Latsis Symposium 2019

High-Resolution Climate Modeling: Perspectives and Challenges

Abstracts

ETH Zürich, Rämistrasse 101, Zürich, Switzerland

21 – 23 August 2019

Poster

Adachi, Sachiho A.

Sachiho A. Adachi; Hirofumi Tomita

RIKEN, Japan

Characteristics of nonlinearity between mean state change and perturbation change

In this study, we investigate characteristics of nonlinearity between changes in mean state component and changes in deviation from the mean state (referred to as perturbation component), in regard to the downscaling method that considers only a part of components in a large-scale climate change. One of the effective tools for estimating future regional climate with high temporal-spatial resolution is dynamical downscaling method using a regional climate model (RCM). The dynamical downscaling method uses general circulation model (GCM) output as the boundary condition of an RCM. Although this is the most basic and conventional downscaling method, two disadvantages are pointed out. One is that RCM output takes over biases of GCM output; the other is that high computational costs are required, because long-term integration is necessary to ensure sufficient samples to discuss changes of climate. Alternative methods to the conventional method are pseudo-warming method and methods derived from it. These methods consider only the changes in the mean state component of a large-scale future climate change. This makes it possible to overcome the weaknesses of the conventional downscaling approach. Specifically, the pseudo-warming method has following advantages. (1) The model bias of GCM output can be reduced by using reanalysis data for present climate, (2) the long integration period is not necessary, and furthermore (3) the method can evaluate regional climate response to a certain experimental condition; that leads to an understanding of mechanism of regional climate change.
On the other hand, the pseudo-warming method assumes the same perturbation component between present and future climates. There are two concerns raised by the assumption. One is the significance of the future changes in the disturbance component. The changes in the disturbance component will have influences on regions where tropical and midlatitude cyclones are projected to change in the future climate. The other is the influence of nonlinearity between the mean state component and the perturbation component. Nonlinearity has been reported to work to suppress the precipitation increase associated with changes in the mean state component, particularly at heavy precipitation. The sensitivity experiment using RCM, such as the pseudo-warming method, is useful to extract the regional climate response to certain components in a large-scale climate change. Therefore, it is important to understand what features the non-linear effects have. In this study, we discuss the characteristics of non-linear effects between the changes in two components using output from downscaling experiments in western Japan.
Reference: Adachi et al., 2017, Nature Communications, doi:10.1038/s41467-017-02360-z

Oral

Ahrens, Bodo

Bodo Ahrens; Christopher Purr; Erwan Brisson

Goethe University Frankfurt am Main

Space-time dynamics of convective rain cells in climate change simulations

Convection permitting climate models (CPMs) agree on an increase in short-term heavy precipitation in the future. The increase in heavy hourly precipitation is often investigated as the scaling rate of high percentiles of precipitation with temperature. While daily scaling rates conform with the Clausius-Clapeyron rate, a variety of scaling rates has been reported in the literature depending on location and the respective percentile (e.g., Knist et al. 2018) for short term (e.g., hourly) precipitation. In order to understand this variety in precipitation-temperature scaling, we investigate the statistics of lifecycle characteristics of convective precipitation cells. We do this by applying a cell tracking algorithm to 5-min precipitation data of COSMO-CLM simulations covering the area of Central Europe.
Under the assumption of the RCP8.5 scenario, there is an increase in heavy precipitation events at the end of the century compared to present day conditions. While the number of all precipitating convective cells remains similar to present day numbers, there is a shift in the mean and maximum intensity from weak cells to strong cells. As a consequence, the number of heavily precipitating cells increases (+174% for cells with a mean intensity larger than 25 mm/h). The area of convective cells also increases while the frequency distribution of cell lifetime does not change.

Anders, Ivonne

Poster

Ivonne Anders; Nauman Khurshid Awan; Georg Pistotnik; Michael Hofstaetter

ZAMG, Vienna

Influence of spectral nudging on convection permitting simulations

Recent projects focusing on high resoluiton regional climate simulations (3 km and below) have opened a new field of research within the regional climate modelling (RCM) community. The convection permitting scales have been of particular interest for many research groups as convection remains an important phenomenon still not correctly represented in models even at such high resolutions.

Coppola et. al. 2018 suggest that in climate simulations the large scale fields departs significantly from the driving re-analysis even after a month. In former investigations on coarser resolutions at e.g. 25km or 10km we found that applying spectral nudging (Storch et al. 2008) significantly improved the representation of the observed large scale fields the same as for the resulting precipitation and near surface temperatur. the model results. Besides the conventional forcing of the regional climate model at its lateral boundaries, applying the spectral nudging technique means that inside the model area the model is forced to accept the analysis for large scales whereas it has no effect on the small scales.

Within the framework of CORDEX-FPS on convection a large number of European institution carry out regional climate model simulations for the past and the future covering the Alpine Region (as the mandatory domain) at very high spatial resolution of 3km. In the evaluation run (1999-2014) we applied spectral nudging in the first nesting step from the global reanalysis ERAinterim to 0.11° (~12 km) European domain. In the second nesting step from the forcing at 0.11° to the final resolution of 0.0275° (~3 km) for the Alpine Region we did not applied the nudging. In a second simulation chain we didn’t use spectral nudging for the first nest neither the second nesting step.

We will show simulation results for six special convective precipitation events in the past (between 2000-2018) investigating the different nesting strategies mentioned above in short simulations. Furthermore we will present first results of evaluation runs of the longer period with special focus on the resulting precipitation, temperature and radiation.

Arsouze, Thomas

Oral

Thomas Arsouze[1]; Miguel Castrillo[1]; Lionel Renault[2]; Mario Acosta[1]; Francisco Doblas-reyes[1]

[1] Barcelona Supercomputing Center; [2] Laboratoire d'Etudes en Géophysique et Océanographie Spatiale, Toulouse

A very-high resolution configuration of the EC-Earth climate model: focus on the role of mechanical air-sea interactions.

Global high resolution climate models have demonstrated that coarse horizontal atmospheric and oceanic resolution from typical climate models is a limiting factor to correctly reproduce climate mean state and variability, and recent publications highlight the need for increasing resolution for better simulating climatic processes such as El Nino Southern Oscillation (ENSO), the Gulf Stream and its interactions with the atmosphere or monsoon rainfalls, among many others. The Earth Science department of the Barcelona Supercomputing Center (BSC) has recently developed a coupled version of the EC-Earth 3.2 climate model at a groundbreaking resolution of about 15 km (EC-Earth3.2 UHR) for all the climate system components.

EC-Earth3.2 comprises three major components: the atmospheric model IFS (Integrated Forecasting System) Cy36r4, the ocean model NEMO 3.6, which also includes the LIM3 sea-ice model, and OASIS3 that couples the main components. The resolution of EC-Earth3.2 UHR has ~2M horizontal grid points points with 91 vertical levels for the atmospheric component (T1279L91) and ~13M horizontal points with 75 vertical levels for the oceanic model (ORCA12L75). Compared to standard climate simulations, the increase in horizontal and vertical resolution as well as a reduced time-step leads to an increase in computing resources by two orders of magnitude.

We proposed to run this EC-Earth UHR configuration in the framework of the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6, HighResMIP coordinated exercise). It offers a framework for building a large multi- model ensemble of high-resolution simulations with a low resolution counterpart. The production and analysis of this simulation is also defined as a deliverable of the PRIMAVERA European project (H2020).

Although generally much weaker than winds, surface oceanic currents effect on atmospheric stress influences both the atmosphere and the ocean (“current feedback”, referred as CFB). By reducing the energy input from the atmosphere to the ocean, the current feedback slows down the mean oceanic currents but also induces a dampening of the mesoscale activity by roughly 30% via an "eddy killing", i.e., a sink of energy from eddies to the atmosphere. It has been shown that such an interaction partly controls the dynamic of the Western Boundary Currents. Historically, CFB effect was generally not implemented in climate models because of the coarse resolution used.

We show here for the first time, using the EC-Earth UHR configuration where oceanic mesoscale activity is explicitly reproduced, an analysis at global scale and over a long time-range of the current-feedback on the global scale oceanic circulation and energy budget, as well as on atmospheric response.

Aschwanden, Mathias

Oral

Mathias Aschwanden[1]; Thomas Frölicher[1]; Stephen Griffies[2]

[1] University of Bern / Oeschger Centre for Climate Change Research (OCCR); [2] NOAA/GFDL

Modelling marine heatwaves using high resolution Earth system models

Marine heatwaves (MHWs) - prolonged periods of extreme warm ocean temperatures - have occurred in all ocean basins over the last few decades, with devastating impacts on marine ecosystems and cascading impacts on economies and societies. Earth system models suggest that MHWs will become more frequent and intense under future global warming. However, such projections are almost exclusively done with low resolution ocean models (typically 1°) that are too coarse to resolve mesoscale processes, which may affect sea surface temperature variability by altering local heat transport and atmosphere-ocean interactions.

Here we use simulations from three coupled climate models of the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) with different ocean grid resolution (CM2.6: 0.1°, CM2.5: 0.25° and CM2-1deg: 1°), but with the same atmospheric resolution (0.5°) to quantify the impact of ocean-grid resolution on the representation and changes of different MHW characteristics. For all of these models, we analyze daily sea surface temperature from a 200-year preindustrial control simulation and an 80-year global warming experiment with CO_2 increased by 1% per year. Preliminary results suggest that finer ocean resolution improves the representation of MHW duration and spatial extent as compared to observations, and generally leads to a reduced increase in MHW days and duration with global warming. Results of this study will provide further insight how MHWs form and evolve over time.

Ban, Nikolina

Keynote

Nikolina Ban[1]; Roman Brogli[1]; Laureline Hentgen[1]; Nico Kröner[1]; David Leutwyler[2]; Stefan Rüdisühli[1]; Christoph Schär[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] Max-Planck-Institute for Meteorology, Hamburg

Exploiting kilometer-scale resolution for climate change simulation over Europe

The increase in temperature leads to an overall intensification of the water cycle in a future climate, but it is still very uncertain how different components of the water cycle will change. The uncertainties are larger for highly variable precipitation, especially heavy short-term convective precipitation that can lead to potential hydrological impacts such as droughts, floods, erosion, landslides and debris flows. Conventional climate models are not suited to assess short-term heavy events due to the need to parameterize deep convection, but with recent advances in high-performance computing, it becomes feasible to run kilometer-scale climate simulations where convection is explicitly resolved.

Here we present decade-long convection-resolving climate change simulations at a horizontal resolution of 2.2 km on a computational domain with 1536x1536x60 grid points over Europe. Such computationally demanding simulations have become feasible with a COSMO (Consortium for Small-Scale Modeling) model version that runs entirely on Graphics Processing Units. We compare a present-day simulation driven by ERA-Interim reanalysis with the corresponding Pseudo-Global Warming (PGW) simulation to project climate change. The PGW simulation is driven by ERA-Interim reanalysis modified by the mean annual cycle of climate changes derived from a CMIP5 model. With this approach, resulting changes are due to large-scale warming of the atmosphere and due to slow-varying circulation changes.

In this presentation, we will compare different modeling approaches (convection-resolving versus convection-parameterizing), and discuss the effects on changes in the water cycle. We will show that heavy precipitation and water fluxes intensify with a warmer climate, but the rate of an intensification depends on the region investigated. We also discuss how a new analysis system based on a virtualization environment developed within the crCLIM project (Convection-resolving climate modeling on future supercomputing platforms; www.crclim.ch) can be used to investigate potential changes in the water cycle and extreme events at high spatial and temporal resolution.

Keynote

Bauer, Peter

Peter Bauer

ECMWF, Reading

European leadership in defining the future role of high-performance computing, big data handling and artificial intelligence in numerical

Weather and climate prediction are high-performance computing application with outstanding societal and economic impact ranging from the daily decision-making of citizens to that of civil services for emergency response, and from predicting weather drivers in food, agriculture and energy markets as well as for risk and loss management by insurances. With the apparent effects of global climate change, weather patterns are likely to change as well with unprecedented effects on extremes such as wind storms, flood, heat waves and droughts. Forecasts are based on millions of observations made every day around the globe and physically based numerical models that represent processes acting on scales from hundreds of metres to thousands of kilometres in the atmosphere, the ocean, the land surface and the cryosphere. Forecast production and product dissemination to users is always time critical and forecast output data volumes already reach petabytes per week.

Meeting the future requirements for forecast reliability and timeliness needs 100-1000 times bigger high-performance computing and data management resources than today – towards what's generally called 'exascale'. To meet these needs, the weather and climate prediction community is undergoing one of its biggest revolutions since its foundation in the early 20th century. This revolution encompasses a fundamental redesign of mathematical algorithms and numerical methods, the adaptation to new programming models, the implementation of dynamic and resilient workflows and the efficient post-processing and handling of big data. Due to these enormous computing and data challenges, artificial intelligence methods offer significant potential for gaining efficiency and for making optimal use of the generated information for European society.

The paper will give an overview of the challenges, but also present the emerging variety of possible solutions to numerical methods, programming models, data handling and workflows. A crucial achievement over the past five years has been the convergence of the weather, climate and computational science communities to address these challenges together.

Belusic, Danijel

Oral

Danijel Belusic; Fuxing Wang; Petter Lind; Heiner Körnich; David Segersson; Jorge H. Amorim

SMHI, Norrköping

Benefits of sub-kilometer dynamical downscaling for urban areas

Under the urban expansion and climate change, cities are facing a number of environmental problems such as extreme precipitation and flooding, heat waves and air pollution. Models at convection-permitting resolutions (1 - 4 km) can resolve urban areas and the appropriate treatment of urban areas is needed in these models. However, the heterogeneity of urban landscape occurs at even smaller scales and many users are interested in specific effects of different urban design solutions, such as green infrastructure, on local weather and climate.

Here we investigate the benefits and feasibility of using sub-kilometer resolution for urban modelling with different model configurations. The convection permitting climate model HCLIM-AROME, which is coupled with the SURFEX Town Energy Budget (TEB) model, is used to downscale ERA-Interim at a range of resolutions (3 km – 300 m) for the city of Stockholm. At the same time, SURFEX-TEB is run in offline mode at the resolution of 300 m, using lower-resolution HCLIM-AROME atmospheric forcing. This allows investigation of two effects: benefits of using high resolution for urban areas, and benefits of using the coupled atmospheric and surface model compared to the much less computationally expensive offline surface model. The multi-scale simulations are validated against various urban observations.

Berthou, Ségolène

Oral

Ségolène Berthou[1]; Elizabeth J. Kendon[1]; David P. Rowell[1]; Simon Tucker[1]; Rachel Stratton[1]; John Marsham[2]; Malcolm Roberts[1]; Catherine Senior[1]

[1] Met Office, Exeter; [2] University of Leeds

Enhanced future changes in wet and dry extremes over Africa at convection-permitting scale

African society is particularly vulnerable to climate change. The representation of convection in climate models has so far restricted our ability to accurately simulate African weather extremes, limiting climate change predictions. We will show results from climate change experiments with a convection-permitting (4.5km grid-spacing) model, for the first time over an Africa-wide domain (CP4A). The model realistically captures hourly rainfall characteristics, unlike coarser resolution models. We find that CP4A shows greater future increases in extreme 3-hourly precipitation compared to a convection-parameterised 25km model (R25) across much of Africa. CP4A also shows future increases in dry spell length during the wet season over western and central Africa, which are weaker or not apparent in R25. Here we provide a regional focus on the Sahel, showing that even in regions getting wetter in the future, intra-seasonal variability of rainfall increases in CP4A, unlike in R25. These differences appear to relate to the more realistic representation of convection in CP4A, and its response to increasing atmospheric moisture and stability. We conclude that, with the accurate representation of convection, projected changes in both wet and dry extremes over Africa may be more severe.

Bretherton, Christopher

Keynote

Christopher Bretherton[1]; Pornampei Narenpitak[1]; Marat Khairoutdinov[2]

[1] University of Washington, Seattle; [2] Stony Brook University

Is tropical cyclogenesis unexpectedly predictable?

A near-global cloud resolving model with 4 km horizontal grid spacing is used to simulate an aquaplanet with a zonally-symmetric SST that is maximum in the Northern Hemisphere, analogous to the east Pacific during September. At the north edge of the ITCZ, numerous tropical cyclones (TCs) are spontaneously produced.

By introducing small random humidity perturbations into the simulation at a particular time, we investigate the intrinsic predictability of tropical cyclogenesis in this idealized but realistic-looking multiscale system. TCs develop in nearly the same place in all three ensemble members until more than 10 days into the simulation, well after the precipitation and water vapor path have become decorrelated at small scales. Using a vorticity budget, we investigate the TC intensification process and why it seems unexpectedly insensitive to the stochastic nature of deep convection.

Brienen, Susanne

Poster

Susanne Brienen; Michael Haller; Barbara Früh

DWD, Offenbach

Analysis of convection-resolving COSMO-CLM simulations for Germany

The influence of climate change on the transport infrastructure is adressed in the German research project "Network of Experts - Adapting transport and infrastructure to climate change and extreme weather events". Temperature, precipitation and wind are key parameters. As information are required locally and the transport infrastructure is specifically vulnerable to extreme events, climate model output at high spatial and temporal resolution is needed. For this, we ran simulations with the regional climate model COSMO-CLM at 2.8 km grid spacing (convection permitting) for the area of Germany and for the time period 1971 -2100. The COSMO-CLM simulations were nested in 12km EURO-CORDEX runs with COSMO-CLM driven by ERA40/ERA-Interim and MIROC5 (RCP8.5 scenario). These high resolution simulations are further applied in the project to a statistical downscaling technique to generate a high resolution climate projection ensemble.

We analyze the RCM simulations regarding average and extreme conditions and with an additional focus on the added value compared to the forcing simulations at lower resolution. The area of interest is Germany and related river catchments and we use the HYRAS observational data sets, which are further developed in another part of the project, for evaluation.

Brogli, Roman

Poster

Roman Brogli; Silje Sørland; Nikolina Ban; Christoph Schär

ETH Zürich, Atmospheric and Climate Science

Are Pseudo-Global Warming Simulations Suitable to Assess Climate Change?

