Towards global km-scale modeling and Digital Twins of the Earth System

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Oral presenters:

Bretherton, Chr.. - Caldwell, P. - Dixon, R. - Merlis, T. - Peinado Bravo, A. - Rackow, Th. - Satoh, M. - Skamarock, W. - Stier, Ph.

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Keynote Speakers

A room with a view (climate modeling in the space of observations)

Bjorn Stevens – Max Planck Institute for Meteorology

Storm-resolving Earth-system models offer an ansatz to the representation of the climate system that differs structurally from that we have used for the past thirty years. As such they represent a fundamental change in how we model climate. In addition to offering a more physically representation of the climate system, km-scale coupled models are exciting through their ability to embolden theory, and by virtue of physical, rather than statistical, representation of processes. Particularly the latter opens the possibility to understand to what extent process level constraints constrain the behavior of the climate system -- to ask how well we understand the atmospheric general circulation and its climate. In short, storm-resolving Earth-system models are as exciting for the problems they solve as they are for the ones they do not.

In my talk I will summarize efforts at the Max Planck Institute for Meteorology to develop multi-decadal simulations of the coupled climate system at km-scales. Initial studies and coupled simulations of the annual cycle on 2.5 and 5.0 km grids will be presented, and lessons from these efforts will be drawn. Based on this ongoing work, grand challenge problems for global climate modelling, both physical and technical will be presented.

Global storm and ocean-eddy resolving earth system models

Tomoki Miyakawa – The University of Tokyo

Several research groups around the world started to develop a new generation of Earth System Models (ESMs), which have the capability to resolve the vertical energy transport associated with deep convective clouds in the tropics, ocean eddies and sea-ice leads in the high latitudes. These models matured to a degree, that they can be evaluated and tested in inter-comparison projects. In the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND) project, first a summer period with only atmospheric models, then a winter period with atmospheric and coupled models was simulated with several of this new generation models. These models are becoming a powerful tool for prediction at subseasonal to seasonal time-ranges which require skillful representation of fine-scale structures of atmosphere and ocean as well as planetary scale fluctuations. Moreover, first multi-year simulations with ESMs with horizontal resolutions finer than 5km are becoming reality and soon, full climate integrations will be not only possible, but also feasible. We will present results from the DYAMOND inter-comparison project, demonstrating their capabilities. We will also show results from ensemble weather prediction attempts using a storm-resolving ESM.

Oral Presentations

Aerosol-convection interactions in global storm resolving simulations

Philip Stier – University of Oxford

Aerosol-cloud interactions have long remained the largest uncertainty in our understanding of anthropogenic perturbations to the climate system. The assessment of their global and regional climate effects has generally been based on global climate models, in which convection is parameterized and cannot directly respond to aerosol perturbations.

However, results from limited area cloud resolving models show significant aerosol effects on deep convection: in the first cloud resolving model (CRM) intercomparison study with focus on aerosol effects on convective clouds, the Houston Deep Convective Cloud case study of the Aerosols, Clouds, Precipitation and Climate (ACPC) initiative, models consistently simulate the following effects for higher cloud condensation nuclei (CCN) concentrations: a slowdown of the warm rain formation in the warm base of deep convection with an associated increase in cloud water and a decrease in rain water; 5%-15% stronger updraft velocities; as well as a significant increase in upper tropospheric ice [Marinescu et al., 2021; van den Heever et al., 2022]. These results are consistent with our large-domain ICON CRM simulations over the north Atlantic [G. Dagan et al., 2020], also showing a significant increase in upper tropospheric ice with increasing cloud droplet numbers. Through idealised CRM simulations over the Amazon, using the ICON model with prescribed aerosol plumes based on MACv2-SP, we further demonstrate that also aerosol radiation interactions significantly influence the formation and development of convective cells: surface cooling below the smoke drives suppression of convection that increases with smoke optical depth, while the elevated heating promotes initial suppression and subsequent intensification of convection overnight with a corresponding diurnal response of high precipitation rates. Enhanced cloud droplet numbers perturb the bulk cloud properties and suppress low-to-moderate precipitation rates. Both aerosol-cloud and aerosol-radiation interactions result in enhanced high-altitude ice clouds that have a strong positive longwave radiative effect [Herbert et al., 2021]. While such limited area simulations provide detailed insights into the underlying physical processes and drivers, they neglect the coupling to the large-scale circulation and in particular the budgetary constraints on precipitation arising from the conservation of energy and water [Guy Dagan and Stier, 2020] and invoke the risk of the overall response being dominated by boundary conditions.

In this presentation we will show results from month-long global storm-resolving simulations including aerosol effects using ICON, transitioning the framework of idealised aerosol perturbations using the MACv2-SP plume model to the global scale. This provides a global assessment of aerosol effects on climate, including their effect on convective clouds. This idealised framework is easy to implement in global storm-resolving models, such as used in DYAMOND, and could serve as template for the assessment of aerosol effects in future global storm-resolving model intercomparison studies, such as proposed under the GEWEX Aerosol Precipitation (GAP) initiative.

