Representing model uncertainty for climate forecasts

Antje Weisheimer
ECMWF & University of Oxford, UK

Initialised forecasts on climate time scales from months to seasons ahead are routinely issued at ECMWF using its coupled Earth System model. The physical basis for such estimates arises from the effect on the atmosphere of predictable seasonal-timescale signals arising from the ocean and the land surface. Monthly and seasonal predictions provide estimates of forecast of weekly and seasonal-means of the coming month and season.

ECMWF's currently operational seasonal forecast model (System 4 or S4) consists of the atmospheric component IFS that contains an explicit representation of model uncertainties through the Stochastically Perturbed Physical Tendencies (SPPT) and the Stochastically Perturbed kinetic energy BackScatter (SPBS) schemes, and the ocean model NEMO. A set of retrospective seasonal forecasts over the period 1981-2010 with and without stochastic parametrisations was used to estimate the impact of SPPT and SPBS on the model climatology and biases and on the forecast performance (for details see *Weisheimer et al., 2014*).

It was found that the schemes (primarily SPPT) lead to a reduction of the overly active tropical convection and a reduction of the associated model biases for OLR, total cloud cover, precipitation and winds especially in the tropical Western Pacific which is a crucial geographical region for ENSO. It was further found that SPPT improves the frequency of MJO events in all 8 phases and increases their amplitude. For a discussion of the impact of the different SPPT scales on tropical precipitation see also *Subramanian et al., 2016*. In terms of forecast quality, several examples of improvements due to stochastic perturbations were presented: more skilful and reliable tropical temperature and precipitation forecasts up to two weeks, significant increases in the MJO spread, and a better calibrated forecasts of SSTs in the western tropical Pacific. These improvements are a combination of the effects of having a beneficial increase in the ensemble spread and a reduction in the ensemble-mean forecast errors with stochastic perturbations.

Some hypotheses have been put forward as to why SPPT leads to a systematic shift of the distribution of precipitation in the tropics. These include mathematical effects of the product of two distributions of random variables (as in the multiplicative SPPT scheme), the existence of non-linear physical thresholds affected by the stochastic perturbations, e.g. the trigger for deep convection or super-saturation, the tapering of the boundary layer in SPPT and related inconsistencies, e.g. in the surface fluxes, the asymmetric nature of specific humidity and precipitation, and the tuning of the model in its deterministic formulation rather than the stochastic one (noise-induced drift). Work is currently under way to better understand the physical mechanisms behind those.

A problem with the surface moisture fluxes in SPPT was found which indicated a drying in the atmosphere compared to the unperturbed control members. This lead to large P-E imbalances which are not acceptable for climate simulations with SPPT (*Davini et al., 2016*). A fix that empirically corrects for the loss of humidity was introduced and showed that the flux problem could be eliminated. At the time of writing it is very likely that this SPPT fix to conserve humidity will become operational in the next IFS model update.

The land surface is a key component for seasonal prediction due to its inherent longer time scales. However, there exist large uncertainties in poorly constrained land surface parameters that are often unquantified. We have introduced different schemes to account for such uncertainties by explicitly representing them in the land surface model of the coupled ECMWF model (*MacLeod et al., 2015*). The schemes perturb two key hydrological parameters in either a static or stochastic way. We have also tested a stochastic tendency perturbation scheme for soil moisture and soil temperature using different settings of the spectral pattern generator. The results are promising and show improved probabilistic forecasts for cases of strong land-atmosphere coupling like the European heat summer of 2003. We also find a general improvement in the reliability of extreme soil moisture forecasts when the parameter perturbations are activated.

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