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SafeLand

Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies

7th Framework Programme
Cooperation Theme 6 Environment (including climate change)
Sub-Activity 6.1.3 Natural Hazards

Deliverable 3.4

Report on projected changes in meteorological extreme events in Europe with a focus on Southern Italy, the Alps, Southern Norway, and Romania:
Synthesis of results

Work Package 3.1 – Climate change scenarios for selected regions in Europe

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Revision: 1

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SUMMARY

The SafeLand work package 3.1 focuses on climate change scenarios for selected regions in Europe. The main objective is to provide information on expected climatic changes in Europe on different scales with focus on meteorological extreme events. These are in particular heavy precipitation events which can act as triggers for severe landslides. Three deliverables, D3.1, D3.2, and D3.3, have been carried out. This report presents a synthesis and discussion of the results. The analysis concentrates on projected future changes in heavy precipitation for four target regions in Europe: Southern Norway, Southern Italy, the Alps, and Romania. In winter a general trend towards more and more intense heavy precipitation events is found in particular for southern Norway. Also, strong trends are projected in mountainous regions. In summer, decreasing trends of heavy precipitation dominate in the simulations over southern Europe. However, increasing trends in the extreme events are found for some regions which become drier otherwise.

Note about contributors

The following organisations contributed to the work described in this deliverable:

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CONTENTS

1 INTRODUCTION

Prolonged periods of rainfall and intense daily precipitation events can act as effective triggers for severe land slides and flood events. These hazards are able to cause enormous losses of infrastructure, cultural heritage, and human lives.

It is therefore of high importance to understand the processes that could possibly change the nature of heavy precipitation events in the future. In a warming climate due to enhanced greenhouse gas concentrations in the atmosphere, precipitation in general and its upper percentiles in particular are expected to increase. Whereas the mean precipitation is proposed to change due to the global energy budget, the heavy precipitation is expected to change due to the increased amount of the column-integrated water vapour which the atmosphere can hold when the air temperature is increasing. This hypothesis is based on the Clausius-Clapeyron relation, which describes the nonlinear increase of the saturation vapour pressure of water to the temperature. Also, the availability of moisture is expected to steer the intensity of heavy precipitation events. On the other hand, the location, frequency, and intensity of heavy precipitation could possibly change due to dynamic causes like the large-scale circulation of the atmosphere, which modifies the transport of moisture to certain regions.

Since meteorological extreme events, in particular heavy precipitation events, are often associated with regional or local scale characteristics, high resolution regional climate models (RCMs) represent an appropriate tool to investigate such events and their changes in the future.

The classical hydrostatic RCMs are currently able to reach grid refinements down to about 10 x 10 km^2 resolution. Even higher resolutions can be reached with non-hydrostatic RCMs. Although it is reasonable to aim for the highest resolution, simulating large spatial domains with a very high resolution can be computationally very expensive. Therefore the resolution is chosen depending on the domain and the focus of interest. The focus of the SafeLand work package (WP) 3.1 is the analysis of climate change scenarios for selected regions in Europe. To investigate changes in meteorological variables on a wide range of scales, the resolution is stepwise refined within WP 3.1. In deliverable 3.1 (D3.1), entitled “Overview on and post-processing of available climate change simulations for Europe on a spatial scale of 25*km* with a special focus on meteorological extreme events” changes in heavy precipitation over the whole European domain are analyzed; in deliverable 3.2 (D3.2), entitled “REMO climate change simulations with 10*km* horizontal resolution for case study sites in Southern Italy, the Alps, Southern Norway, and Romania” simulations in different regions over Europe are performed and their output described; deliverable 3.3 (D3.3), entitled “Analysis of selected extreme precipitation events with the COSMO-CLM model on a spatial scale of 2.8 *km*” concentrates on localized heavy precipitation events at hot spot areas for land slides in Europe.

This report provides a synthesis of the major achievements in the SafeLand WP 3.1. The most important results from the deliverables D3.1, D3.2, and D3.3 are summarized and discussed. This report focuses in particular on the four target regions: Southern Italy, the Alps. Southern

Norway, and Romania. In chapter 2 a short overview of the deliverables in WP 3.1 is given, in chapter 3 an overview over the main results is given, and finally, the results are discussed and concluded in chapter 4.