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Climate changes in a global-storm resolving model

Timothy Merlis – Princeton University

We present analysis of the global-storm resolving model (GSRM) simulations of XSHiELD: eXperimental System for High-resolution prediction on Earth-to-Local Domains developed by the Geophysical Fluid Dynamics Laboratory. Year-long simulations of a control simulation and those with perturbed SST and carbon dioxide concentration are examined and compared to corresponding simulations with approximately 25-km horizontal resolution. With an eye toward synthesizing the effects of better resolving convective scales on the planetary scale, we examine small and large scales. On smaller scales, we assess measures of the spatial organization of convection and their connection to moist energetics. Key aspects of moist energetics, such as the outgoing longwave radiation, depend on the simulated cloud distribution. On large scales, we assess the simulated response of the Walker circulation and large-scale cloud radiative effects to warming. Here, we examine the sensitivity to horizontal resolution and integration length---a key challenge given the computational expense of GSRMs.

Convergence of Aqua-planet Experiments with Explicit Convection at resolution from 157 km up to 1.2km. How far are we from ITCZ convergence?

Angel Peinado Bravo – Max Planck Institute for Meteorology

General Circulation Models (GCMs), as used for current climate simulations, are meant to present the large-scale climate state properly. Nevertheless, they have shown persistent biases in large-scale features of the general circulation and basic climate statistics. One of those features is the Intertropical Convergence Zone (ITCZ), where the circulation is dominated by the vertical energy transport, which in GCMs is largely modeled by a parameterization of convection. Alternatively, convection can be explicitly resolved when the horizontal resolution is refined to a few kilometers as in global storm resolving models (GSRM). However, questions arise with these new models and technologies: Does the simulation of tropical circulations converge? How far do we need to refine the horizontal model resolution to obtain convergence of statistical climate characteristics of the ITCZ or a better representation of convection and the atmosphere?

The present study examines the convergence rate in time and grid spacing from 150km to 1.2km using ICON, a global storm resolving model, for different climate statistics on an aqua-planet. We use this configuration to reduce the effect of complex interaction with land, topography, sea ice, and seasons and focus our attention on the atmospheric phenomena, in particular and convection. This simplified setup allows to achieve robust statistics with relatively short integration and captures many features of the earth's atmosphere. Even with these simplifications, simulations of aqua-planets with different GCMs showed a divergent response in precipitation and clouds to external forcing (Stevens and Bony, 2013) and more recently confirmed by Retsch et al., (2019) for a single model when transforming to km-scale. We present the convergence behavior in different aspect of the ITCZ such as surface precipitation, jet position at 350 hPa and 850 hPa, cloud distribution, water and energy budget between others.

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EarthWorks

William Skamarock – National Center for Atmospheric Research

EarthWorks is a US National Science Foundation funded project to create an accelerator-enabled high-resolution km-scale coupled earth system model, based on the Community Earth System Model (CESM), capable of running at the cloud-permitting and ocean eddy-permitting resolution needed for exascale weather and climate applications. EarthWorks uses the Model for Prediction Across Scales (MPAS) atmosphere and ocean GPU-enabled dynamical cores, and it employs a single uniform horizontal geodesic mesh for atmosphere, ocean, and land surface model components. The use of a single horizontal mesh allows us to bypass much of the computational complexity arising from coupling models using different meshes, thus greatly simplifying the coupling technology and significantly reducing the coupling cost.

The GPU-enabled MPAS-Atmosphere dynamical core was developed as part of an ongoing project at NCAR with IBM, NVIDIA and the University of Wyoming and is running operationally at The Weather Company/IBM producing short-term global forecasts. The GPU-enabled version of the MPAS-ocean model has been constructed within a development effort led by the Department of Energy's Los Alamos National Laboratory. The atmosphere and ocean dynamical cores employ OpenACC directives to access GPU capabilities.

Our target horizontal cloud-permitting and ocean eddy-permitting global geodesic mesh has a cell spacing of 3.75 km and has approximately 42 million cells, and we will employ O(100) vertical levels in the atmospheric component – the most costly component in the coupled system. Our target simulation rate is 0.5 simulated years per day for the fully coupled system in 2025. Benchmarks of the GPU-enabled MPAS atmosphere model and the ocean model indicate that this throughput is potentially achievable on next-generation systems that are expected to be in place in 2025.

