EMI R&D 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	2026
Project Title:	Numerical modeling of precipitation climatology and its sensitivity to climate change effects on the Apennines mountains
Computer Project Account:	spitsilv
Principal Investigator(s):	Lorenzo Silvestri
Affiliation:	University of Perugia, Perugia, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………….…… ……………………………………………………….……
Start date of the project:	01-01-2025
Expected end date:	31-12-2027

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)	5.000.000	45	5.000.000	0
Data storage capacity	(Gbytes)	10.000	0	10.000	0

Summary of project objectives (10 lines max)

The main objectives of the project are:

1) Understand and explain the main physical processes constituting the observed precipitation climatology over central Italy

2) Understand and explore possible causes of the recent climate trends observed in the precipitation climatology especially over the Apennines.

3) Generalise and build theoretical models for the effects of climate change on orographic convection and precipitation.

Summary of problems encountered (10 lines max)

We are currently working on identifying the correct initial conditions and model configuration to enable us to simulate a stationary deep convective system over idealised orography. So far, we have not managed to achieve such a configuration using interactive surface fluxes and uniform initial conditions based on the observed soundings provided. We are exploring real simulation cases (15 September 2022) from the previous report to understand the role of the horizontal moisture gradient (i.e. moisture jets impinging on the mountain barrier instead of uniform flow), as previously discussed in the literature (Bresson et al., 2012). Therefore, we are testing small-domain simulations on our local machine so as not to waste SBU from the special project. This will ensure that the full SBU account is available for testing a high-resolution LES simulation on such a stationary system whenever we find the right initial conditions.

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

We have simulated the real event of 15 September 2022 at resolution of 2 km over the whole Mediterranean Region (see related Special Project SPITSARA by Paolina Bongioannini Cerlini and Miriam Saraceni). We are testing different initial conditions and model configuration in our idealized setup for CM1 model, in order to obtain a quasi-stationary deep convective system over orography. Currently, the uniform moisture conditions are not able to produce such stationary system with interactive surface fluxes.

The next steps will be:

1) an extended study of the real simulation of 15 September 2022 and especially the initial condition of moisture and how it is distributed before impinging on the Apennines

2) replication of the quasi-stationary convective system obtained by Miglietta and Rotunno (2009) to be used as a control run

3) application of non-uniform initial condition (jet-like) to moisture field to understand their impact on quasi-stationary deep convective system

List of publications/reports from the project with complete references

None

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

The idealised simulations have been performed with the Cloud Model 1 either in a squared or rectangular domain with a size of 500 km on the meridional direction and a size ranging from 500 km to 1000 km on the meridional direction to evaluate also the effect of domain size on organization of convection. Such size is based on the real domain we are trying to simulate that is represented in Figure 1:

