Model Uncertainty in Ensemble Forecasting: Stochastic Physics and Truncation Error

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The first year of this project was dedicated to exploring the time-step sensitivity of non-linear atmospheric models. Initially, during the first 6 months we used two models of different levels of complexity (Lorenz-63 equations and a quasi-geostrophic - QG - model) to show that solutions with small but different time-steps will diverge (decouple) from each other after a certain finite amount of simulation time. The time of this decoupling depends on the time-step in a logarithmic way (due to the exponential growth of perturbations), which implies that decoupling time can be predicted.

The logarithmic nature of decoupling time also implies that however small the time-step may be, there is always a finite point in time after which the numerical solution diverges. Using a QG model we show that truncation errors caused by different time-steps evolve in a substantially different manner when compared to initial condition errors. Initial condition errors grow exponentially as expected while truncation errors show an initially rapid growth followed by a plateau (slow error growth) and then exponential error growth until saturation. We propose a simple analytic model of truncation error growth that considers the relative error growth rates in the stable and unstable directions, to explain the QG truncation error behavior.

During the second six-month period we tested the time-step sensitivity of the Navy Operational Global Atmospheric Prediction System (NOGAPS). As with the QG model, there is an initial rapid perturbation growth, followed by a period of slower growth. This initial growth may be a manifestation of the model integrations with different time steps moving toward their own attractors. However, the overall behavior of the error is quite different from the QG model. For example, the difference between the errors due to the different time-steps is smaller in NOGAPS.

Another relevant difference is that NOGAPS errors are starting to feel the effects of saturation after just a few days of simulation. A relevant outcome of this study is the fact that the magnitude of the truncation error is significant (up to 40-60%), when compared with the total forecast error of NOGAPS (forecasts minus analysis). In NOGAPS, there is also a similar (to the Lorenz63 and QG models) qualitative logarithmic relationship between decoupling time and the time-step of the integration.

In terms of ensemble design these results suggest that ensemble spread may be enhanced by using different temporal resolutions for different ensemble members. Preliminary experiments seem to indicate that this is indeed the case. Analyzing the ensemble spread based on two weeks of daily T119L30 (600 and 300s time-step) 32-member ensembles, shows that changing the time-step of half of the ensemble members results in increased spread and a decreased number of outliers. For example, for global 500-hPa height, the number of outliers was reduced by 8% and 14%, on average, for forecast times of 5 and 10 days, respectively. These preliminary experiments suggest that varying temporal resolution may be a natural way to introduce more variability due to model uncertainty into ensemble formulation.

During the first year of this project we have followed closely the work plan initially proposed of assessing the impact of the time-step truncation error on a hierarchy of atmospheric models: Lorenz-63 equations, QG model and NOGAPS.