Currently, CPU versions of all the component models of the coupled system are running within the CESM framework, and both coupled and uncoupled (i.e., atmosphere only, atmosphere and land-surface only, ocean only) simulations have been completed at multiple resolutions. Work has begun on coupling the components and developing accelerator-enabled versions of the atmospheric physics (beginning with the Community Atmosphere Model (CAM6) physics) and other coupled components including the CICE sea ice model, the GLIMMER ice sheet model and CLM5 land model. We will discuss the motivation for this project, issues confronted so far, results to date pushing CESM-MPAS global resolution up to our target 3.75 km cell spacing, and development and testing plans for the near future. EarthWorks will be available as a fully documented open-source model at the end of this project.

Improving climate models using nudge-to-fine corrective machine learning

Christopher Bretherton – Allen Institute for Artificial Intelligence

Machine learning (ML) is used to correct the physical parameterizations of a real-geography coarse-grid global atmosphere model of grid spacing 25-200 km to make the model evolve more like a reference fine-grid global simulation. We run training simulations in which the temperature and humidity of the target coarse model are nudged to the reference on a 3-hour time scale. The nudging tendencies and downwelling surface radiative fluxes are learned as functions of column thermodynamic state, insolation, and terrain height. The learned tendencies are used in forecasts to correct the combined physical parameterization tendencies. We apply this 'nudge-to-fine' approach to the US operational weather forecast model FV3GFS, using two specified-SST configurations. In the first configuration, we train and test with a year-long global storm-resolving model (GSRM) with SSTs from 2020. Specifically, GFDL used their X-SHiELD configuration of FV3GFS (3 km horizontal grid spacing, 79 vertical levels), with AI2's diagnostics for inline coarse-graining to 25 km of outputs needed for the ML workflow. In the second configuration, we train and test a single ML scheme on four simulations with a 25 km grid and climatological seasonal cycles of SST offset -4 K, 0 K, 4 K and 8 K from the present climate. This is a computationally tractable pilot study for applying future multiyear GSRM simulations across multiple climates.

In both cases, the ML correction can bring seasonal-mean land precipitation patterns of 200 km baseline model simulations at least 15% closer to the reference fine-grid simulation. The stability and accuracy of the method on multiyear timescales depend somewhat on the random seeds used for the neural nets. Challenges and prospects for further improvement of this approach will be discussed.

Reference: Bretherton, C. S., B. Henn, A. Kwa, N. D. Brenowitz, O. Watt-Meyer, J. McGibbon, W. A. Perkins, S. K. Clark, and L. Harris, 2022: Correcting coarse-grid weather and climate models by machine learning from global storm-resolving simulations. J. Adv. Model. Earth. Syst. https://doi.org/10.1029/2021MS002794

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Progress with the Simple Cloud-Resolving E3SM Atmosphere Model

Peter Caldwell – LLNL

The Simple Cloud Resolving E3SM Atmosphere Model (SCREAM) is a new global atmosphere model designed for 3 km horizontal grid spacing. The main novelty of SCREAM is that it was written in C++ using the Kokkos library to work well on both GPU and CPU architectures. It also features a sophisticated cloud/turbulence scheme meant to handle the partially-resolved cloud dynamics expected at convection-permitting resolutions. This talk will describe progress finalizing the C++ model and results from a 40 day DYAMOND2 simulation performed with an F90 prototype of SCREAM.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Sensitivity of Mesoscale Convective System Tracking Algorithms to Detection Thresholds and Data Resolution: A Comparison Useful for High Resolution Model Analysis

Ross Dixon – University of Nebraska – Lincoln

Simulation of mesoscale convective systems (MCSs) in general circulations models (GCMs) is a challenge due to the importance of multiscale interactions between convective-scale dynamics, microphysics, and the large-scale environment. Global simulations are performed at a wide range of resolutions from relatively coarse resolutions (~50-200 km) to very high resolutions (< 5 km) and everything in between. We would like to be able to use these simulations to better understand how MCSs are represented in models, but first we need a framework to compare MCS identification across a wide range of scales. In this study we explore the sensitivity of a simple MCS detection and tracking algorithm to varying spatial and temporal resolutions of the input data, along with the thresholds that are used to detect potential MCSs. We begin with one month of NCEP merged 4-km resolution infrared brightness temperature data which is available every 30 minutes for the global tropics (30S-30N). This data was coarsened to spatial resolutions of 16 km and 32 km and temporal resolutions of 1 hour and 3 hours. MCS detection and tracking was then performed on the combinations of the three spatial resolutions and three temporal resolutions. This algorithm (based on Huang et al. (2019)) uses a simple area overlap method to track cloud clusters which are identified using three different size thresholds: small (> 5,000 km2), medium (> 25,000 km2), and large (> 60,000 km2).

For each of these sets of resolutions and thresholds the tracking and detection of MCSs is performed and MCS characteristics (number, distribution, size, duration, diurnal cycle, precipitation) are collected. We find that as the resolution of the dataset increases there are more MCSs detected, smaller and faster storms are represented, and non-precipitating clusters decreases.