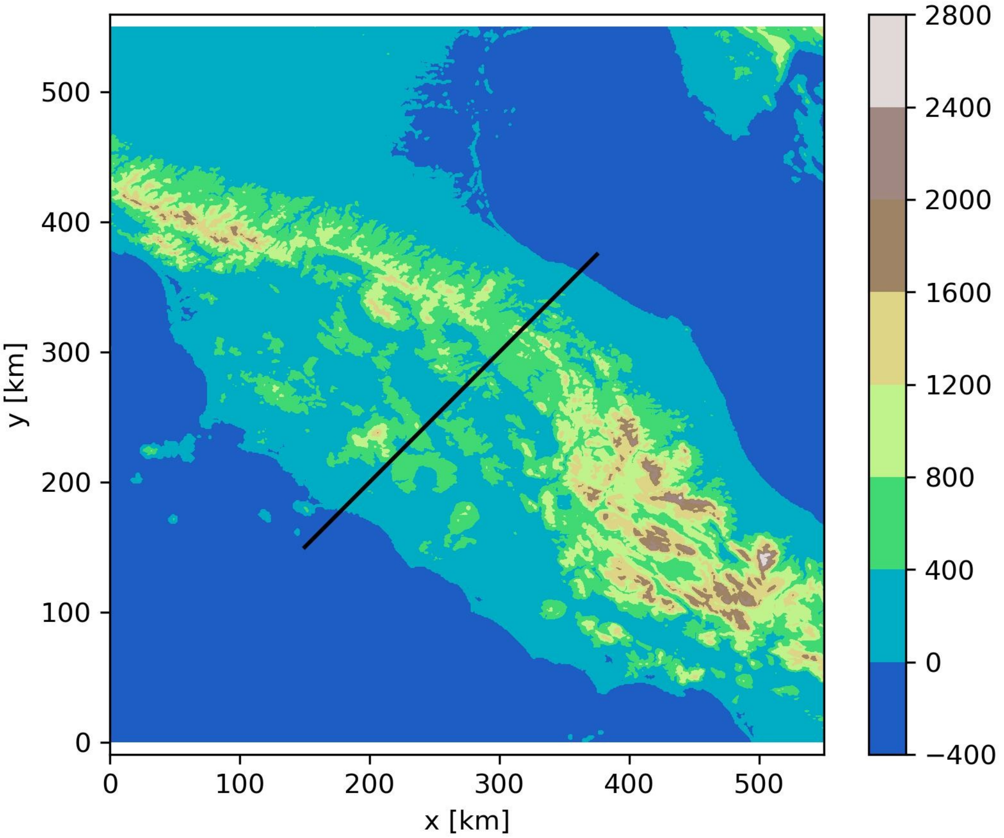

Figure 1: Terrain height from Digital Elevation model for the Central Italy. The black solid line shows the point used to evaluate cross section.

The cross section of mountains along the south-west north-east direction is used to understand the peak of mountain range and the width, as shown in Figure 2:

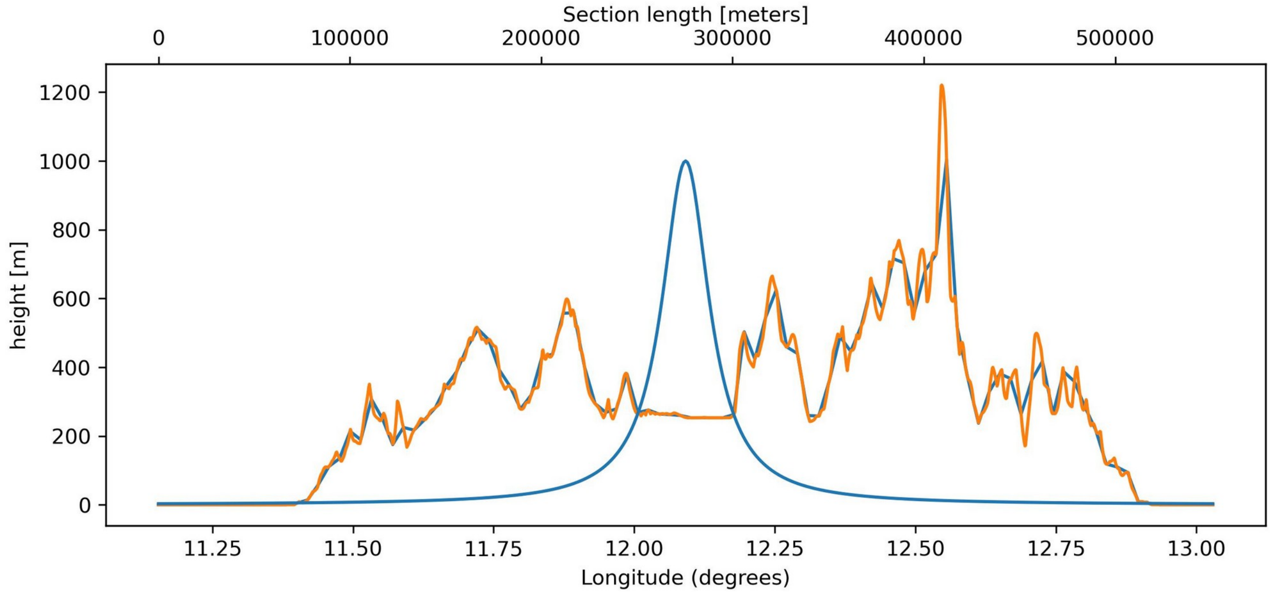

Figure 2: Cross section of Digital elevation model orography (orange line) and idealized bell-shaped mountain used in the simulation (blue line).

From the cross section plot we can see how complicate is the orography of the Apennines to be modeled in a simple profile. For the moment, we maintain a very simple profile with maximum height of about the same of the higher Apennines cross section (about 1000 m) and a total mountain width of about 30 km. The ideal mountain is located along the meridional direction at x=250 km for the squared domain experiment and at x=650 km, where the domain is elongated along the x direction.

