Assessment of Representations of Model Uncertainty in Monthly and Seasonal Forecast Ensembles

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INTRODUCTION

To be useful, any prediction of weather or climate must include a reliable assessment of forecast uncertainty. The need for reliable estimates of forecast uncertainties implies that predictions must take explicit account of inherent uncertainties in the prediction process, and therefore be probabilistic in nature.

Although uncertainty arising from the limited accuracy and coverage of global weather observations is an important contributor to weather forecast uncertainty, in recent years it has increasingly become acknowledged that forecast model uncertainty is also a crucial source of prediction error. Indeed, for climate prediction, model uncertainty is the dominant source of forecast error.

Here we assess the skill of different representations of model uncertainty (MME, PPE and SPE; see coloured boxes below) using IPCC-class global coupled ocean atmosphere models, in monthly and seasonal forecast mode. These ensembles were generated as part of the EU-FP7 ENSEMBLES project, which promoted the concept of probabilistic and seamless prediction across a range of timescales from seasons to a century.

The Brier Skill Score (BSS) for lower and upper tercile events of near-surface temperature and precipitation is used to quantify the forecast performance relative to a simple climatological forecast. BSS>0 indicate a more skilful forecast than climatology.

CONCLUSIONS

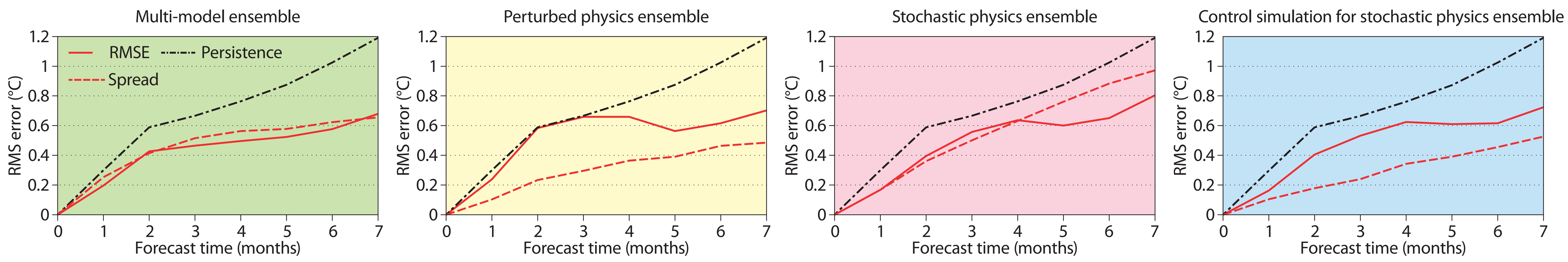
On the monthly timescale the system with stochastic parametrization generally provides the most skilful probabilistic forecasts and the system without representation of model uncertainty never provides the best forecasts.

On the seasonal timescale the results are more mixed: the multi-model ensemble provides more often the best forecasts of near surface temperature, whilst the stochastic parametrization ensemble provides more often the best forecasts of precipitation. This result may indicate the need to extend the notion of stochastic parametrization into the ocean and land surface model.

No corresponding control ensemble, based on the same underlying model as PPE but with fixed parameter values, was available for comparison. Hence the results should not be interpreted as implying that the PPE method is overall worst of the three techniques studied – the relative poor results from PPE (e.g. in the first month) could reflect that the underlying model itself was relatively poor.

The representation of model uncertainty in climate change projections is particularly problematic as there is, as yet, little verification data to assess potential representations. The notion of seamless prediction suggests that the results presented here may be relevant on longer multi-decadal timescales and that stochastic parametrizations should now be developed for multi-decadal climate predictions using earth-system models.

ENSO FORECAST SKILL



Skill comparison for predicting Niño3 SST anomalies in the ENSEMBLES multi-model ensemble (MME), the perturbed physics ensemble (PPE), the stochastic physics ensemble (SPE) and the control simulation for the SPE system (CTRL) showing the ensemble mean RMSE (red solid), the ensemble spread (red dashed) and the RMSE of a simple persistence reference forecast (black dash-dotted) as a function of forecast lead time.

