SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	Short-range re-analysis and forecast to investigate extreme weather events using COSMO and ICON model
Computer Project Account:	SPITGARB
Principal Investigator(s):	Valeria Garbero (mcy0), valeria.garbero@arpa.piemonte.it
Affiliation:	Arpa Piemonte, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Massimo Milelli (mcy), massimo.milelli@cimafoundation.org
Start date of the project:	January 2022
Expected end date:	December 2024

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	900.000	257.651	900.000	499.174
Data storage capacity	(Gbytes)	300	280	400	350

Summary of project objectives (10 lines max)

The aim of the project is to use the most advanced numerical modelling to analyse case studies from the recent past, in order to identify critical issues and improve the forecast of future events, not only in case of strong precipitation, but also in case of heat waves, strong wind, etc. The COSMO and ICON models will be used at high horizontal resolution to re-analyse and re-forecast past extreme events. Different model configurations will be tested using new physical parameterization schemes and different initial and boundary conditions to find out which is the best configuration representing the severe events on rather small time and space scales. Temperature, relative humidity and wind will be compared with the observations provided by meteorological stations and radiometers using standard statistic indices (MB, RMSE, etc.). Precipitation will be verified using the innovative fuzzy technique that compares the data estimated by the national radar mosaic with the simulated maps.

Summary of problems encountered (10 lines max)

None.

Summary of plans for the continuation of the project (10 lines max)

The project will be continued by analysing other case studies, chosen in agreement with the Civil Protection Department, using the 2 available NWP models, ICON and COSMO, at very high resolution. Both heavy precipitation events over Italy and heat waves over Turin will be investigated and different model configurations will be used to figure out which configuration best reproduces the events.

List of publications/reports from the project with complete references

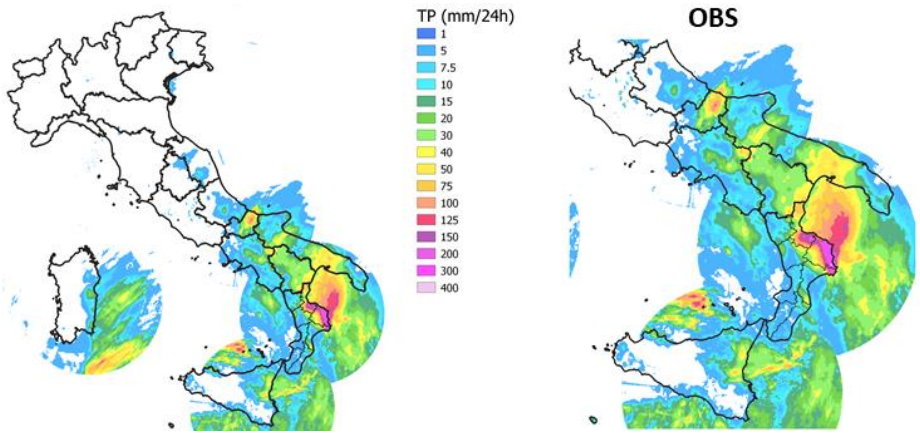
Paper in preparation.

Summary of results

Since the beginning of the project, different case studies have been analysed and re-analysis and re-forecast have been performed using COSMO and ICON at high-resolution. In the following we describe the most salient.

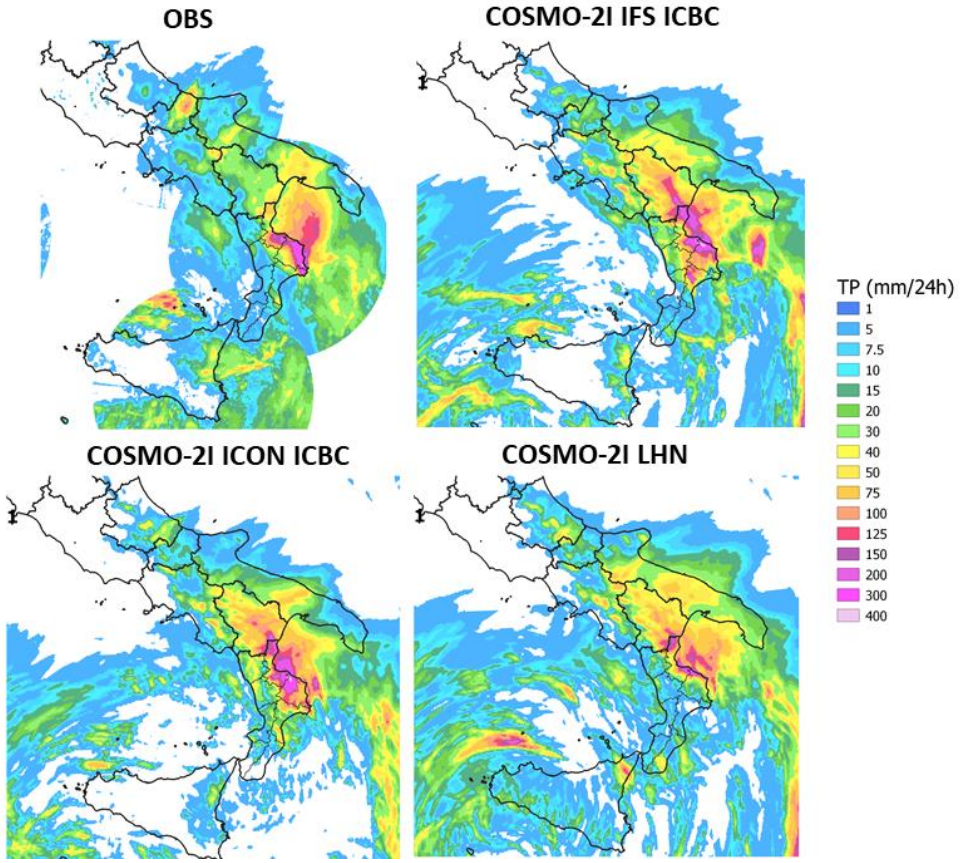
<u>21-22 November 2020, Campania region</u>