Initial condition were discussed in the previous report and are represented by the sounding observed at Decimomannu station on the 15 September at 00:00 UTC. This initial condition is reported on Figure 3.

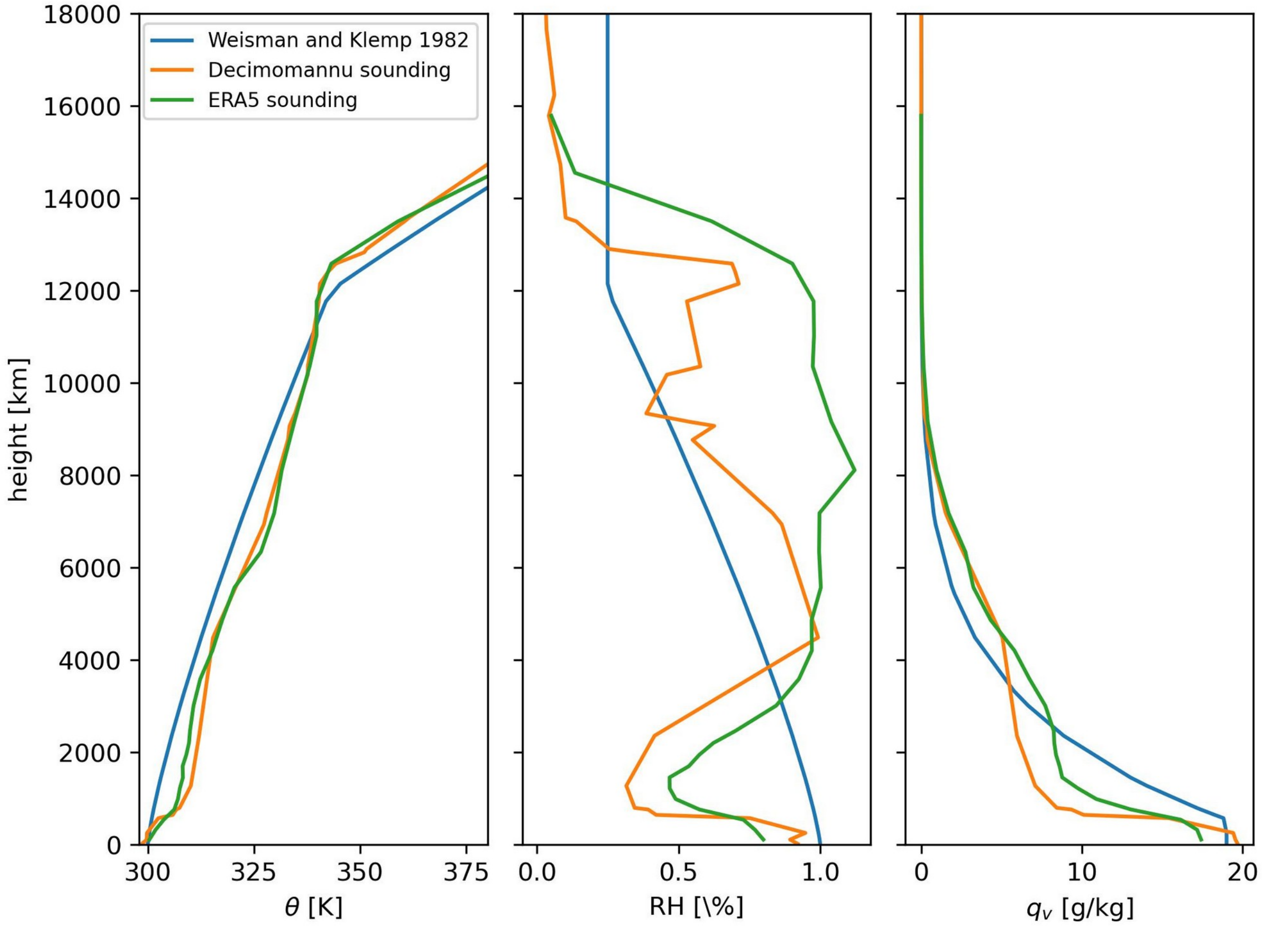

Figure 3: Comparison of vertical profiles of potential temperature, relative humidity and specific humidity as obtained from the theoretical shape of Weisman and Klemp (1982), the sounding from Decimomannu and the sounding from ERA5 at Decimomannu. Time is 15th September 2022 at 00:00 UTC.