The climate in a regional hindcast simulation can be altered by modifying the lateral boundary conditions with expected future changes. Using such a modified simulation, the effect of future climate change can be assessed. This technique is known as the pseudo-global warming method. Pseudo-global warming simulations are gaining popularity in high-resolution climate modeling, as they can reduce the computational cost for climate projections. We present how well future climate change can be simulated by pseudo-global warming simulations. To achieve this, we run pseudo-global warming simulations at a coarse resolution of 0.44°, and compare to standard regional climate projections, driven by a global climate simulation. We show that daily precipitation statistics from standard climate projections are very accurately reproduced by pseudo-global warming simulations. Differences between different global climate models are clearly larger than between pseudo-global warming simulations and the associated standard climate projection. Our results suggest that pseudo-global warming simulations can readily be used to assess future climate change.

Keynote

Brown, Jed

Jed Brown

University of Colorado

Algorithms, architectures, and community for high-resolution climate modeling

Advances in hardware and algorithmic efficiency are enabling a push to higher resolution climate modeling, but also exposing fundamental challenges in simulation rate, convergence of coupled models, and sustainable community software development. While today's architectures and those on the horizon deliver unprecedented throughput and energy efficiency, latency improvements have not kept pace and have become a principal bottleneck to meeting operational and policy time constraints. We are also experiencing renewed diversity and heterogeneity in compute platforms, leading to uncertainty in performance portability. These challenges are compounded by increased competition for talent from industry and an environment in which software contributions are often overlooked in academic research circles. In this talk, we will investigate some promising algorithmic techniques for latency-limited scaling regimes, remaining open problems, and opportunities for increasing sustainability and agility in climate modeling communities

Bush, Mike

Poster

Mike Bush

Met Office, Exeter

The Met Office Unified Model/JULES Regional Atmosphere and Land (RAL) configurations: Developing a unified science configuration for

The Met Office Unified Model (UM) allows seamless forecasting on timescales relevant for short-range NWP right through to timescales relevant for climate applications.

Currently we have not been able to generate a single science configuration which performs effectively in both the mid-latitudes and tropics. Therefore we have two sub-versions known as RAL1-M for the mid-latitudes and RAL1-T for the tropics.

One of the major reasons why we need two configurations is that convection is sometimes very under-resolved in the UK in km scale models, particularly in the case of small, shallow showers. This can manifest itself as small showers initiating too late or not at all. In order to cope with this, RAL1-M has several aspects of its configuration to encourage the model fields to be less uniform and help convection initiate, namely stochastic perturbations and relatively weak turbulent mixing. Another difference is that RAL1-M uses the diagnostic Smith Cloud scheme whilst RAL1-T uses the prognostic cloud scheme PC2.

This talk will give an update on convective-scale regional atmosphere land (RAL) model development at the Met Office and around the UM partnership. We will report on progress on the goal of achieving a unified configuration and look ahead towards the next major developments of the model which include a scale aware convection parametrization suitable for models with grid spacings O(1-100km).

The ultimate aim is a common set of science that works well everywhere and on all timescales.

Poster

Castrillo, Miguel

Miguel Castrillo[1]; Mario Acosta[1]; Oriol Tinto[2]; Kim Serradell[1]

[1] Barcelona Supercomputing Center; [2] Barcelona Supercomputing Center, UAB

Driving Earth System Models to groundbreaking resolutions

Recent studies have established that the typical atmospheric and oceanic resolutions used for the CMIP5 coordinated exercise (Coupled Model Intercomparison Project, phase 5), i.e around 40km-150km globally, are a limiting factor to correctly reproduce the climate mean state and variability. BSC has developed a coupled version of the EC-Earth 3.2 climate model at a groundbreaking horizontal resolution of about 15km in each climate system component. In the atmosphere the horizontal domain is based on a spectral truncation of the atmospheric model (IFS) at T1279 (approx. 15 km globally, i.e. the highest resolution we can use with the standard IFS - higher resolutions would require e.g. nonhydrostatic parameterizations) together with 91 vertical levels. The ocean component (NEMO) is run on the so called ORCA12 tripolar (cartesian) grid at a horizontal resolution of about 1/12° (approximately 16 km), with 75 vertical levels, whose thickness increases from 1m below surface up to 500m in the deep ocean.

The HighResMIP coordinated exercise, as part of the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6), offers a framework for building a large multi-model ensemble of high resolution simulations with a low resolution counterpart following a common experimental protocol. This coordinated exercise will allow for identifying the robust benefits of increased model resolution based on multi-model ensemble simulations. BSC is following the HighResMIP protocol by running two twin 100-year simulations using this Very High Resolution configuration. These simulations will represent an extensive source of information for the writing of the next Assessment Report of the Intergovernmental Panel on Climate Change.

The increase in capability of Earth System Models (ESMs) is strongly linked to the amount of computing power, given that the spatial resolution used for global climate experimentation is a limiting factor to correctly reproduce climate mean state and variability. However, higher spatial resolutions require of new and High Performance Computing (HPC) platforms, where the improvement of the computational efficiency of the ESMs will be mandatory. In this context, deploying a new very high resolution configuration of a coupled ESM into a new and more powerful HPC cluster as MareNostrum IV is a challenging task, involving a technical expertise to optimise the computational performance of such a novel configuration. Within the ESiWACE EC H2020 project, the T1279-ORCA12 demonstrator was developed and ported to MareNostrum IV, being now use in production within the H2020 PRIMAVERA project and following the HighResMIP protocol as stated above.

As part of our interest in pushing forward the adoption of groundbreaking spatial resolutions in ESMs, BSC is working together with Mercator Océan in the deployment and assessment of extremely high resolution global grids running with the newest NEMO release (NEMO4). This effort will provide information on the major bottlenecks constraining its scalability, in order to address the ever-increasing demands of oceanic forecasting and facilitate the deployment of these configurations in the next years. Special focus is being put into 1/36º resolution, one of the demonstrators that will validate the work inside the IMMERSE EC H2020 project.

Chan, Steven

Oral

Steven Chan[1]; Segolene Berthou[2]; Giorgia Fosser[2]; Elizabeth Kendon[2]; Hayley Fowler[1]

[1] Newcastle University; [2] Met Office, Exeter

Recent developments in convection-permitting climate modelling at the UK Met Office

At the UK Met Office, climate change simulations at convection-permitting scale have recently been completed across a number of different regions: at 4km resolution for Africa, 2.2km for a pan-European domain and also a 12-member ensemble at 2.2km over the UK as part of the next set of UK climate projections (UKCP18).

Over Europe, the 2.2km projections also show an enhanced intensification of extremes at convection permitting scale compared to coarser resolution. There is evidence of a changing seasonality of hourly extremes. A relatively muted summer extreme change across Europe is found, which contrasts with the much larger autumn and winter increases. The most significant mean precipitation increases also occur during autumn and winter; whilst, a robust summer drying and warming signal is found for Northern Europe.

These results are from only one model, so it is not possible to estimate model uncertainty. As a step towards addressing this, UKCP18 is providing the first ensemble of convection-permitting climate simulations, allowing an initial exploration of uncertainties. Early work has looked at the occurrences of hot, cold and dry spells.

Chang, Hsin-I

Poster

Christopher Castro[1]; Ibrahim Hoteit[2]; Hsin-I Chang[1]; Raju Attada[2]; Thang Luong[2]

[1] University of Arizona; [2] King Abdullah University of Science and Technology

Extreme weather impact assessment in Saudi Arabia and operational to sub-seasonal forecasting

The Arabian Peninsula (AP) is an arid climate region but often experiences extreme rainfall events that cause numerous hazards, including heavy human and economic losses. Severe weather associated with convective thunderstorms is becoming more intense globally and in the AP. Severe weather impacts for operational and seasonal forecast concerns requires improved meteorological data at sub-daily time scale, necessary to resolve the effects of individual thunderstorms. The objective of this work is to perform extreme weather impact assessment for the Kingdom of Saudi Arabia. A retrospective 40-year regional climate model simulation will be performed using resolution regional climate model at convection-permitting horizontal grid spacing capable of explicitly resolving convective thunderstorms. Then an equivalent reforecast product at the sub-seasonal (3-4 week) timescale will be developed and applied during the time period of October to March, when the majority of severe weather in the Kingdom occurs. The methodological approaches will evaluate the forecast capability of existing operational numerical forecast models for short-term extreme events and seasonal forecast capability. There are likely specific ‘periods of forecast opportunity’ during the course of the active thunderstorm season when local climate in the AP has known and relatively strong ties to coupled ocean-atmosphere variability. We will identify such periods and assess the potential of extending the predictability of the system through data assimilation and stochastic sensitivity analysis. The proposed products will serve to inform severe weather impact assessment and potential for operational decision making.

Chang, Hsin-I

Oral

Hsin-I Chang[1]; Sujan Pal[2]; Christopher Castro[1]; Francina Dominguez[2]

[1] University of Arizona; [2] University of Illinois at Urbana-Champaign

Towards Improvement in Convective Precipitation Forecast in the Southwest United States using Convective-Permitting Regional Climate

Accurate regional and local scale seasonal climate forecast and its impact on water availability is important in many practical applications like agriculture, water resource planning, and long term decision making. Specific for the warm season, when convective activities are the dominant precipitation source, existing operational products, i.e. North American Multi-Model Ensemble (NMME), have lower forecasting skill in warm season precipitation than the cool season (Kirtman et al. 2014) due to the poor representation of convective precipitation. Convective precipitation has exhibited a significant increase in intensity during the last thirty years from increases in atmospheric moisture and instability, and mid-latitude atmospheric circulation is more amplified with more persistent blocking patterns. The warm season is therefore becoming more extreme.
To fully realize the potential in improving the simulation of convective precipitation, we dynamically downscaled NMME models using the Weather Research and Forecasting model (WRF) at a convective-permitting resolution. A decade long (2000-2010) dynamically downscaled WRF simulation is generated using global reanalysis of Climate Forecast System data (CFSR) as forcing data. Convection-permitting innermost domain is centered over the Southwest U.S., at the core of North American monsoon and covers the entire Colorado River Basins. In this study, we have shown the improvement of convection-permitting model product in representing mean and extreme precipitation climatology in both Upper and Lower Colorado basins, significantly improved from simulations at meso-β resolution. It is evident that use of regional climate model at convection-permitting scale adds value to better spatial and temporal representation of precipitation which is also consistent with previous studies (Prien et al. 2015, Liu et al. 2016). Hence it appears to be an important initial step towards seasonal to subseasonal (S2S) forecasting using downscaled product from global CFS forecast models.

Dobler, Andreas

Oral

Andreas Dobler; Cristian Lussana; Jan Erik Haugen

Norwegian Meteorological Institute

Using km-scale observations to evaluate convection permitting simulations for Norway – or vice versa?

Decadal convection permitting climate simulations for the Norwegian mainland show good performance when comparing them to gridded observation data at 1 km resolution. However, Norway has a considerable area where in-situ measurements are sparse or error-prone, and the interpolation of station data to a fine scale grid is challenging by itself. Hence, such an evaluation may yield uncertain or misleading results on the model performance.

In this presentation we want to show that despite clear biases in model precipitation at station locations, the model data can be combined with in-situ data to overcome the uneven station network over the Norwegian mainland. Although the evaluation in remote regions without station data is not directly possible, qualitative assessments indicate an improvement in the precipitation climatologies. For instance, for the wettest area in Norway located around the Ålfotbreen glacier in the south-west, the combined data provides a mean annual precipitation of more than 5700 mm. This agrees well with amounts indicated by measurements of snow accumulation length and drainage from river basins, while the purely observation based estimates are almost 2000 mm lower. Further, the observed (but not measured) increase of precipitation from the flat inland regions towards the more mountainous coastal areas over northern Norway is only reconstructed when combining both types of precipitation data. Using in-situ observations only, the gradient is not captured, due to a lack of observations at higher altitudes in this area.

Currently, there are indirect evaluation studies ongoing, where the combined data is used as forcing data for snow- and hydrological modeling. We plan to present results from these studies, which will provide further insight on possible improvements by combining in-situ observations and long-term convection permitting climate simulations.

Fita Borrell, Lluís

Poster

Lluís Fita Borrell[1]; Sophie Bastin[2]; Anna A. Sörensson[1]; Jan Ppolcher[3]

[1] Centro de Investigaciones del Mar y la Atmósfera (CIMA); [2] Laboratoire Atmosphères, Milieux, Observations Spatiales, Paris / IPSL, Paris; [3] Laboratoire de Météorologie Dynamique, Paris

Exploration of land-atmosphere interaction with CP climate simulations

The CORDEX FPS Alps experiment establishes a first-of-its-kind framework of international collaboration in regional climate dynamic downscaling experiments at cloud resolving resolution. Previous climate exercises, have usually not resolved explicitly different processes of the climate explicitly due to their coarser spatio-temporal resolution. The development of a climate exercise at the storm scale, more typical of the weather prediction studies, should enable for the first time, the analysis of some of these phenomena in terms of their impact and role in the regional or local modulation of the climate. We understand that the FPS is one of the first experiments which should enable the exploration of some of these processes.

In this study we focus on a series of phenomena of the land-atmosphere interaction which have not been previously deeply analysed in climate studies. Our primary interest is to study the impact of the heterogeneity of the surface fluxes on the development of convection during summer, while other subjects are the representation of katabatic/anabatic winds and the land/sea-breeze. The region of study is the Alps and Po valley area, using the outcomes of on-going ERA-Interim forced WRF model simulations from the CORDEX FPS Alps experiment being carried out by the IPSL. The study is a first attempt to analyse some of these different features in terms of: (1) if they are represented in the simulations, (2) explores if the resolution is high enough to capture them and (3) if the complexity of the physical parametrizations at the given resolution is high enough to enable their correct representation. Although begin an initial exploratory study, different observations (when available) are used to compare model results with measurements. When the desirable observations are not available, a climatological categorization of the phenomena from the simulations is provided. The analysis is completed with the study of the impact of the resolution by comparing the outcomes at the 2 domains (11 km and 3 km) being used at the experiment.

This study aims to explore, open and discuss the new opportunities that (should) arise from this first-of-its-kind climate exercises. Which land-atmosphere dynamics or other interactions can be expected to be properly resolved and which aspects are still required to be improved from the modelling community in order to properly represent and analyse the unresolved ones.

Früh, Barbara

Poster

Trang Van Pham[1]; Christian Steger[1]; Burkhardt Rockl[2]; Klaus Keuler[3]; Susanne Brienen[1]

[1] DWD, Offenbach; [2] Helmholtz-Zentrum Geesthacht; [3] Brandenburg University of Technology Cottbus-Senftenberg

ICON-CLM - a new regional climate model for the CLM-Community

On the 20th of January 2015, ICON replaced GME as the operational model for weather forecast at Deutscher Wetterdienst (DWD), and in December 2016, a domain with grid refinement for Europe (ICON-EU-Nest) within the global ICON replaced COSMO-EU for high-resolution forecasts on the European domain. In the second half of 2020, the Limited-Area-Mode of ICON (ICON-LAM) will replace the high resolution COSMO for the German domain and DWD will stop to use the COSMO model operationally after 15 years. This implies that the next unification of COSMO and COSMO-CLM (COSMO 6) will be the last one.
In order to have a state-of-art tool for climate applications for the upcoming years, the CLM-Community decided to develop a new regional climate model (ICON-CLM, ICLM) based on the limited-area mode of ICON (ICON-LAM). DWD started the development of ICON-CLM in the project ProWas (Projection Service for Waterways and Shipping) – a joint pilot program of several German Federal Agencies – to prepare a regular federal forecasting and projection service about the influence of climate change on coastal and waterway traffic. During the last 1.5 years several achievements have been reached in cooperation with the CLM-Community. A first version of ICON-CLM is now available and has already been integrated into the starter package (ICLM-SP). The technical infrastructure in the starter package, the evaluation routine and the test-suite were built in a way that they work very similar to respective package for COSMO-CLM. This should facilitate the transition to the new model for users of COSMO-CLM and enable them to use their existing scripts and programs in a very similar way. ICLM and ICLM-SP was installed and tested on different computer systems. Long term simulations were carried out and several configurations were tested. The test simulations reveal that this first version of ICON-CLM is already able to produce results with a bias in the same range as the latest version of COSMO-CLM. Thus, ICON-CLM shows great potential to replace COSMO-CLM in the medium term.

Fuhrer, Oliver

Keynote

Oliver Fuhrer[1]; Torsten Hoefler[2]; Xavier Lapillonne[1]; David Leutwyler[3]; Carlos Osuna[1]; Christoph Schär[4]; Thomas Schulthess[5]; Hannes Vogt[6]

[1] MeteoSwiss, Zürich; [2] ETH Zürich, Scalable Parallel Computing Lab; [3] Max-Planck-Institute for Meteorology, Hamburg; [4] ETH Zurich, Atmospheric and Climate Science; [5] ETH Zürich, Theoretical Physics; [6] CSCS, Lugano

What does it take to achieve global 1 km resolution climate simulations?

How far are we from achieving global cloud-resolving climate simulations on leadership supercomputers? We present results from an ultrahigh-resolution, non-hydrostatic regional climate model for a near-global setup running on Europe's largest supercomputer Piz Daint. In a large software effort, the code has been systematically adapted for architectures accelerated with graphics processing units (GPUs), that deliver the main fraction of the computing power of Piz Daint. Simulations at an average grid spacing of 0.93 km (1.9 km) achieve a simulation throughput of 0.043 (0.23) simulated years per day and an energy consumption of 596 MWh per simulated year.

Using this simulation as a performance baseline, we discuss implications and challenges on the road towards cloud-resolving, global climate simulations on future exascale supercomputers. It is argued that such simulations are within reach, but significant software challenges need to be addressed. Using the example of COSMO, we illustrate that current programming paradigms for implementing climate models are not a good fit for the rapidly evolving hardware landscape of high-performance computing and will need to be reconsidered.

Gentine, Pierre

Oral

Pierre Gentine

Columbia University, New York

Harvesting high-resolution data

We are witnessing a golden era in Earth observations and in the development of high-resolution simulations that are resolving many processes, such as deep clouds and turbulence (e.g., cloud-resolving models or direct numerical simulations). Those datasets can be used not only to inform the development of parameterizations but also to directly try and represent subgrid-scale processes. I will show such examples applied to cloud-resolving simulations and turbulent data. Then I will develop to show how one can still constrain the underlying physics (mass and energy conservation in particular) to yield a better predicting model that is both less data greedy and respects some key physical constraints.