Re-analysis and re-forecast of an extreme event that affected the Campania region between November 21 and 22, 2020, have been carried out using COSMO and ICON in different configurations. The event was characterized by very heavy and persistent rainfall, localized mainly on the Ionian-Northern slope; the province of Crotone was the most affected with many stations recording cumulative rainfall exceeding 300 mm. The figure shows the precipitation estimated by merging the radar national composite and rain-gauges (Dewetra) on 21st 2020.

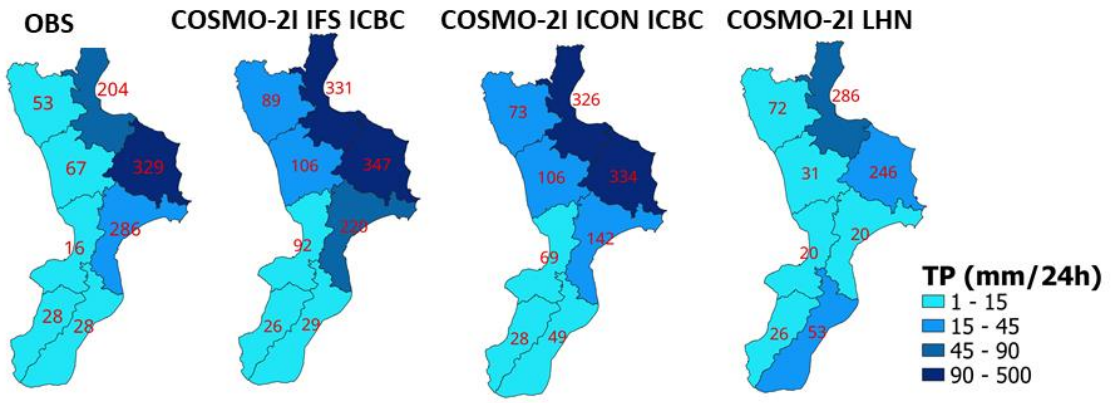


Re-analysis were performed using COSMO, varying initial and boundary conditions, and ICON at 2 km resolution:
- EXP1: COSMO run with initial and boundary conditions provided by IFS analysis at 9 km
- EXP2: COSMO run with initial and boundary conditions provided by ICON analysis at 13 km
- EXP3: COSMO run with initial conditions provided by COSMO-2I analysis (letkf+latent heat assimilation) and boundary conditions provided by IFS at 9 km

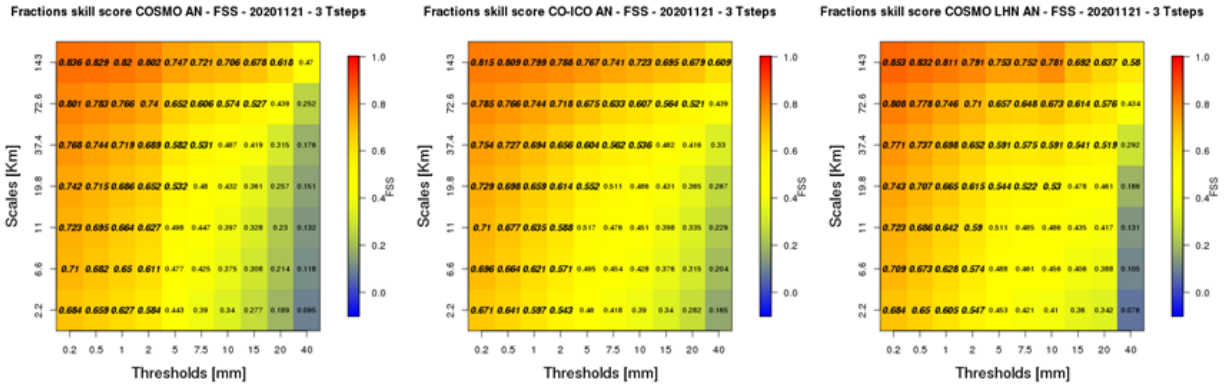
A qualitative evaluation is performed through the eyeball method: the figure compares the precipitation pattern observed and simulated on 21st 2020 over Campania region and points out that the experiments 1 and 2 better reproduce the event.



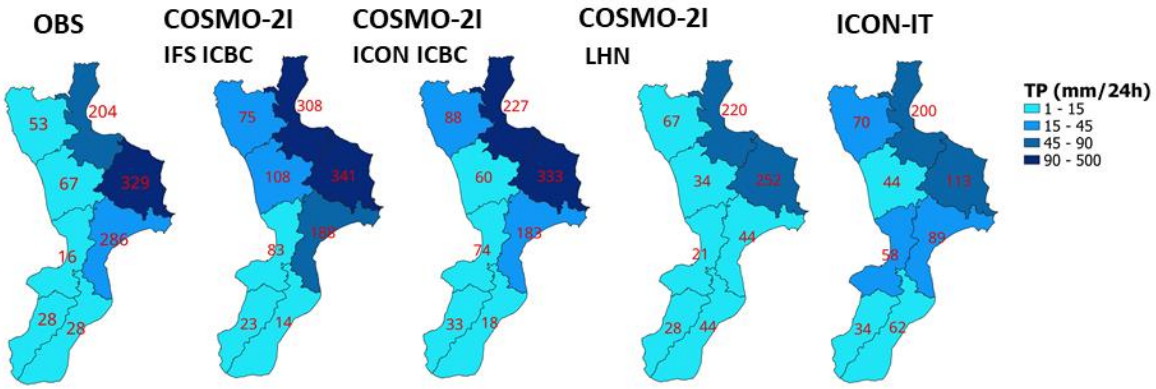
A more quantitative evaluation is carried out by calculating the QPF over the region's warning zones, which show an underestimation in the mean and maximum values over zones 6 and 7 by the EXP3 re-analysis. The reanalyses that best reproduce the observed QPFs are those obtained by adopting the initial and boundary conditions provided by ICON.



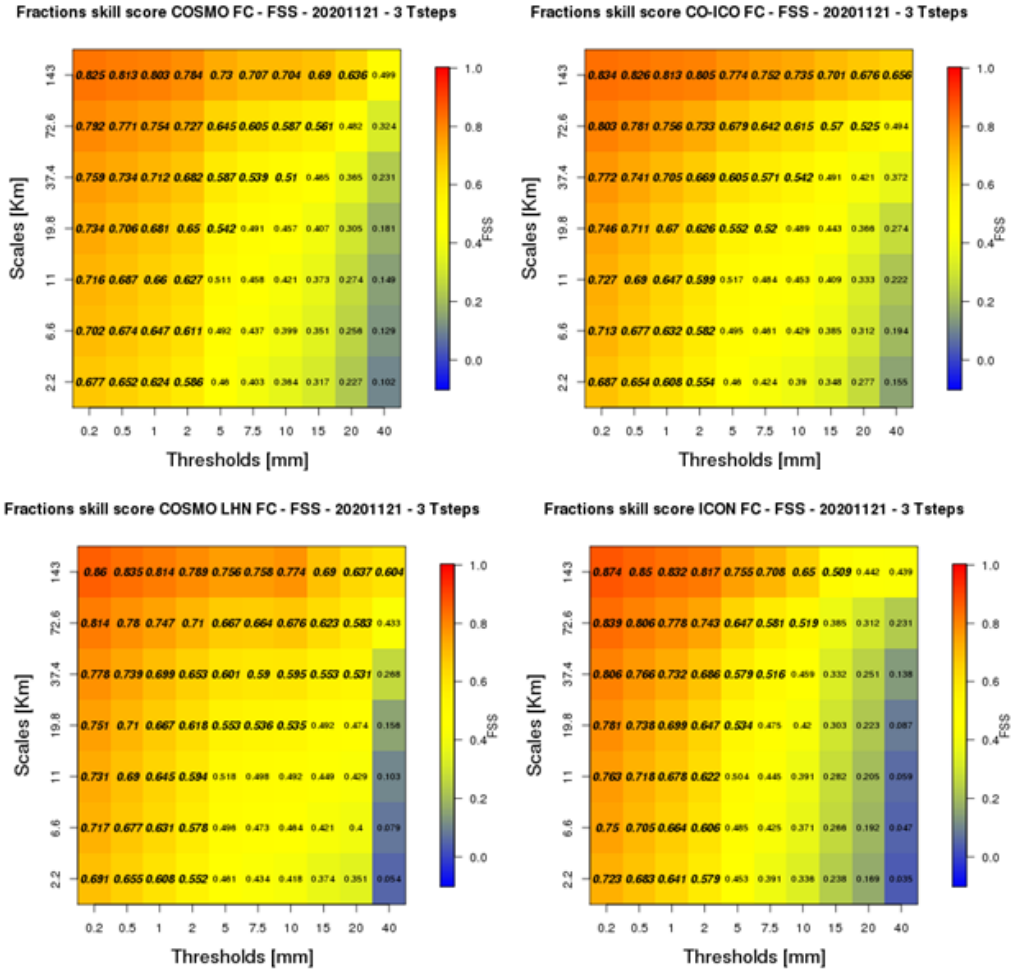
Precipitation was further verified through the fuzzy technique. In the following figure the FSS calculated for the first 24 hours of forecast (D0, 20201121) by using the 3D fuzzy is shown: the scores point out similar performance for low thresholds for all the simulations and improvement for medium to high thresholds for COSMO runs adopting ICON's initial and boundary conditions but especially those performed with the operational initial and boundary conditions provided by COSMO-2I (LHN). EXP2 and EXP3 configurations reach the FSS_{useful} for the highest threshold of 40 mm/3h at 143 km and EXP3 reaches the FSS_{useful} for the 20 mm/3h threshold at 37 km. EXP1 doesn't reach any FSS_{useful} any for 40 mm/3h thresholds.
This result seems to contradict what the QPFs showed, but we must bear in mind that the fuzzy is applied on the whole of Italy, and therefore evaluates the event in its entirety, while the QPFs were calculated only on the warning areas of Calabria, and evaluate the model's performance on that area. This points out how verification is a complex process made up of different pieces and facets, all of which are important to analyse to have a complete view.