The parameters used here to build the Weisman and Klemp (1982) profile (WK) shown in Figure 3 were: z_tr=12000 m, th_tr=343 K, t_tr= 213 K, th_0=300 K, qv_pbl= 0.019 g/kg. The comparison shows that the actual profile is warmer of about 2/3 K than the WK profile across all the free troposphere. Moreover with respect to the humidity profile, it is much drier in the lower free troposphere and upper boundary layer (of about 5/10 g/kg), and moister on the upper troposphere. Such features are a first difference in the input with respect to idealized simulations in the literature (Miglietta and Rotunno 2012). The initial wind profile is set to constant in the west-east direction and with a magnitude equal to 10 m/s. This constant wind speed and direction is somehow different from the observed situation (Figure 4) where the wind is more aligned with the north-west in the lower troposphere (below 800 hPa) with respect to the south-west direction in the upper troposphere (above 800 hPa). Moreover the wind speed seems to have a constant increase with height with a local maximum at about 900 hPa.

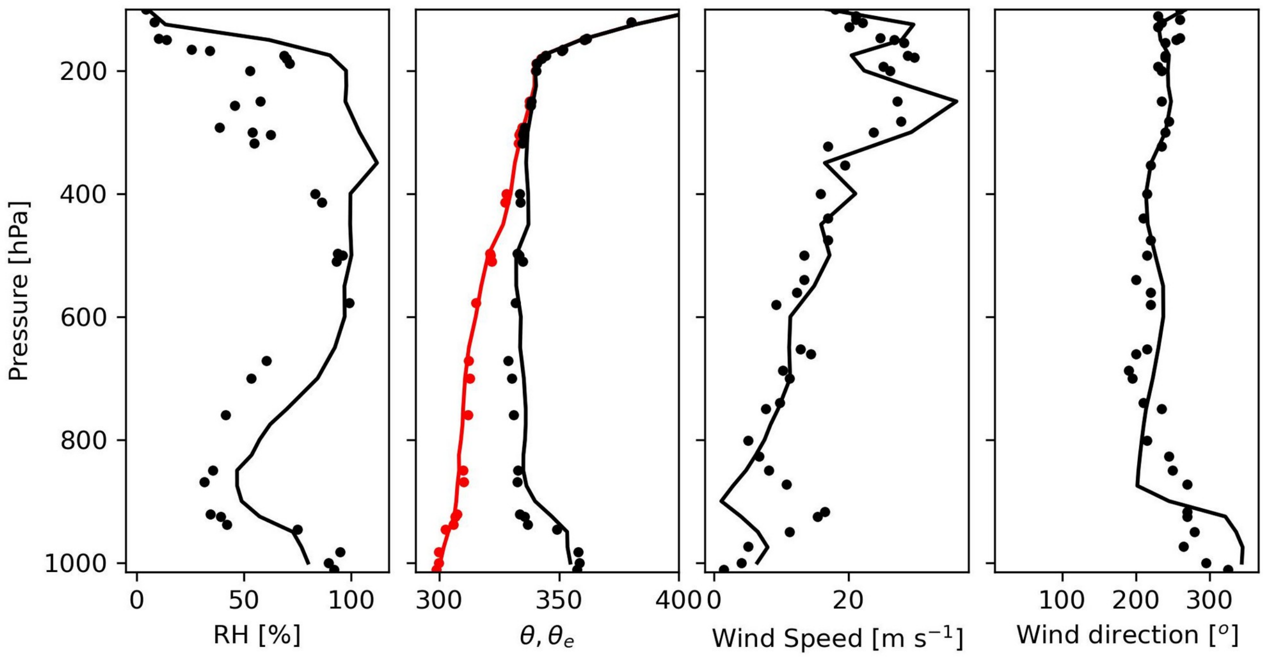

Figure 4: Vertical profiles of main quantities from ERA5 sounding (solid line) and Observations (dots) as used for evaluating initial conditions.

