Regional Cooperation for
Limited Area Modeling in Central Europe

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A-LAEF and TOUCANS 3D turbulence

Martin Belluš, Petra Smoliková, Mario Hrastinski, Maria Derková, et al. presented by Martina Tudor

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Outline

We use ACCORD system with canonical model configuration ALARO.

- Resolved turbulence kinetic energy calculation
- The turbulence scheme TOUCANS
- Across horizontal resolutions
- Available numerical horizontal diffusion
- Available features in TOUCANS: L3DTURB
- Conclusions

Resolved turbulence kinetic energy calculation

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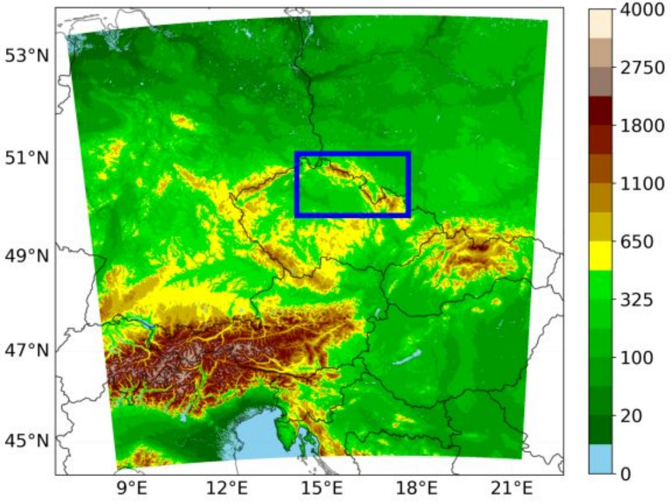
- principles of Reynolds averaging for u, v, w
- turbulence flow separated in slowly changing mean value and fast varying turbulent perturbation $x = \overline{x} + x'$
- the mean value is calculated for each grid point as moving time average over 15 minutes
- then perturbations are obtained by subtracting the mean from the total value
- $TKE = \frac{1}{2}\left(u'^2 + v'^2 + w'^2\right)$
- spatial averaged finally over the subdomain and over the time window of 2 hours, when a convective system passes the subdomain



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The turbulence scheme TOUCANS

(J.F.Geleyn, I.Bašták Ďurán et al.)

T - Third

O - Order moments

U - Unified

C - Condensation

A - Accounting and

N - N-dependent

S - Solver for turbulence and diffusion

The turbulence scheme TOUCANS

- uses two prognostic energies - TKE and TTE=TKE+TPE
- TPE is used only for a modification of the stability parameters
- the vertical turbulent fluxes are proportional to the local gradients of the diffused variables, but the stability parameters and the turbulent exchange coefficients are not strictly local anymore and have a prognostic character
- these characteristics enable the scheme to model both turbulence and clouds in the planetary boundary layer

Across horizontal resolutions

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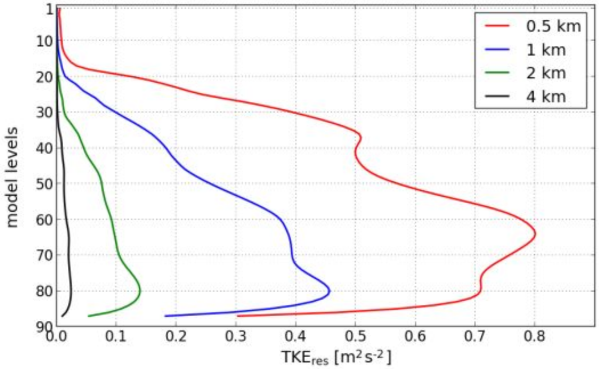
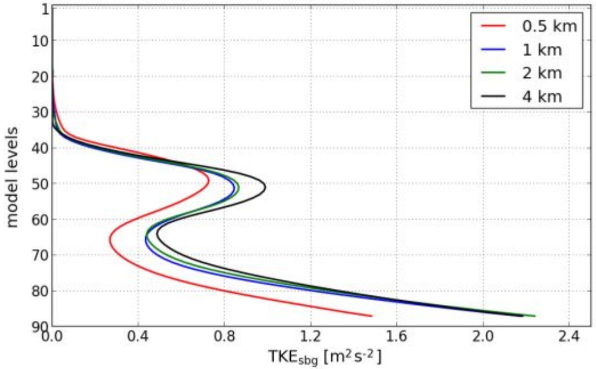
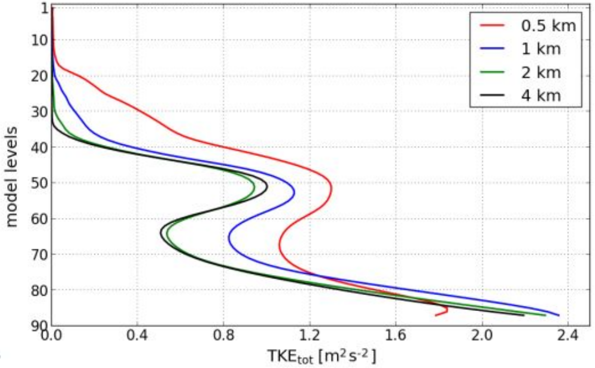
resolved TKE



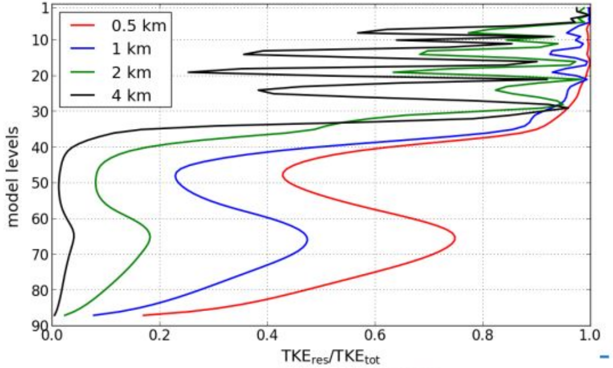
subgrid TKE



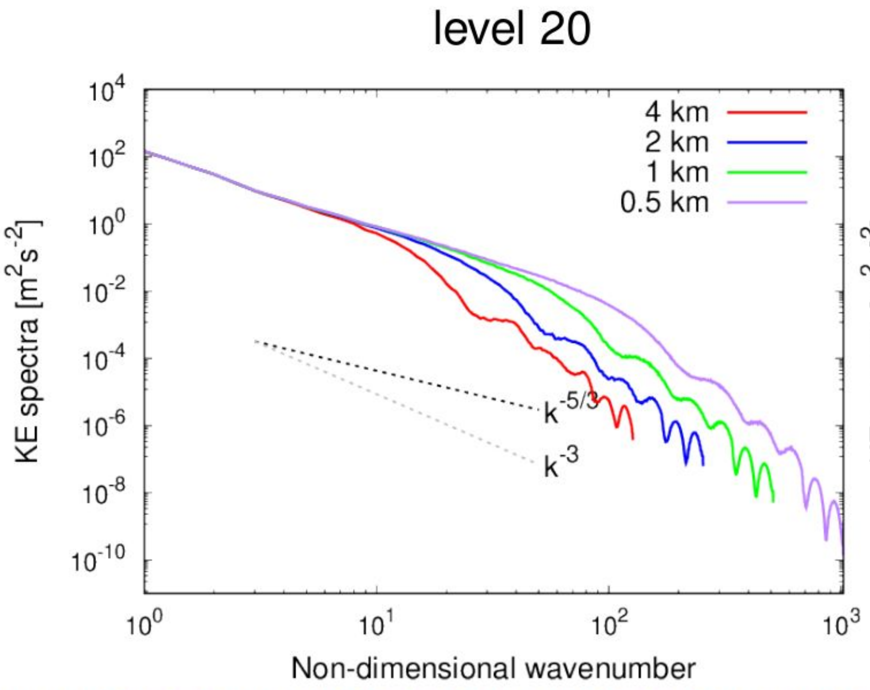
total TKE

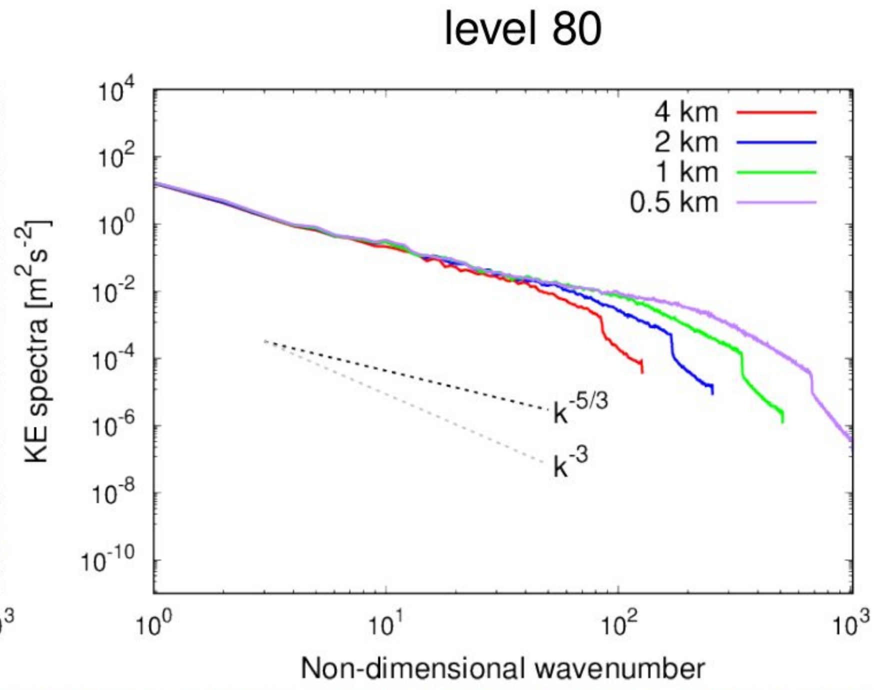


share of resolved/total TKE



Kinetic energy spectra at 15 UTC 21 June 2018





Available numerical horizontal diffusion

- Spectral diffusion on model variables $u, v, d, T, ln(p/\pi)$
  - vertically dependent, stronger close to model top
- Semi-Lagrangian horizontal diffusion (SLHD, Váňa)
  - flow dependent
  - the strength evaluated in each grid point
  - applicable on all advected fields (model variables, TKE, TTE, hydrometeors etc.)
  - needs two kind of supporting spectral diffusions (one applied close to he model top and the second scale selective to remove noise from the orographic adjustment)
  - inner parameters tuning is cumbersome, but it seems to work well across horizontal resolutions

