Ensemble model error at Météo-France

François Bouttier and many colleagues - Sept 2017

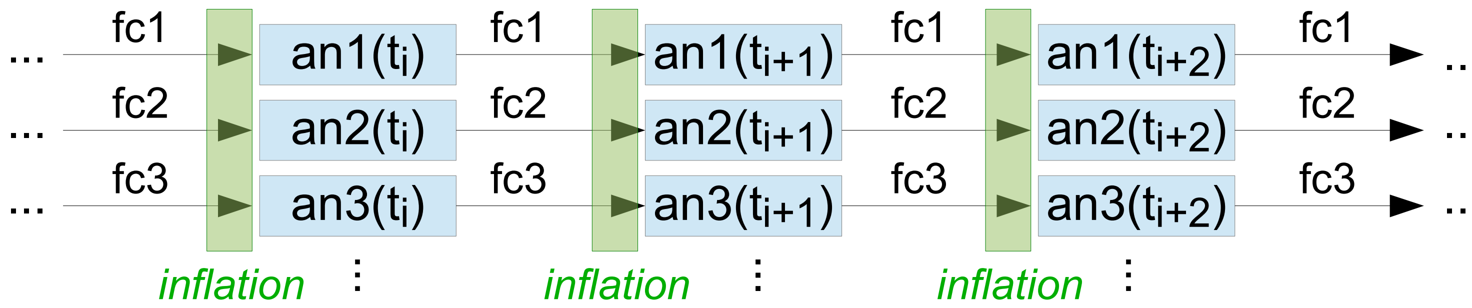
- **Ensemble Data Assimilations**
- **Global Arpege-EPS (PEARP)**
- **Regional Arome-France-EPS**
- **Diagnosing model error**

Ensembles at MF

	Data Assimilation		Ensemble Prediction
Global	'AEARP' ARPEGE EDA 6h-4DVar, 25 members dx=50km	IC perturbations →	'PEARP' ARPEGE EPS 35 members dx~10km
	↓ boundary conditions		↓ boundary conditions
Regional	'AEArome' Arome EDA 3h-3DVar, 50 members dx=3.8km *(in 2018)*	*IC perturbations* → *(in 2018)*	'PEArome' Arome-France EPS 12 members dx=2.5km

I. EDAs at MF (global and regional)

(see also talk by L. Raynaud)



Principle :

- n instances of same full fledged data assimilation system
- each one leads its (nearly) own life = full nonlinear error cycling

Perturbations :

- random noise on observations
- surface (through surface obs perturbations - to be replaced by direct perts.)

Model error scheme : ***adaptive inflation***

- on each cycle, diagnose ensemble spread-skill consistency
- multiplicative inflation of first-guess perturbations :

$$x_i = \overline{x} + \alpha\ (x_i - \overline{x}) \qquad (\text{ i = member index})$$

EDAs at MF : model error by inflation

… → $an1(t_i)$ → $an1(t_{i+1})$ → $an1(t_{i+2})$ → …

… → $an2(t_i)$ → $an2(t_{i+1})$ → $an2(t_{i+2})$ → …

… → $an3(t_i)$ → $an3(t_{i+1})$ → $an3(t_{i+2})$ → …

⋮ ⋮ ⋮

In practice, the inflation compensates EDA lack of spread :

- AEARP : 6-hourly inflation factor ~20%
- AEArome : 3-hourly inflation factor ~10%

Why do we need inflation ?

- forecasts lack *model error* spread
- analysis steps lack representation of *analysis error* sources :
  - not all analysis errors come from obs errors
  - obs errors likely contain correlated errors e.g. uncorrected forward operator biases
  - unresolved analysis scales
- likely mechanisms :
  - too smooth background structure functions → lack of small-scale errors
  - multivariate J_b cross-correlations are regressions → need to add the unexplained variance

II. global ARPEGE EPS configuration

'PEARP' = Prévision d'Ensemble modèle ARPÈGE

(see also MF poster)

Principle :

- 4.5-day range issued at 6 & 18utc (to avoid overloading computer around 00/12utc)
- 34 undistinguishable perturbed members
- 1 'control member' (= operational deterministic model except resolution : 10kmL90 instead of 7.5kmL105)

Perturbations : (ref : Descamps et al, QJRMS 2015)

- initial : combination of EDA & Singular Vector perturbations
- SVs are tuned for short ranges (18-h optimisation), some target cyclonic areas
- surface : not yet perturbed

Model error scheme : ***multiphysics***

- one single dynamical core
- random draws from 10 different physical parametrisation packages
- packages include current deterministic model and its previous versions
- adds significant spread, mainly through varying systematic errors

