Perturbing hydrology parameters in seasonal forecasts

David A. MacLeod[a]* Hannah L. Cloke[bc], Florian Pappenberger[d] and Antje Weisheimer[ad]

[a]Deptartment of Physics, University of Oxford, Oxford, UK, [b]Department of Geography and Environmental Science, University of Reading, UK
[c]Department of Meteorology, University of Reading, UK, [d]European Centre for Medium-Range Weather Forecasts, Reading, UK
*E-mail: macleod@atm.ox.ac.uk

SPECS
Seasonal-to-decadal climate Prediction for the improvement of European Climate Services

INTRODUCTION

Methods to explicitly represent uncertainties in weather and climate models have reduced model biases and improved forecast skill when implemented for the atmosphere. However, these methods have not yet been applied to the land surface.

At certain times and in certain places the land surface is strongly coupled to the atmosphere, such as during the 2003 heatwave over Europe when dry soil led to extreme summertime temperatures. Improvements in the representation of uncertainty in the land surface may then lead to improvements in forecast for the atmosphere in cases like this.

We analyze seasonal experiments performed with the ECMWF weather and seasonal climate forecasting model, the Integrated Forecasting System (IFS), with different kinds of perturbation made to the land surface, in order to investigate the effect of explicitly incorporating uncertainty in this domain.

EXPERIMENTS

The control experiment setup is as follows:

- Four month seasonal forecasts initialised at the start of every May for 1981-2013
- 25 member ensemble, with initial condition perturbations.
- Atmosphere: IFS Cycle 41R1, T255 resolution, 91 vertical levels. Atmospheric stochastic schemes SPPT & SKEB switched on.
- Ocean: NEMO 1 degree, 42 vertical levels
- Land surface: Tiled ECMWF Scheme for Surface Exchanges over Land (TESSEL), with revised land surface hydrology (H-TESSEL), using 4 vertical levels.

Six experiments were carried out with perturbations to the land surface, detailed in the table below. The first experiment uses a static perturbation of key soil parameters α and γ_{sat} (van-Genuchten alpha and saturated hydraulic conductivity, both related to soil moisture transport). Perturbations are taken from the set {-80%, -40%, 0, 40%, 80%}, where the perturbation percentage applies to the default parameter for the soil type at a particular gridpoint.

ID	Description, including SPG scale weighting
PP	*Perturbed parameters α and γ_{sat}*
ST	*Stochastic tendencies, all SPG scales weighted equally (0.32/0.32/0.32)*
SP-equal	*Stochastic parameters, all SPG scales weighted equally (0.32/0.32/0.32)*
SP-mirror	*Stochastic parameters, mirrored SPPT SPG scales (0.06/0.18/0.52)*
SP-5th	Stochastic parameters, using jjust the 5th SPG scale (1 year decorrelation time)

Table 1: List of land surface perturbation experiments carried out

The remaining four experiments use different kinds of stochastic perturbation applied to either the hydrology parameters or the tendencies of soil moisture. The method of generating the stochastic perturbations is detailed below.

GENERATING STOCHASTIC PERTURBATIONS

The method for generating perturbations follows that used for the atmospheric stochastic scheme in IFS, SPPT. This method add a stochastic perturbation to variable's tendency, X, via multiplicative noise, i.e.: $X_p = (1 + r\mu)X$

where X_p is the perturbed tendency, r is a random number and $\mu \in [0, 1]$ is a factor used for reducing the perturbation amplitude close to the surface and in the stratosphere.

The random number comes from an evolving 2D field, correlated in space and time, produced by a spectral pattern generator (SPG). The SPG is a three-scale two-dimensional AR1, designed to mimic the typical scales present in the atmosphere (figure 1, left). The field at any instant is a summation of three independent AR1 processes, each with a different decorrelation length and time scale.