2 THE MODEL CHAIN

The analyses discussed in WP 3.1, are related to model output from different RCMs at a range of spatial resolutions. In D3.1, changes in heavy precipitation simulated by an ensemble of regional climate models are investigated. The simulations stem from the EU FP6 project ENSEMBLES. Regional climate models need lateral boundary forcing data like temperature, wind, surface pressure and moisture and surface boundary conditions like the temporal variable sea surface temperature and sea ice extent, which are provided by different general circulation model (GCM) simulations. The GCM simulations are forced by changing greenhouse gas concentrations according to the A1B scenario of the 4^{th} IPCC Assessment Report (IPCC, 2001). The regional simulations are performed for the time period 1961-2099 and cover the whole European domain with a spatial grid resolution of 25 x 25 km^2.

In D3.2, climate change simulations at 10 x 10 km^2 spatial resolution are performed with the regional climate model REMO (Jacob, 1997; Jacob 2001; Jacob et al., 2001; Jacob et al., 2007), for three European sub-regions: Northern Europe, Eastern Europe, and Italy and the Alpine area. The grid refinement to a resolution of 10 x 10 km^2 is achieved using a double-nesting procedure: In the first step, which was carried out in the above mentioned ENSEMBLES project, the regional climate model REMO at 25 x 25 km^2 resolution has been nested into the global climate model ECHAM5/MPI-OM. A second step of grid refinement is carried out in the SafeLand D3.2: the simulations of REMO at 25 x 25 km^2 provide the boundary data for the REMO simulations at 10 x 10 km^2. The simulations in D3.2 are carried out for the time period 1951-2050 with changing greenhouse gas emissions according to the A1B scenario.

A further step of grid refinement is applied in D3.3, which focuses on localized climatic changes at four test sites located in different regions of Europe. In fact, for this purpose, the 10 x 10 km^2 resolution simulations from D3.2 serve as boundary conditions for the non-hydrostatic regional climate model COSMO-CLM (Rockel et al. 2008) at a resolution of 3.8 x 3.8 km^2. These simulations are carried out for areas of 300 x 300 km^2, centred on selected geographical points. These are Nedre Romerike (Norway), Pizzo d'Alvano (Italy), Barcellonette (France), and Telega (Romania).

In this way, the climate change simulations carried out in SafeLand WP 3.1 are connected to each other and can be seen as a model chain. The RCM simulations zoom from the whole European perpective to small regions, which may be hot spots for the occurrence of land slides. The model domains and the model chain are illustrated in Figure 1 and Figure 2, respectively.

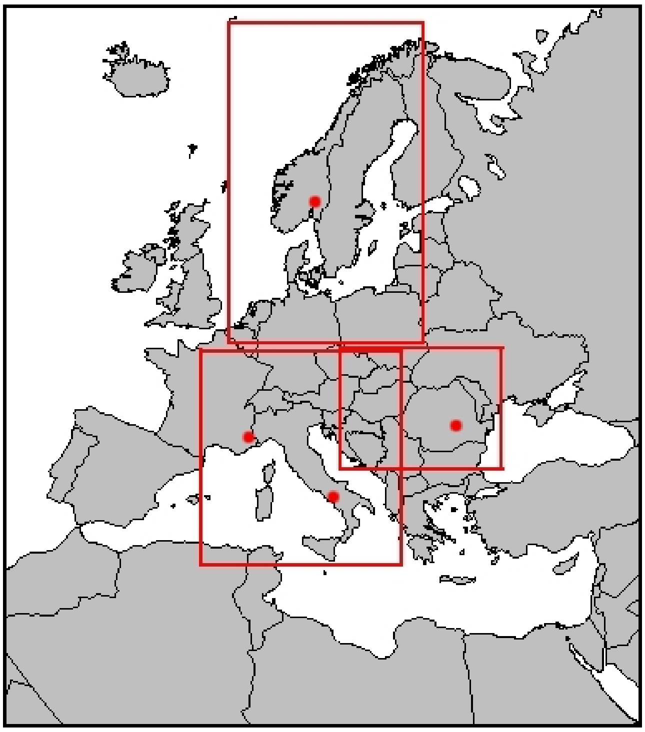

Figure 1: Ilustration of the model domains: Entire Europe, selected domains for the REMO simulations with 10 x 10 km² grid resolution (red boxes), and the selected points, on which the COSMO-CLM simulations with 3.8 x 3.8 km² grid resolution are centred.