To assess the effect of initial and boundary conditions on the predictions as well, runs in forecast mode were performed with COSMO and with ICON at 2 km resolution, , varying initial and boundary conditions,:
-EXP1: COSMO runs in forecast mode with operational set-up and initial and boundary conditions provided by IFS at 9 km;
- EXP2: COSMO runs in forecast mode with operational set-up and initial and boundary conditions provided by ICON at 13 km;
- EXP3: COSMO runs in forecast mode with operational set-up and initial conditions provided by COSMO-2I analysis (letkf+ latent heat assimilation) and boundary conditions provided by IFS forecasts at 9 km (COSMO-2I operational conditions);
- EXP4: ICON runs in forecast mode with operational set-up and initial and boundary conditions provided by ICON at 13 km.
The run that best reproduces the precipitation pattern, both in mean and maximum values, is EXP2, which adopts the initial and boundary conditions of ICON. Both EXP3 and EXP4 significantly underestimate the mean and maximum values in the eastern sector of the region (figure below).



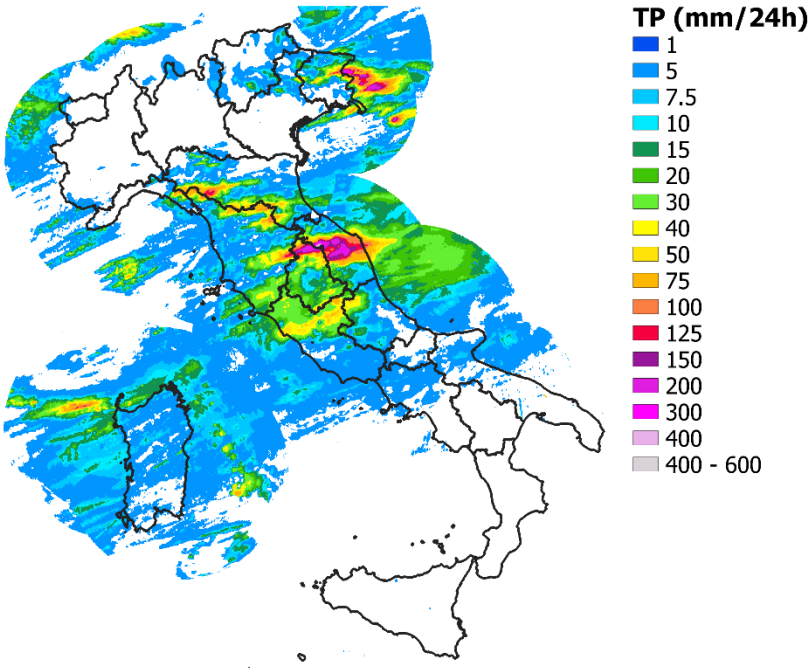
The fuzzy verification shows similar performance for low thresholds and an improvement for medium to high thresholds for the runs adopting the ICON initial and boundary conditions, but especially those carried out with the operational initial and boundary conditions (LHN). In analogy to what has been discussed for the reanalysis, this result is not in contradiction with that on the QPFs but is a useful building block for understanding and evaluating the models.