The diurnal cycle of MCS initiation and growth is sensitive to choice of detection thresholds, but not to the resolution of the input data. We also explore the sensitivity of precipitation associated with MCSs to the resolution and thresholds using the GPM IMERG product. Finally, we apply the algorithm to the brightness temperatures output by three global DYAMOND GEOS simulations with resolutions of 3 km, 12 km, and 50 km. We show some preliminary results on the ability of this model at these three resolutions to properly produce the diurnal cycle of tropical MCS initiation and upscale growth.

Storm-resolving simulations with IFS-NEMO/FESOM in the NextGEMS project

Thomas Rackow, presented by Tobias Becker – European Centre for Medium-Range Weather Forecasts (ECMWF)

We give an overview of the global coupled storm-resolving simulations performed so far with IFSNEMO and IFS-FESOM2 for the H2020 Next Generation Earth Modelling Systems (NextGEMS) project. The project aims to build a new generation of eddy- and storm-resolving global coupled Earth System Models. Such models will constitute the substrate for prototype digital twins of Earth as envisioned in the EU's ambitious Destination Earth project.

NextGEMS relies on several model development cycles, in which the models are run and improved based on feedback from the analysis of successive runs. In an initial set of storm-resolving coupled simulations, the models were integrated for 75 days, starting in January 2020. ECMWF's Integrated Forecasting System (IFS) has been run at 9km and 4km global spatial resolution. The runs at 9km were performed with the deep convection parametrization, while at 4km, the IFS was run with and without the deep convection parametrization. So far, the underlying ocean models NEMO and FESOM2 were run on an eddy-permitting 0.25° resolution grid in a single-executable configuration with IFS. Based on the analysis by project partners during a Hackathon organised in October, several key issues were identified both in the runs with IFS, and in those run with the second storm-resolving coupled model developed in NextGEMS, ICON.

We will describe the model improvements made to IFS-NEMO/FESOM based on the lessons learned from the first runs, which will be included for the second round of simulations. These mainly consist in vastly improved conservation properties of the coupled model systems in terms of water and energy balance, which are crucial for longer climate integrations, and in a much more realistic representation of the snow and surface drag. The second round of NextGEMS simulations will also target eddy-resolving resolution in large parts of the global ocean (better than 8km) to resolve mesoscale eddies and leads in sea ice. This is thanks to a refactored FESOM2 ocean model code that allows for efficient coupled simulations in the single-executable context with IFS via hybrid parallelization with MPI and OpenMP.

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Toward the 220 m mesh global simulation with NICAM

Masaki Satoh – Atmosphere and Ocean Research Institute, The University of Tokyo

The highest resolution simulation with NICAM (Non-hydrostatic Icosahedral Atmospheric Model) was with a horizontal size of about 870 m (Miyamoto et al. 2013) using the K computer. Now, the allocation time of the supercomputer Fugaku for a global simulation with a mesh size of about 220 m (grid-division level 16; or GL16) is approved. We will conduct this simulation and show a preliminary result in this workshop. A global simulation with a global 220 m mesh run can be viewed as a global large-eddy simulation for deep convective clouds, and we expect that deep convections will be better captured globally.

Toward the global 220 m simulation, we conduct a stretched NICAM in which the mesh structure is transformed to obtain finer mesh intervals in the target region. The GL11 mesh configuration gives about a 3.5 km mesh size for the global quasi-uniform grid, while the mesh size can be as fine as 350 m by setting the stretch factor to 100 (the ratio between the maximum and the minimum grid sizes). This model is used for the collaboration analysis study involving numerical models and observation data over the Tokyo metropolitan area, called the ULTIMATE (ULTra-sIte for Measuring Atmosphere of Tokyo Metropolitan Environment) project (Satoh 2021). We evaluate cloud microphysics schemes of numerical models using extensive observation data in the Tokyo area. Using the dual-polarization Doppler weather radar operational by the Japan Meteorological Agency, we compared the stretch-NICAM result with that obtained by the observation. Because NICAM can be used as both global and regional models, we can immediately test globally using the scheme improved by the regional configuration with the stretched NICAM (Roh et al. 2020, Noda et al. 2021). We will use the present results to improve the cloud microphysics scheme tested on the global 220 m simulation.

