Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

Uncertainty simulation in ALADIN-LAEF

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Outlook

- **ALADIN-LAEF (in short)**
  - Introduction
  - Specifications
  - Evaluation
- **Uncertainties and their simulation (IC, LBC, model)**
  - Multiphysics (ALARO-0, ALARO-1, ...)
  - Stochastic physics (surface prognostic variables)
  - Combined approach (SPPT + MP + ESDA, ...)
- **Known issues**
  - Drying effect (supersaturation adjustment)
  - Instability (tapering function)
  - Spectral pattern generator (new SPG)

ALADIN-LAEF (introduction)

What is it?
It is meso-scale ensemble system Aire Limitée Adaptation dynamique développement InterNational - Limited Area Ensemble Forecasting (ALADIN-LAEF) based on the limited area model ALADIN and profiting from advanced multi-scale ALARO physics.

Where it comes from?
It has been developed in frame of RC LACE consortium. ALADIN-LAEF became operational in 2011 (18 km/37 levels), it was upgraded in 2013 (11 km/45 levels + ESDA) and currently it is undergoing major upgrade (5 km/60 levels + many other changes).

What is the purpose?
It is focusing on short range probabilistic forecast and delivery of operational products to the RC LACE partners twice a day, up to 72 hours.

Where it runs?
The system runs operationally on HPCF at ECMWF, containing 16 perturbed members and 1 unperturbed control run.

How is the uncertainty simulated?
We use different strategies to simulate the uncertainty of the IC and of the numerical model, while the perturbations at the boundaries are prescribed by the downscaled information from ECMWF EPS.

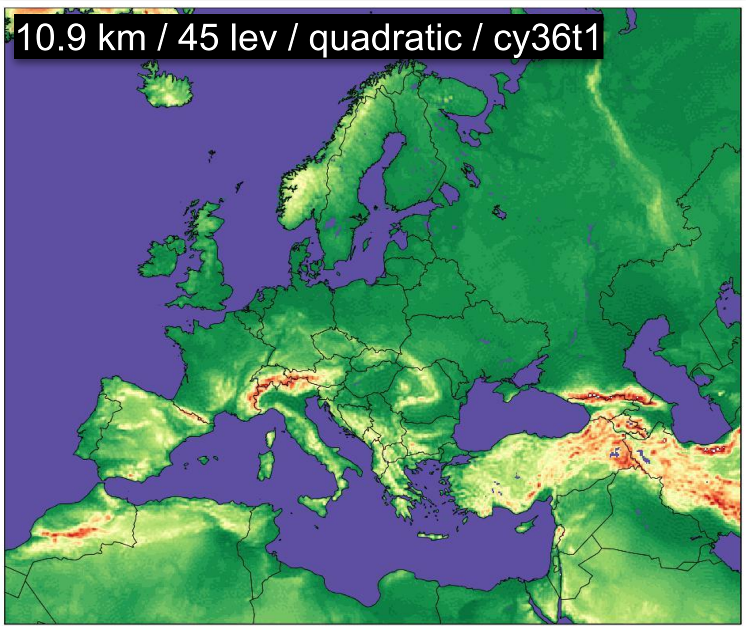
ALADIN-LAEF (specifications)

ALADIN-LAEF	current	new
Code version	cy36t1	cy40t1
Horizontal resolution	10.9 km	4.8 km
Vertical levels	45	60
Number of grid points	500x600	750x1250
Grid	quadratic	linear
Time step	450s	180s
Forecast length	72 h (00/12 UTC)	72 h (00/12 UTC)
Members	16+1	16+1
IC perturbation	ESDA [surface], breeding-blending [upper-air]	ESDA [surface], blending (Phase I) / ENS BlendVar (Phase II) [upper-air]
Model perturbation	ALARO-0 multi-physics	ALARO-1 multi-physics + surface SPPT
LBC perturbation	ECMWF ENS	ECMWF ENS
Scripting	SMS/Shell/Perl	ecFlow/Python/Perl

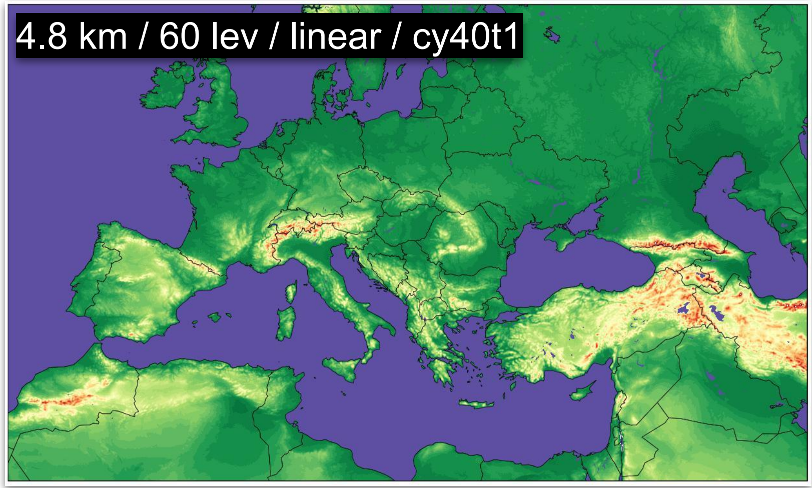
ALADIN-LAEF system specifications for current and new (upgraded) version, which is expected to become operational this year.

ALADIN-LAEF (specifications)

current



new



new ALADIN-LAEF

- phase I: ESDA+Blend (IC); SPPT+ALARO-1 MP (model)
- phase II: ENS BlendVar (IC)

ALADIN-LAEF (specifications)

Uncertainty simulation

ESDA:

$$\Delta T_s = \Delta T_{2m}$$

$$\Delta T_p = \frac{1}{2\pi} \Delta T_{2m}$$

$$\Delta W_s = \alpha_s^T \Delta T_{2m} + \alpha_s^H \Delta H_{2m}$$

$$\Delta W_p = \alpha_p^T \Delta T_{2m} + \alpha_p^H \Delta H_{2m}$$

BLENDING:

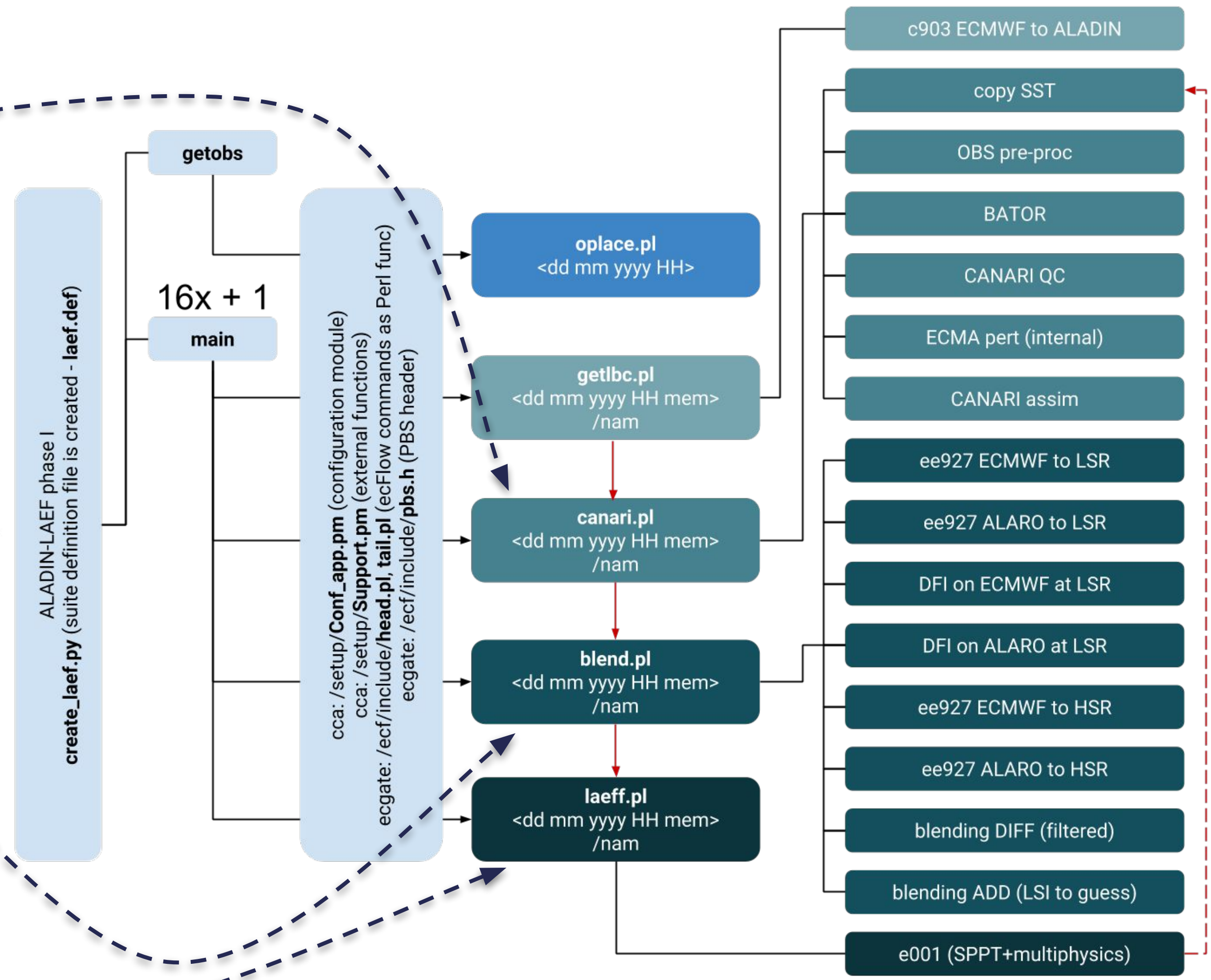
$$IC^n_{blend} = a^n_{breed} + \{ \overline{(a^n_{sv})_{trunc}} - \overline{(a^n_{breed})_{trunc}} \}$$

$$IC^n_{blend} = LS^n + a^n_{breed}$$

SPPT + MP:

