Collaborative Research Center WAVES TO WEATHER · WORLD METEOROLOGICAL ORGANIZATION · High Impact Weather Project WWRP · DFG Deutsche Forschungsgemeinschaft

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Conference on Predictability and Multi-Scale Prediction of High Impact Weather

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Watercolor by Joseph Egger

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Oral presentations

Session on multi-scale prediction systems

Chair: Jenny Sun, Monday, 12:50

Overview of W2W

George Craig
Meteorological Institute, LMU Munich

Abstract
Waves to Weather (W2W) is a Collaborative Research Center, funded by the German Research Foundation to investigate the limits of predictability and contribute to the scientific foundation of improved forecasting of high impact weather. With over 20 principal investigators and a potential duration of 12 years, W2W represents a major commitment of resources within Germany and an opportunity to contribute strongly to the international community, especially to the HIWeather program of the WWRP. This presentation will give a brief outline of the W2W initiative, present some key scientific results from the first two years, and highlight the potential for cooperation with researchers worldwide.

The new hourly 4D-Var system for the Met Office operational convective-scale UKV model

Bruce Macpherson
Met Office, UK

Abstract

In July 2017, the Met Office implemented a new hourly 4D-Variational data assimilation system for its convective-scale UKV model, replacing the previous 3-hourly 3D-Variational system. We will discuss the motivations, challenges, compromises and practical solutions which were required to achieve a single affordable system which can adequately address 'nowcasting' and 'next day' forecast timescales. We will also outline plans to improve coupling of this deterministic system with our convective-scale ensemble forecasting system.

An extended tropical cyclone prediction system for Australia

Peter Steinle
Australian Bureau of Meteorology

Abstract
Accurate depiction of the detailed structure of tropical cyclones is often necessary to accurately predict the evolution of these storms. This is often achieved with limited area, high-resolution Numerical Weather Prediction (NWP) systems which are traditionally triggered once a storm has been named. This has long been the case in centres such as the Australian Bureau of Meteorology. However, in very remote regions such as the north-west coast of Australia, and the nearby ocean, it can take several days to evacuate people to safety - especially in the case of workers on oil and gas rigs. In these cases, emergency procedures may need to be initiated prior to the storms reaching tropical cyclone intensity. To support these emergency response decisions the Bureau of Meteorology is introducing a high resolution NWP system, capable of providing forecasts out to 5 days. Key measures of success of this system are related to the ability to predict tropical cyclone genesis, changes in behavior including rapid intensification, and wind structures in critical areas. This presentation will discuss ability of a limited area version of the Australian Community Climate and Earth System Simulator (ACCESS) - a local version of the Met Office Unified Model, to meet these needs.

Balanced data assimilation strategies

Gottfried Hastermann
Fachbereich Mathematik, Freie Universität Berlin, Berlin

Abstract
In numerical weather prediction, the multiscale behavior of the atmosphere poses several major challenges. One specific problem occurs in the context of data assimilation. In general the large-scale dynamics of the atmosphere are balanced in the sense that rapid internal or acoustic wave oscillations generally come with negligibly small amplitudes. If such oscillations are excited artificially, however, e.g. through inappropriate initialization or by data assimilation, they can have an adverse effect on forecast quality as they interact with the moist aerothermodynamics of the atmosphere. We therefore investigate two conceptional different approaches to reduce these artificial oscillations, triggered by an analysis step of a sequential Bayesian data assimilation algorithm. The first idea is to develop a new modification for a local ensemble transform Kalman filter, which penalizes imbalances via a minimization problem. In contrast to the preceding case our second idea does not modify the filter algorithm itself, since we only modify the first steps of the subsequent forecast to push the ensemble members back to the slow evolution. For this purpose, we propose the use of certain asymptotically consistent integrators that can blend between the balanced and the unbalanced evolution model seamlessly. As a first step we investigate these two different strategies applied to several toy problems, given by nonlinear ordinary differential equations, for which we can identify and understand the different scales and their interaction intuitively and rigorously. These examples contain a nonlinear balance relation which allows us to observe the artificial oscillations without localization. Furthermore, we investigate the proposed methods applied to the rotational shallow water model, where despite of the linear geostrophic balance relation, the localization of the data assimilation algorithm excites artificial rapid internal waves.

Strategies for multi-scale data assimilation using a 3DVAR system

Juanzhen Sun
NCAR, Boulder, CO, USA

Abstract As operational NWP models are running increasingly at higher resolutions, it becomes critical to initialize these models with convection-resolving observations, such as those from Doppler radars. A challenging question for successful assimilation of these data is how to allow large analysis increment from them while not causing damages of the large-scale balance in the forecast background. In this presentation, some strategies that aim to answer this question, including a multi-step procedure and a large-scale analysis constraint for radar data assimilation, are described. A recent study on the impact of the choice of momentum control variables on limited-area models will also be discussed. The impacts of these methodologies on improved convective-scale analysis and forecast will be shown for case studies and for real-time semi-operational testing.

Approaches to convective scale data assimilation

Tijana Janjic-Pfander
Hans Ertel Center for Weather Research, German Weather Service

Abstract
Past studies have shown that ensemble Kalman filter (EnKF) algorithm can be applied to the convective scales since it is capable of handling complex and highly nonlinear processes. However, some challenges for the convective scale applications still remain. These include a need to estimate on convective scale, fields that are nonnegative (such as rain, graupel, snow) and to use data sets such as radar reflectivity or cloud products that have the same property. What underlines these examples are errors that are non-Gaussian in nature causing a problem with the EnKF that uses Gaussian error assumptions to produce the estimates from the previous forecast and the incoming data. Since the proper estimates of hydrometeors are crucial for prediction on convective scales, the question arises whether the EnKF method can be modified to improve these estimates. In this talk, we first review the challenges that convective scale data assimilation methods are facing when assimilating radar data. We show the behavior of the localized EnKF with respect to preservation of positivity, conservation of mass, energy and enstrophy in toy models that conserve these properties. In order to preserve physical properties in the analysis as well as to deal with the non-Gaussianity in an EnKF framework, Janjic et al. 2014 proposed the use of physically based constraints in the analysis step to constrain the solution and therefore change the analysis error statistics. In experiments designed to mimic the most important characteristics of convective motion, it was shown that the mass conservation- and positivity-constrained rain significantly suppresses noise seen in localized EnKF results. This is highly desirable in order to avoid spurious storms from appearing. In addition, the root mean square error is reduced for all fields and total mass of the rain is better simulated.

What observations do we need for convective-scale data assimilation?

Martin Weissmann[1], Stefan Geiss[1], Tobias Necker[1], Leonhard Scheck[1], Josef Schroettle[1], Takemasa Miyoshi[2], Juan Ruiz[3]

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[3]University of Buenos Aires, Argentina

Abstract
Regional models with a grid spacing of a few kilometres ("convective-scale models") explicitly represent deep convection and hazards related to convective systems are often primary forecast events. This results in low predictability and calls for the assimilation of spatially dense and temporally frequent observations. In developed countries, there is a wide variety of observed information available ranging from dense surface networks over new remote-sensing instruments, new geostationary satellites to community observations as smart phone sensors, car and roadside sensors and the production of solar and wind power. However, little knowledge exists on what types of observations are most beneficial on which spatial and temporal scales and where we should put our priorities regarding the refinement of observing and data assimilation systems. Given limited resources, we therefore need to assess the impact of existing observation types and the potential impact of observations that are not yet assimilated to make decision on the future evolution of convective-scale data assimilation systems. The HErZ research group at LMU tries to answer these questions using three approaches. First we assess the impact of various observation types in the ensemble modelling system of Deutscher Wetterdienst based on the ensemble forecast sensitivity observation impact (EFSOI). Secondly, we investigate the potential impact and potential impact time of observation types not assimilated yet using the ensemble sensitivity analysis for a 1000-member ensemble simulation of convective summertime precipitation in Germany. Thirdly, we work on including cloud-affected satellite observations in infrared and visible channels in both an idealized OSSE framework and realistic case studies.

SINFONY - Development of a new seamless prediction system for very short range convective-scale forecasting at DWD

Ulrich Blahak, Roland Potthast, Kathrin Wapler, Axel Seifert, Alberto De Lozar, Elisabeth Bauernschubert, Christian Welzbacher, Robert Feger, Lisa Neef, Liselotte Bach, Martin Rempel, Michael Hoff, Markus Junk

Deutscher Wetterdienst, Germany

At DWD a new internal project has been set up to develop its future seamless ensemble prediction system for storm-scale forecasting from observation time up to +6h/+12h forecasts. The focus is on severe summertime convective events with their associated hazards (heavy precipitation, hail, wind gusts, etc.). Up to now, for the first 1-2h this relies mostly on observation-based nowcasting products, whereas convection-allowing ensemble NWP (COSMO-DE-EPS) is only able to reach/outperform the quality of nowcasting at later times. New NWP forecasts are started only every 3 h and after a rather long cut-off time to wait for incoming observational data. Moreover, nowcasting and ensemble NWP are treated as two separate and independent methods, and there are few common products available for the forecasters. The goal of the new project is to narrow down these gaps, on the one hand by enhancements to both nowcasting and NWP separately and on the other hand by mutual information exchange and combination, to further enhance the quality of both. High-resolution observational data (radar, satellite, lightning, GPS-derived moisture, etc.) will be exploited. We consider in particular:

- Nowcasting ensembles, ensembles of "objects", also informed by uncertainties from NWP
- Life cycle in nowcasting, informed by radar, lightning and satellite data and by informations from ensemble-NWP
- Rapid Update Cycle (RUC) ensemble NWP: 1-km-scale, LETKF, hourly update, 40 members, advanced model physics (2-moment microphysics including hail, 3D-turbulence)
- LETKF assimilation in ensemble NWP in observation space of:
  - 3D-radar-data (native observations as well as nowcast "objects")
  - Meteosat SEVIRI IR and VIS satellite data
  - Lightning flash densities using the Lightning Potential Index as a forward operator

- New products combining nowcasting and NWP ensemble information in a probabilistic way for our forecasters

This project has been started in early 2017 and the presentation will give an overview on the plans and present results of first case studies.

Assimilation of visible satellite images for improved prediction of high impact weather

Leonhard Scheck
Meteorological Institute , HErZ, LMU, Munich, Germany

Abstract
Observations from imagers on geostationary satellites provide a wealth of information about convective activity and are therefore seen as a important type of observation for convective scale data assimilation (DA). In particular, the visible and near-infrared channels provide information on the cloud distribution, cloud microphysical properties and cloud structure with high temporal and spatial resolution. Assimilating these observations has the potential to improve forecasts for cloud-related high impact weather events significantly. However, in operational DA systems currently only clear sky thermal infrared and microwave radiance observations are used, which mainly provide temperature and humidity information. Sufficiently fast and accurate forward operators for visible and near-infrared radiances are not yet available, because multiple scattering makes radiative transfer at solar wavelengths complicated and computationally expensive. Only recently we deve loped a loop-up table based 1D radiative transfer method that is orders of magnitude faster than conventional radiative transfer solvers for the visible spectrum and similarly accurate. A preliminary version of a forward operator based on this method, which simulates synthetic MSG-SEVIRI images from COSMO-DE model output, has been completed and implemented in the pre-operational km-scale Ensemble Data Assimilation (KENDA) system of DWD. We discuss this novel operator and demonstrate that the assimilation of visible SEVIRI reflectances improves forecasts on days with strong convective events in summer 2016.

Impact of Orography on Predictability of Deep Convection in an Idealized Ensemble Data Assimilation Testbed

Kevin Bachmann
Meteorological Institute , LMU Munich, Germany

Abstract
The predictability of deep convection lies in the range of tens of minutes and has been discussed broadly in the meteorological community. However, there are boundary forcings on the synoptic and mesoscale that increase the predictability. The impact of such a source of predictability—the orography—is quantified in this study employing an idealized convective-scale Ensemble Data Assimilation system to account for realistic initial condition uncertainty. The idealized COSMO-KENDA consists of the idealized COSMO (Consortium for Small-scale Modeling) model coupled to KENDA (Kilometre-scale Ensemble Data Assimilation), the operational data assimilation tool used at DWD. COSMO-KENDA enables us to directly compare the impact and possible benefits of radar data assimilation in simulations with and without orography. Here a convection-permitting resolution of 2 km is applied over a domain of 512 x 512 km initialized homogeneously with an observed summertime atmospheric sounding. For simulations with small scale initial condition error only, our results suggest a higher practical predictability of background simulations with orography over an entire diurnal cycle due to its structuring effect on precipitation. Orography shifts the believable scale measured by Fractions Skill Score (FSS) from around 80 km to 60 km. The decorrelation scale, a measure of the correlation of precipitating cells within the ensemble, decreases from no correlation to below 100 km in the presence of orography. Moreover, radar data assimilation increases the practical predictability in both simulations till they become nearly indistinguishable. Similar simulations with large-scale initial condition errors only will be performed soon and should provide further insight into realistic initial condition errors and their growth.

From Surface to Atmosphere - Ocean-Wave-Atmosphere interactions in a fully coupled environmental prediction model

Joachim Fallmann
Met Office, UK, Exeter

Abstract
High impact weather is typically manifested through various interactions and feedbacks between different components of the Earth System. An accurate prediction and warning of the impacts of severe weather requires an integrated approach to forecasting and complex processes need to be understood for different weather situations from global to convective scale. Sea surface temperature (SST) is an important factor in air sea interactions influencing local weather and climate but on the other hand however it is also controlled by atmospheric conditions. Ocean waves govern the exchange of momentum at the interface between ocean and atmosphere, modifying local wind speeds and vertical mixing in both ocean and atmosphere. This presentation discusses results from a fully coupled high resolution probabilistic forecast system for the UK at km-scale, consisting of configurations of the Unified Model atmosphere, including the JULES land surface model, coupled to the NEMO ocean model and WAVEWATCH III wave model. Our study focuses in particular on the impact of changing surface forcing resulting from changes in sea surface temperature and ocean surface on the representation of frontal systems over a UK domain. Assessing results from a number of contrasting case studies, we show that model coupling has a significant impact on the forecast timing of atmospheric fronts, modifying wind, wave and precipitation patterns. The sensitivity of the ocean state to changes in the atmospheric evolution resulting from coupling is explored comparing the fully coupled system to its uncoupled atmosphere, ocean and wave configurations. We use data from satellites, wave buoys and rain radar to verify the model results.