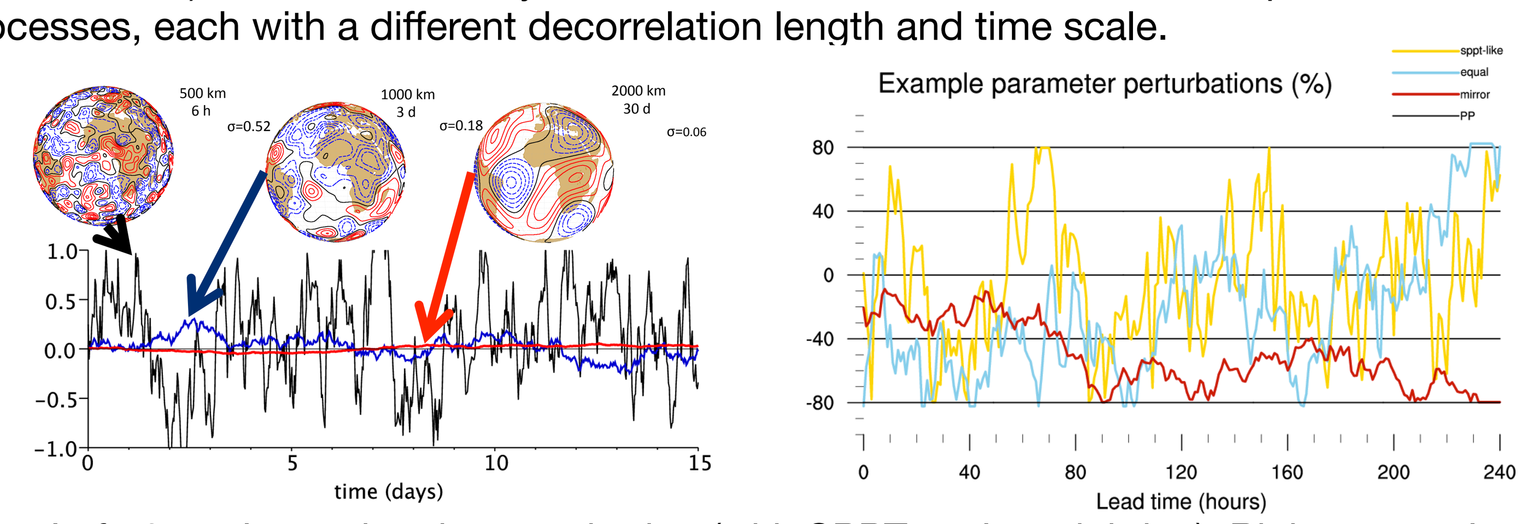

Fig 1 Left: 3-scale stochastic perturbation (with SPPT scale weighting). Right: example parameter perturbations from 3 different SP experiments (static PP perturbation for one parameter also shown).

In SPPT the standard deviations of the amplitudes of the perturbations for the small, medium and large scales are 0.52, 0.18 and 0.06, resulting in a total pattern in which the small scales are perturbed more strongly. These scales have been chosen as representative of the characteristic length and time scales of the atmosphere.

Instead, for the land surface we modify the scales using weightings more focused on the longer and larger scales (see table 1 for details). The ST experiment uses the modified SPG pattern to perturb soil moisture tendencies at every timestep for all four levels equally. The 3 SP experiments use 3 different modifications of the SPG to independently perturb the same two parameters addressed in PP. The default SPPT pattern and examples of alternative SPG weightings used are shown in figure 1.

CONCLUSIONS

Previous work with CY36R4 showed that by perturbing land surface parameters improved forecasts of the hot 2003 European summer (MacLeod et al 2015). We show here that perturbing parameters in CY41R1 gives large improvements in terms of soil moisture reliability (see figs 3 & 4).

Experiments with stochastic parameters and tendencies have also been carried out, but these do not show the improvement in reliability seen for the static perturbed parameter experiment. Of these, the experiment which uses the "slowest" scale (SP-5th) most closely replicates the PP result, however the improvement is not as great.

The model spread/error ratio is increased with perturbation. For soil moisture the SP experiments give the largest improvement, however the PP experiment gives an unusually large increase in spread of soil temperature despite only perturbing soil hydrology parameters.

Work at ECMWF now focuses on perturbing the land-atmosphere coupling parameter.

