Abstract:
Covariant Lyapunov Vectors (CLV) are a powerful and exciting new way of describing geophysical flow instabilities. CLVs allow us to systematically characterize instabilities and predictability and they have potential application in data assimilation and ensemble weather prediction. For instance, in operational weather predictions the most interesting dynamics occur in the unstable directions. These unstable directions need to be selected in a systematic way in order to make useful ensemble predictions. CLVs provide an excellent way to generate the initial conditions because they are adapted to the flow, very robust and provide very good initial conditions (Pazo et al. 2010). Furthermore, performing data assimilation in only the unstable subspace, which is much smaller than the full phase space, potentially improves ensemble predictions and the efficiency of data assimilation schemes (Palatella et al. 2013). Thus, it is crucial to be able to compute CLVs in high-dimensional complex climate models.

So far, CLVs have been computed in relatively simple models. However, Schubert and Lucarini (2015a) have succeeded in computing CLVs for a two-layer quasi-geostrophic model. In a submitted paper, they also characterized blocking events in the same model using CLVs (Schubert and Lucarini 2015b). Now, we want to compute CLVs for a primitive equation model which constitutes the dynamical core of ECHAM.

CLVs are a basis of the tangent linear model. In contrast to classical Lyapunov vectors, CLVs offer a covariant splitting of the tangent space of the flow and physically interpretable patterns describing the dynamics of infinitesimal perturbations, thus allowing for a new interpretation of instabilities in geophysical flows. CLVs and the associated Lyapunov Exponents (LEs) provide the natural extension of the classical modal analysis of the instabilities of base flows to a fully turbulent regime.

In previous work, we have applied the CLV framework to a quasi-geostrophic model and were able to characterize all instabilities (Schubert and Lucarini 2015). Now we plan to compute for the first time CLVs of a primitive equation model. Our goal is to obtain the CLVs in PUMA, a hydrostatic global atmospheric model based on the multi-layer primitive equations on the sphere. Models of this type form the hydrostatic dynamical cores of complex weather and climate models used by IPCC. In particular, PUMA is the dynamical core of ECHAM and the ECMWF model. The advantage of PUMA over full climate models (like ECHAM) is that its tangent linear version can be easily derived because forcing
dissipation have simplified parametrizations. However, the results and insight gained with PUMA can seamlessly be transferred back to these full climate models. Our algorithm can also be used for the ICON model.

We will run PUMA at a horizontal and vertical resolutions of T21/5L and drive the model with a forcing and orography such that a realistic circulation develops. The forcing will be derived from ERA-Interim reanalysis data similar to Sardeshmukh and Sura (2009).

Deriving the tangent linear model for a full-fledged climate model and constructing CLVs is a technically and computationally extremely burdensome task; especially the disk space requirements are very demanding. Thus, our project is a proof of concept study and we aim to develop new algorithms for the efficient computation of CLVs which can then also be applied to full climate models like ECHAM and ICON.

Our project has potential long-term benefits for numerical weather and climate prediction:

1. More efficient ensemble generation for weather prediction
2. More efficient data assimilation algorithms using only the unstable subspace
3. Better characterization of predictability and instabilities
References: