Zentralanstalt für Meteorologie und Geodynamik

Emerging technologies in the numerical forecasting: regional ensemble prediction and nowcasting

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With contribution of many colleagues from ZAMG, LACE, ALADIN…

Outline

- Regional ensemble prediction

  ALADIN-LAEF (Limited Area Ensemble Forecasting)

- Nowcasting

  INCA (Integrated Nowcasting through Comprehensive Analysis)

- Summary

Regional ensemble prediction

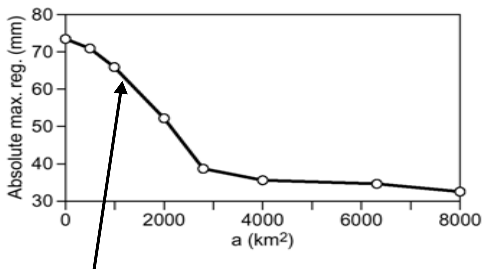
Atmosphere: chaotic and highly non-linear nature

Small errors in analysis, model physics can grow rapidly
and become large, even in a matter of hours.

Global EPS: lower resolution. medium range

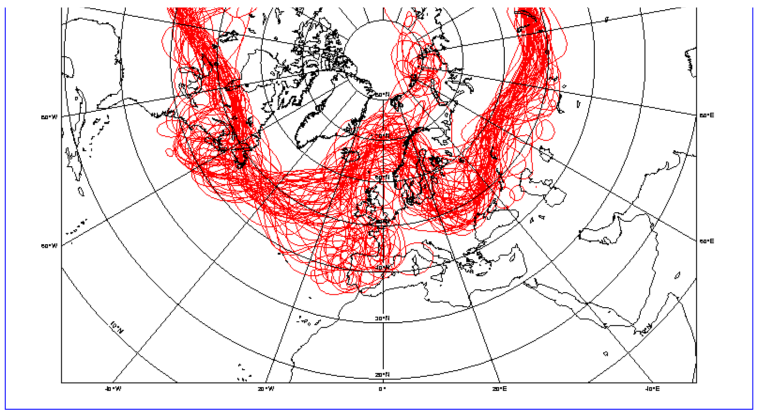
Global NWP models cannot predict extremes of precipitation: need for coupling to LAMs

Extreme rainfall as a function of spatial scale (observational study: Olsson et al, 1999)



EPS cannot resolve circulation features in this range (cf lack of $k^{-5/3}$ spectrum in model)

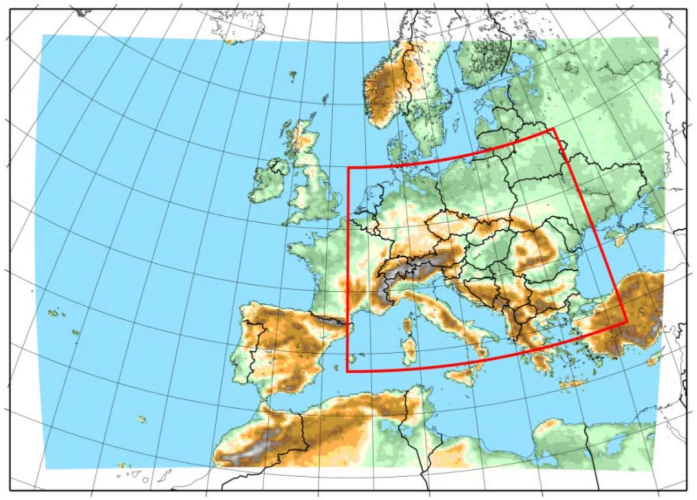
Forecast spread for Wed 13 May 2009



ALADIN-LAEF: Limited Area Ensemble Forecasting

Ensemble size	16+1
Horizontal resolution	18 km
Vertical resolution	37 levels
Runs/Day	2 (00, 12 UTC)
Forecast range	60h
Output-Frequency	1h
Model time step	720s
Coupling-Model	*ECMWF-EPS*
Coupling-Update	6h

