Representing atmospheric model uncertainties: Applications in seasonal forecasts with CNRM-CM

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1. Objectives

To account for atmospheric model uncertainties in the seasonal forecasting system based on CNRM-CM (Voldoire et al. 2013), two stochastic perturbation methods have been introduced in the ARPEGE-Climate atmospheric model, namely:

- **stochastic dynamics** (Batté and Déqué, 2016): prognostic variables (T, q, ψ) are perturbed with random simultaneous corrections (δX) of model errors estimated by nudged seasonal runs over the hindcast period;
- **SPPT** (Palmer et al. 2009): multiplicative physical parameterization tendencies perturbations using a random spectral pattern generator. In ARPEGE-Climate only u,v tendencies are perturbed.

We present here separate assessments of the impact of these methods on seasonal forecast quality.

2. Experiments

Boreal winter seasonal re-forecasts are run over the 1979-2012 period with Nov. 1st initial conditions from ERA-Interim (atmosphere) and ORAS4 (ocean). Ensembles of 30 members are run for each experiment over NDJF. Stochastic dynamics experiments were run with ARPEGE-Climate v6.1-SURFEX at T127L91 (1.4°) resolution and NEMO v3.2 ORCA1° - GELATO.

Stochastic dynamics	REF	SMM	S5D
Ens. member perturbations	T=0 only	Monthly mean **δX**	5-day **δX** sequence

SPPT experiments use ARPEGE-Climate v6.2 at T255L91 resolution.

SPPT	REF	wSPPT3			wSPPT3r		
Time scales	T=0 **δX** perturbation only	6h	3 days	30 days	6h	3 days	30 days
Spatial scales		500 km	1000 km	2000 km	500 km	1000 km	2000 km
Standard dev.		0.30	0.15	0.075	0.075	0.15	0.30

3. Results with stochastic dynamics

Stochastic dynamics is now used in the Meteo-France operational seasonal forecasts. Two approaches for drawing random perturbations are tested here: monthly mean model error corrections (**SMM**) and sequences of 5 consecutive days of corrections (**S5D**), both in cross-validation mode. The impact of the technique on seasonal re-forecast quality is contrasted between variables and regions of interest.

Fig. 1 shows that spread is increased almost everywhere for DJF near-surface temperature, but less so for other fields such as precipitation or geopotential height. Consistent with results with a previous version of CNRM-CM (Batté and Déqué, 2012), a reduction of the Z500 bias over the North Atlantic is found (**Fig. 2**). This translates into tangible improvements in the representation of North Atlantic weather regimes statistics and interannual frequency anomalies (**Tab. 1**). Little difference is found between the two approaches. Elsewhere, impact on forecast quality is limited (not shown, see Batté and Déqué 2016).

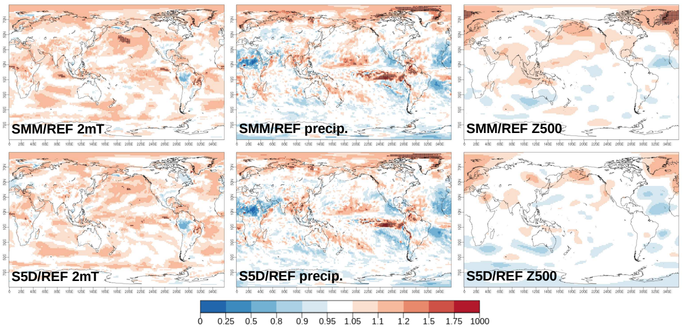

Fig. 1: Relative ensemble spread of SMM (top) and S5D (bottom) re-forecasts with respect to REF for DJF 2-meter temperature, precipitation and 500 hPa geopotential height (left to right). Grid points where spread is significantly larger are marked by dots.

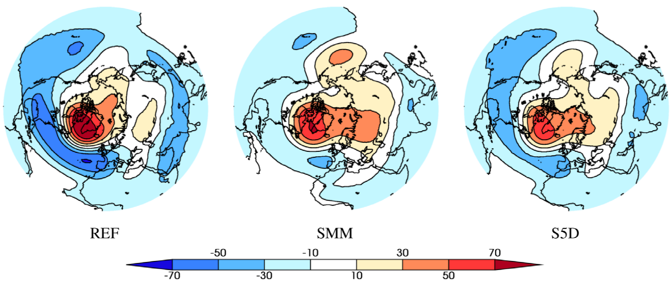

Fig. 2: Bias with respect to ERA-Interim for Z500 DJF 1979-2012 in REF, SMM and S5D

