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Modelling trends in climatic time series using the state space approach

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A typical feature of an atmospheric time series is that they are not stationary but exhibit both slowly varying and abrupt changes in the distributional properties. These are caused by external forcing such as changes in the solar activity or volcanic eruptions. Further, the data sampling is often nonuniform, there are data gaps, and the uncertainty of the observations can vary. When observations are combined from various sources there will be instrument and retrieval method related biases. The differences in sampling lead to uncertainties, also.

Dynamic regression with state space representation of the underlying processes provides flexible tools for these challenges in the analysis. By explicitly allowing for variability in the regression coefficients we let the system properties change in time. This change in time can be modelled and estimated, also. Furthermore, the use of unobservable state variables allows modelling of the processes that are driving the observed variability, such as seasonality or external forcing, and we can explicitly allow for some modelling error.

The state space approach provides a well-defined hierarchical statistical model for assessing trends defined as long term background changes in the time series. The modelling assumptions can be evaluated and the method provides realistic uncertainty estimates for the model based statements on the quantities of interest. We show that a linear dynamic model (DLM) provides very flexible tool for trend and change point analysis in time series. Given the structural parameters of the model, the Kalman filter and Kalman smoother formulas can be used to estimate the model states. Further, we provide an efficient way to account for the structural parameter uncertainty by using adaptive Markov chain Monte Carlo (MCMC) algorithm. Then, the trend related statistics can be estimated by simulating realizations of the estimated processes with fully quantified uncertainties.

This presentation will provide a practical solution to the methodological challenges. It is illustrated by two case studies in trend and trend change point analyses. First, analysis of the recovery of stratospheric ozone using time series constructed from satellite observations by SAGE II, OSIRIS and GOMOS instruments spanning years 1984-2012. Second, a study of global warming related trends in monthly mean temperature records in Finland using homogenized station values from the years 1847-2012.