ALADIN–LAEF Domain & Topography

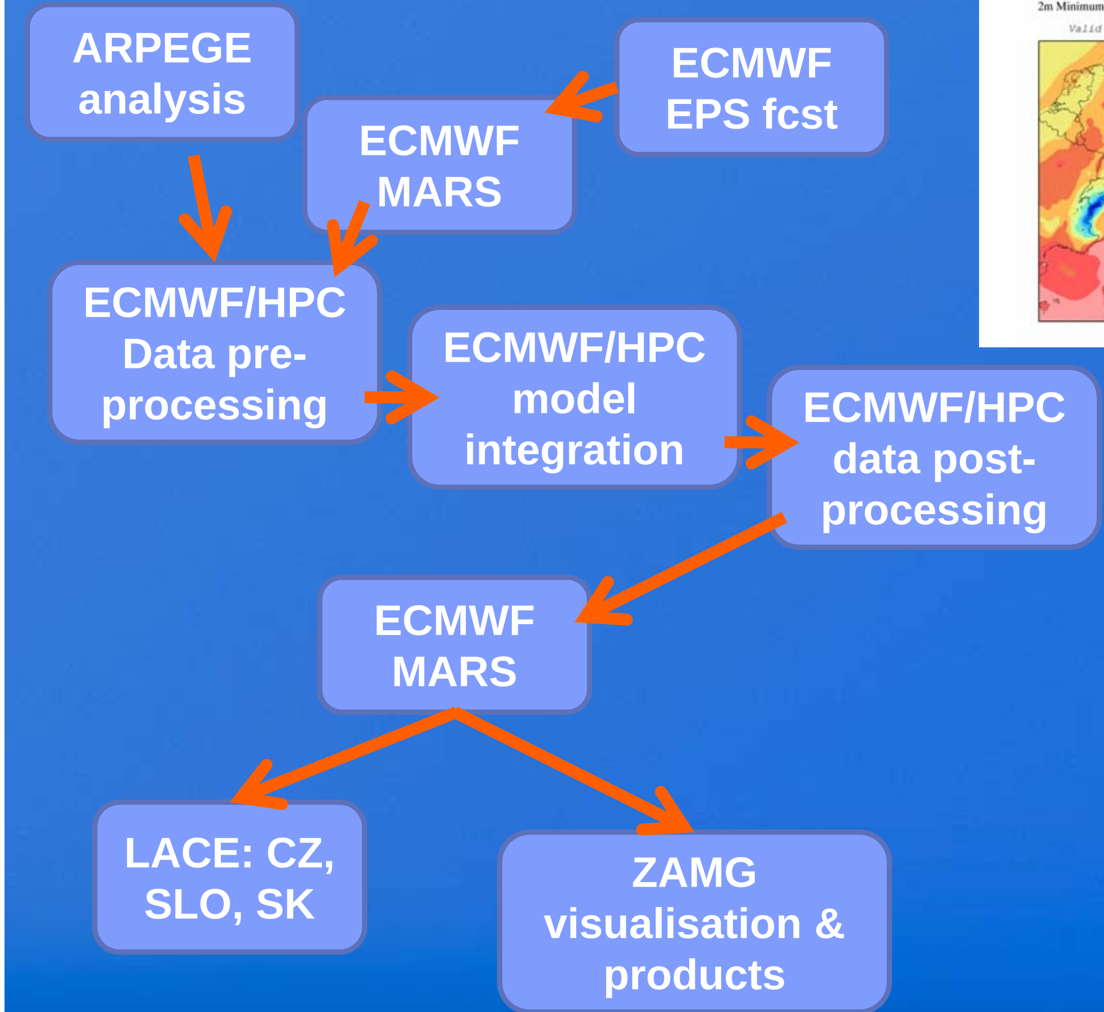


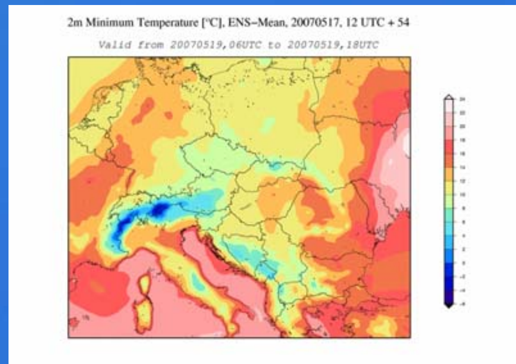
Atmosphere perturbation: **Blending ALADIN Bred + ECMWF EPS**

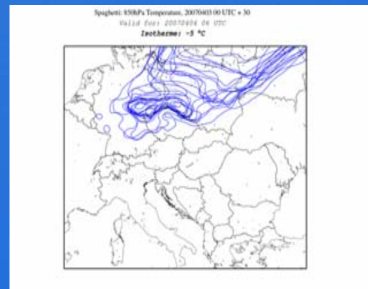
Surface perturbation: **Non-Cycling surface Breeding**

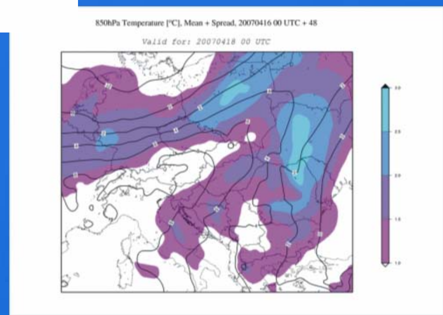
Model perturbation: **multi-physics**

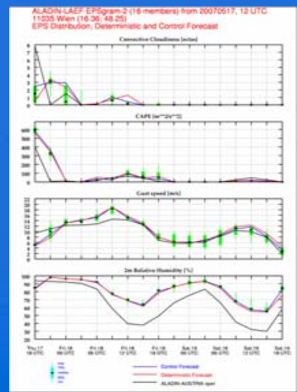
Operation at ECMWF, SMS suite, Time Critical Application II

