REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Germany

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Project Title:

Upscale impact of diabatic processes from convective to near-hemispheric scale

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** DECRAI	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2019-2021:
(To make changes to an existing project please submit an amended version of the original form.)

		2019	2020	2021
High Performance Computing Facility	(SBU)	5M	5M	5M
Accumulated data storage (total archive volume)[2]	(GB)	0	0	0

Continue overleaf

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

Plant-Craig and EDA rescale experiments

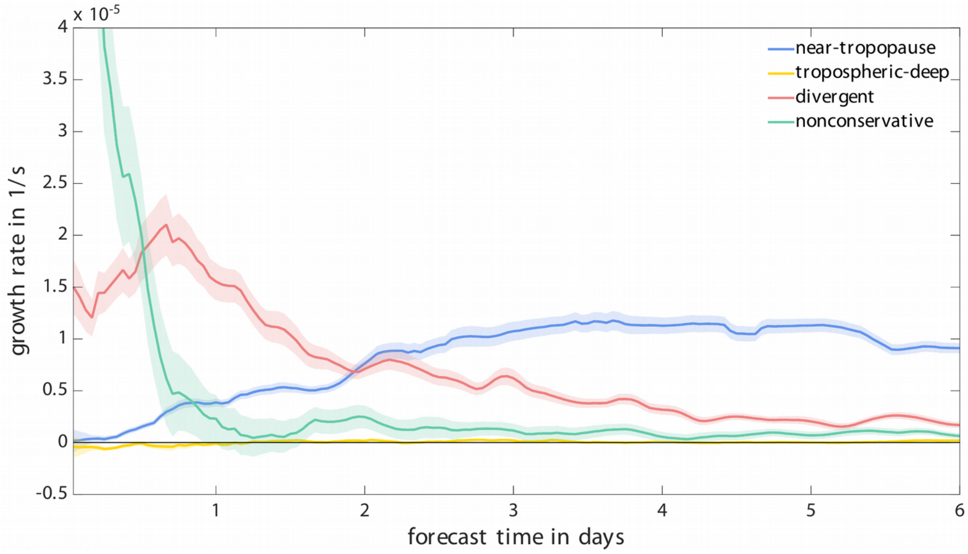
There are primarily two phenomena that lead to a limitation of the predictability of midlatitude weather systems on synoptic scales. First, there is the uncertainty of the initial, synoptic-scale state itself that grows due to processes intrinsic to the dynamics and eventually results in errors that reach the amplitude of the climate variability. Second, processes on smaller scales with much shorter inherent predictability can grow upscale and introduce additional uncertainties into the balanced flow that limit its predictability even if the initial state was perfectly known.

For upscale error growth, Zhang et al. (2007) presented a three stage conceptual model derived from an idealized case study. The first stage describes convective-scale error growth, where the initial perturbation energy on scales up to 200 km doubles on the order of an hour. In regions with moist convection, this growth rate is further increased and after a few hours significant error structures are basically confined to these regions. Consequently, the intrinsic predictability of convective processes is much shorter than for the geostrophic dynamics. The fast initial growth however slows down quickly and finally saturates on the order of 12 hours, leading to a complete or random displacement of individual convective cells. The resulting variability in upper level divergence and gravity wave propagation introduce geostrophic adjustment processes, propagating the errors onto larger scales and getting them into geostrophic balance (stage two, see Bierdel et al. 2018). In stage three, this balanced, small-amplitude perturbation grows further, now directly driven by synoptic-scale instabilities as for synoptic-scale uncertainty in the initial state. Recent work has shown that at this stage the error growth is basically driven by tropopause-near, barotropic interactions rather than baroclinic instability (tropopause-deep interactions).

Zhang et al. (2007), Selz and Craig (2015a,b) and many others have shown that the intrinsic predictability of the synoptic-scale and the planetary flow is limited by upscale error growth from convective instability. This view of course excludes potential source of predictability on very large time scales like sea surface temperature anomalies or the sea ice distribution and considers “pure” geostrophic turbulence only. Although the origin of the intrinsic limit is clear, its precise evaluation is difficult because of the wide range of spatial and temporal scales involved. Ensembles of global convection permitting simulations over about twenty days and a reasonable number of cases are still computationally too expensive. Only single case studies and two member ensembles at this high resolution have been performed very recently (Judt, 2018).

The idea of this special project was therefore to solve the problem of computational cost by lowering the resolution on the one hand but using a stochastic convection scheme (Plant and Craig, 2008) on the other hand that models the individual updrafts by random draws from underlying distributions and thus projects the “true” convective variability onto the model grid. In that sense the scheme is scale-adaptive by construction. In the past episode of this special project an ensemble of 12 cases with 5 realizations (members) of the Plant-Craig (PC) convection scheme has been successfully carried out (Selz, 2018). A comparison with the ensemble predictions of the ECMWF as an representation of current forecasting capabilities showed that current forecasts can possibly be improved by about 3.5 days through perfecting the initial conditions. At 14 forecast days of the PC ensemble this gap increases to 6 days, meaning that a current eight day forecast is as good as a 14 day forecast of our estimation of the intrinsic limit. This additional cap may be related to sampling techniques of the model error such as singular vectors and Stochastically Perturbed Parameterization Tendencies (SPPT).

New diagnostic tools have been developed in the meantime by our colleagues from the University of Mainz. Their work aims to investigate the different physical processes that drive the error growth (Baumgart et al., 2018) and thus is able to tell apart the different stages (Zhang et al, 2007, see above). One very useful tool is the spatially integrated error enstrophy and its split-up into different contributions using Potential Vorticity (PV) inversion techniques. The figure below shows the development of these contributions during the first five days of error growth of the PC ensemble (averaged over all cases and members): Initially the divergent contribution dominates which indicates that the error growth is mainly driven by convection (Bierdel et al., 2018). After about two days the tropopaus-near (barotropic) contribution becomes most important, indicating that the error growth is now mostly large-scale driven. Previous work has also shown that for ECMWF ensemble forecasts the near-tropopause component dominates right from the beginning. This diagnostic is thus able to distinguish the origin of error growth independent of growth rates or error magnitudes.



