Mathematics of the Weather 2022

Registrants Book

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Affiliation: Goethe Universität Frankfurt, Frankfurt am Main, Germany

Abstract: Gravity-Wave Parameterization Allowing for Wave Transience and Oblique Propagation Ulrich Achatz (1), Gergely Bölöni (2), Young-Ha Kim (1), Georg Sebastian Völker (1), Günther Zängl (2) (1) Goethe Universität Frankfurt, Frankfurt am Main, Germany (2) Deutscher Wetterdienst, Offenbach, Germany The work to be reported here is motivated by two issues in the atmospheric sciences: (1) For a long while to come, global climate models will not be able to resolve an important part of the atmospheric gravity-wave (GW) spectrum explicitly. Many aspects of both the global circulation and of atmospheric variability down to seasonal and sub-seasonal time scales cannot be described by these models without taking subgrid-scale (SGS) GWs into account. (2) Moreover, results from models integrated at gravity-wave resolving resolutions, i.e. on the km-scale horizontally and on the 100m-scale vertically, will keep on needing insight from conceptual understanding as it is provided by coarser-scale models with robust and physically based sub-models for SGS dynamics. Parameterizations of SGS GWs can help on both issues. Yet, traditional approaches suffer from two limitations. They rely on steady-state equilibrium profiles that one could obtain from a constant GW source, and hence neglect all transience resulting from variable sources and from interactions with a variable resolved flow (steady-state approximation), and they also only allow for vertical GW propagation, hence neglecting the possibility of oblique propagation from the source (single-column approximation). The Multi-Scale Gravity-Wave Model (MS-GWaM) implemented into the German weather and climate community code ICON is the first SGS GW model that is not subject to these limitations. It uses a Lagrangian approach for propagating GW wave action through the atmosphere and through spectral space, and it provides GW flux convergences from integrals of corresponding spectral contributions. In a first step it had been implemented such that wave transience is allowed but no horizontal propagation. In this setup it is especially the statistics of modelled GW fluxes that turns out to be much better in agreement with balloon and satellite observations. Probability density functions exhibit the observed long tails (i.e. intermittency) while steady-state parameterizations do not reproduce them well. Recently MS-GWaM has been extended to also describe horizontal GW propagation. The modelled horizontal distributions of GW momentum fluxes in the stratosphere turn out to be very different from the ones obtained in the classic single-column approach. It has also been shown that MS-GWaM, while being computationally costlier than traditional GW parameterizations, provides a more realistic simulation of atmospheric GWs that is by several orders of magnitude more efficient than GW resolving global models. The talk will describe theory and numerical techniques employed, and it will analyze important difference between the results of MS-GWaM and conventional GW parameterizations. References: Bölöni, G., Kim, Y.-H., Borchert, S., and U. Achatz, 2021: Toward transient subgrid-scale gravity wave representation in atmospheric models. Part I:

Propagation model including nondissipative wave–mean-flow interactions. J. Atmos. Sci. 78, 1317-1338 Kim, Y.-H., G. Bölöni, S. Borchert, H.-Y. Chun, and U. Achatz, 2021: Toward transient subgrid-scale gravity wave representation in atmospheric models. Part II: Wave intermittency simulated with convective sources. J. Atmos. Sci., 78, 1339–1357

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Abstract: A Discontinuous Galerkin solver as a possible alternative dynamical core for the ICON model Michael Baldauf, Florian Prill Deutscher Wetterdienst, Offenbach, Germany Currently, a new dynamical core for the weather and climate forecast model ICON, based on the Discontinuous Galerkin (DG) method, is under development at the Deutscher Wetterdienst (DWD). The DG method combines conservation of the prognostic variable via the finite volume approach with higher order accuracy via the finite element approach. The basic ingredients of a DG solver for the 3D non-hydostatic Euler equations on a sphere are presented: the use of local coordinates (and their natural base vectors) on a prism grid to circumvent any singularities on the sphere, a nodal DG discretization in combination with either fully explicit Runge-Kutta (RK) or IMEX-RK (for a horizontally explicit-vertically implicit (HEVI) treatment) time integration schemes, and tensor product implementations of the finite elements and quadratures to increase efficiency. Results from a prototype DG code (called BRIDGE) and comparisons with analytic reference solutions are shown, together with a very first efficiency comparison with the ICON model on a quasi-isotropic grid.