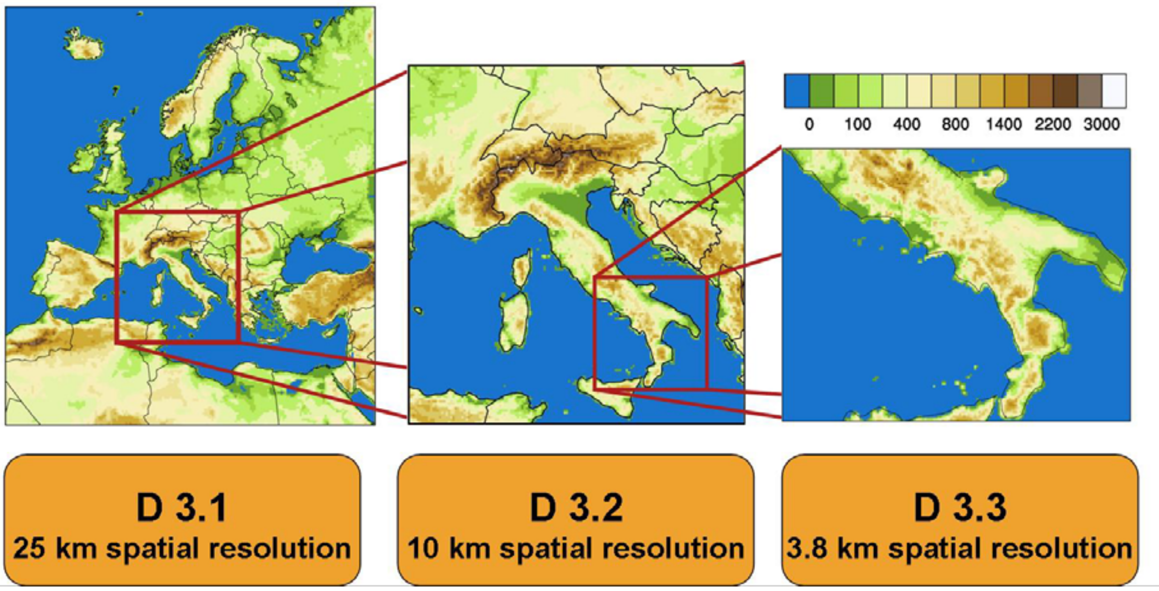

Figure 2: Ilustration of the downscaling chain, example: Italy. From left to right: Entire Europe, selected domain for the REMO simulations with 10 x 10 km² grid resolution and the selected area of the COSMO-CLM simulations with 3.8 x 3.8 km² grid resolution.

3 SYNTHESIS OF RESULTS

3.1 RESULTS OF DELIVERABLE D3.1

In deliverable D3.1, future trends in heavy precipitation simulated by an ensemble of regional climate models are investigated. The simulations cover the time period from 1961 to 2099 and the whole European domain with a resolution of 25 x 25 km^2. An extreme-value analysis with time dependent parameters is applied to daily sums of precipitation. In that way, trends of the 99^{th} percentile, which refers to a return value of an event that occurs about once per season, can be estimated at each grid point of the model domain. Summer and winter are examined separately to identify seasonal characteristics in the patterns of changes.

The changes across the ensemble of eight RCM simulations are tested for their robustness in terms of inter-simulation agreement. Uncertainties in RCM simulations may be caused in particular by processes which take place on scales smaller than resolved by the RCM resolution and have to be parameterized. One of these parameterizations is the convection scheme for cumulus clouds. Across the ensemble of RCMs used in deliverable D3.1, a variety of these schemes is implemented. Another source of uncertainty can be the driving global model, which influences the large-scale dynamics in the RCM. Different global climate models simulations are used as boundary conditions for the RCMs in this analysis. The analysis of the robustness therefore gives an idea about the uncertainty of changes. Robust changes are found for many regions of Europe, both in winter and summer.