	NAO+			Blocking			NAO-			Atl. Ridge		
Run	*Freq.*	*Length*	*Corr.*	*Freq.*	*Length*	*Corr.*	*Freq.*	*Length*	*Corr.*	*Freq.*	*Length*	*Corr.*
ERA-I	32.1%	9.48	-	24.4%	7.14	-	18.8%	9.27	-	16.6%	5.85	-
REF	26.5%	8.28	0.21	23.4%	6.56	-0.03	24.0%	8.90	0.25	16.8%	6.41	-0.06
SMM	28.0%	8.36	0.33	23.8%	6.78	-0.12	21.8%	9.35	0.41	17.1%	6.38	-0.06
S5D	28.0%	8.35	0.17	23.8%	6.97	0.00	21.9%	9.16	0.54	17.1%	6.38	-0.01

Tab. 1: North Atlantic weather regime mean statistics for DJF 1979-2012 (frequency and length in days) as computed in ERA-Interim (top row) and the REF, SMM and S5D forecasts, and correlation of regime frequencies with ERA-Interim for each experiment. Model Z500 daily anomalies are projected onto EOFs of ERA-Interim data, and weather regimes shorter than 3 days are discarded. Statistics closest to ERA-Interim as well as highest correlations are highlighted in blue.

4. Preliminary runs with SPPT

The stochastic dynamics method (part 3) has a limited impact on the spread of our seasonal forecasting system, and could be complemented by other stochastic techniques. The SPPT method has therefore been implemented in ARPEGE-Climate; preliminary re-forecast ensembles with different settings of amplitudes for the different time and space scales were run (see part 2). Only u, v wind tendencies are perturbed due to high model sensitivity to these perturbations. **Fig. 3** shows the (very limited) impact of these perturbations on 2mT RMSE (evaluated by the RMS skill score).

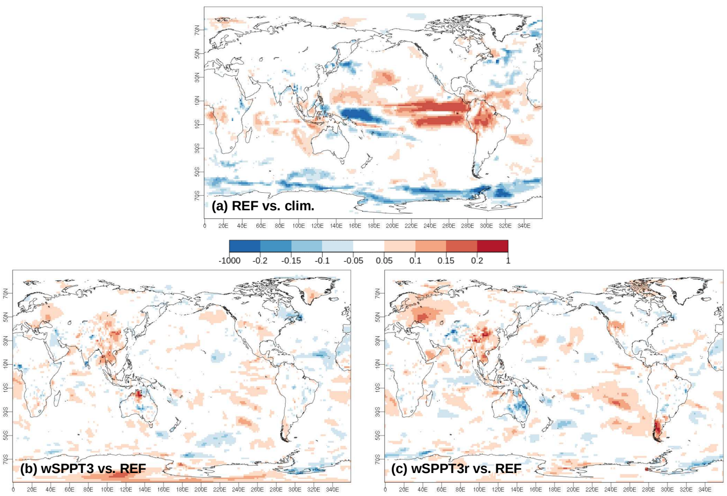

Fig. 3: RMSSS for DJF 2mT re-forecasts for REF with respect to ERA-Interim climatological forecast (a), and for wSPPT3 (b) and wSPPT3r (c) with respect to REF.

5. Conclusions and Future work

Two different approaches to stochastic perturbations have been studied in the ARPEGE-Climate atmospheric model in a seasonal forecasting framework with CNRM-CM. The stochastic dynamics technique consists in random perturbations to the model dynamics, intended to be representative of model error or drift at long time scales. We show that these perturbations are beneficial over the Northern Hemisphere mid-latitudes for Z500 re-forecast quality and representation of sub-seasonal variability. However, they have limited influence on ensemble spread.

SPPT introduces multiplicative noise to the model physical tendencies and has been shown to improve forecast quality in other seasonal forecasting systems (Weisheimer et al., 2014; Batté and Doblas-Reyes, 2015). The current settings used for the perturbations in ARPEGE-Climate yield disappointing results in terms of ensemble spread (not shown) and have little impact on forecast quality. Future work includes further tuning of the method and adjustments to the prognostic physics in the model to avoid instabilities.

Prospects at CNRM for the seasonal forecasting system include assessing the impact of stochastic perturbations in the ocean component NEMO.

References and Acknowledgements:

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Analysis of hindcast skill was performed using the R packages s2dverification and SpecsVerification developed in the framework of FP7-SPECS, and Python Numpy and Matplotlib libraries.

SEVENTH FRAMEWORK PROGRAMME

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