SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2016/17
Project Title:	Upscale impact of diabatic processes from convective to near-hemispheric scale
Computer Project Account:	spdecrai
Principal Investigator(s):	Greorge Craig
Affiliation:	Meteorologisches Institut Ludwig-Maximilians-Universität München
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	2016
Expected end date:	2018

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	2.5M	0.48M	2.5M	1.2M
Data storage capacity	(Gbytes)	500GB	0GB	500GB	0GB

Summary of project objectives
(10 lines max)

In this project we will investigate 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 will be possible by recent developments in numerical atmospheric modeling (ICON) and stochastic parameterization (Plant-Craig). The non-hydrostatic ICON model allows for local grid refinements while the Plant-Craig convection scheme is able to emulate convective uncertainty at non-convective permitting resolutions. These two tools will form 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 mid-range global weather prediction. In addition we will investigate the presence and definition of meteorological regimes in space and time that define or modify error growth properties.

Summary of problems encountered (if any)
(20 lines max)

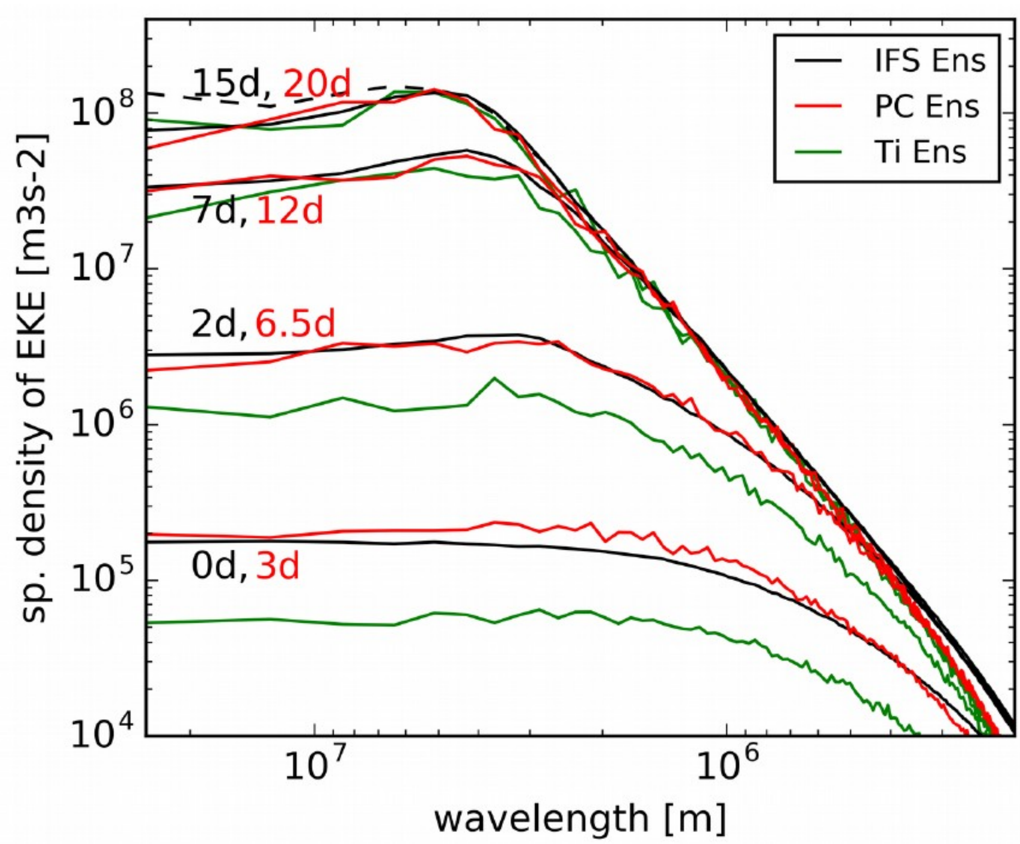
The Plant-Craig scheme implemented into ICON produced a strong cold bias by cooling the globally-average upper-level temperature by 0.1K per forecast day. This problem was related to the (unusual) formulation of the thermodynamic equation in the ICON model and could be solved not until Dec 2016. Because of this problem the computing time allocation in 2016 could not be used up as planned.

Summary of results of the current year (from July of previous year to June of current year)

ICON upscale error growth experiments

Assuming a perfect model these experiments are suited to estimate intrinsic limits of predictability of the atmospheric flow up to the planetary scale that arise from the short predictability time of convective motions. Even if the initial state of the atmosphere was perfectly known the low intrinsic predictability timescale of the convection of around 12 hours will generate uncertainties on these scales that will grow upscale and eventually contaminate even the planetary scale and lead to a complete loss of predictability related to atmospheric turbulence (other sources of predictability in other earth systems may however still exist). Since convection-permitting simulations on the globe for such long lead times are still far too expensive to conduct we used the Plant-Craig stochastic convection scheme instead to simulate the uncertainties that arise from the convection without the need to resolve it. A comparison to convection-permitting simulations in a limited-area model has shown that the emerging error amplitudes are similar (Selz and Craig, 2015).