Tuning parameters of SLHD

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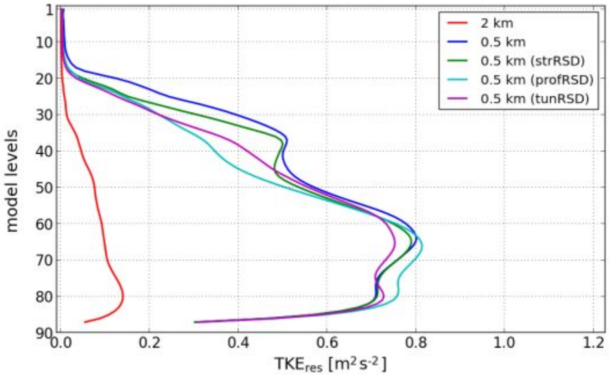
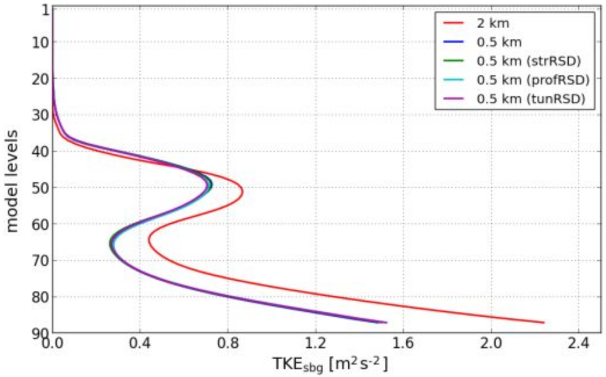
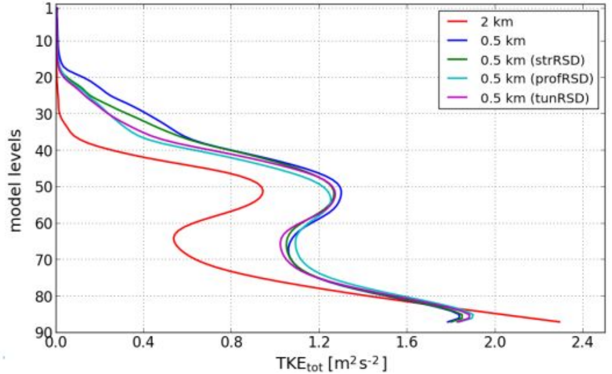
resolved TKE



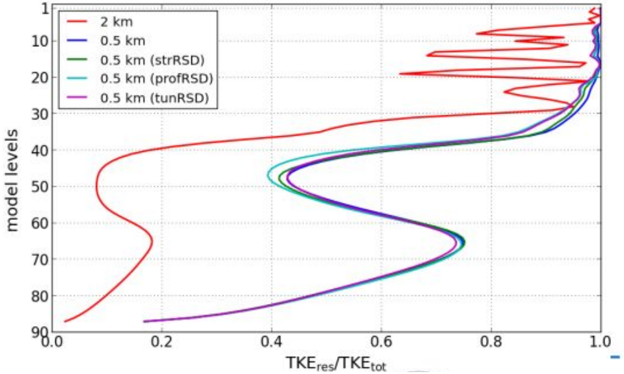
subgrid TKE



total TKE



share of resolved/total TKE



TKE with parameterizations and numerical diffusion

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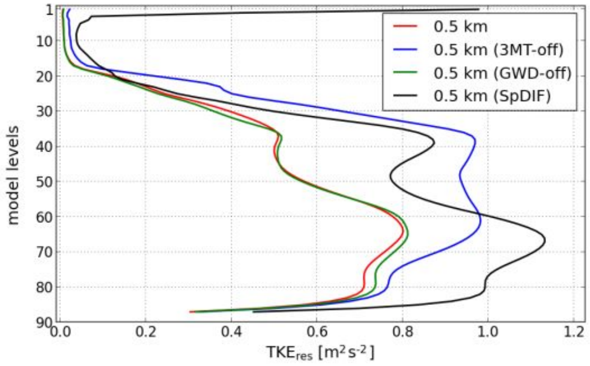
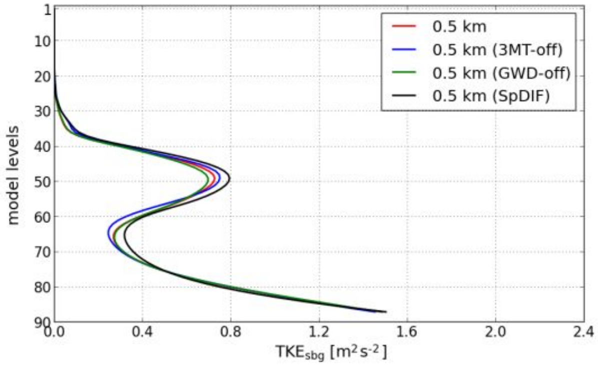
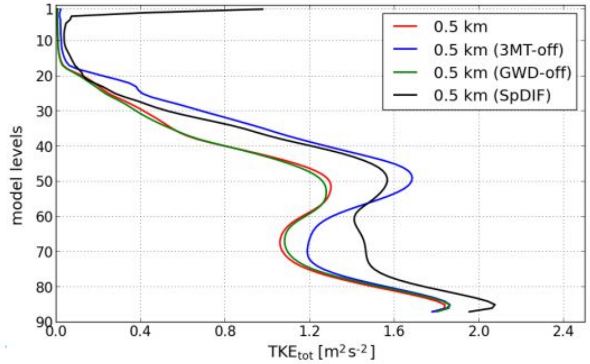
resolved TKE



