SPECIAL PROJECT FINAL REPORT

Project Title:	Upscale impact of diabatic processes from convective to near-hemispheric scale
Computer Project Account:	spdecrai
Start Year - End Year :	2019 - 2021
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Summary of project objectives

The main goal of this project is to study upscale error growth and its role in limiting predictability, especially with respect to convection and its (deficient) representation in numerical models. By applying a stochastic convection scheme we seek to reduce the model error close to the gridscale. This improved model setup enables a more accurate investigation of the transition from current practical to intrinsic predictability and the impact of the convection scheme to those limits, even at relatively low resolution. Furthermore, we explore the significance of global space-time spectra as a diagnostic tool for understanding the dynamics of the atmosphere and differences and error in model simulations.

Summary of problems encountered

The relativly low bandwidth of the file transfer from ECMWF to our university, where the data was further processed and analyzed, caused some delay. We would very much appreciate if at the new center in Bologna this bandwidth could be significantly increased, since we expect an even higher data volume during the next special project.

Experience with the Special Project framework

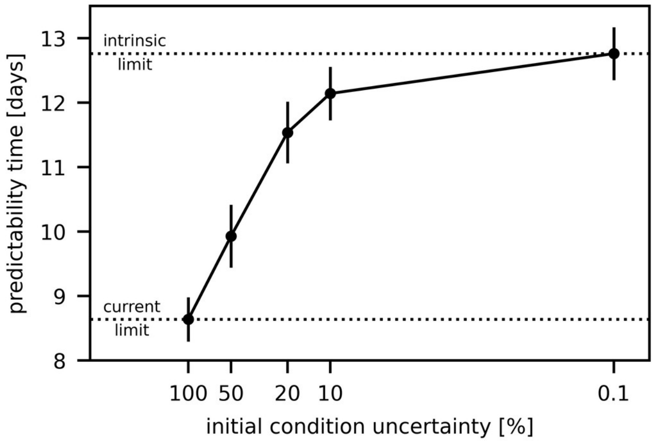
We have been happy with the application and progess reporting procedure. Given the amount of granted computing time, the required lengths of the reports and applications seem appropriate and not to elaborate. We would however be interested to receive some feedback on the proposed ideas and reported results from ECMWF scientists.

Summary of results

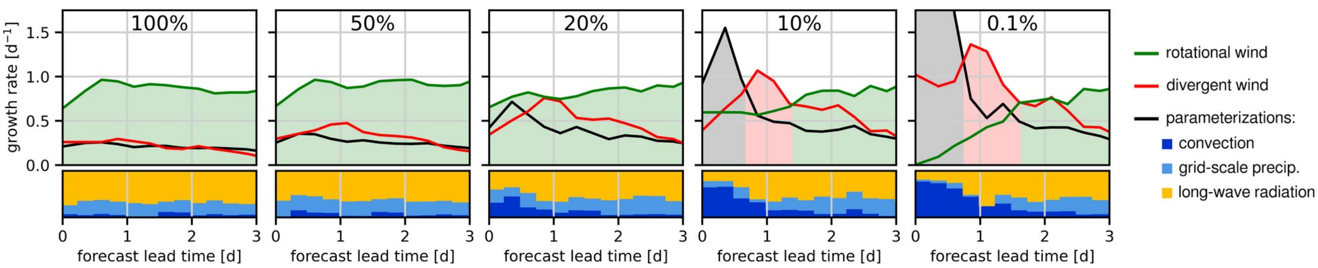
a) The transition from practical to intrinsic predictability of midlatitude weather

The main result from this special project considers the transition from practical to intrinsic predictability of midlatitude weather, i.e. we investigated the effects of future improvements of the initial condition uncertainty on predictable lead time and on physical processes that are responsible for error growth. Details can be found in Selz et al., 2022 and here we give only a short summary. We simulated 12 cases, evenly distributed over one year, with 5 member global ICON ensembles at 40km resolution. The initial conditions for the ICON ensembles were taken from ECMWF's ensemble data assimilation system, which provides a good estimate of current uncertainty in the initial conditions. These experiments have been repeated several times, but the spread of the initial condition ensemble is reduced in several steps from 100% down to 50%, 20%, 10% and 0.1%, respectively.