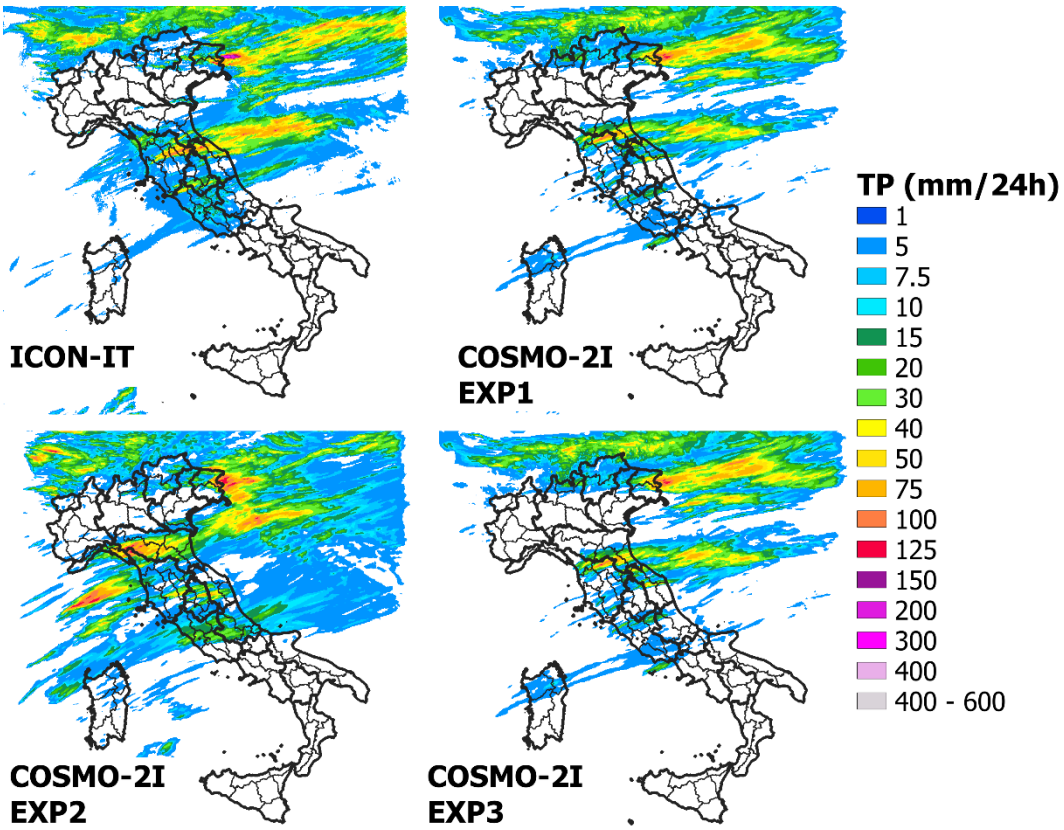
15 September 2022, Marche region

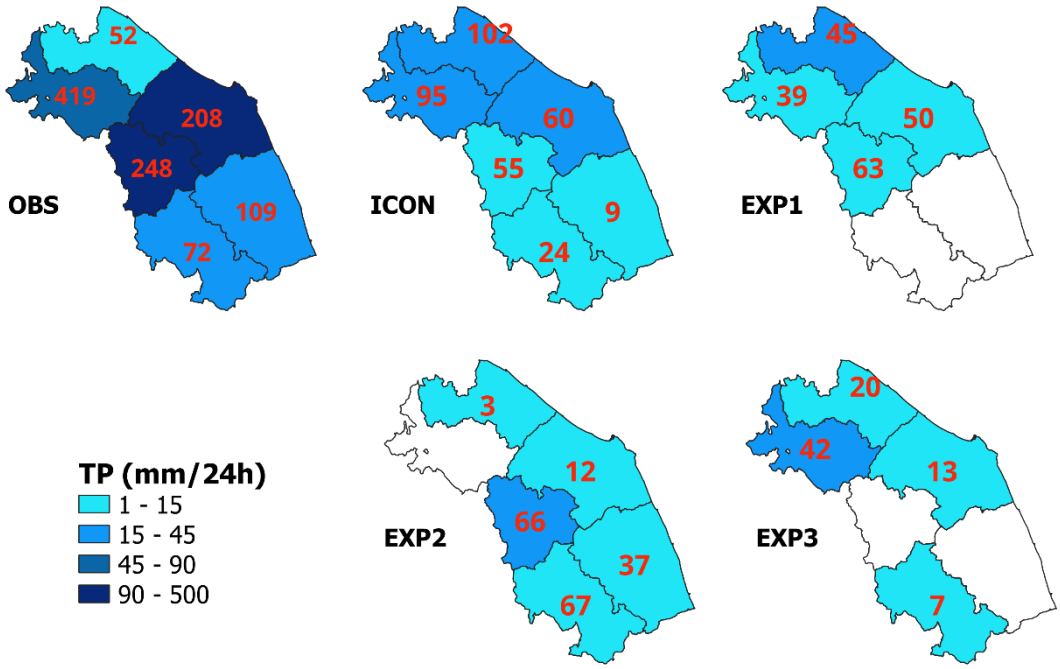
The event that affected the Marche region on 15 September 2022 was characterised by very intense and persistent rainfall, associated with organised thunderstorm systems, which originated in the central-northern mountainous and hilly areas of the region and later extended to the coastal area, causing widespread criticality in the basins. The province of Ancona was the worst affected with many stations recording cumulative rainfall exceeding 300 mm.