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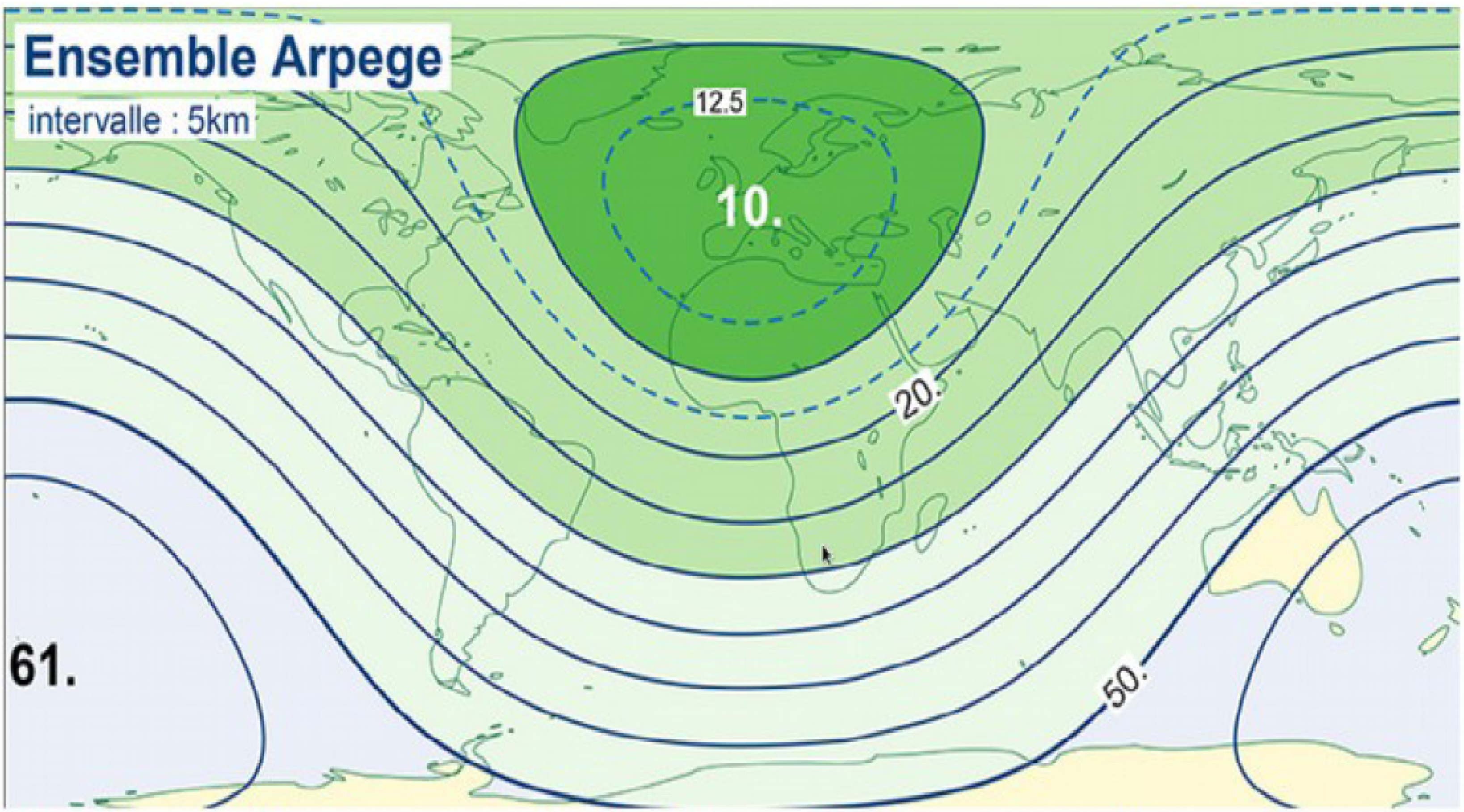
ARPEGE-EPS model geometry

Variable horizontal resolution, so conceptually both a global and regional ensemble.



ARPEGE EPS model error : multiphysics

The 35 member physics are drawn from 10 possible physics combinations.
Differences with respect to operational physics :

physics index	turbulence	convection	other
0	-	-	-
1	Louis	-	ECUME sea flux
2	Louis	KFB	-
3	Louis	KFB + CAPE closure	-
4	non-advective TKE	PCMT	-
5	-	EDKF	-
6	-	PCMT + EDKF	-
7	-	PCMT + KFB	-
8	-	PCMT	-
9	-	-	modified GWD

KFB = shallow Kain-Fritsch-Bechtold
EDKF = eddy-diffusivity Kain-Fritsch
PCMT = Prognostic Convection/Microphysics/Turbulence
TKE=Turbulent Kinetic Energy
GWD = gravity wave drag

(+ multiple radiation & cloud schemes in 2018)

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Comparing global model error schemes with other centres

(info not necessarily up to date ; ensemble DAs are not mentioned)

- BMRC (Australia until 2010), CMA, CPTEC : no model error
- ECMWF : SPPT + SKEB (stochastic error backscatter) in atmosphere only
- JMA (Japan): SPPT
- UKMO, KMA (S Korea): random parameters + SCV (stochastic convective vorticity, similar to SKEB)
- MF (France): multiphysics
- MSC (Canada) : multiphysics + SPPT + SKEB
- NCEP (USA): STTP (stochastic total perturbation scheme, similar to SPPT)

ARPEGE EPS model error : tests and plans

SKEB :

- tested, not much improvement

SPPT :

- tested, not much improvement
- frequent model crashes with strong SPPT tunings = touchy MF physics

plans :

- use ECMWF's SPP for ARPEGE-physics-specific parameters
- get rid of multiphysics (tedious maintenance work)

III. Regional AROME-France-EPS

in operational production since Oct 2016

2017 operational setup :

- model : AROME-France, **dx=2.5km** (dx=1.3km in AROME-F déterministic) grid=750x800, 90 levels
- base : **9/21utc** (coupling is 3h older)
- production : **12 members up to 45h range**
- (no lagged product generation)