MONTHLY TEMPERATURE AND PRECIPITATION FORECAST QUALITY OVER LAND

Lead time: 1 month

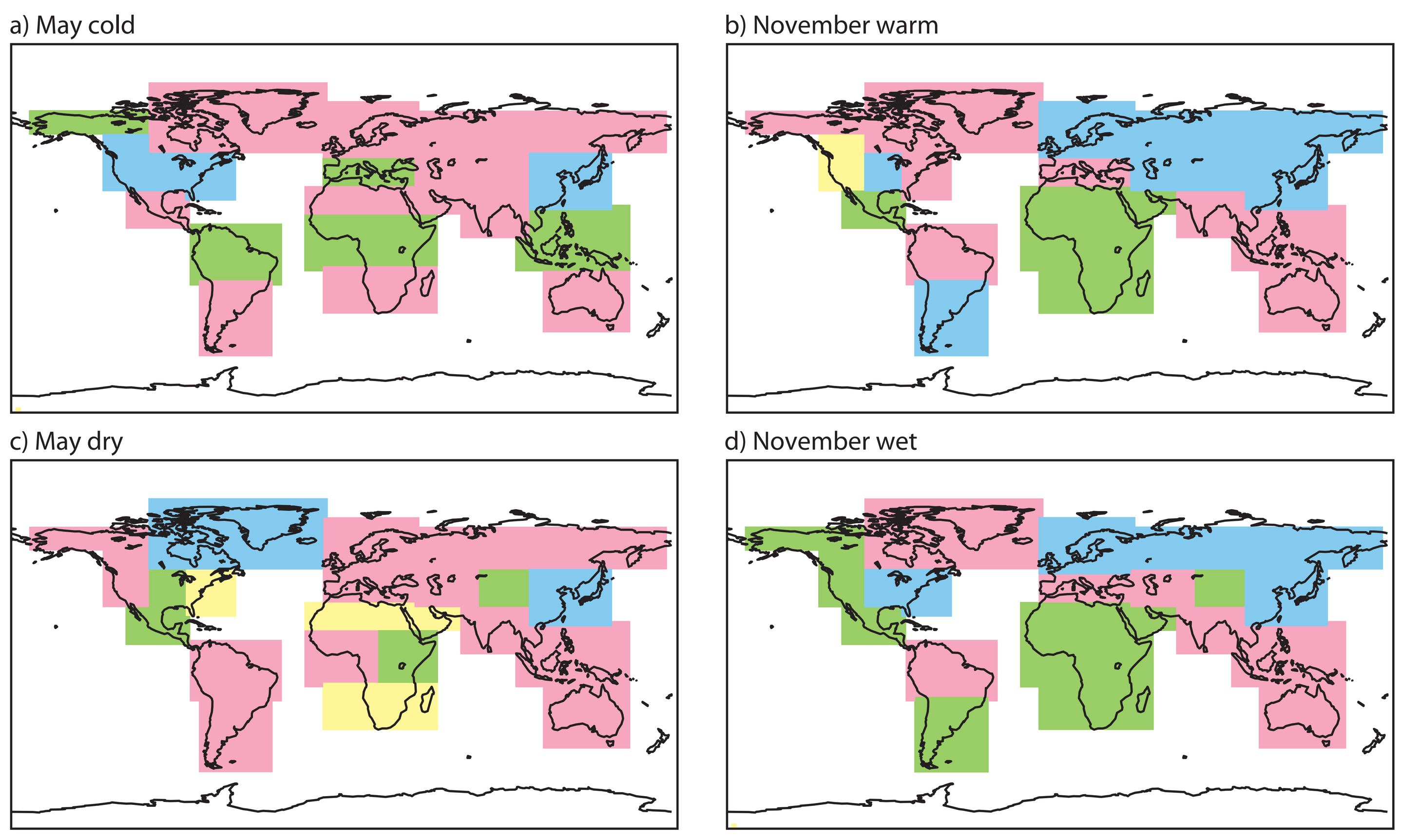
	T2m				Precipitation			
	May		Nov		May		Nov	
	Cold	Warm	Cold	Warm	Dry	Wet	Dry	Wet
MME	0.178	**0.195**	0.141	0.159	0.085	0.079	0.080	0.099
PPE	0.059	0.054	-0.012	0.033	0.031	0.009	0.031	0.000
SPE	**0.194**	0.192	**0.149**	**0.172**	**0.104**	**0.118**	**0.095**	**0.114**
CTRL	0.147	0.148	0.126	0.148	0.044	0.061	0.058	0.075

Brier Skill Scores for predicting eight events of global land area 2m-temperature and precipitation for the four forecasting systems. Bold figures indicate the system with the highest score.