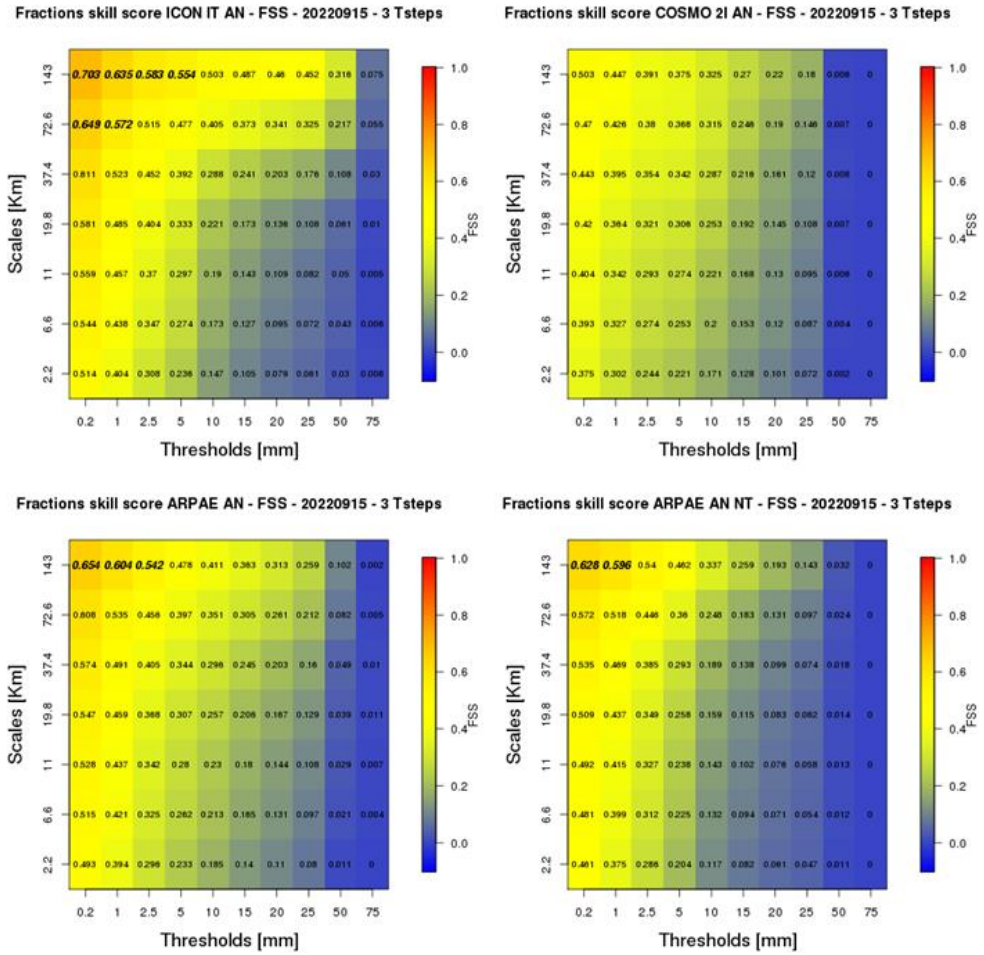
The figure shows the 24h precipitation estimated by merging the radar national composite and rain-gauges (Dewetra).