Giorgetta, Marco

Poster

Marco Giorgetta; Monika Esch; Luis Kornblueh; Elisa Manzini

Max-Planck-Institute for Meteorology, Hamburg

The quasi-biennial oscillation in an idealized model of tropical convection

The question of how the quasi-biennial oscillation (QBO) responds to the warming climate so far could not be resolved on the basis of general circulation models. Some predict a shortening while others predict a lengthening of the QBO cycle. Suspected reasons for the diverging answers are the sensitivity of the QBO dynamics, especially of the simulated tropical wave spectra to the details of convection parameterizations as well as the uncertainty in the parameterized gravity waves drag. Therefore we develop a QBO experiment at convection permitting resolution so that no parameterizations are needed for convection or gravity wave drag, and the QBO can be simulated directly, relying on resolved waves and explicit convection. To this end, we use of the ICON spherical limited area model (SLAM), where the climate state is controlled by means of prescribed sea surface temperature fields and CO2 concentrations. In this setup specific QBO phases are initialized by a nudging procedure that is switched off after a specified period so that the wave meanflow interaction can be analyzed for the initially prescribed phase state as well as for the freely evolving phase. To test sensitivity to global warming, we contrast results from “current” climate and “+4K climate” simulations.

Glazer, Russell

Oral

Russell Glazer; Erika Coppola

ICTP, Trieste

Convection Permitting Lake-Coupled Simulations of the Lake Victoria Basin

The Lake Victoria Basin is home to largest freshwater lake (Lake Victoria; LV) in Africa and second largest in the world. Each year on the order of 1,000 fisherman are lost on LV during intense night-time thunderstorms. LV is an essential component of the local economy while at the same time being one of the most hazardous lakes in the world. Despite this, until recently, understanding of the processes contributing to heavy rainfall events was very limited. In this study we present the first 3 years of a 10-year (2005-2015) convection permitting (3km grid-spacing) simulation (CPS) of the Lake Victoria Basin using the RegCM version 4.7.0. A lake model is utilized in order to couple the lake regions with RegCM, which has been shown to be of great importance for simulating a realistic lake surface temperature (LST) over LV. The simulated LST from the CPS shows a general warm bias when comparing to ARC Lake observations, however the annual cycle of LST is well represented by the CPS. In the coarser simulation the LST has a large cool bias because of the absence of any lake coupling and this contributes to a large dry bias over LV. The CPS shows a much-improved seasonal rainfall pattern over LV, however there is a general overestimation of the rainfall by the CPS during the peaks in the rainy seasons (March-May; October-December). The CPS shows an improved ability to produce extreme rainfall (>100mm/day) over the western portion of the lake which is consistently found in satellite and in-situ observations. The distribution of rainrates over LV in the CPS is much closer to satellite derived rainfall observations compared to the coarse simulation, demonstrating the improvements made to the simulation of cloud microphysics processes when moving to convection permitting grid-spacing. Mesoscale circulations associated with the diurnal cycle over LV are an important driver of intense night-time thunderstorms. An analysis of the diurnal rainfall cycle over LV shows that the CPS well represents the timing of nocturnal rainfall over the lake which is associated with a strong landbreeze, however the daytime peak in rainfall over the land surrounding the lake is too early. An analysis of extreme nocturnal rainfall events over the lake in satellite observations shows a clear migration from the previous daytime peak in rainfall westward onto the lake during the night. This suggests a connection between extreme rainfall events at night and the preceding daytime peak in rainfall over land. In the CPS these daytime peaks over the land occur too early and the lakebreeze circulation appears weak compared to the nocturnal landbreeze which is very prominent. These simulations are being conducted in association with the Climate Extremes in the Lake Victoria Basin (ELVIC) CORDEX Flagship Pilot Study.

Glazer, Russell

Poster

Paolo Stocchi[1]; Emanuela Pichelli[2]; Jose Abraham Torres[2]; Erika Coppola[2]; Russell Glazer[2]; Filippo Giorgi[2]

[1] ENEA, Bologna / ICTP, Trieste; [2] ICTP, Trieste

Analysis of climatic simulations by RegCM4 at convection permitting scale

Recent advances in high−performance computing allowed a number of international groups to carry out very high resolution (<4 km) regional climate model experiments. The evaluation of these experiments have shown that an increase in RCM resolution and, in particular, at the convection-permitting (CP) scale, will lead to a better representation of the spatial and temporal characteristics of heavy precipitation events and climate extremes at medium and small scales.
Climate simulations at very high resolution have so far largely been limited to subcontinental domains and the number of regions for which these simulations have been evaluated are still rather limited.
Some Regional climate projects about the topic, also including climate projections, have been recently realized to make more robust conclusions on the added value of CP simulations to future climate projections.
Here, we present some CP climate simulations performed in the framework of the project CORDEX FPS on convection and the European Climate Prediction System (EUCP) project, using the non-hydrostatic version of the RegCM4 model. The simulations are carried out at 3km resolution over three different regions (Pan-Alpine, Central Europe, and South-East Europe). These simulations are driven by the ERA-Interim reanalysis for the period 2000–2009, and by the global climate model (GCM) HadGEM2-ES over three time slices each one of them covering a 10-year period: the historical (1996-2005), the near future (2041-2050) and the far future (2090-2099) under the RCP8.5 scenario.
The RegCM4 simulations driven by HadGEM2-ES (1996-2005) and ERA-Interim are evaluated against a wide range of validation data sets, including in-situ and satellite-based observation of precipitation; then changes in the future for the global climate model run are analyzed. Preliminary results show that the RegCM4 CP simulations are able to reproduce quite well the spatial distribution and the intensity of the precipitation field at the sub-daily scale. The small-scale spatial variability of precipitation is enhanced although the model performance can depend on the orographic morfology of the area.

Goergen, Klaus

Poster

Klaus Goergen[1]; Sophie Bastin[2]; Ben Bourgart[1]; Rita Margarida Cardoso[3]; Daniel Coquelin[1]; Andrey Martynov[4]; Jesus Fernandez[5]; Theodore M. Giannaros[6]; Øivind Hodnebrog[7]; Stergios Kartsios[8]; Eleni Katragkou[8]; Torge Lorenz[9]; Josipa Milovac[5]; Kirsten Warrach-Sagi[10]; Pedro Soares[3]; Stefan Sobolowski[9]; Heimo Truhetz[11]; Stefan Kollet[1]

[1] FZ Jülich; [2] Laboratoire Atmosphères, Milieux, Observations Spatiales; [3] Universidade de Lisboa; [4] University of Bern; [5] Universidad de Cantabria; [6] National Observatory of Athens; [7] CICERO, Oslo; [8] Aristotle University of Thessaloniki; [9] NORCE, Bergen; [10] Universität Hohenheim; [11] Universität Graz

Soil moisture-temperature coupling in a CORDEX FPS convection permitting WRF RCM ensemble

Concurrent with the ever-increasing capability of high performance computing (HPC) systems, convection-permitting regional climate model (RCMs) simulations have become more and more feasible, at the same time providing a comprehensive challenge to HPC-related technologies themselves. Such high-resolution regional climate models with a more detailed representation of heterogeneous land surface properties, as well as an explicit treatment of deep convection have shown a number of improvements in the simulation of meteorological processes and the climate system at the meso-gamma scale. Based on an ensemble of convection-permitting RCM evaluation simulations for a central European domain over the Alps, this study investigates results from the application of drought- and heatwave-related indices in the context of soil-moisture temperature coupling as part of the terrestrial segment of the land-atmosphere coupling. Analyses focus on: (i) The difference (not so much added value as we do not compare to observations) of the nested convection-permitting resolution 3km runs with reference to their 15km driving runs; and (ii) differences among 11 members of a multi-physics evaluation experiment. The higher resolution leads not only to different precipitation timings, distributions and amounts, the larger heterogeneity at the surface and subsurface, as well as the larger orographic variance lead, e.g., to altered terrestrial water cycle processes, which in turn affects the coupling. The RCM base data used in this study are from an unprecedented ERA-Interim driven evaluation experiment from 2000 to 2009 that is part of the WCRP CORDEX Flagship Pilot Study (FPS) "Convective phenomena at high resolution over Europe and the Mediterranean". Here we use 11 WRF ensemble members from 11 international FPS participant groups, as a subset of the overall FPS ensemble. The WRF models are run in a one way double-nesting setup, with a 15km European and a joint FPS 3km Alpine domain. To allow for a clear separation of cause and effect relationships, these runs were done in a highly constrained setup, using the same spinup, initial and boundary condition files and a common model configuration with systematically altered microphysics, boundary layer, surface layer, aerosol, and shallow cumulus convection schemes as well as different land surface models. Given the big data challenges associated with convection-permitting simulations' temporal and spatial resolutions, CMORized data is used from the joint data store of the FPS project at the Juelich Supercomputing Centre as part of the federated data infrastructure of the Helmholtz Data Federation, as a building block towards the European Open Science Cloud. For the first time, the data analysis is aided by an early adopter version of the newly developed Helmholtz Analytics Toolkit (HeAT), a distributed tensor framework in Python for high performance big data analytics. HeAT is built around PyTorch and can make full use of heterogeneous HPC system environments with CPUs and GPUs using OpenMP/MPI hybrid parallelism.

Gonzalez-Roji, Santos J.

Poster

Santos J. Gonzalez-Roji; Martina Messmer; Christoph C. Raible; Thomas F. Stocker

University of Bern, Oeschger Centre for Climate Change Research

Sensitivity of high-resolution precipitation and temperature to physics parameterization options in WRF over equatorial regions

East Africa and Western South America are regions of high heterogeneity and complexity in terms of precipitation patterns and climate variability. This complexity stems from regional and large-scale controls, such as topography, lakes and the influence of surrounding oceans. This has implications for precipitation and temperature and hence, water availability, biodiversity and ecosystem services. Thus, this study focuses on the impact of different physics parameterizations in high-resolution experiments performed with the Weather Research and Forecasting (WRF) model, and how these options affect the simulation of precipitation and temperature patterns in these two regions.

It is clear that weather and climate in tropical areas are influenced by physical processes different from those important for the mid-latitudes. Hence, it is crucial to obtain a large set of simulations that can be used to test the parameterizations available in the WRF model. Thus, several numerical downscaling experiments are run over Kenya and Peru nesting the WRF model inside a global data set generated by the Community Earth System Model (CESM). A cascade of increasing grid resolutions is used in the experiments. The innermost domains have a resolution of 3 and 1 km, and thus reach convection permitting scales. In these experiments the parameterization options of the planetary boundary layer (PBL), land surface and lake models, cumulus and microphysics schemes are also changed and their sensitivity to precipitation and temperature is tested.

Downscaled precipitation driven by the CESM simulation is strongly underestimated when adopting parameterizations in WRF typical for the mid-latitudes. However, preliminary results indicate that precipitation amounts and also patterns can be substantially improved with respect to the observed climatology when changing the cumulus and PBL parameterisations. A remarkable increase in the simulated precipitation is obtained when using the Kain-Fritsch and the Yonsei University schemes for cumulus and planetary boundary layer, respectively. During some summer months, an improvement of up to 100 mm (80 %) can be obtained in the accumulated precipitation in several regions of the domain.

The effect on temperature related to the physics parameterizations in the model is limited over Kenya and Peru and only small changes can be observed in both regions. The reason is that in contrast to precipitation, temperature is included in the initial and boundary conditions provided to WRF. Thus, temperature differences to observations are more strongly related to the driving data of the CESM global model.

Poster

Halenka, Tomas

Tomas Halenka; Jan Karlicky; Michal Belda; Peter Huszar; Tereza Novakova

Charles University in Prague

On the urban effects in high resolution regional climate simulations

The number of population living in the cities is growing and this is especially true for the largest ones, megacities. However, even smaller cities like the City of Prague (about 1.5 M) can suffer significantly and the night time temperature difference can achieve more than 5°C. To assess the impact of cities and urban structures on weather, climate and air-quality, modelling approach is commonly used and the inclusion of urban parameterization in land-surface interactions is of primary importance to capture the urban effects properly. This is especially important when going to higher resolution, which is common trend in operational weather forecast, air-quality prediction as well as regional climate modeling, and which is necessary for proper assessment of impacts in the cities and of the effectiveness of adaptation and mitigation options applied within cities. It is valid not only for extreme heat waves impact prediction, but as well in air-quality prediction and in long term perspective in connection to climate change impacts. This provides the background for the new project within Operational Program Prague - The Pole of Growth "Urbanization of weather forecast, air-quality and climate scenarios for Prague", shortly URBI PRAGENSI.

In the comparison of different urban parameterizations in WRF and RegCM we demonstrate the importance of urban models in the high resolution simulations, especially under conditions of heat waves. There are differences in the impacts of such parameterizations in different models, but basically all are able to capture the effects of urban heat island in these simulations, which can be quite significant and achieve up to about 8-10 °C difference between the city and its vicinity for large cities, in the City of Prague it can be more than 5°C during night time. More detailed analysis of the effects in terms of energy balance in the city and remote areas in high resolution simulations will be presented, as well as the impacts on other parameters, especially those connected to air-quality like mixing layer height, stability, etc.

Hall, Alex

Oral

Alex Hall

UCLA, Los Angeles

Why changes in extreme precipitation are different upon downscaling: a case study in California

We present results of downscaling of extreme atmospheric river events over California. Using the WRF model, we downscaled several dozen atmospheric river events corresponding to historical (end of the 20th century) and future (end of the 21st century) time periods. The large-scale forcing dataset was the Community Earth System Model Large Ensemble (LENS), which consists of 30 ensemble members initialized differently, and then forced by historical forcing and RCP8.5. The large-scale forcing dataset has a resolution of roughly 1 degree, while the WRF model was configured with a resolution of 3km. For both the historical and future periods, we selected the most extreme atmospheric river events in the entire LENS ensemble for downscaling. Thus the purpose of the experiments is to ascertain the effect of anthropogenic forcing on the most extreme atmospheric river events in the region. The future events are all associated with roughly a 30-50% increase in precipitation amount, with large variations across the region in the precipitation increase. The overall downscaled precipitation increase in WRF differs significantly from that simulated in LENS, and also has significant geographical structure. The overall precipitation increase in WRF is larger in part because of its enhanced resolution and the Clausius-Clapeyron relationship: High elevations capable of wringing out the extra moisture available in the atmospheric rivers of the warmer climate are resolved in WRF, but not in LENS. In addition, systematic changes in wind direction and speed and atmospheric stability in the future events in LENS lead to systematic changes in the intensity and geographical distribution of WRF's precipitation. Thus a combination of thermodynamical and dynamical effects must be invoked to explain the differences between the high resolution model solutions and those of the coarse-resolution forcing model.

Hart, Neil

Oral

Neil Hart[1]; Richard Washington[1]; Rachel Stratton[2]

[1] University of Oxford; [2] Met Office, Exeter

Why convective-permitting models are needed for simulating subtropical weather and climate

Tropical-extratropical interactions present a unique multi-scale problem to the simulation of rainfall in the subtropics. Over southern Africa, as across the Southern Hemisphere, upper-level westerly waves interact with deep convection to produce the subtropical convergence zones which dominate regional hydroclimates. These systems are often responsible for sub-daily rainfall extremes, as large-scale forcing supports the development of organised deep convection in semi-arid continental regions. The annual cycle of these tropical-extratropical cloud bands is a first order control on the timing and magnitude of rainfall during the wet season over southern Africa. Climate models typically struggle to represent the sub-daily rainfall extremes, the dynamics by which deep convection modifies the upper-level waves, and the correct annual cycle of these tropical-extratropical cloud bands in the region.

In this study, we present improvements in simulating this regional climate with a pan-African 4.5km convective-permitting model. First, the convective-permitting model overcomes large-scale mean state biases present in the parent global model. This improvement arises from increased upward mass flux in the tropics and stronger local Hadley overturning into subtropical southern Africa. This reduces upper-tropospheric meridional shear, thereby supporting the subtropical westerly wave propagation necessary for tropical-extratropical cloud bands. Additionally, increased subsidence reduces spurious convection responsible for the wet rainfall bias in the parent model. Together, these improvements result in an improved annual cycle over subtropical southern Africa. These improvements are pronounced in early to mid-summer but by late summer substantial rainfall biases emerge; we discuss some caveats and reasons for this departure of the simulation from observed reality.

Second, there are improvements in the synoptic-scale simulation of the tropical-extratropical interactions. The convective-permitting model improves coupling between the westerly waves and convection embedded in their leading edge. Organised convection thus has the potential to have an upscale impact on the propagation of these waves, diagnosed through modifications to the potential vorticity structures of these waves. We show that this is in part due to persistence and organization of convection during the afternoon, a feature lacking in a comparative simulation with a convection-parametrized model. In conclusion, the results presented in this study demonstrate that large-domain convective-permitting regional climate simulations in the subtropics are able to represent to the upscale impacts of convection often missing from parametrized simulations.

Heim, Christoph

Poster

Christoph Heim[1]; Davide Panosetti[1]; Linda Schlemmer[2]; Christoph Schär[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] Goethe University Frankfurt am Main

The Influence of the Resolution of Topography and Surface Fields on the Simulation of Orographic Moist Convection

Currently, major efforts are underway to refine the horizontal resolution of weather and climate models to kilometer-scale grid spacing (Δx). In addition to refining the representation of the atmospheric dynamics and enabling the use of explicit convection, this will also provide higher resolution in the representation of topography and surface fields. The current study investigates the influence of these resolution increments on the simulation of orographic moist convection. Nine days of fair-weather thermally-driven flow over the Alps are analyzed. Two sets of simulations run with the COSMO Model are compared, each consisting of three runs at Δx of 4.4, 2.2, and 1.1 km: one using a fixed representation of topography and surface fields at Δx of 4.4 km, and one with varying representation at the resolution of the computational mesh.

Higher resolution in the topography and surface fields results in the following changes: The total accumulated precipitation increases. The onset time of precipitation is delayed, it lasts longer and the amplitude of its diurnal peak is reduced. The spatial and temporal distribution of precipitation during day time is only marginally affected by the topographic details, but nighttime convection to the South of the Alps (triggered by cold-air outflow from the valleys) is very sensitive to topography and lasts longer. More generally, the individual convective cells are weaker and smaller, but their number increases. More shallow convection is observed together with a reduction in deep convective activity.