Figure 3 displays the number of RCM simulations which agree on a positive trend in the 99^{th} percentile of daily precipitation in winter (left) and summer (right). A number above 4 indicates that the majority of simulations projects a positive trend, a number below 4 that the majority projects a negative trend in heavy precipitation. The darker the red or blue colour, the higher is the robustness.

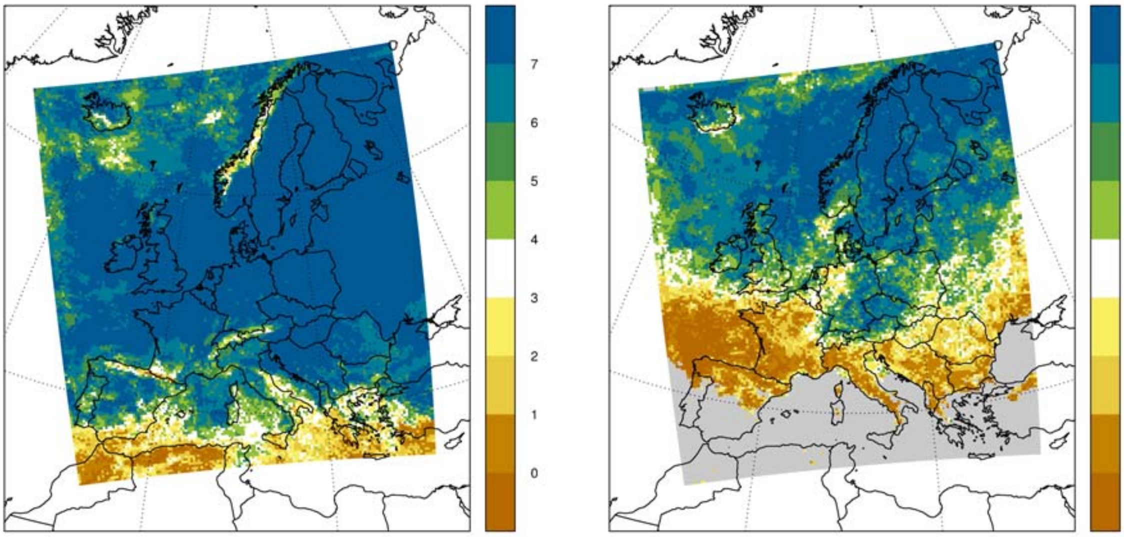

Figure 3: Number of models which agree on a positive change in the 99th percentile of daily precipitation for winter (left) and summer (right).

The large-scale pattern of heavy precipitation changes appears to be consistent across the simulations. In winter the simulations agree in particular well on the positive changes in heavy precipitation over the northern and central European land masses. Inconsistencies are mainly found in regions where regional features play a large role. This is in particular the case in the mountainous regions or at the foothills of the mountains. In summer most model agree on the positive trends in heavy precipitation over Scandinavia and on the negative trends over southern Europe. Largest inconsistencies are found in the transition zone across central Europe which separates areas with positive trends in the North and areas with negative trends in the South.

The main regions of interest in SafeLand WP 3.1 are Southern Norway, Southern Italy, the Alps and Romania. Figure 4 to 7 show cut-outs of these regions for the trends in the *99th* percentile of daily precipitation from the simulation with the RCM REMO, driven by the GCM ECHAM5/MPI-OM. The simulation is chosen exemplarily here, since its model output variables serve as boundary conditions for the simulations carried out in D3.2.