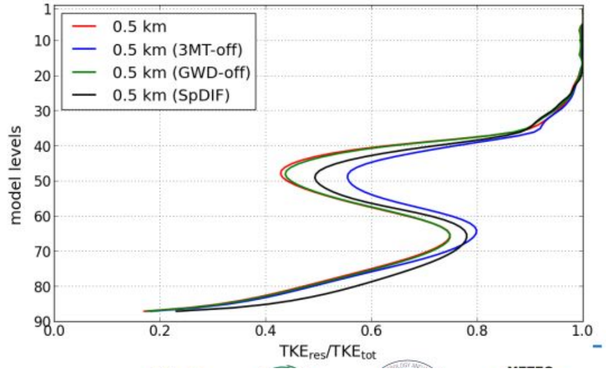
subgrid TKE



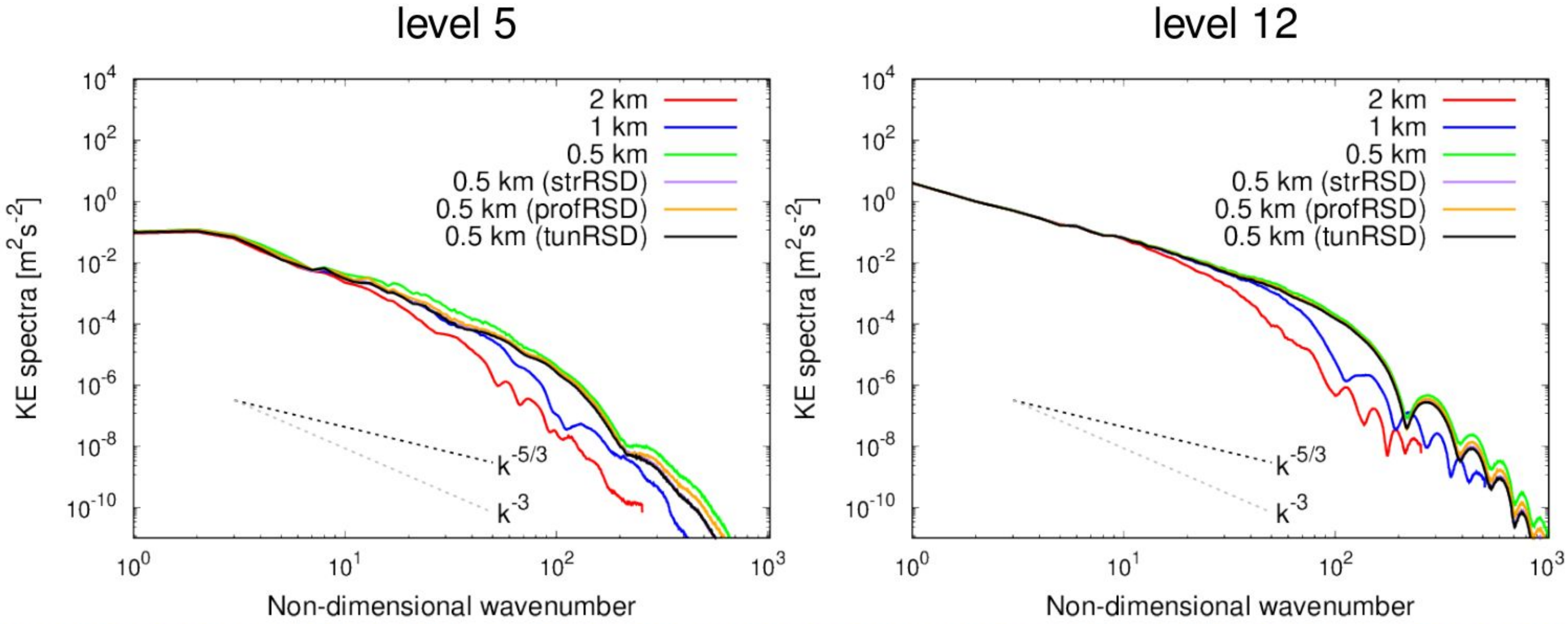
total TKE



share of resolved/total TKE



Kinetic energy spectra at 15 UTC 21 June 2018



Available features in TOUCANS: L3DTURB

L3DTURB is an available feature of the dynamical core of ACCORD based on the semi-Lagrangian halo for horizontal derivatives estimation and on TOUCANS for horizontal stability dependency functions evaluation. It was implemented by Filip Váňa and Ivan Bašták Ďurán.

Horizontal second order diffusion of the shape

$$\frac{dV}{dt} = -K_M^{hor}\frac{\partial^2 V}{\partial x^2} - K_M^{hor}\frac{\partial^2 V}{\partial y^2} + \dots$$

$$\frac{dT}{dt} = -K_H^{hor}\frac{\partial^2 T}{\partial x^2} - K_H^{hor}\frac{\partial^2 T}{\partial y^2} + \dots$$

where it is assumed that

$$\frac{\partial K_{M/H}^{hor}}{\partial x} + \frac{\partial K_{M/H}^{hor}}{\partial y} = 0$$

Available features in TOUCANS: L3DTURB

$$K_M^{hor} = L_K^{hor} C_K \sqrt{e_k}\, \chi_3^{hor}(Ri)$$
$$K_H^{hor} = L_K^{hor} C_K \sqrt{e_k}\, \phi_3^{hor}(Ri)$$

with

K_M^{hor} ... horizontal diffusion coefficient for motion

K_H^{hor} ... horizontal diffusion coefficient for heat

$L_K^{hor} = min(L_K, \sqrt{\Delta x \cdot \Delta y})$ ... horizontal length scale

C_K ... closure constant

e_k ... subgrid turbulent kinetic energy

$\chi_3^{hor}(Ri)$ ... horizontal stability dependency function for motion

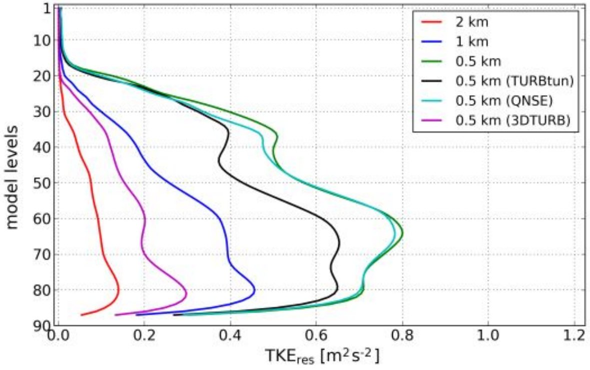
$\phi_3^{hor}(Ri)$ ... horizontal stability dependency function for heat

Available features in TOUCANS: L3DTURB

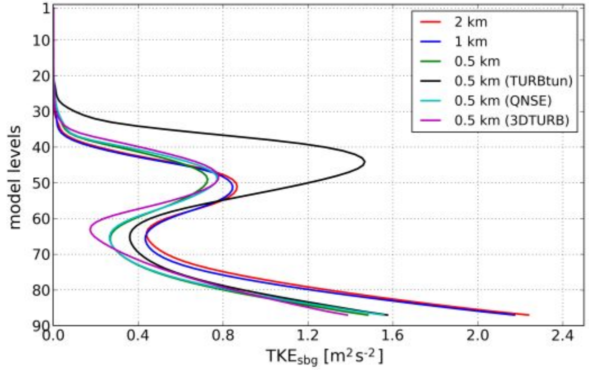
$\frac{\partial^2 \psi}{\partial x^2}$ and $\frac{\partial^2 \psi}{\partial y^2}$ are calculated throught weights in semi-Lagrangian scheme for model variables ψ

TOUCANS

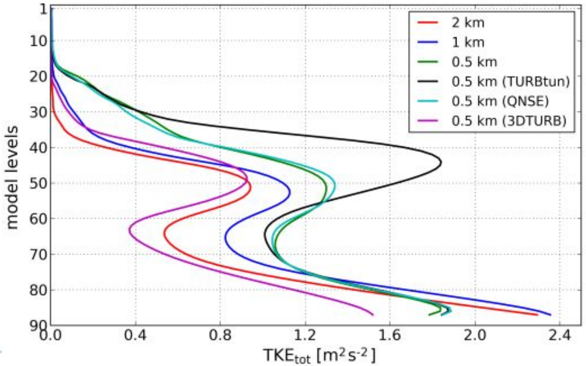
resolved TKE



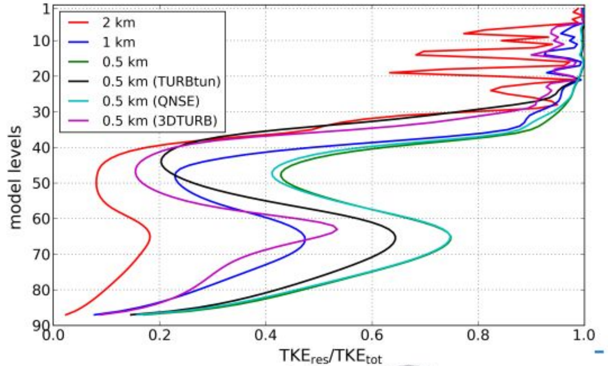
subgrid TKE



total TKE



share of resolved/total TKE



Outline

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- A-LAEF - ALARO limited area ensemble forecast
- System specs
  - **Domain, resolution frequency, etc**
  - **Perturbations**
  - **Examples of output (postprocessing)**
  - **Verification results agains deterministic**
- Examples of operational results
  - High impact precipitation cases
- Impact of change of IFS cycle

More cases

A-LAEF operational domain

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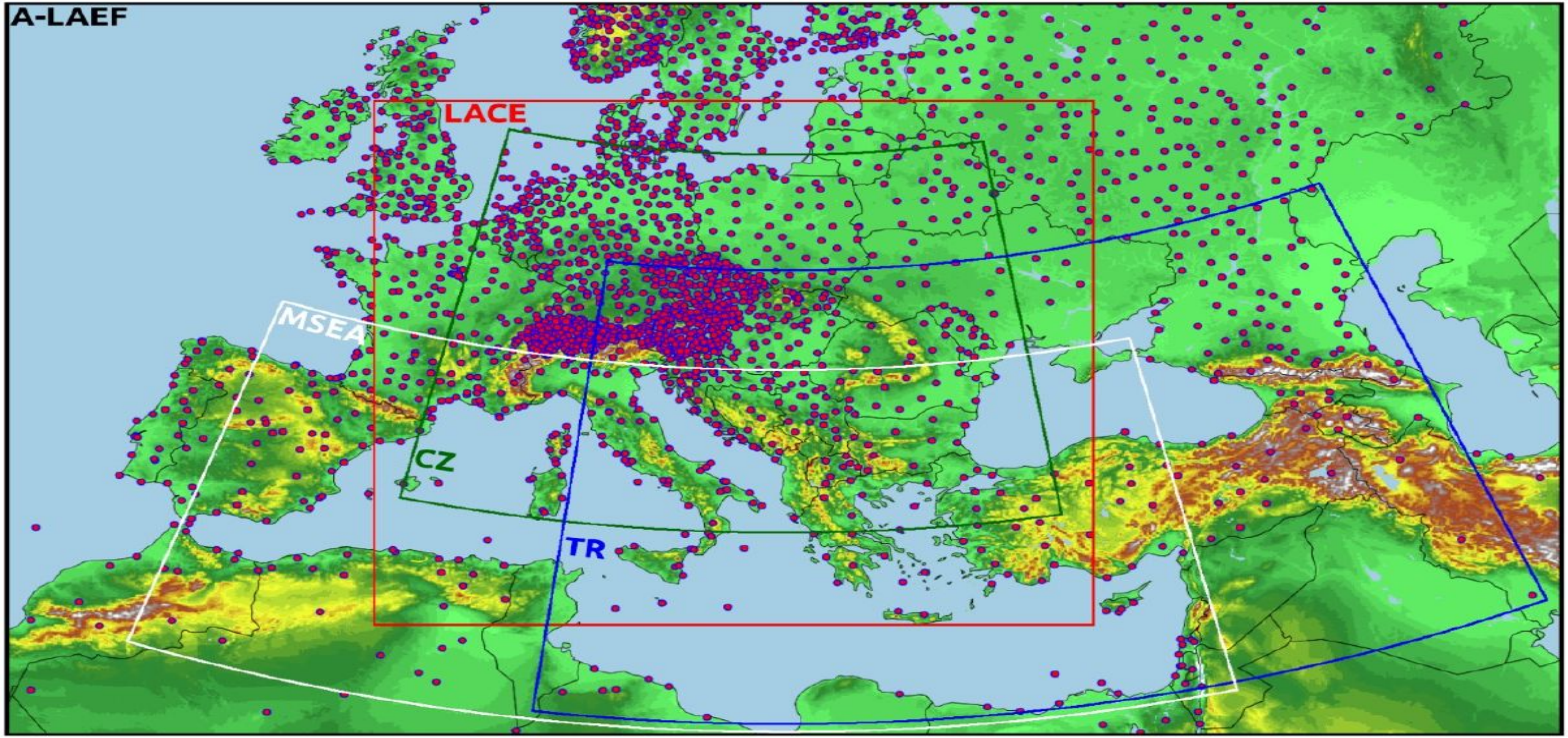