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Abstract: The performance of separate bias Kalman filter (SepKF) in correcting the model bias for the improvement of soil moisture profile is evaluated by assimilating the near-surface soil moisture observations into a land surface model. Firstly, an observing system simulation experiment (OSSE) is carried out, where the true soil moisture is known, two types of model bias (i.e., constant and sinusoidal) are specified and the bias error covariance matrix is assumed to be proporational to the model forecast error covariance matrix with a ratio λ. Secondly, a real assimilation experiment is carried out with the measurements at a site over the Northwest China. In the OSSE, the soil moisture estimate with the SepKF is improved compared with ensemble Kalman filter (EnKF) without the bias filter, because the SepKF can properly correct the model bias, especially in the situation with a large model bias. However, the performance of the SepKF will become slightly worse if the constant model bias increases or the temporal variability of the sinusoidal model bias becomes large. It is suggested that the ratio λ should be increased (decreased) in order to improve the soil moisture estimate if the temporal variability of the sinusoidal model bias becomes high (low). Finally, the assimilation experiment with the real observations also shows that the SepKF can further improve the estimation of soil moisture profile compared with the EnKF without the bias correction.

Joshua Dorrington #29

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Abstract: The need to truncate the equations of fluid mechanics in order to integrate them numerically, also necessitates the introduction of parameterisation schemes to represent neglected sub-grid-scale processes. In atmospheric physics, these schemes must also include the impacts of clouds, orographic drag, and land-surface effects. In recent years, the value of stochastic parameterisation schemes has become apparent. By moving beyond a deterministic 'best-guess' of the subgrid scale and embracing a probabilistic approach, improvements in forecast dispersion and reductions in subgrid scale error have been shown. Less intuitively, large scale aspects of the earth system such as ENSO, sea-ice dynamics and Euro-Atlantic circulation variability can all be improved by stochastic forcing. However, the mechanism for such improvements is not well understood, making it hard to leverage the potential utility of stochastic forcing in a systematic way. In this talk I will discuss the impact of stochastic forcing on a highly-nonlinear toy model: a six-equation chaotic system featuring multimodal, quasi-stable dynamics and flow-dependent predictability. I will explain how the bifurcation structure and geometry of the system permits small-scale Gaussian noise to radically alter the low-frequency, large-scale properties of the flow, and will comment on the potential role of these processes in more realistic atmospheric systems.

Dale Durran #30

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Abstract: We compare the performance of an ensemble-weather-prediction system based on a global deep-learning weather-prediction (DLWP) model with reanalysis data and forecasts from the European Center for Medium Range Weather Forecasts (ECMWF) ensemble for subseasonal weather prediction. The model is trained using ECMWF ReAnalysis 5 (ERA5) data with convolutional neural networks (CNNs) on a cubed-sphere grid using a loss function that minimizes forecast error over a single 24-hour period. The model predicts eight 2D shells of atmospheric data on quasi-uniform global grids at resolutions ranging from 40x40 km to 150x150 km. Notably, our model can be iterated forward indefinitely to produce forecasts at 6-hour temporal resolution for any lead time. We present case studies showing the extent to which the model is able to reproduce the dynamical evolution of atmospheric systems and its ability to learn "model physics" to forecast two-meter temperature and precipitation. Sources of ensemble spread and the performance of the ensemble are discussed relative to the ECMWF S2S ensemble forecasts.

Fangxin Fang #8

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Abstract: Machine learning and data assimilation for atmospheric and pollution modelling F. Fang1, M. Cheng1, I.M. Navon2, C.C. Pain1, S. Cai1, Y. Wang1 1 Department of Earth Science and Engineering, Imperial College London, Prince Consort Road, London, SW7 2BP, UK. URL: http://amcg.ese.imperial.ac.uk 2 Florida State University, USA Numerical simulations of fluid dynamics have been indispensable in many applications relevant to physics and engineering. For improving predictive capability, numerical algorithms have become increasingly sophisticated and complicated by using more spatial and temporal resolution of datasets. Deep learning techniques applied to fluid flow modelling have gained significant attention in recent years. Advanced deep learning techniques achieve great progress in rapidly predicting fluid flows without prior knowledge of the underlying physical relationships. However, machine learning-based models for long lead-time forecasts remain a significant challenge due to the accumulation of uncertainty along the time dimension in online deployment. To tackle this issue, ensemble Kalman filter (EnKF) has been introduced to machine learning-based long term forecast models to reduce the uncertainty of long lead-time forecasts of chaotic dynamic systems. The performance of the hybrid models has been demonstrated by a Lorenz 96 model and a pollution prediction example. Our results show that the use of EnKF in machine learning-based models successfully corrects online model errors and significantly improves the real-time forecasting of dynamic systems for a long lead-time.