In winter the trends in heavy precipitation over Southern Norway (Figure 4, left) are positive up to 30 % in the lowland areas and negative over the mountains. In the western coastal area, where precipitation is well known to be frequent, heavy precipitation is not projected to increase much. It has to be noted that the robustness across the ensemble is low in the mountains and along the coast line (see Figure 3). In other words, the REMO results in this

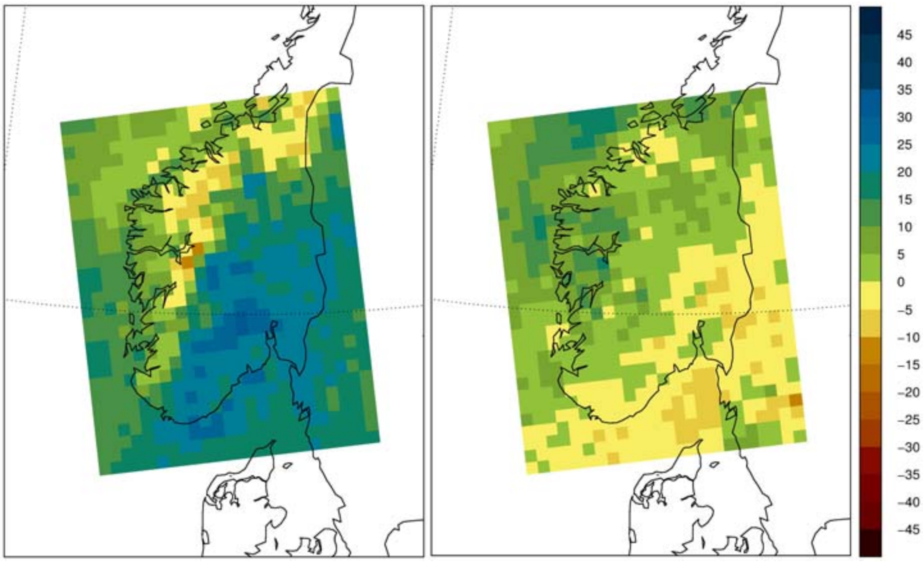

Figure 4: Relative trend of the 99th percentile of daily precipitation in % over Southern Norway for 1961-209, winter (left) and summer (right).

region are not consistent with all other simulations of the ensemble. In summer (Figure 4, right) the trends in heavy precipitation are negligibly small over Southern Norway.

For Romania (Figure 5), REMO projects increasing trends of the *99th* percentile of daily precipitation in winter, and decreasing trends dominate in summer. In winter, the trends are strong in particular over the Carpathian Mountains. In this region, the trends tend to be positive also in summer, but are comparatively weak.

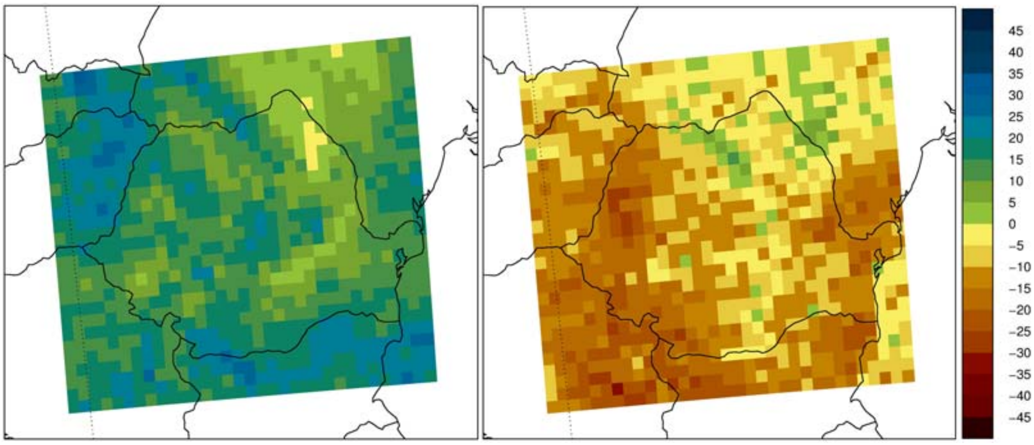

Figure 5: Relative trend of the 99th percentile of daily precipitation in % over Romania for 1961-209, winter (left) and summer (right).