Session on scale interactions and error growth

Chair: George Craig, Tuesday, 09:00

Improving Stochastic Parametrisation Schemes using High-resolution Model Simulations

Hannah Christensen
NCAR, USA

Abstract
Stochastic parametrisation schemes are used in NWP to represent uncertainty in the forecast due to unresolved processes. Whereas traditional deterministic parametrisation assumes the existence of a scale separation between the resolved and unresolved scales, stochastic schemes acknowledge that in reality this scale separation does not exist. Instead the sub-grid scales are represented as a combination of a predictable deterministic component and an unpredictable stochastic component. Within this framework, memory and spatial correlations can be included, explicitly representing the impact of sub-grid processes on scales above the truncation scale, and thereby the transfer of errors from sub-grid to larger scales.

In this presentation I will give some background on the use of stochastic parametrisations in NWP, and the variety of approaches that have been proposed. I will discuss the use of high-resolution model simulations to learn about the form these stochastic schemes should take in order to skilfully represent unresolved variability. This methodology can also be used to motivate improvements to existing stochastic schemes, and I will finish by proposing one such improvement. This is shown to benefit forecast skill for a set of cases in which the synoptic initial conditions were more likely to result in a European 'forecast bust'.

Error growth from the micro- to the synoptic scales governed by the geostrophic adjustment process

Lotte Bierdel, Tobias Selz, George C. Craig

Ludwig-Maximilians-University of Munich

Abstract

Recent numerical studies suggest that convective instability and latent heat release quickly amplify errors in numerical weather predictions and lead to a complete loss of predictability on scales below 100 km within a few hours. These errors then move further upscale, eventually contaminating the balanced flow and projecting onto synoptic-scale instabilities. According to this picture, the errors have to transition from geostrophically unbalanced to balanced motion while propagating through the mesoscale. Geostrophic adjustment was suggested as the dynamical process of this transition but could so far not clearly be identified. In the presented study an analytical framework for the geostrophic adjustment of an initial pointlike pulse of heat (modeling a convective cloud or an error within the prediction of a cloud) is developed on the basis of the linearized, hydrostatic Boussinesq-equations. A time-dependent solution for both the transient and the ba lanced f low components is derived from the analytical model. Spatial and temporal scales of the geostrophic adjustment mechanism are deduced and three characteristics of the solution are shown to be potentially useful for identifying the geostrophic adjustment process in numerical simulations. These three predictions are then tested in the framework of error growth experiments in idealized numerical simulations of a convective cloud field. Three different rotation rates are employed in order to identify the geostrophic adjustment mechanism and allow a quantitative comparison with the predictions of the analytical model. As will be shown, the numerical simulations agree well with the predictions developed from the analytical model. Based on this findings it is suggested that upscale error growth through the atmospheric mesoscales is governed by the geostrophic adjustment process.

Role of Initial and Model Errors in Uncertainty of Weather Forecasts

Adrian Tsz-Yan Leung[1], Ted Shepherd[1], Sebastian Reich[1 2], Martin Leutbecher[3]

[1]University of Reading, [2]University of Potsdam, [3]ECMWF

Abstract
Errors in operational weather forecasting are attributed to initial and model uncertainties. To develop a theoretical framework of error growth, it is useful to understand the roles of these sources of error and the interplay between them. We examine these issues in the context of idealised surface quasi-geostrophic (SQG) and 2D barotropic vorticity (2DV) dynamics. The SQG model has been argued to be more relevant to mesoscale dynamics than 2DV. We first quantify the scale-dependence of predictability time, which Lorenz in his 1969 paper had concluded was critical for determining whether the predictability limit was finite. Contrary to Lorenz's prediction, we find evidence of finite predictability even with a -3 spectral slope. We then assess the role of model error. By perturbing the stochastic forcing term it is found that, apart from an initial adjustment phase, the growth behaviour is qualitatively indistinguishable from that of initial er ror. Th is suggests that for sufficiently small initial error, model error - which is unavoidable in an operational context - may dominate error growth.

The impact of convection in the West African monsoon region on global weather forecasts - explicit vs. parameterised convection simulations using the ICON model

Gregor Pante, Peter Knippertz

Institute of Meteorology and Climate Research (IMK), Karlsruhe Institute of Technology (KIT)

Abstract

The West African monsoon is the driving element of weather and climate during summer in the Sahel region. Poor representation of convection in numerical models can result in unrealistic forecasts of the monsoon dynamics. Arguably, the parameterisation of convection is one of the main deficiencies in models over this region. Overall, this has negative impacts on forecasts over West Africa itself but may also affect remote regions, as waves originating from convective heating are badly represented. Here we investigate those remote forecast impacts based on daily initialised 10-day forecasts for July 2016 using the ICON model. One set of simulations employs the default setup of the global model with a horizontal grid spacing of 13 km. It is compared with simulations using the 2-way nesting capability of ICON. A second model domain over West Africa with 6.5 km grid spacing is sufficient to explicitly resolve mesoscale convective systems in this region. In the 2-way nested simulations, the prognostic variables of the global model are influenced by the nest through relaxation. Simulations with explicit convection produce cooler temperatures in the lower troposphere over the northern Sahel due to stronger evaporational cooling. Overall, the feedback of variables from the nest to the global model shows positive effects when evaluating the forecasts with IFS analyses. Outside Africa the effect of the 2-way nesting becomes visible after some days. The forecast of 850 hPa temperature over Europe at day 10, for instance, is as good as for day 9 in the stand-alone global model. These improvements result most likely from a better representation of African easterly waves and Rossby waves. This work shows the importance of the West African region for global weather forecasts and the potential of convective permitting modelling in this region to improve the forecasts even far away from Africa in the future.

Quantifying the added value of convection-permitting climate simulations in complex terrain: a systematic evaluation of WRF over the Himalayas

Ramchandra Karki[1], Shabeh ul Hasson[1 2], Lars Gerlitz[3], Udo Schickhoff[1], Thomas Scholten[4] and Jürgen Böhner[1]

[1]Univ. of Hamburg, [2]Institute of Space Technology, Islamabad, [3]GFZ German Research Centre for Geosciences, Potsdam, [4]Univ. of Tübingen

Abstract
Mesoscale dynamical refinements of global climate models have shown their potential to resolve intricate atmospheric processes, their land surface interactions, and subsequently, realistic distribution of climatic fields in complex terrains. Given that such potential is yet to be explored within the Himalayan region of Nepal, we investigate the skill of the WRF model with different spatial resolutions in reproducing the spatial, seasonal, and diurnal characteristics of the air temperature and precipitation as well as the spatial shifts in the diurnal monsoonal precipitation peak over the Everest, Rolwaling, and adjacent southern areas. For this, the ERA-Interim reanalysis has been dynamically refined to 25, 5, and 1 km (D1, D2, and D3) for one year, using the one-way nested run and parameterized convection for the outer but explicitly resolved convection for the inner domains. Our results suggest that D3 realistically reproduces the monsoonal precipitation, as compared to underestimation by D1 but overestimation by D2. All three resolutions, however, overestimate precipitation from the westerly disturbances, owing to simulating anomalously higher intensity of few events. Temperatures are generally reproduced well by all resolutions; however, winter and premonsoon seasons feature a high cold bias for high elevations while lower elevations show a simultaneous warm bias. Unlike higher resolutions, D1 fails to realistically reproduce the regional-scale nocturnal monsoonal peak precipitation observed in the Himalayan foothills and its diurnal shift towards high elevations, whereas D2 resolves these characteristics but exhibits a limited skill on the river valley scale due to the limited representation of the narrow valleys at 5 km resolution. Nonetheless, featuring a substantial skill over D1 and D2, D3 simulates almost realistic shapes of the seasonal and diurnal precipitation and the peak timings even on valley scales. These findings clearly suggest an added value of the convective-scale resolutions in realistically resolving the topoclimates over the central Himalayas, which in turn allows simulating their interactions with the synoptic-scale weather systems.

Tropical transition of Hurricane Chris (2012) over the North Atlantic Ocean: A multi-scale investigation of predictability

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Abstract
Tropical cyclones that evolve from a non-tropical origin may pose a special challenge for predictions, as those storms often emerge at the end of a multi-scale cascade of atmospheric features and processes. Climatological studies have shown that the "tropical transition" (TT) pathway plays a prominent role in particular over the North Atlantic Ocean. The presented TT case study investigates the ensemble prediction of North-Atlantic Hurricane Chris (2012). Strong upper-level Q-vector convergence and a sharp lower-level thickness gradient indicate strong baroclinic processes associated with the precursor trough and formally categorize Chris as a strong TT showcase. The principal goal is to examine whether abrupt forecast improvements in the mean and spread of the tracks, intensities, and cyclone phase space parameters are related to changes in the uncertainty on larger scales. For that purpose, the key atmospheric features in the antecedent planetary - and sy noptic-scale dynamics were identified in ECMWF ensemble forecasts and then clustered into distinct scenarios. Results show that predictions of the storm occurrence, the necessary reduction in vertical wind shear prior to the TT, as well as of the TT itself are related to the structure of the precursor trough at 300 hPa. Whereas a consistent occurrence of a cyclone is found in the members that exhibit a trough, the members showing a cut-off feature no cyclone at all. The best prediction of the actual transition to a tropical cyclone occurs within the cluster representing elongated weakening troughs that are about to cut off. It is further remarkable that marked changes in the number of tracks as well as track errors are found at the time when noticeable events in the antecedent planetary flow pattern - such as a wave-breaking or a merging of two PV streamers - happen.

Dynamics and predictability of Medicanes in the ECMWF ensemble forecast system

Enrico Di Muzio[1], Andreas H. Fink[1], Michael Riemer[2], Michael Maier-Gerber[1]

[1]Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology
[2]Institute of Atmospheric Physics, Johannes Gutenberg University Mainz,

Abstract
Medicanes are intense tropical-like cyclones that occasionally strike the Mediterranean region. These storms constitute a major threat due to strong winds, intense precipitation and flooding. While initially originating from extratropical systems with a baroclinic energy source, Medicanes later undergo a transformation referred to as tropical transition (TT), thereby developing tropical-like features such as a warm core, deep convection near their center and a largely axisymmetric appearance. The dynamics and predictability of several Medicanes in the ECMWF ensemble prediction system (EPS) are analyzed in this contribution, from the planetary scale down to the mesoscale. The influence of Rossby wave breaking (RWB) on the formation and early phase of the storms is assessed by linking the uncertainties of Rossby wave forecasts to storm intensity and position. The uncertainty in position and depth of upper-level precursor troughs is then linked to RWB as well as to different storm development pathways. A suite of methods and diagnostics is employed, including storm track comparison, cyclone phase space diagrams and isoline clustering, to assess the extent to which TT occurs and ultimately the ability of the ECMWF EPS to accurately predict Medicanes. Results suggest that large-scale processes are instrumental in determining storm occurrence, whereas the link with storm intensity is weaker. Overall, the EPS members that have larger errors in large-scale processes also tend to have poorer accuracy in storm intensity, position and structure. Storm-feature-based cluster analysis sheds further light on the link between the uncertainty in storm evolution and forecast uncertainty of larger-scale features. Spatial uncertainty in storm tracks is high even for short lead times, whereas structure changes linked to TT are usually better forecast. A jump in forecast accuracy is found between 3 and 5 days lead time for most storms, marking a limit in mesoscale predictability due to larger-scale errors propagating to smaller scales.

Identification of Rossby Wave packets using Local Finite Amplitude Wave Activity

Paolo Ghinassi[1], Volkmar Wirth[1], Tobias Selz[2], George C. Craig[2]

[1]Johannes Gutenberg University Mainz, Germany
[2] Meteorological Institute Munich, LMU, Munich, Germany

Abstract
Upper tropospheric Rossby wave packets (RWPs) are often associated with weather sys- tems and can thus have a strong influence on surface weather. They sometimes act as pre- cursors to blocking or intense extratropical cyclones and are, in this sense, connected with severe weather episodes. Therefore, understanding the dynamics of RWPs is of fundamental importance in the context of predictability. This contribution presents local finite amplitude wave activity (LWA) as a novel diagnos- tic for RWPs. LWA, which is an extension of the finite amplitude wave activity of Nakamura and Solomon, is proportional to the local meridional displacement of contours of potential vorticity (PV) from zonal symmetry. The advantage of using LWA consists in the fact that its formulation does not make any small amplitude assumption; it is able to faithfully iden- tify nonlinear phenomena such as Rossby wave breaking, blocking, PV streamers, or cutoffs. Furthermore, LWA has an exact conservation relation which allows one to formulate a bud- get equation for its evolution and to quantify the impact of non-conservative processes as a residuum from the LWA budget. Following the main idea of upscale error propagation, this diagnostic is applied to data from the global forecast model ICON to quantify the error growth at the planetary scale. At the same time, the LWA budget equation is used to estimate the magnitude of the nonconservative term. A challenge in this context is the cascade of enstrophy to smaller scales, which results in an unavoidable sink term in the LWA budget. The results show that nonconservative processes play a non-negligible role in the propagation of RWPs, suggesting that their misrepresentation in the models can lead to poor forecasts.