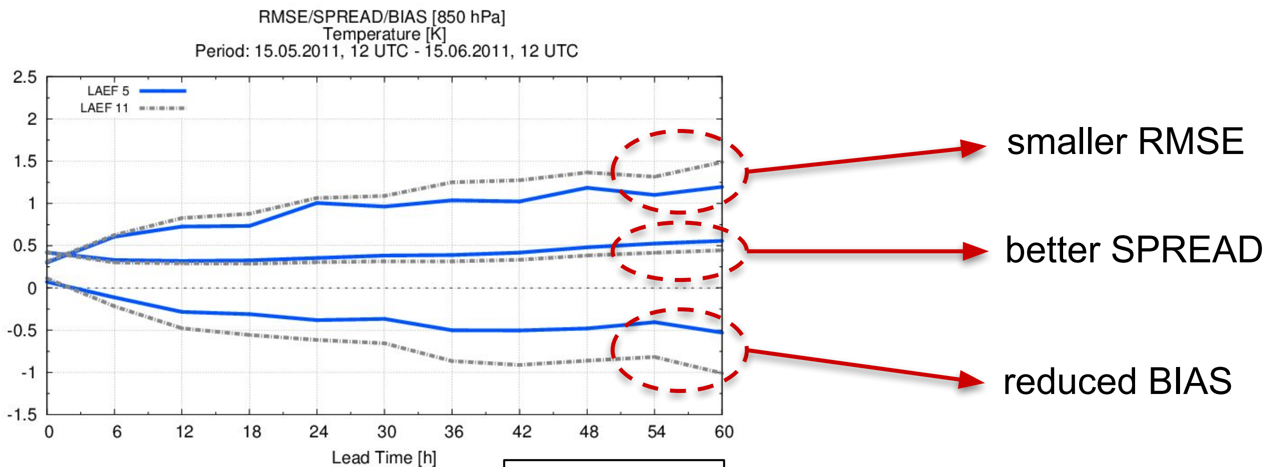
$$\frac{\partial e_j}{\partial t} = A(e_j, t) + P'(e_j, t)$$

$$P'_j(e_j, t) = (1 + r_j(\lambda, \varphi, t)_{D,T}) P_j(e_j, t)$$

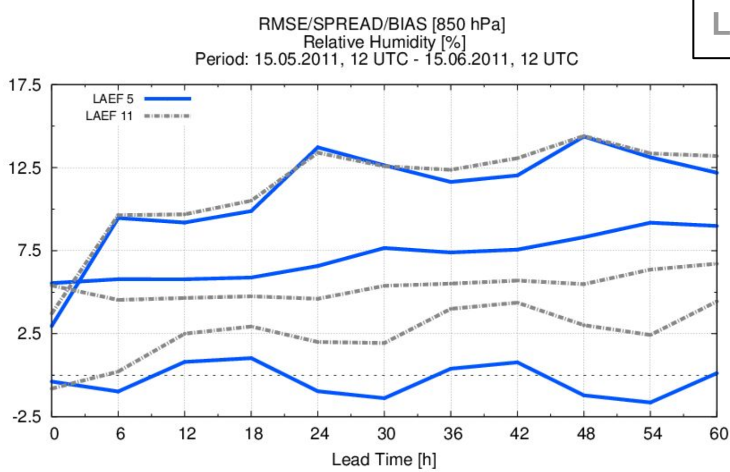


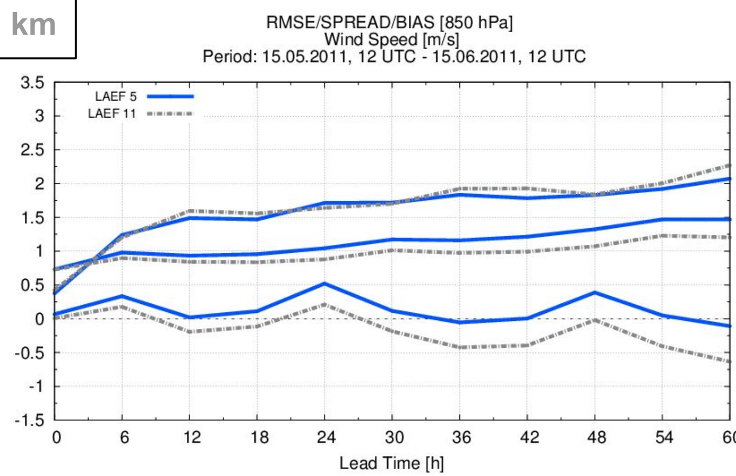
ALADIN-LAEF (evaluation)

Old (11 km) vs new (5 km) ALADIN-LAEF verification at 850 hPa



LAEF 5 km
LAEF 11 km

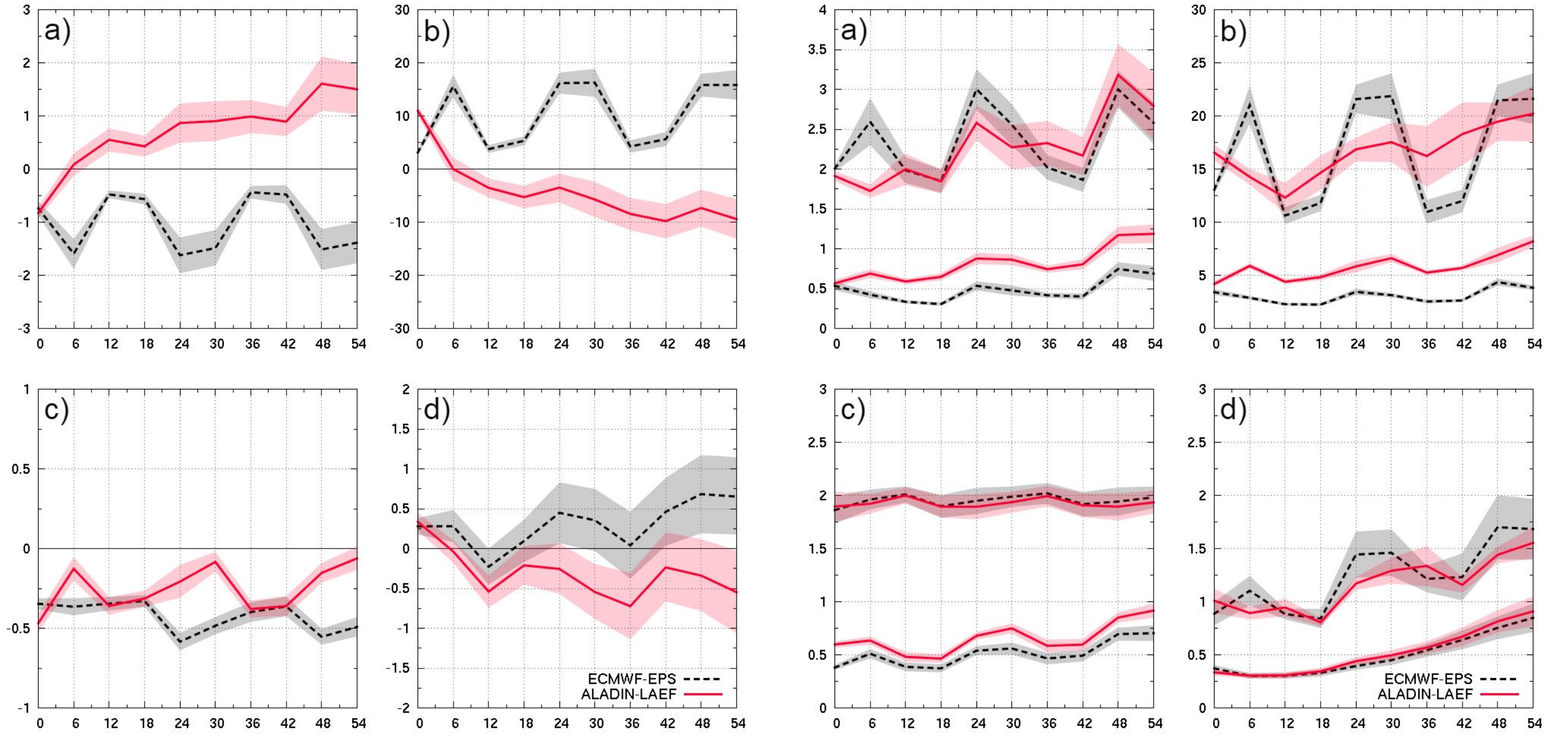




ALADIN-LAEF (evaluation)

ALADIN-LAEF phase I vs ECMWF downscaled (surface verification)

The added value of new ALADIN-LAEF over the downscaled ECMWF ENS is obvious for the surface parameters, while it is rather neutral in the upper-air (not shown).



ALADIN-LAEF phase I (red lines) and ECMWF-EPS downscaling (black dashed lines) for surface parameters: a) T2m, b) RH2m, c) FF10m, d) MSLP (BIAS - left, RMSE/Spread - right). The shaded area denote 10% and 90% confidence intervals for given experiment.

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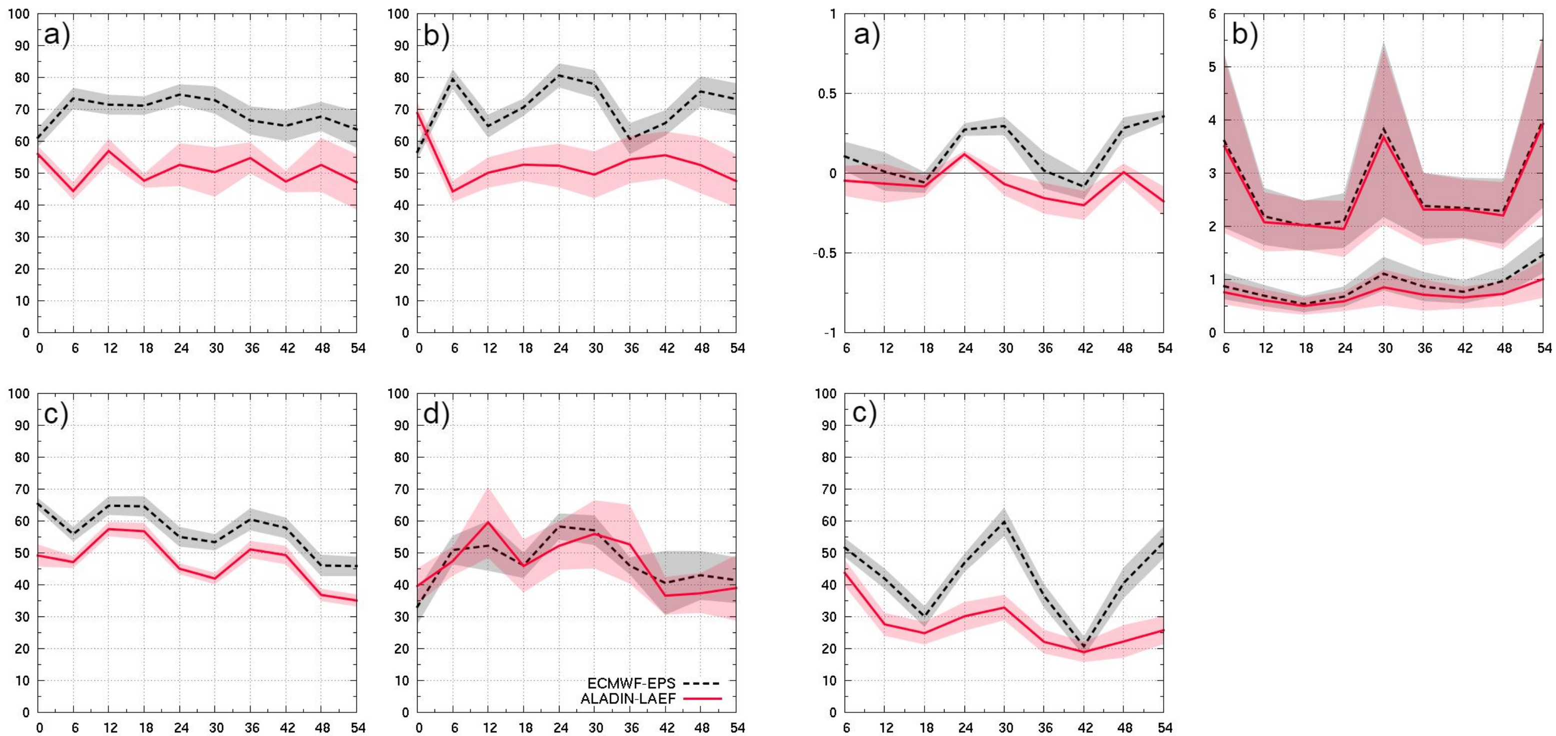


ALADIN-LAEF phase I (red lines) and ECMWF-EPS downscaling (black dashed lines) for surface parameters: a) T2m, b) RH2m, c) FF10m, d) MSLP (Outliers - left) and a) BIAS, b) RMSE/Spread, c) Outliers for RR6h (right). The shaded area denote 10% and 90% confidence intervals for given experiment.