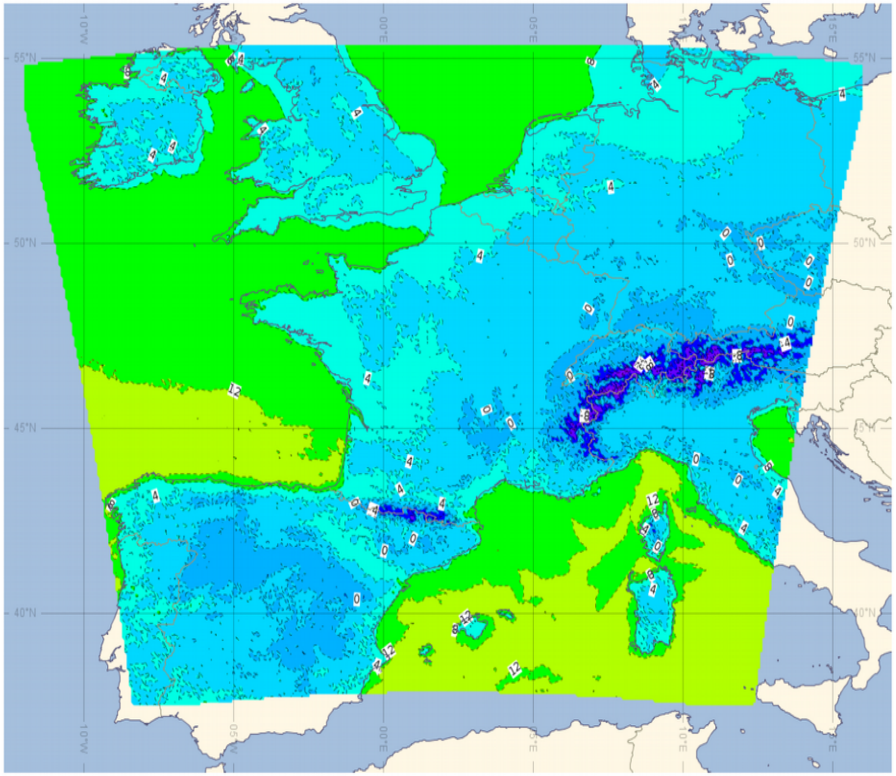
Perturbations :

- **lateral boundaries:** clustered global PEARP ensemble
- **initial**: global PEARP ensemble + centering on 3DVar analysis of AROME-France (dx=1.3km)
- **surface:** initial & constant perturbations
- **model:** stochastic perturbations of physics tendencies (SPPT)

Plans (2018):

- 6-hourly productions
- ensemble data analysis (EDA) initial perturbations

AROME-France-EPS domain



J+1 18h

base 21h — Arome EPS → 45h range

base 0h — Arome → 42h range

AROME static surface-model perturbations

'Static' model error scheme : Random space-correlated error patterns are added/multiplied to surface fields at initial time :

Initial perturbations, short-lived : (t ~1 day)

- top soil T and water content
- snow depth

Initial perturbations, long-lived : (t ~several days)

- deep soil T and water content

Initial perturbations, constant :

- SST
- sea surface fluxes
- vegetation index, heat coeff, leaf area index
- land albedo, roughness length

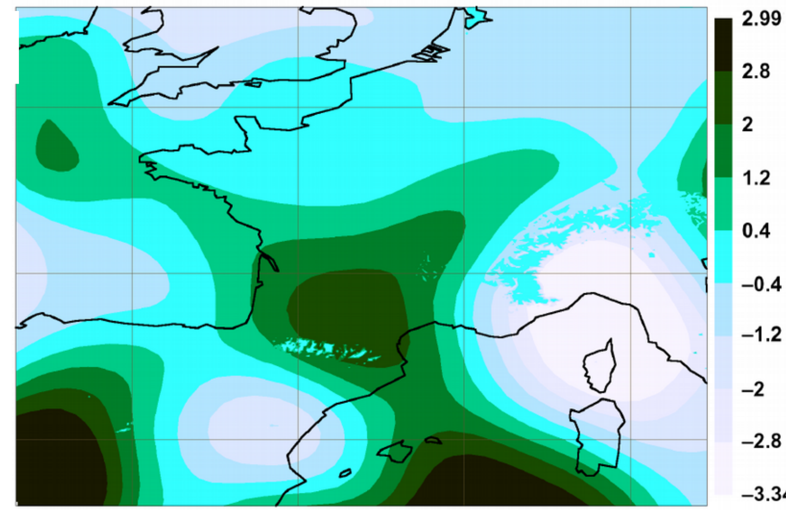
Persistent surface perturbations are equivalent to a multiphysics (multiparameter) scheme.

Results :

- improves low-level spread of T, HU, wind)
- Most of the impact comes from SST, soil water & temperature.

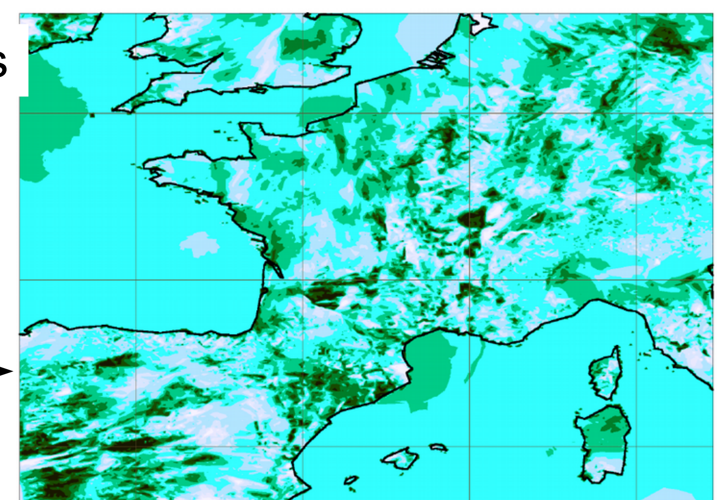
Future : mix with EDA-generated perturbations