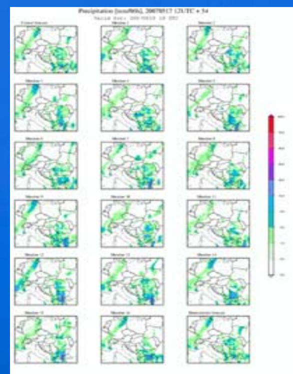




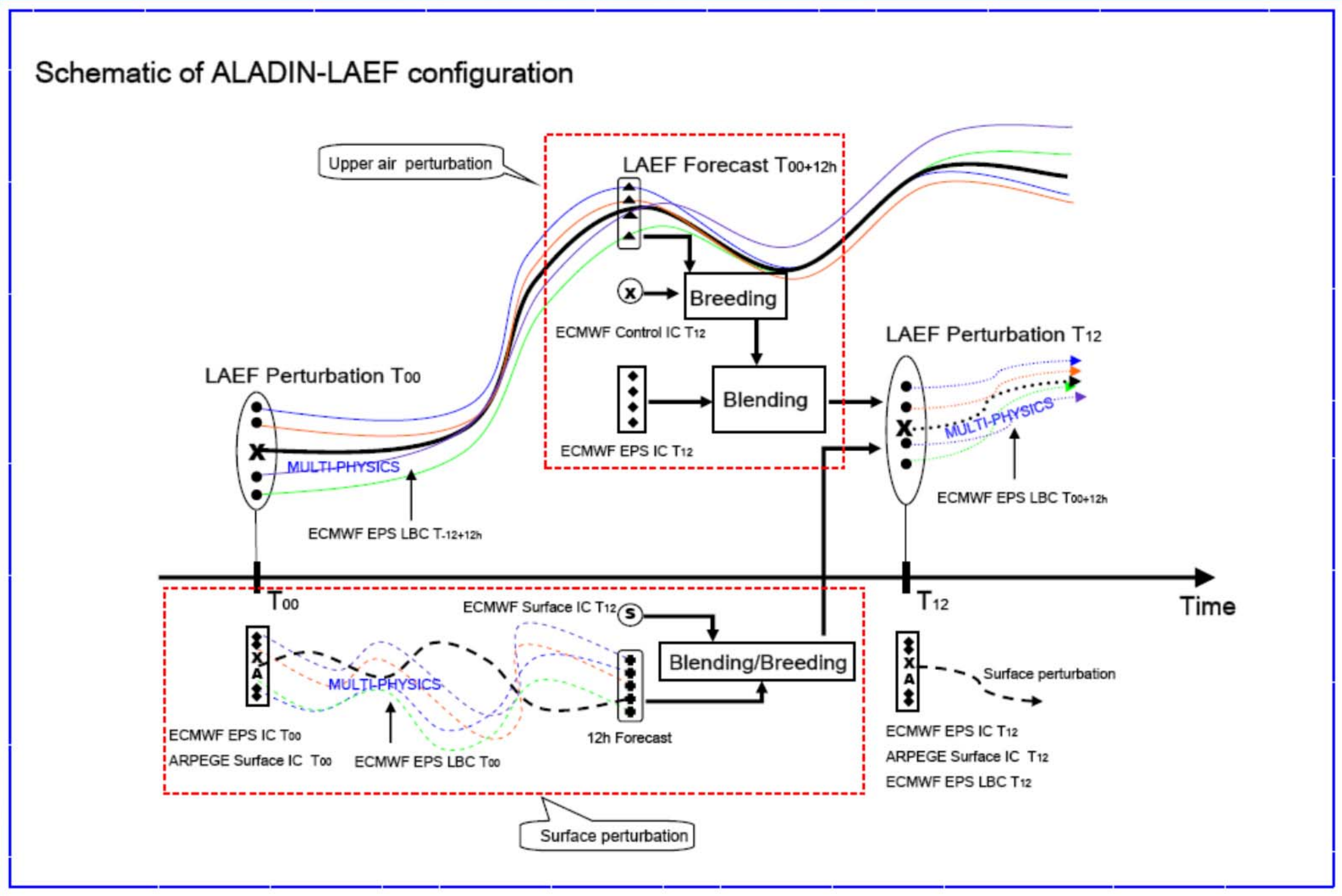




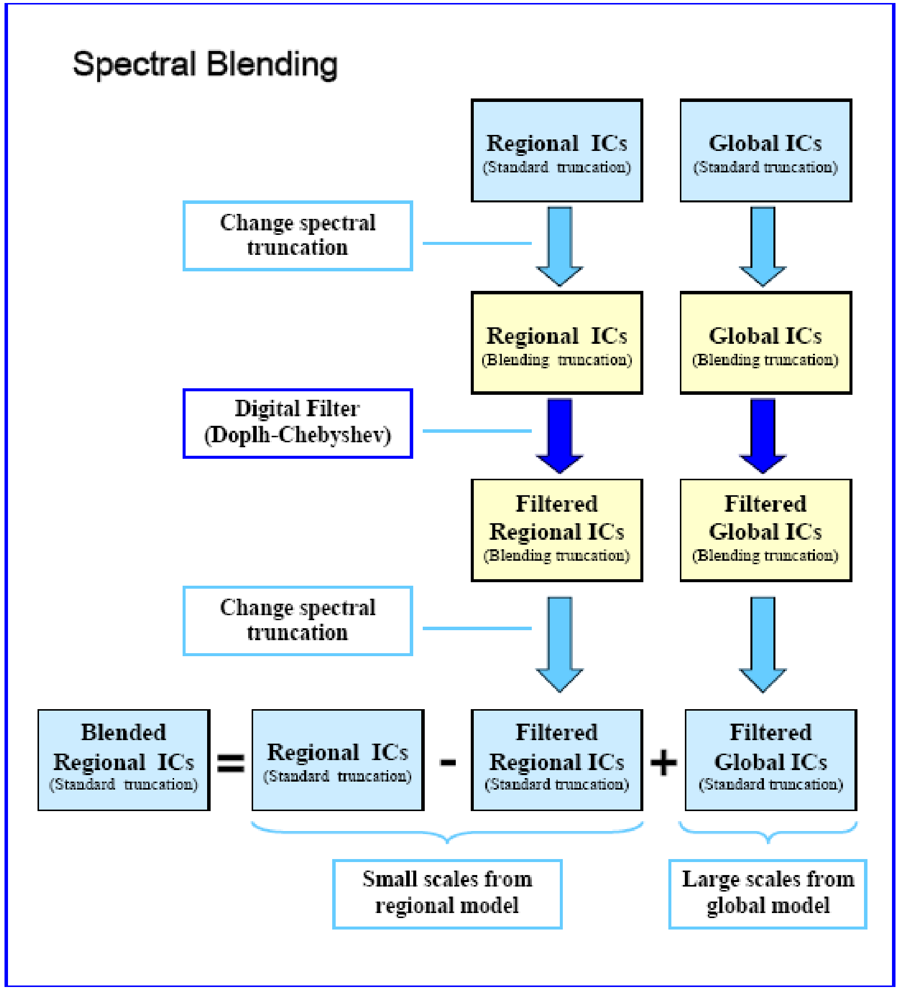




ALADIN-LAEF: design



Blending: Theory



The Blending method

Following the idea by Machenhauer and Haugen (1987) and considering perturbed variable *G* from global ensemble, and *R* from regional ensemble, both *G* and *R* are valid at the resolution of regional model, their full harmonic Fourier expansions are given by:

$$G(x) = \sum_{m=-M}^{M} G_m e^{2i\pi(mx/L_x)} \quad ; \quad R(x) = \sum_{m=-M}^{M} R_m e^{2i\pi(mx/L_x)} \qquad (1)$$

where *M* is the maximum wave numbers, and L_x is the horizontal wavelengths in *x* direction. Let *J* be the number of grid-points of the whole regional domain along the *x* direction , the inverse truncated Fourier transform, i.e. the spectral coefficients G_m and R_m are obtained by:

$$G_m = \frac{1}{J}\sum_{j=0}^{J-1} G(j) e^{-2i\pi(jm/J)} \quad ; \quad R_m = \frac{1}{J}\sum_{j=0}^{J-1} R(j) e^{-2i\pi(jm/J)} \qquad (2)$$

As we mentioned above, the blending is applied on full grid-point resolution of the regional model but with a lower spectral resolution (we call it the blending truncation), which represents the scale resolved by the global data assimilation. We change the spectral truncation from the original resolution to the blending spectral resolution, For both *G* and *R*, their full harmonic Fourier expansions are given by:

$$G(x) = \sum_{m=-LM}^{LM} G_m^{LOW} e^{2i\pi(mx/L_x)} \quad ; \quad R(x) = \sum_{m=-LM}^{LM} R_m^{LOW} e^{2i\pi(mx/L_x)} \qquad (3)$$

where ***LM*** is the maximum wave numbers of the blending spectral truncation, the inverse truncated Fourier transform, i.e. the spectral coefficients G_m^{LOW} and R_m^{LOW} are obtained by:

$$G_m^{LOW} = \frac{1}{J}\sum_{j=0}^{J-1} G(j) e^{-2i\pi(jm/J)} \quad ; \quad R_m^{LOW} = \frac{1}{J}\sum_{j=0}^{J-1} R(j) e^{-2i\pi(jm/J)} \qquad (4)$$

The blending truncation is determined by the resolution of global analysis, i.e. the resolution of the data assimilation of the global model
regional model. The estimation of the blending spec