SEASONAL TEMPERATURE AND PRECIPITATION FORECAST QUALITY OVER LAND

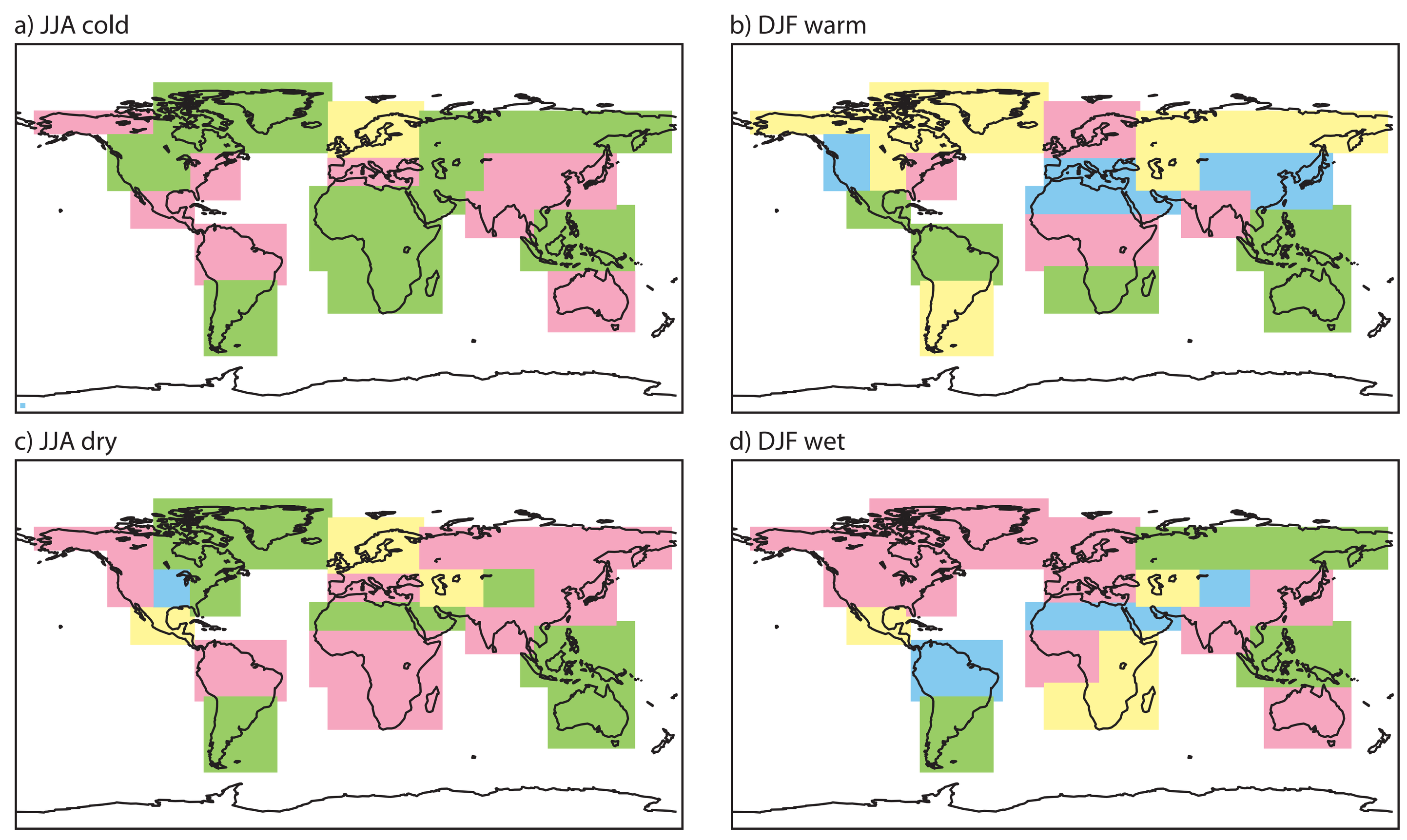
Lead time: 2–4 months

	T2m				Precipitation			
	JJA		DJF		JJA		DJF	
	Cold	Warm	Cold	Warm	Dry	Wet	Dry	Wet
MME	**0.084**	**0.082**	**0.037**	**0.090**	0.023	0.030	0.041	0.039
PPE	0.004	0.046	-0.001	0.064	0.013	0.006	**0.046**	0.035
SPE	0.059	0.054	0.019	0.076	**0.037**	**0.037**	0.040	**0.062**
CTRL	-0.024	-0.002	-0.011	0.063	-0.032	-0.020	0.037	0.042



Probabilistic skill comparison for cold May (a), warm November (b), dry May (c) and wet November (d) between the ENSEMBLES multi-model ensemble (MME), perturbed physics ensemble (PPE), stochastic physics ensemble (SPE) and the control simulation for the stochastic physics ensemble (CTRL) on forecast lead time 1 month. The forecasting system with the highest Brier Skill Score is indicated.