Almut Gassmann #3

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Abstract: Voronoi meshes employing C-grid staggering are meanwhile widely used in the atmospheric and ocean modeling communities. While a bunch of higher order advection schemes for tracers are available, such an upgrade of the order of advection for momentum has not yet been proposed and is in fact difficult to achieve, because the standard at most second order accurate momentum advection scheme uses the vector invariant form together with the TRSK vector reconstruction for the tangential velocity. Gassmann (2018) modified the energy conserving usage of the absolute vorticities in TRSK in such a way that the whole vector invariant form can approximately be cast in advection form. The availability of an advection form is a prerequisite for enhancing the order, because an upstream direction can be identified. The present contribution explains how a higher order add-on to momentum advection can be cast as a divergence of an additional pseudo-stress tensor. This stress tensor is a pseudo-stress tensor, because it allows locally for both, anti-diffusion or diffusion of momentum, respectively. Such a mix of dominating diffusion and correcting antidiffusion is known from standard higher order upstream advection schemes. Choosing the ‘divergence of a tensor’-form allows for keeping the budget of total energy fixed via a partial differentiation rule. The method will be first presented in shallow water mode on equilateral hexagons. As a second step, this method is applied to the baroclinic wave test on the sphere. The results reveal that ‘noodling’ of vorticity isolines is largely alleviated. This is important in order to get a better understanding of whether model generated gravity waves from jets and fronts are reliable features or artifacts due to numerical inaccuracies. Taking the shallow water model a test bed, the potential danger of the Hollingsworth instability will be discussed. It is discussed that this instability is associated with small scale divergent motions, not with vortical motions. The traditional enstrophy conserving scheme features the instability, even if it has less noise in vorticity at the grid scale than the classical energy conserving scheme. It will also be demonstrated that the upstream add-on to momentum advection does not give raise to the Hollingsworth instability.

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Abstract: For both the meso- and synoptic scale, reduced models exist that give insight into atmospheric dynamics. For the mesoscale, the weak temperature gradient approximation is one of several approaches, while for the synoptic scale, the quasi-geostrophic theory is well established. However, how these two scales interact with each other, is usually not included in such reduced models, thereby limiting our current perception of flow dependent predictability and upscale error growth. Here, we explicitly address the scale interactions by developing a two-scale asymptotic model for the meso- and synoptic scales with two, coupled sets of equations for the meso- and synoptic scale, respectively. The mesoscale equations follow a weak temperature gradient balance and the synoptic scale equations align with quasi-geostrophic theory. Importantly, the equation sets are coupled via scale interaction terms: eddy correlations of mesoscale variables impact the synoptic potential vorticity tendency and synoptic variables force the mesoscale vorticity (for instance due to tilting of synoptic scale wind shear). Furthermore, we impose different diabatic heating rates as proxies for the effect of latent heating on the different scales and distinguish between a weak, heating regime with O (4K/3.5h) mesoscale heating rates and a strong heating regime with O (40K/3.5h) mesoscale heating rates. With weak heating, the upscale impact of the mesoscale on the synoptic scale is only of dynamical nature. With strong heating, the upscale impact also includes thermodynamical effects. We evaluate the applicability of the mathematical model to realistic, numerical weather simulations and find good agreements between the theory and the simulations. The scale interactions and the imposed diabatic heating can provide new insight into atmospheric dynamics, flow dependent error growth characteristics and predictability.

Edgar Huckert #27

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Abstract: XXX is a program system allowing people in different locations to cooperate. The Program is situated at the internet site *** and each participant has his/her own user area. Service routines, such as compiler and plot routines are provided and allow to create meteorological toy models. Service and example routines associated with the book "Mathematics of the weather", Springer are provided. An example are the weights to be used to obtain 4th order differentiation formula of the Kreiss-Oliger type with irregular grids.

Takuya Kawabata #12

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Abstract: Kawabata and Ueno (2020) have developed a storm-scale particle filter with the JMA nonhydrostatic model called as NHM-RPF (NonHydrostatilce Model R-estimating Particle Filter). NHM-RPF succeeded to represent non-Gaussianity of initiation and development stages of a Cb with 1000 ensemble simulations and showed the origin of the non Gaussianity was the updraft on the top of the boundary layer in an OSSE. For this study, we proposed a novel method to distinguish between Gaussian and non-Gaussian distributions of PDFs. The Gaussianity of the PDFs was evaluated using the Bayesian Information Criterion (BIC) to compare goodness-of-fit of Gaussian, two-Gaussian mixture, and histogram models. Only in the case that the BIC value of the Gaussian was the smallest between these three, the PDF was evaluated as Gaussian. Other cases are non Gaussian. We will present the methdology as well as the result of the RPF experiment.

Rupert Klein #2

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Abstract: Effects of an intermediate "diabatic layer" (DL) on quasi-geostrophic (QG) dynamics (joint work with Lisa Schielicke, Boualem Khouider, Stephan Pfahl) Motivated by an ongoing multiscale asymptotic analysis for incipient hurricanes, we were forced to reconsider the quasi-geostrophic (QG) theory in [1]. Close inspection reveals that the classical QG-Ekman theory is inadequate for the representation of, e.g., the development of convective mixed layers or other strong diabatic processes that often affect the stability of the atmosphere in the lower 2 to 4 km. This contribution will briefly touch upon the hurricane-related motivation, summarize the three-layer asymptotic analysis for what we now call QG-DL-Ekman theory, and present as a sample application a semi-analytical solution for the "spin-up of a heat low" as discussed, e.g., in [2]. [1] Klein R., Schielicke L., Pfahl S., Khouider B., QG-DL-Ekman: Dynamics of a diabatic layer in the quasi-geostrophic framework, JAS, 79:3, 887-905 (2022) [2] Racz Z., Smith R.K., The dynamics of heat lows, QJRMS, 125, 225-252 (1999)