obtained as follows:

$$T_R^{cut} = \sqrt[3]{T_G^{a\,2} \times T_R^{f}}$$

Where T_G^a is the spectral truncation of the global data
equivalent truncation of global model corresponding t
model.

The maximum wave numbers of the blending spectral truncation is then calculated by:

$$LM = M \times (T_R^f / T_R^{cut}) \qquad (6)$$

The blending ratio T_R^f / T_R^{cut} should be larger than ratio between the average resolution of global model over the regional domain and the resolution of the regional model.

The scale selection in the blending is by employing the digital filter technique, which was originally used for the initialization of meteorological fields in NWP. Its detailed description can be found in Lynch and Huang (1992).

For any model state G_m^{LOW} and R_m^{LOW}, denoted in the following *as* f_n, known at $\{f_{-N}, \ldots, f_{-1}, f_0, f_1, \ldots, f_N\}$, it may be regarded as the Fourier coefficients of a function $F(\theta)$

$$F(\theta) = \sum_{n=-N}^{n=N} f_n \times e^{-in\theta} \qquad (7)$$

where θ is the *digital frequency*. The filtering of *f* could be conducted by multiplying $F(\theta)$ by a function $H(\theta)$:

$$H(\theta) = \begin{cases} 1 & if \quad |\theta| \le \theta_c \\ 0 & if \quad |\theta| \ge \theta_c \end{cases} \qquad (8)$$

θ_c is the *cutoff frequency*. In ALADIN digital filter initialization, the non-recursive Dolph-Chebyshev filter is applied (Lynch et al. 1997), which is given by

$$H(\theta) = \frac{T_{2N}[x_0 \cos(\theta/2)]}{T_{2N}(x_0)} \qquad (9)$$

h is specified by choosing a
nomials, which is defined as:

(10)

ls can be obtained from the

(11)

For the low-frequency range, $H(\theta)$ falls from 1 to $r=1/T_{2N}(x_0)$ as $|\theta|$ goes from 0 to θ_c, and for the high frequency range $\theta_c \le |\theta| \le \pi$, $H(\theta)$ oscillates within $\pm r$. Let f_n^* denote the low-frequency part of f_n, clearly:

$$H(\theta) \cdot F(\theta) = \sum_{n=-N}^{n=N} f_n^* e^{-in\theta} \qquad (12)$$

and

$$f_n^* = \sum_{k=-N}^{k=N} (H \cdot F)_k f_{n-k} = \sum_{k=-N}^{k=N} h_k f_{n-k} \qquad (13)$$

