SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Upscale impact of diabatic processes from convective to near-hemispheric scale
Computer Project Account:	spdecrai
Start Year - End Year :	2016 - 2018
Principal Investigator(s)	George Craig
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Other Researchers (Name/Affiliation):	Tobias Selz Meteorologisches Institut Ludwig-Maximilians-Universität München Theresienstr. 37 80333 München Germany

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

In this project we investigated the process of upscale propagation of uncertainty in the atmosphere over three orders of magnitude in spatial scale, from convective clouds to hemispheric waves. This was possible with the development and usage of a stochastic parameterization (Plant-Craig) for convection. The Plant-Craig convection scheme is able to emulate convective uncertainty at non-convective permitting resolutions. This tools has formed the basis for a series of error growth experiments to address open questions about basic characteristics, mechanisms and the practical importance of upscale error growth in medium-range global weather prediction. In addition, limited area simulations at convection-permitting resolution have been performed to identify dynamical regimes.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

No problems encountered.

Experience with the Special Project framework

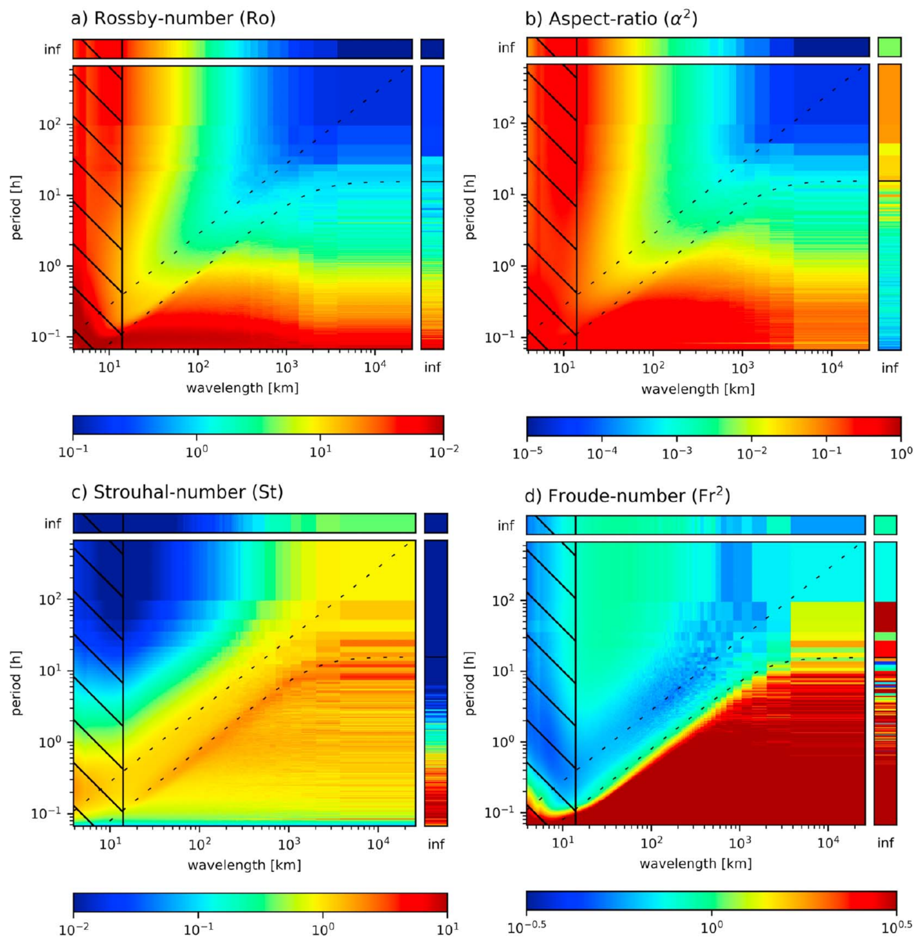
(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

No problems encountered.