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Poster Presentations

DT107 – GFDL X-SHiELD: A global storm-resolving model within a unified weather-climate modeling system

Lucas Harris – NOAA/GFDL, presented by Kai-Yuan Cheng – Princeton University

We have developed the eXperimental System for High-resolution prediction on Earth-to-Local Domains (X-SHiELD), a 3.25-km resolution FV3-based global storm resolving model. This model is a configuration of the unified SHiELD weather-to-subseasonal prediction system, which itself is the short-term component of the GFDL Seamless Modeling Suite, and interfaces with the NOAA Unified Forecast System. X-SHiELD uses explicit deep convection, an advanced six-category microphysical scheme, a prognostic TKE PBL scheme, and an interactive mixed-layer ocean. This model is designed to better understand the global characteristics of deep convection, its interactions with synoptic- and planetary-scale circulations and modes of variability, and how explicit convection affects surface-atmosphere interactions, cloud-radiation-precipitation interactions, and stratosphere-troposphere coupling. It is also useful for demonstrating the stability and accuracy of FV3, the SHiELD physical parameterizations, and our workflow for this difficult frontier problem; can serve as the foundation for OSSEs; and provides copious data for machine learning applications.

We have performed several year-long integrations of X-SHiELD with 2020's analyzed SSTs and also in warmed climates. We present basic simulation characteristics from these simulations. X-SHiELD reproduces observed circulations, variability, clouds, precipitation, convection, and radiation with good fidelity, although some cloud biases still persist. We are able to explore the fate of convectively-transported air from the deep tropics into the subtropics and beyond, including for the first time establishing the Lagrangian nature of the Hadley circulation. We are also able to investigate the geographical and annual distribution of intense and rotating convection cells. Simulations in warmed climates demonstrate the response of clouds and convection to increased CO_2 and SSTs. We discuss prospects for further use of these simulations and their value to the broader community.

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DT108 – Improvement of NICAM toward the achievement of global cloud-resolving climate simulations

Daisuke Takasuka – Japan Agency for Marine-Earth Science and Technology

Cloud-related processes such as convection and cloud-radiation interactions have large uncertainties in the climate system. One of powerful approaches that challenge this issue is a climate simulation with global cloud-resolving models (GCRM). Considering recent rapid advances in computational performance, climate modeling studies with GCRM (~ 5 km mesh) can be active in the near future. It is thus important to progress the further development and tuning of GCRM to make it more reliable for climate simulations where both climate mean states and disturbances are well reproduced.

In this study, we work on the improvement of NICAM (Nonhydrostatic Atmospheric ICosahedral Model) to be aimed at successful GCRM climate simulations. In particular, we focus on the cloud microphysics and turbulent processes, which can significantly affect cloud–moisture–circulation feedbacks, and examine the impacts of their improvement on mean states and disturbances. For this purpose, we conducted the three experiments; 1) with the cloud microphysics setting used for the HighResMIP climate simulation in which the radiation balance is valued (EX_MIP); 2) with the cloud microphysics setting optimized for MJO simulations (EX_MJO); and 3) with the intermediate microphysics setting between 1) and 2) and the turbulent diffusion scheme turned on around convective cores (EX_MIX). All the experiments were run at 14-km horizontal mesh with 38/78 vertical layers for 1 year from Jul. 1, 2004.

The comparison of annual mean precipitation suggests that EX_MIP has the double ITCZ structure over the Pacific in boreal fall and spring, whereas this bias disappears in EX_MJO and is reduced even in EX_MIX. In the mean radiation field, a large negative OLR bias is realized for EX_MJO, which is mitigated in EX_MIX. When the power spectra of tropical convection are compared, we find that more divergent (more rotational and low-frequency) types of convective disturbances are favored in EX_MIP (EX_MJO), and that EX_MIX can spontaneously reproduce both types in a good balance, including the MJO. These results indicate that the EX_MIX setting is directed toward a realistic simulation in terms of mean states and disturbances.

Based on the above insight, we will specify the key ingredients needed for GCRM climate simulations and conduct long-term experiments with around 5 km mesh. At this time, we have finished a one-year simulation at 3.5-km horizontal mesh and will show its results in the presentation.

DT109 – Improving the representation of convective precipitation in ECMWF's Integrated Forecasting System for the NextGEMS project

Tobias Becker – European Centre for Medium-Range Weather Forecasts

In the H2020 Next Generation Earth Modelling Systems (NextGEMS) project, we aim at building a new generation of eddy- and storm-resolving global coupled Earth System Models. At storm-resolving scales (1-9 km), deep convective systems are becoming at least partially resolved, which means that the parameterisation of deep convection can possibly be switched off. This has many potential benefits. For example, there is a stronger physical link between deep convection and the large-scale circulation, and results are less dependent on some hidden details in the parameterisations, and therefore easier to interpret.

However, to take advantage of these potential benefits, two main problems need to be overcome. The first problem is that at storm-resolving scales, explicit convection is triggered too late and too scarcely because subgrid-scale heterogeneity is not resolved and convective inhibition is thus too hard to overcome. The second problem is that at storm-resolving scales, the mixing of updrafts with their immediate environment is underestimated, as most of the scales on which the mixing happens are not resolved.