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A-LAEF operational specs

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Code version	cy40t1
Horizontal resolution	4.8 km
Vertical levels	60
Number of grid points	1250x750
Grid	Linear
Time step	180 seconds
Forecast length	72 hours (00/12 UTC)
Members	16+1
Initial condition perturbation	ESDA (surface) + spectral blending by digital filter initialisation (upper-air)
Model perturbation	ALARO-1 multi-physics (4 clusters) + surface stochastic physics (SPPT)
LBC perturbation	ECMWF ENS

TABLE 1 A-LAEF system specifications.

The A-LAEF system runs operationally on the High Performance Computer Facility (HPCF) at the European Centre for Medium-Range Weather Forecasts (ECMWF) twice a day with the integration starting at 00 and 12 UTC producing 72 hour forecasts. The ensemble consists of 1 unperturbed control run and 16 perturbed members involving initial condition uncertainty, model error simulation and coupled in lagged mode to perturbed lateral boundary conditions coming from the ECMWF EPS.

A-LAEF operational specs

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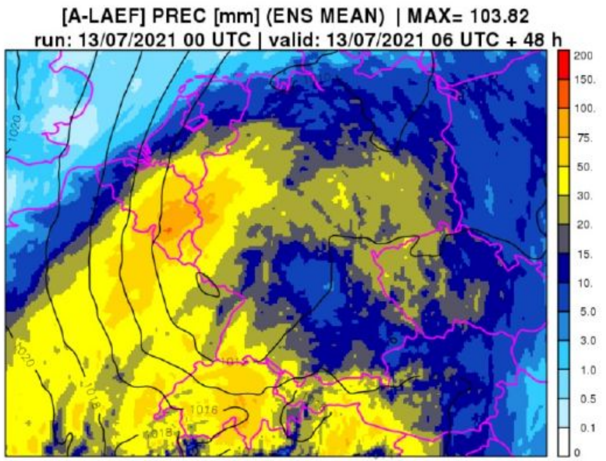
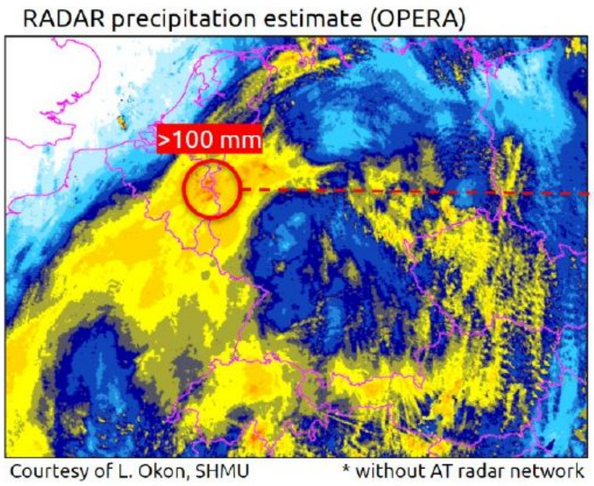
LBC perturbations: *coupled in lagged mode to perturbed lateral boundary conditions coming from the ECMWF EPS.*

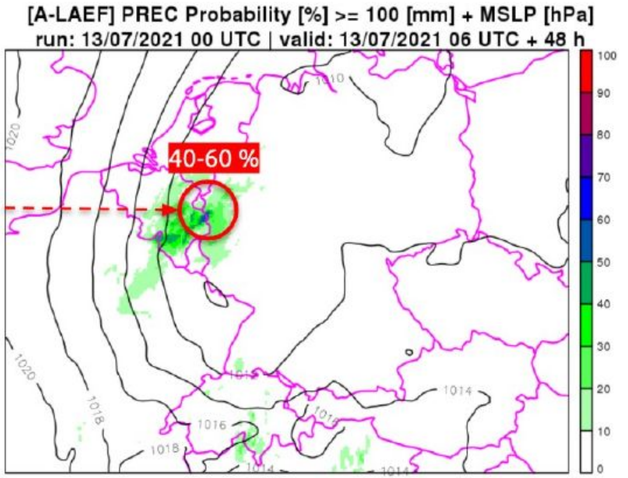
IC perturbations - surface: *The uncertainty of the initial conditions in A-LAEF is simulated by the ensemble of surface data assimilations (ESDA) (Belluš et al., 2016), where surface and soil prognostic fields are handled separately from the upper air. Each ensemble member has its own data assimilation cycle with randomly perturbed screen-level (near-surface) measurements of temperature and relative humidity.*

IC perturbations: upper air: *Uncertainty of the upper-air fields in the initial conditions is simulated by upper-air spectral blending by digital filter initialisation (Derková and Belluš, 2007; Wang et al., 2014). The spectral blending method allows a sophisticated combination of uncertainties for different scales. While large ones are well simulated by the driving EPS, small ones are natively resolved by the target mesoscale system. It also ensures consistency between the initial conditions and lateral boundary conditions (LBC).*

13th July 2021 flood Be/De/Ne







- The precipitation estimate by the OPERA radar network, the A-LAEF ensemble mean forecast starting at 00 UTC on 13 July 2021, and the A-LAEF forecast starting at the same time of the probability for a precipitation threshold of at least 100 mm, valid for the 48-hour accumulation period from 13 July 2021 until 15 July 2021 (06 to 06 UTC).

4th Oct 2021 EU record precipitation

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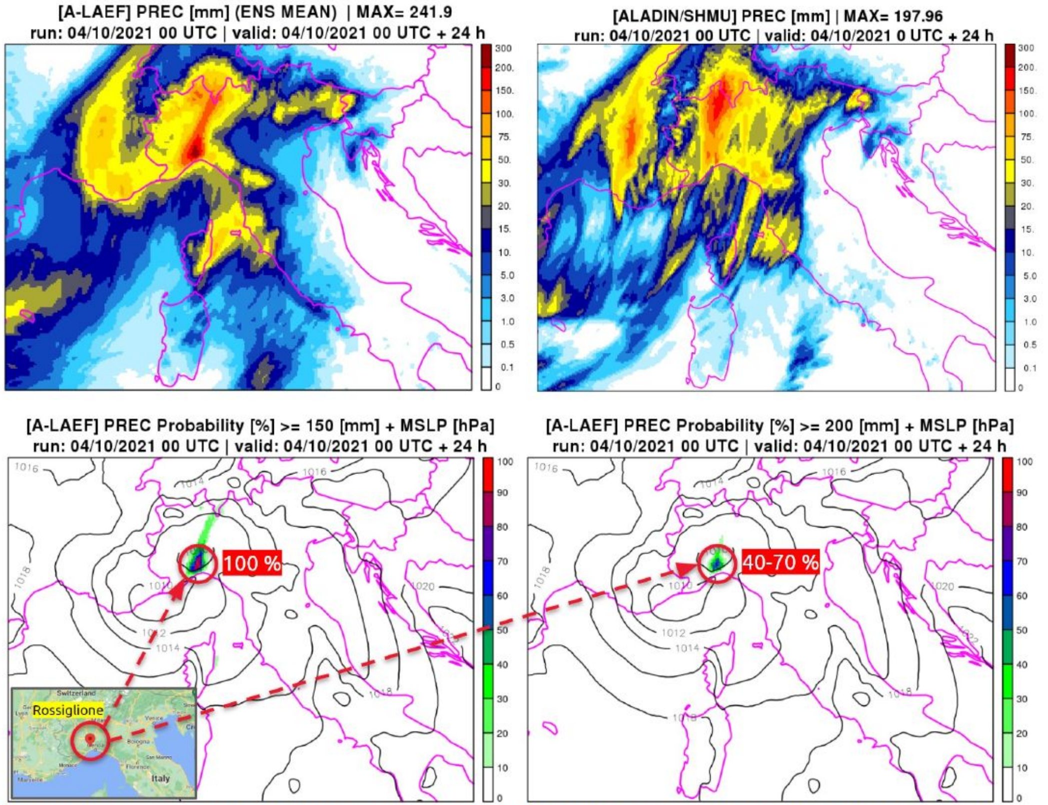
- 24 hr prec: the A-LAEF ensemble mean precipitation forecast, and the ALADIN/SHMU deterministic precipitation forecast, starting at 00 UTC on 4 October 2021
- The A-LAEF forecast of probability for a precipitation threshold of at least 150 mm, and at least 200 mm



