Geophysical Research Abstracts
Vol. 16, EGU2014-11663, 2014
EGU General Assembly 2014


# Statistical Mechanics Of The Baroclinic Instability

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Instabilities in the atmosphere can be studied through the classical linear instability analysis. The classical unstable normal modes are non-local perturbations which describe correctly the behavior close to the stationary state of a system. They are completely determined by the Jacobimatrix of the stationary state. However, in a fully turbulent flow the atmosphere is evolving chaotically on a strange attractor. The resulting exponential divergence of nearby trajectories makes it necessary to generalize the classical linear instability analysis to time dependent background states. In this case the Covariant Lyapunov Vectors (CLV) are the correct generalization of the classical unstable normal modes. In contrast to their classical counterparts they are non-orthogonal, non-local and norm independent. The asymptotic growth rates of the CLVs are given by the Lyapunov spectrum of the dynamical system. Therefore, the perturbation space can be divided into asymptotically growing and decaying perturbations. This means they exactly span of the stable, unstable and neutral manifold of the attractor. If weather is seen as a small disturbance to a background flow, it can only develop in the direction of the unstable covariant perturbations. Furthermore, the exact description of the unstable manifold is relevant for data assimilation since the error growth can be restricted to the unstable manifold alone.

Recently several algorithms were developed which allowed it to compute efficiently CLVs. We apply the algorithm by Ginelli et al. to a forced-dissipative quasi-geostrophic two-layer model in a periodic channel. The CLVs are then decomposed into a product of normalized vectors and a corresponding growth factor. This allows to characterize the normalized CLVs by the means and fluctuations of the relevant energy transformations, heat and momentum fluxes. The energy transformations between the CLVs and the background trajectory exhibit the interplay of barotropic and baroclinic instabilities and are interpreted as a generalized Lorenz energy cycle between perturbations and background state. The first order contribution to the heat and momentum transport of the CLVs vanishes and is dominated by the non-linear feedback term of the CLVs. Furthermore, the influence of the meridional temperature gradient and the chosen resolution is presented.