Atlantic-European weather regimes: physical processes governing their life cycles and applications

Christian M. Grams
ETH Zurich, Switzerland / KIT Karlsruhe, Germany

Abstract
The large-scale midlatitude flow is dominated by Rossby wave activity along the upper-level midlatitude wave guide and jet stream. In the Atlantic-European region this activity occurs in preferred quasi-stationary, persistent, and recurrent states, so-called weather regimes. Weather regimes explain most of the atmospheric variability on sub-seasonal time scales. An extended definition of year-round Atlantic-European weather regimes based on 37 years of ERA-Interim reanalysis data helps to elucidate the physical processes governing their life cycles. A specific focus lays on the role of atmospheric blocking and of diabatic outflow driven by cloud-condensational processes at distinct weather regime life cycle stages. Weather regimes help to assess the potential for extreme weather as discussed exemplarily for atmospheric river occurrence in Europe. Also they help to understand multi-day volatility in continent-scale, near-surface wind speed with important implications for the planning of wind energy deployment across Europe. Finally, a recent forecast bust demonstrates the challenges in predictability imposed by the multi-scale interactions governing weather regime life cycles.

Multi-scale Sensitivity and Predictability of High-Impact Extratropical Cyclones

James D. Doyle, Carolyn A. Reynolds, Clark Amerault

U.S. Naval Research Laboratory, Monterey

Abstract
We explore initial condition sensitivity and mesoscale predictability aspects of the extratropical waveguide and several extratropical cyclones [Desmond, St. Jude's Day, Nina], which had a severe impact on Europe. In this presentation, we will also address multi-scale predictability aspects that impact waveguide as part of the North Atlantic Waveguide and Downstream Impact Experiment (NAWDEX). Results from the adjoint, tangent linear, and nonlinear models for the atmospheric portion of the nonhydrostatic COAMPS model underscore the importance of the low- and mid-level moisture distribution and multi-scale interactions with the waveguide. We utilize the adjoint to understand how small perturbations of moisture, winds and temperature evolve into downstream disturbances that impact the waveguide and cyclones. The adjoint diagnostics indicate that the intensity of severe winds and rainfall in these storms are especially sensitive to perturbations in the mois ture and temperature fields and to a lesser degree the wind fields. The forecast sensitivity to diabatic heating is also quantified using the adjoint. Despite large differences in structure and evolution, cyclone development was always critically sensitive to relatively small filaments of water vapor within the larger-scale plumes of enhanced moisture often similar to an atmospheric river near the waveguide. We place the predictability results in the context of a very active period of waveguide activity that occurred during Dec. 2013-Feb. 2014, which serves to further highlight the importance of moisture sensitivity along water vapor plumes. The results of this study underscore the need for accurate moisture observations and data assimilation systems that can adequately assimilate these observations in order to reduce the forecast uncertainties for these high-impact extratropical cyclones. However, given the nature of the sensitivities and the potential for rapid perturbation and error growth, the intrinsic predictability of these severe cyclones may be limited.

Dynamics of forecast errors in a quantitative PV framework

Marlene Baumgart[1], Michael Riemer[1], Tobias Selz[2], Volkmar Wirth[1], Franziska Teubler[1], Simon Lang[3], George C. Craig[2]

[1]Institut für Physik der Atmosphäre, Johannes Gutenberg-Universität Mainz, [2]Ludwig-Maximilians-University of Munich, [3]ECMWF, Reading

Abstract
High-impact weather is often related to Rossby wave packets near the tropopause. The predictability of high-impact weather is therefore related to the predictability of the associated Rossby wave packet. For medium-range weather forecasts it is still an issue to correctly represent Rossby wave packet evolution and thus the tropopause structure involved in the weather event. In the potential vorticity (PV) perspective, the largest forecast errors are concentrated along the dynamical tropopause. PV errors often organize and amplify within Rossby wave packets near the tropopause. Previous studies indicate the importance of specific processes such as baroclinic instability or diabatic processes to synoptic-scale forecast error growth. The relative importance of the individual processes has, however, not been quantified yet. In this work, we quantify the processes governing PV error growth near the tropopause, i.e., tropopause-near dynamics (influence of upper-level PV anomalies), tropospheric-deep interaction (influence of lower-level PV and potential temperature anomalies), upper-tropospheric divergence (mostly related to latent heat release below), and direct diabatic PV modification. Error growth is analyzed for real case studies of the ECMWF model and for ICON simulations, in which the only 'error' source are differences in the stochastic convection scheme. One of these case studies is related to a Medicane development, which caused an extreme precipitation event over Sardinia in November 2013. The PV framework indicates a large importance of tropopause-near dynamics to synoptic-scale error growth, which highlights the importance of (nonlinear) Rossby wave dynamics to error growth.

HIWeather: Predicting & Warning Weather-Related Hazards

Brian Golding

Met Office, UK

Abstract
The introduction of km-scale convection-permitting Numerical Weather Prediction models has produced a step change in weather forecast guidance. However, current results give only glimpses of what ought to be achievable. With focused efforts by meteorologists in partnership with other physical and social scientists, this breakthrough can produce a revolution in weather-related hazard warnings, saving millions of lives, worldwide. The World Meteorological Organisation's High Impact Weather project (HIWeather) has identified challenges in the forecasting and warning production and delivery chain, which it aims to facilitate research into. Concentrating on short duration hazards, the project's five research pillars address weather processes, hazard modelling, impact modelling, warning communication and evaluation. In my talk, I shall give an overview of HIWeather, its achievements and its plans, focusing on challenges in km-scale prediction in the context of the requirements of decision makers.

Probabilistic forecasting and statistical post-processing methods

Chair: P. Steinle, Tuesday, 15:00

Statistical post-processing of ensemble weather forecasts

Tilmann Gneiting

Heidelberg Institute for Theoretical Studies, Germany

Abstract
Ensemble prediction systems typically are biased and uncalibrated, and so they benefit from statistical post-processing. I will review state-of-the-art approaches for doing this, such as Bayesian model averaging (BMA) and ensemble model output statistics (EMOS) or heterogeneous regression. A major challenges lies in the modeling of physically realistic inter-variable, spatial, and temporal dependence structures in postprocessed forecast fields, for which ensemble copula coupling (ECC) and the Schaake shuffle are attractive options.

An Operational Global System for forecasting Point rainfall and Flash flood risk

Tim Hewson, Fatima Pillosu, Ervin Zsoter
Forecast Department, ECMWF, Reading

Abstract

ECMWF is now post-processing raw gridbox rainfall forecasts (RAW) from its ensemble to deliver point rainfall forecasts (POINT). These new products have many applications and are now being introduced into operations. This presentation will show (i) how the post-processing system operates, (ii) verification scores, (iii) a flash flood case study, and (iv) options for further improvements. The post-processing technique employed is downscaling, from an ensemble gridbox precipitation forecast (a single number, e.g. for a 12h total), to a probabilistic representation, for that gridbox solution, of point rainfall (i.e. for any site within the gridbox). The final gridbox forecast is then the sum of the POINT realisations from each member. The post-processing relies on one being able to predict, a priori, using simple parameters, how the relationships between RAW and POINT will vary. This encompasses sub-grid variability and mean bias. There is clear-cut evidence that these aspects depend strongly on the meteorological setting (e.g. is the rainfall convective), on geography, and on time of year. This will be explained. Clearly if POINT probabilities for extreme totals are elevated, then so is the risk of flash floods. The post-processed output may prove competitive alongside or at least complementary to post-processed output of limited area ensembles. A novel aspect is that a training period of only 1 year was required, which equates to hundreds of years in a traditional site-based post-processing approach. Furthermore forecasts are not confined to sites where we have observations, but are for everywhere. We have verified POINT alongside RAW forecasts using 1 year of global observations. Regarding reliability, for POINT the rank histogram is almost perfectly flat. Regarding resolution, ROC area scores show that the POINT product for 5 days ahead matches the skill of the RAW product for about 1 day ahead (for high totals, e.g. 50mm/12h).

Analog based post-processing of navigation-related hydrological ensemble forecasts

Stephan Hemri
Heidelberg Institute of Theoretical Studies, Heidelberg, Germany

Abstract
Inland waterway transport benefits from probabilistic forecasts of water levels. State-of-the-art hydrologic ensemble forecasts inherit biases and dispersion errors from the atmospheric ensemble forecasts they are driven with. Such systematic errors call for the application of statistical post-processing methods like ensemble model output statistics (EMOS). In this study training periods for EMOS are selected based on forecast analogs, i.e. historical forecasts that are similar to the forecast to be verified. The highly autocorrelated structure of time series of water level calls for custom-tailored measures of similarity. Hydrological series distance (SD), the hydrological matching algorithm (HMA), and dynamic time warping (DTW) prove to be adequate approaches. EMOS forecasts for water level at the gauges Kaub, Cologne, and Ruhrort along river Rhine with training periods selected based on SD, HMA, and DTW compare favorably with reference EMOS forecast s, based on either seasonal training periods or on training periods obtained by dividing the hydrological forecast trajectories into runoff regimes. Reference: Hemri S., and B. Klein (2017), Analog based post-processing of navigation-related hydrological ensemble forecasts, Submitted to Water Resources Research.

Automated flood potential advisories based on vertically integrated atmospheric moisture fluxes

Irina Mahlstein[1], Jonas Bhend[2], Christoph Spirig[2], Mark Liniger[2], Olivia Romppainen-Martius[1]
[1]University of Bern/ Institute of Geography, [2]MeteoSwiss

Abstract
The aim of this project is to estimate the potential for an automated flood early warning system in Switzerland. Earlier work has shown that atmospheric rivers, characterized by integrated water vapor transport (IVT), can cause major flooding events in Switzerland. Exceptionally high values of IVT in conjunction with wind perpendicular to the Alps are necessary for flooding to occur. As atmospheric rivers are large-scale synoptic systems, it should be possible to forecast these in a global numerical weather prediction system with relatively low resolution multiple days in advance. Here, we analyze the forecast quality of IVT forecasts of ECMWF's IFS model. We find that IVT is skillfully predictable at least up to 10 days ahead. This offers a longer time range to prepare for potential flooding events than would be possible when using the high-resolution limited area model COSMO-E providing forecasts up to 6 days ahead. In order to put the forecasts into historic context, we use ERA Interim data to calibrate the IVT forecasts. Calibration of IVT forecasts is achieved by quantile mapping. The calibrated IVT forecast can now be visualized together with the historic data which allows users to decide whether a potentially dangerous situation is arising or not.

Predictability of precipitation over tropical northern Africa using TIGGE, statistical postprocessing and statistical forecasting methods

Peter Vogel[1 2], Tilmann Gneiting[2 3], Peter Knippertz[1], Andreas H. Fink[1], Andreas Schlüter[1]

[1]Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology
[2]Institute for Stochastics, Karlsruhe Institute of Technology
[3]Heidelberg Institute of Theoretical Studies

Abstract
Precipitation forecasts are of high socio-economic importance for agriculturally dominated societies in tropical northern Africa. In the first part of this contribution, we assess the performance of operational global numerical weather prediction (NWP) models against climatological forecasts for accumulation periods of 1 to 5 days for the periods of the West African Monsoon during 2007-2014. To reveal the full NWP potential, we rely on the TIGGE database that contains nine global NWP ensemble precipitation forecasts, correct for systematic calibration errors by applying the state-of-the-art statistical postprocessing techniques Bayesian Model Averaging (BMA) and Ensemble Model Output Statistics (EMOS), and verify against station and satellite-based gridded observations. To the best of our knowledge, this is the first study to assess the quality of raw ensemble and postprocessed precipitation forecasts over tropical northern Africa. For each of the nine ensembles, raw ensemble precipitation forecasts are poor compared to climatology, with low calibration and reliability. It implies that raw ensembles struggle to predict the amount, but also the occurrence of precipitation. BMA and EMOS postprocessed forecasts outperform raw ensemble forecasts, but disappointingly, improvements relative to climatology are small. These results hold for different sub-regions, all years, 1 to 5-day accumulated precipitation forecasts, and for station and gridded observations at scales up to several hundred kilometres. This implies that precipitation forecasts from the world's best numerical weather prediction centers have major deficiencies over tropical northern Africa, demonstrating the lack of good precipitation forecasts for this region. In this situation, statistical forecasts may be a promising alternative. In the second part of this contribution we assess their potential and show that meteorologically interpretable and statistically meaningful spatio-temporal dependencies for precipitation exist. Statistical forecasts that only take advantage of these dependencies already outperform climatological forecasts, and we expect further improvements by adding meaningful predictors.

Taking into account hydrodynamic parameters and initial soil moisture uncertainties in an ensemble-based flash-flood forecasting system

Beatrice Vincendon
CNRM (Météo-France and CNRS)

Abstract
Mediterranean flash floods (FF) are quite devastating. Increasing the lead time of FF forecasts is crucial to better anticipate their impact. Hydrometeorological prediction is affected by several sources of uncertainty. The major uncertainty comes from the quantitative precipitation forecasts (QPF) used to drive the hydrological models. But uncertainty also affects the nitial soil moisture knowledge and the hydrological model himself. In this study, several hydrometeorological ensemble prediction system (HEPS) are designed and compared. They are based on the AROME convective-scale atmospheric model and on the ISBA-TOP hydrological model, which is dedicated to Mediterranean fast responding rivers. The uncertainty on QPF is sampled by two methods. First, an atmospheric ensemble at convective scale based on AROME, AROME EPS, is used to drive ISBA-TOP. The second method consists in introducing perturbations in AROME deterministic outputs. Those perturbations are based on rainfall forecast errors previously studied in term of rainfall amounts and location of the heaviest rains. The obtained scenarii of precipitation can be used to produce an discharge ensemble forecast. Both methods can be combined so as to manage the uncertainty on QPF at several scales and to increase the ensemble size. Another step is to consider the hydrological modelling and initial soil conditions uncertainties. The sensitivity of ISBA-TOP to its parameters and initial soil moisture has been investigated. Perturbation methods varying the three parameters that have the highest impact on discharge simulations as well as initial soil moisture allow to simulate an ensemble of discharge forecasts. Finaly, an HEPS considering several sources of uncertainty can be achieved. The rainfall scenarii from AROME-EPS are used to drive ISBA-TOP on which the perturbation of parameters and initial soil moisture fields is applied. The skill of the different HEPS that have been built has been assessed for several catchments and cases.