The 0.1% experiment represents only a very small "butterfly"-like initial condition perturbation, that serves to estimate the intrinsic limit of predictability, which is the predictability horizon that arises from scale interactions in the atmosphere and cannot be overcome. The study relies on the ability of the model to simulate error growth realistically (perfect model assumption) but uses a model that is of course imperfect. We attempted however to improve the model with respect to upscale error growth from convective motions by extending ICON with the stochastic convection scheme of Plant-Craig. In addition to the 5 experiments mentioned above, we simulated reference experiments with deterministic convection, singular vector perturbations and increased resolution (see Selz et al., 2022 for details).



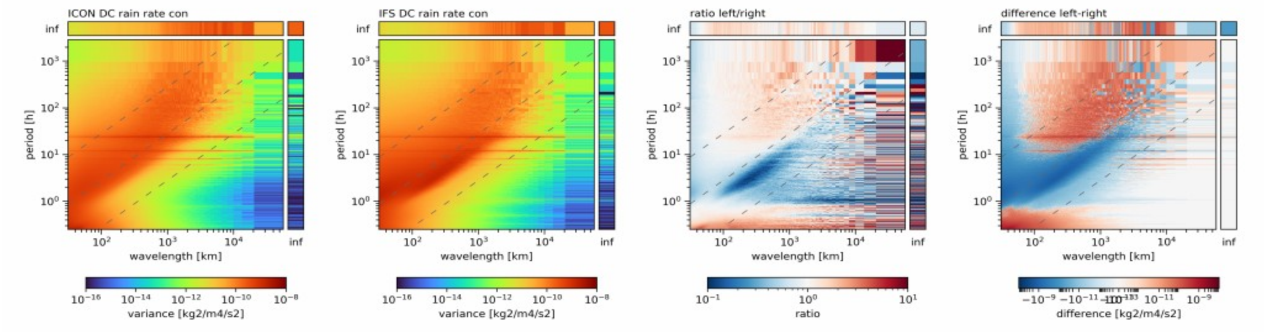
The Figure above shows the impact of the initial condition uncertainty on the time interval, over which we can predict the winds at tropopause level into the future (more precisely the time at which the 300hPa DKE reaches half the climatological variability). Although the absolute times depend on the variable, the metric and the accuracy requirement of the user, we can expect to gain about 4-5 additional forecast days, if we were able to make the initial conditions (almost) perfect. We can also see that this gain can essentially be achieved with a reduction of the initial condition uncertainty by 90%. This reduction would brings us already very close to the intrinsic limit and hence further improvements will lead to diminishing returns. The good news is, that we are currently still in the regime where initial condition improvements are highly beneficial in extending predictability.



We further investigated the physical processes that are responsible for error growth by means of the potential enstrophy diagnostics that have been developed based on an earlier special project (Baumgart et al., 2019). The second figure shows the growth rates over the first three days separated by process. With current initial condition uncertainties (100%, left) we see that error growth is driven by rotational component of the flow right from the start, which is associated with synoptic-scale and Rossby-wave dynamics and 2D turbulence. This situation changes however at the 10% initial condition uncertainty level, where latent heating from convection is dominating error growth early in the forecast, followed by error growth in the divergent part of the flow and eventually the rotational component dominates again. This indicates that with small amplitudes of initial condition uncertainty, predictability is limited by an upscale interaction process from convection via geostrophic adjustment to synoptic and planetary scales and that once this upscale process becomes dominant, further improvement of the predictable time span is very limited.

b) Global space-time spectra and their value in model evaluation

In a second line of work we explored global space-time spectra and their potential as a diagnostic for comparing different models and model configurations. The spectral distribution, especially of energy, has been shown to have a large impact on scale interactions and error growth and thus potentially impacts predictability. ICON runs at 10km resolution with high frequency output have been performed to compute global space-time spectra for several variables. Christian Kühnlein (ECMWF) has provided similar simulations, computed with the IFS model. The figure shows an example of the space-time spectral diagnostic applied to the convection scheme precipitation rate, comparing an ICON and an IFS simulation for January 2020.



The space-time spectra provide a detailed analysis of the temporal and spatial characteristics and difference between the models. In both models the precipitation rate is concentrated in a diagonal band, which indicates advection with a speed of 5-20m/s as the dominant process. However, within this advective band the IFS model shows a higher activity at the lower boundary of the band, i.e. at advection speeds of about 20m/s.