As a consequence of both of these problems, simulations with ECMWF's Integrated Forecasting System (IFS) performed for the NextGEMS project show that as soon as the parameterisation of deep convection is switched off, the characteristics of convective precipitation are strongly biased, in agreement with many past studies. Tropical deep convection is associated with too much convective instability, too high updraft buoyancy and too strong updraft velocities, resulting in too intense and too localised precipitation events that occur over land too late during the day. The large-scale pattern of mean precipitation is biased as well, particularly the amount of precipitation in the inter-tropical convergence zone is strongly overestimated.

Here we focus on the rain band over the tropical Pacific at 5°N, which is about twice as strong in the NextGEMS Cycle 1 IFS simulations compared to observations. We do a sensitivity study, testing how different assumptions in the moist physics schemes relevant to storm-resolving scales affect the results. For example, some of the parameters defined in the clouds and microphysics parameterisations assume that the convective updraft only covers a part of the grid cell, while we expect it to cover the whole grid scale at storm-resolving scales. We show that by choosing a setup that is more suitable for storm-resolving simulations, we can significantly improve the representation of convective precipitation in the IFS, both with respect to the intensity and the spatial pattern in the tropics.

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DT110 – Microphysics dependency on the reproducibility of the MJO in the NICAM DYAMOND 2 experiment

Tamaki Suematsu – RIKEN Center for Computational Science

Recent advances in computational power have enabled increase in model resolutions to include explicit formulations of cloud microphysics processes to a class of atmospheric models referred to as the global cloud-resolving models (GCRM). The elimination of convective parameterizations in GCRM, which was one of the largest sources of uncertainties in the simulated atmosphere, has made GCRMs powerful tools to realistically simulate and conduct detailed investigations of convective systems. However, considerable uncertainties remain in the formulations of cloud microphysics that neither observation nor theory can adequately constrain. To address these issues and provide a platform for intercomparison of GCRMs, the DYAMOND initiative was launched in 2017 as the first GCRM model intercomparison project. In this study, we present results from experiments conducted on NICAM for participation in the 2nd phase of the DYAMOND project, which targets the boreal winter season of 2020.

Following the DYAMOND2 protocol, 40-day integrations were run on NICAM at a horizontal resolution of 3.5 km with 78 vertical levels from Jan. 20, 2020. We conducted the integrations in two microphysics settings for comparison: one optimized for the reproducibility of the Madden-Julian Oscillation (MJO; MJO-tuned) in sub-seasonal integrations, and another optimized for longer integrations (highresMIP), which prioritizes the global energy balance. The integration period included an MJO event from late January 2020 to mid-February 2020.

The comparison of the simulation results between MJO-tuned and highresMIP microphysics settings revealed that although there is a systematic low bias of outgoing longwave radiation in the regions of upward motion in the tropics for both settings, they both successfully reproduce the eastward movement of the convective envelope of the MJO from over the Indian ocean to the dateline in the first 20 days of the integration. However, past the 20th day of the integration, locations of the convective activities of the two experiments start to diverge, and were maintained near the dateline, as in the observation, only for the MJO-tuned setting. The differences in the evolution of the MJO was related to the systematic differences in the convective systems reproduced between the two settings, in which the highresMIP setting was accompanied by more tropical depressions and MJO-tuned setting was accompanied by more sporadic convections. Analyses of the simulated mean states of the atmosphere in the two simulations suggested that these differences were attributed to differences in the partitioning of frozen hydrometeors, which in turn resulted in more statically stable and unstable mean tropospheric states for the highresMIP and MJO-tuned settings, respectively.

Our results revealed the sensitivity of the population of the convective systems to the microphysics settings in GCRM and indicated that careful assessment of microphysics settings is essential for reliable simulation of the atmosphere with GCRMs.

DT111 – Monsoon 2.0 – Kilometer-scale time slices of various background climates

Lukas Kluft – Max Planck Institute for Meteorology

The objective of the project “Monsoon 2.0” is to advance our understanding of extreme-weather changes under global warming. The Monsoon project is build around time-slice global storm-resolving simulations of the boreal-summer monsoon under different background climates.

The central component of "Monsoon 2.0" are cloud-resolving simulations (5 km grid) for different climate scenarios based on the Coupled Model Intercomparison Project Phase 6 (CMIP6). These mini-ensembles cover the full monsoon period (April–September) under different climate projections, or altered treatment of cloud microphysics. The CMIP6 dataset provides 3-hourly input fields for the sea-surface temperature (SST) and sea-ice concentration. The high temporal frequency of the boundary data allows us to capture the diurnal cycle of SST and thus its impact on deep convection and precipitation events. In total around 20 ensemble simulations have been performed.

In addition, we performed two simulations on a finer 2.5 km horizontal grid. These simulations aim to investigate the statistics of extreme precipitation events and are motivated by the severe floodings in South-West Germany and central China in July 2021. Both simulations are initialised using operational forecast data provided by the the European Centre for Medium-Range Weather Forecasts (ECMWF). Each simulations covers a simulation period of 20 days. The temporal proximity of the two flooding events allows us to compare different lead times in the prediction of both events. Thus, we want to elucidate the impact of initial and boundary conditions on the extreme events.