RESULTS

Impact on spread

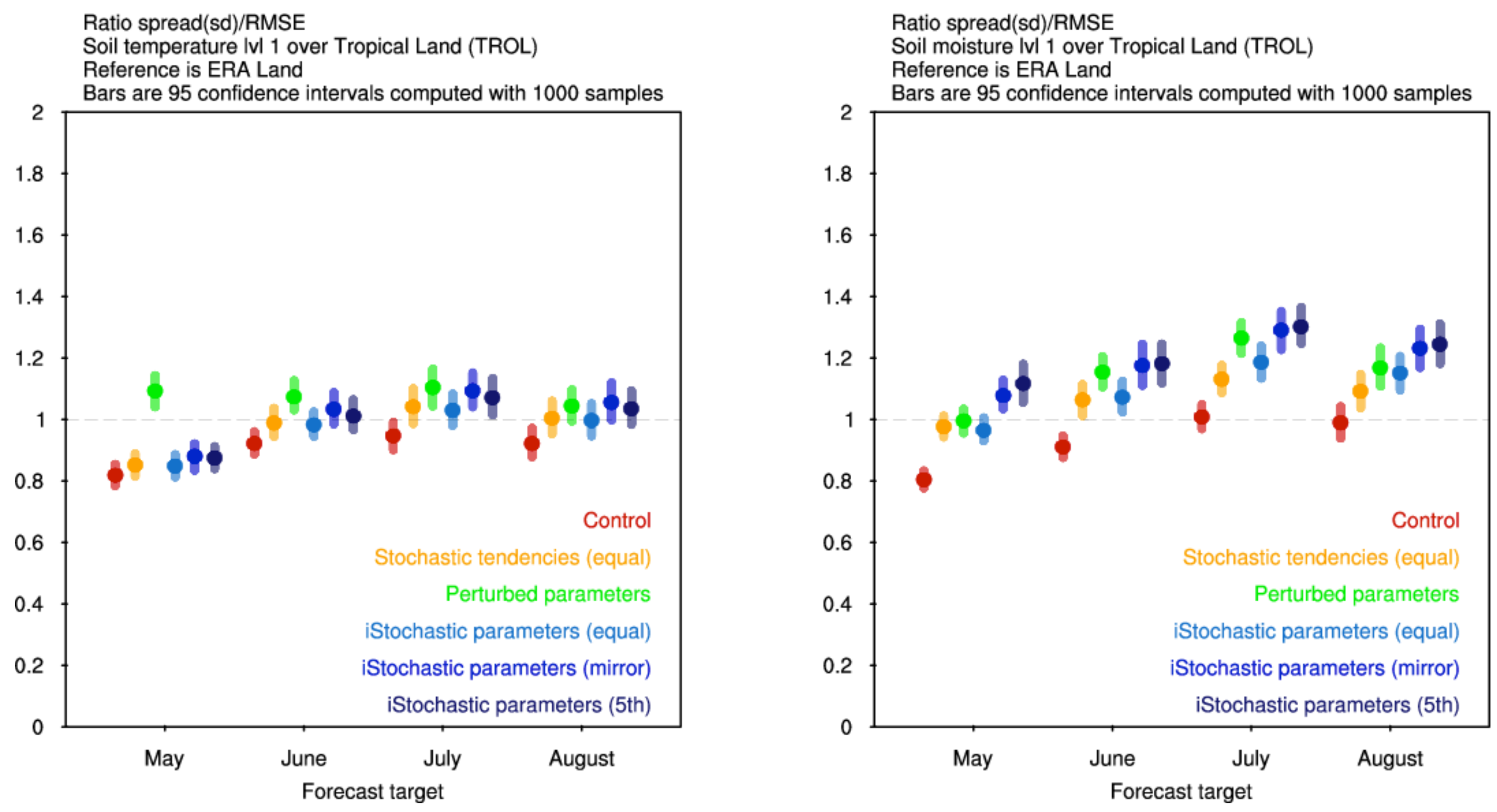

Fig 2 Spread/error for JJA soil temperature (left) and soil moisture (right) for all experiments.

Perturbation experiments tend to increase the spread/error, with greater impact when larger time/ space scales are used to generate the perturbations. We also observe that the PP experiment has an unusually large impact on the spread of the soil temperature (considering that we only perturb parameters related to hydrology).