Uncertainties and their simulation

Uncertainty (or error) of measurement:

- Random
- Systematic error
- Reading uncertainty

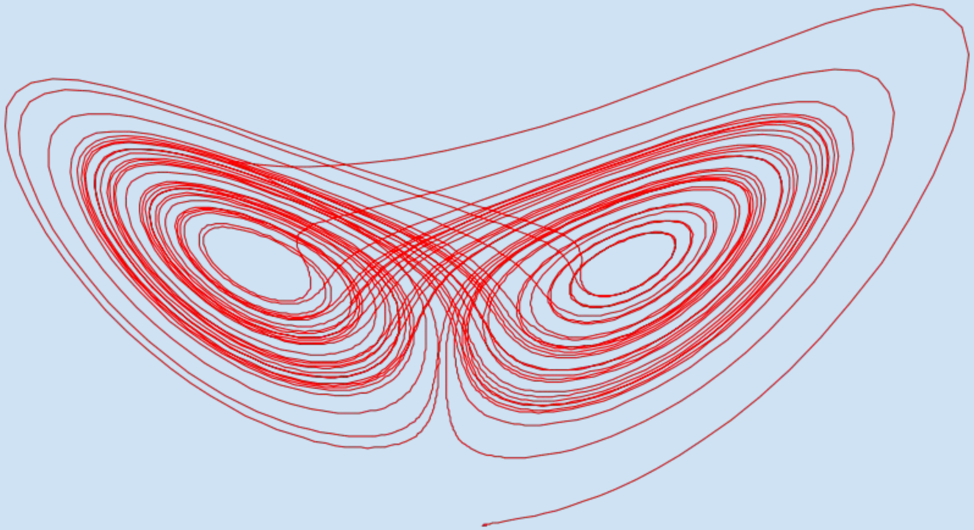
Uncertainties and their simulation

Uncertainty (or error) of measurement:

- Random → Chaotic behaviour
- Systematic error → Model is approximation of reality
- Reading uncertainty → Initial conditions

Weather system:

- Chaotic behaviour
- Model is approximation of reality
- Initial conditions



Chaos: When the present determines the future, but the approximate present does not approximately determine the future. (Edward Lorenz)

Uncertainties and their simulation

Two different sources of uncertainties in NWP

- Initial and boundary conditions (see papers)
  - Ensemble data assimilation (IC)
  - Spectral blending (LBC)
- <u>Numerical model</u> (the approximation rather than the accuracy)
  - Multiphysics (ALARO-0, ALARO-1, ...)
  - Stochastic physics (surface prognostic variables)
  - Combined approach (SPPT + MP + ESDA, ...)

NCSB vs ESDA

Bellus, M., Y. Wang, and F. Meier, 2016: **Perturbing Surface Initial Conditions in a Regional Ensemble Prediction System.** Mon. Wea. Rev., 144, 3377–3390,https://doi.org/10.1175/MWR-D-16-0038.1

Wang, Y., M. Bellus, J. Geleyn, X. Ma, W. Tian, and F. Weidle, 2014: **A New Method for Generating Initial Condition Perturbations in a Regional Ensemble Prediction System: Blending.** Mon. Wea. Rev., 142, 2043–2059, https://doi.org/10.1175/MWR-D-12-00354.1

Spectral blending

Multiphysics

P

P P P

P

P

Multiphysics (cy36t1, 11 km, 45 lev)

member	MIC	DPC	SHC	RAD	TRB	GUD
MP01						
MP02						
MP03						
MP04						
MP05						
MP06						
MP07						
MP08						
MP09						
MP10						
...MP16						

MIC - micro-physics
- ALARO-0 using Xu-Randall type LS condensation
- ALARO-0 using Smith type LS condensation
- Lopez microphysics

DPC - deep convection
- 3MT (Modular Multi-scale Microphysics and Transport)
- Bougeault and Geleyn scheme
- 3MT + cellular automaton

SHC - shallow convection
- Geleyn (1987) based shallow convection
- Kain-Fritsch-Bechtold shallow convection scheme

RAD - radiation
- Geleyn et. all 2005, Rittern and Geleyn 1992
- RRTM and Morcrette 1991 (ECMWF)

TRB - turbulence
- pseudo-prognostic TKE, Geleyn et. al 2006
- Cuxart-Bougeault-Redelsperger prognostic TKE

GUD - gust-wind diagnostics
- classical ALADIN approach
- combination of ALADIN, Meso-NH and Brasseur
- TKE based approach (Meso-NH)

Multiphysics (old LAEF vs new LAEF)

16 → 4x4

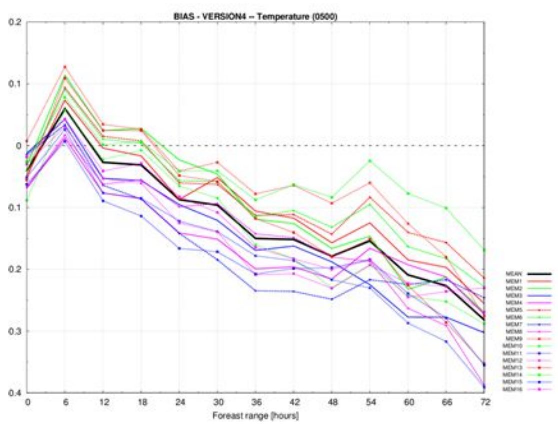
Multiphysics (cy40t1, 5 km, 60 lev)

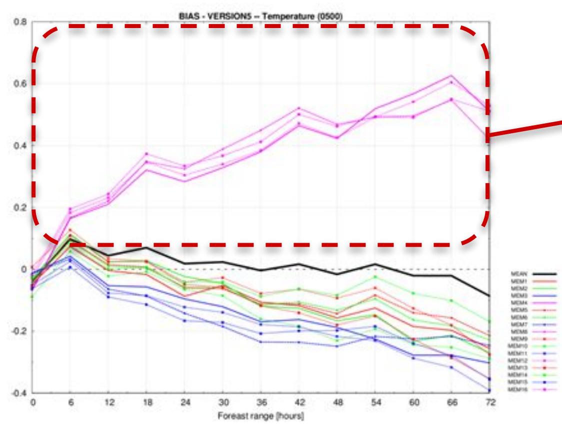
Testing different configurations...searching for the fantastic four

VERSION 4					VERSION 5				
	used for members					used for members			
EXP57	01	05	09	13	EXP57	01	05	09	13
EXP01	02	06	10	14	EXP01	02	06	10	14
EXP55	03	07	11	15	EXP55	03	07	11	15
EXP58	04	08	12	16	EXP00	04	08	12	16

16 EPS members

- EXP57 – ALARO-1 modified turbulence
- EXP01 – ALARO-1 reference
- EXP55 – ALARO-1 modified microphysics + deep convection
- EXP58 – ALARO-1 modified turbulence, microphysics and deep convection
- EXP00 – ALARO-0 reference





ALARO-0 reference

Temperature BIAS at 500 hPa for the ensemble version 4 (left) and version 5 (right).

Multiphysics (cy40t1, 5 km, 60 lev)

	set	ref	description of parameter
LAB12	F	T	ALARO-1 microphysics: Abel-Boutle 2012 (independent of ACRANEB2 and TOUCANS)
LCVGQM	F	T	ALARO-0: modulation of humidity convergence closure
LCVGQD	F		
LENTCH	F	T	ALARO-0: memory in adaptive detrainment
LSCMF	F	T	ALARO-0: mesh fraction's influence on the entrainment rate
LSMGCDEV	T		
LXRCDEV	F	T	ALARO-0: Xu-Randall used in adjustment

LAEF members			
01	05	09	13
02	06	10	14
03	07	11	15
04	08	12	16

Multiphysics (cy40t1, 5 km, 60 lev)

	set	ref	description of parameter
CGMIXLEN	EL3	EL0	ALARO-1 TOUCANS: equivalent of 'AY' in ALARO-0
CGTURS	QNSE	MD2	ALARO-1 TOUCANS: turbulence model II
LPRGML	F	T	ALARO-0: situation-dependent mixing length
C3TKEFREE	1.39	1.183	ALARO-1 TOUCANS
C_EPSILON	0.798	0.871	ALARO-1 TOUCANS
ETKE_OLAM	0.324	0.29	ALARO-1 TOUCANS
NUPTKE	0.504	0.5265	ALARO-1 TOUCANS

LAEF members			
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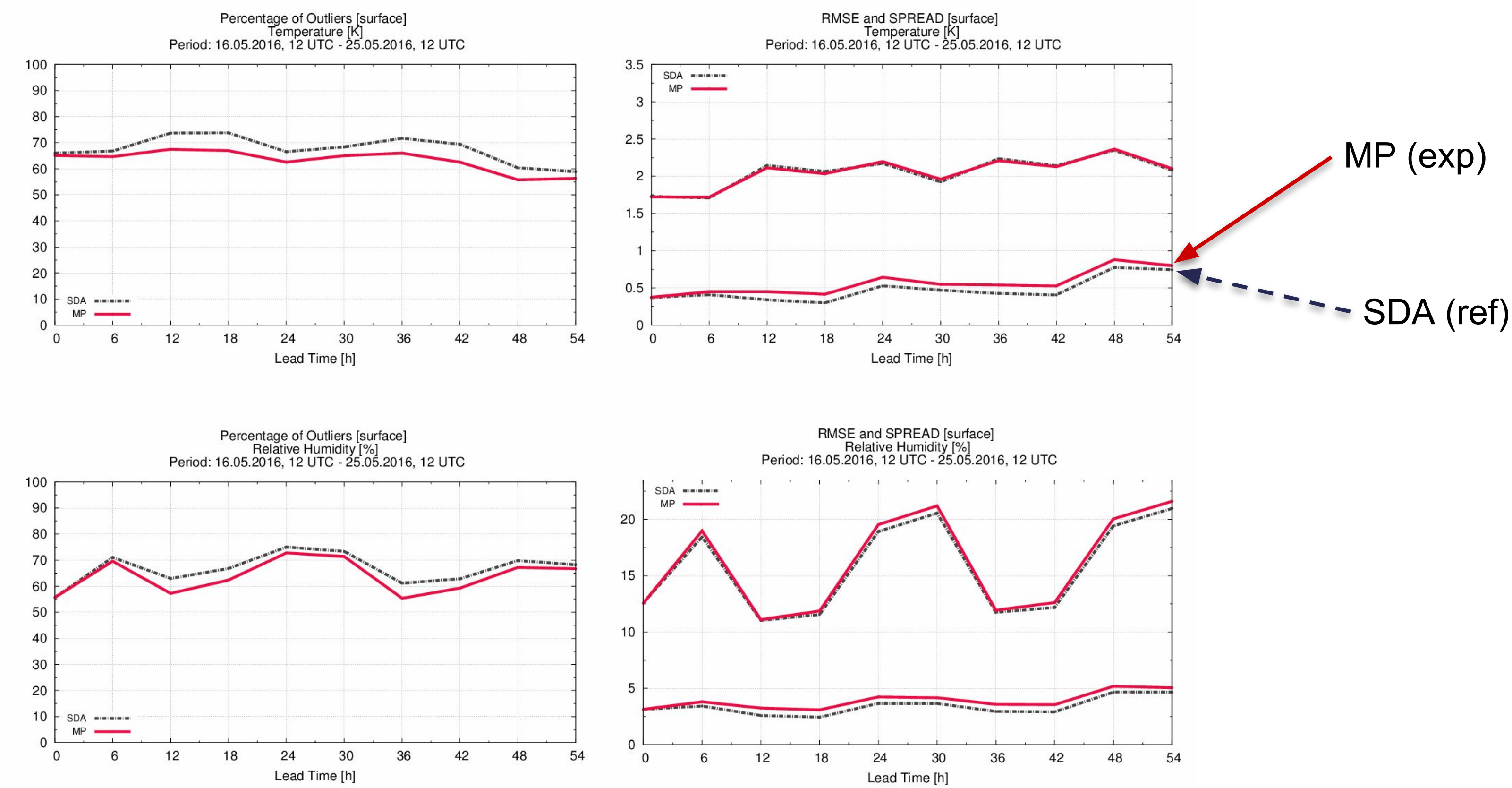
Multiphysics (cy40t1, 5 km, 60 lev)