Joseph Klemp #5

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Abstract: Title: Modifying the Height-Based Vertical Coordinate in MPAS to Permit a Constant Pressure Upper Boundary for Geospace Applications By: Joseph Klemp and William Skamarock For applications extending into the thermosphere, realistic simulations may require an upper boundary that permits vertical expansion/contraction of the atmosphere in response to strong internal heating/cooling rates. In adapting MPAS for geospace applications, a modification of the height-based vertical coordinate is presented that relaxes the rigid-lid constraint and permits the coordinate surfaces at upper levels to transition toward a constant pressure surface at the model's upper boundary. This modification is conceptually similar to a terrain-following coordinate at low levels, but now modifies the coordinate surfaces at upper levels to conform to a constant pressure surface at the model top. Since this surface is evolving in time, the height of the upper boundary is adaptively adjusted to follow a designated constant pressure upper surface. This alteration in the original height-based vertical coordinate employed in MPAS requires only minor modifications to the numerics and little additional computational expense. The viability of this modified vertical coordinate formulation is verified in a 2-D prototype of MPAS for an idealized case of upper-level diurnal heating.

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Abstract: Increasing the mesh resolution is one the most important tools for increasing the accuracy of numerical simulations. However, increasing the mesh resolution globally increases the amount of data and computational time substantially. In the exascale-era sub-km meshes are becoming more and more popular for atmospheric models, making it especially difficult to manage the vast amount of data efficiently. With dynamic adaptive mesh refinement (AMR) we locally control the resolution of a mesh in areas of interest, using a fine resolution only where it is explicitely needed and keeping the mesh coarse elsewhere. Thus, we concentrate the data and computing power and significantly reduce the simulation costs while keeping the same numerical accuracy. Vice versa, the resolution can be increased while keeping the same runtime. Managing adaptive meshes induces new challenges such as load-balancing, mesh management, ghost layer computation etc. Developments in the recent years have extended the scalable and efficicient tree-based AMR approach from quadrilaterals/hexahedra to various element shapes such as triangles, tetrahedra, pyramids or prisms and have been implemented in our AMR library t8code. It is a third-party library that adresses these challenges and can be integrated by solver environments in order to enable AMR. In our presentation we will give an introduction to AMR and how we use it for atmospheric simulations. We will give an overview of ongoing and past projects, such as our contributions to PilotLab Exascale Earth Sytem Modelling (Pl-ExaESM) or the lossy data compression for data coming from atmospheric simulations. Furthermore, we will demonstrate the efficiency of our methods with recent benchmark results on current supercomputers, showing that t8code scales on up to at least 1 million MPI ranks and over 1 Trillion mesh elements.

Oswald Knoth #10

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Abstract: A CG/DG dynamical core for numerical weather prediction Spectral elements are a common approach in numerical weather prediction. Besides their stability issues they are well suited for high performance computing because of the high computational load per grid element. I will present a dynamical core implemented in the new programming language Julia. The main goal is to compare continuous and discontinuous Galerien methods for the horizontal discretization combined with different type of vertical discretization. The implementation is realized at the moment for a cubed sphere grid or any quad spherical mesh and reuse part of the software components for the different spatial discretization. Integration in time is accomplished with W-Rosenbrock methods with an approximate Jacobian in the vertical direction. Numerical results are presented for two-dimensional slice examples and the moist baroclinic instability on the sphere.

Jinxi Li #9

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Abstract: Despite many progresses in simulating multi-scale atmospheric processes using the numerical discretisation of partial differential equations, the instability for long-term simulations and the interactions between large-scale and small-scale phenomena cannot be seamlessly filtered. Physics-informed neural networks (PINN), trained to solve supervised learning tasks while respecting any given laws of physics described by general nonlinear partial differential equations, are nowadays gaining renewed interest and they are replacing many practical implementations of the forecasting systems. However, currently most neural networks are trained in Python code while numerical weather prediction models are almost based on Fortran code, which is the barrier for the information exchanges. In this study, we propose a convolutional neural network (CNN) combined with full multi-grid method based on rectangular adaptive mesh refinement techniques to predict the time evolution of field values in advection-diffusion equations. All coefficients of kernels in our neural network are unlearnt but determined by the coefficients from the spatial-temporal discretization using finite difference method. The applicability of this neural network ranges from static adaptive (rectangular) grid to dynamic adaptive anisotropic (triangular) grid. We demonstrate that this CNN network with multi-grid method can emulate the classic linear advection process with the similar accuracy and present comparisons with solutions obtained using different FD discretisations and nonlinear iterations for advection-diffusion equations. This method may become particularly interesting due to the expected essential gains in the execution speed.