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DT112 – On the resolution dependence in GFDL AM4 model: from 50km to 6km

Pu Lin – Princeton University/GFDL

We performed a series of aqua-planet simulations using the GFDL AM4-MG2 model, varying horizontal resolutions from 50km to 6km. With an identical cumulus parameterization, the precipitation from the cumulus parameterization decreases with resolution, mostly from the deep plume. The global mean resolved precipitation increases with resolution, but the sensitivity on the resolution weakens and reverses sign regionally at the finer resolutions. It has been argued that the magnitude of the vertical velocity increases with resolution, which leads to stronger extremes and stronger means in the resolved precipitation. Contrarily, we found that the distribution of the resolved precipitation intensity in the deep tropics does not show a longer tail at the higher resolution when coarse-grained to the same grid. Instead, most of the resolved precipitation changes occur at the moderate intensity range. A robust sensitivity to horizontal resolution is found in the organization of the precipitation and associated circulation in the deep tropics. At the finer resolution, the “pop-corn” type precipitation is greatly reduced, and longitudinal extent of the convective system expands. Such change in the organization state is found in both resolved and parameterized convection.

DT113 – Plans and Prospects for an RHP in the United States: Creating a Regional “Digital Twin”

Tim Schneider – NCAR/RAL

Planning for a GEWEX Regional Hydroclimate Project (RHP) over the Contiguous United States (CONUS) continues apace. The mission of this ten-year effort is to understand and characterize the water, energy, and carbon cycles in the Anthropocene. This mission is being driven by a need for climate equity and justice and for tools to address water, food, energy, and ecosystems security in a changing future. Our goal is to become an “Initiating RHP” by the end of calendar year 2022.

A community of scientists has formed to develop a science plan. Four broad themes have emerged, thus far: closing the gap between models and observations; improving our tools to understand and address a changing hydroclimate; determining the water, energy, and carbon budgets at the surface with greater fidelity in a rapidly changing world; integrating the socio-economic, physical, and indigenous sciences. By filling-in the value chain that drives from data, to information, to knowledge, and finally to wisdom, a fifth emerging theme is that this project creates an opportunity to build a regional ‘digital twin’ of the CONUS. This is in alignment with WCRP Digital Earths Lighthouse Activity, and supports management, planning, and policy at various levels. All of this enables convergent science, which is needed to rise to the challenges of the Anthropocene. This talk will present the key elements of the dynamically evolving science plan, and provide an update on the status of the project.

DT114 – Small-scale precipitation objects in a global convection permitting model: its characteristics, impacts, and sensitivities to model choice

Christopher Terai – Lawrence Livermore National Laboratory

A recent growth in the number of modeling groups running global convection-resolving simulations allows a comparison of how clouds and convection are represented across models when subgrid parameterizations play a smaller role. As a submission to the DYAMOND2 model intercomparison, the U.S. Department of Energy’s Simple Cloud Resolving E3SM Atmosphere Model (SCREAM) project ran and submitted a forty-day hindcast simulation of January/February 2020. Despite several improvements seen in the precipitation compared to a traditional global climate model, SCREAM forms too many small-scale (less than 50km) precipitating objects over the Tropical oceans when compared with satellite retrievals. These precipitating objects, termed ‘popcorn rain,’ mainly form from clouds with high rain-to-cloud water ratios and with tops lower than 600 hPa.

We first present a set of analyses to characterize the clouds and processes that produce popcorn rain and examine its impacts on Tropical variability, circulation, and extreme precipitation intensity. Then we present a set of model experiments using the doubly-periodic capability of SCREAM to show how the frequency of popcorn rain responds to changes in microphysical and dynamical model parameter choices and discuss the advantages and disadvantages of potential fixes to the popcorn rain.

This work was conducted under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-831984

DT115 – Superiority of Global Storm Resolving Models for Daily and Sub-Daily Precipitation Statistics Confirmed

Hsi-Yen Ma – Lawrence Livermore National Laboratory

Daily and sub-daily precipitation statistics are investigated from three global model ensembles: (a) Global Storm Resolving Models (GSRMs) with typical horizontal resolutions of ~4 km, (b) “high”-resolution global models with typical resolutions of ~50 km and (c) “standard”-resolution global models with typical resolutions of ~100 km. Compared to two different observational products, GSRMs convincingly exhibit superior performance for statistics of more intense precipitation events including their diurnal cycle, spatial propagation and the amount contributed by intense precipitation, but not for statistics of weaker or shorter duration precipitation. Both high- and standard-resolution models fail to simulate the correct phase and amplitude of diurnal cycle of precipitation and the propagating convection in the Central US, but high-resolution models show relative improvement in the distribution of precipitation frequency and amount, especially for intense precipitation.

