Perturbing the atmosphere in coupled seasonal forecasts: lessons from CNRM-CM and EC-Earth

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A tale of two methods... and two models

Stochastic dynamics (Batté and Déqué 2012)

- Correction-perturbation of model prognostic variables
- Randomly substracting *a priori* estimated model errors
- Non-gaussian uncentered perturbations
- Consistency in space and between variables

SPPT (Palmer et al. 2009)

- Random perturbations of physical parametrization tendencies
- White noise with AR(1) regression in time
- Consistency in time and space (combination of patterns)
- Track record of improving spread and forecast quality (Weisheimer et al. 2014)

Two seasonal prediction systems based on different GCMs

- CNRM-CM (Voldoire et al. 2013) : post-CMIP5 version with ARPEGE v6 (prognostic physics)
- EC-Earth v3.0.1 (Hazeleger et al. 2010)

Presentation outline

1. The "stochastic dynamics" technique
2. Impact of SPPT
3. Forecast system development : what next ?

Stochastic dynamics in CNRM-CM

Estimation of the perturbation population

- Nudged coupled seasonal re-forecast run : NDJF 1979/80–2012/13
- **Weak nudging** ($\tau = 1$ month) of temperature, vorticity and specific humidity in the atmosphere towards ERA-Interim
- Tapering in the upper and lower levels of the atmosphere
- $\delta X(t) = \frac{X^{\text{ref}}(t) - X(t)}{\tau}$ stored each day

Nudging

$$\frac{\partial X}{\partial t}(t) = \mathbf{M}(X(t), t) + \frac{X^{\text{ref}}(t) - X(t)}{\tau}$$

In-run perturbations

- Use $\delta\tilde{X}$, correction term from another year, as a perturbation for time t in seasonal re-forecast for year y
- Different sets of corrections are drawn for each ensemble member
- Corrections are simultaneous for the three fields, drawn from other years of the re-forecast period, within the same calendar month

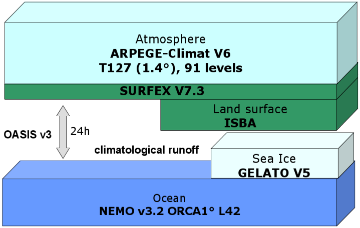
Perturbations

$$\frac{\partial X}{\partial t}(t) = \mathbf{M}(X(t), t) + \delta\tilde{X}(t)$$

Coupled seasonal re-forecasts with CNRM-CM

Boreal winter (NDJF) ensembles

- REF : reference coupled model experiment without perturbations
- "Stochastic dynamics" experiments :
  - SMM : random monthly mean corrections of ARPEGE tendency errors applied to each member
  - S5D : random sequences of five consecutive days of error corrections applied to each member
- 30-member ensembles ; NDJF 1979/80–2012/13 re-forecast period (34 years)



Components of the CNRM-CM system (Voldoire et al. 2013)

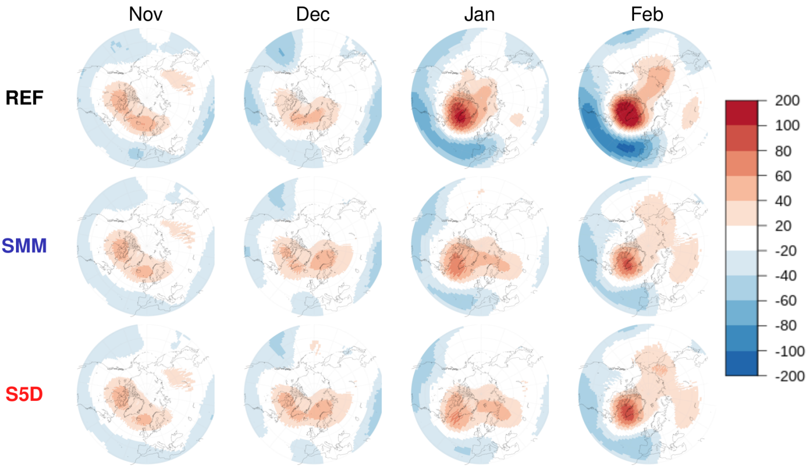
Initialization

- Atmosphere : ERA-Interim (Dee et al., 2011)
- Ocean : NEMOVAR reanalysis

Evaluation

- ERA-Interim as reference
- CRU for surface temperature over land
- Deterministic and probabilistic forecast quality

Impact on Z500 bias development



Mean evolution of Z500 bias according to forecast time over the 1979/80–2012/13 re-forecast period for experiments REF, SMM and S5D.

North Atlantic weather regimes and NAO index

Weather regime statistics and NAO skill

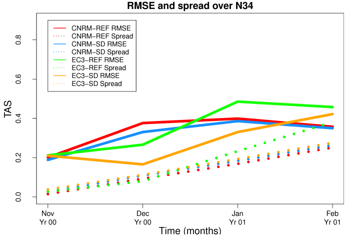
	NAO+		Blocking		NAO-		Atl. Ridge		NAO index
Run	*Freq.*	*Length*	*Freq.*	*Length*	*Freq.*	*Length*	*Freq.*	*Length*	*r*
ERA-I	32.1%	9.48	24.4%	7.14	18.8%	9.27	16.6%	5.85	-
REF	26.5%	8.28	23.4%	6.56	24.0%	8.90	16.8%	6.41	0.41
SMM	28.0%	8.36	23.8%	6.78	21.8%	9.35	17.1%	6.38	0.38
S5D	28.0%	8.35	23.8%	6.97	21.9%	9.16	17.1%	6.38	0.54

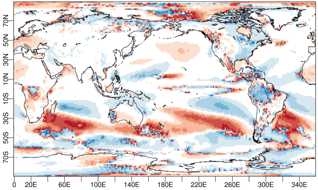
- Perturbations generally improve weather regime frequency when compared to ERA-Interim statistics
- They also improve the regime residency w.r.t. REF even when it is too short
- Very little difference is found between both methods
- NAO skill is best with S5D

Impact in EC-Earth

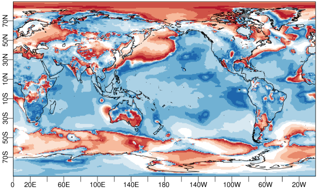
Experiments

- EC-Earth 3.0.1 with IFS cy36r4
- Gridpoint nudging of T, q, u, v ; $\tau = 4$ days
- Compared to CNRM-CM run with stronger τ (15 days for T,q and 5 days for Ψ)
- NDJF 1993-2009 with GLORYS ocean reanalyses

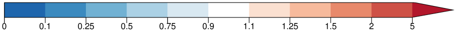




(a) CNRM-CM DJF



(b) EC-Earth3 DJF



Relative absolute bias with respect to REF ensembles in CNRM-CM and EC-Earth3 ensemble forecasts with stochastic dynamics

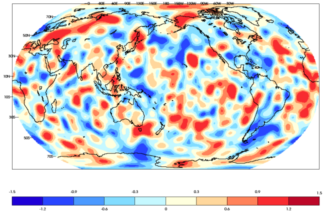
The SPPT method

Description

- Method developed at ECMWF (Buizza et al., 1999 ; Palmer et al., 2009)
- Random multiplicative coefficients applied to physical tendencies of atmospheric variables
- $X_p = (1 + \mu r)X_c;$ with $X = u, v, T, q$
- Spectral coefficients of r are defined by an AR(1) process forced with gaussian random numbers ; μ is used to taper perturbations close to the surface and in the stratosphere

r patterns

- Space and time decorrelation scales
- Several patterns can be linearly combined
- Same r for all variables and model levels



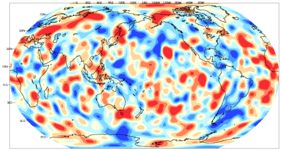
Sets of experiments for SPPT in EC-Earth3

Reference experiment

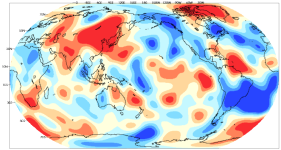
- T255L91 atmospheric resolution, ORCA1L46 ocean resolution
- 10 member ensemble, startdates May and November 1993-2009
- Verified against ERA-Interim reanalysis data

SPPT experiments with different amplitudes in patterns

Name	Scale 1			Scale 2			Scale 3		
	σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)
SPPT3	0.125	2000	30	0.250	1000	3	0.500	500	0.25
SPPT2L	0.288	2000	30	0.173	1000	10	-	-	-