We tested various configuration both on domain size, lateral boundary conditions and surface characteristics:

Experiment	Domain	NS_lateral	WE_lateral	Bottom_BC
Exp1	Squared (550*550)	Periodic	Open-Radative	Land-surface model with mountain, semi-slip (Tsk=301)
Exp2	-	Open-radiative	Open-radiative	-
Exp3	Elongated (1000x550)	-	-	-
Exp4	-	-	-	Land-surface model without mountain, semi-slip (Tsk=301)
Exp5	-	-	-	Water surface, SST=301

Cumulated rain

The cumulated rainfall shows always a larger peak close to the flow inlet and a secondary smaller peak over the mountain ridge (Figure 5 to Figure 9). Both over land and over sea, with or without mountain, the initial conditions together with bottom boundary conditions are such that the convection starts suddenly and large rainfall rates are reached close to the western boundary. The only way we find to kill the initial convection and produce a stationary system over the mountain was to adopt the simulation settings by Miglietta and Rotunno (2009): free-slip bottom boundary conditions and LES setup without surface fluxes, radiation and PBL scheme. In that case we get a much smaller cumulated rainfall but which remains stationary over the mountain ridge (not shown). The simulation over water (without mountain, Figure 9) shows a delayed rainfall development with respect to those performed over land (with or without mountain, Figure 5 to Figure 8).
The secondary peak of cumulated rainfall encountered in caused by the creation of a squall line which form from the large convective systems present at the inlet boundary (Figure 10 to 12). Such squall line propagates eastward and dissipates at the mountain ridge for those experiments with a mountain, while it dissipates at the end of the domain for those experiments without the mountain. The squall line is present also in the simulation over water. The intensity of squall line precipitation

rate in simulation with mountain is higher than those without mountain. However, such squall line system is not recreated after it dissipates at the end of the domain or at the mountain ridge.