Reduced set of ALARO-1 namelists with tuned microphysics, turbulence and deep convection



Temperature (up) and relative humidity (bottom) verification for the period of 10 days from 16 to 25 May 2016, 12 UTC run of the full LAEF ensemble (16 members). The percentage of outliers (left) and RMSE of the ensemble mean with ensemble spread (right) are shown for the reference (SDA, black dashed) and multiphysics experiment (MP, red).

Stochastic physics

Stochastic physics

Stochastic parameterization techniques have been developed at ECMWF since the end of last century and now are widely used by many operational centres in their EPSs. Formerly known simply as stochastic physics, the scheme based on the approach of Buizza, Miller and Palmer (1999) was later referred as BMP and finally revised under the name Stochastically Perturbed Parameterization Tendencies (SPPT), which better represents this class of model uncertainties (2009).

ensemble member's state

resolved non-parameterized processes (e.g. dynamics)

perturbed tendency of the parameterized processes

$$\frac{\partial e_j}{\partial t} = A(e_j,t) + P'(e_j,t)$$

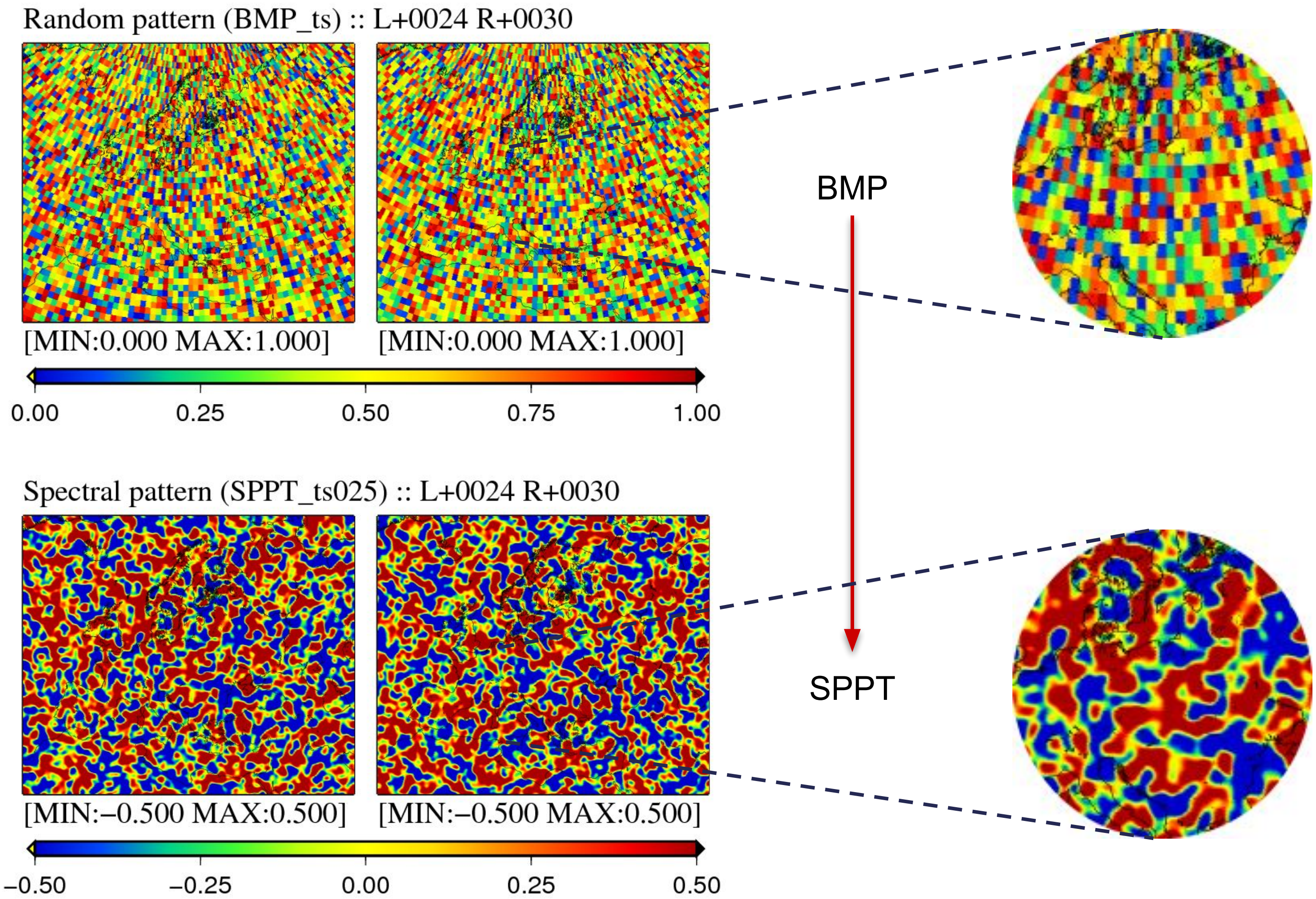
$$P'_j(e_j,t) = (1 + r_j(\lambda,\varphi,t)_{D,T})\, P_j(e_j,t)$$

uncertainty of subgrid physical processes

random number

unperturbed tendency of the parameterized processes (grid-box average)

Stochastic physics (random numbers)



Stochastic physics (application)

- SPPT is called each time step in grid-point space
- Applied on total physics tendencies
    - Surface SPPT (implemented for the first time in ALADIN-LAEF)

local variable	global variable	denotation	name (tendency of)
ZTDTS	PTENTS	T_s	surface temperature
ZTDWS	PTENWS	W_s	liquid water
ZTDWSI	PTENWSI	W_{si}	frozen water
ZTDWL	PTENWL	W_r	water on leafs
ZTDSNS	PTENSNS	S_n	water in snow
ZTDALBNS	PTENALBNS	A_n	snow albedo
ZTDRHONS	PTENRHONS	ρ_n	snow density

Direct perturbation of deep soil prognostic fields (such as deep soil temperature or deep soil moisture) is intentionally avoided, because they naturally change slower in time with some delay with respect to the surface.

- Upper-air SPPT (original idea of ECMWF, different story)

T	q	U	V

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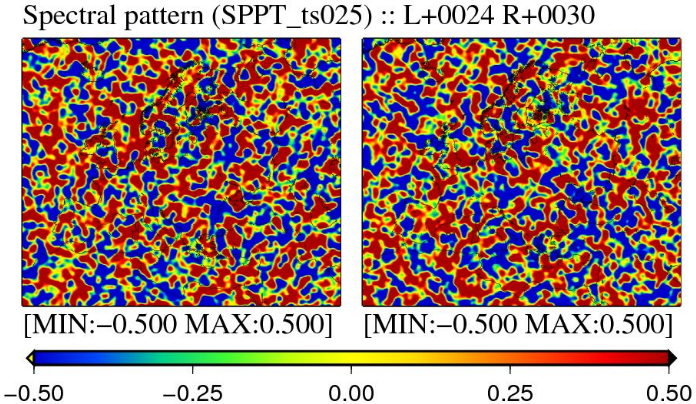
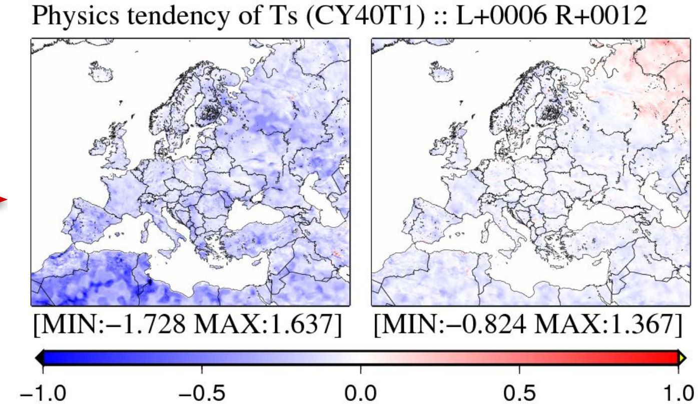
- Upper-air SPPT (original idea of ECMWF, different story)

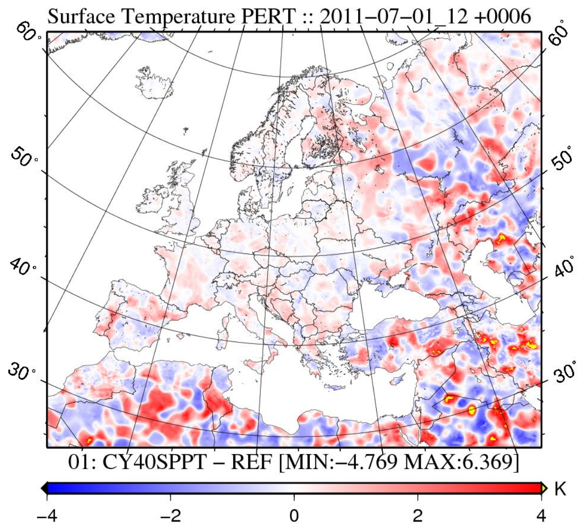
T	q	U	V

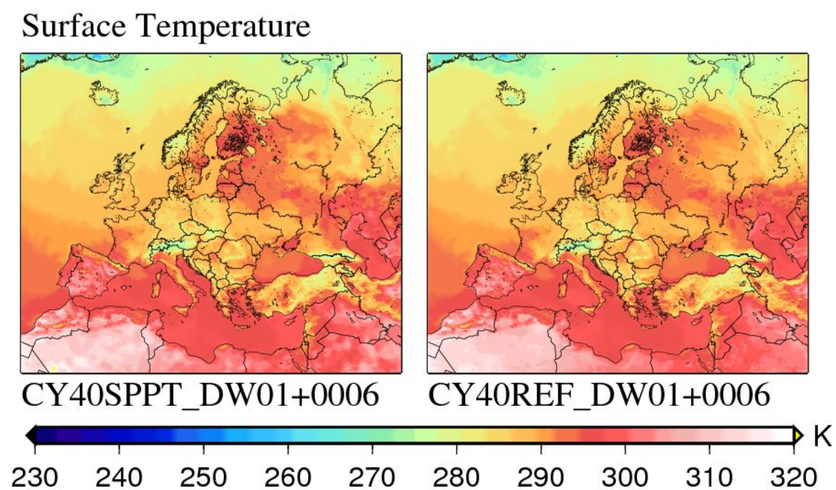
issues when applied in LAMEPS
- drying effect
- gaussian distribution
- instability