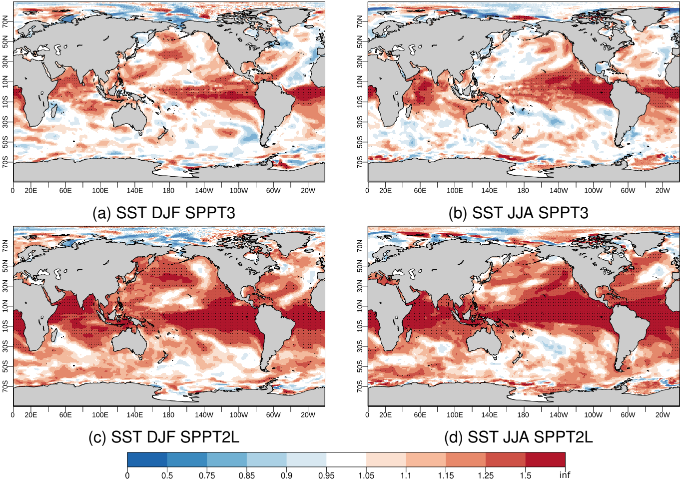
SPPT3 pattern



SPPT2L pattern

Impact on SST prediction : ensemble spread

Relative spread with respect to REF experiment



Adapted from Fig. 5 in Batté and Doblas-Reyes (2015)

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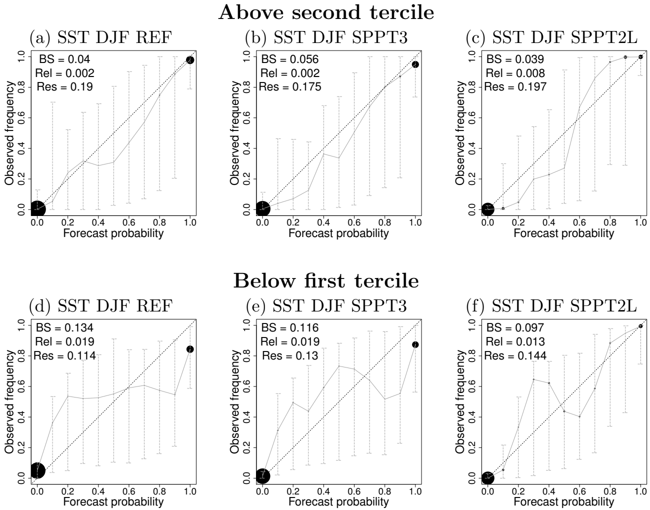
Impact on SST prediction : probabilistic scores

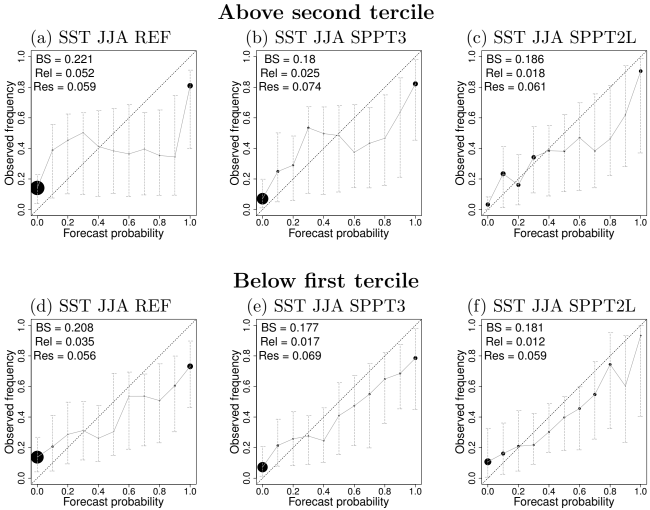
Impact on Niño 3.4 SST probability forecasts



Figs. 10-11 in Batté and Doblas-Reyes (2015)

Impact on SST prediction : probabilistic scores

Impact on Niño 3.4 SST probability forecasts



Figs. 10-11 in Batté and Doblas-Reyes (2015)