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DT117 – Tropical ice clouds assessment in Global Storm Resolving Model: methodology using ice water path as spectral variable

Maximilien Bolot – Princeton University

Tropical ice clouds play an important role in the energy balance of the tropical atmosphere, and the new generation of Global Storm Resolving Model (GSRM), with the capacity of globally resolving convective and mesoscale motions, promises to advance our understanding of these clouds.

This new generation of model also creates new opportunities for comparison with measurements since their horizontal resolution is comparable to that of active sensor measurements.

In the first part of this presentation, we argue for a methodology of comparison of model and observations using ice water path (IWP) as a spectral variable. The methodology bypasses the issue of cloud spatial variability and allows to assess the cloud

representation across a wide range of scales.
By aggregating model output and measurements in IWP – pressure space, spectral signatures can be obtained and compared.
To illustrate the methodology, we use the X-SHiELD experimental Cloud Resolving Model, developed at NOAA/GFDL, and observations based on 2C-ICE and DARDAR, with the addition of the 2B-FLXHR-LIDAR radiative transfer algorithm for the validation of broadband fluxes.
In the example of X-SHiELD, the methodology reveals biases of cloud top height in anvils, which point to deficiencies in the microphysics of cloud ice that are likely shared by other models using similar microphysics packages.
In the second part of the presentation, we apply the methodology to obtain the spectral signature of mass, vapor and ice fluxes in tropical cloud clusters. We show in particular that the combination of longwave cooling at the top of deep convection and heating in anvils drives a thermally reverse circulation in the tropical tropopause layer whose effects on troposphere to stratosphere transport is seasonally varying.

DT118 – West-WRF NRT Forecast Simulations

Nora Mascioli – University of California, San Diego

The Center for Western Weather and Water Extremes (CW3E) has developed an optimized version of the Weather Research and Forecasting model (WRF), named West-WRF, that is run in near-real-time (NRT) forecast mode in support of decision making and scientific research of extreme weather events over the Western U.S. West-WRF NRT is run daily with a 0000 UTC initialization from December through March, using a 9-km domain covering much of western North America and the eastern Pacific, and a 3-km domain covering California and offshore areas. West-WRF NRT provides gridded model forecasts, tailored for the representation of atmospheric rivers and western U.S. precipitation, out to 7 days for the 9-km domain and 5 days for the 3-km domain. CW3E runs a 200-member West-WRF ensemble at 9-km grid spacing daily during the winter season, which is constructed using two different global ensemble forecast models as input, 100 unique multi-physics combinations, and stochastic perturbations.
Performance of the West-WRF forecast products during the 2021-2022 season will be discussed, along with description and examples of West-WRF decision support tools produced by CW3E.

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DT119 – Anthropogenic aerosol perturbations in global storm-resolving simulations – Philipp Weiss – University of Oxford
Aerosols originate from natural processes, like dust storms or sea spray, but also from human ac- tivities, like biomass burning or fuel combustion. Despite their small size, aerosols strongly influence Earth's climate. Aerosols scatter and absorb radiation referred to as aerosol-radiation interactions but also modify the properties of clouds, as cloud droplets form on aerosol particles, referred to as aerosol-cloud interactions.[1, 2] Storm-resolving simulations allow us to examine long-standing ques- tions related to these interactions. Such simulations resolve atmospheric motions on scales of about 5 km and consequently represent important atmospheric processes like convective updrafts that were parameterized previously.[3]
Regional storm-resolving simulations revealed significant effects of aerosols on clouds and provided insights into the underlying processes and drivers. Dagan et al.[4] examined shallow and deep convective clouds over the Atlantic Ocean and found that an increase in the cloud droplet number concentration leads to an increase in the upper tropospheric ice and water vapor. Marinescu et al.[5] compared simulations of deep convective clouds over Houston and found that higher concentrations of cloud condensation nuclei are associated with stronger updraft velocities. Herbert et al.[6] examined the impact of biomass burning over the Amazon and found that smoke induces changes in the diurnal cycle of clouds and precipitation.
Our poster presents first results from global storm-resolving simulations with and without an- thropogenic aerosol perturbations. In contrast to regional simulations, global simulations include the coupling to large-scale circulation and in particular the budgetary constraints on precipitation due to the conservation of energy and water.[7] Our simulations are performed with the atmospheric model ICON[8] in which aerosol perturbations are represented with the plume model MACv2-SP.[9] The sea surface temperature and sea ice are prescribed. Our analysis includes 40 days in the biomass burning season from 22th August to 31st September 2020 and aims to understand how aerosol perturbations impact the energy budget, hydrological cycle, and large-scale circulation.[10]

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