Ts



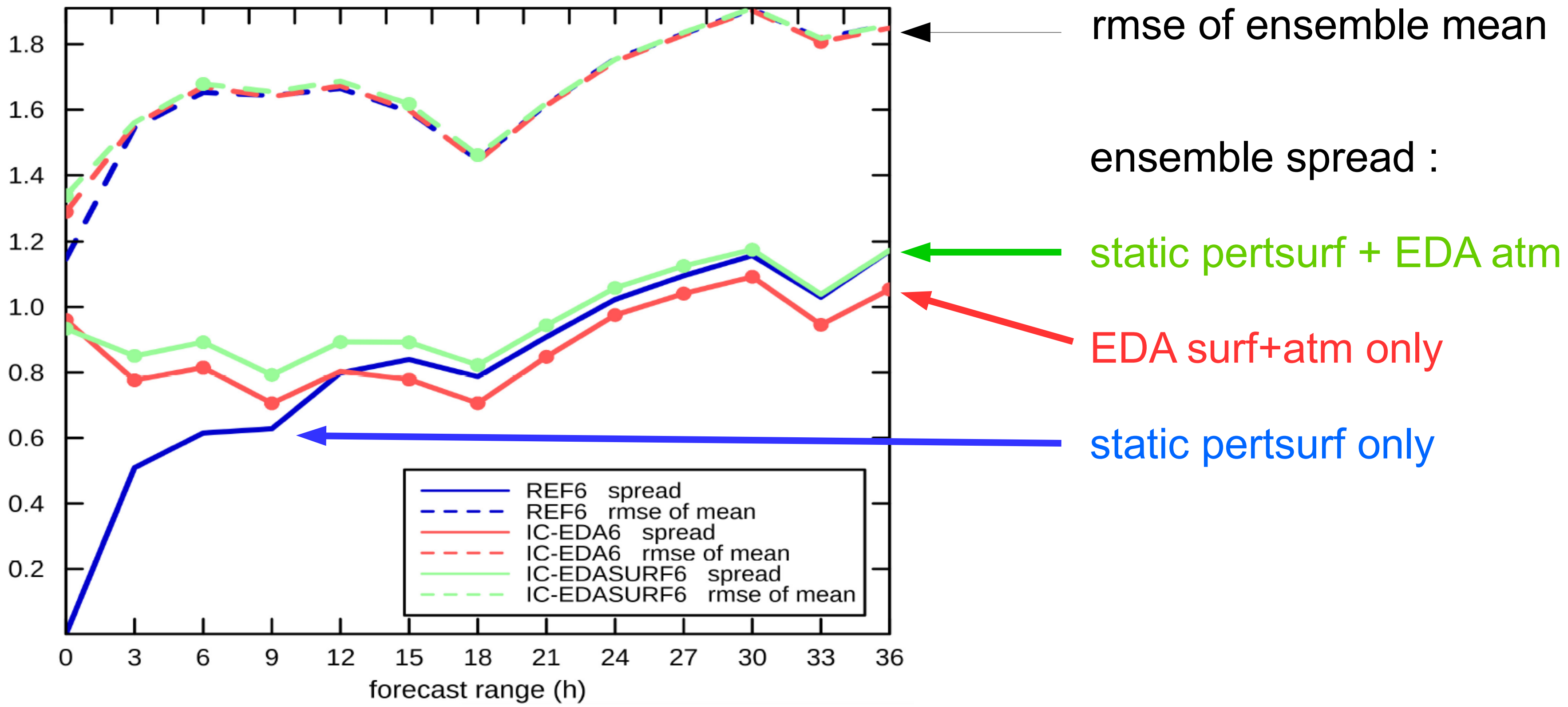
(Bouttier et al 2015)

Ts



AROME surface-model perturbations : static vs EDA

Impact on spread-skill consistency :



EDA ICs good at short ranges, but miss long-lived surface errors.

Static surface-model perturbations alone take time to influence the atmosphere.

The best is a mix of both.

(Ideally, EDA needs a surface perturbation scheme, but long-term surface stability is an issue)

AROME-EPS : atmospheric SPPT

Model error scheme adapted from ECMWF SPPT : (Palmer et al 2009)

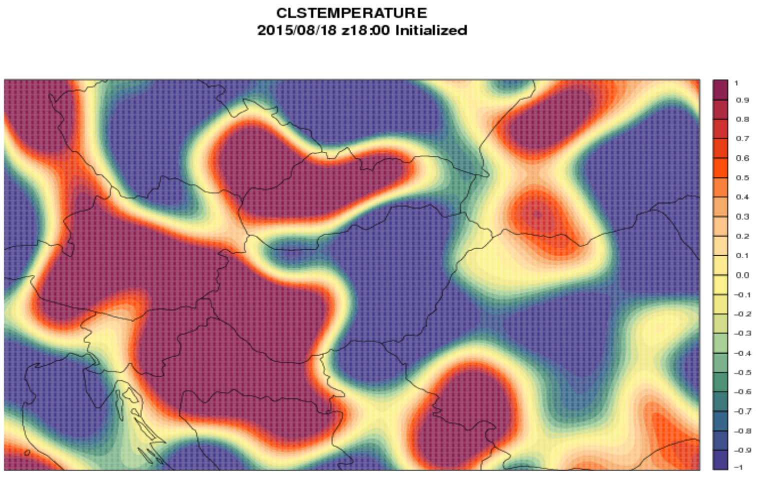
$$dx_i /dt = DYN(x_i) + (1 + \alpha\, r_i)\, PHY(x_i)$$

where :

- is the model state, member i
- DYN = dynamical tendencies
- PHY = physical tendencies
- α = static vertical profile (damping at bottom & top of troposphere)
- r_i = 2D random error pattern
  - correlated in space & time (separable, prescribed correlations)
  - truncated Gaussian PDF at each point (prescribed std.dev and limiter)
  - same for model variables (U, V, T, Qv) (TKE and condensed water are not perturbed)

Main differences with ECMWF :

- quasi-Gaussian horizontal correlations (2D bi-Fourier spectral pattern generator)
- only 1 pattern (3 at ECMWF)
- no supersaturation limiter



(M. Szucs, Hungarian Met Service)