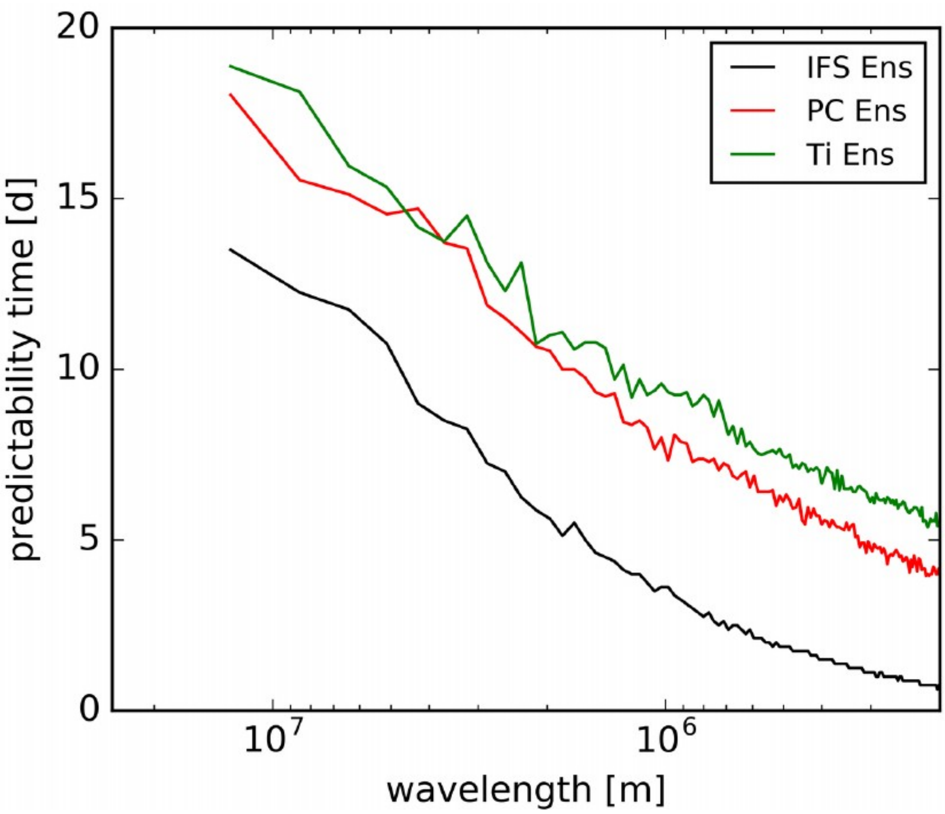
So far 12 cases of global simulations have been performed, starting from 1 Jan 2016 up to 1 Dec 2016 in monthly steps. Each simulation has been run for 30 days and four ensemble members have been generated for each case: Two realizations of the stochastic convection scheme of Plant and Craig (PC) (by using a different random seed) and two realizations of the Tiedtke scheme (Ti) (by introducing gridscale noise initially). The ICON model was used in R2B6-resolution (approximatelly 40 km). Mid-latitude error kinetic energy (EKE) spectra of the wind at 300hPa have been calculated, where the error spectrum is defined as the kinetic energy spectrum of the difference wind between the two realizations of either the Plant-Craig or the Tiedtke scheme. For comparison the error spectra from the ECMWF forecast ensemble are also computed. Here the difference wind between all possible combinations of members is calculated and then averaged. The result is displayed in the figure below for selected points in forecast lead time, averaged over all twelve cases and both hemispheres.



The plot indicates that the error kinetic energy in the ECMWF system at 0d forecast lead time (initial conditions) compares approximately to the error in the Plant-Craig ensemble after three days of forecast. This gab grows further to about 4.5 days for the 2d ECMWF forecast vs. 6.5d PC-forecast and finally settles to about 5 days at 7 days vs. 12 days and beyond.