Hentgen, Laureline

Oral

Laureline Hentgen; Nikolina Ban; Christoph Schär

ETH Zurich, Atmospheric and Climate Science

Clouds in extended convection-resolving climate simulations over the tropical Atlantic

Trade-wind clouds are crucial for the Earth’s climate system, due to their large radiative effects and the feedbacks associated with the global energy and water cycles. Accurately representing such clouds and their mesoscale organization still poses a difficult challenge. As a consequence, the representation of low-level marine clouds is a major source of uncertainties in climate projections. Global climate models are run at grid spacings that are too coarse to explicitly capture cloud processes, and thus use cloud and convection parametrization schemes. The associated limitations are considered to be one of the main causes of uncertainties in equilibrium climate sensitivity and climate change.

Advances in high-performance computing now allow running high-resolution convection-resolving climate simulations over extended continental-scale domains with regional climate models. Following this state-of-the-art approach, we perform ten northern hemisphere winter simulations at 2.2 km horizontal grid spacing over a computational domain with 2303x1536x60 grid points covering the tropical Atlantic. The simulations are performed with an advanced version of the COSMO model that runs entirely on GPUs. Comparison of simulated clouds against satellite images shows that, contrary to convection-parameterizing simulations (12 km grid spacing), convection-resolving simulations capture remarkably well the spatial and temporal variability in trade-wind clouds. Validation against satellite data also shows that this significantly reduces biases in precipitation and radiation. Further, the relationship between organized shallow cumulus clouds and properties of the atmospheric boundary layer (such as pronounced low-level trade-wind inversions) appear well captured. Interannual variability of cloudiness is also evaluated. The study suggests that kilometer-scale climate simulations are promising tools to address key uncertainties in climate change.

Imamovic, Adel

Poster

Adel Imamovic[1]; David Leutwyler[2]; Linda Schlemmer[3]; Christoph Schär[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] Max-Planck-Institute for Meteorology, Hamburg; [3] DWD, Offenbach

Do springtime soil moisture anomalies matter for Midlatitude summer precipitation? Lessons from idealized and continental-scale climate

Observational evidence and theoretical considerations hint at a potentially important role of soil moisture anomalies for continental summer precipitation. A credible representation of soil moisture precipitation interactions within weather and climate models is therefore a potentially important link to improve daily, sub-seasonal and seasonal forecasts of deep-convective summer precipitation. Assessing the control of soil moisture on precipitation has remained a major challenge largely due to the uncertainties related to parameterized convection. The computational cost for a study with explicit convection has restricted many simulations to small domains or short time periods so far. Here we use a GPU-accelerated version of the regional climate model COSMO to assess the impact of springtime soil moisture anomalies on summer precipitation. The analysis encompasses entire continental Europe and 10 summers (JJA) between 1999 and 2008 laterally driven by ERA-Interim at a grid spacing of 2 km.

The coupling between soil moisture and precipitation is overall positive. The increase in rain amount with soil moisture however originates from an increase in precipitation intensity and less so by an increase in wet-hour frequency. In other words: moister soils lead to more intense summer precipitation and therefore to a larger rain amount. Companion simulations with lower resolution and parameterized convection also find a positive coupling, which albeit results from an increase in wet-hour frequency. Equally important, a systematically larger sensitivity to soil moisture anomalies is found, which points to an overestimation of the soil moisture precipitation coupling in models with parameterized convection.

In order to better identify regimes in which the soil moisture precipitation-feedback is particularly strong, we additionally run simulations with idealized surface fields. In these, we compare the sensitivities to a larger set of uniform and local soil moisture anomalies. Results suggest, that the sign of the soil moisture-precipitation feedback strongly turns negative in presence of soil moisture heterogeneities. However shallow orography of less than 500 m height are sufficient to neutralize the feedback.

Johansen，Hans

Oral

Hans Johansen

LBNL, Berkeley

Adaptive Mesh Refinement for Global Nonhydrostatic Atmospheric Simulations

We present a higher-order finite volume discretization for non-hydrostatic atmosphere dynamics on the cubed sphere. We use an implicit-explicit time discretization, where the horizontal dynamics are explicit, while the vertical non-hydrostatic system is treated implicitly. We pay careful attention to discretizations at cubed sphere boundaries and with vertical mappings, to preserve accuracy in both space and time. In addition, we have added higher-order adaptive mesh refinement (AMR), which allows us to run global calculations at a relative coarse resolution, while following dynamic features using much (often 16x or more) finer resolution. This presents several challenges with multi-resolution accuracy, and coupling to column physics at different scales in space-time. We demonstrate this with tracking tropical cyclones using a simple column physics model. We are also able to investigate the impact of orography on dynamic features, and show a few of the issues associated with typical coarse or smoothed treatments of the terrain. We have optimized the excessively complex algorithm to perform well on massively parallel systems with SIMD/SIMT architectures, using block-structured loop stencil calculations, batch-parallel implicit vertical solves, and overlapping computation with data movement where possible. Although it is not a production climate code, we are hoping to apply it as a research tool to evaluate sub-1 km physics interacting with global dynamics, for systems that would otherwise be infeasible to simulate.

Karger, Dirk Nikolaus

Poster

Dirk Nikolaus Karger; Niklaus E. Zimmermann

Swiss Federal Research Institute WSL

Bridging the gap – downscaling precipitation and temperatures to very high resolutions

Global circulation models (GCMs) nowadays operate at spatial scales close to 50 km resolution. For many applications this resolution is still to coarse, and especially ecological, agricultural, and hydrological studies are in need of higher resolution climate data. To bridge the gap between the coarse GCM resolution and the actual high resolution needed by many impact studies, statistical downscaling is often applied to GCM output in combination with interpolated observation data from climate stations. Here we present CHELSA (Climatologies at high resolution for the earth's land surface areas) algorithm developed for downscaling precipitation and temperature from GCM output to 1km using a combination of mechanistically derived predictors using model output statistics, remote sensing data, and observational correction from climatic stations. The temperature algorithm is based on statistical downscaling of atmospheric temperatures with the inclusion of solar radiation effects. The precipitation algorithm incorporates orographic predictors including wind fields, valley exposition, and boundary layer height, with a subsequent bias correction from climatic stations. We can show that data derived from the CHELSA algorithm compares well with similar standard gridded products and station data. We additionally compare the performance of the downscaled climate data in applied studies, especially in species distribution modelling and show that we can increase the accuracy of species range predictions. We further show that CHELSA climatological data has a similar accuracy as other products for temperature, but that its predictions of precipitation patterns are more realistic and can increase GCM performance by up to 20 %.

Katragkou, Eleni

Poster

Stergios Kartsios[1]; Andreas Prein[2]; Iris Presvelou[1]; Eleni Katragkou[1]

[1] Aristotle University of Thessaloniki; [2] NCAR, Boulder

Investigating biases in the regional climate simulation of WRF-AUTH in the framework of the CORDEX FPS on Convective phenomena at high

Advances in computer sciences and HPC infrastructures raised the opportunity for the climate community to exploit global and regional climate models at finer spatial and temporal resolutions. Convective-permitting regional climate simulations (CP-RCM) at kilometer scales are now possible, even though they are time consuming and require a significant amount of computational and storage resources. Evaluation studies designed to optimize model performance prior to execution of multi-year CP-RCM simulations are recommended, to ensure the best possible model performance at a minimum computational expense. The aim of this study is to evaluate the WRF-AUTH simulation participating in the ensemble of the CORDEX Flagship Pilot Study on convective phenomena at high resolution over Europe and the Mediterranean. We downscale the ERA-Interim driven 0.11 EURO-CORDEX simulations over the wider 0.03 Alpine region. We perform two seasonal-long runs (DJF 2004, JAS 2005) and evaluate them with different observational datasets (EOBS, EURO4M-APGD, MESAN reanalysis) focusing on temperature and precipitation. The magnitude of temperature bias is strongly dependent on the observational datasets. Compared to EOBS the temperature bias in the Alps ranges from -4.3 to 0.69 K in DJF 2004 and -0.9 to 2.9 K in JAS 2005, respectively (1st and 99th percentiles). Compared to the MESAN reanalysis, this range increases for both seasons (-5.0 to 1.6 K in DJF 2004 and -1.8 to 3.9 K in JAS 2005, respectively), with the largest errors located over mountainous areas collocated with the largest observational uncertainties. Precipitation biases depend on model resolution and seasonality, with the convection-permitting simulation having generally smaller biases. Discrepancies occur mostly in JAS 2005, where convection processes are dominant. This work was supported by computational time granted from the Greek Research and Technology Network (GRNET) in the National HPC facility - ARIS – under project ID PR003005 – COPERATE.

Kawase，Hiroaki

Keynote

Hiroaki Kawase

MRI-JMA, Japan

Future projection of snowfall and snow depth in Japan using non-hydrostatic regional climate model

The coastal areas of Sea of Japan receive a lot of snowfall in Japan. In winter, the cold air outbreaks frequently occur around Japan. The dry and cold northwesterly from the continent obtains a large amount of water vapor from the warm Sea of Japan, causing heavy snowfall along the Sea of Japan coast, which is the same as the sea effect of the Baltic Sea or the lake effect of Great Lakes in the US. In addition, the high mountain ranges in central Japan strengthen upward wind, known as the topographic effect, resulting in enormous snowfall over the mountains areas. During the cold air outbreaks, the small-scale convection over the Sea of Japan is important to simulate the snowfall over the Sea of Japan side regions. In addition, the horizontal distribution of snowfall and snow cover strongly depend on the complex Japanese mountains. Therefore, the high-resolution, i.e., convection-permitting, regional climate simulations are required to reproduce and project the snowfall and snow cover in Japan.

The non-hydrostatic regional climate model (NHRCM) was developed by Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA). The NHRCM is a non-hydrostatic model but uses the Kain-Fritsch cumulus convective parameterization when the horizontal resolution is coarser than 5 km grid spacing. The NHRCM runs as the convection-permitting model when its resolution is finer than 5 km. Our Japanese research group conducts the high-resolution simulations using the convection-permitting NHRCM and the large ensemble regional climate projections using NHRCM with 20 km grid spacing (NHRCM20). We evaluated the snowfall and snow cover simulated by NHRCM in the present climate and in the future climate.

The comparison of NHRCM with 2 km and 5 km grid spacing (NHRCM02 and NHRCM05, respectively) reveals that the NHRCM05, which is a non-convection-permitting model, cannot simulate the small-scale convection over Sea of Japan, resulting in not only the underestimation of snowfall over the ocean and coastal areas but also the overestimation of them over the mountainous areas. For the future climate projection, the NHRCM02 shows that the seasonal marches of snowfall and snow depth will change due to global warming. The large ensemble simulations of NHRCM20 indicated that the heavy snowfall can increase at the inland-area and mountainous areas in central Japan due to global warming. Finally, the highest-resolution simulations using NHRCM with 1 km grid spacing (NHRCM01) are performed over the limited areas and in the selected years. The NHRCM01 indicates that the accumulated snowfall during the winter will not decrease over the high Japanese mountains in the end of 21st century under the RCP8.5 scenario. The monthly snowfall in the mid-winter can increase due to global warming. These changes are clearer in the heavier snowfall years, which indicates that the interannual variation of mid-winter snowfall become large at the Japanese high mountainous areas in the future climate.

Knutti, Reto

Public Lecture

ETH Zürich, Atmospheric and Climate Science

Why do we need better climate models?

As our understanding improves, more observations become available, and computational capacity increases, climate models continue to increase in complexity to synthesize all that knowledge. The hope is that as more and more processes are considered at greater realism and higher resolution, the models will converge to reality. But are they really, how do we know, and indeed should they? What information do we need from these models? Are they built to understand processes, to quantify past changes, or to predict the future?

This public lecture, aimed also towards people outside the climate modeling field, will give an overview on climate change, the role of models to quantify past and future changes and to inform mitigation and adaptation decisions. It aims to give a broad perspective on the challenges and opportunities of the next generations of weather and climate models and their value to society.

Kotlarski, Sven

Poster

Sven Kotlarski; Andreas M. Fischer

MeteoSwiss, Zürich

The added value of high resolution climate modelling for climate services

The CH2018 Swiss climate scenarios have been released in November 2018 and will serve as a reference for climate impact studies and adaptation assessments in Switzerland. The CH2018 scenarios are based on the EURO-CORDEX simulation ensemble, combined with a bias adjustment exercise to produce daily scenarios at local scale. Half a year after publication, CH2018 is already widely used by the Swiss climate impacts community and first results regarding the impact of future climate change on different natural and socio-economic systems are already available.

However, user feedback also indicates that the present scenarios are limited to some extent and that certain user requirements cannot be fulfilled so far. These issues include (a) the non-availability of sub-daily scenarios, (b) the partly distorted inter-variable consistency, and (c) the high or unclear uncertainty of changes in extremes. In theory, the integration of high-resolution climate scenarios at convection permitting can be expected to improve on these aspects.

The present contribution will outline the mentioned issues in more detail and will seek to propose ways on how to integrate high-resolution climate scenarios into available scenario products.

Lenderink, Geert

Oral

Geert Lenderink[1]; Hylke de Vries[1]; Hayley Fowler[2]; Segolene Berthou[3]

[1] Royal Netherlands Meteorological Institute (KNMI); [2] University of Newcastle; [3] Met Office, Exeter

Evaluating rainfall statistics in convection-permitting simulations using a dew point temperature scaling framework

Temperature scaling is a popular tool to analyse sub-daily precipitation extremes in the context of a changing climate. In this method, sub-daily precipitation is paired with the 2m temperature, and dependencies on temperature are derived using a binning method or quantile regression. Here, we apply the method using dew point temperature, which is a direct measure of humidity near the surface, and circumvents problems with the approach in dry continental areas. Using dew point temperature, generally scaling rates at or beyond the Clausius-Clapeyron (CC) rate of 6-7% per degree are obtained. There is a debate in the literature on the relation between present-day derived scaling rates and long-term climate change, and the realism of super CC scaling. However, we do find evidence from both modelling results and long-term observed trends, that they are in fact related, but also that this may not be a trivial relation. One reason is that scaling mostly captures the thermodynamic response of precipitation extremes due to moisture increases, whereas large-scale circulation change, soil drying and lapse rate changes may affect long-term trends as well. Based on the relevance of scaling for climate change, we evaluated the scaling behaviour in convection-permitting climate simulations, and compared the results to high resolution hydrostatic climate runs. We find that the scaling behaviour is robust in convection-permitting model simulations, at least when results are aggregated to a scale of ±10x10 km. Two different convection-permitting models, HCLIM and UKMO_UM, showed very similar scaling behaviour for a re-analysis driven run. Scaling results in HCLIM for a GCM driven experiment for the present-day climate are very close to those for the re-analysis driven run. Even in an end of century climate run, with generally much dryer climate conditions in western Europe, results close to those for the control period are obtained. In contrast, scaling results in hydrostatic model simulations show a much wider variety of behaviour, which also appears to be reflected in the climate change response. Our conviction is therefore that in order to have faith in future climate projections of sub-daily precipitation extremes, models should be able to reproduce the observed scaling relations.

Keynote

Leung, L. Ruby

L. Ruby Leung

Pacific Northwest National Laboratory, Richland

Modeling Mesoscale Convective Systems and Their Large-Scale Environments

Mesoscale convective systems (MCSs) are responsible for ~60% of summer rainfall in the U. S. Great Plains and 50-60% of tropical rainfall globally. Deficiency in representing MCSs contributes significantly to climate model biases in simulating the precipitation and its diurnal variability over the central U.S. and tropical circulation, with important implications to modeling the regional and global water cycles. In the past decades, observed increases in springtime total and extreme rainfall in the central U.S. have been dominated by increased frequency and intensity of long-lasting MCSs. Understanding the environmental conditions producing long-lived MCSs is therefore a priority in determining how the characteristics of precipitation may change in the future. Regional and global variable resolution models are being used to perform convection permitting simulations of MCSs and their interactions with the large-scale environment. The large-scale and mesoscale ingredients identified from the simulations and analysis of CMIP5 models provide a framework for understanding and modeling the potential changes in MCSs and hydrometeorological extremes in the future.

Leutwyler, David

Poster

David Leutwyler[1]; Christoph Schär[2]

[1] Max-Planck-Institute for Meteorology, Hamburg; [2] ETH Zurich, Atmospheric and Climate Science

Barotropic Instability of a Cyclone Core at Kilometer-Scale Resolution

Secondary disturbances spawning frontal waves along the fronts of occluding mid-latitude low-pressure systems have been identified decades ago from satellite images and during field campaigns. After the FASTEX field campaign, research on this phenomenon had initially slowed down, as operational weather and climate simulations were generally unable to represent these instabilities explicitly. Today's flagship supercomputers allow performing simulations at kilometer-scale resolution on computational domains covering the entire lifecycle of synoptic-scale systems, enabling explicit representation of small-scale disturbances embedded in large-scale circulations.

We demonstrate these capabilities in two different types of kilometer-scale simulations. First, in a ten-day-long near-global simulation of an idealized moist baroclinic wave, performed at 1 km grid spacing and employing 16001x36006x60 grid points. Second in a real-case simulation of an extratropical low-pressure system, driven by ECMWF's operational analysis.

At kilometer-scale resolution, both simulation configurations display clear evidence of embedded meso-scale vortices spawning along frontal systems of mature extra-tropical cyclones. The vortices appearing in the real-case simulation can also be identified in satellite imagery of the same system. The simulated developments are due to a barotropic instability mechanism and driven by strong low-level horizontal wind shear. While the generates scales are in principle amenable at model resolutions around 10-50 km, the instability mechanism itself relies on the representation of a narrow shear zone, requiring about 5 times finer resolution. The simulations allow validating theory previously assessed with highly-idealized simulations of two-dimensional elongated potential vorticity strips in more complex simulation configurations and demonstrate that the flow regimes suppressing or fostering of barotropic vortices can co-exist in the same synoptic system. Far away from the cyclone core the instability is suppressed by the large-scale flow, while variations along the frontal structure allow the instability to develop near the cyclone core.