Stochastic physics (application)



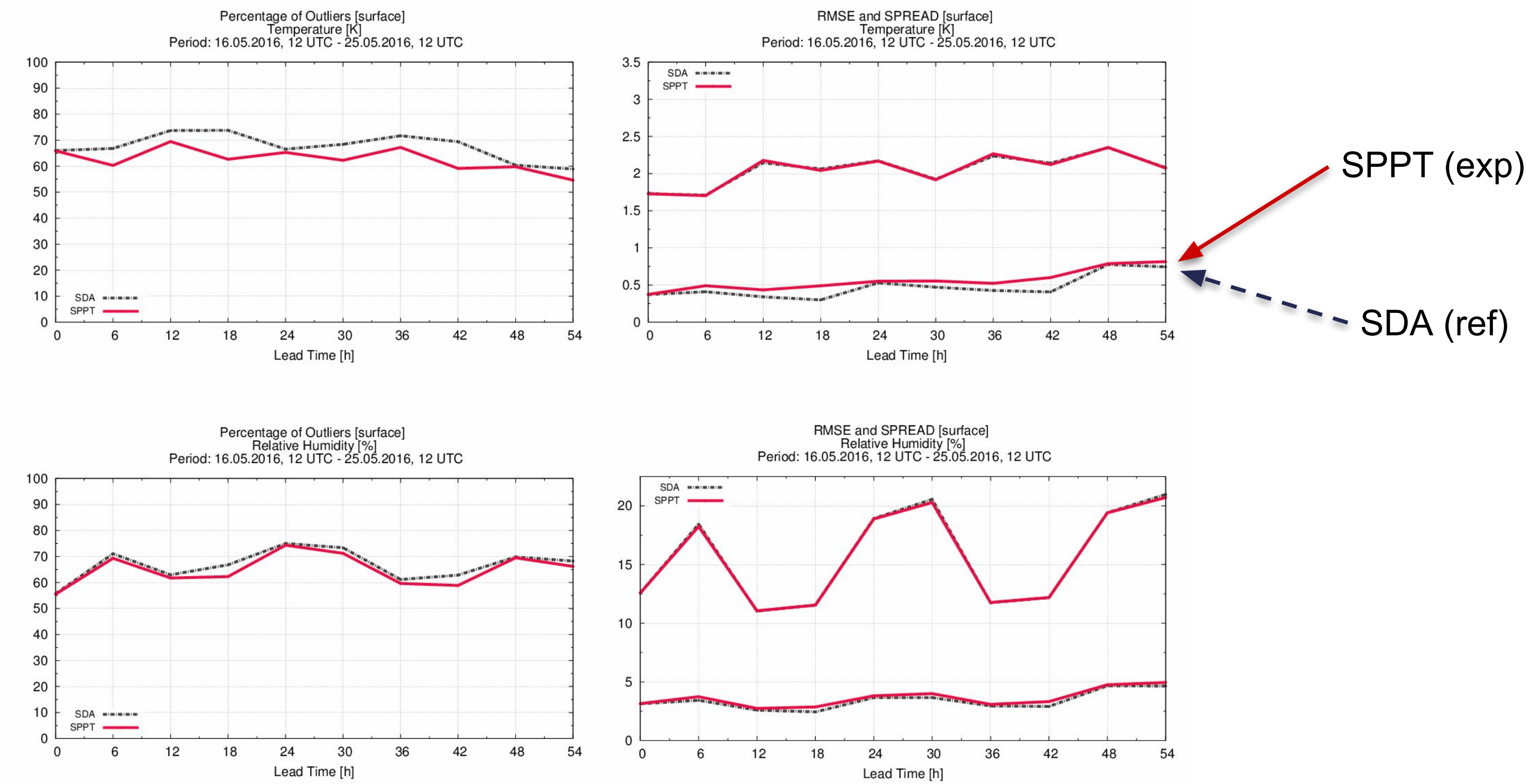






Stochastic physics (cy40t1, 5 km, 60 lev)

SPPT is called each time step in grid-point space for ISBA prognostic fields (except deep soil)



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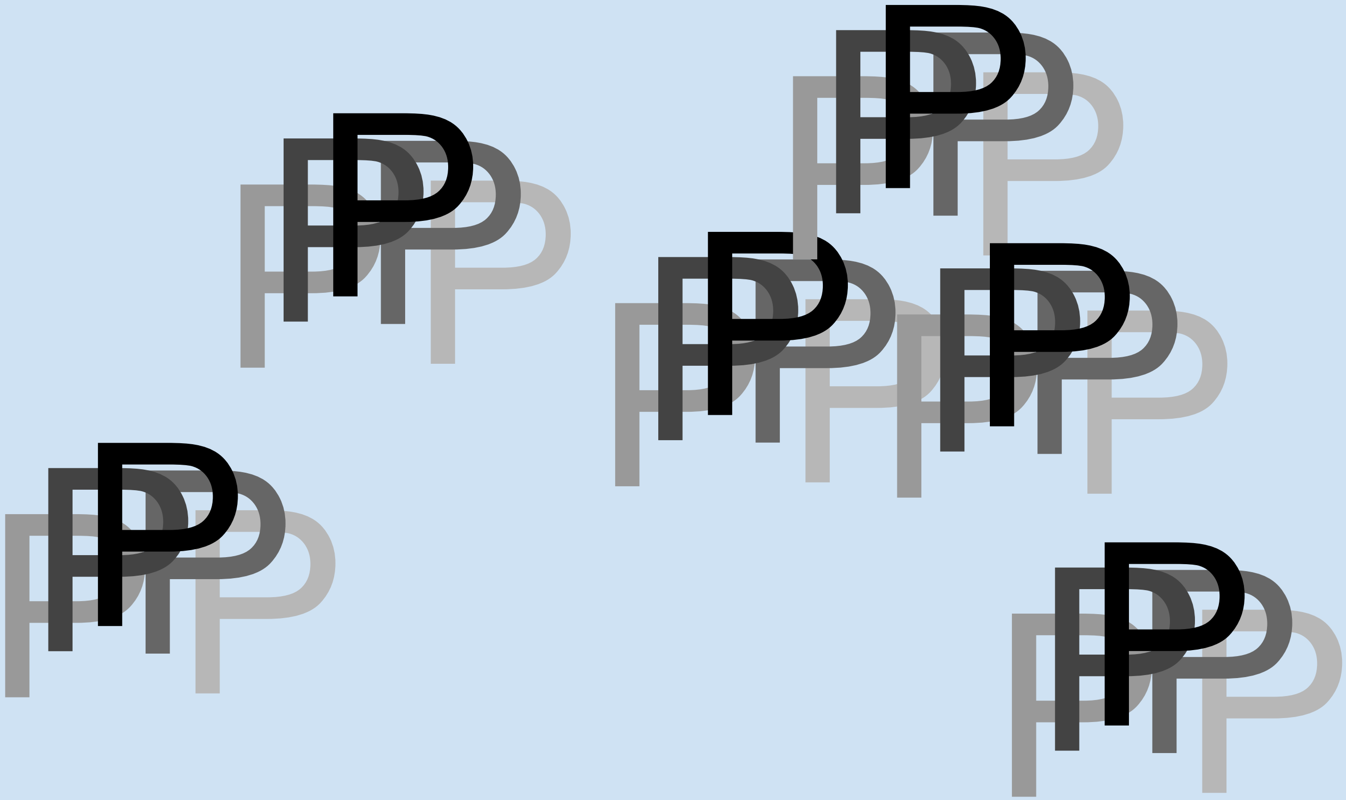
Combined approach

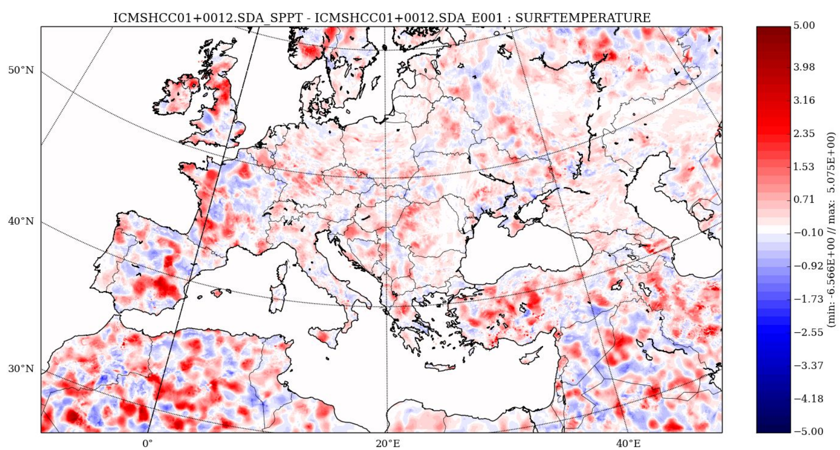


Combined approach (SPPT+MP)

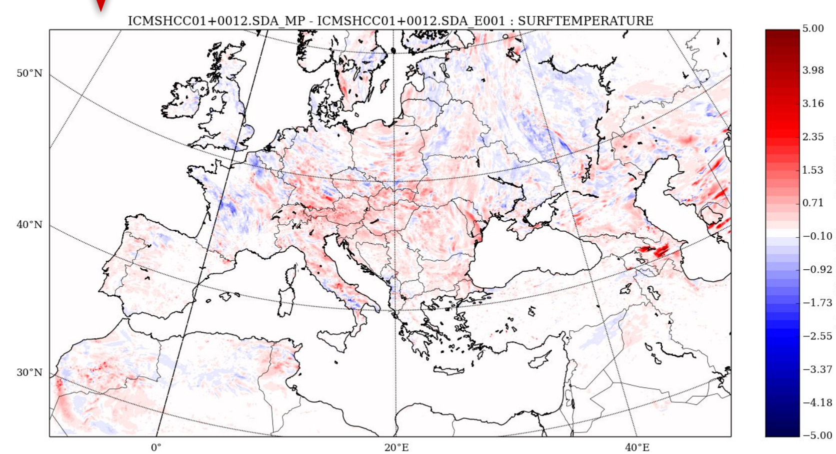
Model perturbations for new ALADIN-LAEF

LAEF members			
01	05	09	13
02	06	10	14
03	07	11	15
04	08	12	16

Stochastic physics (surface)



Multiphysics



Surface temperature perturbation due to SPPT after 12h of integration (left) and due to MP for 3 different namelist configurations (right). The fourth namelist configuration is default ALARO-1 physics.