Besides the diurnal cycle being clearly visible in the convective precipitation rate, it can be seen that the convection scheme produces increased high frequency variability up to scales of about 1000km, which is more pronounced in ICON than in IFS. This is likely related to the trigger function (test parcel ascent) of the convection scheme, which may turn convective cells on and off again at consecutive calls. These artificially short-lived cells may contribute to the fact that we saw slower error growth in simulations with parameterized convection (Selz et al, 2022), since they may remove instability without a corresponding dynamical impact. This high frequency variability can be seen even more pronounced in the cloud-base mass flux (not shown) and poses a serious challenge in the development of a stochastic convection scheme based on Tiedtke-Bechthold and the theory of Craig and Cohen, 2006. In collaboration with DWD, who has already done the technical implementation, we are currently investigating options to make the closure mass flux more steady, so that stochastic variations can be applied on top of that in a largely consistent way.

Space-time spectra of several other variables have also been investigated, including kinetic energy, available potential energy, vertical wind and divergence. We also performed runs without a deep convection scheme (but still at 10km resolution) for comparison. Investigation of the interpretation and significance of these spectra is ongoing, and we are considering extending the study to include era5 reanalysis data.

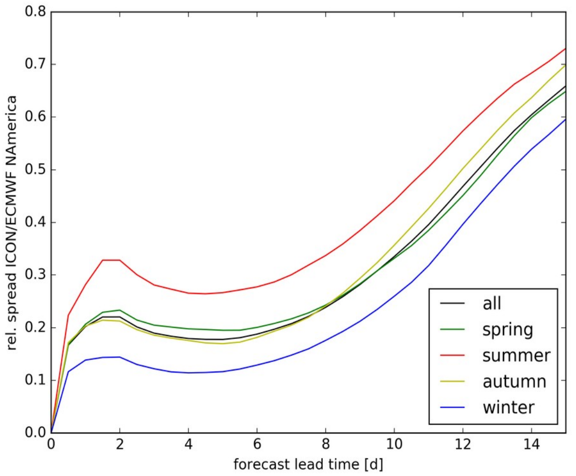
c) Latent heat perturbations over North America

An other part of the computing resources been used to further explore the specific role of continental convection and the associated latent heat release in the prediction of weather downstream. Past studies (e.g. Rodwell et al., 2013) suggested a degrading influence of convection over the North American continent on forecast quality over Europe. This hypothesis has been explored using the ICON global model together with perturbations of latent heat over North America.

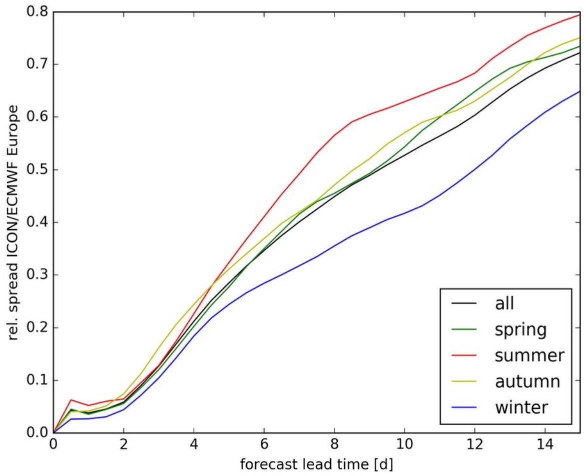
To do so, the ICON model has been used to simulate one year (2016) of 15 day forecasts, starting from 0 UT at every day of the year. In addition to an unperturbed run, latent heat perturbations over the North American continent have been applied early on in the forecast (the first 48h of simulation time). One run with 75% of the normal latent heat and one run with 125% of the normal latent heat has been computed. Thus we computed for each day in 2016 a small, three member ICON ensemble that accounts for potential uncertainties in the latent heating over North America.

First, we measured the impact of the latent heat perturbation over North America on the forecast in terms of the spread, that they generated and computed the standard deviation of Z500 of the 3-member ICON ensemble over North America and Europe as a function of forecast lead time. To better assess the magnitude of this spread we divided it by the standard deviation of the ECMWF ensemble forecasts at equal location and forecast lead time. The figures below show the results, which are also separated by season.