Re-analysis of the event have been carried out using COSMO and ICON at high resolution (2.2 km) in different configurations:
- EXP1: COSMO runs in hindcast mode with operational set-up and initial and boundary conditions provided by IFS analysis at 9 km;
- EXP2: COSMO runs in hindcast mode with operational set-up and initial and boundary conditions provided by ARPAE analysis at 2.2 km (letkf+ latent heat assimilation+reflectivity volumes assimilation)
- EXP3: COSMO runs in hindcast mode with new "icon-like" physics and initial and boundary conditions provided by ARPAE analysis at 2.2 km
- EXP4: ICON runs in hindcast mode with operational set-up and initial and boundary conditions provided by ICON analysis at 13 km.
Simulation results are compared in figure and show that none of the investigated configurations can reproduce the observed event, as also shown by the average and maximum QPF calculated in the Marche warning areas for the different set-up. The COSMO reanalyses do not correctly identify the areas of greatest impact, neither in the average nor in the maximum values, resulting even worse than the operational run. On the contrary, the ICON reanalysis shows a timid improvement, as pointed out by the fuzzy verification.


ICON-IT
COSMO-2I
EXP1
COSMO-2I
EXP2
COSMO-2I
EXP3
TP (mm/24h)
1
5
7.5
10
15
20
30
40
50
75
100
125
150
200
300
400
400 - 600

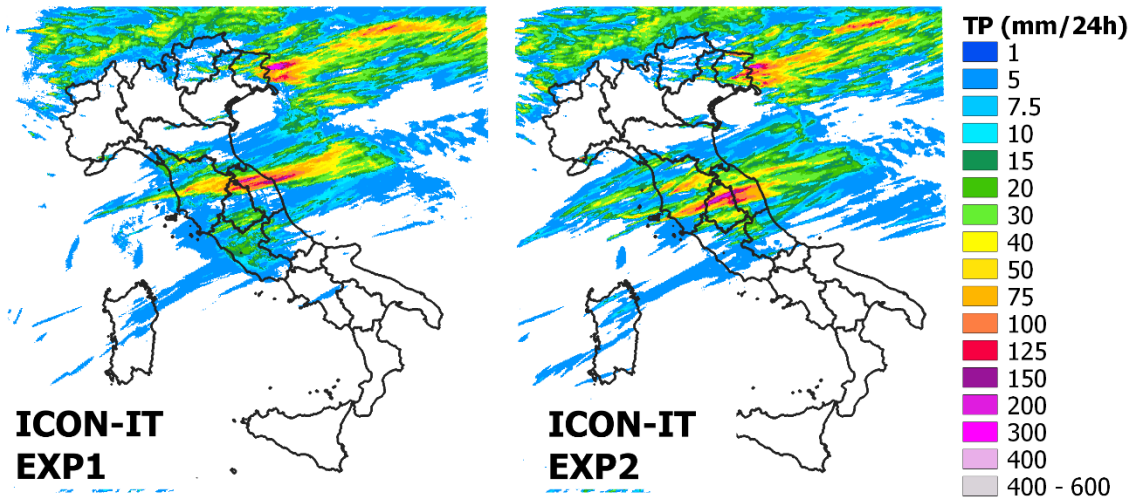

OBS
52
419
208
248
109
72
ICON
102
95
60
55
9
24
EXP1
45
39
50
63
TP (mm/24h)
1 - 15
15 - 45
45 - 90
90 - 500
EXP2
3
12
66
37
67
EXP3
20
42
13
7

