Application of Ensemble Transform Kalman Filter in Numerical Weather Prediction at the Hungarian Meteorological Service

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The main objective of numerical weather prediction (NWP) is to give a precise estimation of the future atmospheric state, i.e. a forecast. The changes in the state of the atmosphere can be described by a system of non-linear partial differential equations. These hydro-thermodynamic equations represent physical laws, such as conservation of energy (First Law of Thermodynamics), momentum (Newton's Second Law of Motion) and mass (continuity equation). This system with initial conditions is the NWP problem, which cannot be solved analytically. Limited area models, where the horizontal domain of the model is regional, need boundary condition as well. NWP models solve this problem numerically, and these models are extremely sensitive to initial conditions, so it is crucial to precisely specify the state of the atmosphere at the initial time in the model.

The so-called analysis scheme creates the best possible initial conditions for the forecast model. Measurements from many different sources are available, like traditional weather surface observations, radiosonde and aircraft measurements, weather satellites and radars for instance. For creating the initial conditions, that is, the analysis, basically two sources of information are accessible: forecasts from the NWP model and the observations, both including their error characteristics. Within the scheme at every analysis time (typically at every 6 hours) an estimation of the state of the atmosphere is provided by the forecast model, and this information has to be optimally combined with the measured data to create the initial conditions.

For linear models, the widely applied Kalman Filter would give solution for the problem: an initial state for the forecast model (the analysis), given that measured data are available, and the forecast made from this analysis would be the estimate of the future atmospheric states. Additionally, it also provides the estimation error and estimation error covariance matrix, which is the main interest in weather prediction, i.e. the forecast error. For non-linear models, such as NWP models, Kalman Filter is not applicable. In addition, due to computational reasons, an approximation is also necessary. NWP models, such as ALADIN/HU, which is the operational weather prediction model at the Hungarian Meteorological Service, are of dimension $n \approx 10^7$, and Kalman Filter would need the cost of $2n$ model integration, i.e. it would need to run the forecast model $2n$ times, which is not applicable in such a high dimensional system.

Ensemble Kalman Filter (EnKF) is a Monte-Carlo implementation of the classical Kalman Filter, which is applicable in NWP and can be used for non-linear models. The main idea is to use a set of initial conditions, that is, an ensemble of analysis, for the forecast model, which would be run k times (the size of the ensemble) to provide the ensemble of the estimates. The provided forecasts would represent a statistical sample of the state of the atmosphere. The ensemble mean would represent the best estimate for the atmospheric state, the deviations from the mean would represent estimation error, i.e. forecast error, and the ensemble (empirical) covariance matrix would represent the estimation error covariance matrix.

Ensemble Transform Kalman Filter (ETKF) is a version of EnKF, where a transformation simplifies the analysis scheme. Instead of running the analysis scheme k times, for creating the ensemble of initial conditions, it transforms the ensemble of forecasts into the ensemble of analysis. This realization of Kalman Filter is to be implemented into the operational ALADIN/HU model at the Hungarian Meteorological Service. At the current, early stage of the research, the frame of the ETKF procedure is working within the ALADIN/HU model with the ensemble size of 11. As a primary validation of the scheme, the transformation part of the procedure was tested, by using an estimation error covariance matrix constant in time, since the time-dependent computation of the covariance matrix is still under construction. Results show that the created ensemble has too small spread, i.e. it does not represent the estimation error well. Thus further improvement of the transformation technique is needed, and the computation of the time-dependent covariance matrix has to be developed.