SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	Flow-dependence of the intrinsic predictability limit and its relevance to forecast busts
Computer Project Account:	spdecrai
Principal Investigator(s):	Prof. George Craig
Affiliation:	Meteorologisches Institut Ludwig-Maximilians-Universität München Theresienstr. 37 80333 München Germany
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	2022
Expected end date:	2024

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)	30M	30M	90M	1.05M
Data storage capacity	(Gbytes)	0	0	0	0

Summary of project objectives

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 uncertainty growth to the magnitude of initial condition uncertainty 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.

Summary of problems encountered (10 lines max)

None.

Summary of plans for the continuation of the project (10 lines max)

Unfortunately, funding for our project "Waves to Weather" will end on July 2024. Therefore, we are currently in the process of revising our plans for future work. But we are planing to basically continue the work on the project objectives with a potential delay based on some other funding source. For the current year, it is planned to spend the computational resources on a proper evaluation of the new stochastic scheme. In addition, we are planing to extend the global high-resolution reference runs for further testing low-resolution models with respect to error growth, including recent models based on neural networks.

List of publications/reports from the project with complete references

None yet.

Summary of results

Last year's computational resource have been used to compute a five member ensemble of a three-day forecast with global convective-permitting resolution (ca. 2.5 km grid spacing). The simulations have been computed with the German ICON model, which is a non-hydrostatic model on a icosahedral grid. A case was chosen with significant summertime convection over the continents, especially North America (init time 26.06.2021, 0 UTC). The initial conditions for the ensemble were taken from the ECMWF-EDA system, however, the magnitude of the perturbation was largely reduced to 0.1%. The purpure of this ensemble was to estimate as accurately as possible fast intrinsic error growth from tiny perturbation, i.e. the so-called butterfly effect (see e.g. Selz and Craig, 2015a). This fast error growth is usually initiated in regions with moist convection and is not well simulated with coarser resolution models: Simulations with lower resolution and a convection scheme, which only estimates the average effect of many clouds, are unable to reproduce the fast decorreltion of the cloud field and hence slow down and misrepresent the initial error growth (Selz and Craig, 2015b).

In the past we have shown that the Plant-Craig stochastic convection scheme is able to successfully reproduce the faster growth rates from tiny initial perturbations at lower model resolution, but this has been shown only with a small sample and in a limited-area model (Selz and Craig, 2015b). After this promising result, we have used the Plant-Craig stochastic convection scheme to estimate the intrinsic limit of predictability in global models (Selz 2019) and also to estimate the remaining improvement potential with respect to current weather forecasts (Selz et al., 2022). The Plant-Craig scheme, however, still uses the outdated Kain-Fritsch plume model, which causes problems and biases in the simulation, especially in the tropics. Furthermore, it is computationally quite expensive and complicated due to its generation of the complete cloud sample at every grid box.

Because of that, a new stochastic convection scheme based on the operationally used Tiedtke-Bechtold scheme is being developed in collaboration with the German Weather Service (DWD). It is based on similar ideas as the Plant-Craig scheme (Craig and Cohen, 2006), but the implementation of the stochastic component has been simplified according to Machulskaya and Seifert, 2019. First test runs of the new scheme have been done during the current year, and after all issues are settled it is planed to do a proper evaluation of the new scheme based on a reasonable large sample of cases. The results of the first test runs are outlined below.

First, Fig. 1 shows that the addition of a stochastic component to the Tiedtke-Bechtold scheme did not introduce relevant biases in the upper atmospheric variables. The deviations from climatology are similar in the stochastic and deterministic version of the scheme. This is in contrast to the Plant-Craig scheme, which introduced large biases, especially with respect to cloud ice in the tropical tropopause (not shown).

Second, we tested the additional variability that is introduced by the stochastic component of the scheme. Fig. 2 shows that the upward mass flux variability which the stochastic scheme generates well matches the theory of Craig and Cohen, 2006. Related to that, we show in Fig. 3 that the frequency of precipitation rates (here displayed for the tropics) is shifted by the stochastic scheme towards a few more intensely precipitating cells on the expense of many cells with very small precipitation rates. This indicates a potential improvement to the "too much drizzle" problem, which convection schemes tend to have. Note that the total precipitation pattern remains largely unchanged (not shown). A more sophisticated evaluation of precipitation is planned in future work.