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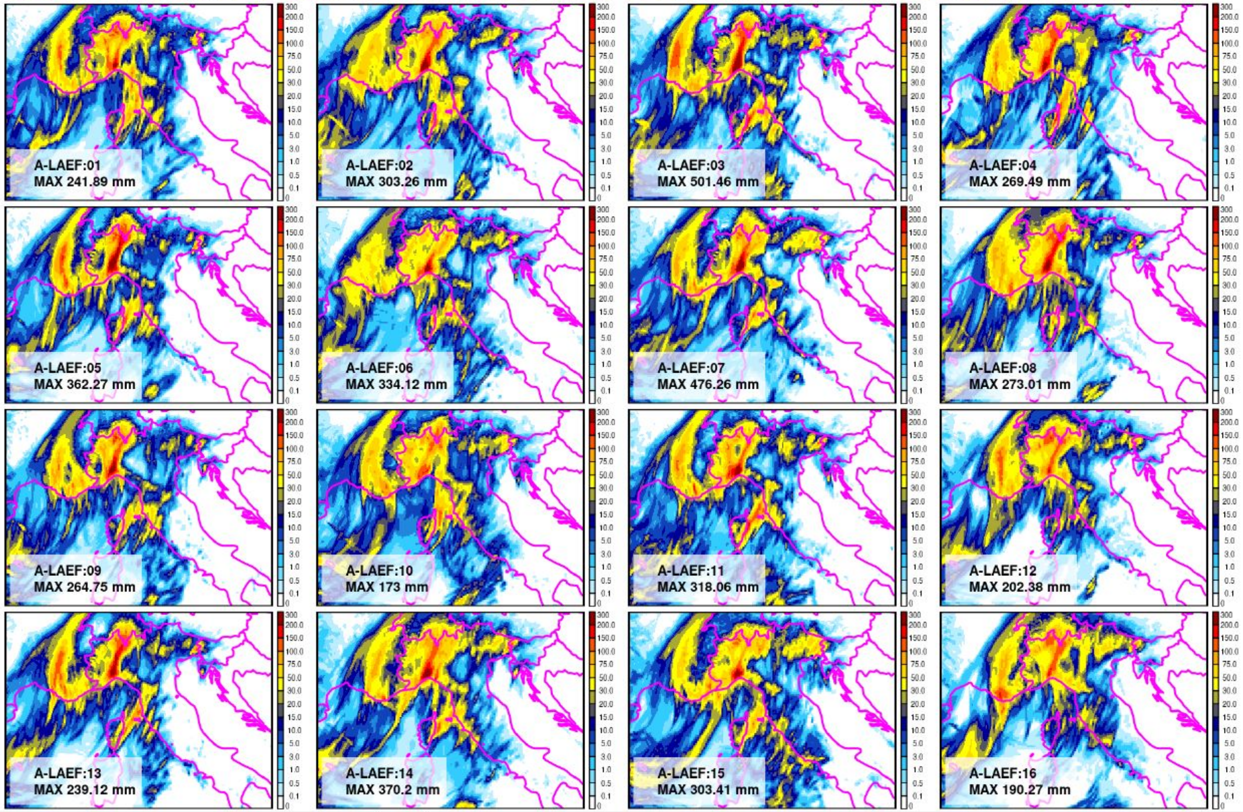
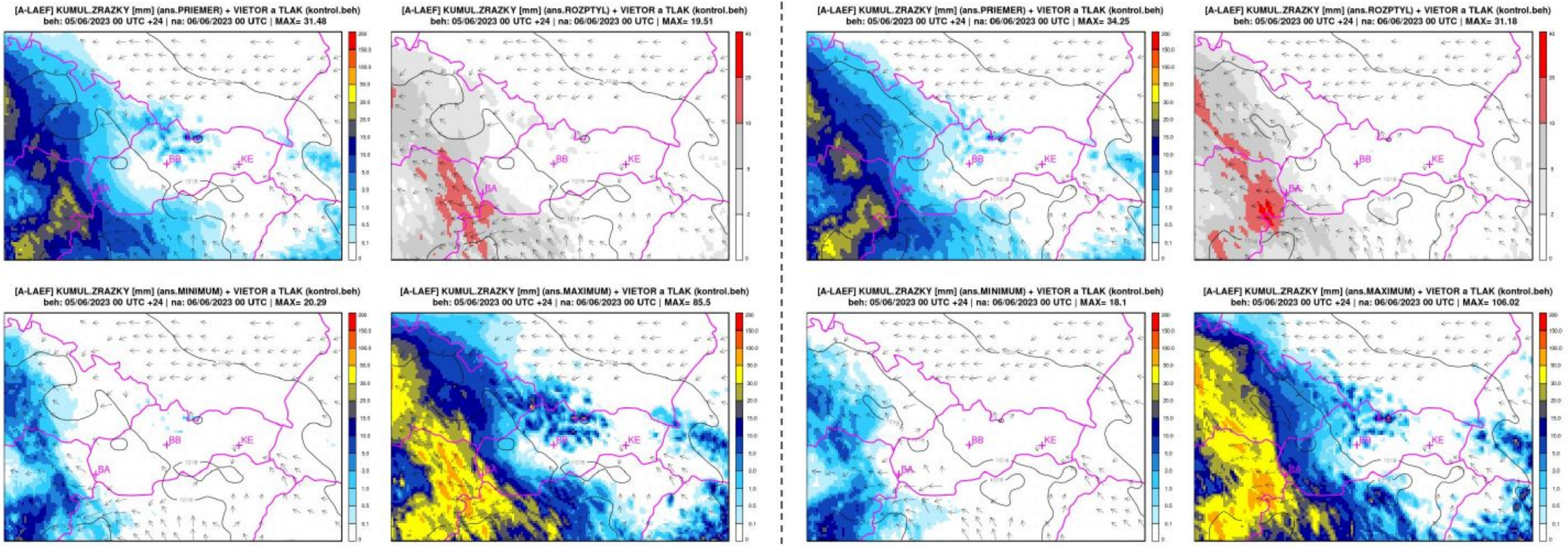
4th Oct 2021 EU record precipitation

- Different scenarios for 24-hour precipitation on 4 October 2021 in northern Italy by the perturbed A-LAEF ensemble members, in forecasts starting at 00 UTC on the same day. A maximum of 501 mm was predicted by member 03.



A-LAEF coupled to cy47r3 vs cy48r1

cy47r3 (oper) cy48r1 (e-suite)



- Accumulated precipitation: EPS mean, spread, min, max +24h

A-LAEF coupled to cy47r3 vs cy48r1

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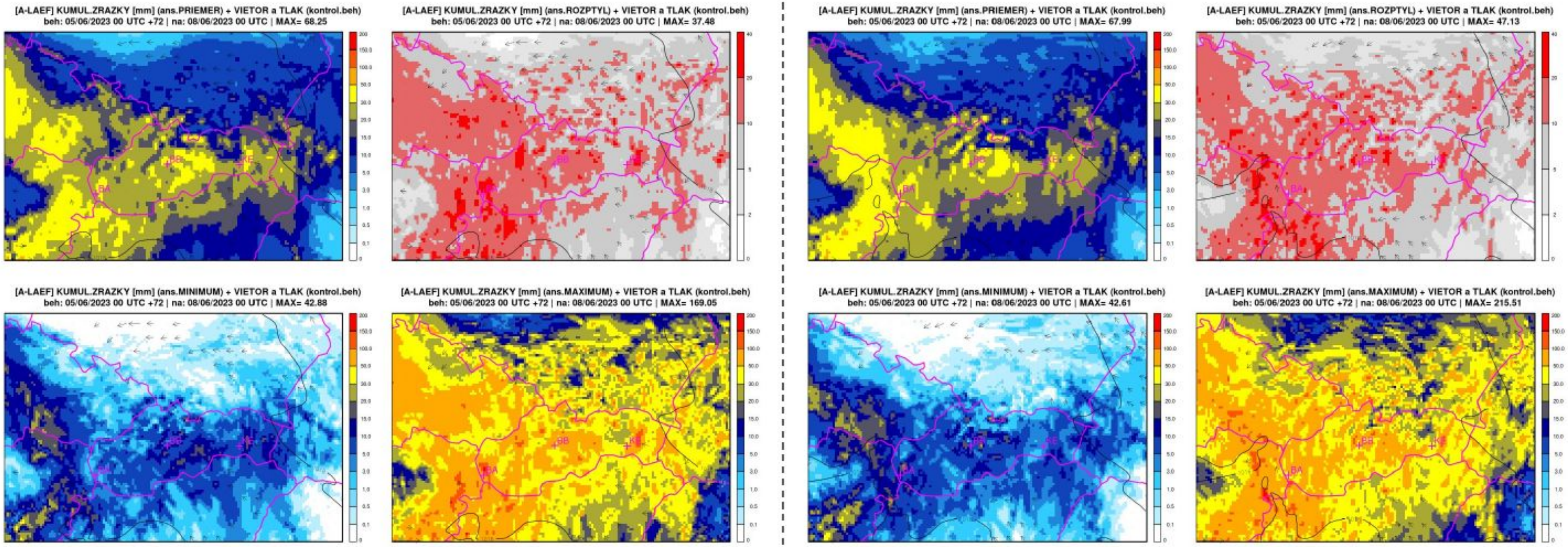
cy47r3 (oper) | cy48r1 (e-suite)