Lind, Petter

Oral

Petter Lind[1]; David Lindstedt[1]; Danijel Belusic[1]; Fuxing Wang[1]; Erik Kjellström[1]; Andreas Dobler[2]; Oskar Landgren[2]; Erika Toivonen[3]; Joni-Pekka Pietikäinen[3]; Rasmus A. Pedersen[4]; Ruth Mottram[4]; Dominic Matte[5]

[1] Swedish Meteorological and Hydrological Institute, Sweden; [2] Norwegian Meteorological Institute, Norway; [3] Finnish Meteorological Institute, Finland; [4] Danish Meteorological Institute, Denmark; [5] University of Copenhagen, Denmark

20-year simulations over the Nordic region with a convection-permitting climate model – benefits and added value of kilometer-scale resolution

Projected future climate changes in northern Europe are among the largest in the world, driven to a large extent by the strong positive feedback involving reduction of snow and ice as the climate warms. At the same time, northern Europe is in many respects a complex region with steep topography (the Scandinavian mountains), long coast-lines and a large number of lakes. Climatologically, the region is situated between different dominant climate regimes; the mild maritime North Atlantic and its storm track in the west and the dry Eurasian continental regime in the east. The large temperature contrasts between seasons are accompanied by low temperatures and widespread snow climate in winter and heat waves and intense convective rainfall in summer. Due to this complexity, uncertainties in future climate responses are in part related to the inability of coarser climate models to represent fine scale surface properties, land-sea contrasts as well as small scale atmospheric processes that frequently
occur in these environments such as convection and local wind systems. For example, the intensities of precipitation extremes are expected to increase as climate warms. However, there are indications that the rate of change may be stronger in models with kilometer-scale resolution compared to coarser climate models, the former generally representing convective processes more accurately. Furthermore, there has been an increased need for more detailed information from impact researchers, stakeholders and policy makers, for example for urban planning. However, so far there has been a scale gap between climate information provided by climate models and the needs of end users. In response to these challenges the Harmonie-Climate regional climate model (HCLIM-AROME) has been run at 3 km grid spacing over the Nordic region with boundary conditions from the global reanalysis product ERA-Interim covering years from 1997 to 2017. In this study we validate the performance of HCLIM-AROME with
particular focus to quantify the added value. The high model grid resolution combined with the extensive simulated time period which enables assessment on climatological time scales makes this study one of very few for this region.

Lindstedt, David

Poster

David Lindstedt[1]; Petter Lind[1]; Danijel Belusic[1]; Fuxing Wang[1]; Erik Kjellström[1]; Andreas Dobler[2]; Oskar Landgren[2]; Erika Toivonen[3]; Joni-Pekka Pietikäinen[3]; Rasmus Anker Pedersen[4]; Ruth Mottram[4]; Dominic Matte[5]

[1] Swedish Meteorological and Hydrological Institute, Sweden; [2] Norwegian Meteorological Institute, Norway; [3] Finnish Meteorological Institute, Finland; [4] Danish Meteorological Institute, Denmark; [5] University of Copenhagen

Validation of the snow climate in a regional climate model at 3 km grid spacing over Scandinavia

Observations of the northern hemisphere snow cover show that it has decreased over time. Both the length of the snow season and the maximum snow depth has generally decreased. Exceptions to this are found in some mountain regions including the Scandinavian mountains where significant trends are lacking. Projected future changes in the climate in northern Europe are among the largest in the world. The anticipated strong future warming is to a large extent connected to the positive feedback effect involving reduction in snow cover when the climate gets warmer. Uncertainties relating to how large this reduction will be relates partly to the inability of coarser scale climate models to properly represent properties of the snow climate in regions of complex topography like Scandinavia. In this study we evaluate the performance of a high-resolution regional climate model (RCM) with respect to simulated snow conditions over Scandinavia. The Harmonie-Climate model (HCLIM38-Arome) has been run at 3 km grid spacing with boundary conditions from the global reanalysis product ERA-Interim covering years from 1997 to 2017. The high resolution of the model allows for more detailed studies of the altitude-dependency of the simulated snow in mountain regions compared to global climate models or current state-of-the-art RCMs. It also allows for investigations of high-impact events including lake effect snow fall that frequently appears in the Baltic Sea region during winter. Several aspects of the snow climate are investigated and compared to observations: snow fall amount and fraction of precipitation that falls as snow, the length of the season with snow on the ground and the maximum snow depth. The long integration covering 20 years allows for evaluating the performance in reproducing interannual variability and long-term trends.

Lochbihler, Kai

Poster

Kai Lochbihler[1]; Geert Lenderink[1]; A. Pier Siebesma[2]

[1] Royal Netherlands Meteorological Institute (KNMI); [2] Delft University of Technology

Response of extreme precipitating cell structures to atmospheric warming

With increasing temperatures it is likely that precipitation extremes increase as well.
While, on larger spatial and longer temporal scales, the amplification of rainfall extremes often follows the Clausius-Clapeyron (CC) relation, it has been shown that local short-term convective precipitation extremes may well exceed the CC rate of around 6.5 %/K.
Most studies on this topic have focused exclusively on the intensity aspect while only few have examined (with contradictory results) how warmer and moister conditions modulate the spatial characteristics of convective precipitation extremes and how these connect to increased intensities.
Here, we study this relation by using a large eddy simulation (LES) model.
We simulate one diurnal cycle of heavy convective precipitation activity based on a realistic observation-based strongly forced case setup.
Systematically perturbed initial conditions of temperature and specific humidity enable an examination of the response of intensities and spatial characteristics of the precipitation field over an eight degree dew point temperature range.
We find that warmer and moister conditions result in an overall increase of both intensities and spatial extent of individual rain cells.
Colder conditions favor the development of many but smaller rain cells.
Under warmer conditions we find a reduced number of individual cells but their size significantly grows along with an increase of intensities over a large part of a rain cell.
Combined, these factors lead to larger and more intense rain cells that can produce up to almost 20 % more rain per degree warming, and therefore have a large impact.

Lüthi, Samuel

Poster

Samuel Lüthi[1]; Nikolina Ban[1]; Sven Kotlarski[2]; Christian Steger[1]; Christoph Schär[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] MeteoSwiss, Zürich

Alpine Snow Cover in Kilometer-Scale Climate Simulations

The recent development of high-resolution climate models offers a promising approach in improving the simulation of precipitation, clouds and temperature. However, higher grid spacing is also a promising feature to improve the simulation of snow cover as it allows to represent topography in more detail and to resolve convection explicitly. In this study we analyze the snow cover in a set of decade-long high-resolution climate simulation with horizontal grid spacing of 2.2 km over the greater Alpine region. We compare it against observations and lower resolution models (12 and 50 km), which use parameterization of convection. The simulations are integrated using the COSMO (Consortium for Small-Scale Modeling) model.

The validation of snow water equivalents (SWE) in the simulation of present-day climate driven by ERA-Interim, against an observational dataset, reveals that the high-resolution simulation clearly outperforms simulations with grid spacing of 12 and 50 km. These simulations underestimate the cumulative amount of SWE over the whole annual cycle by 33 % (12 km simulation) and 56% (50 km simulation) while the high-resolution simulation shows a difference smaller than 1 %.

Comparison of scenario simulations driven by GCM MPI-ESM-LR (2081-2090 RCP8.5 vs 1991-2000) reveals a strong decrease of SWE over Alps consistent with previous studies. Previous studies had found that the relative decrease becomes gradually smaller with elevation, but this finding was limited to low and intermediate altitudes (as a 12 km simulation is only capable resolving the topography up to ~2500 m asl). In the current study we find that the height gradient reverses sign, and relative reductions in snow cover increases above 3000 m asl, where important parts of the cryosphere can be found. This more pronounced decline emphasizes the value of the higher grid spacing. Overall, we show that high-resolution climate models offer a promising approach in improving the simulation of snow cover in Alpine terrain.

Manning, Colin

Oral

Colin Manning[1]; Elizabeth Kendon[2]; Hayley Fowler[1]; Ségolène Berthou[2]

[1] Newcastle University; [2] Met Office, Exeter

Does a convection permitting climate model improve the representation of wind gusts across Europe?

This study examines whether a high resolution convection permitting climate model (CPM) can improve the representation of extreme wind gusts which are found to be underestimated in low resolution climate models. This caveat raises issues in their ability to be used to assess the future risk posed by wind storms, as the potential wind damage associated to a given storm is largely driven by the 10m maximum wind gusts across a storm's footprint.

Wind gusts are driven by large-scale pressure gradients and small-scale convective processes. As climate models are generally run at a low resolution, these convective processes are parameterised leading to the oversimplification and misrepresentation of convection. Convective processes are better represented by CPMs which are run at a high enough resolution to explicitly resolve convection. It is therefore thought that this may also lead to better estimation of wind gusts.

We assess whether the CPM has an added value in its representation of extreme wind gusts. The CPM dynamically downscales ERA Interim reanalysis (ERAI) data to a 2.2km resolution over a European domain for the period 1998 – 2010. The added value of the CPM is determined from the CPM's departure from the driving reanalysis data and its comparison with observed wind gusts extracted from stations across Europe in the HadISD dataset. Between the datasets, we compare results from an extreme value analysis of wind extremes, including 10m wind speeds and wind gusts, throughout the CPM domain for the extended winter (October – March) and extended summer (April – September) seasons separately. This is accompanied by an event-based analysis where we compare storm characteristics, such as their overall severity, footprint and wind gusts within the storm as well as a comparison of their large-scale features such as pressure-gradients. Initial results indicate little difference between ERAI and CPM wind speeds in winter and that wind storms are well constrained by ERAI in the CPM. However, large differences between ERAI and the CPM can be found throughout Europe during summer, with the largest differences seen in parts of Southern Europe. This is likely due to the explicitly resolved convective processes in the CPM that are more prevalent during summer.

Oral

Martynov, Andrey

Andrey Martynov; Timothy Raupach; Olivia Martius

University of Bern/Oeschger Centre for Climate Change Research

Simulated hailstorms over Switzerland in May 2018 in current and future climate conditions

Several remarkable hailstorms have occurred on the territory of Switzerland during the month of May, 2018.

This period has been simulated, using the WRF4.0 model at a convection-permitting resolution (1.5 km), using different microphysical schemes (Thompson, Morrison, P3).
The surrogate climate change approach has been used for imitating the climate conditions, corresponding to the end of the 21st century (CMIP5 model data, RCP8.5 scenario).
The HAILCAST-1D model output has been used as a measure of simulated hail size and 5-minute 3-D radar reflectivity field has been used for cell identification and tracking.
Hailstorms produced in the current climate and in surrogate climate change simulations have been examined using neighborhood methods and a storm-tracking algorithm. Current-climate simulated hailstorms were compared with the ground observations and MeteoSwiss radar data.
The influence of microphysical schemes to the characteristics of simulated hailstorms has been studied.

Mass，Cliff

Oral

Cliff Mass

University of Washington

Ensemble-based High-Resolution Regional Climate Modeling

In regions such as the western U.S., complex terrain and land-water contrasts are dominant drivers of the regional climate. Thus, relatively coarse resolution GCMs are inadequate for determining the regional implications of climate change, with a large literature suggesting that a 12-15 km grid spacing or better is required for fidelity of the critical mesoscale circulations. Statistical downscaling, while useful, cannot deal with the non-linearities and complexity of climate change over the region and thus dynamical downscaling is required. Such dynamical downscaling is resource intensive and has typically done in a deterministic mode.

This present will present the results of an ensemble-based regional climate modeling effort, running the WRF model at 12-km grid spacing for a period of 130 years (1970-2100). A total of 12 downscaling runs have been made driven by the CMIP5 GCM simulations that showed the best synoptic fidelity over the region during a contemporary period. The necessity for careful attention to nesting domain structures will be discussed and some of the initial results of this ensemble downscaling will be presented. This will include a review of the variability among the downscaled runs and their fidelity over a contemporary period. This talk will also discuss some unexpected “climate surprises” made evident by a collection of high-resolution climate runs.

Meyer, Bettina

Oral

Bettina Meyer; Jan Olaf Mirko Härter; Olga Henneberg

Niels Bohr Institute, Copenhagen University

Cold pool collisions as a crucial forcing for convective triggering

New convective cells occur at increased likelihood near cold pool gust fronts – as was shown by observations and high-resolution simulations alike. However, pinning down whether this is due to single gust fronts or collisions of multiple ones is much less settled. Conceptual models show that this very distinction, single vs. multi-CP collisions, may be key to the character of the spatial organization of the resulting cloud and precipitation field.
This motivates the extension of convection parameterization schemes to include the effects of CPs, such as the spatial organization of the surface moisture field. For convection-resolving models (CRM), at resolutions of order 10km, this requires the coupling of neighboring grid cells. For such a nearest-neighbor approach it is important to understand whether convection is already enhanced at a single CP gust front – and if so, how strong such a CP has to be to show an effect – or only at the collision of multiple CPs. This very distinction may be translated into how many neighboring cells need to show CP activity in order to increase the convection likelihood.
To study these questions, we use idealized large-eddy simulations (LES). In order to disentangle thermodynamic and dynamic forcing effects of the CPs, we consider a purely dry setup, where moisture is only traced as a passive scalar. In this dry setup, the likelihood of triggering convection is assumed to scale with the height and strength of the updrafts, generated at the gust front of the CP. The simulations show that the more energetic the CP, i.e., the more initial energy is provided by rain evaporation, the more vigorous updrafts are generated. To understand this scaling in more detail, we study the energy budget of a conceptual model, consisting of three players: a cold air downburst determining the provided potential energy, a peripheral rotating torus and the updrafts generated in the ambient air in front of the CP. Preliminary results suggest that in such a model the division into linear and rotational motion, defined by the spreading velocity of the cold pool gust front and the rotational energy stored in the peripheral torus, is crucial.
A similar LES setup is used to study collisions between two to three CPs. These simulations show that the maximum vertical velocities resulting from CP collisions are up to a factor three higher than at an undisturbed CP front. The highest vertical velocities are found in two-CP collisions, however, updrafts that are generated in a three-CP collision extend higher up into the atmosphere. This may support the formation of deep convective events in contrast to shallow convection clouds that are often observed near single cold pool gust fronts.

Milovac, Josipa

Oral

Josipa Milovac[1]; Klaus Görgen[2]; Jesús Fernández[1]; Kirsten Warrach-Sagi[3]; Álvaro Lavín Gullón[1]; Joachim Ingwersen[3]; Volker Wulfmeyer[3]

[1] University of Cantabria; [2] Forschungszentrum Jülich; [3] University of Hohenheim (UHOH)

Sensitivity of a high-resolution RCM to land-surface forcing in representing land-atmosphere feedbacks

Continuous increase in computational resources allows for regional climate models (RCMs) to run at convection permitting (CP) scale, where deep convection is explicitly resolved and not parameterized. Convection parametrizations have a strong influence on precipitation uncertainty in coarser climate simulations, also increasing inter-model variability. Therefore, CP-RCMs are expected to better represent precipitation climatology, with special emphasis on extreme events related to convective processes. For the first time, a multi-model ensemble of such high-resolution RCMs over the Mediterranean is being produced within the framework of the international CORDEX - Flagship Pilot Study on Convective phenomena at high resolution over Europe and the Mediterranean (FPS-CEM).

As model resolution increases, accuracy and resolution of input information, such as land use and soil texture, become more important. Quality of these data may have a strong impact not only on surface fluxes, but also on the representation of boundary layer evolution and precipitation, which depends on the strength of the land-atmosphere coupling.

In this work, we used the Weather Research and Forecasting (WRF) model, where this static information is, by default, based on MODIS land use and FAO soil texture. We adapted higher resolution and up-to-date data sets for WRF, based on CORINE (at 100 m resolution) for land use and on HWSD and BÜK databases (at 1 km resolution) for top soil texture data. These new static data have been used by all WRF groups involved in the FPS-CEM.

We extended the case-study experimental design of the FPS-CEM (Coppola et al. 2018) to include the WRF sensitivity to these available static data. For this experiment, we generated two 8-member ensembles, one for a summer and one for a winter case. The two cases resemble the two test cases (Austria and Foehn case) conducted in climate mode (~1 month long). For each case, 4 simulations differing in combinations of the static data have been conducted twice, with different physical parameterization settings.

In this study we focus on representation of land-surface-atmosphere (LA) feedback processes over the Alpine domain on CP scale, and its sensitivity to (1) land-surface static forcing, (2) season, and (3) WRF configuration. To quantify the strength of LA coupling for each grid, we use coupling metrics appropriate for relatively short time scales, such as mixing diagram. Furthermore, we explore the impact of land-surface changes on the potential for convection and precipitation occurrence.

Mooney, Priscilla A.

Poster

Priscilla A. Mooney; Stefan Sobolowski

NORCE Norwegian Research Centre

Investigating the impact of anthropogenic land cover changes with a convection permitting model

Changing land cover from open landscapes to forestry is gaining traction as a viable government led action in Europe to reduce atmospheric CO2. In fact, pilot afforestation programs have already begun in parts of Norway. However, the impact of these anthropogenic changes to land cover on the regional climate is poorly understood, particularly at high latitudes. It is possible that such changes to the land cover could counteract the original intentions of the afforestation policy. For example, a study by de Noblet-Decoudre et al. (2012) has shown that impacts from land cover change on the regional climate can be as important as greenhouse gas forcings. This study examines the impact of land cover changes for afforestation purposes on the climate system at local and regional scales. ERA-Interim reanalysis data is downscaled to 3 km for the period 1996-2005 over Norway using the Weather Research and Forecasting (WRF) model. Two high-resolution 10-year regional climate simulations are performed which differ by land cover. The first simulation (CTRL) represents the land use and land cover of present day Norway while the second simulation transforms current open landscapes (e.g. grasslands) to evergreen forests. Comparisons between these simulations show the potential impacts of land cover changes on the local and regional climate due to afforestation.

Poster

Münnich, Matthias

Matthieu Leclair; Matthias Münnich; Nicolas Gruber

ETH Zurich

ROMSOC - A High-resolution Regional Earth System Model for Eastern Boundary Upwelling Systems

Eastern Boundary Upwelling Systems (EBUS) are regions of exceptionally high biological productivity, fueling a high percentage of global fisheries. Their marine ecosystems are particularly vulnerable to climate change because ocean temperature, stratication, pH and oxygen levels are all projected to change significantly posing multiple stressors for EBUS' marine life. The way these stressors will unfold in the future depends sensitively on how global climate change projects itself onto local weather. Of particular importance is the future evolution of upwelling, the primary mechanism determining the high productivity but also the high vulnerability of EBUS. The magnitude and shape of upwelling is determined by the alongshore wind stress, which is driven by large-scale gradients in sea-level pressure, but locally strongly modified by topography and local air-sea interactions. Especially important is the coastal wind drop-off within the first 50 km offshore, as this determines both the Ekman transport as well as the wind-stress curl driven upwelling. This drop off, which is poorly captured by even the most advanced atmospheric reanalysis projects, is also relevant for the oceanic mesoscale eddy activity and the regional circulation pattern. Thus, many elements that are of critical importance for determining how marine coastal ecosystems will evolve in the future depend on weather and climate processes occurring at scales of a few kilometers, i.e., at scales that are out of reach not only for current climate models but also those in the foreseeable future.
To address this challenge, we developed a high-resolution fully-coupled regional oceanatmosphere
marine biogeochemistry model to study how EBUS regions in the Pacific will evolve in the future, with a particular focus on marine extreme events. The oceanic part consists of the Regional Ocean Modelling System (ROMS) and the Biological Ecological Cycling (BEC) model. We employ the OASIS3-MCT coupler to couple this model to the nonhydrostatic COSMO regional atmosphere model widely used for numerical weather prediction. We call the resulting Regional Earth System Model by a fusion of its components ROMSOC. Our first simulations with this new model for the California Current System are promising. The near-shore wind drop-off is simulated more accurately than provided by current reanalysis products improving the quality of upwelling and the long-shore ocean currents. We will provide detailed evaluations of ROMSOC and an outlook of the first set of applications.