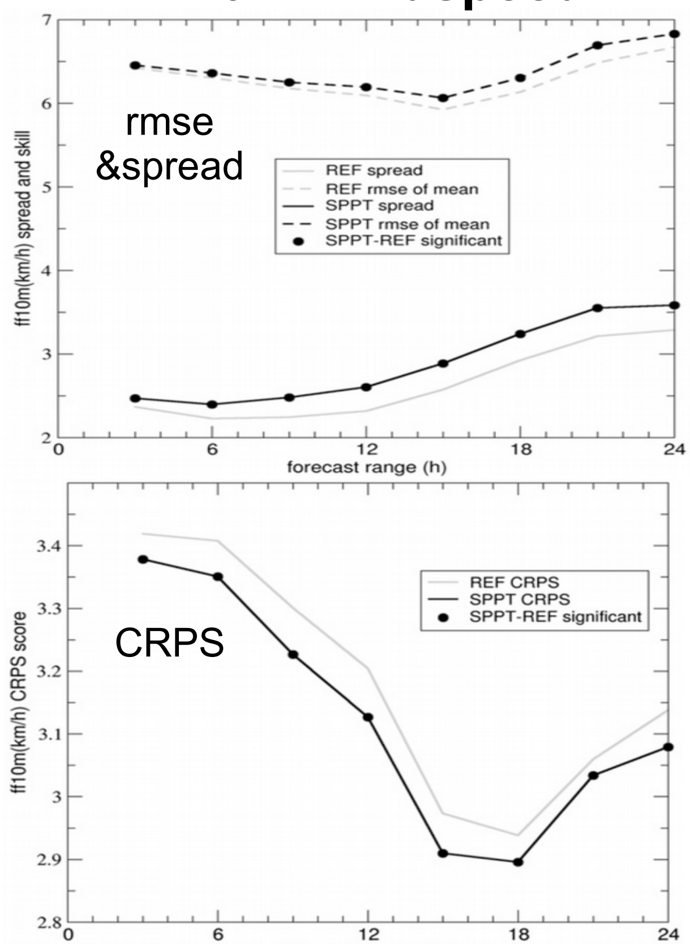
AROME-EPS SPPT impact

- adds beneficial spread to low-level T, HU, wind, cloudiness
- small but robust improvement of performance measures (Brier, ROC, etc)
- mostly neutral impact on precip, undesirable drying effect

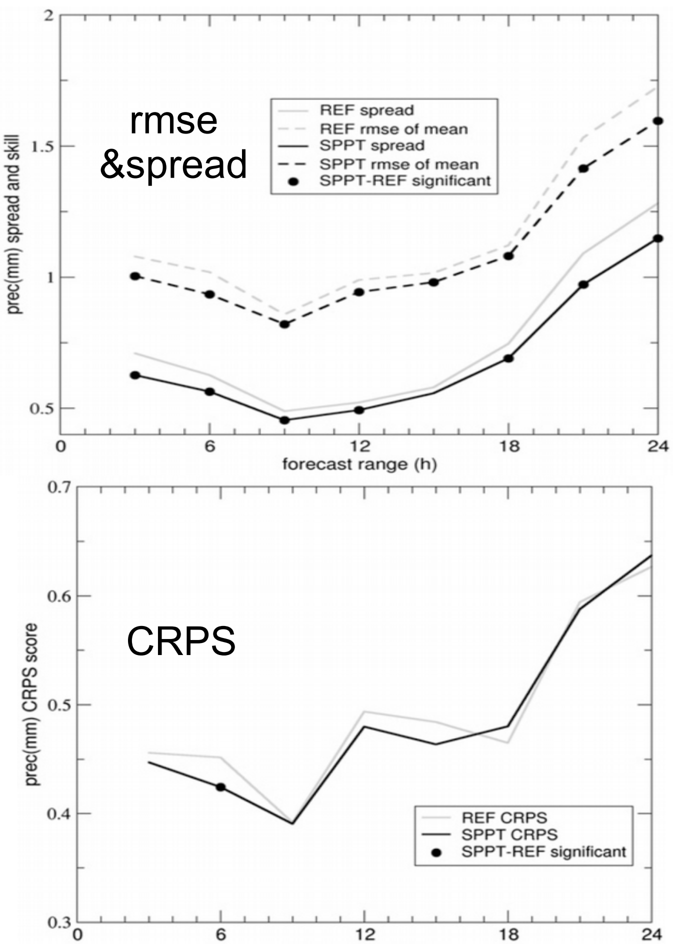
caveat : *'in an underdispersive ensemble, anything that adds spread will improve scores'*

SPPT
very good for
underspread
wind

10m windspeed



6-h rain



(Bouttier 2012)

SPPT
decreases
precip spread
by drying
effect.

neutral impact
on scores.