Sándor István Mahó #14

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Abstract: Excitation of mixed Rossby-gravity waves by non-linear interactions on the sphere The equatorial mixed – Rossby gravity wave (MRGW or MRG mode) is of special interest, since it plays an important role in shaping tropical subseasonal variability. We study the generation mechanism of the MRG mode with a non-linear, spectral shallow water model (TIGAR) which applies Hough harmonics as basis functions. By virtue of using Hough harmonics, the MRG mode appears as a prognostic variable in the model, which enables to quantify the role of non-linear interactions in the excitation and the growth of this mode. We confirm that MRGWs can be produced by a linear process which requires a forcing that is asymmetric with respect to the equator. However, the key finding is the manifestation of non-linear excitation of the MRG mode that involves interactions between waves originating from a heat source and the asymmetric mean flow. We find that the flow asymmetry is a key factor for the growth of the MRGW, since its amplitude is roughly proportional to the strength of flow asymmetry. The simulations also demonstrate that the non-linearly generated MRGWs have synoptic scales in agreement with previous observations, and the maximal amplitude is shifted to larger scales in a more asymmetric flow. Barotropic instability development, which in general increases flow asymmetry, is found to amplify the generated MRG mode energy at a scale that is identical to the fastest growing mode. We highlight, that the non-linear generation process likely explains the planetary (larger) scales and the greater MRGW amplitude in the middle atmosphere compared with the troposphere. In fact, in the latter the persistent asymmetry of convective forcing and the background flow makes it difficult to quantify the relative importance of the linear and the non-linear generation process.

Fedor Mesinger #23

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Abstract: Cut-cell Eta in weather and climate: Lessons learned Fedor Mesinger (1), Katarina Veljovic (2) , Sin Chan Chou (3) , Jorge L. Gomes (3), André A. Lyra (3), and Dušan Jovic (4) 1) Serbian Academy of Sciences and Arts, Belgrade, Serbia (fedor.mesinger@gmail.com) 2) Faculty of Physics, Univ. of Belgrade, Belgrade, Serbia (katarina@ff.bg.ac.rs) 3) Center for Weather Prediction and Climate Studies (CPTEC), INPE, Cachoeira Paulista, SP, Brazil (chou@cptec.inpe.br) 4) NCEP Environmental Modeling Center (EMC), College Park, MD, USA (dusan.jovic@gmail.com) Abstract The Eta, while being as of 1993 the primary NCEP regional forecasting model, did well. Thus, it increased the accuracy of 48 hr precipitation forecasts to become higher than the 24 hr forecasts of its predecessor, the NGM. Nevertheless, concerned about the Gallus-Klemp problem and a poor result of an experimental Eta in forecasting a downslope windstorm, the NCEP/EMC management decided to abandon the eta coordinate. After several years of development including a more advanced data assimilation, its planned replacement, the NMM, was compared against the Eta in a 2006 4+ month parallel and chosen to replace the Eta. In retrospect, one might wonder about the justification of that decision, given that precipitation scores of the Eta were clearly better than those of the NMM (e.g., Mesinger and Veljovic 2017), and that there was little else favoring the NMM in terms of objective scores. In addition, it has turned out that the Gallus-Klemp problem was relatively easy to address by a redesign of the eta discretization to eliminate its step corners, arriving at a simple cut-cell scheme (Mesinger and Veljovic 2017). A subsequent result deserving attention is that showing the Eta advantage over the ECMWF model, generally considered as “the benchmark to beat” among multitude of present-day models. When an upper-tropospheric trough was crossing a major topographic barrier, all 21 of the Eta ensemble members repeatedly achieved better 250 hPa wind speed scores than their ECMWF driver members, using each of three different skill measures (Mesinger and Veljovic 2020). A puzzling by product of that experiment is that of the Eta ensemble switched to use sigma, Eta/sigma, also achieving during that time 250 hPa wind speed scores better than their ECMWF driver members, although not to that extent as the Eta members. It follows that the Eta must include feature or features additional to the eta coordinate responsible for its advantage over the ECMWF. An experiment we have done strongly suggests that the finite-volume van Leer type vertical advection of the Eta, implemented in 2007, is a significant contributor to this advantage. In this experiment, having replaced a centered finite-difference Lorenz- Arakawa scheme this finite-volume scheme enabled a successful simulation of an intense downslope windstorm in the lee of the Andes. While apparently a widespread opinion that it is a disadvantage of terrain intersecting coordinates that “vertical resolution in the boundary layer becomes reduced at mountain tops as model grids are typically vertically stretched at higher altitudes,” a very comprehensive 2006 NCEP parallel gave just the