The ICON-PC ensemble that has been carried out so far used a relatively coarse resolution of about 40km (R2B6). Although the PC scheme is basically scale-adaptive in the sense that it projects the appropriate convective variability onto the model grid, error growth might be affected in low resolution simulations by weak gradients and thus weakened instabilities. Therefore it is planned to repeat a part of the ICON-PC ensemble (4 of 12 cases) at a much higher resolution of 13km (R3B7) and compare the error growth rate and saturation times.

Although the ICON-PC ensemble that was carried out so far gave an estimate of where the limit of predictability compared to current forecasting capabilities is, a question that hasn’t yet been answered is by how much the current initial condition error has to be reduced until this limit is hit. Therefore a combined ensemble of rescaled initial condition perturbations from the ensemble data analysis (EDA) system and the Plant-Craig scheme has to be carried out. Thanks to the enstrophy diagnostic of Baumgart et al. (2018) mentioned above only short term forecasts are necessary in order to assess if the intrinsic limit is reached: It is reached when the divergent component in the very beginning of the simulation starts to dominate the near-tropopause contribution. It is planned to start with an unreduced EDA-PC-ensemble where five realizations of the PC scheme are carried out from five random members of the ECMWF ensemble forecasting system initial conditions (without singular vectors). After that it is planned to reduce the EDA-perturbations by a factor of 10 and further by a factor of 100. Depending on the results a further refinement by factors of two can be done to constrain the result. The factor will give an estimate until what values of the initial condition errors can be reduced until further reduction will not be useful any more.

NAWDEX radiation and latent heat release experiments

The North Atlantic Waveguide and Downstream Impact Experiment (NAWDEX) field campaign took place in Iceland in September and October 2016 involving 3 aircrafts and additional radiosonde measurements. One of the goal of the field campaign was the investigation of the tropopause moisture gradient and to measure its sharpness and exact location. It is a known problem of model simulations that sharp gradients in the atmosphere are smoothed out with simulation time. Mainly via long wave radiation the sharpness of the tropopause moisture gradient is coupled to the dynamics by generating a Potential Vorticity (PV) dipole through radiative cooling. In addition, in regions of deep tropopause folds the moisture gradient can become horizontal which means that radiative effects cannot be simulated correctly with the usual 2-dimensional radiation scheme that is implemented in the model.

An other goal of NAWDEX was to assess the impact of diabatic heating through condensation and freezing in the Warm Conveyor Belt. Again these processes couple the moisture field to the dynamics via the generation of PV dipoles. Above the maximum heating rates negative PV anomalies are generated in the upper tropopause. This might be an important process, especially in the generation and maintenance of atmospheric blockings.

Goal of this work package is to simulate several of the most interesting NAWDEX cases and apply perturbations to the radiation scheme and to the microphysics scheme to study the dynamical impact of uncertainties in the long-wave radiation and latent heat release. Also the impact of 3-dimensional radiation at horizontal moisture gradients will be investigated either by implementing a 3D radiation scheme into the model of by simulating the appropriate cooling in some other way.

References

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Bierdel, L., T. Selz, and G. C. Craig, 2018: Theoretical aspects of upscale error growth on the mesoscales: Idealised numerical simulations. *Q. J. R. Meteorol. Soc.*

Judt, F., 2018: Insights into atmospheric predictability through global convection-permitting model simulations. *J. Atmos. Sci.*, in press.

Selz, T., 2018: Estimating the intrinsic limit of predictability using a stochastic convection scheme. *J. Atmos. Sci.,* under review.

Selz, T., and G. C. Craig, 2015a: Upscale Error Growth in a High-Resolution Simulation of a Summertime Weather Event over Europe. *Mon. Wea. Rev.,* **143 (3)**, 813-827.

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Zhang, F., N. Bei, R. Rotunno, C. Snyder, and C. C. Epifanio, 2007: Mesoscale predictability of moist baroclinic waves: Convection-permitting experiments and multistage error growth dynamics. *J. Atmos. Sci.*, **64 (10)**, 3579–3594.

Justification of requested computer resources

It is planned to use the ICON model (the new global model of DWD) for the error growth experiments (together with the Plant-Craig convection scheme) and also for the radiation- and microphysics-perturbation experiments. The computational cost of an ICON simulation has been measured from past usage to equal about 9e-5 SBU per (horizontal) gridpoint and forecast timestep. The simulation data will be transferred to a local data server and further processed by local computing resources. Therefore no permanent storage capacity at ECMWF will be necessary.

The requested computing time is calculated as follows:

High-res. PC error growth experiments:
4 cases, 5 members, 31-day simulations at R3B7 (13km): 4.9 MSBUs

EDA-rescalse error growth experiments:
5 EDA-values, 12 cases, 5 members, 3-day simulations at R3B7 (13km): 7.2 MSBUs

NAWDEX experiments:
50 7-day simulations at R3B7 (13km): 2.8 MSBUs

These computational costs sum up to 14.9 MSBUs or rounded to 5 MSBUs per year, which is our request.

Technical characteristics of the code

The ICON model and the Plant-Craig stochastic convection scheme are written in Fortran90 and use both shared memory multiprocessing (via OpenMP) and distributed memory parallelization (via MPI). The ICON model together with the Plant-Craig scheme has been run on the ECMWF supercomputer several times without problems and with very good scalability during the previous phase of this special project.