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Nonlinear balance issues in Kalman filter data assimilation

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It is a well-known problem in data assimilation that the insertion of observations into numerical models excites spurious inertia-gravity waves, which, aside from contaminating forecasts, can cause the assimilating model to reject subsequent observations. An initialization step, where the assimilated analysis is projected onto the slow manifold via a balance approximation, results in a rejection of that part of the analysis which projects onto the inertia-gravity manifold.

Because four dimensional assimilation schemes such as the Kalman Filter develop dynamically-consistent forecast error covariance matricies, one might think that the covariance matrix should therefore also contain enough information about balance such that an analysis increment is made in a balanced way, and an additional initialization step is unnecessary. However, because of approximations and assumptions made within the assimilation scheme (such as the use of a tangent-linear model or forecast ensembles), it is not clear to what extent 4D assimilation schemes can retain the balance that exists in the true state.

We investigate the representation of balance within different approximations to the nonlinear Kalman Filter, using a simple model of atmospheric balanced dynamics, based on that of Lorenz (1986). The model admits motions of two timescales, with a controllable timescale-separation parameter, and can be initialized either on or off an asymptotically-defined balance manifold. The model is simple enough that the actual assimilation is readily understandable in terms of slow and fast modes. Basic experiments with different balance and assimilation parameters illustrate the issues inherent in the problem of 4D data assimilation for systems with multiple timescales. In particular, a comparison between the Extended and Ensemble Kalman Filters shows that the particular method of evolving error covariances may have a great affect on the

assimilation scheme’s treatment of nonlinear balance.