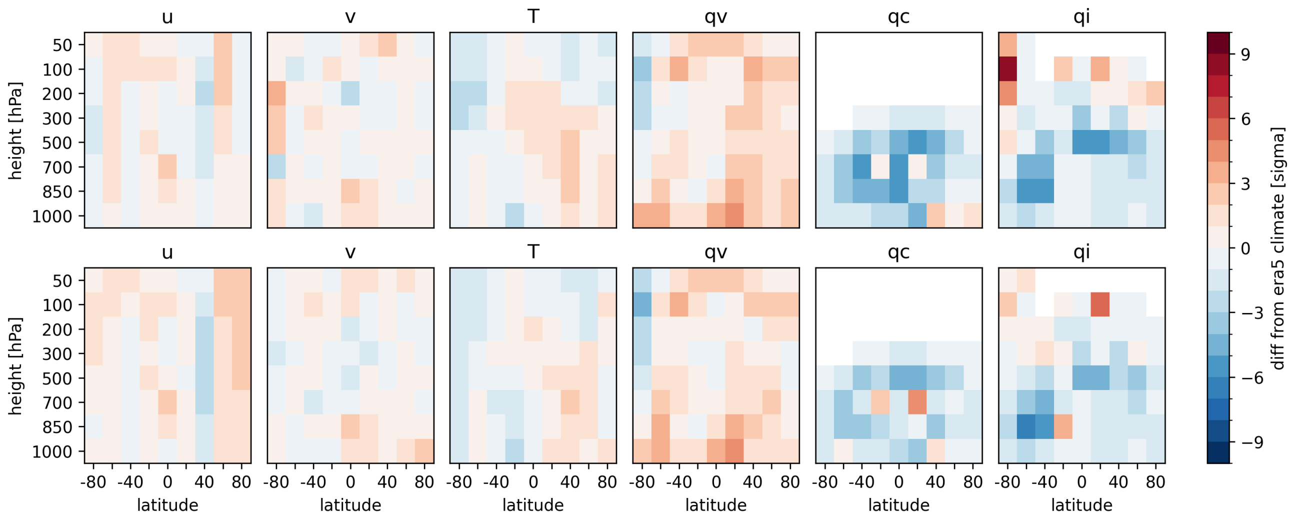

Figure 1: Several fields at 14 days forecast lead time, averaged over 10° latitude bands, relative to era5 climatology. The first row shows the simulation with the deterministic Tietke-Bechthold scheme, while the second row shows the run with the new stochastic scheme.

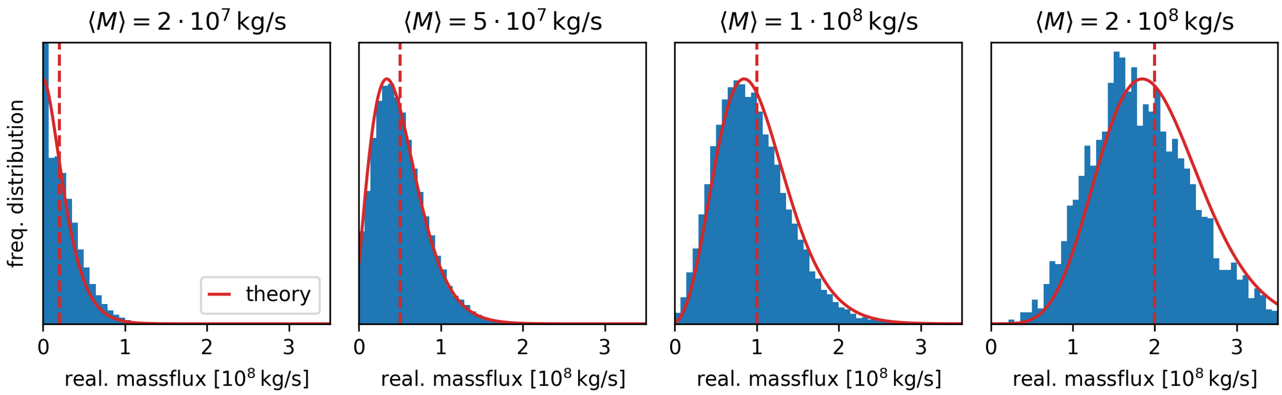

Figure 2: Mass flux distribution realized by the stochastic scheme for four different mean mass fluxes (<M>). The red line shows the theoretical distribution, based on Craig and Cohen, 2006.