Representation of mechanical lifting by subgrid-scale orography using stochastic perturbations

Miriam Hirt
Meteorological Institute Munich, LMU, Munich, Germany

Abstract
We aim to improve the model representation of convection triggering using physically based stochastic parameterization. Our scheme represents the effect of mechanical lifting by subgrid- scale orography on the initiation of convection. The mechanical lifting is parameterized as stochastic perturbations of the vertical velocity which are based on the internal gravity wave formalism and a high resolution orography data set. Thereby the perturbation amplitudes depend on the average stability of the boundary layer, the steepness of the sub-grid scale orography and the intensity of the horizontal wind fields. Spurious pressure perturbations are minimized by also perturbing the horizontal wind field to yield balanced, i.e. 3d non-divergent perturbations. The influence of these perturbations on convective precipitation is examined by considering several case studies with the COSMO model. A complementary stochastic perturbation scheme has already been developed by Kober and Craig (2016). It considers the boundary layer variability and its impact on convection triggering and has been successfully applied to three case studies. Such physically based stochastic parameterizations account for the poor representation of the unresolved scales and thus produce more reliable forecasts and enhance the ensemble spread. They are therefore often considered as a desirable method to represent model error in ensemble forecasts.

Forecast Variability of the blocking system over Russia in summer 2010

Lisa-Ann Quandt
IMK-TRO, KIT, Karlsruhe, Germany

Abstract
The Euro-Russian blocking in summer 2010 was related to high impact weather, including a mega-heatwave in Russia. A set of scenarios for the synoptic evolution during the onset, mature stage and decay of the block are extracted from the THORPEX Interactive Grand Global Ensemble multimodel ensemble forecast. These scenarios represent the key features of the forecast variability of the block and of the resulting surface impacts. Two heat indices and a fire index were computed to highlight the forecast variability in societal impacts. The study is a proof of concept, showing how information about surface impacts can be derived from available operational ensemble forecasts in an effective manner. Comparing the forecast for the heat wave's impact on large spatial domains, and on a near grid point scale, identifies challenges forecasters may face when predicting the development of a heat wave. Moreover, the dynamical processes are identified which were res ponsible for the forecast variability of the block during all three stages of the life-cycle. Although the block's onset was highly predictable, the increase in temperature and the extension of the heat affected area differed between the scenarios. During the mature stage of the block, the variability of its western flank had a considerable influence on the precipitation and heat distribution. Since the blocking was maintained after the analyzed decay in two of three scenarios, the predictability of the decay was low in this forecast. The heat wave ended independently from the block's decay, as the surface temperature and the impact indices decreased in all scenarios. For all phases of the block, its forecast variability was related to the performance of diabatic forcing over the North Atlantic. There were also other relevant dynamical processes (like the interaction with transient eddies) whose importance differed for the three phases of the block's life-cycle.

Predictability of frontal waves and cyclones as a function of scale and intensity

John Methven[1], Thomas H. A. Frame[1], Nigel M. Roberts[2], Helen A. Titley[2]

[1]Meteorology, University of Reading, UK
[2]Met Office, UK

Abstract
At the end of mid-latitude storm tracks the majority of precipitation and high wind events are associated with the passage of cyclones, fronts embedded within them or frontal waves developing on those fronts. Even variation in monthly-averaged precipitation for the UK depends primarily on the fraction of the month that cyclonic features are passing overhead. Therefore, we expect the forecast skill in high impact weather, especially at longer lead times, to depend on the forecast skill for cyclonic features and any bias in cyclone properties with lead time. The statistical properties and skill in predictions of objectively identified and tracked cyclonic features (frontal waves and cyclones) are examined in MOGREPS-15, a global 15-day version of the Met Office Global and Regional Prediction System (MOGREPS). The number density of cyclonic features and area-averaged enstrophy are found to decline with increasing lead-time, with analysis fields containing larger numbers of weaker features which are not sustained past the first day of the forecast. It is found that the feature number density and enstrophy of forecasts produced using model versions that include stochastic energy backscatter saturate at higher values than forecasts produced without stochastic physics. The ability of MOGREPS-15 to predict the locations of cyclonic features of different strengths is evaluated at different spatial scales by examining the Brier Skill of strike probability forecasts: the probability that a cyclonic feature center is located within a specified radius. The skill is found to be maximized for the most intense features, with the spatial scale at which skill is maximized increasing with lead-time from 650km at 12h to 950km at 7 days. Forecast skill remains above zero at these scales out to 14 days for the most intense cyclonic features. This finding has interesting implications for flow dependence in high impact weather predictability.

Forecaster's Dilemma: Extreme Events and Forecast Evaluation

Sebastian Lerch[1], Thordis L. Thorarinsdottir[2], Francesco Ravazzolo[3], Tilmann Gneiting[1 4]

[1]Institute for Stochastics, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2]Norwegian Computing Center, Oslo, Norway
[3]Free University of Bozen/Bolzano, Bozen-Bolzano, Italy
[4]Heidelberg Institute for Theoretical Studies

Abstract
In public discussions of the quality of forecasts, attention typically focuses on the predictive performance in cases of extreme events. However, the restriction of conventional forecast evaluation methods to subsets of extreme observations has unexpected and undesired effects, and is bound to discredit skillful forecasts when the signal-to-noise ratio in the data generating process is low. Conditioning on outcomes is incompatible with the theoretical assumptions of established forecast evaluation methods, thereby confronting forecasters with what we refer to as the forecaster's dilemma. For probabilistic forecasts, proper weighted scoring rules have been proposed as decision-theoretically justifiable alternatives for forecast evaluation with an emphasis on extreme events. Using theoretical arguments, simulation experiments, and a case study on probabilistic wind speed forecasts, we illustrate and discuss the forecaster's dilemma along with potential remedies.

Quantifying the skill in probabilistic forecasts for the sea breeze deriving from large-scale variables

Carlo Cafaro
Department of Mathematics/Meteorology, University of Reading, United Kingdom

Abstract

High resolution (kilometre-scale) regional models can represent the dynamics of mesoscale phenomena that cannot be captured currently in global simulations. They can generate flow structures that are qualitatively similar to observations (for example frontal banding in precipitation). However, for kilometre-scale ensemble forecasts downscaled from global ensemble members, there is no additional observational information so any improvement in probabilistic forecast skill must derive from small scale dynamics and the differences between large-scale members. Here, the prediction of the probability of sea breeze occurrence by the Met Office 2.2 km ensemble (MOGREPS-UK) is compared to a Bayesian statistical model driven by physical parameters derived from the parent global 33 km ensemble (MOGREPS-G). The question is what proportion of forecast skill is derived solely from knowledge of the large-scale environment and what information is gained from downscaling that cannot be represented by this reduction of the problem ? A new method for identifying sea breezes is proposed for deriving the probabilistic forecast of sea breeze occurrence from the MOGREPS-UK ensemble. The Bayesian statistical forecast was created using paired MOGREPS-UK and MOGREPS-G ensemble members as a training dataset. Although MOGREPS-G is not able to represent the dynamics of the sea breeze, it can generate a probabilistic forecast that correlates well (from day to day) with the MOGREPS-UK (2.2km) forecasts. The correlation generally decreases with increasing lead time. This shows that the likelihood of inland occurrence of the sea breeze has predictive skill using only two large-scale parameters and their statistical relationship with small-scale phenomena. The approach has potential applications to the probabilistic prediction of high impact weather.

Session on extreme weather events

Chair: P. Knippertz, Wed. 09:00

Multi-scale predictability of severe weather from a diagnostic perspective

Linus Magnusson

European Centre for Medium-range Weather Forecasts, UK

Abstract Predicting high-impact weather events is a crucial task for forecasting centres and is clearly a multi-scale issue. On the subseasonal timescale, the aim is to predict flow-regimes that have higher likelihood of extreme events. In the medium-range the challenge is to predict the timing, position and duration of the event. However, for some types of extreme weather it is still difficult for current models to capture the intensity even at the shortest scales. As extreme events by nature are rare, and each case is unique, a statistical evaluation is not straightforward. It is therefore necessary to identify key features for the development of the extreme events that are possible to verify and to identify where also less extreme cases will be useful. In the presentation I will give examples of high-impact events to demonstrate the challenges in sub-seasonal, medium-range and short-range predictions and what type of signals are expected. I will give example of evaluation and diagnostics that can be undertaken to better understand the predictability and limitations of the capability.

Role of Rossby wave packets for Northern Hemisphere heat waves

Georgios Fragkoulidis[1], Volkmar Wirth[1], Philipp Zschenderlein[2], Andreas H. Fink[2]

[1]Johannes Gutenberg University, Mainz, Germany
[2]Karlsruhe Institute of Technology

Abstract
Heat waves are projected to become more severe due to global warming, with events like the 2003 (Europe) and 2010 (Russia) heat waves occurring more frequently. Our main objective is to further our understanding on the role of upper-troposphere Rossby wave packets (RWPs) during such cases of high impact weather. Diagnosing RWPs provides information about the local Rossby wave activity. To this end, we use reanalysis data to quantify the statistical connection between RWP amplitudes and lower-troposphere temperature extremes. Although a spatio-temporal variability is evident, it is found that during boreal summer in many regions of the mid-latitudes the probability of lower-troposphere temperature extremes increases considerably with the amplitude of the associated RWPs. Over central Europe, up to 55% of these temperature extremes concur with the highest 20% of RWP amplitudes. Comparison with a hemispheric waviness metric based on Fourier amplitudes sho ws that the non-circumglobal RWP amplitudes are much better suited to quantify the connection with temperature extremes. The advantage of identifying and following the evolution of RWPs rather than planetary waves is also revealed by investigating the role of upper-troposphere dynamics during individual heat waves.

Dynamics and Predictability of the 2016 late summer Heat Waves over Europe

Philipp Zschenderlein[1], Georgios Fragkoulidis[2], Andreas H. Fink[1], Volkmar Wirth[2]

[1]Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Karlsruhe, Germany

[2]Johannes Gutenberg University, Institute of Atmospheric Physics, Mainz, Germany

Abstract

Heat waves have manifold socio-economic and health impacts. Therefore, it is very important to understand the atmospheric dynamics and predictability leading to extremely high temperatures. During the late summer/early fall 2016, Europe was affected by unusually late heat waves between the end of August and middle of September. Primarily, Central and Western Europe were affected by extremely high temperatures. The 44.8 °C maximum temperature observed in Sevilla on 5 September 2016 was the highest on record for any September month at this station. The heat waves were marked by three distinct peaks, accompanied with unusual high geopotential height and temperature values for this time of the year. These successive periods all followed the passage of large-amplitude Rossby wave packet passages which developed over western North America with an amplitude of more than one standard deviation above the August-September average. Lagrangian trajectory analysi s reveal ed, that air masses during the peak of the heat waves originated both from maritime and subtropical regions or stalled in the target region over several days, thereby being effectively heated by solar radiation. Due to subsidence from higher levels, air parcels were warmed while descending to the surface. The ability of the ECMWF Ensemble Forecasts to predict these extreme temperatures was investigated for different forecast lead times. The first and the last heat wave were predictable up to 120h before the event, whereas the second peak showed comparable predictability only 72h prior to the event. The causes of these differences in predictability will be investigated with respect to large-scale Rossby wave dynamics vs. synoptic to mesoscale processes.

The extratropical transition of Typhoon Sinlaku (2008): challenges in modelling and mechanisms determining structural changes

Hilke Lentink
IMK, Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract
The extratropical transition (ET) of a tropical cyclone is often associated with high impact weather. At the same time, the complexity of the structural changes makes it difficult for models to adequately forecast the development. Therefore it is necessary to improve the dynamical understanding of ET, as well as the understanding of the challenges involved in modelling such events. An excellent case study for this goal is the ET of Typhoon Sinlaku in 2008 since it was investigated during the T-PARC field campaign (2008), providing a unique measurement dataset for the analysis of structural changes during ET. This research is divided into two parts. In the first part, the objective is to analyse the sensitivity of the numerical weather prediction model COSMO in simulating the cyclone structure during ET. The model is initialised with different setups, using both standard initial data as well as data in which Sinlaku's vortex is replaced by a more realistic version, using observational data and the piecewise PV inversion technique. In this case study the initialisation of the model plays a key role in obtaining an adequate simulation. A reliable simulation is only obtained when the initial cyclone structure is improved and additionally relocated with respect to land in a high resolution setup. In the second part, the objective is to obtain a better understanding of the mechanisms that determine the structural changes during ET. The actual ET period of Sinlaku was postponed by orographic blocking of low-level midlatitude air. Descending motion played a key role in the changing cyclone structure, resulting in a stable area near the circulation center. The sinking air is caused by three mechanisms: evaporative cooling, frontolysis and a vertical-wind-shear-related dipole in vertical motion. All three mechanisms are vertically co-located and lie over the area of strongest low-level wind speeds.

A Perspective on Forecasting Cyclonic Storms from ECMWF's Meteorological Analysts

Tim Hewson

Forecast Department, ECMWF, Reading, UK

Abstract
Meteorological analysts at ECMWF regularly study aspects of recent and current analyses and forecasts, and compare with verification metrics. The main purpose of this is to identify and study issues with the model handling of different events, including storms, with a particular focus being high impact events. A web-based "daily report" is written each weekday, culminating on Friday afternoons in a weather "discussion" that involves many staff from across ECMWF. The ultimate goal of all this is to accelerate model improvements, and to ensure that ECMWF continues to focus on key user requirements. Most of the analysts used to be forecasters. The winter season 2016-17 delivered a wide range of interesting and on occasion destructive cyclonic storms to northwest Europe. This presentation will draw on the work of the ECMWF analysts, and on follow-up investigations, to highlight various predictability and modelling issues associated with these different cyclones. Model limitations that users still need to be aware of will be highlighted. Windstorm, rainstorm and snowstorm phenomena will all be covered. One key result is that in spite of the huge progress made in NWP in recent years rapid cyclogenesis and related hazards continue to pose major problems for models, even at very short ranges. Sometimes investigations highlight where the ECMWF model can be improved, and also how we can better help the users with new types of product. Examples of progress in these areas will be included.