- Accumulated precipitation: EPS mean, spread, min, max +72h

A-LAEF coupled to cy47r3 vs cy48r1

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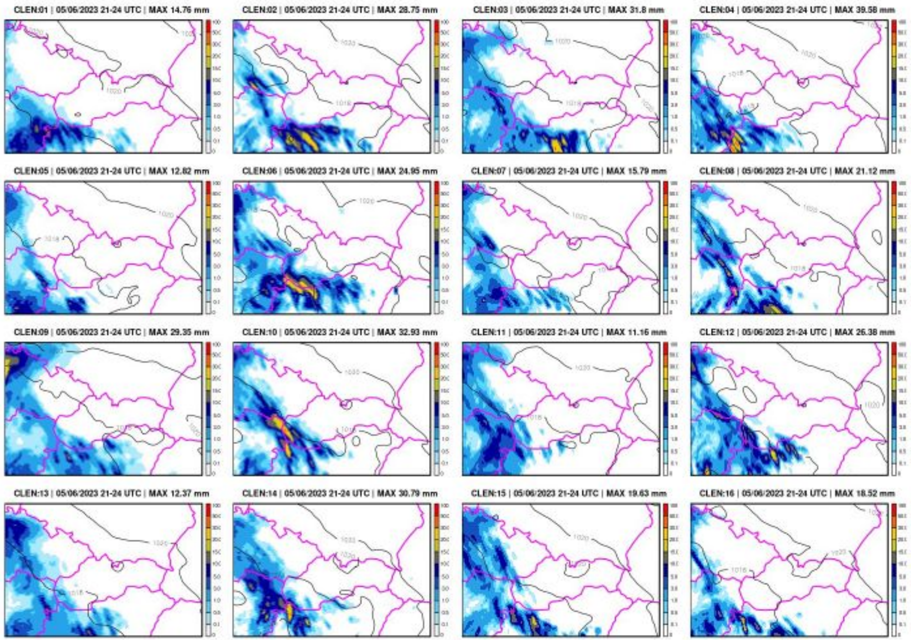
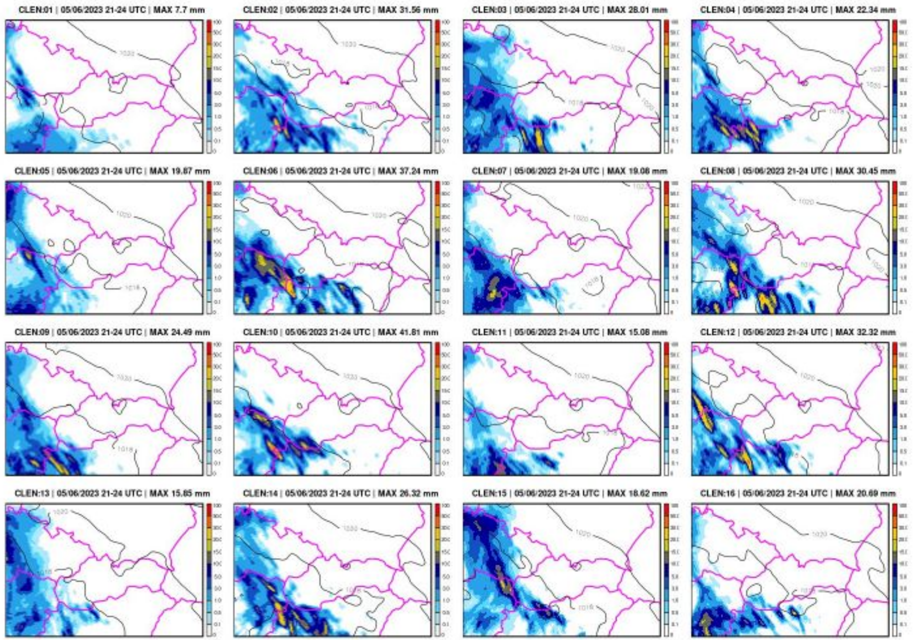
cy47r3 (oper)



cy48r1 (e-suite)



- 3-hourly accumulated precipitation (16 perturbed members) +24h

A-LAEF coupled to cy47r3 vs cy48r1

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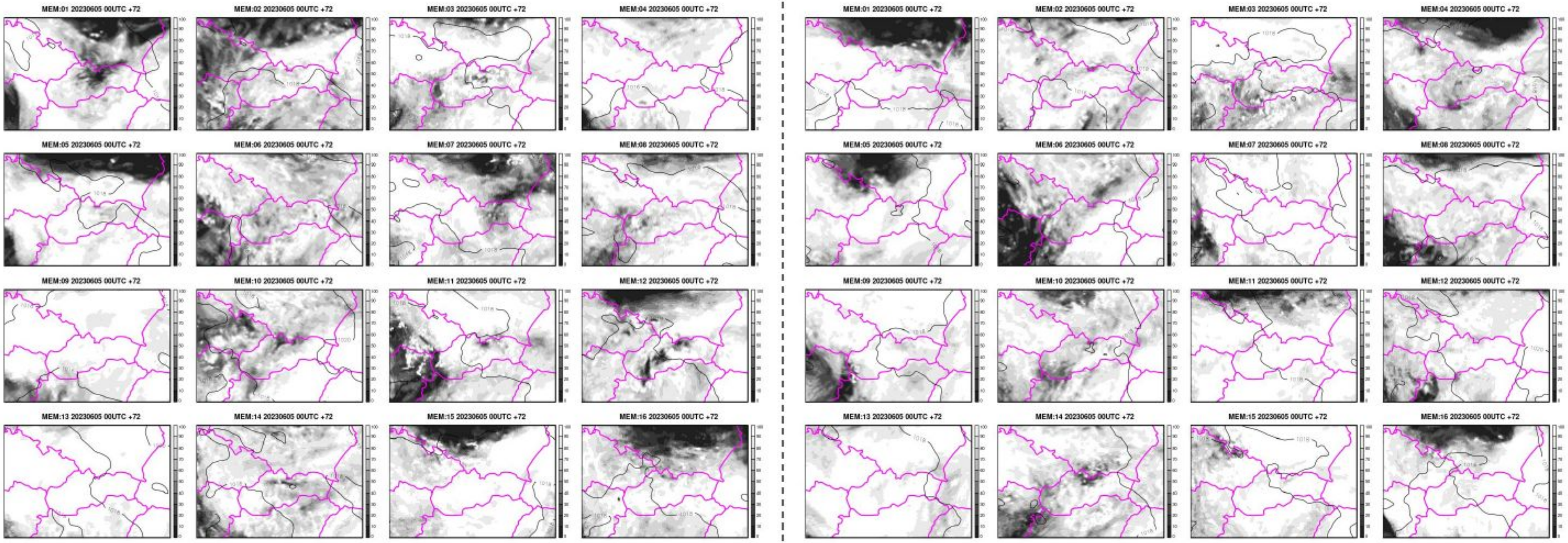
cy47r3 (oper) | cy48r1 (e-suite)



- Total cloud cover (16 perturbed members) +72h. [Note the differences for individual members, this is also caused by the fact that cloudiness is less predictable parameter and even small changes become more pronounced after a longer integration (+72h).]

Heavy snowfall - 25-27 Feb 2023 (A-LAEF)

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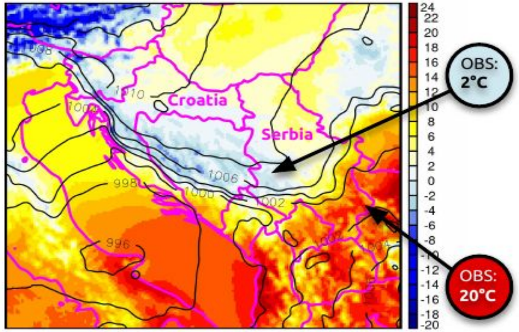
The abrupt onset of winter conditions in the Balkans came after a period of unseasonably warm weather, causing:

- a large amount of fresh snow
- strong wind (causing snow drifts)
- traffic connection cut off
- interrupted electricity supply
- big temperature differences (2-22°C in Serbia)

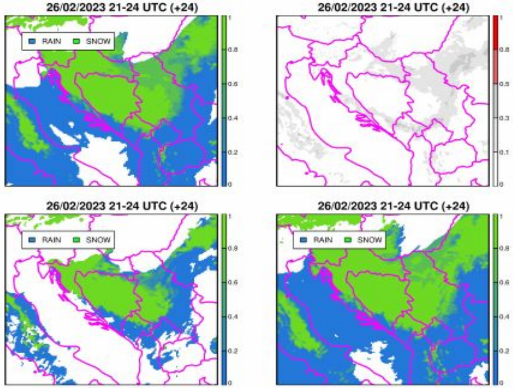
These extreme weather changes were well captured by the A-LAEF forecast.