Summary of results

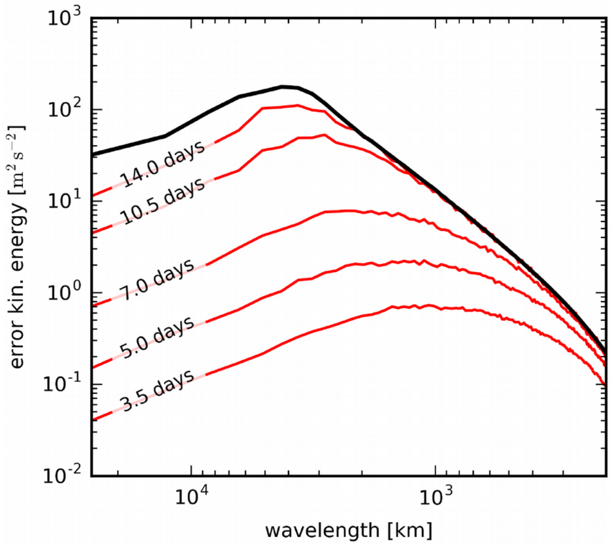
(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

A part of the computing time of the project was used for a convection-permitting limited area model simulation with COSMO on a large domain that covered several time the Rossby radius of deformation. A summer time case in 2016 with high convective activity over central Europe was simulated. Simulation time was seven days and a very high output frequency (2 minutes) was used to enable a Fourier transformation in time as well as in space. With this setup dynamical regimes on the mesoscale have been investigated by evaluating the space-time dependence of non-dimensional numbers like Rossby-, Froude- or Strouhal number. The non-dimensional numbers are defined by fractions of the magnitudes of certain terms in the equations of motion and the thermodynamic equation. The results have been published in Craig and Selz, 2018.



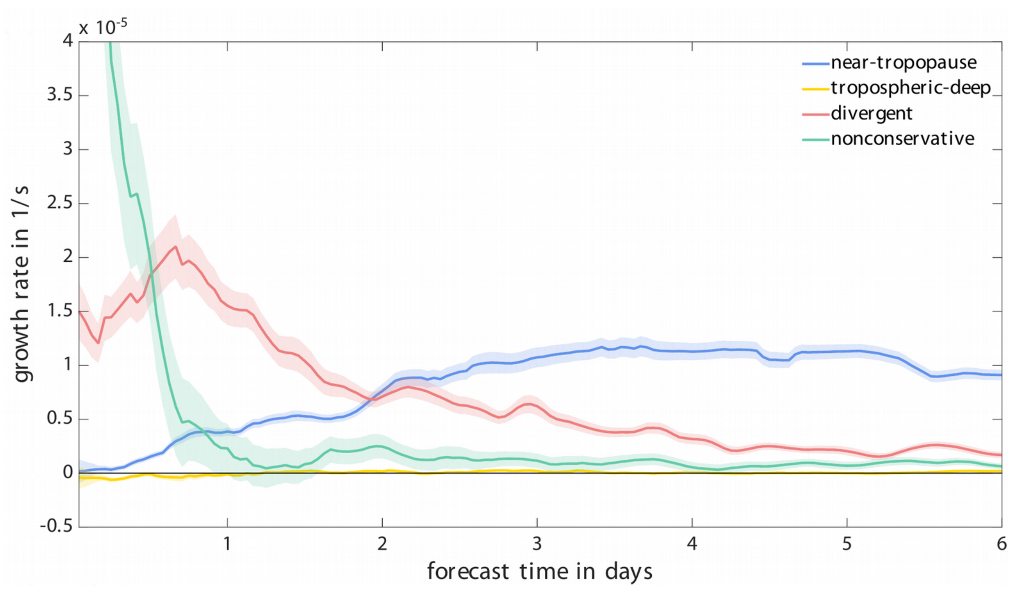
The figure above shows the space-time dependence of four selected non-dimensional numbers. As expected, the Rossby number (Ro) is small for spatial scales larger than about 1000 km and temporal scales larger than about a day. The Strouhal number (St) shows two basic regimes that are oriented along the diagonal: One regime of very low St in the upper left corner and one regime of a maximum in St along the dispersion relation of gravity waves (the lower dashed line). The first regime implies that the Eulerian temporal change of potential temperature is negligible against advection, which is an indication of stationary gravity waves excited by slowly varying large-scale winds over orography. In the second regime on the other hand the Eulerian change dominates advection, which is a property of propagating gravity waves, exited by deep convection. The Froude number (Fr) shows neutral values in both of these regimes but indicates a minimum just above the gravity waves dispersion relation. A low Froude number indicates a small Lagrangian change of the potential temperature compared to the vertical advection of the background stratification. It thus indicates the accuracy of the weak temperature gradient approximation. This approximation has been widely used to analyze tropical convection but the results above suggest that is has some validity in the midlatitudes as well, although it is not as good as e.g. the geostrophic (small Rossby number) approximation on large scales. See Craig and Selz, 2018 for more details.

