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The equivalent weights particle filter

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The majority of data assimilation schemes rely on linearity assumptions. However as the resolution and complexity of both the numerical models and observations increases these linearity assumptions become less appropriate. A need is arising for data assimilation schemes, such as Particle filters, which are fully nonlinear. Particle filters aim to represent the full probability density of the state of the system given the observations (the posterior) by an ensemble of particles. The importance of each particle in determining the posterior is given by the likelihood of that particle, or the distance between the particle and the observations. 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. Hence the ability of the particle filter to represent the full posterior is severely diminished.

Proposal densities have been used in the past to bring the particles closer to the observations, thus increasing their likelihood, and making their weights more equal. However, even the so-called 'Optimal Proposal Density', which draws samples from the transition density given the future observations, suffers from wildly varying weights when the number of independent observations is large. The recently proposed Implicit Particle Filter falls in the same category.

Here we look at the effect of using proposal densities as part of a particle filter in a high dimensional system, exploring the freedom of proposal density to not only bring the particles close to the observations, *but also to ensure that the final weights are equivalent*. With the majority of particles being both close to the observations and having equivalent significance, the ability to represent a multi-modal posterior density with only a few particles starts to be realised.

The success of the scheme is examined using the Barotropic Vorticity equation with a state dimension of over 50,000 in a highly nonlinear regime. Specifically, we observe the system every 50 time steps, while the decorrelation time of the dynamics is about 25 time steps, resulting in a very nonlinear data assimilation problem. We present a thorough analysis of the performance of the new scheme in this geophysical model of intermediate complexity. The spread of the ensemble and the marginal posterior probability density functions are discussed, in particular as the number of state variables observed is decreased, both uniformly and blacking out large patches of state space.