Combined approach (SPPT+MP)

Model perturbations for new ALADIN-LAEF

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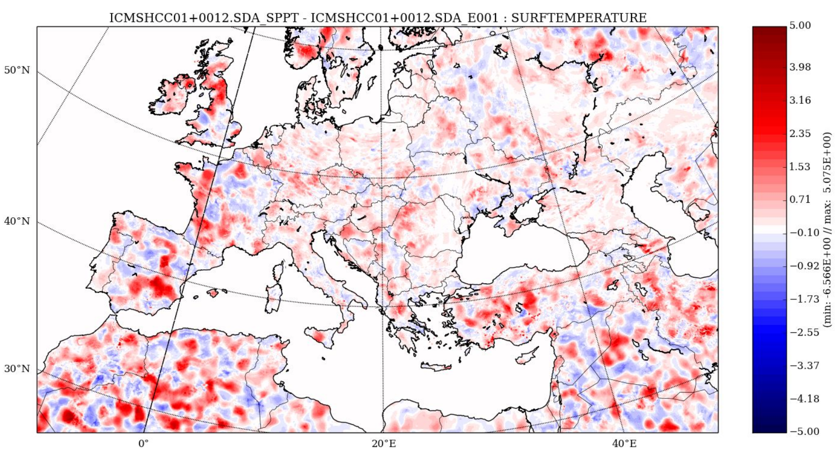
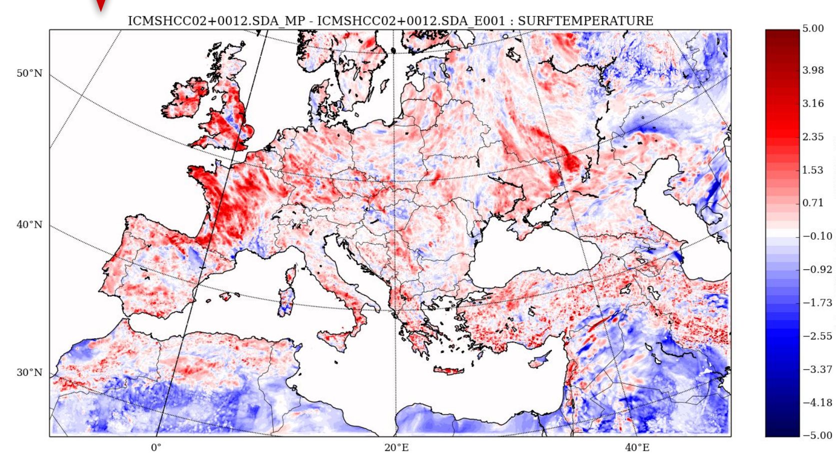


Multiphysics



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Combined approach (SPPT+MP)

Model perturbations for new ALADIN-LAEF

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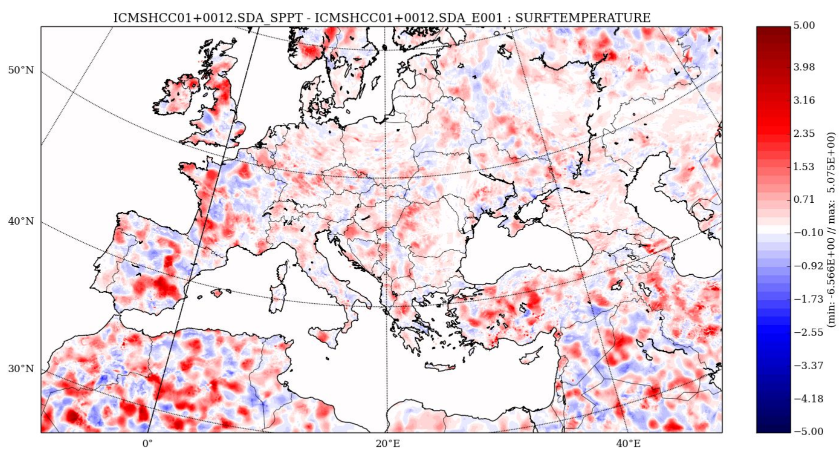

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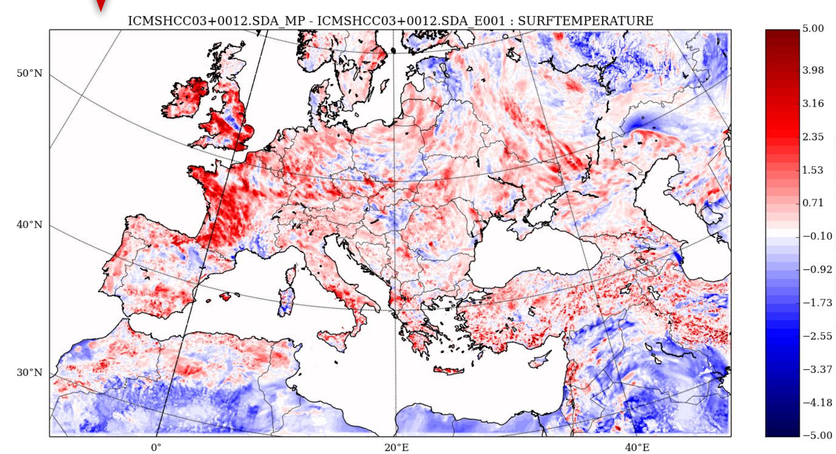

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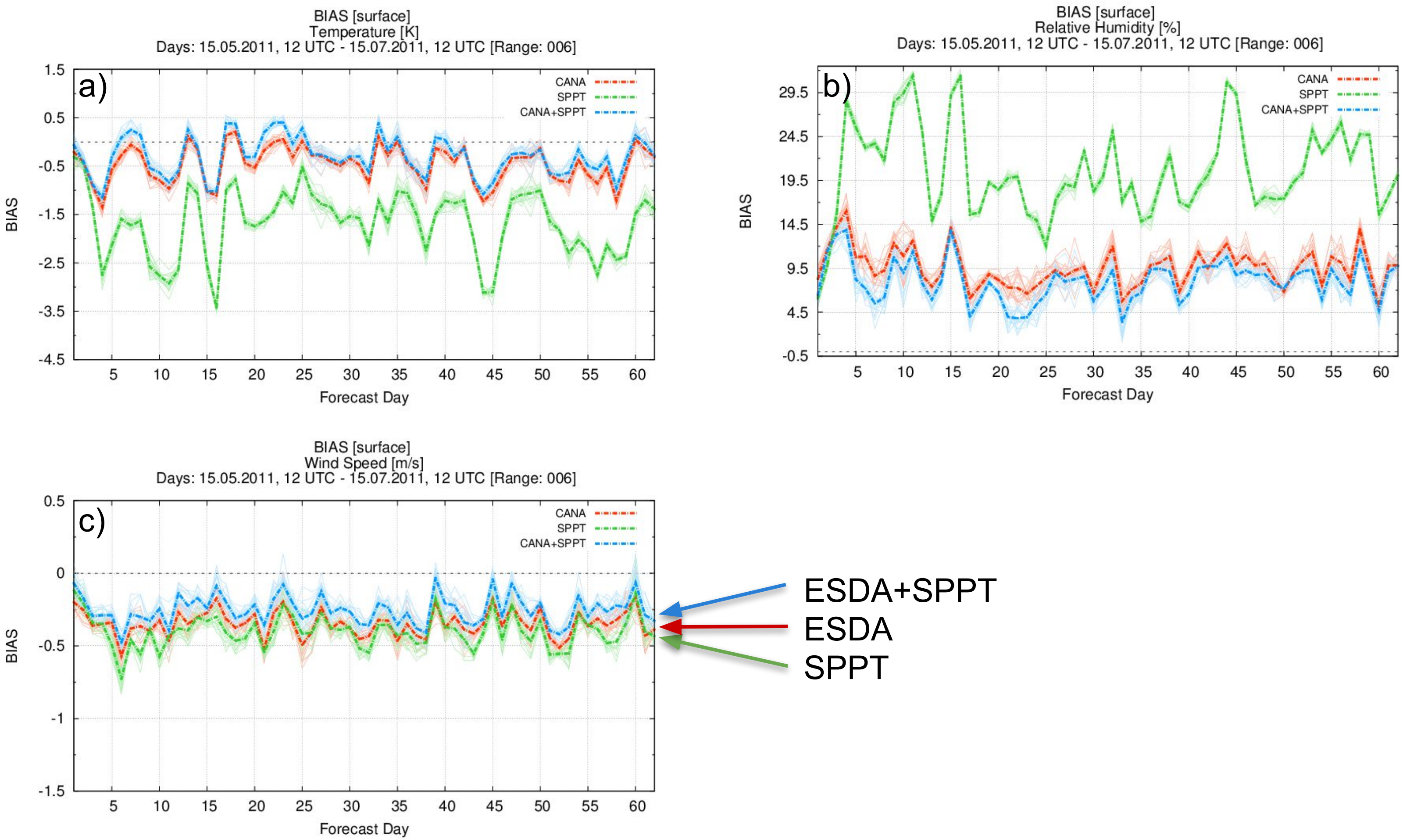
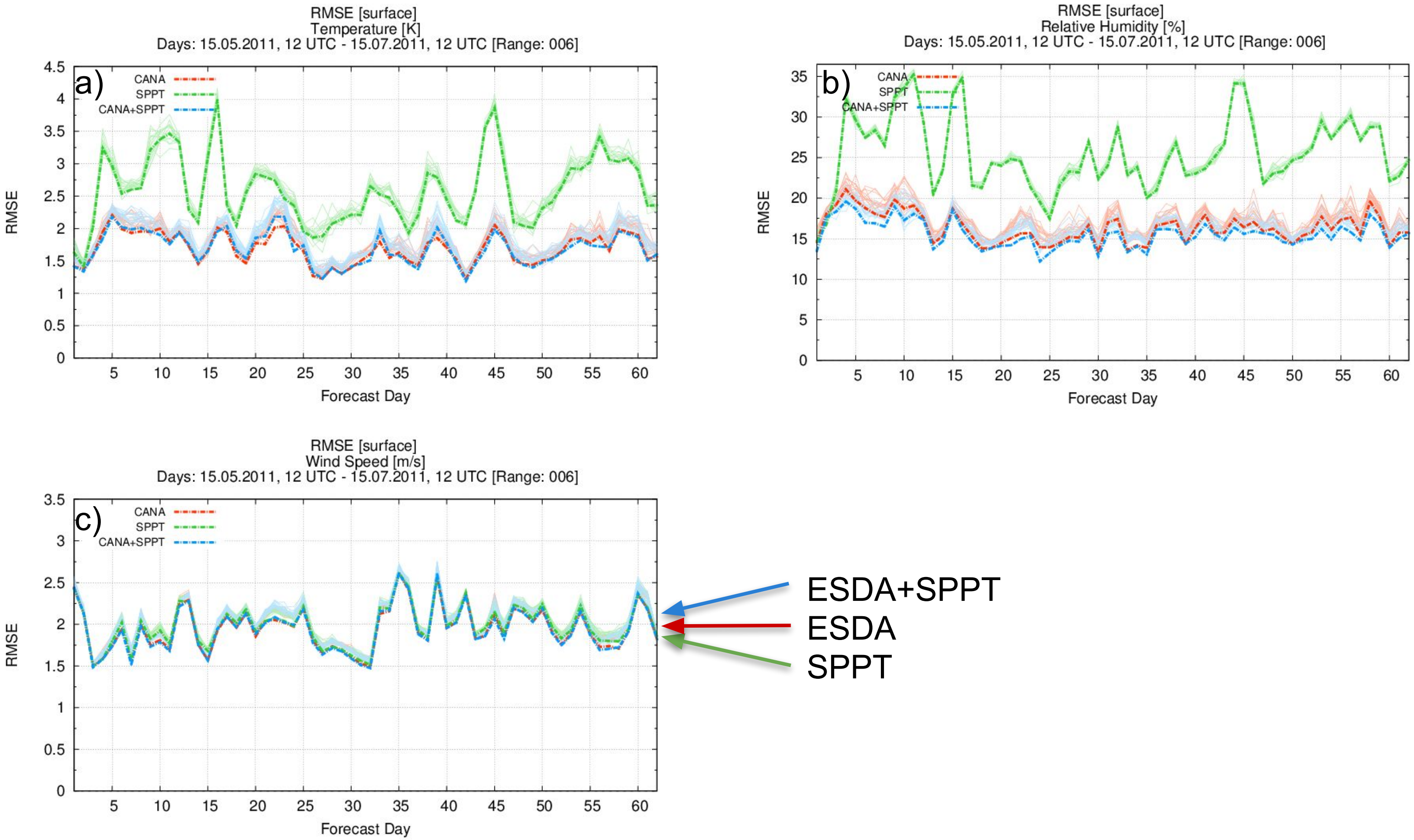
Combined approach (ESDA+SPPT) - BIAS