Over the Alps (Figure 6), heavy daily precipitation events are projected to increase on the south side in winter, but only insignificantly change on the north side. In summer, the trends are positive over the locations with the highest altitudes (see Figure 2), but mainly negative over the foothills.

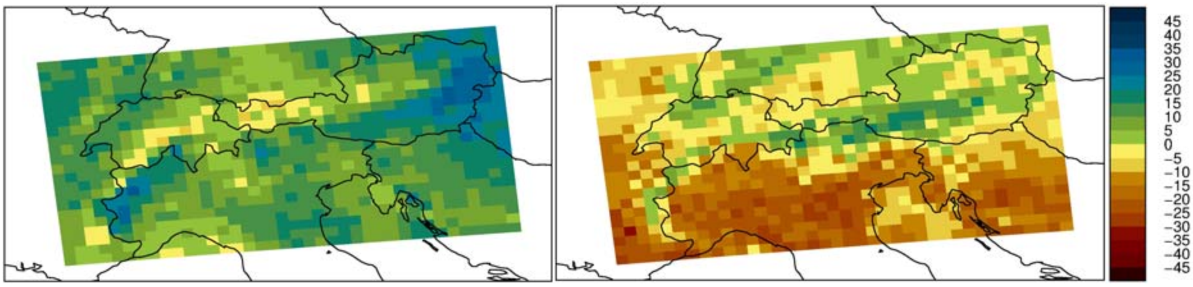

Figure 6: Relative trend of the 99th percentile of daily precipitation in % over the Alps for 1961-209, winter (left) and summer (right).

In Southern Italy, REMO simulates weak changes of heavy precipitation for winter. In the northern part of the area, the trends tend to be positive, the more southerly, the more the trends tend to be negative. In summer, decreasing trends in heavy precipitation dominate over the land masses.

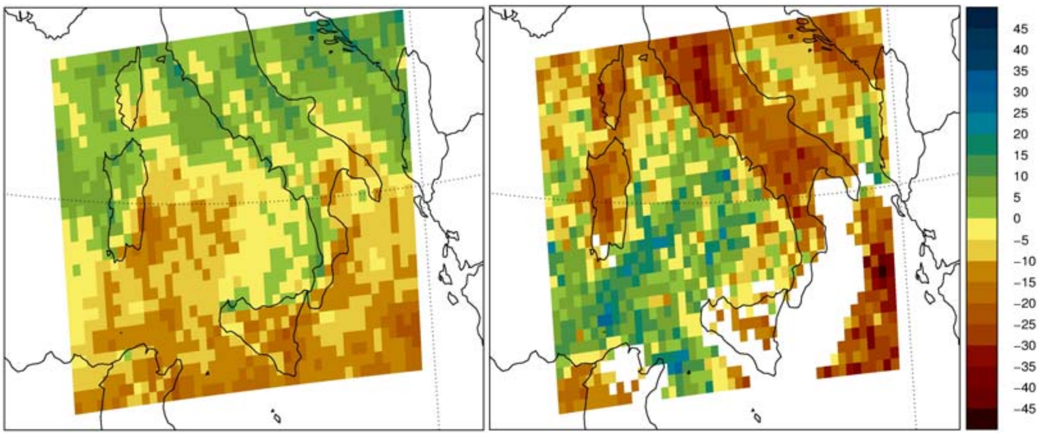

Figure 7: Relative trend of the 99th percentile of daily precipitation in % over Southern Italy for 1961-209, winter (left) and summer (right). White colours mark grid boxes which were excluded from the analysis because the 95th percentile is below 0.5 mm.

It is important to remark that the robustness of the results across the ensemble of RCM simulations (Figure 3) is weak over the coastal region of southern Norway and over southern Italy in winter and over the Alps both in winter and summer. Therefore, the trends simulated by another model than the RCM REMO, whose results have been shown exemplarily in Figure 4-7, might differ considerably. The analysis from the whole ensemble of RCM simulations is shown in D3.1.

