] Atmospheric, Earth, and Energy Division, Lawrence Livermore National Laboratory, Livermore, CA, U.S.A. (lee1061@llnl.gov)
[2] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, U.S.A.
[3] NOAA Earth System Research Laboratories, Chemical Sciences Laboratory, Boulder, CO, U.S.A.

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.

* * *

Question 1 <name>:
Question 2 <name>:

12- - Vertical grid-refinement for stratocumulus clouds in ECHAM-HAM

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

In 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.

* * *

Question 1 <Kwinten Van Weverberg>: What is the typical model thickness at the level of stratocumulus clouds? We found in the UM a fairly small impact of grid refinement, mainly since the vertical resolution seems fine enough to resolve the stratocunulus vertically in many cases.

DN: The typical model layer thickness at the level of stratocumulus clouds is about 300 m. In our model the vertical grid refinement does seem to increase the cloud cover (used only in the radiation scheme) on many occasions.

Question 2 <Martin Köhler>: Very interesting. You probably need sub-layers in radiation, CC, microphysics and turbulence (top entrainment).

DN: Yes, this could indeed be the case. However, we want to avoid the numerically diffusive mapping between the refined and the original grid. Therefore we explored applying the refinement only in one scheme.

Final Discussion:

New methodology:

- High-Tune tuning tool & renderer tool : available to the community ~ more than 30 persons to each tutorial
- DEPHY format: to ease the use of new/more cases with LES available -> Going beyond limited number of golden case studies
- LagTraj or LS)2D:Python package to derive forcing from ERA-5 for new cases
- Using extensively observations: object-oriented evaluation or more meaningful variable states -space emphasis on physical processes
- Stress on estimating the different uncertainties and their origin (for tuning without overtuning, for ensembles ex: SPP...)
- Perturbed experiments to evaluate models
- uncertainties of high-resolution simulation need to be well estimated
- emulators to build new LES cases

New developments:

- introduction of memory and organization (convergence line, population dynamics on a microgrid,...)
- stochastic behaviour
- microphysics (ice formation processes, ice aggregation,...)
- cloud-radiation interaction (3D radiative effect, overlap, optical properties…)
-

Use of Machine Learning:

- to replace costly bit of parameterization but conserving conservations equations in the classical finite/volume finite difference form (transport by mass flux, radiative transfer equations)
- to help understanding the behaviour of the models
- to tune the model on a process basis

Steven Boeing: Quick follow-up to Robert's remark: yes, it makes sense to try to prevent duplicating efforts where possible. We have contacted Bart to check how similar Lagtraj and LS2D are, and others working on similar tools are certainly welcome to contact us (when we started this we mainly felt there wasn't a tool at the time that made the process of extracting forcings self-documenting).

Najda : thanks again. It’s really nice to see that reflecting on tools and methodology is an efficient way to improve our models and to do some physics at the same time!!