Nakano, Masuo

Poster

Masuo Nakano[1]; Hisashi Yashiro[2]; Chihiro Kodama[1]

[1] Japan Agency for Marine-Earth Science and Technology (JAMSTEC); [2] R-CCS/RIKEN

Single Precision in the Nonhydrostatic Icosahedral Atmospheric Model (NICAM)

Reducing the computational cost of weather and climate simulations would lower electric energy consumption. From the standpoint of reducing costs, the use of reduced precision arithmetic has become an active area of research. Here the impact of using single precision arithmetic on simulation accuracy is examined by conducting Jablonowski and Williamson's baroclinic wave tests using the dynamical core of a global fully compressible nonhydrostatic model. The model employs a finite volume method discretized on an icosahedral grid system and its mesh size is set to 220 km, 56 km, 14 km, and 3.5 km. When double precision arithmetic is fully replaced by single precision arithmetic, a spurious wavenumber-5 structure becomes dominant in both hemispheres, rather than the expected baroclinic wave growth only in the northern hemisphere. It was found that this spurious wave growth comes from errors in the calculation of grid cell geometrics. Therefore we performed an additional simulation using double precision for calculations that only need to be performed for model setup, including calculation of grid cell geometrics, and single precision everywhere else, meaning that all calculations performed each time step used single precision. In this case, the model successfully simulated the growth of the baroclinic wave with only small errors and a 46% reduction in runtime. These results suggest that the use of single precision arithmetic will allow significant reduction of computational costs in next-generation weather and climate simulations using a fully compressible nonhydrostatic global model with the finite volume method.
We will further examine the performance of the single precision model with full physics by aqua planet experiments. The result would be presented if the experiments went well.

Palmer, Tim

Keynote

Tim Palmer[1]; Jan Akmann[1]; Mat Chantry[1]; Peter Düben[2]; Sam Hatfield[1]; Milan Kloewer[1]; Andrew McRae[1]; Leo Saffin[1]

[1] University of Oxford; [2] ECMWF, Reading

Reduced precision for high resolution

For many modelling groups, it would be convenient if we could continue to run high-resolution climate models with default 64-bit precision. However, for the foreseeable future (i.e. even with exascale HPC) the use of double precision will prevent 1km resolution climate models being run over sufficiently long timescales for such models to be practically useful. However, even in principle, the stochastic parametrisation programme implies that global 64-bit precision is unnecessarily profligate. At ECMWF, global high-resolution integrations are now routinely run using 32-bit precision numerics. The question addressed in this talk is whether it is feasible that ultra high resolution climate models could be run with mostly 16-bit numerics. Results will be given of work on both the IFS dynamical core and IFS parametrisations, run using 16 bit emulators. It is concluded that 16-bit high resolution climate models are certainly conceivable, though there are good reasons to suppose that floating-point representations may not be ideal at these highly truncated precisions (and that so-called posits are preferable).

Pedersen, Rasmus Anker

Poster

Rasmus Anker Pedersen[1]; Danijel Belušić[2]; Ole B. Christensen[1]; Andreas Dobler[3]; Petter Lind[2]; David Lindstedt[2]; Erika Toivonen[4]; Fuxing Wang[2]

[1] Danish Meteorological Institute, Denmark; [2] Swedish Meteorological and Hydrological Institute, Sweden; [3] Norwegian Meteorological Institute, Norway; [4] Finnish Meteorological Institute, Finland

Future climate change in the Nordic region - new insights from a convection-permitting climate model

Kilometer-scale climate model simulations have been shown to provide added value compared to traditional, coarser regional model simulations. However, due to the high computational costs of running these models, they have rarely been used on climate time-scales. In a joint effort to provide improved projections of future climate change in the Nordic region, the meteorological institutes in Denmark, Finland, Norway, and Sweden have produced a set of simulations with a convection-permitting climate model. The small ensemble includes 20-year simulations of a historical control climate along with mid- and late 21st century projections based on the RCP8.5 scenario. The simulations are done using the Harmonie-Climate regional model (HCLIM-AROME) with non-hydrostatic physics at a 3 km resolution in a domain covering more than 5 million square kilometers.

The Nordic domain provides a versatile testbed for the model as it includes Arctic regions, mountain ranges, vast lakes, and flat coastal areas. The increased ability to represent small scale processes on the surface and in the atmosphere might impact the future projections of convective precipitation as well as local temperature, wind, and circulation patterns. This study will present a first look at the new future projection from HCLIM-AROME and how it compares to existing projections. We will assess if and where the potential added value from this kilometer-scale model translates into changed projections in the different parts of the Nordic region.

Prein, Andreas

Keynote

Andreas Prein[1]; Roy Rasmussen[1]; Die Wang[2]; Scott Giangrande[2]

[1] National Center for Atmospheric Research, Boulder; [2] Brookhaven National Laboratory

Simulating Organized Convective Storms in Climate Models

Mesoscale Convective Systems (MCSs) play an important role in earth's energy balance and are essential for the water cycle in the tropics and mid-latitudes. These systems are prolific rain producers and are the main cause of warm-season flooding. Observations showed that MCSs became more frequent, intense, and long-lived in the Central U.S. during the past 30 years. These changes are difficult to capture in state-of-the-art climate models due to misrepresentations of the complex MCS process interactions that operate across various orders of scales.

Convection-permitting climate models (CPCMs) substantially improve the representation of MCS properties such as their size, movement, and precipitation characteristics. However, CPCMs are operating in the gray-zone of turbulent motion and have known deficiencies in simulating small-scale processes (e.g., entrainment, updrafts). Here we use an ensemble of idealized MCS simulations to better understand the impacts of simulating in the gray-zone of convection. Our aim is to gain insights in convergence behaviors of MCS processes (e.g., draft characteristics, precipitation properties, and cold pool structures).

We use the Weather Research and Forecasting (WRF) model to simulate 10 idealized mid-latitude MCS cases in three atmospheric regimes: hydrostatic (12 km horizontal grid spacing; Δx), gray-zone (Δx = 4, 2, and 1 km), and large-eddy-scale (Δx = 500 and 250 m). We use observations from Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facilities (e.g., radar wind profilers, surface measurements, radiosondes) to derive observed MCS properties (e.g., up- and downdrafts) for model evaluation. Our results show that MCS properties such as the MCS movement, precipitation volume, and vertical mass flux can be captured in gray-zone simulations besides their poor representation of up- and downdraft properties. This is due to error-cancelation effects in gray-zone simulations. To understand the possible effects of these error-cancelations on climate change projections, we create a 10-member ensemble of end-of-century MCS cases and discuss the impacts of model resolution on MCS processes in future climate conditions.

Rüdisühli, Stefan

Poster

Stefan Rüdisühli[1]; Michael Sprenger[1]; David Leutwyler[2]; Christoph Schär[1]; Heini Wernli[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] Max-Planck-Institute for Meteorology, Hamburg

Attribution of Precipitation to Cyclones and Fronts Over Europe in a Kilometer-Scale Regional Climate Simulation

Precipitation over Europe is abundantly produced by cyclones and fronts. Frontal precipitation is typically a combination of stratiform and convective precipitation. Convection in turn plays an important role in the production of heavy precipitation that can result in flash floods. However, precipitation often occurs also at larger distances to the fronts and cyclones, and is often influenced by other factors such as topography.

Climatologically, cyclonic and frontal precipitation are commonly studied based on reanalyses with relatively low spatial resolutions and parameterized convection. Explicitly resolving deep convection, however, substantially improves the representation of convective precipitation. While for climate simulations, this is currently not feasible at global scales, new computational technologies such as GPUs have enabled kilometer-scale climate simulations at continental scale. We perform a detailed analysis of the climatological distribution of precipitation in relation to cyclones and fronts over Europe for the nine-year period 2000-2008, based on hourly output fields of a decadal kilometer-scale (2.2 km) model simulation with resolved deep convection, which has been conducted with a GPU-enabled version of the COSMO model.

We identify cyclones and fronts as two-dimensional features and track them over time. Our tracking algorithm is based on feature overlap and size and accounts for splitting and merging events. Cyclones are identified based on closed contours of geopotential height at 850 hPa enclosing up to three local minima, and subsequently tracked to exclude short-lived heat lows. Fronts are identified based on equivalent potential temperature gradients and wind at 850 hPa; we first detect cold- and warm-frontal regions, then track them separately, and finally categorize them based on track properties as synoptic (large and mobile) or local (small and/or stationary). To adequately capture convective precipitation away from fronts and cyclones, we additionally identify areas with simultaneously relatively high values and low gradients of geopotential height at 850 hPa. To assess the influence of cyclones and fronts on the precipitation distribution, we define seven mutually exclusive components based on the extent of, and/or distance to, these features: high-pressure/low-gradient (e.g., summer convection); cyclonic (cyclone center); concurrent (e.g., T-bone/occlusion area); cold- and warm-frontal; far-frontal; and residual.

We present a nine-year climatology of precipitation attributed to fronts and cyclones. High-pressure/low-gradient precipitation occurs almost exclusively over land and primarily in summer. Frontal precipitation peaks in winter, with larger warm-frontal and concurrent than cold-frontal contributions, especially over the North Atlantic; and it is lowest in summer, with mostly cold-frontal contributions over the continent. Cyclonic precipitation is largest over the North Atlantic (especially in summer), as well as over and around the northern Mediterranean Sea (except in summer). In the Mediterranean, precipitation peaks in fall and winter, mainly due to cyclonic, cold- and far-frontal, and residual contributions, along with some high-pressure/low-gradient precipitation in fall. Precipitation over the Alps is strongly enhanced

compared with most other areas, principally due to cold-frontal and residual contributions, as well as very large high-pressure/low-gradient contributions in summer.

Schär, Christoph

Poster

Christoph Schär[1]; Oliver Fuhrer[2]; Andrea Arteaga[2]; Nikolina Ban[1]; Christophe Charpilloz[1]; Salvatore Di Girolamo[3]; Laureline Hentgen[1]; Torsten Hoefler[3]; Xavier Lapillonne[2]; David Leutwyler[4]; Katherine Osterried[5]; Davide Panosetti[1]; Stefan Rüdisühli[1]; Linda Schlemmer[6]; Thomas Schulthess[7]; Michael Sprenger[1]; Stefano Ubbiali[7]; Heini Wernli[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] MeteoSwiss, Zurich; [3] ETH Zürich, Scalable Parallel Computing Lab; [4] MPI-Met, Hamburg; [5] ETH Zürich, C2SM; [6] DWD, Offenbach; [7] ETH Zurich, Theoretical Physics

Exploring kilometer-scale climate modelling strategies

Currently major efforts are underway towards refining the horizontal grid spacings of climate models to about 1 km, either by increasing the resolution of current GCMs, or by extending the computational domain of high-resolution RCMs. There is well-founded hope that this increase in resolution represents a quantum jump, as it enables replacing the parameterizations of moist convection and gravity-wave drag by explicit treatments. It is expected that this advance will improve the simulation of the water cycle and extreme events, and reduce uncertainties in climate projections. However, the development of such modeling strategies requires a concerted effort.
In exploring high-resolution climate models, we utilize an RCM that allows decade-long continental-scale simulations at 2 km resolution. The model employed is a version of the COSMO model that runs entirely on graphics processing units (GPUs). It is demonstrated that horizontal resolutions around 1 km enable the credible simulation of many mesoscale phenomena. Although cloud structures are not yet fully resolved, analyses suggest that there is convergence at grid resolutions around 2 km in a bulk sense.
On a technical level, it is argued that the output avalanche of high-resolution simulations will make it impractical or impossible to store the data. Rather, repeating the simulation and conducting online analyses may become more efficient. A prototype system of this type will be presented. An assessment will be provided of the potential of these novel approaches. The presentation is largely based on a paper that is currently in review with the Bulletin of the American Meteorological Society.

Schiemann, Reinhard

Poster

Reinhard Schiemann; Andrew G Turner; Ambrogio Volonté; Pier Luigi Vidale; Nicholas Klingaman; Benoît Vannière

National Centre for Atmospheric Science, University of Reading

COnective-Scale Modelling in China – forcings, variability, and upscale effects (COSMIC)

China receives most of its precipitation during the East Asian summer monsoon (EASM), a complex and inherently multiscale phenomenon that is difficult to represent in Global Climate Models (GCMs). In particular, the representation of moist convection has been singled out as the largest source of uncertainty for a range of phenomena in models where moist convection is parameterised, which is of obvious relevance to the warm-season EASM precipitation that dominates Chinese rainfall. In the COSMIC (COnective-Scale Modelling in China – forcings, variability, and upscale effects) project, the EASM will be evaluated in a recent set of global high-resolution simulations where the convective parameterisation is fully or partially disabled in the Hadley Centre climate model (HadGEM3). These simulations, which are multi-year at about 10km resolution and span 40 days at about 6km resolution, are of sufficient length to evaluate key aspects of EASM variability at diurnal-to-seasonal timescales. This poster will present an overview and early results of COSMIC. In particular, HadGEM3 simulations with different treatments of convection will be evaluated with regard to their ability to present the complex diurnal rainfall cycle over China including the near-midnight rainfall peak over the Tibetan Plateau and the late-afternoon peak over many parts of eastern and southern China.

Schlemmer, Linda

Poster

Ivan Bašták Duran[1]; Ritthik Bhattacharya[1]; Astrid Eichhorn-Müller[1]; Linda Schlemmer[2]; Anurose Theethai Jacob[1]; Jürg Schmidli[1]

[1] Institute for Atmospheric and Environmental Sciences, Goethe University Frankfurt; [2] Deutscher Wetterdienst, Hans Ertel Centre for Weather Research

The Atmospheric Boundary Layer in Numerical Weather Prediction

The atmospheric boundary layer (ABL) plays an important role in numerical weather prediction and climate simulations. Its structure and evolution have a strong impact on near-surface weather and climate. ABL processes, such as turbulence and coherent motions, for example, contribute to the formation and development of clouds and thunderstorms. They also largely control the exchange of momentum, heat, water and other constituents between the land surface and the free atmosphere. Small-scale orography leads to coherent motions in the complex-terrain ABL, such as thermally driven flows and internal gravity waves, which strongly impact surface drag and vertical transport. Many of these impacts are not adequately represented in current physics parameterizations. We address these topics with the following approaches:
A turbulence scheme with two prognostic energies (Bašták et al. 2018) has been developed and implemented in ICON. This parametrization enables the unified modelling of ABL turbulence and clouds. Its combination with the Assumed Probability-Density Function (APDF) (Larson and Golaz 2005) ensures consistency between turbulent fluxes and cloud-related quantities, which improves the representation of ABL clouds. The need to correctly simulate physical processes, at present and future model resolutions partly resolved and partly parametrized, calls for scale-aware parametrizations. The two-energies turbulence scheme is currently being extended to consider the grid resolution. The goal is to achieve a continuous transition between resolved and subgrid-scale transport across the convective (100 m-10 km horizontal resolution) and turbulence grey zone (100 m-1 km).
In addition to this parameterization effort in the grey-zone we make use of large-eddy simulations (LES) to gain deeper process understanding. We use high-resolution idealized LES to analyze the relationship between the organization of precipitating shallow cumulus convection and higher-order turbulence moments of moisture quantities, which could be used for future parametrization of cloud organization.
To gain further knowledge about the stable boundary layer, idealized LES and single-column model simulations are used to better understand the onset and breakup of fog. These simulations are also being used to understand and benchmark the behavior of the ABL and surface layer schemes of numerical weather prediction models in stable scenarios in comparison with LES.
To address the gravity-wave interaction with the stable boundary layer, an idealized direct numerical simulation (DNS) setup is exploited. DNS simulations provide an extension to LES simulations to very fine scales in cases where the validity of Monin-Obukhov similarity theory (non-homogeneous surface, stable stratification, potential intermittency) becomes questionable.
In order to validate the developed parameterizations, data from the upcoming FESSTVaL field camapaign will be used. Thereby, we will heavily rely on ground-based remote sensing systems such as coordinated LIDAR scans.

Bašták Ďurán, I., J. Geleyn, F. Váňa, J. Schmidli, and R. Brožková, 2018: A Turbulence Scheme with Two Prognostic Turbulence Energies. J. Atmos. Sci., 75, 3381–3402, https:

//doi.org/10.1175/JAS-D-18-0026.1

Larson, V. E. and J. Golaz, 2005: Using Probability Density Functions to Derive Consistent Closure Relationships among Higher-Order Moments. Mon. Wea. Rev., 133, 1023–1042, https://doi.org/10.1175/MWR2902.1

Schulthess, Thomas

Keynote

Thomas Schulthess

ETH Zurich

Bridging the Software and Performance Gap to Exascale for Weather and Climate

During the early 2020s, the fastest supercomputers will reach exaflops-scale performance. The most affordable exascale systems will be GPU accelerated with offerings from multiple vendors. At the same time, there are many open questions on how the programming models will evolve in the coming decade. In this talk I will discuss software strategies for weather and climate codes to take advantage of these new architectures. At the same time, we will look at strategies to overcome the performance gap for global simulations with 1km horizontal resolution and decent throughput.