a) North America

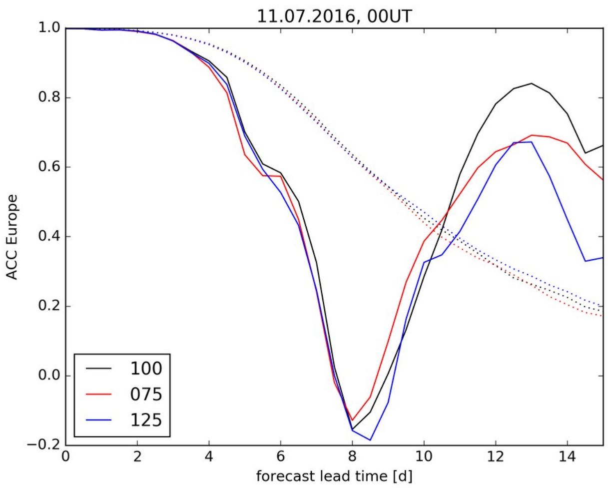


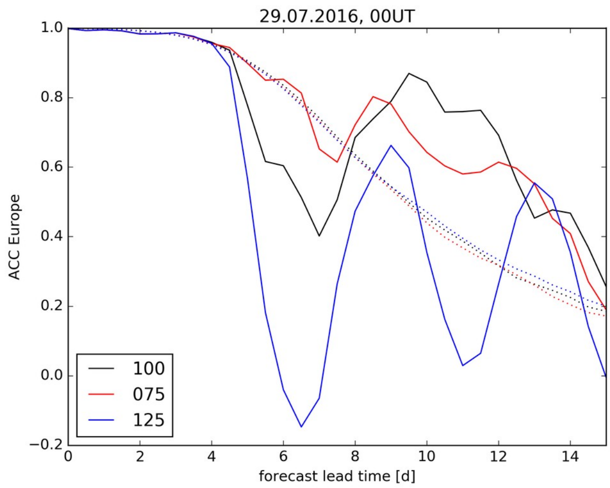
b) Europe



In the North America plot the impact of the perturbations is directly visible. They are active for 48 hours and till then the spread is continuously increasing relative to the spread of the ECMWF ensemble from zero initially to about 30% in summer and only about 10% in winter. This seasonal dependence is expected and reflects the much more intense convection over land at summertime. Over Europe, the spread starts to significantly increase after 2-3 days of forecast lead time. It is initially quite insensitive to the magnitude of the initial perturbation over North America and shows little seasonal dependence. After 5 days into the forecast this seasonal dependence starts to show and further increases untill 8-10 days of forecast lead time. About 5 days is also the expected time for a perturbation to cross the Northern Atlantic. These results suggest a significant impact of latent heat release and convection over the Northern American continent for the forecast over Europe.

Though the average effect of the latent heat perturbations on forecast quality over Europe (measured by the 500hPa anomaly correlation) is quite small (not shown), in individual events, the impact can be much larger. As suggested by the Rodwell-study, convection over the US and its deficient representation in the model could lead to particularly bad forecasts over Europe about 6 days later. In our yearlong time series we see examples both in favour as well as in contrast to this hypothesis, as illustrated by the following two example figures.





The figure on the left-hand side shows the ACC over Europe of the forecasts started on 11th of July 2016 and shows a clear dropout in forecast quality at 8 days forecast lead time. This forecast “bust” however does not seem to be connected to the latent heat perturbation and thus to convection over North America, since the perturbation show only a very little impact. On the other hand for the forecast started on 29th July 2016, the latent heat perturbation show a huge impact on forecast quality, at 6-7 days forecast lead time. While the reduced latent heat run performs more or less like an average forecast, the increased latent heat run generates a very significant forecast bust with an ACC drop into the negative range.

Though we are not planing to publish the results of these small 3-member experiments, they have provided further inside into convection, error growth and its relation to forecast busts. This helped us design a much larger experiment in a new, already approved special project (“Flow-dependence of the intrinsic predictability limit and its relevance to forecast busts”) to investigate the relationship of practical and intrinsic predictability, especially in such “extremely” bad forecast events.

List of publications/reports from the project with complete references

Selz, T., M. Riemer and G. Craig, 2022: The transition from practical to intrinsic predictability of midlatitude weather. JAS. doi.org/10.1175/JAS-D-21-0271.1

Poster at ECMWF model uncertainty workshop, May 2022

Talk at EGU, May 2022

Talk at DWD ICCARUS meeting, March 2021

Future plans

We will continue this work with a new special project (“Flow-dependence of the intrinsic predictability limit and its relevance to forecast busts”) by first extending the approach discribed in part (a) and in Selz et al., 2022 to many more cases to derive a “climatology” of the intrinsic limit and the improvement potential, i.e. to estimate its spatial, seasonal and flow-dependent variability. Furthermore, we are interested in the relationship between variability of the intrinsic limit and forecast quality in current operational systems, especially with repect to dropouts or forecast busts. In a second step we plan to complement this analysis by repeating a few of the most interesting cases with global convection-permitting simulations to further reduce model errors that are caused by convective parameterizations (see our special project application from 2021 for more details).