opposite result. With seemingly equal ABL schemes, the Eta showed a higher surface layer accuracy over high topography than the NMM, using a hybrid terrain-following system (Mesinger 2022). Hundreds of thousands of the Eta forecasts and experiments performed demonstrate that the relaxation lateral boundary conditions almost universally used in regional climate modeling (RCM)–in addition to conflicting with the properties of the basic equations used–are unnecessary. Similarly, frequently applied in RCMs so-called large scale or spectral nudging, being based on an ill-founded belief, should only be detrimental if numerical issues of the limited area model used are addressed. With longer range forecasts and climate change studies being increasingly in focus one may note the use of the eta-like coordinate in a NASA/GISS model (Russell 2007), later implemented in another GISS model run for addressing climate change resulting from increased CO2 content (Hansen 2013). As to the longer range such as subseasonal to seasonal (S2S) and RCM use of the Eta very numerous studies over the South American areas may be noted. As an example, value added by the Eta over its driver global model in trimestral precipitation forecasts for a South American and adjacent oceanic area can be listed (Chou et al. 2020).

Valentino Neduhal #15

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Abstract: TITLE: Decomposition of the tropical divergence into Rossby and non-Rossby components - Traditionally, Rossby and inertia-gravity (IG) dynamical regimes have been treated separately using different sets of equations with different assumptions. A separate treatment of these two dynamical regimes is justified in the extra-tropics where there is a large frequency gap between the two regimes. However, this is not the case in the tropics, where the Rossby wave and IG wave dynamics become non-separable and their frequency gap is filled with the Kelvin and mixed Rossby-gravity (MRG) waves. We refer to the IG, the Kelvin, and MRG waves as non-Rossby waves and investigate their contributions to the divergence spectra of the horizontal wind at different levels and latitudes. Divergence is evaluated using the normal-mode framework in the hydrostatic atmosphere. We derive the analytical expression for the divergence associated with the Rossby and non-Rossby waves as a function of their zonal and meridional wavenumbers. The new framework is applied to the ERA5 reanalysis data for August 2016. The derived total horizontal divergence is verified against the divergence field taken directly from ERA5. The comparison is performed with observations over the tropical Atlantic from Bony and Stevens (2019) and we find that most of the divergence is associated with the non-Rossby modes, with the Rossby wave component 2 orders of magnitude smaller. Spectra of divergence as a function of the zonal wavenumber appear to be almost white and have similar magnitudes at tropospheric levels. The Rossby wave part of the divergence spectra is largest for the zonal wavenumbers smaller than 10 but seldom exceeds 10% of the non-Rossby part. The Kelvin wave part has a significant contribution of 5-30% to the non-Rossby part for all wavenumbers in the tropics. The MRG part is largest for the zonal wavenumbers smaller than 10 but seldom exceeds 20% of the non-Rossby part in the tropics.

Juliane Rosemeier #20

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Abstract: Modern computing architectures become increasingly powerful. To exploit their potential, when solutions to time evolution problems are needed, Parallel-in-time methods, like the Parareal method, can be applied. The Parareal method is a two-level method with a coarse and a fine time grid. Variants of the Parareal method including averaging have been studied and gave very satisfactory results for fluid flow problems like the shallow water equations. An extension of the method to more than two levels will be proposed in the presentation. The increase in the number of levels might be advantageous for two reasons. First, it comes along with increased parallelism and possibly more efficient algorithms. Second, when solving multi-scale problems, we can introduce a level for each scale to capture the behaviour on that scale. An error estimate for the multi-level method and first numerical results will be shown.

Yvonne Ruckstuhl #25

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Abstract: A test of an alternative approach for uncertainty representation in data assimilation Tijana Janjic, Maria Lukacova, Yvonne Ruckstuhl, Bettina Wiebe Quantification of evolving uncertainties is required for both probabilistic forecasting and data assimilation in weather prediction. In current practice, an ensemble of model simulations is often used as primary tool to describe the required uncertainties. In this work, we explore an alternative approach, the stochastic Galerkin, which integrates uncertainties forward in time using a spectral approximation in the stochastic space. First, we investigate the propagation of initial uncertainty in an idealized two-dimensional model that couples compressible non-hydrostatic Navier-Stokes equations to cloud dynamics. The propagation of initial perturbations is followed through time for all model variables during two types of forecasts: the ensemble forecast and stochastic Galerkin forecast. The accuracy of these two types of forecasts is tested for varying ensemble size and number of spectral modes respectively. Second, we investigate the possibility to replace the ensemble forecast in the Ensemble Kalman Filter with a Stochastic Gakerkin simulation. The advantage of this hybrid approach is the potential for high accuracy of background error covariance at low computational costs that renders localization and inflation methods obsolete. We show that the performance of the EnKF indeed converges towards that of the Kalman Filter - Stochastic Galerkin hybrid with increasing ensemble size.