Time series (+6h forecast) for 62 days of validation period for a) temperature, b) relative humidity and c) wind speed.

Combined approach (ESDA+SPPT) - RMSE



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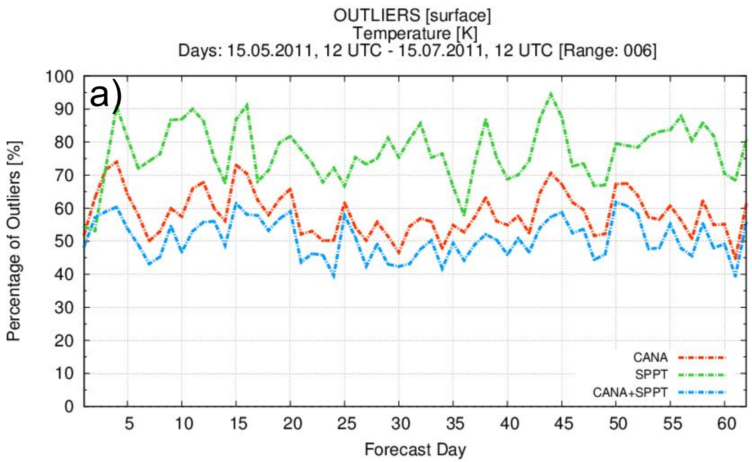
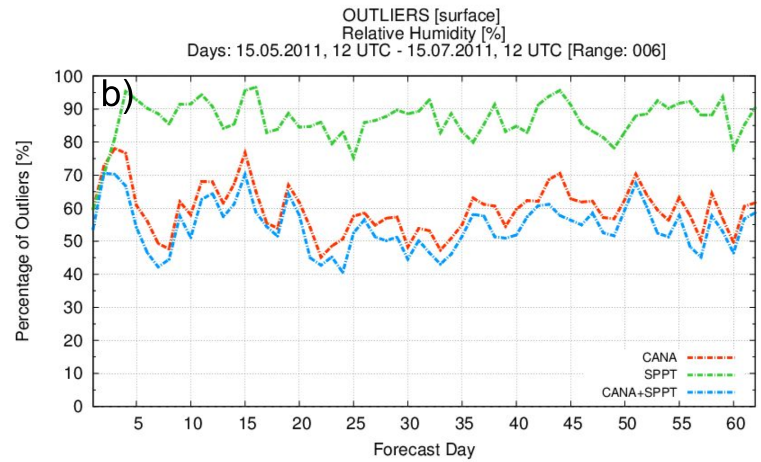
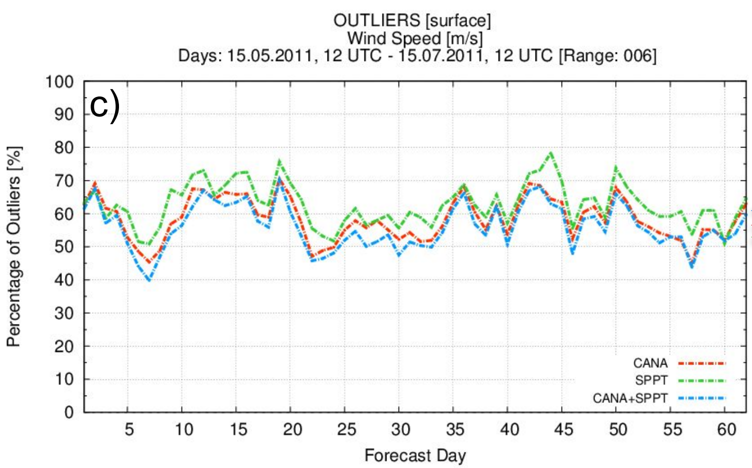
Combined approach (ESDA+SPPT) - OUTLIERS





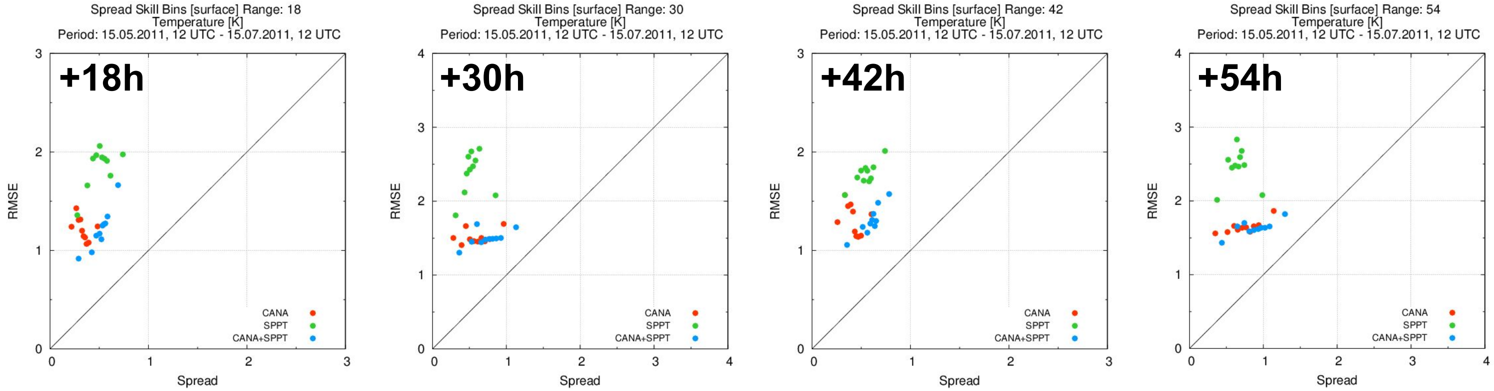


ESDA+SPPT
ESDA
SPPT

Time series (+6h forecast) for 62 days of validation period for a) temperature, b) relative humidity and c) wind speed.

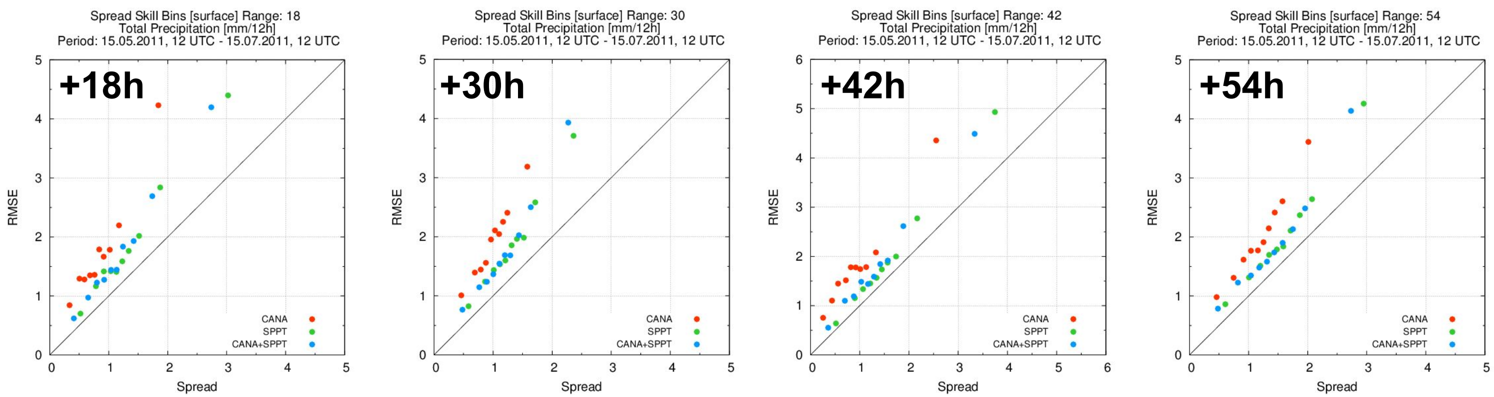
Combined approach (ESDA+SPPT) - SPREAD-SKILL

Temperature (2m)



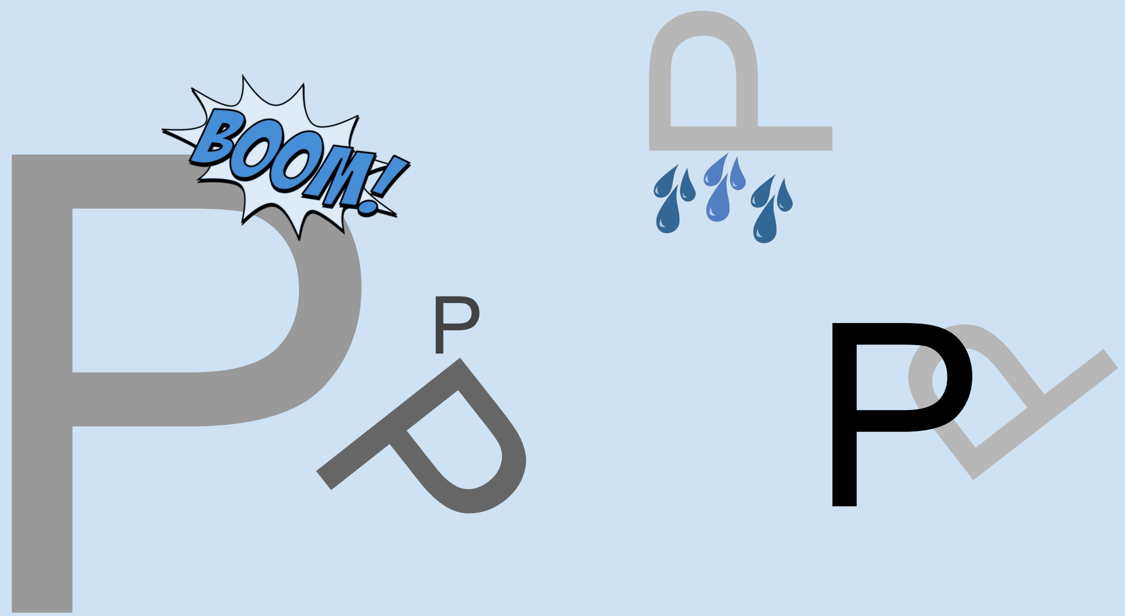
ESDA+SPPT
ESDA
SPPT

Precipitation (12h accumulated)