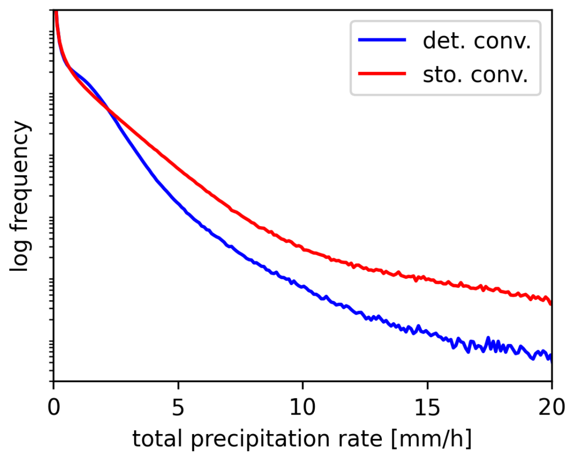

Figure 3: Precipitation rate distribution in the tropics.

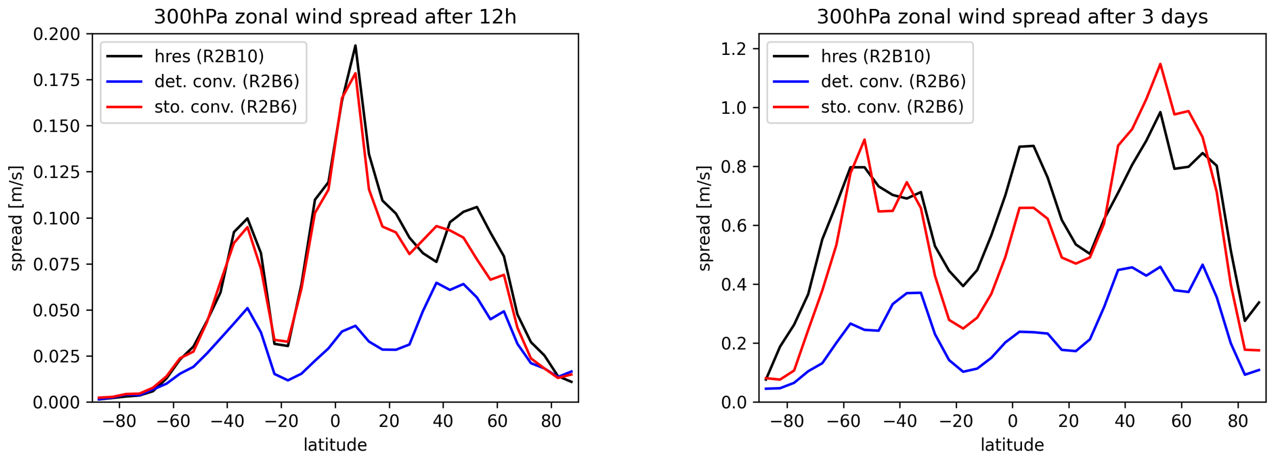

Figure 4: Ensemble spread of simulations started from a tiny initial condition uncertainty (0.1% of EDA spread), after 12h (left) and after 3 days (right). "hres" refers to the convection-permitting reference simulations at 2.5km grid spacing (R2B10). The blue and red line show results from lower-resolution simulations (R2B6, ca. 40km) with the deterministic and the stochastic convection scheme, respectively.

Finally, Fig. 4 shows the spread that developed after 12 hours and 3 days when simulations are started from a tiny initial condition uncertainty to simulate the butterfly effect (0.1% EDA spread, as explained above). The convection-permitting simulations that were described earlier serve as a reference. It can be seen that the new stochastic convention scheme at much lower resolution (40km) is able to very well reproduce the fast error growth originating from convective areas and matches the high-resolution result with a very good agreement. On the other hand, the operational deterministic version largely fails at this task and suffers from too slow initial error growth, which leads to an overconfidence of the ensemble and hence an overestimation of the intrinsic predictability horizon, if this model setup was used for its estimation. We would like to emphasis that in contrast to the former Plant-Craig scheme, the new stochastic Tiedtke-Bechthold scheme also performs very well in the tropics, by basically reproducing error growth there without adding any significant biases (Fig. 1). It will therefore be an excellent tool to investigate open questions about tropical predictability in future work. Furthermore the new global simulations, in contrast to our previous study (Selz and Craig, 2015b), include the southern hemisphere and hence a wintertime, maritime regime with lower-level equilibrium convection. Also in this regime, the new scheme (and the concept of Craig and Cohen 2006) seems to work very well with respect to upscale error growth.

In summary, we conclude that the new stochastic scheme provides an accurate and improved tool to extend our investigation of intrinsic predictability in future work on much larger data samples to address questions about the variability and relevance of the intrinsic limit, without the need to resolve the convective scales explicitly.

References

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