Predictability of wind gusts in winter storms over central Europe

Florian Pantillon[1], Peter Knippertz[2], Ulrich Corsmeier[2]

[1]IMK-TRO, Karlsruhe Intitute of Technology, Karlsruhe, Germany
[2]Karlsruhe Intitute of Technology, Institute of Meteorology and Climate Research

Abstract
Windstorms associated with low-pressure systems from the North Atlantic are the most important natural hazard for central Europe. Although their forecast has generally improved over the last decades, a detailed prediction of the associated wind gusts is still challenging due to the multiple scales involved. The synoptic-scale predictability of 25 severe storms of the 1995-2015 period is investigated using the homogeneous ECMWF ensemble reforecast dataset. It is assessed with three sets of metrics for the storms' dynamics, impact and spatial extent. The ensemble reforecasts capture the storms' dynamics and impact up to 3 days ahead only, which restricts the use of ensemble mean and spread to relatively short lead times. However, the model has some skill in forecasting the area covered by extreme wind gusts up to 10 days, which indicates clear potential for early warning. At smaller scales, the predictability of wind gusts is investigated in the convection-permitting ensemble prediction system COSMO-DE-EPS, which is run operationally at DWD. The focus is on storms involving mesoscale structures that are not well represented by global models. Case studies suggest that the ensemble is underdispersive at the mesoscale and the ensemble spread at the synoptic scale is mostly inherited from the global multi-model forecast the ensemble is downscaled from. Statistical post-processing methods are therefore tested to improve the forecast of wind gusts in winter storms. Finally, the recent field campaign WASTEX (Wind And STorms Experiment) during the winter 2016/17 in Karlsruhe provides high-resolution observations from a Doppler wind lidar during the passage of low-pressure systems. These allow sampling the mixing of high momentum in the boundary layer that results in the strongest gusts on the ground and cover several types of storms, including severe convection embedded in the cold front and a possible sting jet.

Secondary Cyclogenesis along an Occluded Front Leading to Damaging Wind Gusts: Windstorm Kyrill

Patrick Ludwig
Karsruhe Institute of Technology

Abstract
Windstorm Kyrill affected large parts of Europe in January 2007 and caused widespread havoc. In this study the formation of a secondary cyclone, Kyrill II, along the occluded front of the mature cyclone Kyrill and the occurrence of severe wind gusts as Kyrill II passed over Germany are investigated with the help of high-resolution regional climate model simulations. Kyrill underwent an explosive cyclogenesis south of Greenland as the storm crossed poleward of an intense upper-level jet stream. Later in its life cycle secondary cyclogenesis occurred just west of the British Isles. The formation of Kyrill II along the occluded front was associated (i) with frontolytic strain and (ii) with strong diabatic heating in combination with a developing upper-level shortwave trough. Sensitivity studies with reduced latent heat release feature a similar development but a weaker secondary cyclone, revealing the importance of diabatic processes during the formation of Kyril l II. Kyrill II moved farther toward Europe and its development was favored by a split jet structure aloft, which maintained the cyclone's exceptionally deep core pressure (below 965 hPa) for at least 36 h. The occurrence of hurricane-force winds related to the strong cold front over north and central Germany is analyzed using convection-permitting simulations. The lower troposphere exhibits conditional instability, a turbulent flow, and evaporative cooling. Simulation at high spatiotemporal resolution suggests that the downward mixing of high momentum (the wind speed at 875 hPa widely exceeded 45 m/s) accounts for widespread severe surface wind gusts, which is in agreement with observed widespread losses.

Modeling of Severe Convective System from the 21 August 2007 with the COSMO model

Damian Karol Wojcik
Institute of Meteorology and Water Management - National Research Institute

Abstract

The 21 August 2007 severe convective system (SCS) in the Masurian Lake District brought high public attention in Poland. The SCS led to severe surface wind gusts up to 35 m/s that caused extensive damage and loss of life. At that time, numerical weather prediction (NWP) models were hardly capable of forecasting deep convective events of that type. However, the last decade brought unprecedented improvements to the NWP model dynamics, physics, and computational performance. In particular, the decrease of the horizontal grid length by nearly an order of magnitude resulted in "convection-permitting" non-hydrostatic NWP models that attempt to resolve deep convective flows explicitly. Evaluating the skill of convection-permitting contemporary NWP models in forecasting the 21 August 20017 SCS is thus worthwhile and such evaluation contributes to the growth of public safety. Moreover, climate-change-related increase in frequency of severe weather events is expected to continue throughout the 21st century and their skillful forecasting should be a priority. This presentation consists of two parts. First, the meteorological situation from the 21 August 2007 is described. The description includes a synoptic overview and a discussion of available satellite, radar, and weather station data. In the second part, observational data will be used to assess the quality of convection-permitting numerical forecasts provided by the COSMO NWP model. This comparison allows for identifying key aspects of simulated convective development and necessary data needed for successful SCS prediction. Since the storm developed in an environment weakly forced by synoptic-scale processes it is a specific case that is less common in scientific studies but more demanding for NWP models. The methodology includes sensitivity simulations that assimilate additional data collected in the course of this study that are typically not available for routine NWP simulations.

Improving high impact weather and climate prediction for societal resilience in Subtropical South America: Proyecto RELAMPAGO-CACTI

Juan Jose Ruiz

Centro de Investigaciones del Mar y la Atmosfera, Buenos Aires, Argentina and Univ. of Buenos Aires, Argentina

Abstract Subtropical South America is host to many types of weather and climate hazards. The convective systems that initiate near and apart from the complex terrain of the Andes and Sierras de Córdoba are by many measures the most intense in the world, producing hazards such as damaging winds, hail, tornadoes, extreme and unusual lightning behavior, and flash and riverine flooding. These systems are modulated by interannual, intraseasonal, and synoptic drivers, however multi-scale models suffer from extreme biases in low level temperature and humidity due to their poor representation of organized convection and representation of convection near complex terrain, which hampers predictive skill of relevant processes across all timescales. To address these cross-cutting issues, we have proposed a large, multi-agency international field campaign called RELAMPAGO-CACTI, which will address key gaps in physical process understanding in the production of convective storms in this region. RELAMPAGO (Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations) will be a 24-month hydrological meteorological field campaign, with an intensive observing period 1 Nov – 15 Dec 2018 in the near the Sierras de Córdoba (SDC), the Andes foothills near Mendoza, and the region near São Borja, Brazil. A complementary funded 7-month U.S. Department of Energy field campaign called Clouds, Aerosols, and Complex Terrain Interactions (CACTI), which will focus on detailed observations of cloud and aerosol lifecycle near the SDC while an intensive observing period featuring aircraft observations will match RELAMPAGO's. While collecting the observations will enhance knowledge of the processes acting to modulate extremes in the region, a coordinated modeling effort will aim to evaluate coupled weather, climate, and hydrologic models using RELAMPAGO-CACTI observations. In addition, partnerships with the Servicio Meteorológico Nacional (SMN) of Argentina and Brazil's Centro de Previsão de Tempo e Estudos Climáticos (CPTEC), as well as related international and local societal impacts projects such as the World Meteorological Organization's High-Impact Weather project will enable improved end- to-end impacts predictions in this vulnerable region.

Session on high impact weather in urban areas

Chair: S. Grimmond, Wed., 13:30

From urban meteorology, climate and environment research to integrated city services

Sue Grimmond[1], A. Baklanov[2], V. Bouchet[3], Luisa Molina[5], Gufran Beig[6], Heinke Schluenzen[7], Jhoon Kim[8], Pablo Saide[9], Jianguo Tan[4], Ranjeet Sokhi[10], Paulo Saldiva[11], Deon Terblanche[2], X. Tang[2]

[1]University of Reading, UK, [2]World Meteorological Organization (WMO), [3]Environment and Climate Change Canada (ECCC), Montreal, Canada Switzerland, [4]Chinese Meteorological Administration, Shanghai, China, [5]Molina Center for Energy and Environment, [6]Indian Institute of Tropical Meteorology, India, [7]University of Hamburg, Germany, [8]Yonsei University, Seoul, Korea, [9]Chile curently at NCAR, Boulder, USA, [10] University of Hertfordshire , Hatfield · Centre for Atmospheric and Instrumentation Research (CAIR), [11]University of Sao Paulo, Faculty of Medicine, Sao Paulo, Brazil

Abstract
Accelerating urban population growth, especially in developing countries, has become a driving force of human development. Crowded cities are centres of creativity and economic progress, but polluted air, flooding and other climate impacts mean urban environments also face significant weather, climate and environment-related challenges. Increasingly dense, complex and interdependent urban systems make cities vulnerable: a single extreme event can lead to a widespread breakdown of a city's infrastructure often through domino effects. Many organisations, including the World Meteorological Organization (WMO), recognize that rapid urbanization necessitates new types of services which make the best use of science and technology. Such Integrated Urban Weather, Environment and Climate Services should assist

cities in facing hazards such as storm surges, flooding, heat waves, and air pollution episodes, especially in changing climates. The aim is to develop urban services that meet the special needs of cities through a combination of dense observation networks, high-resolution forecasts, and multi-hazard early warning systems, and long-term urban climate projections and modelling for urban planning for sustainable and resilient cities. A number of recent international studies have been initiated to explore these issues. This presentation will provide a brief overview of recent research programs and activities in urban hydrometeorology, climate and air pollution; describe the novel concept of urban integrated weather, climate and environment related services; and highlights research needs for their realisation.

SURF: Understanding and Predicting Urban Convection and Haze

Xudong Liang, S. Miao, J. Li, R. Bornstein, X. Zhang, Y. Gao, F. Chen, X. Cao, Z. Cheng, C. Clements, W. Dabberdt, D. Ding, J. J. Dou, J. X. Dou, Y. Dou, C. S. B. Grimmond, J. Gonzalez-Cruz, M. Huang, S. Ju, Q. Li, D. Niyogi, J. Quan, J. Sun, J. Z. Sun, M. Yu, J. Zhang, Y. Zhang, X. Zhao, Z. Zheng, M. Zhou
State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing, China

Abstract
More than half the global population lives in cities, many with more than 10 million inhabitants (so-called mega-cities). Urbanization modifies atmospheric energy and moisture balances, forming distinct features, e.g., urban heat islands (UHIs) and enhanced/decreased precipitation. These produce significant challenges to science and society, including rapid and intense flooding, heat waves strengthened by UHIs, and air pollutant haze. With the support of The Chinese Ministry of Science and Technology, The Study of Urban-Impacts on Rainfall and Fog/Haze (SURF), brought together international expertise on observations and modeling, meteorology and atmospheric chemistry, and research and operational forecasting. Its overall science objective is a better understanding of urban, terrain, convection, and aerosol interactions for improved forecast accuracy. Beijing is the test case, but the improved understanding is transferable to many large cities globally. Specific objectives include: a) promote cooperative international-research to improve understanding of urban summer convective precipitation and winter particulate episodes via extensive field studies; b) improve high-resolution urban weather and air quality forecast-models; and c) enhance urban weather forecasts for societal applications, e.g., health, energy, hydrologic, climate change, air quality, urban planning, and emergency-response management. Preliminary climatological and case study observational and modeling results are obtained. New scientific insights from SURF include confirmation of the turbulence-wind relationship, i.e., the HOST, over urban canopies, which demonstrates contributions of large coherent eddies in turbulent mixing and energy conservations in interactions between kinetic and thermal energies as stated in Sun et al. (2016). A new composite diagnostic method more accurately estimates diurnal variations of urban PBL-depth using SURF Doppler LiDAR turbulence intensities. It will be applied to reduce systemic differences between simultaneous fixed and mobile LiDAR observations and will be incorporated into IUM operational models to evaluate its role in forecast improvement, as their urbanization schemes require additional development to reduce predicted urban temperature and wind biases. A new anthropogenic cooling-tower latent-energy module was added

to the urban weather model; it reduced model biases, but more work is needed. Analyses of energy balance fluxes from the 325 m Beijing tower and a nearby suburban tower showed reasonable differences, which will be useful in this effort. A SURF “golden case” involving a bifurcating summer convective thunderstorm event was analyzed and correctly simulated with the IUM urbanized model, and its outputs were used to gain insights into bifurcation mechanisms (i.e., deep high-pressure perturbations and downward vertical velocities); other SURF storms will be analyzed for additional insights. Regional and urban aspects of a SURF haze episode were analyzed and correctly simulated with the IUM photochemical model to better understand 4-D transport mechanisms. Urban land surface, anthropogenic heat, and emission impacts on such events will be further investigated. Many challenges still need investigation within the scope of SURF, e.g. development of advanced data assimilation methods for the dense and diverse observations at the urban scale, e.g., aerosol PSDs. While the BEP and BEM urban parameterizations represent current state-of-the-art for high resolution urban forecast models, problems still existed in their estimation and partition between latent and sensible anthropogenic heat components, and for their vertical distributions. The comprehensive SURF data set thus presents unique opportunities to test, calibrate, and develop improvements for such models, as they allow for unique model performance assessments, parameterization development, and golden-case study analyses. Of interest to SURF is to explore new boundaries of high-resolution modeling (to subkilometer scales) for a variety of summer and winter conditions. As urban precipitation-processes involve large-scale and urban forcing, as well as cloud microphysics modifications from natural and urban CCN, aerosol impacts on urban precipitation are still largely unknown. SURF may answer these questions by its planned urbanization of WRF-Chem and by application of the new model to its golden case data sets.