This is a non-recursive digital filter, since f_n^* depends on both past and future values of f_n , but not other outputs values (Lynch et al 1997). h_n is given by:

$$h_n = \frac{1}{2N+1}\left[1 + 2r\sum_{m=1}^{N} T_{2N}\left(x_0 \cos\frac{\theta_m}{2}\right)\cos m\theta_n\right] \qquad (14)$$

The solution of the model, integrated from $-t_N$ to t_N, is weighted averaged:

$$f^*(0) = \sum_{n=-N}^{N} h_n f_n \qquad (15)$$

so that at the end of the DFI a balanced initial state is achieved. In ALADIN DFI, the filter order N is determined by the time step ΔT based on blending truncation and the cut-off period T_s.

Suppose the results of DFI on G_m^{LOW} and R_m^{LOW} are G_m^{*LOW} and R_m^{*LOW}. We obtain the large scale part of the perturbed ICs of global and regional model by

$$G^{LSP}(x) = \sum_{m=-M}^{M} G_m^{*LOW} e^{2i\pi(mx/L_x)} \quad ; \quad R^{LSP}(x) = \sum_{m=-M}^{M} R_m^{*LOW} e^{2i\pi(mx/L_x)} \qquad (16)$$

The symbolic equation of Blending can be summarized after Brožková *et al.* (2006) and Derkova and Bellus (2007):

$$IC_{blend} = \underbrace{R - R^{lsp}}_{regional\ small\ scale} + \underbrace{G^{lsp}}_{global\ large\ scale} \qquad (17)$$

Where IC_{blend} denotes initial condition after blending. After the blending, the filed itself keeps the large scale from global assimilation, and small scale from regional model, but it might be still noisey due to the pure interpolation, therefore an additional DF initialization with a narrow stop-band, could be applied to suppress the noise due to the interplolation.

Blending: feature

Blending global ECMWF EPS with LAEF Breeding

To combine the large-scale uncertainty from ECMWF EPS with the small-scale uncertainty generated by Breeding in LAEF.

LAEF Initial perturbations:

- The scale of the LAEF perturbation is in accordance with the scales of variability resolved by the model.
- The LAEF perturbations are consistent with the perturbation coming through the lateral boundary.
- The LAEF perturbations are effective immediately from the initial time.

Met-office
NCEP
NCAR

ALADIN-LAEF performance

What is the more added value of LAEF to its counterpart ECMWF EPS?

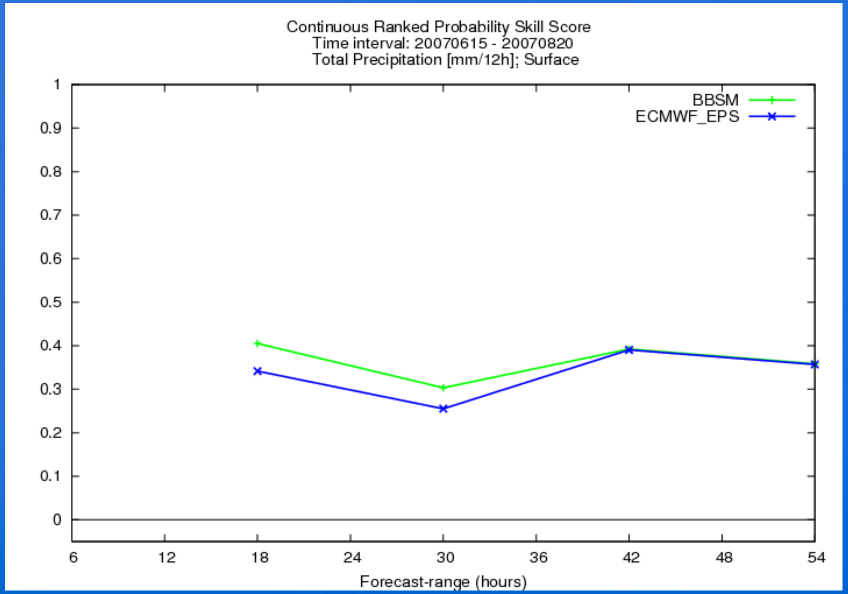
ECMWF EPS ⟷ LAEF

Is LAEF better than its existing high resolution deterministic ALADIN forecast?

ALADIN-Austria ⟷ LAEF

ALADIN-LAEF vs. ECMWF EPS

	ALADIN-LAEF	ECMWF-EPS
Resolution	18km; 37 Levels	T_L399; 62 Levels
Ens. Size	16	50
Model	ALADIN	ECMWF-IFS