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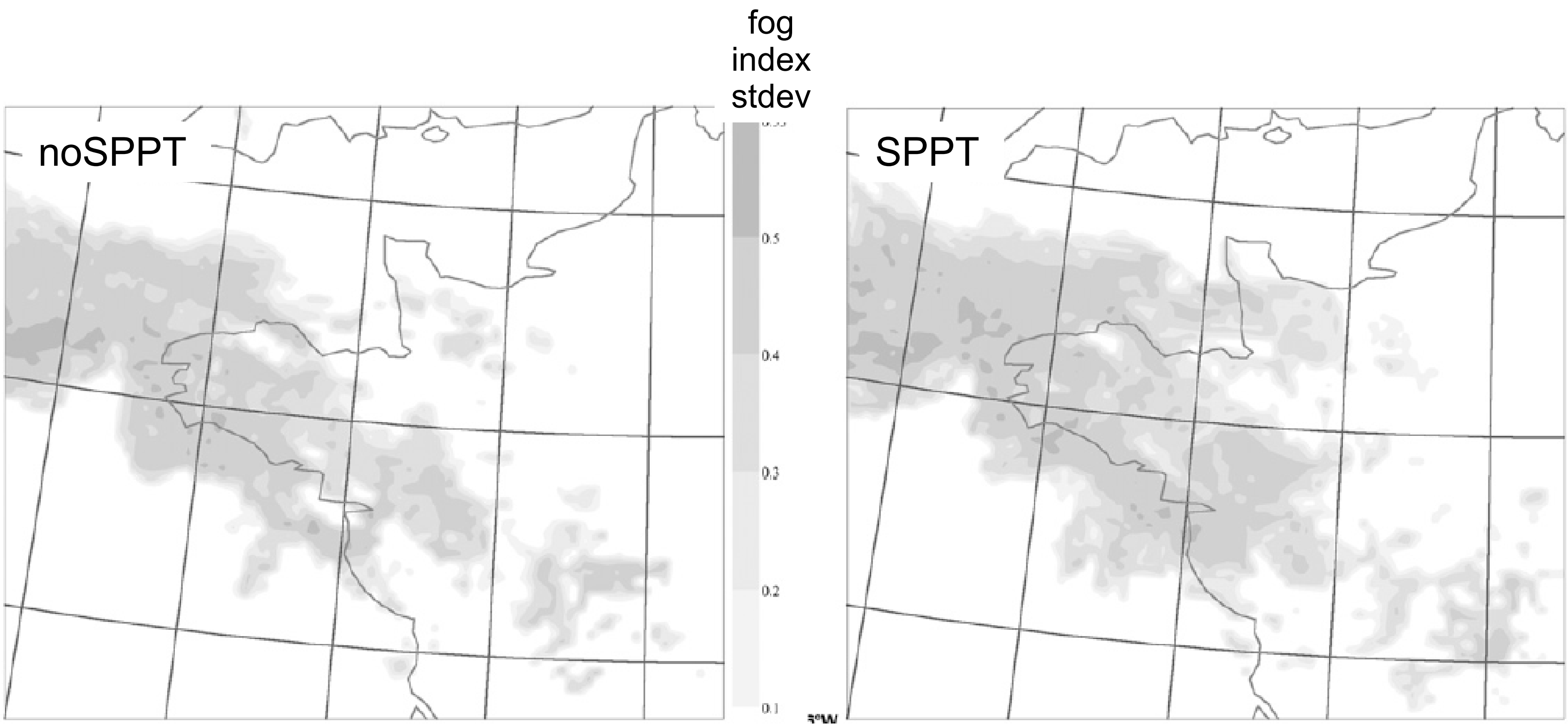
AROME-EPS SPPT impact

- the SPPT-induced spread propagates to non-perturbed parameters like cloud and fog
- discourages on/off behaviour : we put the model into states not necessarily allowed by its original design.



In this case, SPPT ’spreads out’ nonzero fog probabilities over a wider area.

AROME-EPS SPPT comments

Experimental results : *(by L. Raynaud, M. Szucs, ALADIN/HIRLAM/SRNWP partners)*

- weak sensitivity to choice of **correlations**
- the **drying effect** :
  - is poorly understood
  - is an issue for the detection of high precip events
  - can be partly alleviated by a better supersaturation treatment
- **iSPPT** (zero or partial correlations between U V T Qv variables perts.) improves the results
- the model can sometimes **crash** if SPPT is too strong :
  - in thunderstorm situations, blow-ups at low model levels
  - alleviated by reducing the SPPT amplitude and disabling it in the PBL (boundary layer)

Current formulation fails to generate enough spread for some processes :

- rain/snow transition
- fog location & timing
- low-level windspeed is much underdispersive

AROME-EPS SPPT future directions

- extend SPPT to PBL dynamics and microphysical aspects
- improve diagnostics of model error (to avoid confusing it with lack of IC / LBC perturbations)

IV. Diagnosing model error

What do we call 'model error' ?

1) errors in the existing model processes

2) subgrid-scale errors we know about

3) errors we do not know about

Physics perturbations may account for types 1 & 2, but probably not 3 because they restrict themselves to a predefined model architecture.

How can we design perturbations relating to type-3 errors ? We need to **characterize 'missing' ensemble spread** using observations.

Naive method : boost already implemented perturbation sources, until spread is consistent (on average) with skill.

e.g. *var(model error) = var(ens. mean error) - spread*

Problem : we may produce unphysical spread by boosting the wrong kind of perturbation (e.g. spread of initial conditions)

Diagnosing model error : scale dependency

Example : 10m windspeed in Arome-France-EPS wrt in-situ obs :