Nora Schenk #6

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Abstract: An Improved Version of the Localized Mixture Coefficients Particle Filter Applied to Lorenz 1996 and the Regional ICON-D2 Model At the German Meteorological Service (DWD), two particle filter methods were developed which are structured in a way that a consistent implementation in existing LETKF code is possible. The localized adaptive particle filter (LAPF), introduced by R. Potthast, A. Walter and A. Rhodin in 2019, overcomes filter collapse in a high-dimensional framework. This particle filter was further developed by Rojahn et al. (2022) to the local mixture coefficients particle filter (LMCPF) which was tested within the global ICON model. In the LMCPF method the background distribution is approximated by Gaussian mixtures and a Gaussian distributed observation error is assumed. Following a study of Kotsuki et al. (2022), we recently substituted the approximated particle weights in the LMCPF method with the exact Gaussian mixture weights which leads to an increased effective ensemble size and results in a more stable filter with respect to the parameters of the LMCPF. In case of higher effective ensemble sizes, more background information is contained, while the filter degenerates if the effective ensemble size tends to one. In this study, we demonstrate that the LMCPF with exact weights is able to outperform the LETKF within an experimental design reflecting a standard NWP setup and standard NWP scores applied to the dynamical systems Lorenz 1963 and 1996. Furthermore, data assimilation experiments of the improved version of the LMCPF applied in the kilometre-scale ensemble data assimilation (KENDA) system with the limited area mode of the ICON model (ICON-LAM) show stable results for this particle filter method . Besides a mathematical introduction of the LMCPF method and the description of the changes in the improved version, we present experimental results in comparison with the LETKF method in the operational setting at DWD for the ICON-LAM model as well as for the Lorenz models.

Vladimir Shashkin #13

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Registration date: 30 Jun 2022, 15:44

Registration state: Completed

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Abstract: Cubed-sphere shallow-water model using summation-by-parts finite differences Summation-by-Parts Finite Differences (SBP-FD) is an approach for approximation of differential operators satisfying a discrete analogue of integration by parts analytic property. SBP-FD allows to build high-order spatial approximations and prove their stability by the energy method. SBP-FD methods are widely used for approximation of partial differential equations in multiblock domains with logically-rectangular curvilinear mesh inside. Gnomonic cubed-sphere grid is an example of such a domain. However, applications of SBP-FD approximation for the cubed-sphere grid in meteorological context is not an elaborated research area. We present a shallow water model based on SBP-FD approximations using both non-staggered and Arakawa type-C staggered grids. Non-staggered grid version is total-energy conserving and C-type staggered configuration conserves energy for the linearized shallow water equations. Also, both versions are mass-conservative and have discrete analogues of other mimetic properties such as curl-free gradient property. The shallow water model is tested with the commonly used Williamson test suite supplemented with the Galewsky barotropic instability case. High-order convergence is shown for tests with analytical solutions. SBP-FD shallow water model is more accurate than low-order mimetic finite-element counterparts, but slightly less accurate than high-order finite-volume, spectral-elements and discontinuous Galerkin schemes.

Bill Skamarock #17

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Abstract: Atmospheric model configurations for NWP and climate: Vertical resolution and model filters Bill Skamarock NCAR/MMM The atmospheric component of the global Model for Prediction Across Scales (MPAS-A) was developed for high-resolution climate and NWP applications, and its dynamical core employs a lower-order finite-volume approach similar to many research and operational models. In a 2019 published study using MPAS-A, we found that at current NWP resolutions (i.e. dx ~ 15 km) vertical mesh spacing of 200 meters or less is needed for convergence of the kinetic energy spectrum and to resolve critical flow features in the free troposphere and lower stratosphere. Subsequent to that study, we discovered that we can configure MPAS-A with less horizontal dissipation when higher vertical resolution is employed, thus increasing the effective vertical and horizontal resolution. With the increase of the effective resolution, the higher vertical resolution configurations are more efficient than their lower vertical resolution counterparts, and the results argue for moving to higher vertical resolution in many of our applications even if horizontal resolution must be lowered to fit within existing computing limits. The physical phenomena driving these result are atmospheric fronts and their realization in the simulations, and these results have some implications for dynamics underlying the mesoscale kinetic energy spectrum and model physics. In this talk we will outline our vertical resolution results and supporting simulation evidence, and discuss implications for model configurations including mesh spacing and dissipation mechanisms.

Chris Snyder #24

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Registration date: 1 Aug 2022, 06:53

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Abstract: Sampling error in the ensemble Kalman filter for small ensembles and high-dimensional states and observations The effect of sampling error is a fundamental issue for the ensemble Kalman filter (EnKF). Studies to date are restricted to small sampling error (owing to large ensemble size) , or scalar states and observations. I will present analytic and computational results for the more practically relevant case of small ensembles and many state variables and observations. The generality of these results, and their analytic tractability despite working in high dimensions, follows from the use of coordinates in which the Kalman filter update is diagonal, with each observation affecting only a single element of the state vector. A basic outcome is that sampling error in this regime leads to underestimation of the posterior covariance potentially by orders of magnitude, so that covariance localization is essential for any cycling EnKF whose ensemble size is small compared to the state and observation dimensions.

jurgen Steppeler #1

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Registration date: 26 May 2022, 08:48
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Abstract: An overview of the cut cells inlcluding some new results will be given.