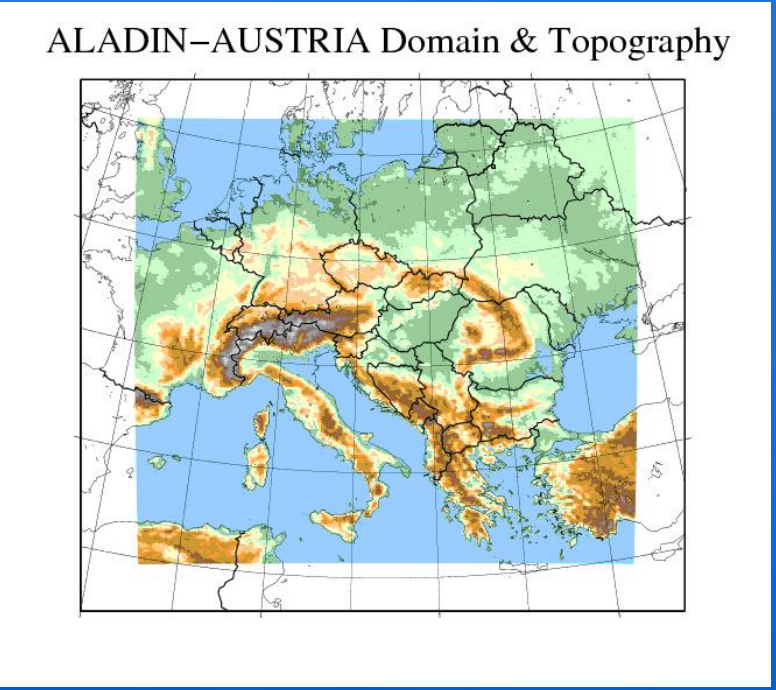


ALADIN-LAEF vs. ALADIN-Austria

Is ALADIN-LAEF adding value to its existing high resolution deterministic ALADIN forecast?

Horizontal resolution	9.6 km
Vertical resolution	60 Levels
Runs/day	00,06,12,18 UTC
Forecast range	72h / 60h
Output-Frequence	1h
Time step	415s
Coupling-Modell	ARPEGE
Coupling-Update	3h

ALADIN-Austria: deterministic



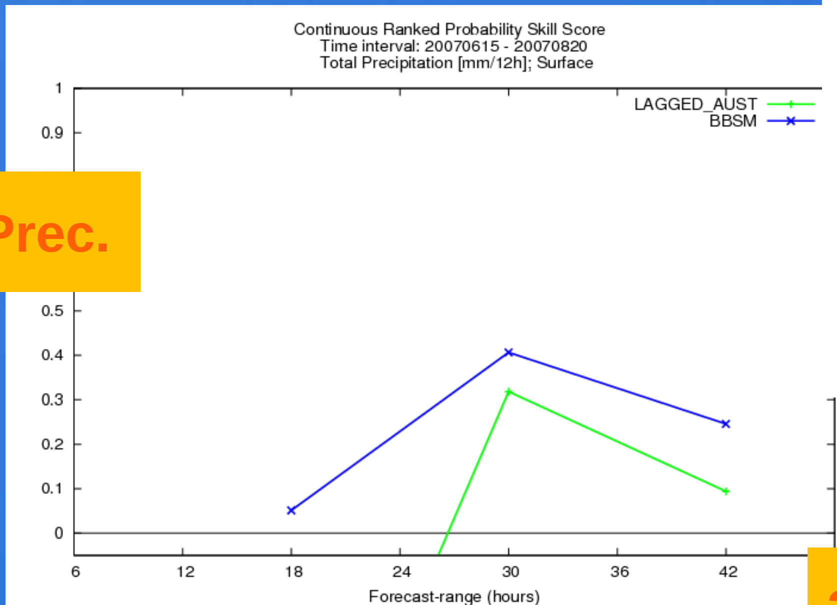
ALADIN-LAEF vs. ALADIN-Austria

	ALADIN-LAEF	ALADIN-AUSTRIA
Resolution	18km;37Levels	9.6km;60 Levels
Ensemble size	16 members	5 members (time lagged)
Forecast	Ensemble mean	deterministic

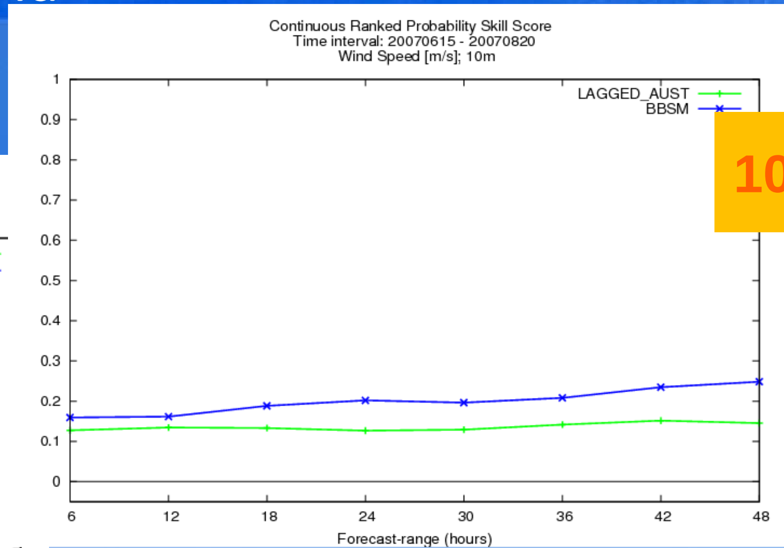
ALADIN-Austria: time lagged EPS

00 UTC:	00	06	12	18	24	30	36	42	48	54	60	66	72
06 UTC:		00	06	12	18	24	30	36	42	48	54	60	66
12 UTC:			00	06	12	18	24	30	36	42	48	54	60
18 UTC:				00	06	12	18	24	30	36	42	48	54
00 UTC:					00	06	12	18	24	30	36	42	48

