REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: Germany

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Project Title: Flow-dependence of the intrinsic predictability limit and its relevance to forecast busts

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.)	2022	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	30M	90M	90M
Accumulated data storage (total archive volume)[2]	(GB)	0	0	0

Continue overleaf

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] These figures refer to data archived in ECFS and MARS. 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.

Principal Investigator

George Craig (george.craig@lmu.de)

Project Title

Flow-dependence of the intrinsic predictability limit and its relevance to forecast busts

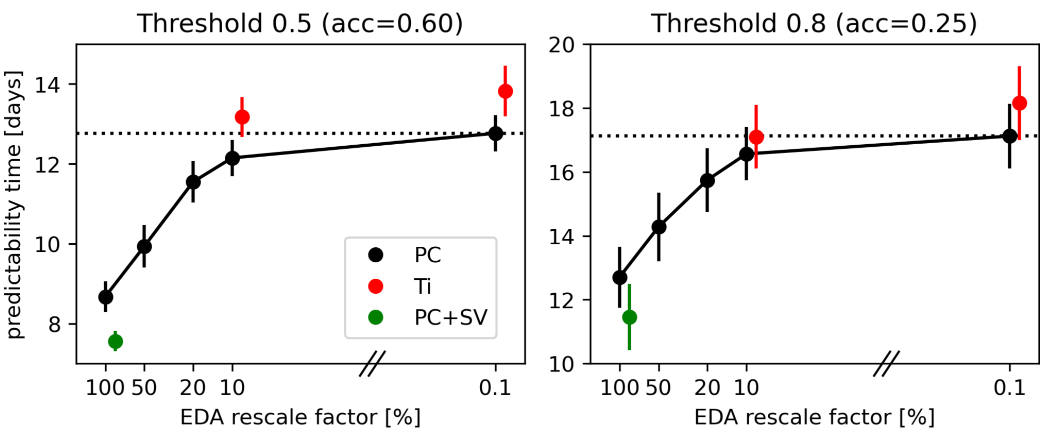
Abstract

Recent numerical experiments suggest that, on average, the accuracy of medium-range weather forecasts in the midlatitudes has not yet reached the intrinsic predictability limit proposed by Lorenz (1969), and further improvements in skill and lead time are possible. However, there is substantial case-to-case variability in error growth, and it is possible that some of the poorest forecasts may already be impacted by the intrinsic limit. To test this hypothesis, we propose to examine the sensitivity of forecast error growth to the magnitude of initial condition error for a large number of cases. These experiments will use a relatively low resolution of the ICON model with a stochastic convection scheme to represent small-scale variability. A selected case study will then be examined in detail using global convection-permitting simulations, where the rapid, small-scale error growth processes are represented as accurately as possible.

1 Scientific Background

It has been known for some time that our ability to predict the weather may be intrinsically limited by rapid growth of small-scale errors (Lorenz, 1969). The intrinsic limit can be estimated by considering the growth of differences between numerical simulations that are perturbed with very small amplitude noise. In previous work we estimated the intrinsic limit of predictability using the ICON numerical model and a stochastic scheme for deep convection (Selz, 2019), since it has been shown that error growth from small initial condition uncertainties is slowed down at coarse, non-convection permitting resolutions (Selz and Craig, 2015).

Recently, we extended this analysis by including additional experiments that are started from a variety of initial condition error amplitudes to investigate the transition from current practical predictability to intrinsic predictability (publication in preparation). The figure below shows one key result from these experiments. The initial condition uncertainty is sampled from ECMWFs ensemble data assimilation system (EDA), and rescaled in amplitude with the factor given on the x-axis. The resulting predictability time is given on the y-axis for two different thresholds (0.5 and 0.8 times a climatological variability). For this work we analyzed 12 cases, distributed over one year with 5 member ensembles, and the figure shows the average over these 12 cases and both hemispheres. The increase in predictability time with decreasing initial condition uncertainty saturates once the initial errors reach about 10% of their current size, indicating that the intrinsic limit of predictability is approached. Zhang et al. (2019) also concluded, using different numerical models, that current NWP systems are relatively far from the intrinsic limit.



Interestingly, the approach to the intrinisic predictability limit is also characterized by a change in the mechanism of initial error growth. Spectral analysis and the potential vorticity diagnostics developed by Baumgart et al. (2019) showed that when the initial condition errors are reduced to around 10% to 20% of current EDA amplitudes, the dominant initial error growth process changes from tropopause-level nonlinear advection to upscale impacts of convective heating.

While it is comforting to know that there is still considerable potential to improve weather forecasts, the conclusions obtained so far concern average behaviours, and do not address the flow-dependence of intrinsic predictability and its seasonal and regional variability. An indication of the importance of this variability comes from the performance of current NWP systems (practical predictability). This is strongly flow-dependent, and has been investigated extensively, with a particular focus on events with unusual low forecast skill, referred to as forecast busts or dropouts. Rodwell et al. (2013) suggested that forecast busts over Europe may be associated with a trough over the Rocky Mountains and mesoscale convective systems over the eastern USA at the forecast initialization time. In addition to the quality of the forecast in these situations, the reliability of the ECMWF ensemble system also decreases (Rodwell et al., 2018), which was attributed to unrealistically weak interactions of the convective systems with the jet stream. Lillo and Parsons (2017) further investigated European bust cases and identified recurving tropical cyclones in autumn and rapid cyclogenesis in the winter as two additional phenomena that may lead to busts, while the Rocky trough bust type is most dominant in spring and summer.