Since the Plant-Craig ensemble represents an estimation of the intrinsic limit of predictability that originates from deep convection the comparison above provides an estimate of how much current forecasting systems can be improved until they hit the intrinsic limit. The results roughly suggests that current forecasts can be improved by 5 days for the largest scales (planetary waves). These five days of possible improvement can be roughly split up into 3 days of improvement through perfecting the initial conditions and another two days of improvement through perfecting the model. This separation is however so far only a crude estimate since the increasing gap between the two ensembles most likely is due to the inflation of the ECMWF ensemble by stochatic physics and singular vectors. While the first is supposed to sample the model error the physical meaning of the singular vectors are not as clear-cut. They could e.g. represent shortcomings in the ensemble data assimilation system or account for the small number of ensemble members.

As in Selz and Graig 2015, the error growth in Tiedtke simulations is slower than in the PC ensemble, which means that Tiedtke model simulations are overconfident with respect to errors that arise from deep convection. However at later forecast lead times this difference gets more and more insignificant since the errors grow only very slowly at the largest scales compared to the faster error growth initially. This means that predictability studies that used a deterministic convection scheme and perturbed with noise are reasonable as long as large scales and longer forecast lead times are considered. This picture is further supported by the the following figure which shows the predictability time over scale defined by the time it takes the error at certain scale to reach 75% of the saturation value. It also states that in a relative sense the potential of improvement is much larger at the mesoscale than at the planetary scale.



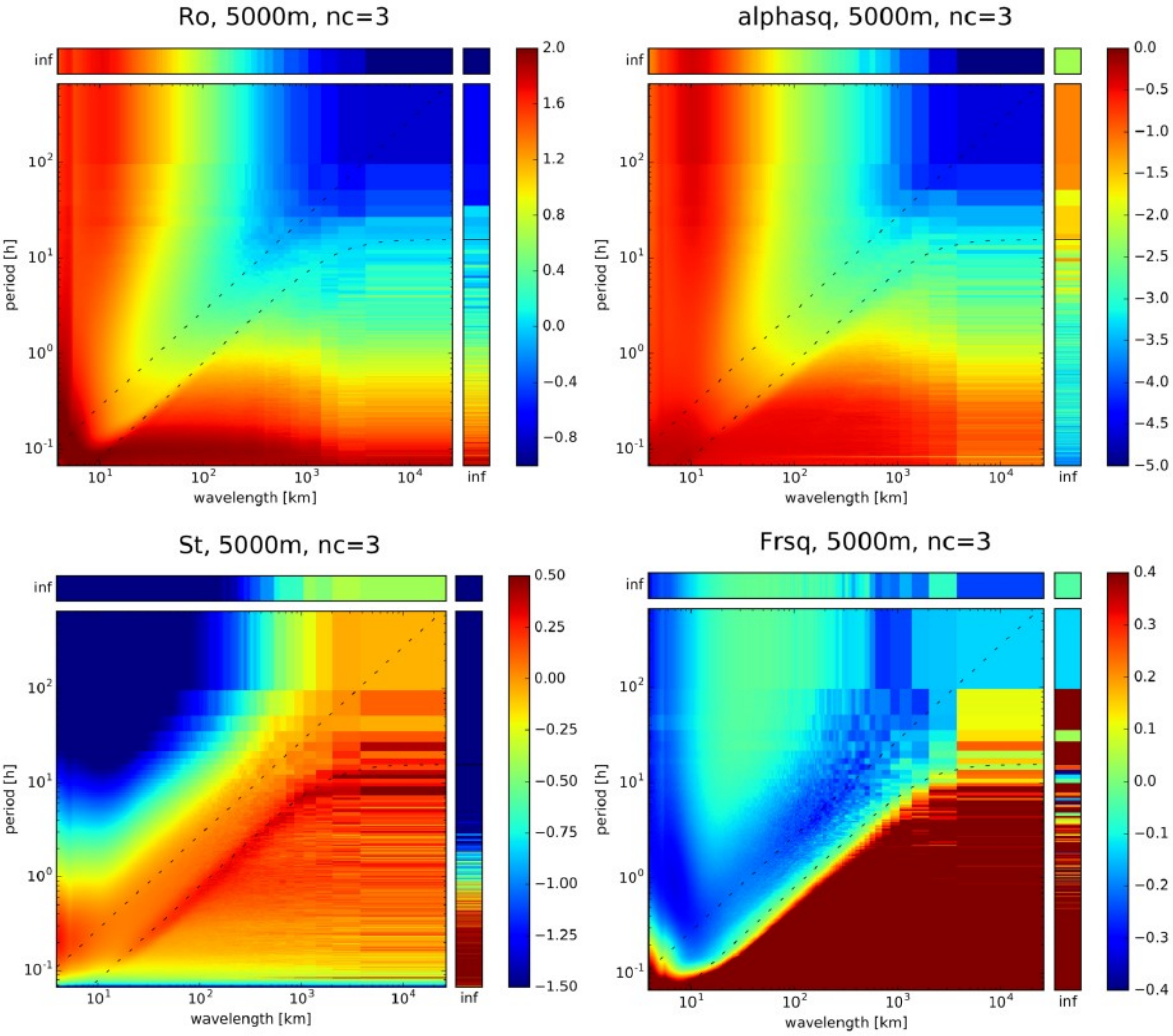
So far the number of ensemble members in the data set is minimal (2). It is planned therefore to extend the current dataset to five ensemble members within the PC-ensemble and the Ti-ensemble with the remaining computational resources. In addition the considered period will be shifted a few month into the future to avoid having the major grid change in the IFS-model cycle (March 2016) within the data period. In addition, tendency terms will be added to the output and will be analyzed together with our project partner form YGU Mainz to identify physical and dynamical processes that drive the error growth at the different stages and in different regimes. First results indicate that difference in the upper-level divergence that arise from the redistribution of deep convection in the PC ensemble are the major source of error growth in the first few days. When this mechanism has created larger perturbations in the PV field barotropic (tropopause-near) interactions start to dominate and eventually at times approaching the error saturation (>10 days) the baroclinic (tropopause-deep) interactions contribute significantly, especially during winter months. These preliminary results have to be confirmed with further improvements to the method and including more ensemble members.

