Geophysical Research Abstracts
Vol. 13, EGU2011-3310, 2011
EGU General Assembly 2011

Efficient Particle Smoothers for large-dimensional problems

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With ever increasing model resolution and more complicated observations the data-assimilation (or inverse) problem becomes more and more nonlinear. This calls for fully nonlinear data-assimilation methods, such as particle filters and smoothers. Filters are optimal for forecasting, but to study the dynamics of the real world, or to improve models, smoothers are more appropriate. In this talk a particle smoother will be demonstrated that is applicable to large-dimansional geophysical problems.

In Particle smoothers (and filters) the importance of each particle in estimating the posterior density is dominated by the likelihood of that particle. In high-dimensional systems with a large number of independent observations the likelihood can differ substantially between particles resulting in only a few having statistical significance. A standard procedure to try and increase the number of particles contributing to the posterior is to use resampling, in which particles with very little input to the posterior are abandoned and replaced with multiple copies of particles with a greater statistical significance. As a consequence the trajectories of particles are no longer continuous beyond the period between observations and hence the title Particle Filter.

The idea of using the proposal density within the particle filter to provide a continuous guidance towards a future observation has already been discussed in the literature. Using the proposal density the aim is to increase the likelihood of all particles by ensuring they end up significantly close to the observation. However the proposal density is not restricted to continuous guidance but offers a much greater freedom in how we treat the particles. In particular it can be used to ensure that the majority of particles have an approximately equal significance in the posterior density and hence remove the need for resampling. Without resampling the trajectories of the particles become continuous over the whole time period leading to a fully nonlinear smoother.

We will show how such a particle smoother is derived, and discuss the application of the Particle smoother to the barotropic vorticity equations, both in the regime with periodic trajectories and in the chaotic regime, with state dimensions of a few thousands and more, using only tens of particles, showing that the degeneracy problem in particle filtering/smoothing is something of the past.