Urban-Rural Temperature Differences in Lagos Metroplois using Geospatial Techniques and Insitu Observations

Ojeh Vincent
WASCAL GSP, Dept of Meteorology and Climate Science,Federal University of Technology, Akure

Abstract
Temperature in the city is modified by urbanisation and human activities as natural vegetation is removed to make room for development. This makes the city warmer than the surrounding rural neighbourhood. The land surface temperature (LST) differences from 1984-2013 in 15 locations using daytime Landsats 5,7 and 8 imageries as well as hourly temperature differences (Tu-r) between the city core (City Hall) and rural area (Okoafo,in the outskirt) of Lagos using one year of meteorological observation and synoptics from June 2014 to May, 2015 are presented. This paper describes results on the Lagos urban heat island (UHI). To date, this subject has not been substantially studied in Nigeria using both remotely sensed and insitu observation data because of the lack of attention to urban meteorology during the last decade thus studies like this is scarce in Nigeria and in Lagos. Results show that LST is increasing with mean daytime UHI intensity of 3.32 °C, 5.33 °C and 8.65°C in 1984, 2000 and 2013 respectively. Observation results show that UHI varies with days of the week, seasons and with synoptic parameters of solar radiation, wind speed and direction and speed and atmospheric pressure and noon and midnight conditions. Results show that the UHI exits throughout the day in the rainy season months but both the UHI and Urban cool island (UCI) occurs during the day and night respectively in the dry season months and in the pre-rainy/dry season transition months. The UCI occurs between 5-6 hours in the afternoon in the dry season. During weekdays heat island intensity of 7.0°C at midnight on Fridays and as high as 8.3°C early morning on Mondays have been observed. The UHI effect is observed at midnight in all months of the year with maximum of 6.5°C in January and minimum of 0.7°C in June.

Characterization of rainfall events and correlation with reported disasters: A case in Cali, Colombia

Cesar Canon-Barriga, Bernhard Tischbein, Janos Bogardi

Zentrum für Entwicklungsforschung, Bonn, Germany

Abstract

Flood maps generally display the area that a river might overflow after a rainfall event takes place, under different scenarios of climate, land use/land cover, and/or failure of dams and dikes. However, rainfall is not limited to feed runoff and enlarge the river: it also causes minor disasters outside the map's highlighted area. The city of Cali in Colombia illustrates very well this situation: its flat topography and its major critical infrastructure near the river make it flood-risk prone; a heavy rainfall event would potentially deplete drinking water, electrical power and drainage capacity, and trigger outbreaks of water-borne diseases in the whole city, not only in the flooded area. Unfortunately, the government's disaster prevention strategies focus on this flooded area and usually overlook the aftermath of these minor disasters for being milder and scattered. Predicted losses in flood maps are potentially big, while those from minor disasters over the city are small but real, and citizens, utility companies and urban maintenance funds must constantly take them over. Mitigation and prevention of such minor disasters can save money for the development of the city in other aspects. This paper characterizes hundreds of rainfall events selected from 10-min step time series from 2013 to 2017, and finds their correlation with reported rainfall-related disasters throughout Cali, identified by date and neighborhood. Results show which rainfall parameters are most likely to indicate the occurrence of such disasters and their approximate location in the urban area of Cali. These results, when coupled with real-time observations of rainfall data and simulations of drainage network response, may help citizens and emergency bodies prioritize zones to assist during heavy storms. In the long term, stakeholders may also implement low impact development solutions in these zones to reduce flood risks.

High-resolution forecasts and radar observations of the 7 June 2016 Hamburg Tornado

Peter Hoffmann[1], Claire Merker[2], Katharina Lengfeld[3]

[1]Department of Mathematics, University of Hamburg, Germany
[2]Meteorological Institute, University of Hamburg [3]Deptartment of Hydrometeorology, DWD

Abstract
A tornado hit the northeastern suburbs of Hamburg on 7th June, 2016. Even though the tornado had an estimated strength of upper end F1 on the Fujita scale and touched down in a densely populated area, it caused only property damage but no injuries or fatalities. In order to resolve such a tornado in a numerical model very high resolution of about 10 m are necessary. Due to high demand on computing power and on data storage of these very high-resolution models, mesoscale numerical forecast models with resolutions of about 1 km are used in practice. They are capable of simulating supercells from which tornados can develop. High-resolution forecasts of the tornado event in Hamburg are conducted with the open source Conformal Cubic Atmosphere Model (CCAM). A three step downscaling method is used to obtain a spatial resolution of 1 km. Initial conditions are taken from the NCEP analysis. To account for urban effects on the atmosphere, CCAM employs a modified TEB parameterization. Observations from a single polarized X-band radar covering the urban area of Hamburg with 60 m spatial and 30 s temporal resolution are used as validation dataset. In contrast to the national C-band radar network, the X-band radar is capable of capturing the hook echo of the tornado as well as the circular pattern in rain rates, because of its higher resolution in space and time. We will present the CCAM simulation of the Hamburg tornado as well as severe weather indices computed from the model output. Forecast validation with X-band radar observations reveals that CCAM simulates a strong convective cell only a few kilometers from the observed tornadic cell with a small time delay. In addition, the calculated severe weather indices show a potential for tornadic thunderstorms.

Session on cloud and PBL processes

Chair: P. Steinle, Tuesday, 09:00

Sub-kilometer Challenges in Convective Boundary-layer Modeling

Jimy Dudhia
NCAR, Boulder, USA

Abstract
The primary scales of transport in the convective boundary layer are below the grid scale of typical NWP models and have to be parameterized. However, even at 1 km grid sizes, some differences emerge in how different treatments of the sub-grid scale affect grid-scale structures that may be important for the forecast. This talk will outline how PBL parameterizations of various types handle being run at higher resolutions down to sub- kilometer scales, and will infer from LES simulations what a more correct behavior should be. Schemes are now being proposed to work more correctly across this so-called grey zone between the parameterization of, and resolving, the primary eddies.

Variability and clustering of mid-latitude summertime convection

Stephan Rasp, Tobias Selz, George C. Craig

Meteorological Institute, Ludwig-Maximilian-University, Munich

Abstract
Stochastic parameterizations of convection, based on simple models of subgrid convective variability, have shown a lot of promise for the advancement of weather and climate simulations. Craig and Cohen (2006; CC06) proposed one such model, based on statistical physics. It assumes a random distribution of the mean-mass flux amongst uncorrelated, non-interacting clouds. This theory predicts a linear scaling of the domain-integrated mass flux variance with the mean mass flux, and an exponential distribution of the individual cloud mass fluxes. In idealized simulations of tropical convection these assumptions and predictions have been shown to hold well. In this study, we test the theory in simulations of real mid-latitude weather. For this purpose we set up 50 member ensemble simulations for 12 days of high-impact weather over Germany. The individual clouds are randomly shuffled by a stochastic boundary layer perturbation scheme. Our results show: The mass flux variance scales linearly over a wide range of scales in agreement with the CC06 theory; the individual cloud mass flux distribution is close to exponential if overlapping cloud objects are separated; unseparated clouds follow a power-law distribution more closely. There are two key systematic deviations in the simulated mass flux variability compared to theory: First medium scales around 50 km have larger variability and second there is a clear diurnal cycle with larger variability in the morning and evening hours. The latter signal is attributed to cloud clustering. Our results support to stochastic parameterizations based on the CC06 theory, but we also suggest ways of improving the representation of convective variability, particularly with regard to cloud organization.

Impact of idealized soil moisture heterogeneity on deep convection

Florian Baur
Meteorological Institute, Ludwig-Maximilians-University Munich, Germany

Abstract
In modern convective-scale ensemble prediction systems different sources of uncertainty are accounted for: initial condition uncertainty, lateral boundary condition uncertainty and the uncertainty inherent in the physical parameterizations. However, research on the relative role of various lower boundary uncertainties (e.g. orography, soil conditions, land use) is in its infancy. It is examined in the present study by introducing idealized soil moisture heterogeneity into realistic simulations with the COSMO model at convective scale resolution. A series of COSMO experiments at 2.8 km grid spacing is performed for various days during the High Impact Weather period of early June 2016 in central Europe when weak synoptic forcing conditions were prevailing resulting in severe flash floods. Under such synoptic conditions the initiation of deep convection is highly dependent on local, small scale effects in the planetary boundary layer. As the soil conditions are a crucial factor influencing the boundary layer, their influence on deep convection and precipitation is investigated by explicitly perturbing the soil moisture. In order to gain understanding how perturbations of surface parameters on different scales affect the precipitation forecast, the relative impact of soil moisture heterogeneity is examined applying different soil moisture patterns. Preliminary results suggest that perturbations of the initial soil moisture conditions on different scales introduce substantial variability in the precipitation forecast. Large-scale soil moisture perturbations seem to show a positive soil moisture precipitation feedback, whereas heterogeneous soil moisture perturbations using a chessboard pattern with different tile sizes show a negative feedback locally.

Sensitivity of clouds and precipitation to surface inhomogeneities under different synoptic conditions over Germany

Linda Schneider
Karlsruhe Institut für Technologie, IMK-TRO

Abstract
The evolution of deep moist convection and subsequent precipitation is strongly linked to the heterogeneity of the underlying surface. Mountains, for example, have a strong influence on the wind field by blocking, flow deviation and/or lifting of air masses but also thermally induced secondary circulations are important. The soil moisture content, on the other hand, primarily influences the surface energy budget and leads to a partitioning of the available energy into sensible and latent heat. Not only do these effects interplay with each other, their strength also might depend on the synoptic conditions. This complexity makes it difficult to properly represent precipitation in numerical weather models due to insufficient understanding and description of physical processes. Within this study we investigate the effect of terrain structure and soil moisture on deep moist convection over Germany, using the COSMO model at high spatial resolution (horizontal grid length of 500 m). Sensitivity studies with modified terrain height and soil moisture were performed for six days. The numerical results show that role of individual mountains is complex and depend on the synoptic conditions. Under weak synoptic forcing, the low-level wind convergence strongly influences the initiation of deep convection, whereas the transport of moisture plays a more dominant role under strong synoptic forcing. The results from this study demonstrate the complexity of multiple processes on different spatial scales for the initiation of deep convection over complex terrain. Within this work we present the findings regarding the surface inhomogeneities in the context of different synoptic forcings to assess the importance of the processes involved for different conditions.

Physically based stochastic perturbations in the boundary layer to represent precipitation and streamflow forecast uncertainty with WRF-Hydro

Joel Arnault
Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Atmospheric environmental Research, Garmisch-Partenkirchen, Germany

Abstract
Fully coupled atmospheric hydrological modeling systems, such as WRF-Hydro, allow for modeling of the complete regional water cycle, from the top of the atmosphere, via the boundary layer, to the land surface, the unsaturated zone, and the flow in the river beds. Such a coupled model like WRF-Hydro can therefore be used to forecast any component of the water cycle, not only precipitation as traditionally done, but also river streamflow and eventually floods. Forecast uncertainty is usually evaluated with a model ensemble. The planetary boundary layer (PBL) physically based stochastic perturbation (PSP) scheme was originally developed in the COSMO model in order to represent forecast uncertainty in convective precipitation (Kober and Craig 2016). This PSP scheme has recently been adapted to the WRF / WRF-Hydro modeling system. The aim of this study is to investigate the potential of the PSP scheme to represent both forecast uncertainties in precipitati on and s treamflow. The case of the intense precipitation events and peak discharge observed in the Inn river basin, Austria, Germany, in the beginning of June 2010, is chosen as an example application. An ensemble of WRF-Hydro forecast simulations is operated using the ECMWF deterministic forecast data and varied PBL schemes. This ensemble is compared with another WRF-Hydro ensemble based on varied PSPs. Results are validated with data from the European Climate Assessment & Dataset and from the Global Runoff Data Centre.

Predictability of ice clouds

Peter Spichtinger
Institute for Atmospheric Physics, Johannes Gutenberg University, Mainz, Germany

Abstract
Ice clouds occur quite frequently in the tropopause region. Since they are usually widespread in the horizontal direction, they have the potential for changing temperature gradients due to diabatic feedbacks with the environment. On the other hand, these clouds often show internal structures, which might also of importance for the diabatic feedback, since inhomogeneous media have different radiative properties than homogeneous ones. Unstable equilibrium states can serve as source for spatial structures, as well known from theory of reaction-diffusion equations (e.g. Turing, 1952). Therefore prediction of possible steady states of ice clouds is important for first estimations of their feedback effects. We develop a simplified ice cloud model and use theory of dynamical systems for determination of possible steady states in phase space. In a first step we investigate the situation of a constant large-scale forcing, which lead to Hopf bifurcations (stable focus vs. stable limit cycle attractors). The system can be characterized as a non-linear oscillator (Spreitzer et al., 2017). In a second step forcing by monochromatic waves is investigated. Despite of the simple structure of the forcing, the system shows very different qualitative behaviour, depending on amplitude and frequency of forcing, e.g. period doubling, quasiperiodic behaviour and even irregular regimes. A first qualitative overview about the predictability of ice clouds is derived from the phase diagram.

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Poster presentations (Monday, 14:35 - 16:00)

Session on multi-scale prediction systems

An additive scheme for treating model error in ensemble Kalman filter

Matthias Sommer
Hans Ertel Centre for Weather Research, LMU

Abstract
Data assimilation algorithms require an accurate estimate of the uncertainty of the prior (background) field that cannot be adequately represented from the ensemble of numerical model simulations. Partially, this is due to the sampling error that arises from the use of a small number of ensemble members to represent the background error covariance. It is also partially a consequence of the fact that the geophysical model does not represent its own error. Several mechanisms have been introduced so far to alleviate the detrimental effects of misrepresented ensemble covariances, allowing for the successful implementation of ensemble data assimilation techniques for atmospheric dynamics. One of the established approaches in ensemble data assimilation is additive inflation, which consists in perturbing each ensemble member with a sample from a given distribution. This results in a fixed rank of the effective model error covariance matrix. In this presentation, a more flexible approach is introduced where the model error samples are treated as additional synthetic ensemble members, which are used in the update step of data assimilation but are not forecasted. This way, the rank of the model error covariance matrix can be chosen independently of the ensemble. The effect of this altered additive inflation method and conventional additive inflation on the performance of the filter is analyzed here. In addition methods for specifying the model error samples are discussed.