Improved reliability of soil moisture quintiles in PP

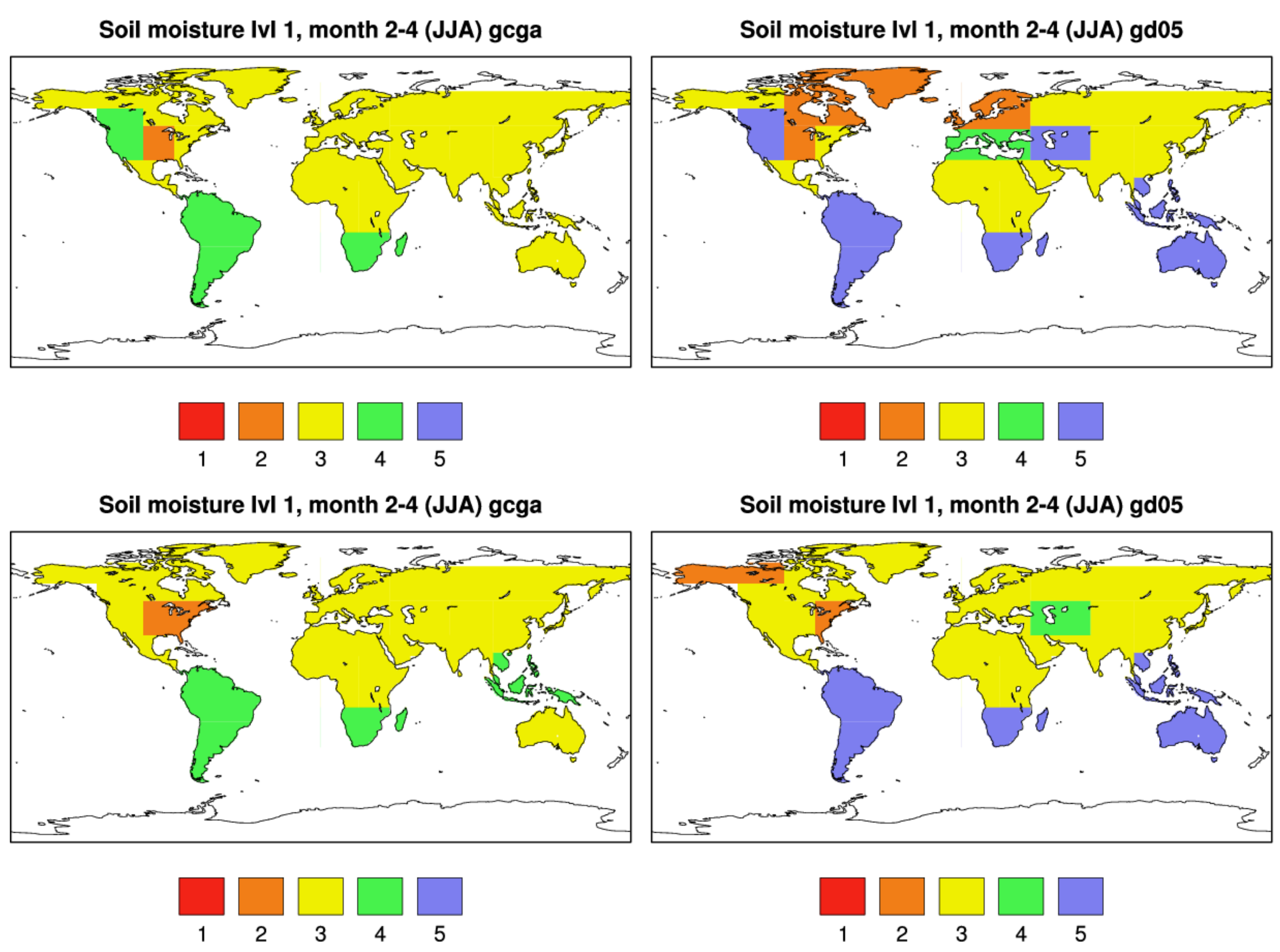

Fig 3 Reliability categories for top level JJA soil moisture upper (top) and lower (bottom) quintiles, for the control (left) and PP (right) experiments. Reliability categories following Weisheimer & Palmer 2014.