Temperature at 2m: EPS mean +12h

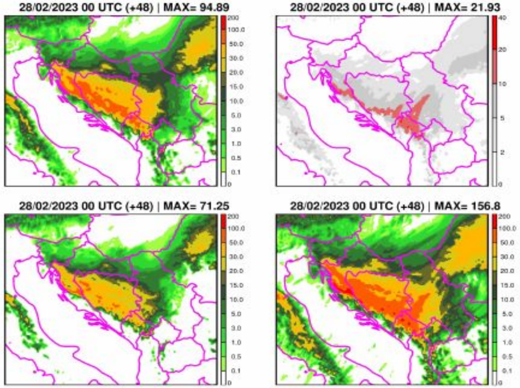
26/02/2023 12 UTC | MIN= -18.75 MAX= 21.54



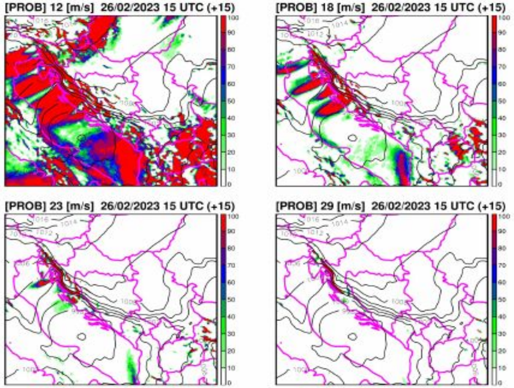
Precipitation type: EPS mean, spread, min, max +24h



Accumulated snow: EPS mean, spread, min, max +48h



Wind gust probability: 12, 18, 23 and 29 m/s +15h



Storm Juliette near Balearic Isl. 27-28 Feb 2023

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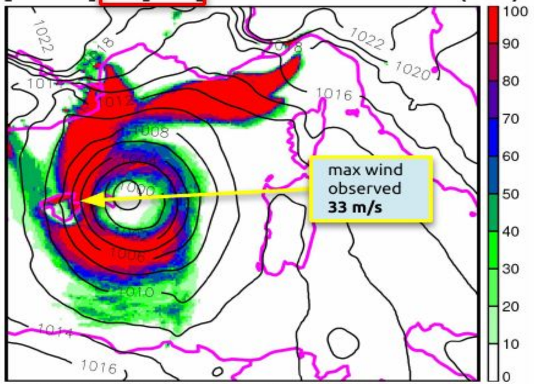
Wind gusts exceeding 100 km/h caused power cuts in various parts of the Mallorca island (with a peak gust of 119 km/h measured on 28 February at Capdepera station). Strong wind was accompanied by outbreak of cold weather and snow in coastal municipalities such as Felanitx, Manacor and Santanyi. The red alert for snow has been extended to the noon of 28 February.

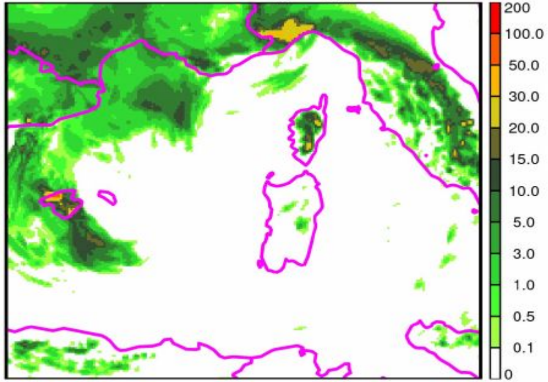
The A-LAEF ensemble system nicely captured the significant depression and the trajectory of its movement south of Sardinia to the coast of Italy, together with snowfall on Mallorca island (up to 70 cm) and strong gusty winds.

[PROB] 23 [m/s] 28/02/2023 03 UTC (+03)

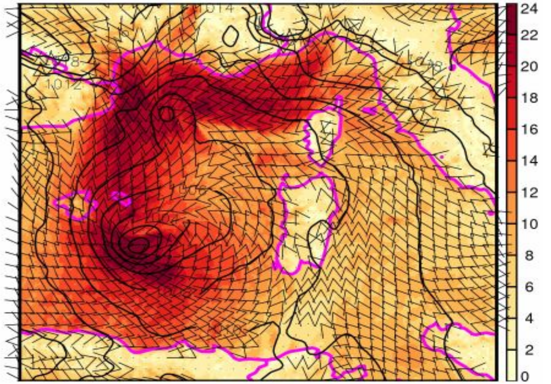


27/02/2023 15-18 UTC (+18)

27/02/2023 18 UTC (+18) | MAX= 69.54



27/02/2023 18 UTC (+18) | MAX= 28.53



Storm Juliette near Balearic Isl. 27-28 Feb 2023

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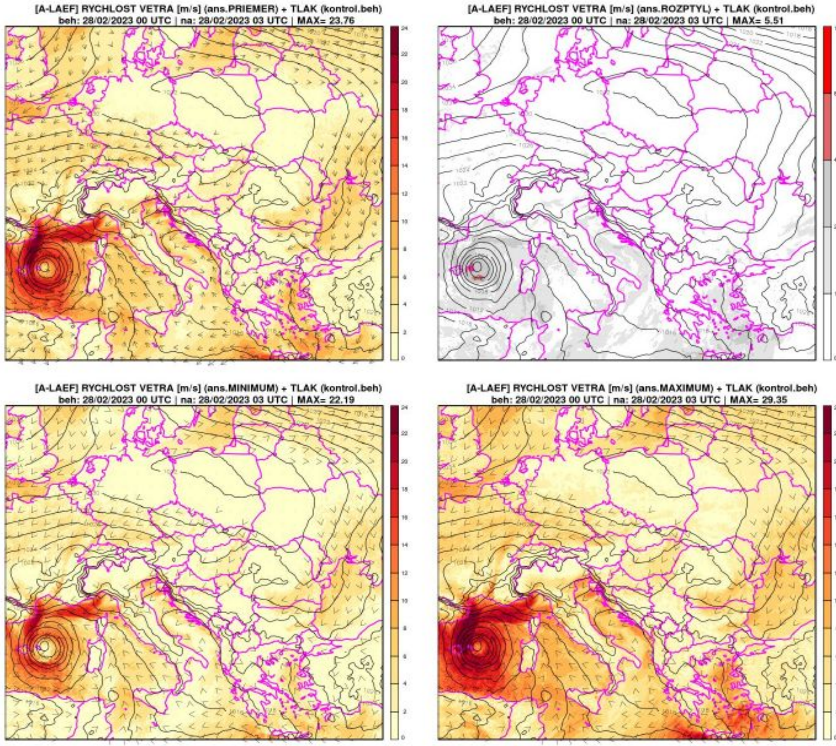
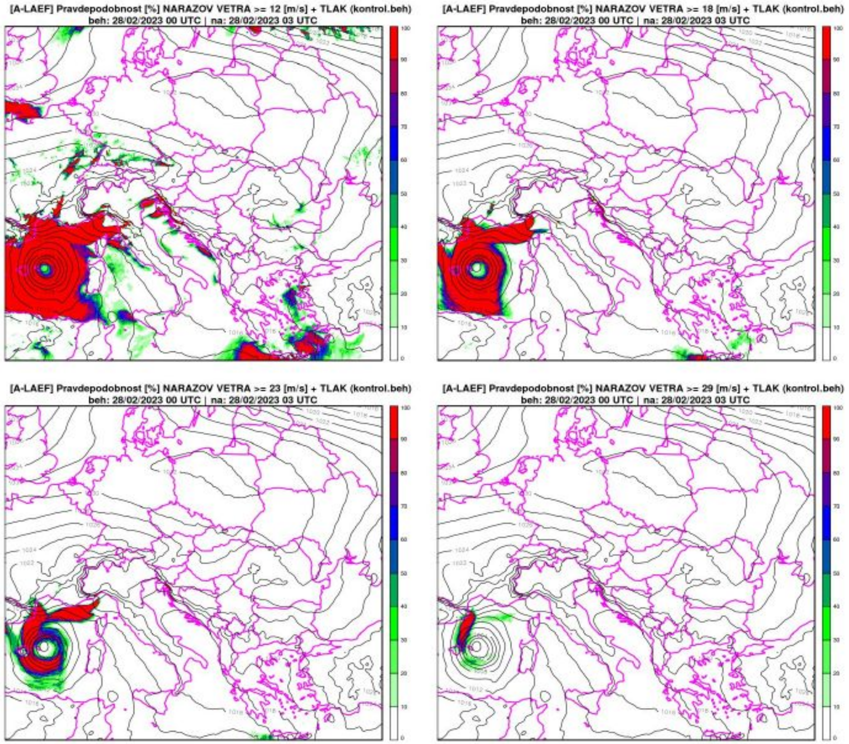
Wind speed: EPS mean, spread, min, max +3h



Wind gust probability: 12, 18, 23 and 29 m/s +3h



Floods in Italy - 16 May 2023

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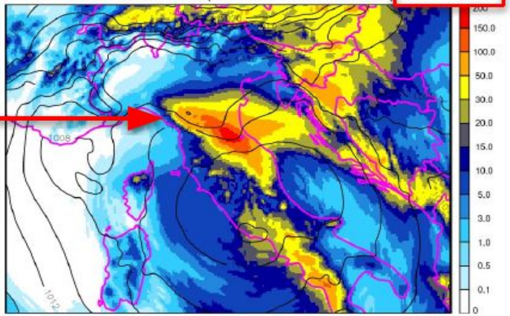
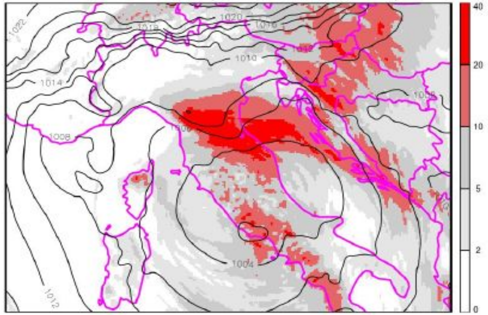
A-LAEF forecast for T+30h lead time

Affected region (Rimini 184 mm @ ogimet)

[A-LAEF] TOTAL PRECIPITATION [mm] (MEAN)
run: 16/05/2023 00 UTC +30 | val: 17/05/2023 06 UTC | MAX= 177.07



[A-LAEF] TOTAL PRECIPITATION [mm] (SPREAD)
run: 16/05/2023 00 UTC +30 | val: 17/05/2023 06 UTC | MAX= 42.43



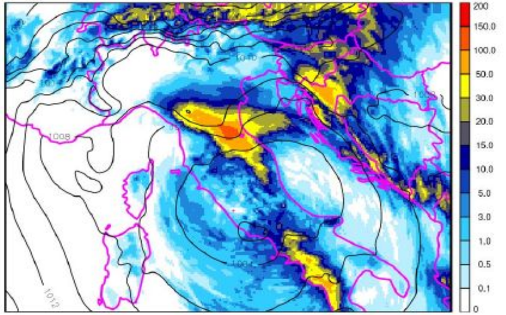
Consequences of heavy rainfall in Italy:

Floods and landslides in the Emilia-Romagna (IT) region have caused eight deaths since 16 May and forced thousands to evacuate their homes.