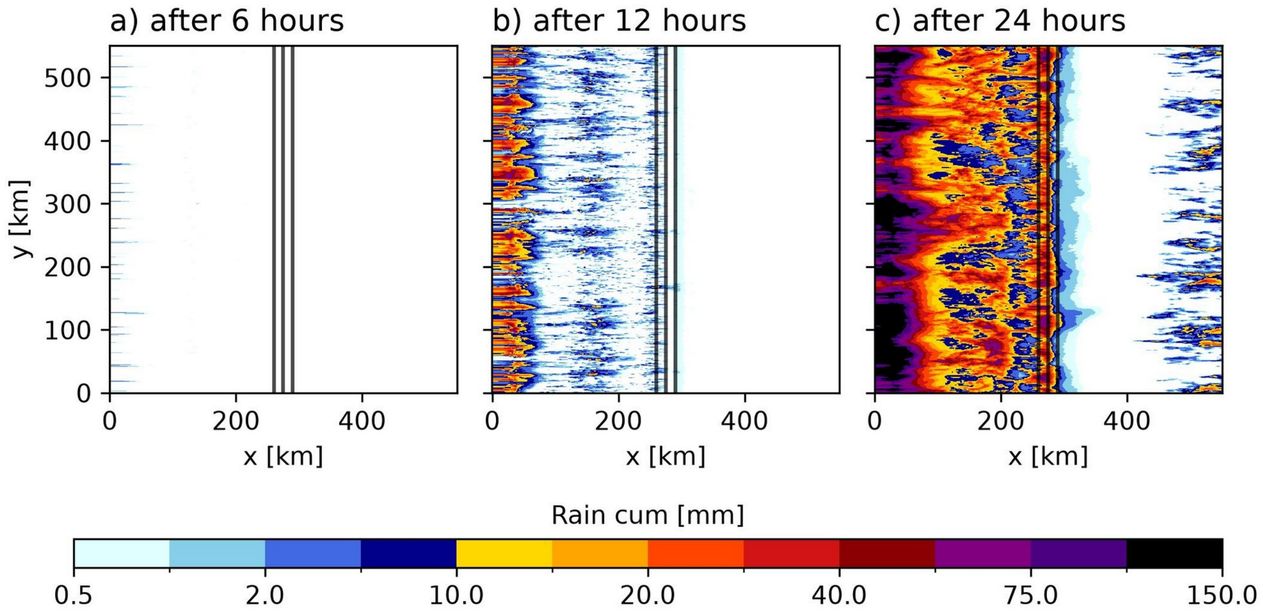

Figure 5: Cumulated rainfall for Exp1

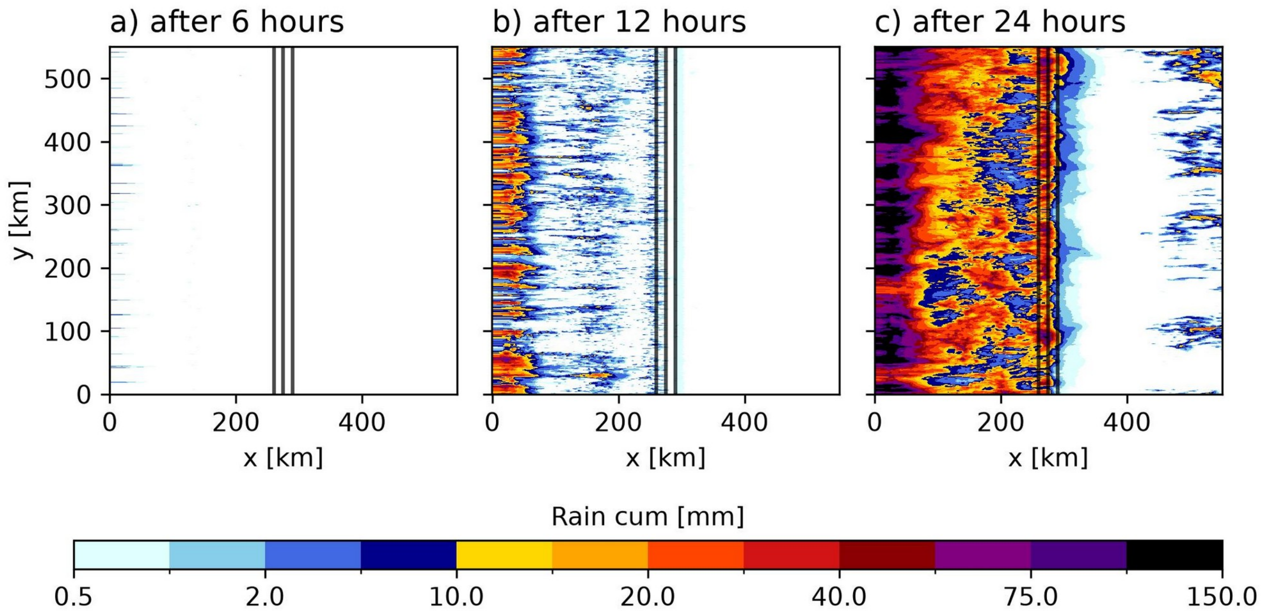

Figure 6: Cumulated rainfall for Exp2

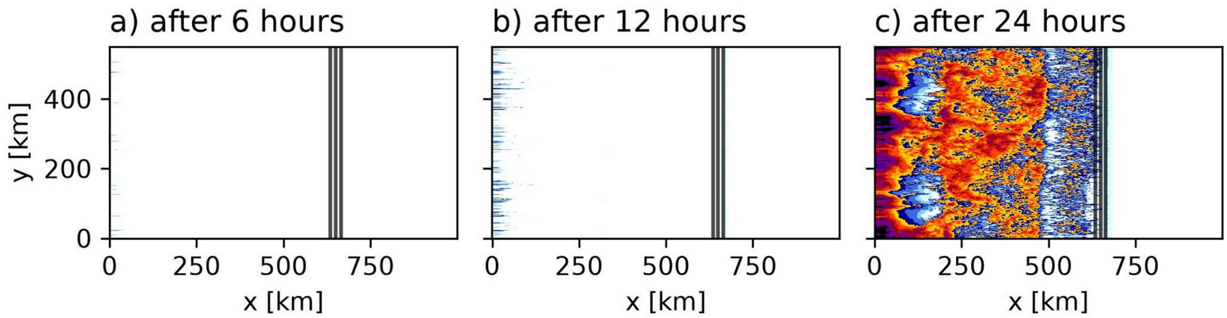

Figure 7: Cumulated rainfall for Exp3