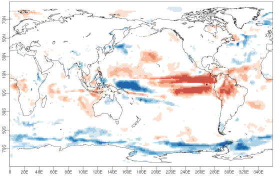
Impact in CNRM-CM

SPPT in CNRM-CM

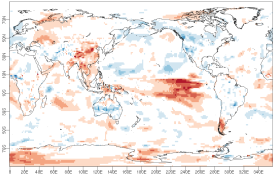
- Slightly updated version wrt SD experiments (ARPEGE v6.2 - T255L91)
- SPPT perturbations of u and v physical tendencies only
- Evaluation for boreal winter over 1979-2012 re-forecast period

Name	Scale 1			Scale 2			Scale 3		
	σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)
SPPT3	0.125	2000	30	0.250	1000	3	0.500	500	0.25

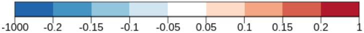
Impact on RMSSS for DJF near-surface temperature



(a) REF (wrt ERA-Interim)



(b) SPPT3 (wrt REF)



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Tentative summary...

Impact of both methods on model bias and forecasting skill (DJF)

	Stochastic dynamics		SPPT	
	Mid lats	Tropics	Mid lats	Tropics
EC-Earth	limited	Bias improved Skill unchanged	patchy	SST bias increase (except Eq. Pacific) Skill improved
CNRM-CM	Z500 bias improved Modest Z500/NAO skill increase	Depends on τ Skill unchanged	patchy	SST bias increase (except Eq. Pacific) ENSO skill improved

What next ?

Multiple layers of complexity

- These conclusions are for one component of the GCMs, one method at a time !
- Non-linear adverse effects, compensation effects
- High uncertainties in (most) skill evaluations due to limited ensembles and hindcast lengths

Future improvements

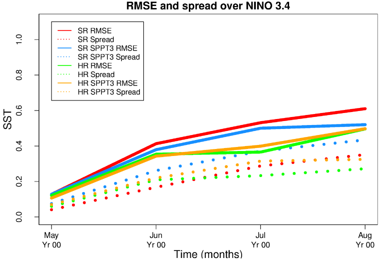
- Perturbations may be as (more ?) relevant elsewhere : ocean component (Brankart et al. 2015 ; Andrejczuk et al. 2016), sea ice (Juricke et al. 2013), land surface (MacLeod et al. 2012), coupling processes (Williams 2012)
- Combining methods requires a step-by-step assessment, bearing in mind possible cancellation/saturation of effects and tuning requirements
- Improvements to SPPT (correct energy budget, iSPPT)

What next ?

Results are not only model-dependent and method-dependent...

But also resolution dependent !

- EC-Earth3 with high resolution atmosphere (T511L91) and ocean (ORCA0.25)
- SPPT (same settings) is still efficient to generate spread
- Higher resolution is more efficient in improving the model RMSE (Prodhomme et al. 2016)



EC-Earth boreal summer Niño 3.4 SST ensemble spread and RMSE according to forecast time (from Berner et al. 2016)

Food for thought

- Tradeoff between computational cost and gain in forecast quality
- Tuning : high resolution version here was not optimally tuned (IFS with T255L91 settings)
- Both high resolution and stochastic perturbations must be implemented alongside continued efforts in model development (physical parameterizations, dynamics, initialization techniques)
- Beware of hasty conclusions !

Thank you for your attention !

Batté L. and M. Déqué (2016) : Randomly correcting model errors in the ARPEGE-Climate v6.1 component of CNRM-CM : applications for seasonal forecasts. *Geosci. Model Dev.* 9 : 2055-2016, DOI : 10.5194/gmd-9-2055-2016

Prodhomme C., L. Batté, F. Massonnet, P. Davini, O. Bellprat, V. Guemas, and F. Doblas-Reyes (2016) : Benefits of increasing the model resolution for the seasonal forecast quality in EC-Earth. *J. Climate.* DOI : 10.1175/JCLI-D-16-0117.1, in press.

Berner J. et al. (2016) : Stochastic parameterization : towards a new view of weather and climate models. *Bull. Am. Met. Soc.* DOI : 10.1175/BAMS-D-15-00268.1, in press.

Batté L. and F. Doblas-Reyes (2015) : Stochastic atmospheric perturbations in the EC-Earth3 global coupled model : impact of SPPT on seasonal forecast quality. *Clim. Dyn.* 45 : 3419-3439, DOI : 10.1007/s00382-015-2548-7