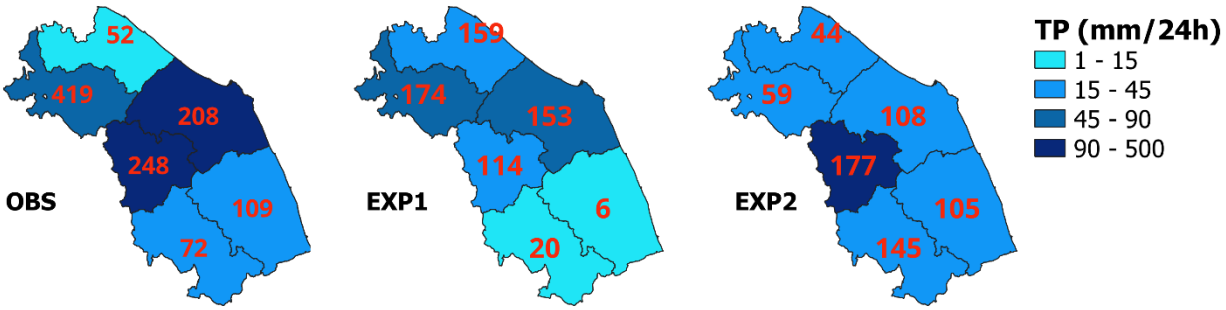


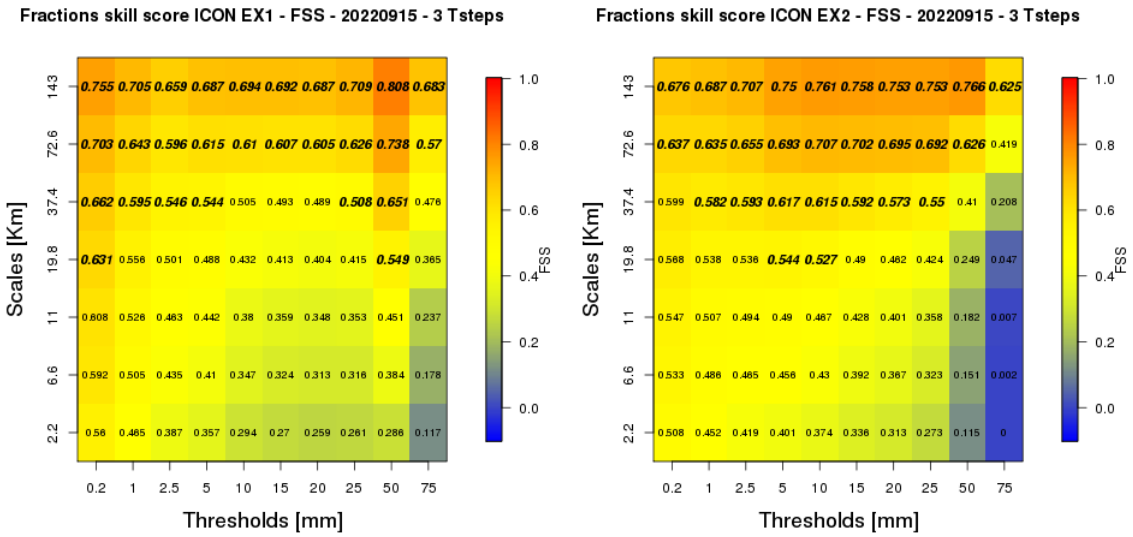
A further analysis was conducted by performing ICON simulations in forecast mode at 2 km resolution, adopting different initial and boundary conditions and modifying some physical parameterisations:

- EXP1: ICON runs in forecast mode with operational set-up (lshallowconv_only = .true.) and initial and boundary conditions provided by the ICON-EU at 6.5 km;
- EXP2: ICON runs in forecast mode with lshallowconv_only = .false.+lgrayzone_deepconv=.true. and initial and boundary conditions provided by ICON-EU at 6.5 km

Both configurations seem to correctly reproduce the v-shape phenomenon occurred over the Marche region, although the areas of greatest impact are slightly different. The mean and maximum 24-hour QFP calculated in the warning areas are underestimated but they would certainly have highlighted a possible criticality. The fuzzy verification also shows a significative improvement in the scores, particularly for the EXP2 configuration.




OBS
52
419
208
248
109
72
EXP1
159
174
153
114
6
20
EXP2
44
59
108
177
105
145
TP (mm/24h)
1 - 15
15 - 45
45 - 90
90 - 500


Fractions skill score ICON EX1 - FSS - 20220915 - 3 Tsteps
Scales [Km]
143
72.6
37.4
19.8
11
6.6
2.2
0.755 0.705 0.659 0.687 0.694 0.692 0.687 0.709 0.808 0.683
0.703 0.643 0.596 0.615 0.61 0.607 0.605 0.626 0.738 0.57
0.662 0.595 0.546 0.544 0.505 0.493 0.489 0.508 0.651 0.476
0.631 0.556 0.501 0.488 0.432 0.413 0.404 0.415 0.549 0.365
0.608 0.526 0.483 0.442 0.38 0.359 0.348 0.353 0.451 0.237
0.592 0.505 0.435 0.41 0.347 0.324 0.313 0.316 0.384 0.178
0.56 0.465 0.387 0.357 0.294 0.27 0.259 0.261 0.286 0.117
0.2 1 2.5 5 10 15 20 25 50 75
Thresholds [mm]
FSS
1.0
0.8
0.6
0.4
0.2
0.0
Fractions skill score ICON EX2 - FSS - 20220915 - 3 Tsteps
Scales [Km]
143
72.6
37.4
19.8
11
6.6
2.2
0.676 0.687 0.707 0.75 0.761 0.758 0.753 0.753 0.766 0.625
0.637 0.635 0.655 0.693 0.707 0.702 0.695 0.692 0.626 0.419
0.599 0.582 0.593 0.617 0.615 0.592 0.573 0.55 0.41 0.208
0.568 0.538 0.536 0.544 0.527 0.49 0.462 0.424 0.249 0.047
0.547 0.507 0.494 0.49 0.467 0.428 0.401 0.358 0.182 0.007
0.533 0.486 0.485 0.456 0.43 0.392 0.367 0.323 0.151 0.002
0.508 0.452 0.419 0.401 0.374 0.336 0.313 0.273 0.115 0
0.2 1 2.5 5 10 15 20 25 50 75
Thresholds [mm]
FSS
1.0
0.8
0.6
0.4
0.2
0.0