Siebesma, Pier

Oral

Pier Siebesma[1]; Fredrik Jansson[2]; Gijs van den Oord[3]; Daan Crommelin[2]

[1] Delft University of Technology; [2] Centre for mathematics and informatics (CWI) Amsterdam; [3] Netherlands eScience Center

LES based regional superparameterisation of the marine subtropics

The Dutch Atmospheric Large Eddy Simulation (DALES) is used in ECMWF's OpenIFS global model to explore the representation of mesoscale variability of subtropical boundary layer clouds over the Atlantic Ocean near Barbados. By enabling this superparameterization only over a designated area it is possible use high-resolution local (DALES) model instances covering the full horizontal extent of the corresponding global model's columns.

This case the LES based superparameterizations can be viewed as a realistic benchmark for parameterized representation of clouds, convection and turbulence.
Shortcomings in this approach can therefore likely be attributed to the scale break introduced by the coupling between the superparameterized processes and the resolved dynamics of the global model.
Analyses shows that the superparameterized clouds and their liquid water content are systematically underestimated creating a "cloud fraction hole"
with unorganized shallow cumulus convection in the superparameterized region.
This lack of clouds is likely related to an underestimation of the humidity variability in the local model instances. The "cloud fraction hole" disappears and organised cloud structures appear if sufficient humidity
variability as dictated by the global model is added to the local model instances.
These results points in the direction that the exchange of variability between resolved and (super)parameterized scales is important missing mechanism for cloud formation and organisation.

Sobolowski, Stefan

Oral

Stefan Sobolowski[1]; Basile Poujol[2]; Segolene Berthou[3]; Steven Chan[3]; Torge Lorenz[1]

[1] NORCE, Bergen; [2] ENS, Paris; [3] Met Office, Exeter

Future precipitation changes over the Alpine region in a multi-model convection-permitting ensemble: a first look

Changes in precipitation at local regional scales in a warmer world remain highly uncertain. This is especially true of both moderate and high extremes (e.g. > 90%-iles and > 99.9%-iles, respectively). While a relationship between increasing model resolution and increasing precipitation (both means and extremes) appears to be present for both GCMs and RCMs there are conflicting results when convection-permitting scales are reached. These differences can be region and/or model dependent. A project under the auspices of the World Climate Research Program's (WCRP) Coordinated Regional Downscaling Experiments Flagship Pilot Studies program (CORDEX-FPS) was established to investigate these, and other issues. This initiative aims to build first-of-their-kind ensemble climate experiments of convection permitting models to investigate present and future convective processes and related extremes over Europe and the Mediterranean. In this presentation we offer a first look at the scenario simulations (RCP8.5 2090-99, timeslices) and an analysis of precipitation changes and their drivers over various sub-regions of a large domain, which cover the Alps, parts of central Europe and the Mediterranean and Adriatic coasts (0-17E x 40-50N). To maintain consistency and compatibility to earlier studies we first examine changes in percentiles, seasonality and wet day frequency before moving on to an investigation of changes in the full distribution using e.g. intensity-duration metrics. Finally we employ process-based metrics using vorticity and vertical velocity to split precipitation into stratiform, orographic and convective categories.

Sprenger, Michael

Poster

Michael Sprenger

ETH Zurich, Atmospheric and Climate Science

Lagrangian Perspective of Orographic Blocking

In Alpine mountain meteorology, orographic blocking is important because of its impact on: a) lee-cyclogenesis; b) the passage and modification of warm and cold fronts; c) the geographical distribution and intensity of (heavy) precipitation events. Traditionally, orographic blocking is studied with Eulerian methods based on the estimation of the inverse Froude number. Here we present a Lagrangian perspective of orographic blocking, and focus in particular on its impact on precipitation patterns.

Winds are taken from COSMO simulations with hourly temporal resolution and at a horizontal resolution of 7 km (covering the years 2000-2002) and, for single case studies, from 2-km COSMO simulations covering whole of Europe. Based on these winds, kinematic forward trajectories are started at a distance of 300 km all around the Alps and at 1500-m altitude. The 24-h trajectories are then investigated in their capability to surmount the Alpine barrier, separated into distinct flow categories, also defined in a Lagrangian way: westerly flow, northerly flow and southerly flow.

As a result a Lagrangian blocking index becomes available at an hourly resolution between 2000-2002, complemented by detailed case studies of orographic blocking at 2-km grid spacing. Composites of precipitation pattern are shown according to flow category and Lagrangian blocking index.

Poster

Steger, Christian

Christian Steger; Jesus Vergara-Temprado; Nikolina Ban; Christoph Schär

ETH Zurich, Atmospheric and Climate Science

Considering topographic effects on surface radiation in a kilometre-scale climate model simulation with a focus on snow cover

Snow is an important component of many mountainous regions as it influences the magnitude and timing of river runoff, causes natural hazards (avalanches) and is a crucial economical factor for areas that depend on winter tourism. In climate models, snow cover plays an important role through its control of near-surface temperature and its impact on the atmosphere through the snow-albedo feedback. Its representation in kilometre-scale climate simulations is, via an enhanced representation of hypsometry and precipitation patterns, considerably improved compared to coarser-scale simulations. Nonetheless, biases in snow cover duration (SCD) remain, as indicated by an evaluation of a COSMO simulation (~2 km) with satellite-derived snow-cover products (MODIS and AVHRR) for the European Alps. These biases reveal a clear dependence on slope aspect, where SCD is overestimated for south-facing grid cells and underestimated for north-facing cells. SCD is, among other factors, controlled by incoming short- and longwave radiation, which contribute to the surface energy balance. In areas with complex terrain, incoming surface radiation fluxes are heavily modulated by local and surrounding topography. Direct shortwave radiation depends on slope angle/aspect and the surrounding terrain, which might cause shadowing. Incoming diffuse long- and shortwave radiation depend upon the local skyview factor and backscattering from surrounding terrain might enhance incoming shortwave radiation. A likely cause for the SCD biases in complex terrain is thus the unaccounted influence of topography on incoming surface radiation. This influence is neglected in most state-of-the-art regional climate models (RCMs), which assume horizontal grid cell surfaces and no lateral influence on radiation fluxes. For simulations with intermediate grid spacing (> 10 km), the neglect is justified by the inability of the model to resolve typical length scales of valleys and mountain ridges. In high-resolution (~2 km) simulations, however, such features are at least partially resolved in the model topography.

To address the biases in SCD, a COSMO simulation with a scheme that corrects incoming surface radiation based on topography is conducted. Radiative fluxes are thereby modified according to local slope angle/aspect, shadowing due to surrounding terrain and the local sky view factor. Results indicate that SCD biases in complex terrain can be considerably reduced with this scheme. As the accurate representation of topographic features scales with horizontal grid-spacing of RCMs, it is expected that the benefits from such schemes will be even more pronounced in simulation with higher spatial resolutions.

Keynote

Stevens，Bjorn

Bjorn Stevens

Max-Planck-Institute for Meteorology, Hamburg

Next Generation Climate Models

Global storm (3-5 km) resolving models are opening new horizons in climate modeling. Results from the DYAMOND intercomparision project, and the German national project on High-Definition Clouds and Precipitation for Climate Prediction (HD(CP)2) are presented. Structural differences between these storm-resolving (and finer resolution) models and conventional climate models are highlighted, as are their convergence properties for clouds and precipitation. Simulations suggest that as non-hydrostatic scales of motion begin to become resolved the sensitivity of the models to resolution enters a different scaling regime. Precipitation processes are largely resolved on kilometric scales, but cloud processes remain sensitive to resolution down to hecto, or even finer scales. The latter strongly influences the energy balance and hence the coupling to the ocean. Despite the sensitivity of cloud processes to resolution at kilometer scales, it is demonstrated that rudimentary aspects of even shallow clouds are captured at storm-resolving scale. This heightens the prospects for representing crucial cloud processes at kilometer scales, and motivates a strategy, which if successful, will change the face of climate prediction.

Stucki, Peter

Poster

Peter Stucki[1]; Paul Froidevaux[1]; Marcelo Zamuriano[1]; Francesco Alessandro Isotta[2]; Martina Messmer[1]; Andrey Martynov[1]

[1] University of Bern; [2] MeteoSwiss, Zürich

Simulations of the 1876, 1910 and 2005 Vb cyclones over the Alps – Sensitivity to model physics and cyclonic moisture flux

In June 1876, June 1910 and August 2005, northern Switzerland was severely impacted by heavy precipitation and extreme floods. Although occurring in three different Centuries, all three events featured very similar precipitation patterns and an extra-tropical cyclone following a "Vb" trajectory around the Alps.

Going back in time from the recent to the historical cases, we explore the potential of dynamical downscaling the 20CR reanalysis from a grid size of 220 km to 3 km. We use the full 56-member ensemble provided in 20CR and the regional model WRF to investigate sensitivities of the simulated precipitation amounts to a set of model configurations. These setups differ in initialization period, physics schemes, or nudging, for instance. The best-performing setup is then applied to assess the sensitivity of simulated precipitation totals to cyclonic moisture flux.

The analyses show that in 20CR, cyclone fields and tracks are well defined in the ensemble for the 2005 and 1910 cases, while deviations increase for the 1876 case. In the downscaled ensemble, the accuracy of simulated precipitation totals is closely linked to the exact trajectory of the cyclone, with slight shifts producing erroneous precipitation. To reproduce the extreme events, continuous moisture fluxes of >200 kg m-1 s-1 from accurate directions are required.

To conclude, we discuss the applicability of the approach for complex historical weather situations such as Vb cyclones.

Sun，Fengpeng

Poster

Fengpeng Sun

University of Missouri, Kansas City

Investigation of Climatic Impacts of Urbanization in Kansas City Metropolitan Area and Mitigation Potentials

Climate change has become a great concern over recent decades, especially how humans have affected Earth's climate. In addition to anthropogenic greenhouse effect, humans in cities have affected local climate through urban heat islands (UHI). In order to reduce the UHI effect, multiple mitigation strategies have been suggested and researched. Cool roofs are one example of this type of strategy, applying a variety of materials in place of traditional roofing materials to increase the structure's albedo. They could potentially play an important role in reducing the anthropogenic impacts on climate in the future. This study uses the Kansas City metropolitan area as a testbed, and applies the high-resolution (1-km) Weather Research and Forecasting (WRF) model, coupled to the single-layer urban canopy model. It investigates Kansas City's current and future UHI and the effect of implementation of cool roofs in this region by a suit of sensitivity simulations, including a control, a scenario without urban land cover, and a scenario with widespread implementation of cool roofs for a baseline early-21st-century period and the end-of-21st-century period. The urbanization induced climate change is compared to greenhouse gas induced climate change, downscaled from global climate model projections. The effectiveness of potential cooling effects of solar reflective roofs to offset warming and mitigate urban heat island effects in the context of both urbanization and greenhouse gas induced climate change is further evaluated. Other climatic impacts of urbanization are also discussed.

Syktus, Jozef

Poster

Jozef Syktus

The University of Queensland

High-resolution Climate Change Projections for Queensland

A comprehensive set of high-resolution downscaled CMIP5 model climate change projections for Queensland region was competed to support the implementation of Queensland Climate Adaptation Strategy (C-CAS). Dynamical downscaling of selected 11 CMIP5 models was completed using variable resolution global climate model CCAM developed by CSIRO. Downscaling was performed following Hoffmann et al (2016) approach where monthly sea surface temperatures from global CMIP5 models were bias corrected for mean and variance and used to force the CCAM in AMIP style experimental setup.

Downscaling from global coarse resolution models was completed in two stages. In stage one 11 CMIP5 models were downscaled with CCAM to 50 km global uniform resolution for period 1950 to 2099. In stage two variable resolution CCAM stretched to 10 km over Queensland region was forced with 6 hourly data from 50 km CCAM simulations using 1D spectral filter (Thatcher & McGregor, 2008)). The high-resolution downscaling was completed for 11 CMIP5 models for period 1980-2099.

High-resolution data has been used to develop Queensland Future Climate data and information portal (https://www.longpaddock.qld.gov.au/qld-future-climate/) which consist of Future Climate Dashboard with extensive set of climate change projection data such as changes in mean climate, heat waves, precipitation and temperature based extreme indices and SPI based droughts and floods.

Presentation will focus on presenting key changes to the Queensland climate during the course of 21st Century with focus on rainfall changes and climate extremes. Comparison of high-resolution projections with coarse resolution CMIP5 modes and 50 km CCAM downscaled will be presented with focus on role of topography simulated climate change signal (Grose eta al., 2019).

Future plans for cloud resolving (~2.5 km) climate change projections for Queensland using variable resolution climate model will be also presented.

Grose MR, Syktus J, Thatcher M, Evans JP, Ji F, Rafter T, Remenyi T. (2019) The role of topography on projected rainfall change in mid-latitude mountain regions, Climate Dynamics, doi: 10.1007/s00382-019-04736-x

Hoffmann, P., Katzfey, J. J., McGregor, J. L., Thatcher, M. (2016). Bias and variance correction of sea surface temperatures used for dynamical downscaling. Journal of Geophysical Research: Atmospheres, 121(21).

Thatcher M., & McGregor J.L. (2008) Using a Scale-Selective Filter for Dynamical Downscaling with the Conformal Cubic Atmospheric Model. Monthly Weather Review, 137, 1742-1752

Tomassini, Lorenzo

Oral

Lorenzo Tomassini[1]; Rachel Honnert[2]; Georgios Efstathiou[3]; Adrian Lock[1]; Stephan de Roode[4]; Pier Siebesma[4]

[1] Met Office, Exeter; [2] Meteo France; [3] University of Exeter; [4] TU Delft

The Grey Zone Project: an intercomparison project of scale-aware approaches to turbulence and convection

With the ever-increasing computer resources, more and more weather and climate models now operate in the convective and boundary layer "grey zone" at horizontal grid spacings in the range of 200 m to 10 km. There is a need to systematically explore the behaviour of models operating in the grey zone, as well as support and compare the development of different scale-aware convection and turbulence parameterizations. By defining the grey zone as the range of resolutions in which both the resolved and the sub-grid contributions to turbulent and convective transport give a non-negligible contribution, it is clear that the resolution range of the grey zone is dependent on the type of turbulence and convection. Consequently, the Grey Zone Project investigates this issue under different atmospheric conditions using a case study approach, which includes both observations as well as ambitious ultra-high resolution simulations.
A second phase of the Grey Zone Project has recently been initiated, including both a shallow convective as well as a deep convective case in the (sub-)tropics. The shallow convective case will centre around the upcoming EUREC4A field campaign. Scientific questions that the project aims to address, and the current status of the community activities will be discussed.

Truhetz, Heimo

Poster

Heimo Truhetz[1]; Klaus Görgen[2]

[1] Universität Graz; [2] FZ Jülich

Effects of a shallow convection scheme in perennial convection permitting CORDEX-FPS WRF simulations

Within the framework of the novel “Flag Ship Pilot Study (FPS) on convective phenomena over Europe and the Mediterranean” (CORDEX-FPS), two ERA-Interim-driven WRF twin simulations have been conducted to investigate the effects of a shallow convection scheme, the independent GRIMS scheme, in a convection-permitting model domain (3 km grid spacing) covering the Alpine region. Following the WRF CORDEX-FPS protocol, the two WRF configurations consist of the same pan-European domain with 15 km grid spacing where deep convection is parameterised with the Grell-Freitas and shallow convection with GRIMS. In the 3 km Alpine domain (where Grell-Freitas is switched off) one WRF configuration keeps the GRIMS scheme active while the other one does not use any shallow convection scheme.

In the presented study, both convection-permitting simulations (including their coarser resolved counterparts) are compared to the analysis fields from the Integrated Nowcasting through Comprehensive Analysis (INCA) system that is operationally used at the Austrian Central Department for Meteorology and Geodynamics (ZAMG). INCA combines in-situ measurements of precipitation from a high-density stations network (more than 300 stations in the Austrian territory and its near surroundings) with remote sensing data (5 weather radar stations distributed over the country) and provides gridded (1 km grid spacing) precipitation fields with a temporal resolution of 15 minutes. In this work, simulated precipitation of June, July, and August from 2006 to 2009 is compared with INCA in Austria on an hourly basis. The analysis focuses on how the shallow convection parameterisation affects the size and the intensity of precipitation events along the diurnal cycle and their dependencies from surface elevation.

Tu, Chia-Ying

Oral

Chia-Ying Tu[1]; Huang-Hsiung Hsu[1]; Shian-Jiann Lin[2]

[1] Academia Sinica; [2] NOAA/GFDL

Applications of Variable-Resolution GCM for Weather and Climate Research

The GFDL Finite-Volume Cubed-Sphere Dynamical Core (FV3) is a scalable and flexible dynamical core for atmospheric simulations. In this study, FV3-powered global atmospheric model with variable-resolution horizontal spacing was applied for both weather and climate research. For weather research, FV3 model initialized with NCEP GFS data was applied to simulate extreme weather events affecting Taiwan from 2015~2018. Considering the complicated terrain and limited area in Taiwan, the horizontal grid spacing was further enhanced in the vicinity of Western Pacific using stretched-grid and nested-grid refinements. Comparing to the C768 uniform-resolution cubed-sphere grid with global 13-km horizontal resolution, the regional refinements using both stretched-grid and nested-grid were set to enhance the horizontal spacing over Taiwan to 3-km. The extreme weather events were simulated using FV3-powered atmospheric model with uniform-resolution grid, stretched-grid and nested-grid. The preliminary result demonstrates robust improvements for precipitation with enhanced horizontal resolution. Although the horizontal resolution over Taiwan in the stretched-grid experiments is approximating to that in the nested-grid experiments, the globally identical configurations for physical parameterizations in the stretched-grid experiments induces less skillful simulation for convective precipitation. Precipitation also influences typhoon track. Comparison of simulations with IBTrACS shows the nested-grid experiments produce less typhoon track errors than stretched-grid and uniform-resolution grid experiments.
As for climate research, FV3-powered GCM using both uniform-resolution cubed-sphere grid and stretched-grid refinement were conducted for AMIP-type integrations. The simulations using stretched-grid configurations demonstrated reasonable global mean climatology comparing to the uniform-grid simulations and observation. Regional orographic precipitation is better simulated in the enhanced-resolution region, as well as the strong typhoon/hurricane activity in western Pacific basin. Nevertheless, there is no significant improvement with resolution refinement for weak and moderate typhoons.
In this study, we describe the applications of global atmospheric model constructed on the cubed-sphere grid using uniform-resolution, stretched-grid and nested-grid refinements for both weather and climate researches to compare the skill for simulating extreme events. Enhanced horizontal resolution does improve simulation of precipitation with better detail and reasonable intensity. Nevertheless, proper configurations or scale-aware ability for physical parameterizations in a global atmospheric model plays an important role.