Joanna Szmelter #19

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Registration date: 19 Jul 2022, 13:56

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Abstract: Unstructured mesh based NFT models for atmospheric flows across the scales Joanna Szmelter1, Mike Gillard1, Francesco Cocetta2 1 Wolfson School, Loughborough University, UK 2 Ocean Modeling and Data Assimilation Division, Centro Euro-Mediterraneo Sui Cambiamenti Climatici, Bologna, Italy We report recent advancements and applications of the Nonoscillatory Forward-in-Time (NFT) schemes based on Multidimensional Positive Definite Advection Transport Algorithm (MPDATA) and a non-symmetric Krylov solver. The reported research addresses both global and limited area non-hydrostatic finite volume models. A particular focus is given to a study of preconditioning of the complex non-symmetric elliptic solvers required for effective simulation of all-scale atmospheric flows involving semi-implicit integration of the non-hydrostatic compressible Euler equations under gravity on a rotating sphere. The Generalised Conjugate Residual (GCR) method is used for the solution of the Helmholtz elliptic problem resulting from the NFT integration. The condition number of its underlying sparse linear operator is O(1010), which necessitates bespoke operator preconditioning. The techniques considered for preconditioning include the Richardson, Jacobi, and Multigrid approaches [1]. Numerical developments will be illustrated using simulations of a global baroclinic instability epitomising evolution of weather systems. The new application of the local NFT model exploits flexibility offered by unstructured meshes. The presentation will report the key finding of a study of the numerical characterisation of stably stratified flows past a single and multiple spheres [2,3]. 1. M. Gillard, J.Szmelter (2021) Development of a class of scalable, energy-efficient Krylov-solvers bespoke for NWP, D1.5 ESCAPE2 report, Horizon 2020 program. 2. F Cocetta, M Gillard, J Szmelter, PK Smolarkiewicz (2021) Stratified flow past a sphere at moderate Reynolds numbers, Computers & Fluids 226, 104998. 3. F Cocetta, J Szmelter, M Gillard (2021) Simulations of stably stratified flow past two spheres at Re= 300, Physics of Fluids 33 (4), 046602.

Friedrich Theunert #22

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Jannik Wilhelm #11

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Abstract: TEEMLEAP - A new TEstbed for Exploring Machine LEarning in Atmospheric Prediction Jannik Wilhelm, Uwe Ehret, Sebastian Lerch, Jörg Meyer, Julian Quinting, Barbara Verfürth and Peter Knippertz – Karlsruhe Institute of Technology (KIT) Despite steady improvements in numerical weather prediction (NWP) models, they still exhibit systematic errors caused by simplified representations of physical processes, assumptions about linear behavior and the challenging task to integrate all available observational data. Weather services around the world now recognize that addressing these deficiencies by Machine Learning (ML) could revolutionize the discipline in the coming decades (cf. Dueben et al., 2021). This requires a fundamental shift in thinking that integrates meteorology much more closely with mathematics and computer science. The TEEMLEAP project at KIT is fostering this cultural change through a collaboration between scientists from the KIT centers Climate and Environment and Mathematics in Sciences, Engineering, and Economics (MathSEE). Currently, an idealized – yet realistic – testbed for exploring ML in weather forecasting is being established. In contrast to weather services, which naturally focus on improvements of NWP models in their full complexity, TEEMLEAP intends to evaluate the application possibilities and potential benefits of ML and new numerical methods in this testbed along the entire process chain of weather forecasting. The process chain in the testbed consists of the following elements: (1) Pseudo-radiosonde observations generated from ERA5 reanalysis data (2) Data assimilation coding environment (DACE) of the German Weather Service (DWD) (3) Icosahedral nonhydrostatic (ICON) modelling framework of DWD (4) Innovative statistical and ML-based methods for post-processing Sensitivity experiments varying the setup of the process chain elements will give new insights and potentially answer inter alia the following questions: • How can we quantify the cost-benefit ratio of the forecast chain? • To which parts of the forecast chain is the forecast skill most sensitive? • How could new mathematical, numerical and ML methods be beneficially utilized regarding these parts of the forecast chain? The results of first sensitivity studies performed with the new testbed will be shown and discussed, and ideas and possibilities for further testbed applications will be illustrated. ________________________________ Dueben, P., Modigliani, U., Geer, A., Siemen, S., Pappenberger, F., Bauer, P., Brown, A., Palkovic, M., Raoult, B., Wedi, N. & Baousis, V. (2021). Machine learning at ECMWF: A roadmap for the next 10 years. ECMWF, 878, https://doi.org/10.21957/ge7ckgm