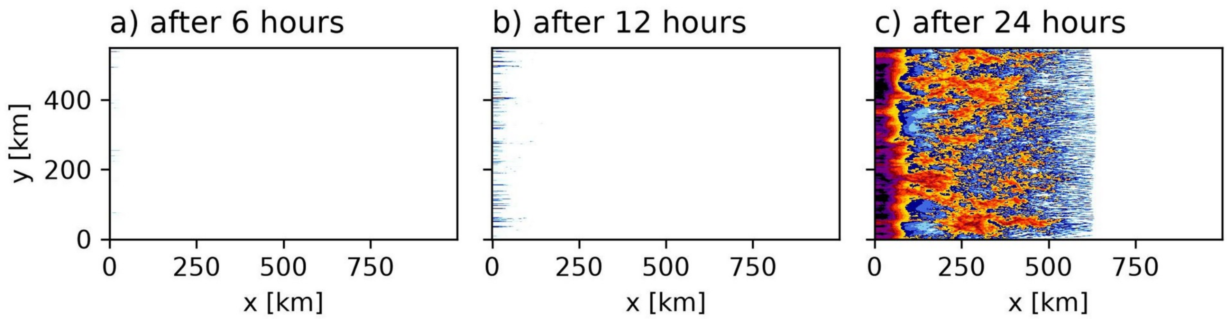

Figure 8: Cumulated rainfall for Exp4

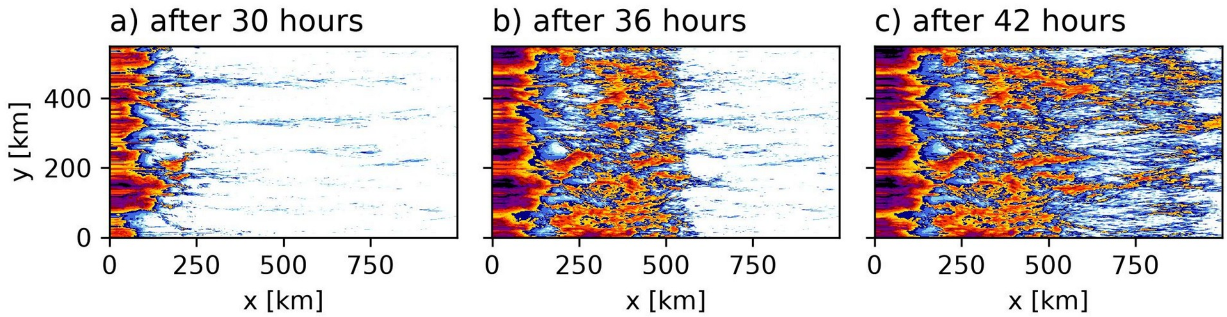

Figure 9: Cumulated rainfall for Exp5. To be noted the different timestep from the previous figures.