Ensemble-Type Kalman Filter Algorithm conserving Mass, Total Energy and Enstrophy

Yuefei Zeng
Hans Ertel Centre for Weather Research, LMU

Abstract
For the numerical discretization schemes, the violation of the enstrophy conservation causes a systematic and unrealistic energy cascade towards the high wave numbers. The same also holds for the data assimilation scheme where the total energy, enstrophy and divergence could be strongly affected by the data assimilation settings. In this paper, we construct the ensemble data assimilation algorithm that conserves mass, total energy and enstrophy. The algorithm uses the B-spline functions for localization and the sequential quadratic programming to impose these nonlinear constraints. Experiments with selected constraints are performed using a 2D shallow water model. It is found that all experiments exhibit comparable RMSE with a slight advantage for ones with the conservation constraint on the enstrophy. However, for the kinetic energy and enstrophy spectra, the experiments with the enstrophy constraint are considerably closer to the true spectra in particular at the smallest resolvable scales. Therefore, imposing the conservation of enstrophy within the data assimilation effectively avoids the spurious energy cascade of rotational part and thereby successfully suppresses the noise generated by the data assimilation algorithm. The 14-day deterministic free forecast, starting from the initial condition enforced by both total energy and enstrophy constraints, produces the best prediction. The same holds for the ensemble free forecasts.

Session on scale interactions and error growth

Mesoscale dynamical regimes in the midlatitudes

George Craig and Tobias Selz
Meteorological Institute, LMU Munich

Abstract
The atmospheric mesoscale covers phenomena ranging in scale from tens to many hundreds of kilometres. Unlike the synoptic scale, where the flow remains close to geostrophic balance, there is no known dynamical approximation that applies to the broad spectrum of mesoscale motions. In this work, the space-time energy spectrum is computed from a numerical simulation of weather for a 7 day period over Europe. It is found that the largest contribution to kinetic energy is associated with speeds of a few metres per second, typical of advective motions. Estimating non-dimensional parameters from the model output for different space and time scales allows the identification of five distinct dynamical regimes. The mesoscale advective regime that contains the most energy is found to satisfy a version of the weak temperature approximation where divergent motions are forced by diabatic processes, although the accuracy of the approximation is weaker than for geostrophic balance on larger scales.

Amplification of the Downstream Wave Train during Extratropical Transition: Sensitivity Studies

Julia Keller
Deutscher Wetterdienst, Offenbach, Germany

Abstract
A tropical cyclone (TC) undergoing extratropical transition (ET) may support the amplification of a Rossby wave train in the downstream midlatitudes. Within the context of downstream baroclinic development, the TC acts as an additional source of eddy kinetic energy (). Previous studies concluded that the impact depends, in particular, on the phasing between the TC and the midlatitude flow and the continuation of the generation during ET. These studies did not quantify the impact of ET on the within a downstream Rossby wave train. The present study uses ensemble sensitivity analysis to examine the sensitivity of downstream Rossby wave train amplification to the budget of the transitioning TC and of the upstream midlatitude features for Typhoon Choi-Wan (2009) and Hurricane Hanna (2008) in ECMWF ensemble forecasts. The amplification of the downstream wave train is measured using the amplitude of its associated maxima. The sensitivity of the maximum's intensity at a particular forecast time to the budget terms of the TC and the upstream midlatitudes at earlier forecast times is determined. The results show that increasing the budget terms within Choi-Wan (Hanna) by one standard deviation can result in an up to 36% (23%) more intense downstream maximum. This is favored by the phasing between Choi-Wan and the midlatitude trough, and the reintensification of Hanna, respectively. By contrast, weaker contributions to downstream Rossby wave amplification arise from budget terms associated with flow fea tures in the upstream midlatitudes.

Storm structure, tropopause evolution, and associated predictability during the extratropical transition of Karl (2016)

Michael Riemer
IPA, JGU, Mainz, Germany

Abstract
Tropical cyclones that undergo extratropical transition (ET) may cause high-impact weather, with Sandy (2012) being an extreme example. The storm evolution during ET is associated with significant forecast uncertainty. This uncertainty affects the jet in the vicinity of ET and from there disperses downstream. Furthermore, high-impact weather in the downstream region has been linked to upstream ET events. The large forecast uncertainty is due to the multi-scale nature of the interaction between the tropical cyclone and the midlatitude flow, ranging from the storm's inner-core cloud processes to the dynamics of Rossby wave packets. We present a process-based, multi-scale study with a focus on the relation of the inner-core convection, storm structure during transition, and the associated tropopause structure. The ET of tropical storm Karl in the North Atlantic is investigated, which occurred during SHOUT and the NAWDEX campaign in 2016. Karl merged during its ET with a concurrently developing midlatitude cyclone. The resulting cyclone exhibited low predictability, making flight planning during NAWDEX difficult. Furthermore, downstream of Karl, heavy precipitation severely affected the Norwegian coast a few days later. Our results indicate that convective-scale uncertainties quickly project on the translation speed during ET, which here had a large impact on the center of the resulting extratropical cyclone and the deformation of the associated upper-level trough. The impact on downstream predictability, however, was relatively small in this case. Potential reasons for the lack of a significant downstream response are discussed.

The downstream impact of dropsonde and extra radiosonde observations conducted during the NAWDEX field campaign in 2016

Matthias Schindler[1], Martin Weissmann[1], Andreas Schäfler[2], Gabor Radnoti[3]

[1]Hans-Ertel Centre for Weather Research, Ludwig-Maximilians-University Munich
[2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Oberpfaffenhofen
[3]ECMWF, Reading

Abstract
Dropsonde observations from three research aircrafts in the north-Atlantic region as well as several hundred additionally launched radiosondes in Canada and Europe were collected during the transatlantic field campaign NAWDEX in autumn 2016. Complemented by dropsonde observations obtained during the SHOUT field campaign in the western Atlantic, this unique dataset was assimilated within the framework of cycled data denial experiments performed with the numerical model of ECMWF. Data assimilation diagnostics such as first guess departure and forecast sensitivity to observation are evaluated and compared to results of Environment Canada and the Naval Research Laboratory. The presented approach enables an investigation of the observational impact on downstream weather evolution as well as an evaluation of model errors and their potential sources as related to specific weather features such as warm conveyor belts.

The North Atlantic Waveguide and Downstream Impact Experiment (NAWDEX)

Andreas Schäfler

Institute of Atmospheric Physics, German Aerospace Center, Oberpfaffenhofen, Germany

Abstract
The North Atlantic Waveguide and Downstream Impact Experiment (NAWDEX) was an international field campaign in autumn 2016 that explored the impact of diabatic processes on disturbances of the jet stream and their influence on downstream high-impact weather. An overview on the science objectives and the 49 research flights is given that were performed with the German High Altitude and LOng Range Research Aircraft (HALO), the Deutsches Zentrum für Luft- und Raumfahrt (DLR) Dassault Falcon 20, the French Service des Avions Français Instrumentés pour la Recherche en Environnement (SAFIRE) Falcon 20, and the British Facility for Airborne Atmospheric Measurements (FAAM) BAe 146. The synoptic situation and related predictability during the observation period from 17 September to 22 October 2016 is depicted. NAWDEX featured three sequences of upstream triggers of waveguide disturbances, their dynamic interaction with the jet stream, a subsequent downstream development, and eventual high impact weather over Europe. Examples of observations are presented to highlight the wealth of phenomena that were sampled, the comprehensive coverage and the multi-faceted nature of the measurements.

Session on probabilistic forecasting and statistical post-processing methods

On the multiday time evolution of ensemble variance: Case studies with the COSMO-E ensemble

Christina Klasa[1], Marco Arpagaus[2], André Walser[2], Heini Wernli[1]
[1]ETH Zurich, Zurich, Switzerland, [2] MeteoSwiss, Zurich, Switzerland

Abstract
The multiday time evolution of ensemble variance of the horizontal wind is investigated with a convection-permitting ensemble for three case studies characterized by different predictability levels of precipitation. To relate the variance growth to dynamical features, the horizontal wind is decomposed into non-divergent and irrotational components. Ensemble variance growth of the irrotational wind strongly depends on moist convective activity. During convective episodes, variance of the irrotational wind is increased, while it decreases when convective activity ceases. Variance of the non-divergent wind is related to the variability of the large-scale flow and is, under convective conditions, additionally increased by interactions between both wind components. Therewith, the time evolution of ensemble variance highly depends on the synoptic conditions and thus on the predictability level of the event. To disentangle the processes relevant to the time variation of ensemble variance, different ensemble experiments are compared. Model physics perturbations (SPPT) increase variance of the irrotational wind during convective episodes, which have a low predictability level of precipitation, and are rather neutral otherwise. In contrast, enhanced lateral boundary condition perturbations augment variance of the irrotational and non-divergent wind in case of strong large-scale advection, i.e., when the predictability level of precipitation is higher.

Early warning products for severe weather events derived from operational medium-range ensemble forecasts

Mio Matsueda[1], Tetsuo Nakazawa[2]
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Abstract
Accurate predictions of severe weather events are important for the society, economy, and environment in regions affected by such events. In the present study, the development and testing of a suite of prototype ensemble-based early warning products for severe weather events, which are now routinely available at $http : //gpvjma.ccs.hpcc.jp/TIGGE/tigge_extreme_prob.html$ (the TIGGE Museum), are reported. The early warning products are based on operational medium-range ensemble forecasts from four of the leading global numerical weather centres: ECMWF, JMA, NCEP, UKMO. In these products, the forecast probability of the occurrence of severe weather events, including heavy rainfall, strong surface winds, and high/low surface temperatures, is defined based on each model's climatological probabilistic density function. Several case studies have demonstrated the ability of the products to successfully predict severe events, including the Russian heatwave in 2010 , the 20 10 Pakistan floods, and Hurricane Sandy in 2012. The construction of a grand ensemble by combining four single-centre ensembles can improve the probabilistic skills of forecasts of severe events, up to a lead time of +360h. The improvements in forecast skills are more pronounced for severe surface temperature and precipitation. The grand ensemble provides more reliable forecasts than single-centre ensembles, particularly with respect to strong wind speeds and severe temperature, aiding the advance detection of severe weather events to help mitigate the associated catastrophic damage, especially in developing countries.

An independent verification metric for observation impact assessment

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Abstract

The assessment of observation impact is crucial to optimize the use of observations in numerical weather prediction. Over the past years different adjoint as well as ensemble methods for the assessment of observation impact have been developed. So far, little attention was given to the choice of the verification metric. Most studies on observation impact used the difference between the forecast and a subsequent analysis expressed in terms of energy (total energy norm) as verification metric. However, this is not optimal for many reasons: The error of the analysis is correlated with that of the forecast, the analysis is potentially affected by model biases, and the total energy does not really reflect the quantities that forecast users are most interested in (such as precipitation and surface wind/temperature). Recent studies introduced observation based verification metrics and demonstrated their benefits for observation impact assessment. This study e xtends t his approach and applies a variety of different metrics for verification - including independent radar observations. The investigated data assimilation system is the operational convective-scale ensemble system of Deutscher Wetterdienst (KENDA/COSMO-DE). We used an ensemble forecast sensitivity to observation impact (EFSOI) method to evaluate the contribution of various observations to the reduction in forecast error. Our study compares different observation-based verification metrics for a six-week high impact weather period in summer 2016. This revealed a particular sensitivity of the impact to model as well as observation biases and sensitivity studies indicated that even small biases can have an influence on the assessed impact. For this reason, we recommend to use independent observations for verification and to compare different verification metrics which ensures a reliable assessment of the impact.

High Impact Weather Prediction over Central and West Africa using WRF-Var Model: A case study

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Abstract

This study evaluates the ability of a WRF model to capture the spatial distribution and the magnitude of atmospheric parameters over Western and Central Africa, as well as the associated atmospheric and near surface conditions. We use the Weather Research and Forecasting (WRF) regional model. Simulations are initialized with the Global Forecast System (GFS) data and Sea Surface Temperature (SST) data. Analyses are updated with the three dimensional variational (3DVAR) technique using prep-bufr. Era-I and TRMM are used as references data. WRF accurately simulates the spatio-temporal propagation and the zonally extended structure of rainfall, as well as of dew point temperature.The results show that rainfall is less likely to occur in those areas where the model indicates no precipitation than it is elsewhere in the domain. Rainfall is more likely to occur in those regions where precipitation is predicted, especially where the predicted precipitation amounts are largest. The probabilities of rainfall forecasts found to possess skill as measured by the Pierce score. Uncertainties in the simulation of intense events in the study domain were noticed.

Predicting the Probability of Lightning Occurrence with Generalized Additive Models

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Abstract
This study investigates the predictability of lightning in complex terrain. The main objective is to estimate the probability of lightning occurrence in the Alpine region during summertime afternoons (12-18 UTC). Predictability is investigated for 3 spatial resolutions, 64 x 64 km^2, 32 x 32 km^2 and 16 x 16 km^2, and 5 forecast horizons from day 1 to day 5.

Lightning observations are obtained from the ALDIS lightning detection network. The probability of lightning occurrence is estimated using generalized additive models (GAM). GAMs provide a flexible modeling framework to estimate the relationship between covariates and the observations. Covariates are spatial and temporal effects and numerous meteorological fields from the ECMWF high resolution run. The optimal model is chosen using a gradient boosting algorithm with out-of-sample log-likelihood as a performance criterion.

Our investigation shows that convective precipitation and mid-layer stability are the most influential meteorological covariates. Both exhibit intuitive, non-linear trends: higher values of convective precipitation indicate higher probability of lightning, and large values of the mid-layer stability measure imply low lightning potential. The performance of the model was evaluated against a climatology model containing both spatial and temporal effects.

These scores show that the method is able to extract valuable information from the ensemble to produce reliable spatial forecasts of the lightning potential in the Alps.

Session on extreme weather events

Formation of a sting-jet during "Christian"

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Abstract
The reanalysis-based study by Martinez-Alvarado et al. (2012) showed that around one third of the 100 most important cyclones in the North Atlantic domain between 1989 and 2009 satisfy conditions for sting jet. Here, the purpose is to try to improve our understanding of one among the major event hitting Northwestern Europe, the sting-jet which formed within Christian (28th of October 2013) over the United-Kingdom and the North Sea. Using a 10km resolution simulation of ARPEGE (the climate and short-range weather prediction model developed at Meteo-France) we decompose the diabatic PV sources process by process using a lagrangian approach. Particular attention is paid to latent heat release associated with precipitation evaporation but also to sensible heat exchange occurring within precipitating areas.