Known issues

- Drying effect (supersaturation adjustment)
- Instability (tapering function)
- Spectral pattern generator (new SPG)

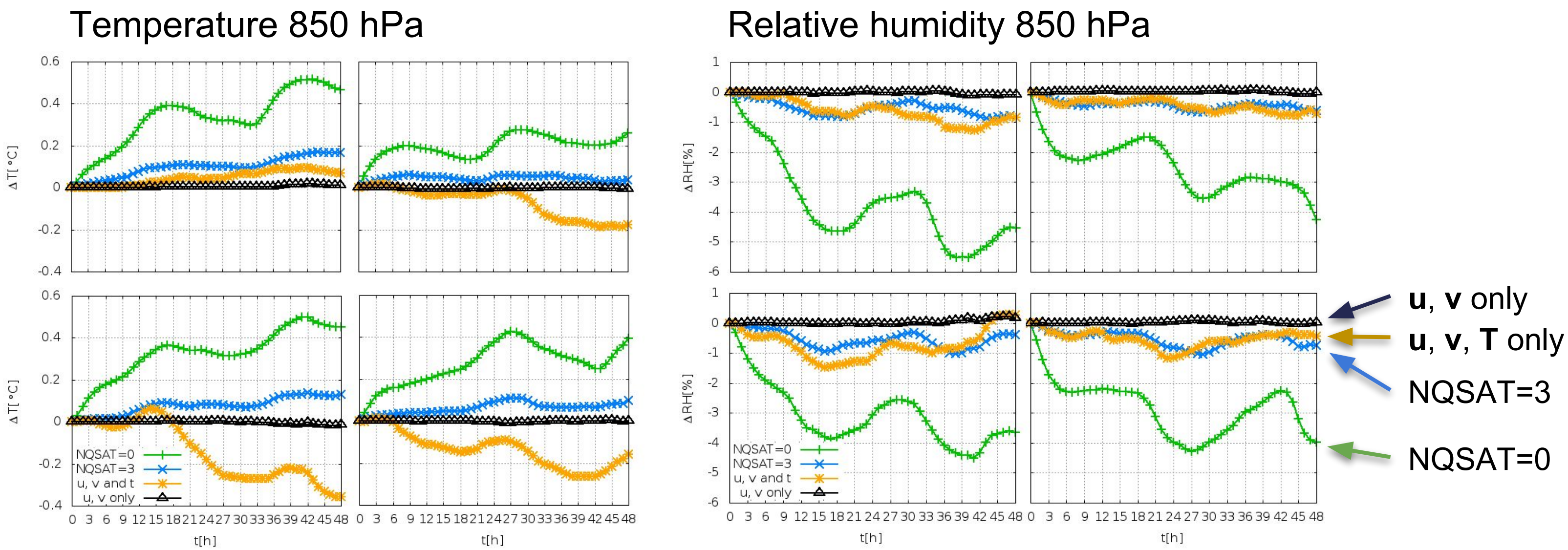


Known issues (drying effect)

When SPPT is applied, there is a chance that the perturbations will push model humidity over the critical level - i.e. oversaturation can be reached. This can be avoided by supersaturation check.

- NQSAT=0 (no perturbations are applied when it would lead to the oversaturation)
- NQSAT=3 (perturbations are scaled down in order to stay just below the saturation)

Both methods cut down many positive humidity perturbations while the negative ones are kept. This clearly leads to the **moisture dissipation in the model (drying effect)**.



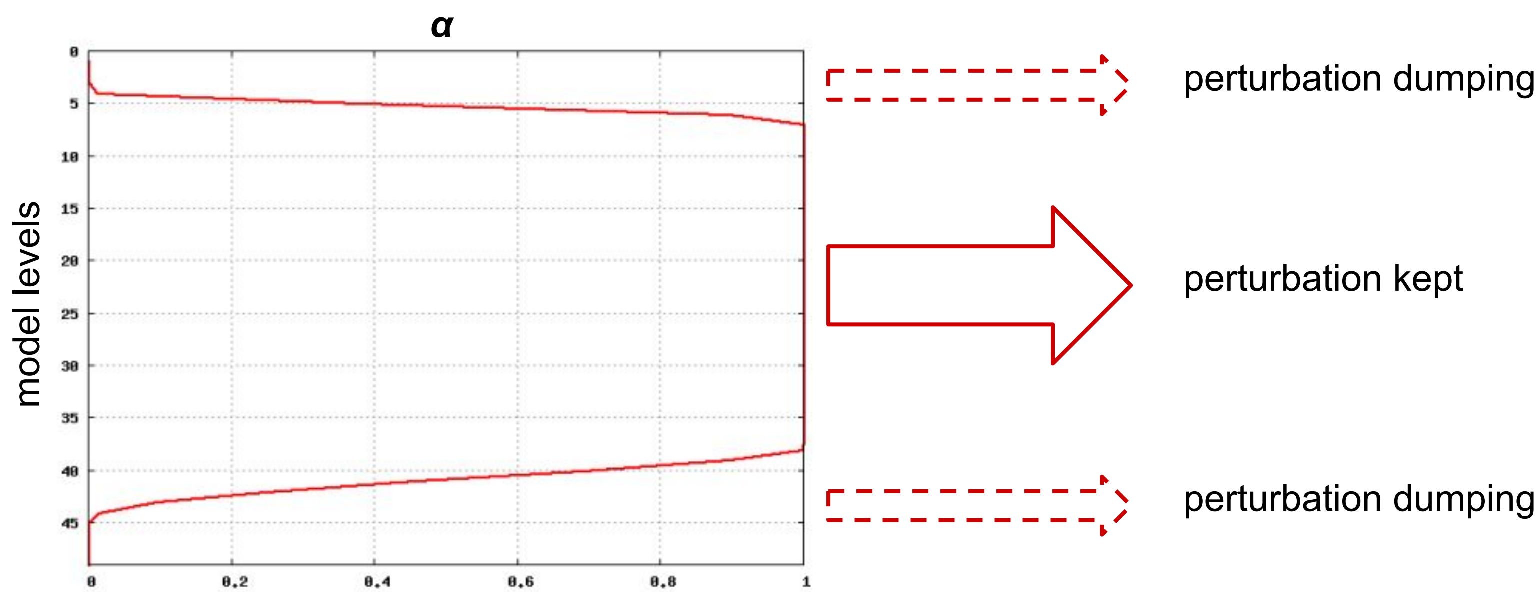
Temperature (left) and relative humidity (right) differences between the experiment with SPPT (8 members) and reference deterministic run at 850 hPa for 4 independent cases.

Known issues (instability)

When SPPT is applied along the whole vertical column, the model instability can be observed in some situations due to unrealistic vertical gradients at the boundaries. This can be eliminated by pushing the perturbations towards zero near the surface and model top.

- Tapering function $P'_{j\,(ej,t)} = (1+\alpha r_j) * P_{j\,(ej,t)}$

It is not yet clear, how to combine this approach with the surface stochastic physics. According the experiments there is a chance, that tapering won't be necessary with the new spectral pattern generator (SPG) and/or within the new approach when partial tendencies from individual parameterizations are perturbed instead of total physics tendencies.

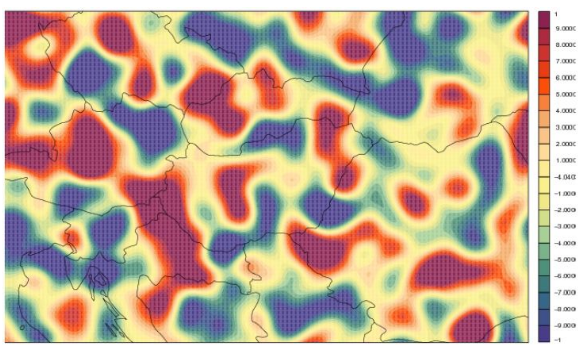


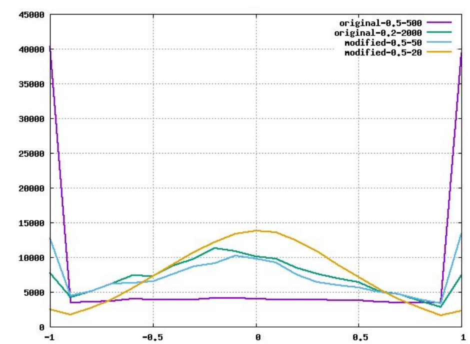
Known issues (spectral pattern generator)

The original pattern generator has some known disadvantages (it was developed for global model).

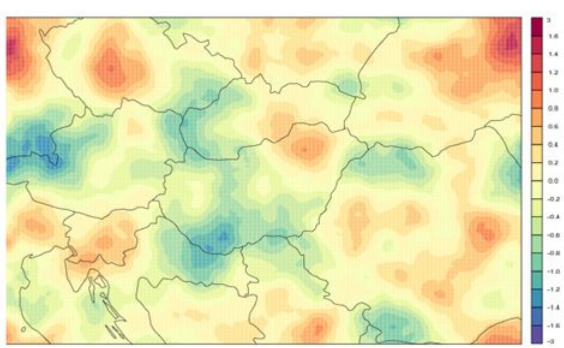
- All spatial scales have the same time correlation
- Statistical distribution of RND on LAM domain is not Gaussian

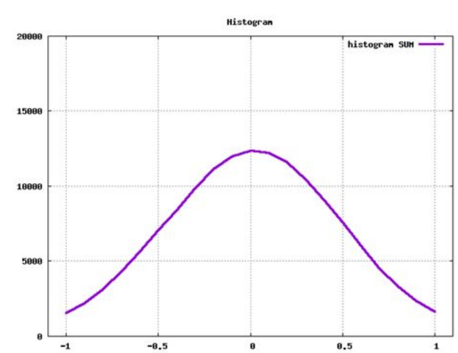
New SPG allows model errors to be represented at various scales. Pattern features are correctly tunable by the namelist values and statistical distribution of RND numbers corresponds to the Gaussian distribution (it was developed for LAM by Tsyrulnikov and Gayfulin, implemented by Mihaly).





original SPG





new SPG

Thank you for your attention!