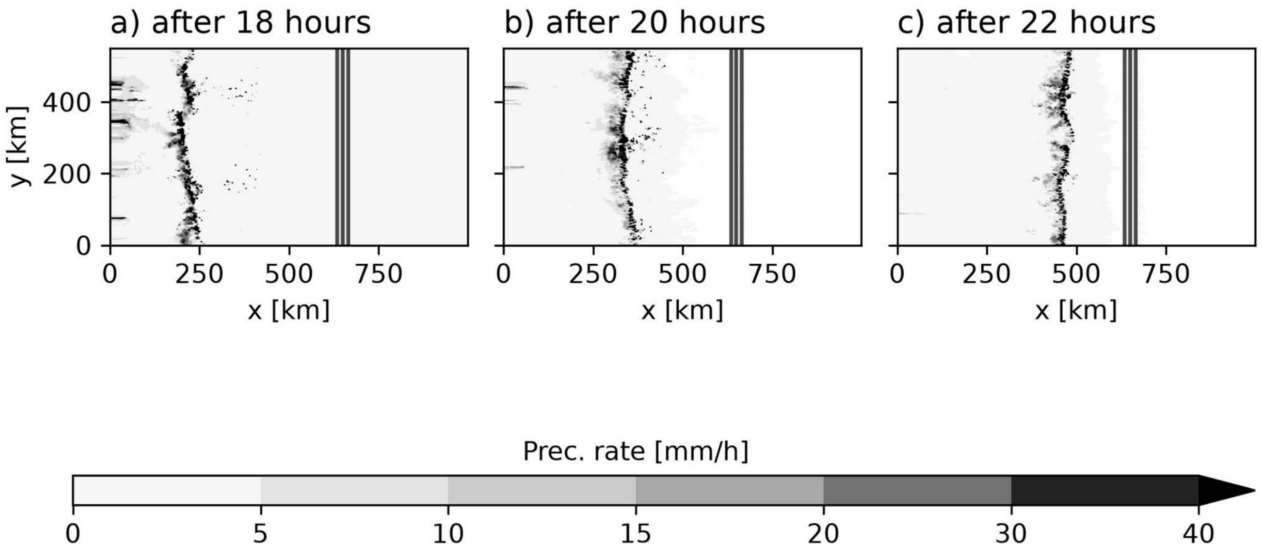

Figure 10: Rainfall rate for Exp3

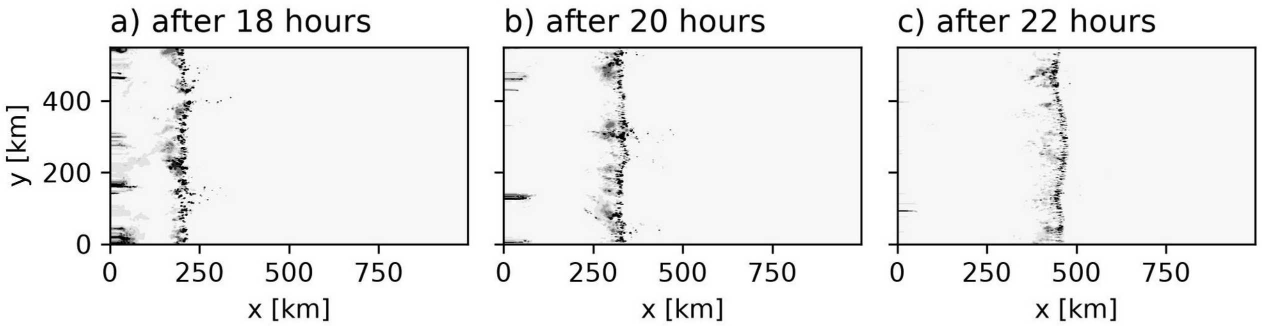

Figure 11: Rainfall rate for Exp4

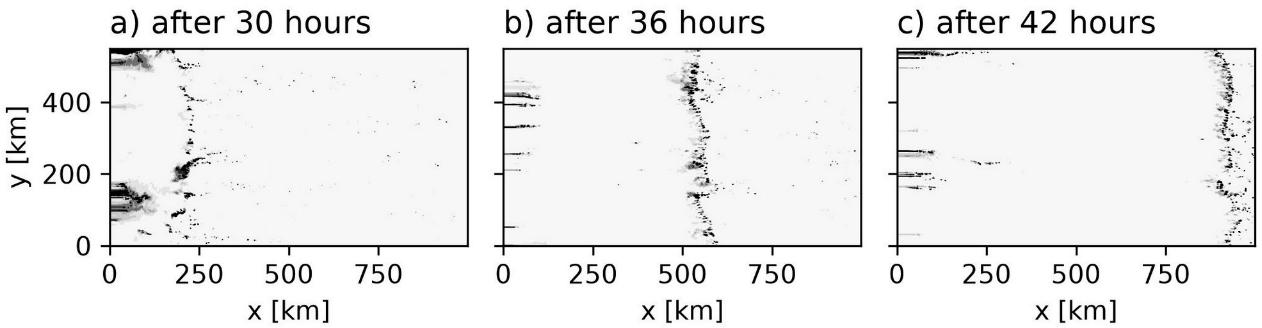

Figure 12: Rainfall rate for Exp5

References:

L. Silvestri, M. Saraceni, and P. Bongioannini Cerlini. Links between precipitation, circulation weather types and orography in central italy. International Journal of Climatology 42.11: 5807-5825, 2022

Bresson E, Ducrocq V, Nuissier O, Ricard D, de Saint-Aubin C. 2012. Idealized numerical simulations of quasi-stationary convective systems over the Northwestern Mediterranean complex terrain. Q. J. R. Meteorol. Soc. 138: 1751–1763. DOI:10.1002/qj.1911

Weisman, Morris L., and Joseph B. Klemp. "The dependence of numerically simulated convective storms on vertical wind shear and buoyancy." *Monthly Weather Review* 110.6 (1982): 504-520.

Miglietta, Mario Marcello, and Richard Rotunno. "Numerical simulations of conditionally unstable flows over a mountain ridge." *Journal of the Atmospheric Sciences* 66.7 (2009): 1865-1885.