Most regions show large improvements in reliability with the PP experiments, these are not replicated with ST or SP-equal, and only partially replicated with SP-mirror (not shown).

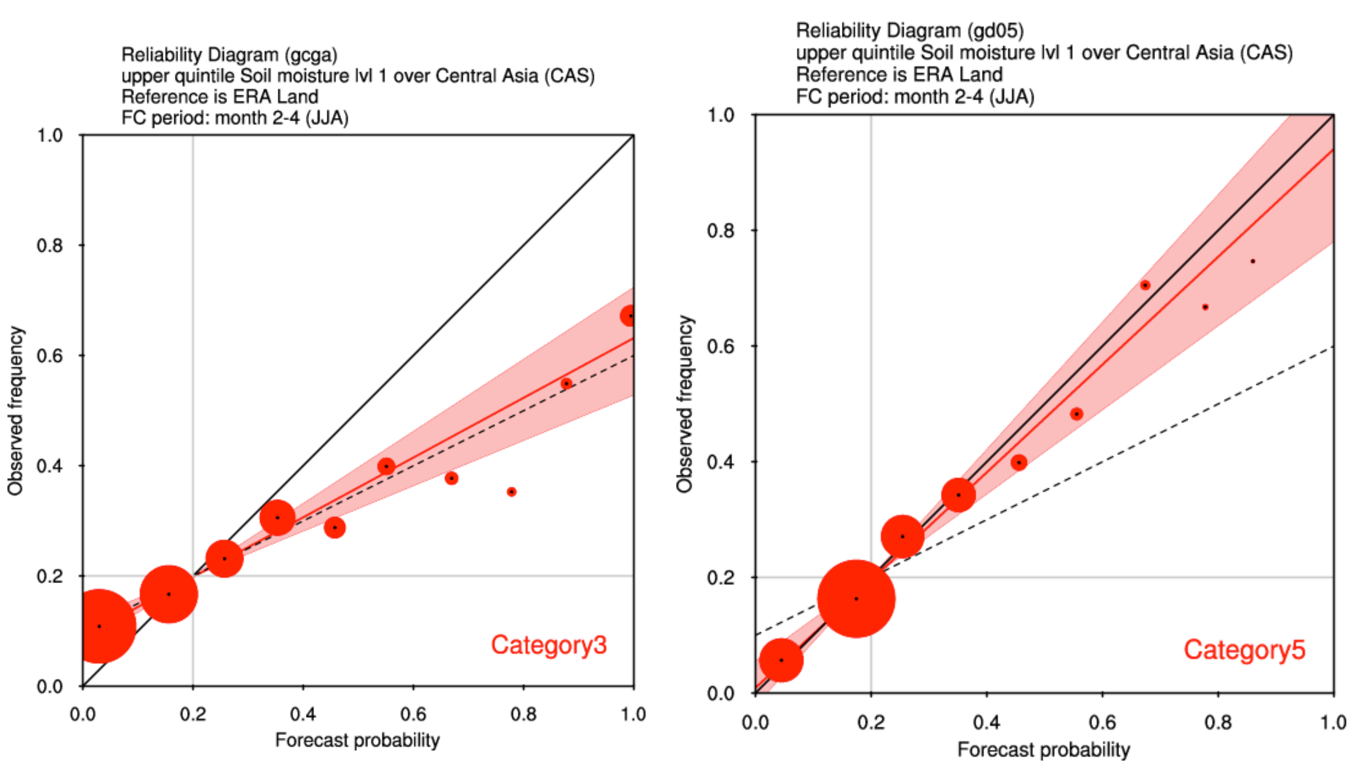

Fig 4 Reliability diagrams for upper quintile top level JJA soil moisture for the control (left) and PP (right) experiments. Similar improvement is seen for lower quintile moisture, and other regions.

See also: MacLeod et al. (2015) Improved seasonal prediction of the 2003 European heatwave through better uncertainty representation in the land surface, QJRMS 142:694 pp 79-90

Weisheimer & Palmer 2014, On the reliability of seasonal climate forecasts J Roy Soc Interface 11: 20131162.