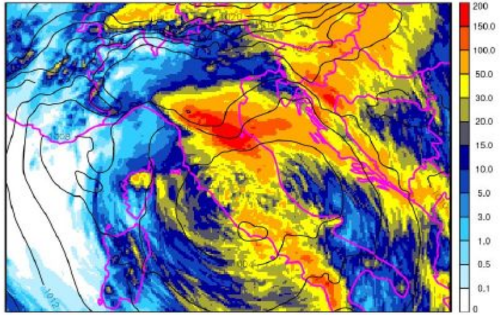
More than twenty rivers and streams overflowed their banks and caused flooding in 37 villages. Authorities reported 250 landslides, including 120 severe landslides in 48 municipalities.

Heavy rainfall was well captured both with respect to the location and amount, even by the A-LAEF ensemble mean.

[A-LAEF] TOTAL PRECIPITATION [mm] (MIN)
run: 16/05/2023 00 UTC +30 | val: 17/05/2023 06 UTC | MAX= 140



[A-LAEF] TOTAL PRECIPITATION [mm] (MAX)
run: 16/05/2023 00 UTC +30 | val: 17/05/2023 06 UTC | MAX= 267.89



24h precipitation accumulation from 06 UTC on May 16 to 06 UTC on May 17, 2023.

Floods in Italy - 16 May 2023

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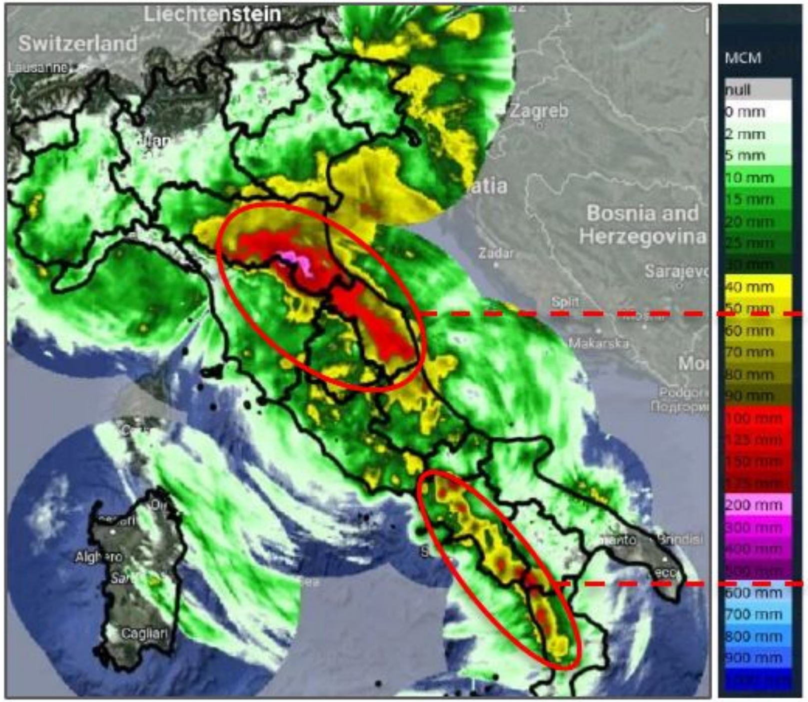
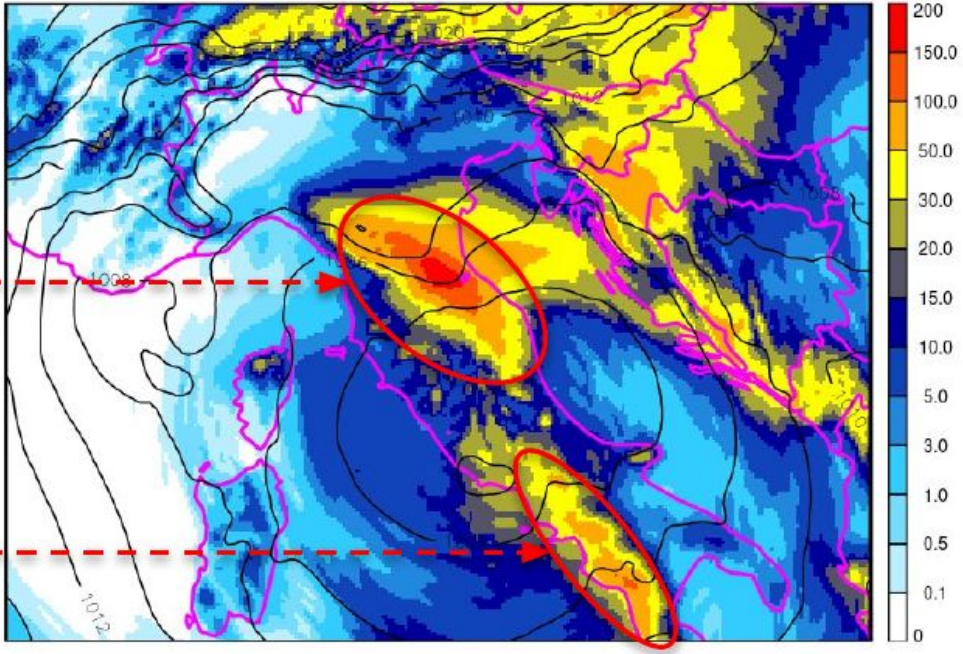
IT radars (accumulated precipitation)



[A-LAEF] TOTAL PRECIPITATION [mm] (MEAN)
run: 16/05/2023 00 UTC +30 | val: 17/05/2023 06 UTC | MAX= 177.07



Floods in Italy - 16 May 2023

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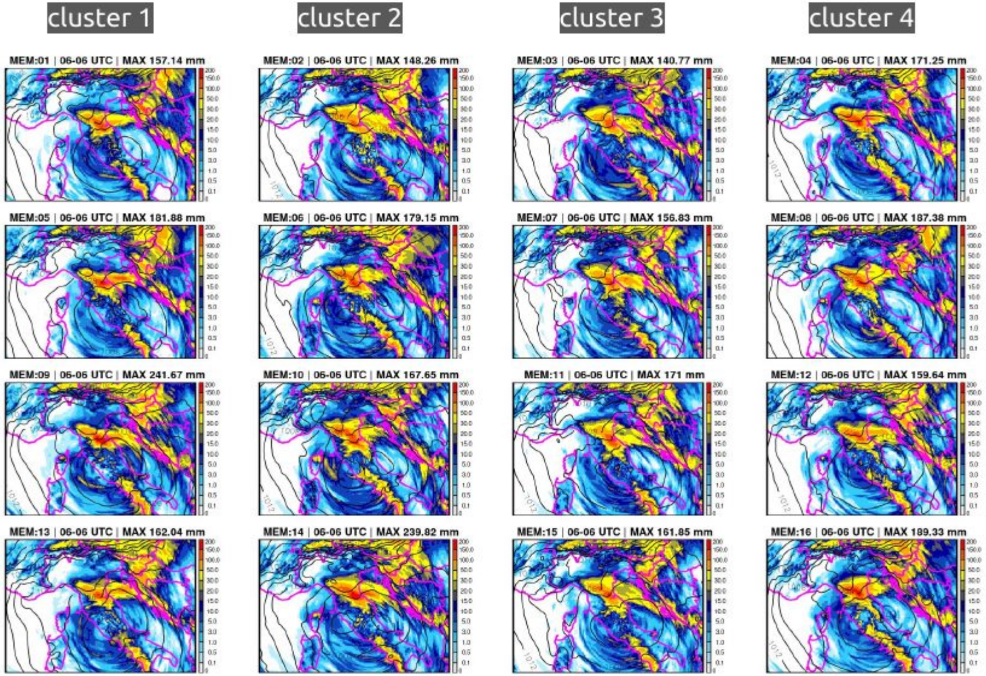
Higher precipitation amounts forecasted by A-LAEF EPS seems to be related to the specific parameterization schemes, since the different schemes and their tunings are used to simulate model uncertainty. Some schemes are obviously more sensitive to such extreme precipitation events, however, the final outcome is the combined effect of the cluster physics settings and stochastic perturbations of physics tendencies in each time step.

In this situation and T+30h lead time, the maximum of the ensemble was **241 mm/24h**, while the minimum was "only" **140 mm/24h**. Looking into the individual physics clusters (we have 4 of them), the maximum average comes from the first one:

cluster	average [mm/24h]	physics tuning
1	185.7	microphysics and deep convection
2	183.7	turbulence
3	157.6	turbulence, microphysics and deep convection
4	176.9	ALARO-1 reference

The differences between EPS min and max were about the same for T+54h lead time, but the individual clusters had more variability between each other, while the maximum average was again obtained by cluster one 194.4 mm/24h and the second highest was cluster 3 with 160.5 mm/24h (not shown).



Physics clustering in columns (16 A-LAEF perturbed members). The differences between individual members of a cluster are due to ensemble of surface data assimilation, stochastic physics and ENS coupling.

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