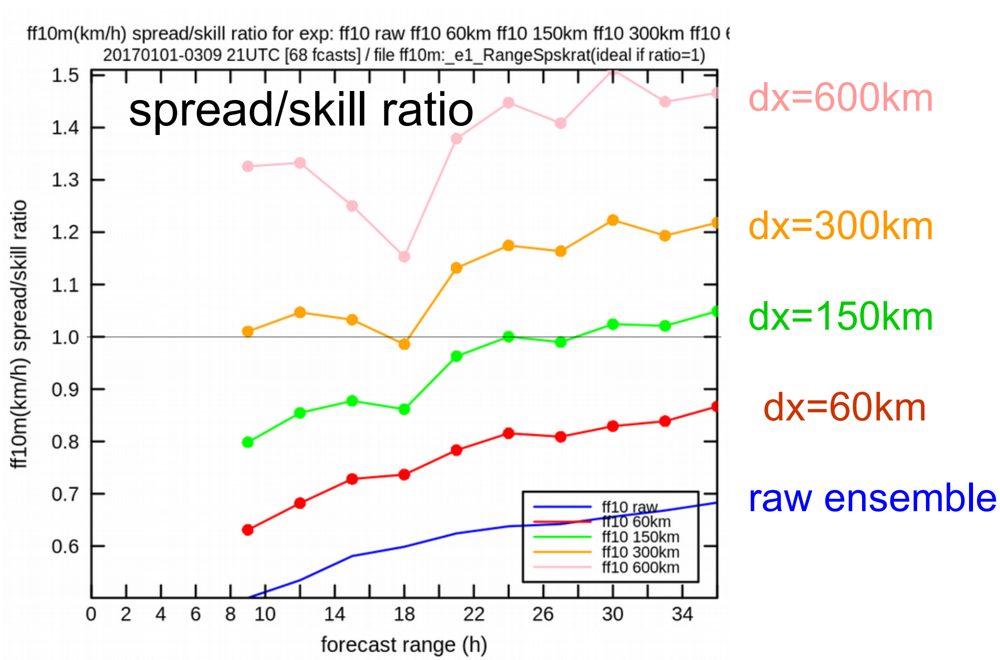
- conventional spread/skill diags indicate the ensemble lacks spread
- not a trivial model bias or obs error problem

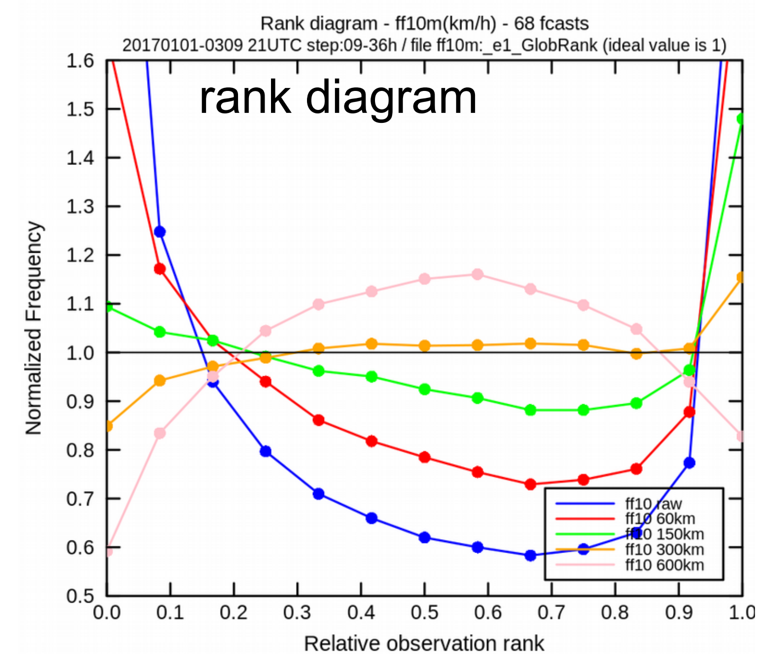
Let us **upscale the verification** by smoothing both obs and model output : the obs network geometry allows smoothing at scales dx=30 to 600km

Probabilistic scores are computed on increasingly large scales (see also the Fractions Skill Score by Roberts & Lean 2008 etc.) over 68 winter days

The ensemble is overdispersive at scales >200km :

spread is lost in the local adaptation of synoptic features





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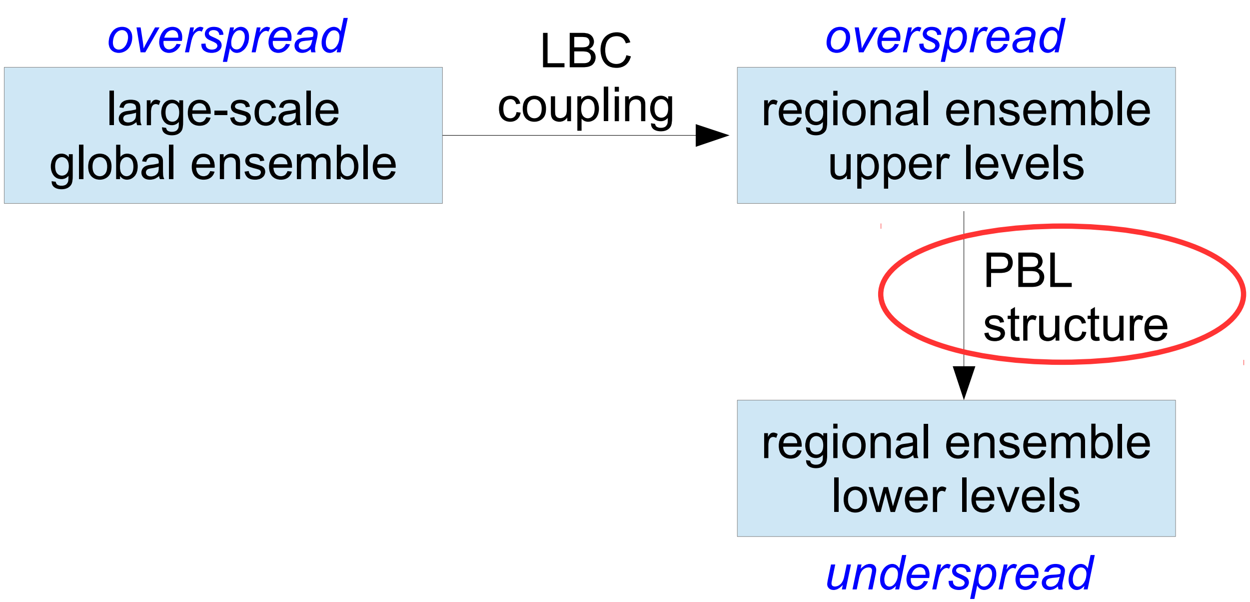
Diagnosing model error : scale dependency