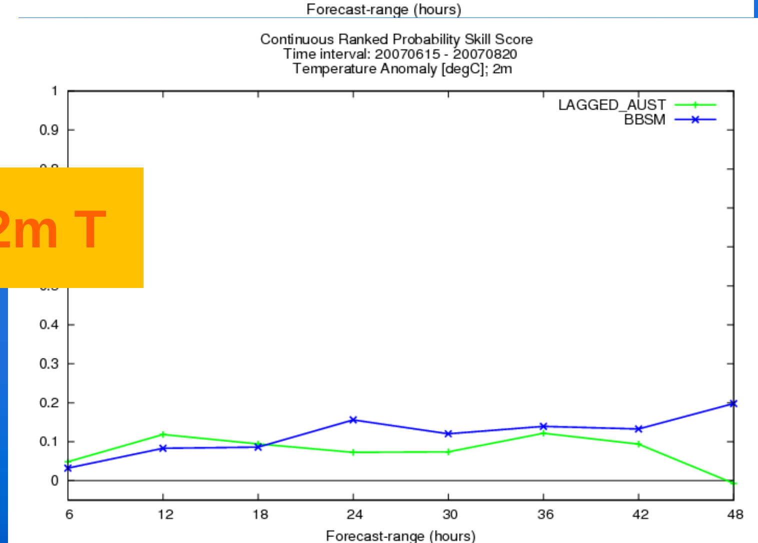
ALADIN-LAEF vs. ALADIN-Austria



Prec.



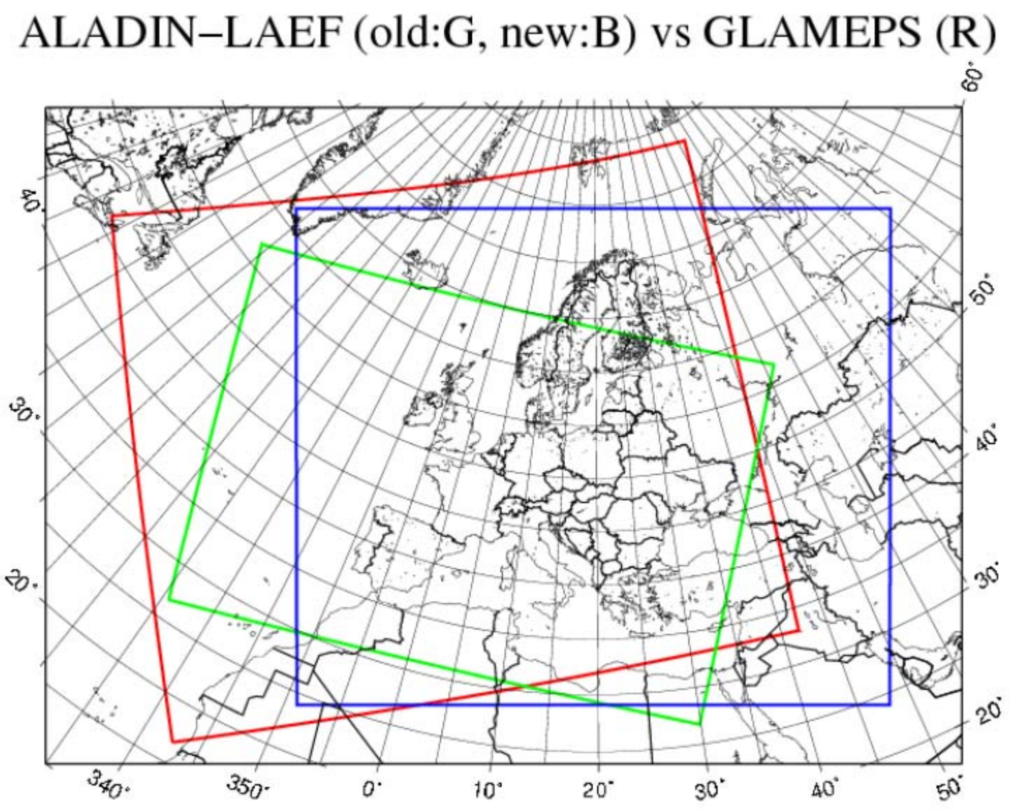
10m W



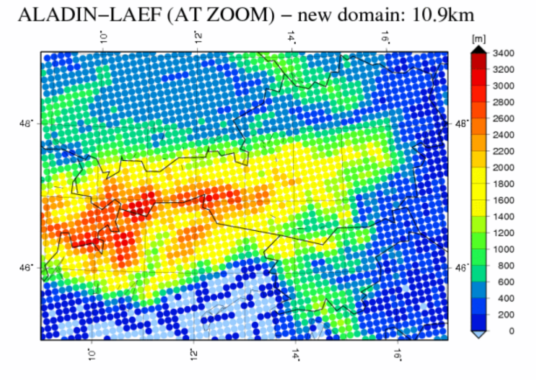
2m T

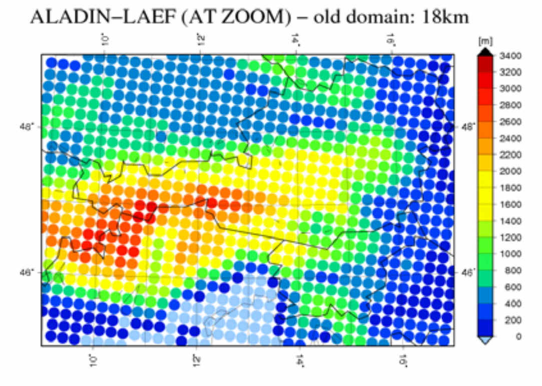
ALADIN-Austria as Reference

ALADIN-LAEF upgrade, cooperation with Turkey



::**Fig.01** Domain boundaries of the operational ALADIN-LAEF (green), new redefined ALADIN-LAEF (blue) and GLAMEPS (red).