Simulating impacts of extreme climate events on urban infrastructure and energy demand over the West Africa Sahel.

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Abstract
Investigating the future climate extremes at regional level is essential in understanding the potential impacts of climate change on humans and natural environment. Indeed, the West African Sahel is vulnerable to extreme climate events due to its low adaptive capacity. Indeed, recent extreme climate events have caused devastating impacts on key urban infrastructure (i.e., water supply and water drainage systems and energy demand) over the region. However, it has been reported (IPCC, 2013) that these extreme climate events are going to increase in both magnitude and frequency in the future because of the on going global warming. Therefore in order to be able to mitigate these impacts and reduce vulnerability to these future climate extreme events, it is necessary to have an idea of potentials by projecting these extremes using high resolution climate model and climate change scenarios. In this work, the Weather Research and Forecasting model (WRF) and two Representative Concentrations Pathway's scenarios, RCP4.5 and RCP8.5 are being used to derive the daily precipitation, daily minimum and maximum temperature. These variables will be then use d to estimate the extreme climate indices that will be used for the analyses.

Identification of Tropical-Extratropical Interactions and Extreme Precipitation Events in the Middle East based on Potential Vorticity and Moisture Transport

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Abstract
Extreme precipitation events in the otherwise arid Middle East can cause flooding with dramatic socioeconomic impacts. Most of these events are associated with tropical-extratropical interactions, whereby a stratospheric potential vorticity (PV) intrusion reaches deep into the subtropics and forces an incursion of high poleward vertically integrated water vapor transport (IVT) into the Middle East. This study presents an object-based identification method for extreme precipitation events based on the combination of these two larger-scale meteorological features. The general motivation for this approach is that precipitation is often poorly represented in relatively coarse model simulations, whereas the synoptic-scale circulation is much better represented. The algorithm is applied to ERA-Interim reanalysis data (1979-2015) and detects 90% (83%) of the 99 th (97.5 th) percentile of extreme precipitation days in the region of interest. Our results show that stratospheric PV intrusions and IVT structures are intimately connected to extreme precipitation intensity and seasonality. The farther south a stratospheric PV intrusion reaches, and the larger the IVT magnitude, the more extreme the precipitation. Our algorithm detects a substantial fraction of the climatological rainfall amounts (40-70%), and a large number of the heavy precipitation days (50-80%) and the top 10 extreme precipitation days (60-90%) at many sites in southern Israel and the northern and western parts of Saudi Arabia. This identification method provides a new tool for future work to disentangle teleconnections, assess medium-range predictability and improve understanding of climatic changes of extreme precipitation in the Middle East and elsewhere.

Changes in summer wind and convective precipitation over the UK and Europe from a regional weather simulation: a case study

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Abstract
Climate change caused by green house gas emissions is now following the trend of rapid warming consistent with a RCP8.5 forcing. Climate models are still unable to represent the mesoscale convective processes that occur at resolutions O(3km) and are not capable of resolving precipitation patterns in time and space with sufficient accuracy to represent convection. The UK Met Office precipitation observations are compared with the simulations for the (1990-1995) period followed by a simulation of a near future period (2031-2036) for a regional nested weather model. The convective permitting model, resolution O(3km), provides a good correspondence to the observational precipitation data and demonstrates the importance of explicit convection for future summer precipitation estimates. The UK summer precipitation is reduced slightly (10%) for (2031-2036) and there is no evidence of an increase in the peak maximum hourly precipitation magnitude. A similar pattern is observed over the whole European inner model domain. The results using the Kain-Fritsch convective parameterisation scheme at a resolution O(12km) in the outer domain, increases summer precipitation by 10% for the UK. The overall future average precipitation rate per event increases, dry periods extend and wet periods shorten. For convective events of less than 4 hours duration, precipitation rates of greater 10mm/hour are 50% more likely to occur than in convective parameterisation solutions at lower resolution. As part of the change, 10m winds of < 3ms-1 become more common - a scenario that would impact on power generation from wind turbines through calmer conditions and cause more frequent pollution episodes.

High Impact Weather forced by Ex-Sanchez (NAWDEX IOP11)

Christian Keil
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Abstract During the NAWDEX campaign high impact weather occurred in the Western Mediterranean in conjunction with the cyclone 'Sanchez' on 12 and 13October 2016. First results on the practical predictability ofprecipitation are presented using operational ensemble forecasts ofCOSMO-LEPS and the convective scale ensemble AROME-EPS.

High Resolution Numerical Modeling of a distinct Extreme Weather Event, 'Cold Surges' over South China

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Abstract
Cold Surges are associated with widespread outbreaks of cold continental air from Siberia, characterized by strong northeasterly winds, sharp temperature drops, and increased surface Pressure during North East Monsoon. These surges severely affect human life and contribute towards considerable economic losses. Since, such an extreme event is a big challenge for the purpose of forecasting, further to curb the economic and societal threats. Thus, modeling the severity and intensity of these distinct extreme weather events, help determine their spatial extent, temporal duration and the associated complexity in understanding its severity as it progresses from Siberia. The present study reviews the modeling performance of the three cold surge events during the year 2008, 2009 and 2016 that was reported in south China. The analysis combines high-resolution regional weather modeling using the Weather Research and Forecasting (WRF) model together with ECMWF re analysis data, satellite based ASCAT wind data, and observational weather station data. We propose that cold surges are firstly driven by the Pressure Gradient Siberian-Mongolian High and the South China Sea, and are further influenced by the presence of intense low-pressure systems situated near the coast of Japan leading to the bifurcation of the cold surge air mass. These low-pressure systems highly influence the cold surge intensity and subsequent trajectory towards the South China Sea (SCS). We propose new criteria based on the pressure gradient for identifying the cold surges in short range time scale over southern China.

Synoptic Analysis and Hindcast of an Intense Bow Echo in Western Europe: The 9 June 2014 Storm

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Abstract
On Pentecost Monday, 9 June 2014, a severe linearly organized mesoscale convective system (MCS) hit Belgium and western Germany. This storm was one of the most severe thunderstorms in Germany in decades. The synoptic-scale and mesoscale characteristics of this storm are analyzed based on remote sensing data and in situ measurements. Moreover, the forecast potential of the storm is evaluated using sensitivity experiments with a regional climate model. The key ingredients for the development of the Pentecost storm were the concurrent presence of low-level moisture, atmospheric conditional instability, and wind shear. The synoptic and mesoscale analysis shows that the outflow of a decaying MCS above northern France triggered the storm, which exhibited the typical features of a bow echo like a bookend vortex and a rear-inflow jet. This resulted in hurricane-force wind gusts (reaching 40 m/s) along a narrow swath in the Rhine-Ruhr region leading to substa ntial da mage. Operational numerical weather prediction models mostly failed to forecast the storm, but high-resolution regional model hindcasts enable a realistic simulation of the storm. The model experiments reveal that the development of the bow echo is particularly sensitive to the initial wind field and the lower-tropospheric moisture content. Adequate initial and boundary conditions are therefore essential for realistic numerical forecasts of such a bow echo event. It is concluded that the Pentecost storm exhibited a comparable structure and a similar intensity to observed bow echo systems in the United States.

Evaluation of moisture sources for the Central European summer flood of May/June 2013 based on regional climate model simulations

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Abstract
Heavy precipitation affected Central Europe in May/June 2013, triggering damaging floods both on the Danube and the Elbe rivers. Based on a modelling approach with COSMO-CLM, moisture fluxes, backward trajectories, cyclone tracks and precipitation fields are evaluated for the relevant time period 30 May-2 June 2013. We identify potential moisture sources and quantify their contribution to the flood event focusing on the Danube basin through sensitivity experiments: Control simulations are performed with undisturbed ERA-Interim boundary conditions, while multiple sensitivity experiments are driven with modified evaporation characteristics over selected marine and land areas. Two relevant cyclones are identified both in reanalysis and in our simulations, which moved counter-clockwise in a retrograde path from Southeastern Europe over Eastern Europe towards the northern slopes of the Alps. The control simulations represent the synoptic evolution of the event re asonably well. The evolution of the precipitation event in the control simulations shows some differences in terms of its spatial and temporal characteristics compared to observations. The main precipitation event can be separated into two phases concerning the moisture sources. Our modelling results provide evidence that the two main sources contributing to the event were the continental evapotranspiration (moisture recycling; both phases) and the North Atlantic Ocean (first phase only). The Mediterranean Sea played only a minor role as a moisture source. This study confirms the importance of continental moisture recycling for heavy precipitation events over Central Europe during the summer half year.

Session on cloud and PBL processes

Parameter estimation for an improved represenation of clouds

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Abstract
The initiation and development of clouds in convection permitting models can be highly sensitive to crudely known parameters such as roughness lengths and the turbulent length scale. Modest changes to these parameters can significantly alter the model output, making their uncertainty a serious source for forecast errors. In most operational weather prediction systems, the uncertainty of these parameters is not taken into account, which contributes to overconfidence of the model output. In this project we investigate the feasibility of estimating parameters simultaneously with the dynamical state using Ensemble Kalman Filter (EnKF) type algorithms by means of state space augmentation. This approach allows the parameters to be updated objectively according to data, leaving them flexible to adjust to recent conditions. In addition, the uncertainty of the parameters is taken into account, thereby capturing the uncertainty of the model output more accuratel y. However, to deal with difficulties associated with convective scale applications, such as non-Gaussianity and constraints on state and parameter values, modifications to the classical EnKF are necessary. We therefore evaluate and extend several recently developed ensemble algorithms that either explicitly incorporate constraints such as mass conservation and positivity of precipitation, or introduce higher order moments on the joint state and parameter estimation problem. We compare their results to the localized EnKF on a common idealized test case. The test case uses perfect model experiments with the one dimensional modified shallow water model that was designed to mimic important properties of convection.

Assimilation of cloud-affected radiances in deep convection - a case study

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Abstract
Thunderstorms caused flash floods in Bavaria during the summer of 2016. Predicting the occurrence in space and time of deep convective clouds, potentially increases the forecast skill for intensity and location of such severe precipitation. The current capability of nowcasting systems often exceed those of numerical weather prediction without data assimilation, at convective time scales < 5 h. To assimilate cloud radiances at the convective scale, we apply the COSMO-KENDA system (Schraff et al., 2016) with idealized conditions for deep convection (Lange and Craig, 2014). We extend the idealized setup with the local ensemble transform Kalman filter (LETKF) by including the radiative transfer model RTTOV to calculate synthetic satellite images (Schomburg et al., 2015). We assimilate cloud-affected radiances of the 6.2 μm and the 7.2 μm water vapor bands by employing the dynamic cloud-dependent error model (Harnisch et al., 2016). We further assimilate solar reflectances (Scheck et al. 2016) and infrared radiances of window channels, taking into account high, medium, and low-level clouds. Challenges in the assimilation exist due to the non-Gaussian and highly non-linear evolving errors of cloud-affected radiances. Assessing an ideal error model, suitable LETKF properties, optimal temporal and spatial resolutions for assimilating cloud-affected radiances in deep convection is our primary goal. In a second step, we consider assimilating the global structure of evolving cloud fields, e.g., spatial variability of radiation, temporal difference of brightness temperature, or fractal dimension of the cloud field.

Aerosol cloud interaction in deep convective clouds over the Indian peninsula using Spectral (bin) Microphysics

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Abstract
The Weather Research and Forecast (WRF) model coupled with a spectral bin microphysical (SBM) scheme is used to investigate aerosol effects on cloud microphysics and precipitation over the Indian peninsular region. The main emphasis of the study is in comparing simulated cloud microphysical structure with in situ aircraft observations from the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX). Aerosol-cloud interaction over the rain shadow region is investigated with observed and simulated size distribution spectra of water drops and ice particles in monsoon clouds. It is shown that size distributions as well as other microphysical characteristics obtained from simulations such as liquid water content, cloud droplet effective radius, cloud droplet number concentration and thermodynamic parameters are in good agreement with the observations. It is seen that in clouds with high CCN concentrations, snow and graupel size distribu tion spe ctra were broader, compared to clouds with low concentrations of CCN, mainly due to enhanced riming in the presence of large number of droplets with a diameter of 10 μm - 30 μm. Hallet - Mossop ice multiplication process is illustrated to have an impact on snow and graupel mass. The changes in CCN concentrations have a strong effect on cloud properties over the domain, amounts of cloud water as well as on the glaciation of the clouds, but the effects on surface precipitation are small when averaged over a large area. Overall enhancement of cold phase cloud processes in the high CCN case contributed to slight enhancement (5%) in domain averaged surface precipitation.

Others

“Waves to Weather” – a collaborative research centre with a decadal trajectory of DFG-funding

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Abstract
The German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) has been operating for some 50 years several mechanisms to fund coordinated research proposals, which had been submitted by multi-disciplinary groupings of university researchers. Collaborative research centres (CRC) focusing on a single location are the largest units; the first ones began to be funded in 1968. From 2000, they exist also as transregional research (TRR) centres at up to three locations. In general, these can receive funding for up to three quadrennial periods. “Waves to Weather “(TRR165) belongs to this category. Furthermore, discipline oriented, generally defined priority programmes (Schwerpunktprogramme, SPP) attract project proposals from the entire country and have a duration of six years. And finally, research units (Forschergruppe, FOR) of less than ten projects address a prescribed topical scientific problem, also during a six-year period.

The poster presentation documents in a compact manner how the atmospheric sciences, and weather related topics in particular, used all three funding mechanisms right from the start of CRCs. It becomes evident that “Waves to Weather” possesses a partly hidden heritage. Some of the earlier, nationally funded research endeavours helped to establish international research contacts which later motivated colleagues from abroad to pursue university careers in Germany and make use of the mentioned mechanisms in a very collaborative way.