The major part of the computing time has been used for global ensemble simulations using the ICON model from DWD and the stochastic convection scheme of Plant and Craig (PC). 12 cases, distributed over one year, each with five ensemble members have been simulated. The aim of these experiments was the estimation of intrinsic limits of predictability that arise from the convection. The main idea was to use the stochastic convection scheme and a cheaper, lower spatial resolution instead of a convection-permitting resolution to simulate the convection and its variability. The quantitative results are summarized in Selz, 2019, a process-based investigation can be found in Baumgart et al., 2019.

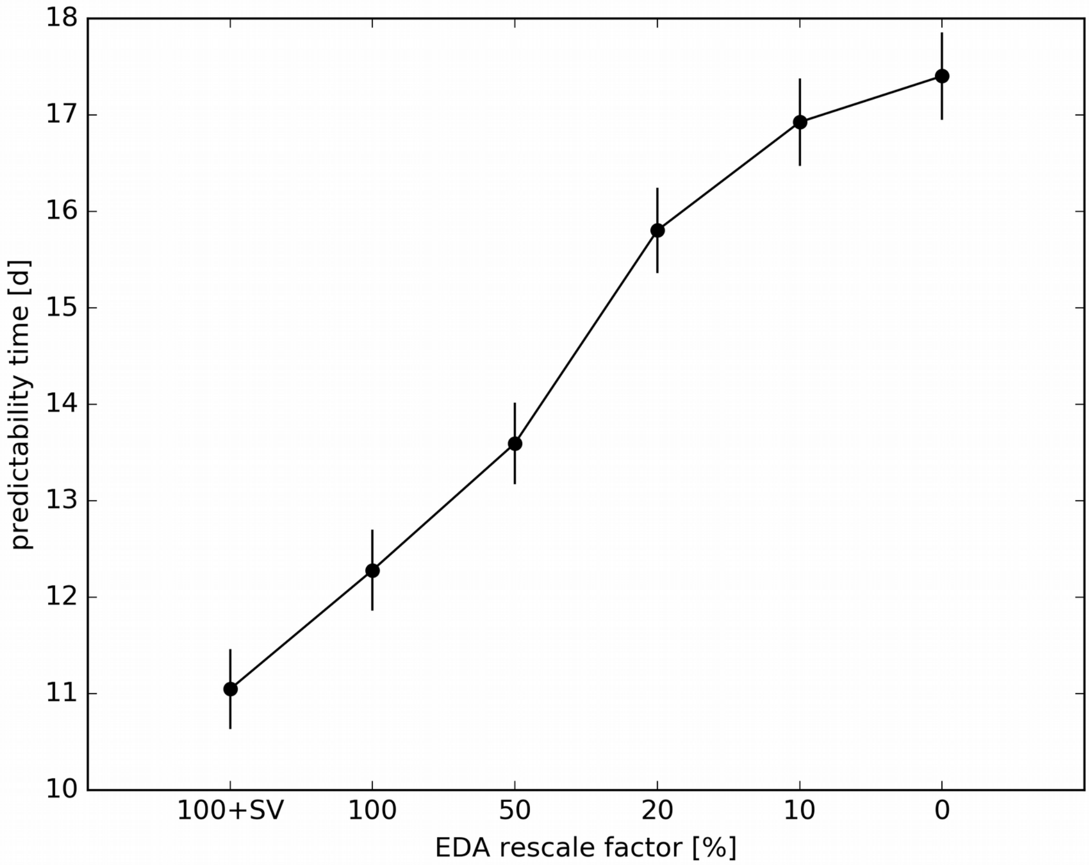


The figure above shows the error growth in the midlatitudes of the PC-ensemble, averaged over all cases and all members. The red lines show spectra of the error kinetic energy at several forecast lead times. The black line shows the background spectrum. A comparison of these errors to the ECMWF forecasting system has been performed to estimate the potential improvement of current forecasting systems until the intrinsic limit is hit: The 3.5-day error of the PC-ensemble compares to the current ECMWF initial condition uncertainty. The 14-day error of the PC-ensemble compares roughly to the errors of an eight day ECMWF forecast. The additional gap of 2.5 days might be related to the model error. In addition to the PC ensemble, an ensemble using the operational deterministic Tiedtke-Bechthold scheme has also been performed for comparison.

A more qualitative, process-oriented investigation of the PC data set has been performed together with our colleagues from the University of Mainz. This work aims to investigate and distinguish the physical processes that drive the error growth (Baumgart et al., 2019). Here, the spatially integrated error enstrophy is considered and is split into different contributions using PV inversion techniques. The figure below shows the development of these contributions during the first five days: Initially the direct diabatic effect and the divergent contribution dominates which indicates that the error growth is mainly driven by convection. After about two days the tropopaus-near (barotropic) contribution becomes most important, indicating that the error growth is now mostly large-scale driven.