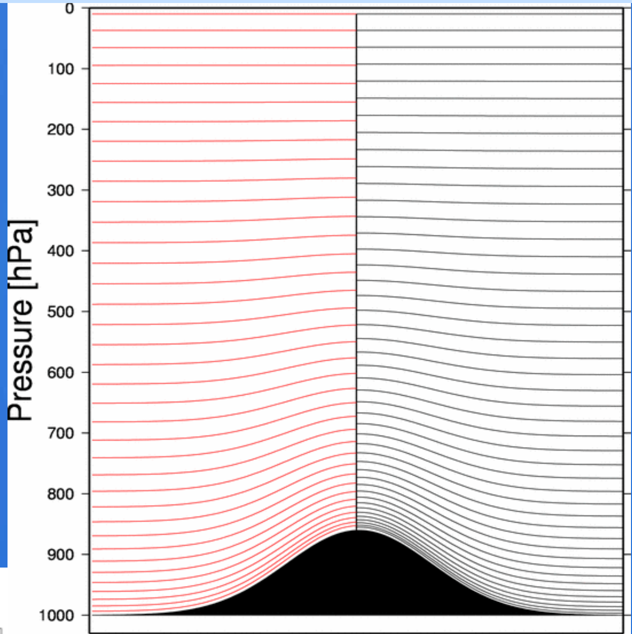


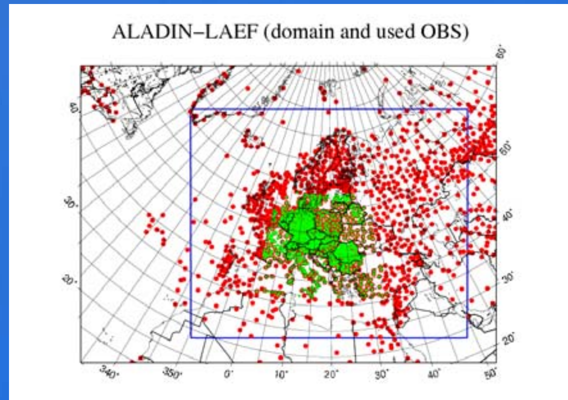


ALADIN-LAEF upgrade, cooperation with Turkey

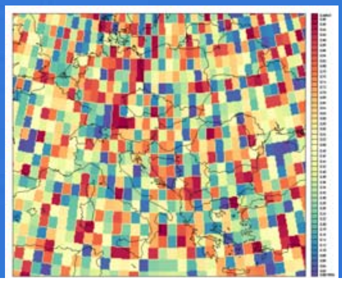
LAEF old vs. LAEF new

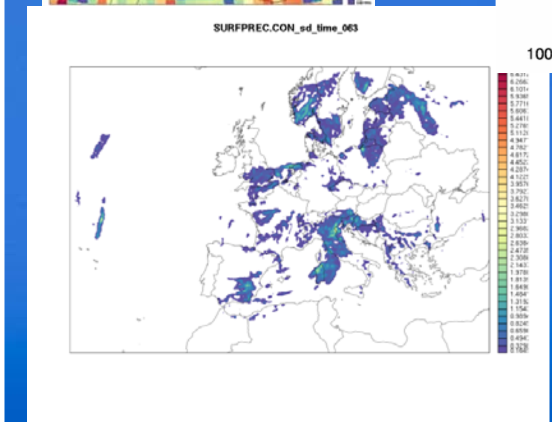
Higher resolution





Stochastic physics





Ensemble land surface assimilation

NAMELIST	MICROPHYSICS	TUNING	DEEP CONV.	TUNING	SHALLOW CONV.	TUNING	RADIATION	TUNING	TURBULENCE	TUNING	GUST DIAG.	TUNING	SCREENING LEVEL DIAG.	TUNING
MP01	ALARO-XR		3MT		JFG87		IFG05		JFG06		RAFTUR		NSCRED	
MP02	ALARO-XR	M3H	3MT	D2L, D3H	JFG87		JFG05	R1H, R3H, R4T	JFG06		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP03	ALARO-XR	M1L, M2L, M3L	3MT	D2H, D3L	JFG87		JFG05	R1L, R3L, R4T	JFG06		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP04	ALARO-XR	M3L	3MT	D3H, D3L	JFG87		JFG05	R1L, R3L, R4T	JFG06		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP05	ALARO-XR	M1H, M2H, M3L	3MT	D2H, D3L	JFG87		JFG05	R1L, R3L, R4T	JFG06		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP06	ALARO-SM		3MT		JFG87		JFG05	R4F	JFG06	T2H, T3L	RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP07	ALARO-SM		3MT	D5T	JFG87		JFG05	R4T	JFG06	T2L, T3H	RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP08	LOPEZ		BG		KFB		ECMWF		CBR		RAFTKE		NSCRED	
MP09	LOPEZ		BG	D1T	KFB		ECMWF		CBR		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP10	LOPEZ		BG		KFB		ECMWF		CBR		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
MP11	LOPEZ		BG	D1T	KFB	S1	ECMWF		CBR		RAFTUR/RAFTKE/RAFB		NSCRED/NSCREL/NSCR	
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Optimsied multi-physics

ALADIN-LAEF publications

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