CTRL
SPE
PPE
MME



Probabilistic skill comparison for cold JJA (a), warm DJF (b), dry JJA (c) and wet DJF (d) between the ENSEMBLES multi-model ensemble (MME), perturbed physics ensemble (PPE), stochastic physics ensemble (SPE) and the control simulation for the stochastic physics ensemble (CTRL) on forecast lead times 2–4 months. The forecasting system with the highest Brier Skill Score is indicated.

MULTI-MODEL ENSEMBLE (MME)

Over recent years, the multi-model ensemble has emerged in weather, seasonal and climate prediction, as a pragmatic tool for representing the effects of model uncertainty.

Here we use five coupled atmosphere-ocean general circulation models developed quasi-independently in Europe within the ENSEMBLES project and initialised using realistic estimates of the observed states. Each model was run from an ensemble of nine initial conditions, this leads to an overall MME size of 45 members.

However, MMEs are limited by the number of models available and their assumed independence, and moreover there is no prior guarantee that the available models faithfully represent true model uncertainty.

PERTURBED PHYSICS ENSEMBLE (PPE)

The problem of limited ensemble size is mostly solved in the alternative approach of an ensemble of perturbed free sub-grid scale parameters within a single model framework.

Here we use the UK Met Office Decadal Prediction System (DePreSys) by perturbing poorly constraint atmospheric and surface parameters. Eight model variants with simultaneous perturbations to 29 parameters and one standard unperturbed version of the model were used. No control run using unperturbed parameter settings is available.

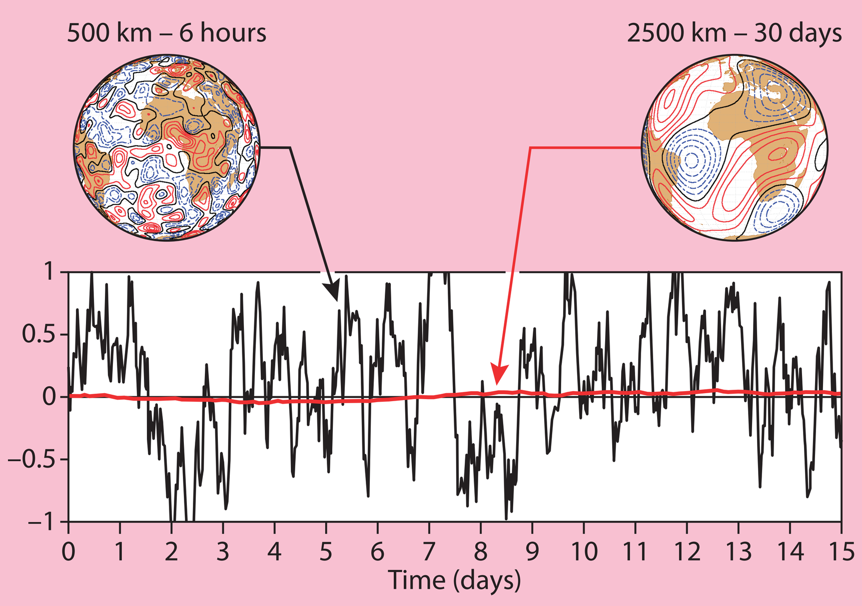
However, the problem of ensuring true model uncertainty is properly represented, is even more acute in the PPE framework, since uncertainty in the structural form of the parametrizations is not addressed.

STOCHASTIC PARAMETRIZATION ENSEMBLE (SPE)

A third approach to representing model uncertainty has emerged in recent years and relies on the idea of using stochastic parametrization in ensemble forecasts.
Here, the underlying deterministic sub-grid bulk-formulae are replaced by an inherently stochastic formulation, recognising that the problem of representing sub-grid tendencies as a function of the resolved variables may not be consistent with underlying scaling symmetries of the dynamical equations or with observations of power law structure in the real atmosphere.

Here, a stochastically perturbed parametrization tendency scheme (perturbations to the wind, temperature and humidity tendencies of physical processes as multiplicative noise with two smoothly varying pattern in space and time, τ = 6 h/30 d and L = 500 km/2500 km) and a stochastic kinetic energy backscatter scheme were applied to the atmospheric part of a recent version of ECMWF's coupled seasonal forecast model.

A control re-forecasts with the ECMWF model without any stochastic physics has also been generated (CTRL).



REFERENCE

Weisheimer, A., T.N. Palmer and **F. Doblas-Reye**s (2011). Assessment of representations of model uncertainty in monthly and seasonal forecast ensembles. *Geophys. Res. Lett.*, **38**, L16703, doi:10.1029/2011GL048123.