The experiments of Selz 2019 have been extended afterwards to not only sample the uncertainty from convection but also include an initial condition uncertainty. Several sets of experiments have been performed where the initial condition uncertainty taken from the ECMWF ensemble data assimilation system is rescaled to 100% (no rescaling), 50%, 20%, 10% and 0% (no initial condition uncertainty, i.e. the original simulations of Selz, 2019). Also one set of experiments was done including the singular vectors (SV). For every experiments 5 members were randomly selected and again 12 cases distributed over one year have been simulated.



As a main result, the figure above shows the mean predictability time that resulted from the different rescaling factors. Predictability time is computed applying a fit function to the error growth curve and setting a saturation threshold. The plot shows that the current initial condition uncertainties dominate the error growth leading to much lower predictability times compared to the pure convective uncertainty experiments. This means that current predictions are on average still far away from the intrinsic limit and thus have room for improvements. Only when the current initial condition uncertainty is reduced to 20%-10% of the current value, simulations come close to the intrinsic limit and further improvements would result in only marginal changes to the forecast quality. A process-based analysis of these simulations using the methods of Baumgart et al., 2019 is planed with a subsequent publication.

Data from the Mars archive (the ERA5-reanalysis) has been used by Selz et al., 2019 to evaluate the Potential Vorticity anomaly over Germany.

List of publications/reports from the project with complete references

Baumgart, M., P. Ghinassi, V. Wirth, T. Selz, G.C. Craig, and M. Riemer, 2019: Quantitative View on the Processes Governing the Upscale Error Growth up to the Planetary Scale Using a Stochastic Convection Scheme. *Mon. Wea. Rev.*, **147**, 1713–1731, https://doi.org/10.1175/MWR-D-18-0292.1

Selz, T., 2019: Estimating the Intrinsic Limit of Predictability Using a Stochastic Convection Scheme. *J. Atmos. Sci.,* **76,** 757–765, https://doi.org/10.1175/JAS-D-17-0373.1

Selz, T., L. Bierdel, and G.C. Craig, 2019: Estimation of the Variability of Mesoscale Energy Spectra with Three Years of COSMO-DE Analyses. *J. Atmos. Sci.*, **76**, 627–637, https://doi.org/10.1175/JAS-D-18-0155.1

Craig, G. C. and T. Selz, 2018: Mesoscale Dynamical Regimes in the Midlatitudes. *Geo. Res. Lett.*, **45**, 1, https://doi.org/10.1002/2017GL076174

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The project is continued with latent heat perturbation experiments over the North American continent to investigat the importance of continental deep convection for the forecast quality over Europe (e.g. Rodwell et al. 2013).