2 Objectives and Research Strategy

The goal of the numerical experiments proposed here is to investigate the intrinsic predictability of a large number of weather situations and to also characterize the flow-dependence of the transition from practical to intrinsic predictability. Although the previous work mentioned above indicates that the transition to intrinsic predictability is still far away on average, it is nonetheless possible that under certain flow conditions and in certain regions this limit might already be close. Indeed, the involvement of convective processes in most of the European bust cases could indicate that the forecast quality already suffers from an unusual low intrinsic limit.

We intend to investigate these issues first by applying our established methodology based on simulations with a stochastic convection scheme and rescaled initial condition perturbations to a large number of case studies to obtain reliable statistics about the flow-dependence of the intrinsic limit and its relation to the practical limit, especially with respect to operational forecast busts. This will enable us to test our cental hypothesis that particularly bad operational forecasts are related to lower intrinsic predictability. In particular, we will assess whether the distance between the practical and the intrinsic limit is reduced, meaning that the possible gain through initial condition and model improvement is smaller than usual. We will also investigate the alternative hypothesis that bad forecasts are mainly caused by the model error becoming more significant, and the possible gain by improvements to the NWP system is even higher than usual.

The second part of the study is motivated by the fact that the approach to the intrinsic predictability limit, as well as many practical forecast busts, are associated with convective processes, and the results may be affected by model error, particularly in the cumulus parameterization. For example, Rodwell et al. (2018) have suggested that outflow height errors in the convection scheme may contribute to the overconfidence of the ensemble system in bust cases due to weak convection-jet stream coupling. To avoid the limitations of the convection scheme, we plan additional global simulations with convection permitting resolution for one selected forecast bust case. These simulations will reduce the model error as much as currently possible and will provide the most accurate method to analyze the growth of the initial perturbations in the presence of deep convection and their coupling to jet stream and Rossby wave activity.

In addition to these main objectives, the high-resolution simulations will also be very valuable for other research questions: They provide the opportunity for a detailed analysis of the kinetic energy spectrum and particular its transition from a -3 to a -5/3 slope, which requires simulations with $< 10\,\mathrm{km}$ resolution. This will continue our previous line of work on spectra using limited area models (Craig and Selz, 2018; Selz et al., 2019). Together with Christian Kühnlein (ECMWF) we have already investigated global spectral analyses in space and time as a method to analyze and compare model runs at 10km resolution (see our progress report 2021) and we would like to extend this comparison to convection permitting resolution and investigate these methods in the context of different dynamical cores. Furthermore, the predictability of larger-scale, stratiform ascent (warm conveyor belts) can be analyzed with much greater accuracy, since they can include convective-type motions as well (Rasp et al., 2016) and their relevance for outflow height and ridge amplification is unclear. The research will be carried out in the framework of the DFG-funded Collaborative Research Centre "Waves to Weather", and the global high-resolution simulations will be made available to other partners investigating additional research questions.

3 Planned experiments and SBU estimates

To plan the simulation experiments in detail, we will start with an analysis of worldwide forecast busts occurrence during the past years in the ECMWF operational forecasting system and available re-forecasts. Rather than focusing on a particular region such as Europe, the goal will be to identify regions and seasons that are prone to outliers with low forecast skill. This part will only require access to the archive but no computational resources at ECMWF.

In the first year of the special project we plan to continue with our approach of investigating intrinsic predictability with ICON simulations at a relatively low resolution (40km) and compensating for that by using the stochastic convection scheme of Plant and Craig (2008). It is planned to simulate one year of initial conditions (365) up to 20 days with a 5 member ensemble, although this strategy may be modified based on the results of the analysis of the operational system. The first experiment will be started from an unchanged initial condition sample from the ECMWF-EDA system, while the second experiment will use a rescaled sample (<= 10%).

The computational cost of this model setup (estimated from previous runs) is 300 SBU per forecast day. With two experiments, started on 365 initial conditions and run for 20 days with five members this sums up to about 22 MSBU. An additional 8 MSBU is requested as a reserve and for test runs with higher resolution, especially convection-permitting resolution.

For the second part (year two and three), we will pick one forecast bust case with apparent low intrinsic predictability based on the dataset described above. For this case we will start ICON simulations with convection-permitting resolution (2.5km) and no deep convection scheme. Again we plan to simulate five ensemble members, but reduce the forecast lead time to six days, which is a typical timescale for a bust to develop. Three experiments with different initial condition amplitudes are planned, e.g. 100%, 50% and 10% times the original EDA sample. The convection-permitting simulations will reduce model error as far as currently possible and will result in a more accurate estimate of how much the forecast in this particular bust case could be improved and how much of it is related to an intrinsic limit.

An ICON global run at this high resolution has not been done so far by us. It has however been done successfully by others (Stevens et al., 2019). As a reference to estimate the required resources we use a 10km ICON run, which requires 16200 SBU per forecast day. For a target resolution of 2.5km this is multiplied by 64 for increased horizontal gridpoints and shorter time step and a factor of 2 for increased vertical resolution, which results in an estimated 2 MSBU per forecast day. Thus, three experiments run for 6 days with 5 members each will cost 180 MSBU, which we distribute over the second and third year of the special project.

4 Technical aspects

ICON is a nonhydrostatic, fully compressible model which explicitly includes horizontal propagating sound waves. Only in the vertical they are solved implicitly (Zängl et al., 2015). It is written in FORTRAN90 and uses both distributed memory parallelization (with MPI) and shared memory parallelization (with OpenMP). It is designed for highly parallel machines and provides a good level of scalability.

Data volume is likely an issue and a limitation for the experiments that are planned in this special project. Although we do not request any long-term storage space in the archive, temporary a high amount of data needs to be stored and transformed to our local computing system at LMU. This may take some time, depending on the available bandwidth. To mitigate these issues we are currently exploring methods of lossy compression within our collaborative research center "Waves to Weather". Depending on the required accuracy, data volume with these methods could be compressed by up to a factor of 10, at least for some datasets.

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