Ubbiali, Stefano

Poster

Stefano Ubbiali[1]; Christoph Schär[2]; Linda Schlemmer[3]; William Sawyer[4]; Thomas Schulthess[1]

[1] ETH Zürich, Theoretical Physics; [2] ETH Zürich; [3] DWD, Offenbach; [4] CSCS, Lugano

A Python-based approach to the physics-dynamics coupling in atmospheric models

Atmospheric models are complex systems where a dynamical core solves the fluid-dynamics equations and a bundle of physical parameterizations express the bulk effect of subgrid-scale phenomena upon the large-scale dynamics. The procedure which molds all the dynamical and physical components into a coherent and comprehensive model is referred to as the physicsdynamics coupling. Whereas parameterizations have been largely studied in isolation, the physics-dynamics coupling has historically received less attention. To a certain extent, this deficiency may be ascribed to the lack of flexibility, interoperability, and usability of traditional frameworks.

We propose a Python framework - code named tasmania - to ease the composition, configuration, simulation and monitoring of Earth system models. The framework features a component-based architecture, with each component being a Python class representing a dynamical or physical process. As a result, the user is given fine-grained control on the execution flow.

Physical components must conform to sympl's (System for Modelling Planets) primitives application programming interface (API). To facilitate the development of dynamical kernels, tasmania provides an abstract base class (ABC) with intended support for multi-stage timeintegrators (e.g., Runge-Kutta schemes) and partial operator splitting techniques, which integrate slow and fast processes with large and multiple small time steps, respectively. To this end, a distinction between slow physics (calculated over the large time step, outside of the dynamical core), intermediate physics (evaluated over the large time step at every stage) and fast physics (computed over the shorter time step at each sub-step) is made. Six coupling mechanisms are currently implemented; hybrid approaches are possible.

The two-dimensional Burgers equations and a simplified hydrostatic model in isentropic coordinates are used as proof-of-concept. Finite difference operators arising from the numerical

discretization of the model are implemented via GridTools4Py - a domain specific language (DSL) for stencil-based codes which offers a high-level entry point to the high-performance GridTools library. Results are showcased highlighting the variety of performance across the diverse coupling methods.

Vannière, Benoît

Poster

Benoît Vannière[1]; Pier Luigi Vidale[2]; Malcolm Roberts[3]; Kevin Hodges[2]; Marie-Estelle Demory[4]

[1] NCAS, Reading; [2] University of Reading; [3] Met Office, Exeter; [4] ETH Zurich, Atmospheric and Climate Science

The water budget of tropical cyclones, from GCMs to convection-permitting models.

The statistics of tropical cyclones (number, intensity…) are generally among the first metrics that are evaluated in new configurations of global high resolution climate models. Despite the crucial role that it plays in their genesis, the water budget of tropical cyclones (TCs) is rarely assessed.

The water budget of TCs was investigated systematically in the models involved in PRIMAVERA and in particular its changes as the horizontal resolution of the atmosphere was increased from one to 0.25 degree. Results have shown a tight relationship between the secondary circulation of TCs and their water budget. More specifically, we showed that the wind speed close to the eye of the cyclone increases with resolution, as could be expected. Interestingly, a comparison with wind profiles derived from QuickScat suggests that several models of the ensemble are already in close agreement with the observations at 0.25 degree. The wind profiles of the low and high resolution configurations converge at a distance of around 500 km from the centre of the storm. One direct consequence is that the moisture inflow at the edge of a 500 km radius cap, and the precipitation averaged in such a cap (a classic measure of TCs precipitation), are relatively insensitive to resolution. However, moisture is redistributed differently within the TC so that high resolution models achieve larger precipitation rates close to the core.

In this paper, we take advantage of HadGEM3 simulations performed recently to evaluate how the structure of simulated TCs evolves beyond 0.25 degree. Those include two simulations at 10 km resolution, with and without parameterised convection, and a 5 km convection-permitting simulation performed as part of project DYAMOND.

First, we use those new simulations to confirm whether or not the radial wind has converged at resolution of 0.25 degree. Second, we will investigate the role of the convective parameterisation versus the large-scale environment in setting the amount of precipitation in TCs. We hope those results can inform on tropical cyclones deficiencies in GCMs.

Oral

Vergara Temprado, Jesus

Jesus Vergara Temprado[1]; Nikolina Ban[1]; Davide Panosetti[1]; Linda Schlemmer[2]; Christoph Schaer[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] DWD, Offenbach

The effects of switching-off parameterized convection at grey-zone resolutions

The grey-zone of convection is defined as the range of horizontal grid-space resolutions in atmospheric models in which some convective processes might be explicitly represented by the dynamics of the model. In these range of resolutions (from around a few km to about a few hundred meters), either using parameterizations for convective processes or relaying on the model dynamics to represent them explicitly could lead to systematic model biases. Here, we explore the effect of parameterizing or not deep and shallow convection in year-long climate simulations over a Pan-European domain using different horizontal resolutions ranging from 50km to 2.2km with a non-hydrostatic model. We find that across the range of horizontal resolutions tested, model biases tend to differ more due to the representation of convection than due to changes in resolution when looking at precipitation intensities and the diurnal cycle of summer precipitation. The short-wave net radiative balance of the atmosphere is the variable most strongly affected by resolution changes from the ones we studied. The results suggest that an explicit representation of convection can be used at much coarser resolutions than previously thought. We will also present results on how the representation of convective processes at grey scale resolutions affect simulated climate change projections.

Vidale, Pier Luigi

Oral

Pier Luigi Vidale[1]; Terry Davies[2]; Benoit Vanniere[1]; Charles Roberts[1]; Grenville Lister[1]; Malcolm Roberts[2]; Simon Wilson[1]

[1] University of Reading, UK; [2] Met Office Hadley Centre, Exeter

Suppression of Semi-Lagrangian advection near the poles in Global Storm Resolving Models

The east-west grid spacing of the UK's operational NWP global model (N1280), also used in climate research, is 15.6 km at the Equator, 10km at mid-latitude and approximately 13 metres along the rows adjacent to the poles; the Global Storm Resolving Model (GSRM) configuration, N2560, recently used in the DYAMOND experiment, uses a grid separation of only 3m in the rows adjacent to the poles.

The use of Semi-Lagrangian/Semi-Implicit schemes enables the use of reasonably long time steps: 4 minutes at N1280 and 1.5 minutes at N2560. However, Courant numbers near the poles can become very large and semi-Lagrangian trajectories may cross, resulting in instability or even failure. Neither reducing the time step nor reducing the grid (increasing the grid length) are viable options, but a much simpler solution to the problem is to introduce a polar cap within which there is no explicit advection and where all advected quantities are derived by interpolating along the diameters of the polar cap, using the values at the edges of the polar cap. There is no communication-on-demand within the polar caps; the physical parametrizations and the solver still operate on the full grid. Since the east-west grid-length is proportional to the cosine of the latitude, the polar cap edges need to be around 1.5 degrees from the poles, to give an east-west grid-length at least one fortieth (around 0.025) that of the equatorial grid-length.

The scheme has been thoroughly tested in NWP case studies for two seasons, but here we focus on suitability for climate applications, starting with conservation of basic variables, and including performance tests with a full set of climate diagnostics. The suppression of SL advection within the polar caps allows both the time step and the solver tolerance to be increased (from 240 to 300 seconds and from 0.0001 to 0.001 respectively) giving a 30% faster computation time in configurations with the full set of (weather and climate) diagnostics. These advances compare well with more traditional performance gains implemented by the Met Office recently: 40% (optimization of stochastic physics) and 30% (parallel/asynchronous history writing with XIOS), respectively. The benefit of suppressing SL at the poles is even more beneficial for the N2560 global climate (DYAMOND) configuration.

Wan, Hui

Oral

Hui Wan[1]; Michael A. Brunke[2]; David J. Gardner[3]; Vincent E. Larson[4]; Huan Lei[1]; Jing Li[1]; Philip J. Rasch[1]; Balwinder Singh[1]; Jeremy A. Sousa[2]; Panos Stinis[1]; Christopher J. Vogl[1]; Carol S. Woodward[1]; Xubin Zeng[1]; Kai Zhang[1]; Shixuan Zhang[1]

[1] Pacific Northwest National Laboratory; [2] University of Arizona; [3] Lawrence Livermore National Laboratory; [4] University of Wisconsin-Milwaukee

Time-step convergence as a useful verification method for atmosphere modeling

General circulation models (GCMs) used in weather prediction and climate projection simulate time evolution of the Earth's atmosphere by solving differential-integral equations. Solution convergence and stability are basic requirements for the numerical methods employed therein. For parameterizations of subgrid-scale processes, much attention has been paid to the sensitivity to spatial resolution while the question "does the solution improve numerically as time step gets shorter" is not often asked. In this presentation, we will show examples from the U.S. Department of Energy's Energy Exascale Model (E3SM) and related equations to demonstrate the value in testing time-step convergence. We will show that:

- For deterministic equation systems, convergence testing can reveal vulnerabilities in the model's continuous formulation (e.g., closure assumption) and issues in the discretization. Resolving convergence issues not only helps improve the inherent physical consistency and numerical robustness of the model but also can lead to significant climate impact.

- For stochastic equation systems, the assessment of convergence can help ensure the numerical solution converges to the intended physical solution when resolution is refined. Time integration methods that accelerate convergence can provide higher numerical accuracy for the same resolution or allow for longer time steps for the same target accuracy.

- Solution convergence can also be used as a test to evaluate if a model produces the expected results in an HPC environment. Factors such as code refactoring, software (compiler and library) updates, new computer architectures and the model variants with reduced or mixed-precision arithmetic can often lead to loss of bit-for-bit reproducibility of the model results. Monitoring the convergence behavior can help determine the significance of the solution differences.

With these examples, we argue that convergence testing is a useful verification tool that deserves more attention from the atmospheric model developers.

Poster

Wang, Ziwei

Ziwei Wang; Elisabeth Moyer

The University of Chicago

Model performance in reproducing observed CAPE distributions

Convective Available Potential Energy (CAPE) is an integral quantity of buoyancy in the convective layer, closely linked to extreme weather with high socioeconomic impacts. Multiple studies suggest that CAPE should follow Clausius-Clapeyron scaling, thus increase in future warmer climate conditions. However, limited use has been made to date of the decades of observational record of CAPE from radiosondes, either to confirm trend projections or to evaluate the performance of high-resolution models. In this project we compare CAPE values over N. America from three sources: from the observational network, from reanalysis (ERA-I), and from high-resolution regional WRF simulations with and without resolved convection. We show that ERA-I reanalysis surface-based CAPE is systematically biased low, primarily through reduction in the tail of high CAPE, and that this bias is mainly driven by errors in reanalysis surface humidity. Correcting surface-level humidity and temperature allows reproducing observed CAPE values extremely well (slope of 0.97 and correlation coefficient 0.96). The implication is that coarse-resolution models, even when nudged by observations, are unable to reproduce CAPE, with largest errors in the most impacts-relevant conditions. Therefore, high-resolution modeling appears necessary for evaluating the impacts of future changes in severe weather. In this work we evaluate CAPE in high-resolution simulations and discuss its use as a diagnostic of model performance.

Watanabe, Shun-ichi

Oral

Shun-ichi Watanabe[1]; Hiroyuki Tsujino[2]; Akihiko Murata[2]; Masayoshi Ishii[2]

[1] Japan Meteorological Business Support Center; [2] Meteorological Research Institute

Coupled atmosphere-ocean regional climate model for Japan and surrounding ocean

The ocean around Japan has a number of small and complex structures such as Kuroshio. Large amounts of heat and moisture are exchanged between atmosphere and ocean, for example, during a cold air outbreak in winter and under a typhoon. Recent studies have demonstrated that such oceanic structures are closely related to the climate over Japan. For example, the path of Kuroshio affects the precipitation and temperature over Japan and the track of extratropical cyclones around Japan. In addition, the rapid seasonal change of sea surface temperature (SST) has an impact on a torrential precipitation over Japan. These findings indicate that the regional-scale atmosphere-ocean interaction is crucial for the climate over Japan. To evaluate these processes in a regional climate model, 1) the improvement of the horizontal resolution of SST used for the lower boundary condition, and 2) the atmosphere-ocean coupling process are indispensable.

In the TOUGOU program, we have been developing a regional coupled atmosphere-ocean model for Japan and surrounding ocean to evaluate the potential effects of atmosphere-ocean interaction on a dynamical downscaling simulation. The atmospheric component of the model is non-hydrostatic regional climate model (NHRCM) and oceanic component Meteorological Research Institute Community Ocean Model version 4 (MRI.COMv4). These models are coupled via a Simple Coupler (Scup). The oceanic model consists of a low-resolution global model (GLBOGCM) and a high-resolution North Pacific model (NPOGCM), in which NPOGCM is two-way nested in GLBOGCM. NPOGCM has a horizontal grid spacing of about 10 km, which can reproduce mesoscale oceanic structures including Kuroshio. NHRCM is coupled with NPOGCM. NHRCM passes mean sea level pressure, total precipitation, surface net shortwave and longwave radiation, sensible and latent heat fluxes and momentum flux to NPOGCM, while NPOGCM gives sea surface temperature and sea ice distribution to NHRCM. To evaluate the performance of this coupled model, we conducted a perfect boundary experiment, in which Japanese 55-year Reanalysis (JRA-55) is used as a boundary condition for NHRCM. Although NHRCM can run as a convection-permitting climate model with horizontal grid spacing of ~2 km, in this run, the horizontal grid spacing is set to 15 km and convection parameterization is used. The preliminary result indicates that this model has a performance comparable to the atmosphere-only NHRCM and ocean-only NPOGCM.

Oral

Weber, Nicholas

Nicholas Weber; Clifford Mass

University of Washington

The impacts of convection-permitting resolution on extended global prediction in MPAS

This talk presents results from four 28-day global simulations using the Model for Prediction Across Scales (MPAS) at uniform convection-permitting (3-km) resolution. The experiments are motivated by previous studies that have documented benefits of convection-permitting resolution for simulated tropical precipitation, propagating convection in the tropics and midlatitudes, the Madden-Julian Oscillation (MJO), and attenuating forecast biases. The 3-km simulations are compared to 15-km MPAS simulations with and without convective parameterization, general circulation model (GCM) reforecasts, global analyses, and satellite (TRMM) measurements to determine the impacts of convection-permitting resolution (and the omission of convective parameterization) on tropical convection, the structure and development of the MJO, extratropical teleconnection patterns, and global forecast skill.

Results of the above simulations show that the convection-permitting simulations exhibit improved tropical convection and greater tropical and extratropical extended forecast skill than their lower-resolution counterparts. Specifically, the 3-km runs produce more realistic tropical rain rate distributions, MJO propagation, and upper-level intraseasonal circulation anomalies in the Pacific/North American region. Vertical profiles of moisture, cloud water, divergence, and apparent heating in tropical convection are also better simulated at 3-km resolution, implying improved radiative effects, dynamic response to convection, and heat/moisture budgets. Implications of global convection-permitting models for climate prediction, focusing particularly on the tropical and extratropical mean state biases, and fidelity of tropical/extratropical teleconnections, will also be discussed.

Yamaguchi, Takanobu

Oral

Takanobu Yamaguchi[1]; Ryuji Yoshida[1]; Peter Bogenschutz[2]; Hsiang-He Lee[2]; Yaosheng Chen[1]; Graham Feingold[1]

[1] NOAA; [2] LLNL, Berkeley

Ameliorating low cloud representation in km-scale global and regional models using the Framework for Improvement by Vertical Enhancement

For km-scale global and regional models, low clouds are unresolved and their representation relies on parameterizations. Although recent advances in microphysical and turbulence parameterizations are promising, these clouds are poorly represented in km-scale atmospheric models. This implies that the interplay between parameterization and other aspects of the model is key for improved representation of low clouds. Following this line of thought, this presentation focuses on the impact of high vertical resolution on the representation of low clouds in large scale models, which is a relatively unexplored aspect due to limitations in computational resources and possible unforeseen numerical/technical difficulties in simulating with massively parallel machines. First, we will discuss how low cloud representation is improved by simply increasing vertical resolution in the Energy Exascale Earth System Model (E3SM) and its single column model, as well as a 2-dimensional Hadley cell circulation simulated with a regional model at a few km horizontal resolution. Second, we will introduce the Framework for Improvement by Vertical Enhancement (FIVE), a new computational method, which will offer better representation of atmospheric boundary layer clouds while limiting additional computational cost due to the increased number of levels. Preliminary results using FIVE will be presented. Last, we will discuss a path to a more computationally efficient FIVE, and associated challenges.

Poster

Zeman, Christian

Christian Zeman[1]; Nikolina Ban[1]; Nils Wedi[2]; Irina Sandu[2]; Christoph Schär[1]

[1] ETH Zurich, Atmospheric and Climate Science; [2] ECMWF, Reading

Model evaluation at convection-resolving scales: Intercomparison and sensitivity analysis of global versus regional models

The increasing availability of computing power allows the use of kilometer-scale convection-resolving weather and climate models for operational forecasts. However, open questions remain regarding the realism of these forecasts. In particular, the validity of the hydrostatic approximation at these scales and the sensitivity of precipitation and vertical wind to time step and resolution are a matter of intense debate.

Here we systematically compare two numerical models with regard to their ability to realistically resolve convective processes: The non-hydrostatic regional Consortium for Small-scale Modelling (COSMO) model with split-explicit 3-stage Runge-Kutta time integration and the global Integrated Forecast System (IFS) by the European Centre for Medium-Range Weather Forecasts (ECMWF) which uses semi-Lagrangian and semi-implicit time integration and can be run in hydrostatic and non-hydrostatic mode. Both models are run with different configurations and resolutions for two convective summer days over Europe.

The model output is compared with observational data from rain gauges over Switzerland, E-OBS and SYNOP data over Europe. Results show that, while general precipitation patterns of the two models agree quite well with observations, the output strongly differs in terms of precipitation frequency and intensity, as well as for vertical wind speeds. Specifically, IFS produces more light precipitation whereas in COSMO the frequency of heavy precipitation events is substantially higher. We also show that vertical wind speeds are highly dependent on model resolution, and discuss the sensitivity of results on differences in numerics, time step size, and the use of hydrostatic approximation in different simulations.