This line of work at its different stages has been already been presented at the "High impact weather and climate conference" in Manchester in July 2016, the COSMO/ICON user seminar at DWD in Offenbach in March 2017 and will be presented at the Convective "The Future of Cumulus Parametrization" in Delft in July and "Conference on Predictability and Multi-Scale Prediction of High Impact Weather" in Landshut in October. After completing the simulations several scientific papers are planned.

Identification of regimes using COSMO

As already indicated above, upscale error growth is not a homogeneous process over the full range of scales that have been considered here. At different time and spatial scales different terms of the underlying equations become important while others become negligible (e.g. rotational effects or non-hydrostatic effects). This phenomenon modifies the flow itself and also the error propagation over time- and spatial scales. This line of work therefore aims for the identification of meteorological regimes that can be described each by an approximated set of equations within a certain space-time range.

To quantitatively define such regimes a numerical simulation has been performed (using COSMO) in convection-permitting resolution (2.8km) on a 7000km times 4500km domain over Europe for 7 forecast days. Output was dumped every 2 minutes in order to resolve the maximal possible range of spatial and temporal scales. A set of non-dimensional numbers, i.e. ratios of the magnitudes of different terms in the equations are calculated and spectral transformed in space and in time. The non-dimensional numbers considered are: Rossby number (Ro), aspect ratio (asphasq), Strouhal number (St) and Froude number (Frsq). Their magnitude of these numbers in the space-time spectrum representation are displayed in the figure below.



Non-dimensional parameters in a space-time diagram. The color bars indicate the decadal logarithm of the respective parameter.

These numbers allow for a quantitative representation of different regimes: The quasi geostrophic regime is given by a low Rossby number (<0.5). The weak temperature gradient regime is given by a low Froude number (<1.0). Gravity wave regimes are defined by a Froude number of order 1 and are further split into two categories using the Strouhal number: Waves with a very low St number are (almost) stationary orographic waves while wave with a high St number are horizontally propagating gravity waves mainly induced by deep convection. A high St number band indeed closely follows the dispersion relation for such waves which is indicated with the lower dotted line in the figure. The region of very high Froude number below this line is the acoustic wave regime, where with our model setup the contained energy is generally very low.

A paper on these results is currently being prepared. In addition they will be presented at the "IAPSO-IAMAS-IAGA joint assembly" conference in Capetown in August and the "Conference on Predictability and Multi-Scale Prediction of High Impact Weather" in Landshut in October by George Craig.

Reference

Selz, T. and G. C. Craig (2015b): Simulation of upscale error growth with a stochastic convection scheme, Geophys. Res. Lett., 42

List of publications/reports from the project with complete references

Past conference contributions

High impact weather and climate conference, Manchester, UK, July 2016

COSMO/ICON User seminar at DWD Offenbach, March 2017

Summary of plans for the continuation of the project

(10 lines max)

The Plant-Graig and Tiedtke ensemble simulation will be extended from 2 to 5 members and the simulation period will be shifted a few month into the future. This will introduce reliability and avoid discontinuities in the IFS system (details above).

After having finished this first ensemble which is ment to investigate intrinsic predictability the focus will be shifted towards more practical forecast problems in current systems (busts) and the role of convection or more general diabatic processes like radiation or latent heat release in Warm Conveyor belts. Within this line of work also cases will be considered and analyzed that were observed during the NAWDEX field campaign in Island in September/October 2016.