Tentative physical interpretation :

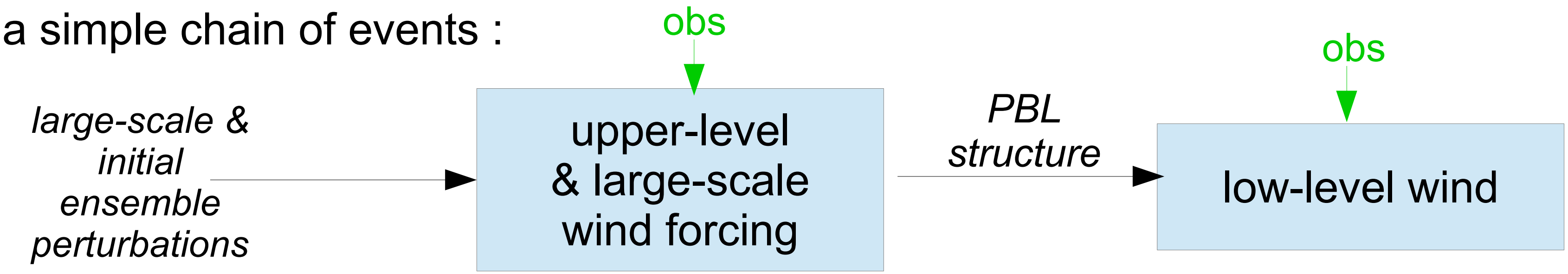
- large-scale LAM upper-level wind is tightly driven by a **global ensemble (PEARP) that is similarly overdispersive.**
- small-scale, low-level wind lacks spread because some wind error sources are missing
  - in the large-scale -> small-scale energy cascade (unlikely : model dynamics are fairly good at these scales)
  - or, in the high -> low level wind transition : **missing model error representation in the PBL** ? (not solved by simple perturbations of physics parameters)

In this situation, increasing synoptic-scale ensemble spread would improve SYNOP-based point probabilistic scores for the wrong reasons.



Diagnosing model error in 'easy' conditions

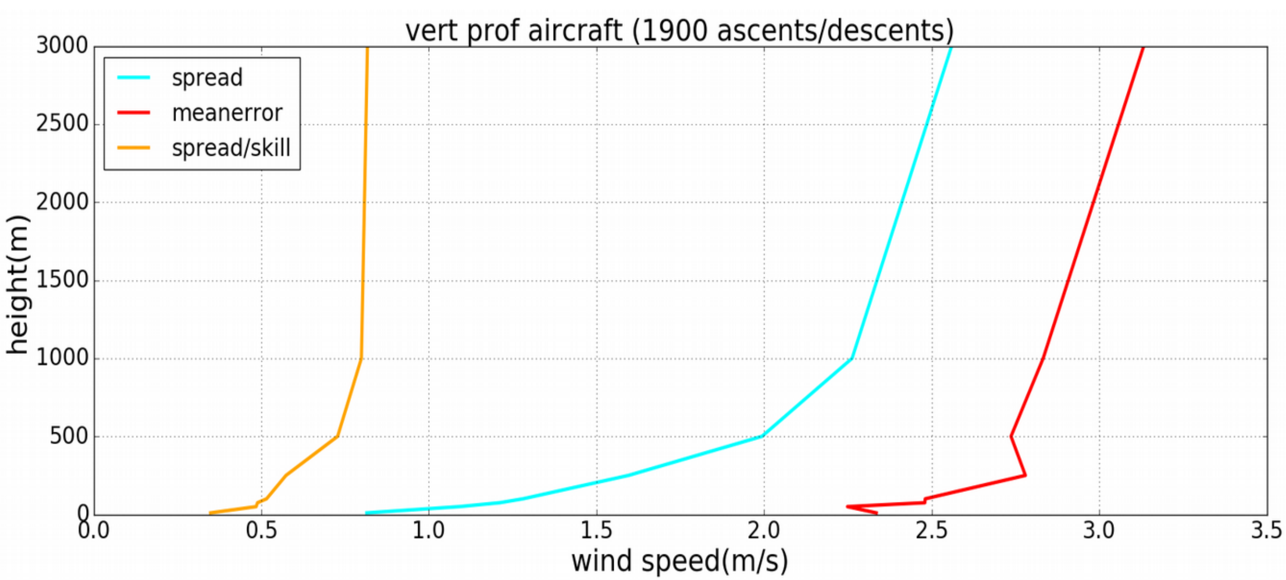
Can we locate missing ensemble perturbations by locating ***sinks of spread*** ?
assuming a simple chain of events :



Study : windspeed in neutral PBLs, using aircraft ascents/descents

- model & obs biases are small
- wind is driven by current upper-level conditions
- spread/skill ratio collapses near the surface, suggesting the ensemble lacks representation of a specific uncertainty source in the PBL.

Usually, several sources of spread interact, making it difficult to tune model error schemes.



(see also Berner et al 2016, MWR 143-1295)

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Summary & Outlook

- diversity of model error strategies in interconnected systems (EDAs, large-scale and fine-scale ensemble)
- each one is clearly beneficial, but they could be made more consistent to ease maintenance (e.g. SPP / SPPT in all systems) and reduce risks of overcompensating some error sources by others

Future priorities :

- **develop** clearly missing model perturbations (surface pert. in EDA, perturbed parametrisations in ARPEGE & AROME models)
- **minimise complexity** : identify & treat the most uncertain processes (rain/snow transition, cloudiness, fog extent, dynamics...)
- **improve model tolerance to perturbations :** numerical blow-ups and ensemble-specific biases (eg SPPT drying)

Thanks for your attention

Questions ?