3.2 RESULTS OF DELIVERABLE D3.2

The task of deliverable D3.2 is to carry out simulations with the regional climate model REMO at 10 x 10 km^2 spatial resolution for three sub-regions of Europe: Northern Europe, Eastern Europe and Italy and the Alps. The simulations are performed in order to provide climate change projections covering the time period from 1951 to 2050. The model output data of D3.2 have been delivered to CMCC as boundary data for simulations with the regional climate model COSMO-CLM at a resolution of 3.8 x 3.8 km^2. D3.2 describes the model setup and the analyses of the temperature and precipitation changes that have been processed from the model output data.

Figure 8 shows the model's representation of the topography in the three domains. One can see that with a grid spacing of 10 x 10 km^2 many regional characteristics, such as wider valleys or even mountain peaks can be resolved. Generally, the altitudes of the mountains tend to be underestimated by the model, since the topography is represented only by an average for each grid box.

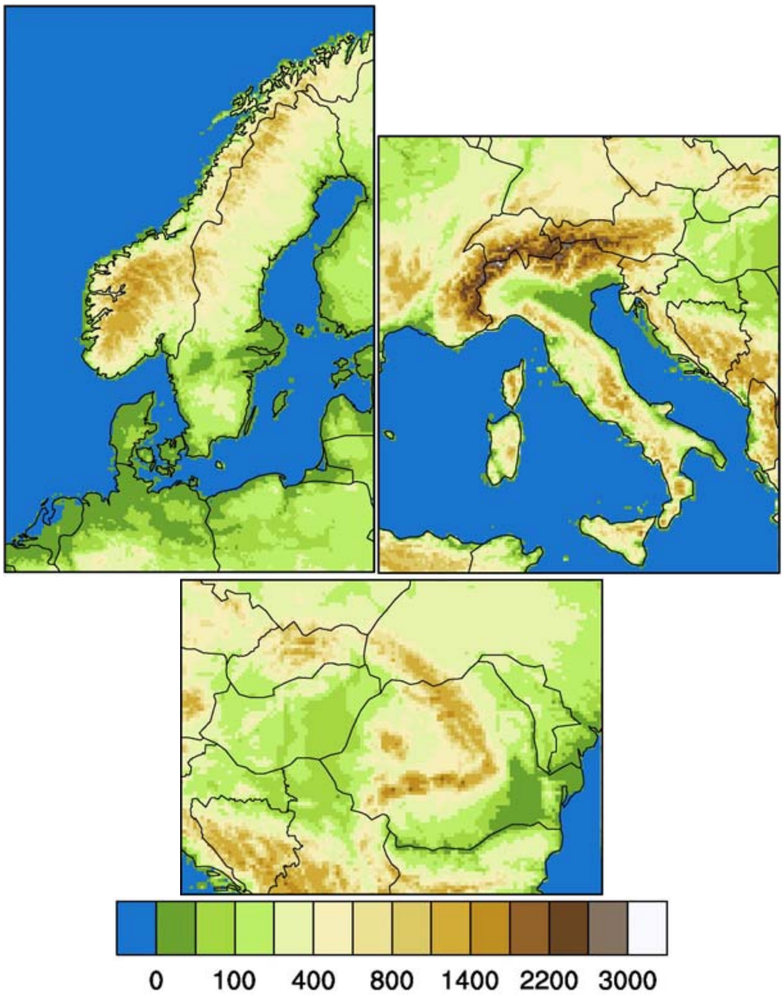

Figure 8: Topography in meters above sea level as it is represented in the model, for Northern Europe (top left), Italy and the Alps (top right), and Eastern Europe (bottom).

The REMO simulations at 10 x 10 *km²* resolution represent temperature and precipitation patterns associated with orographic features and other regional details of the model domains more accurately than REMO simulations at coarser resolution.

The climatic changes projected by the model are analysed by comparing the averages for the time periods 2021- 2051 and 1971-2000 for winter, spring, autumn, and summer separately. Considerable changes are found both for temperature and precipitation. The model projects the 2-meter temperature to increase in each domain, but the magnitudes of change differ depending on various factors, such as orography. In the colder regions, the increasing temperatures may cause a later onset of snow build-up in autumn and an earlier onset of snow melt in spring. Since the snow-free surface is darker, it reflects less sunlight and absorbs a larger fraction of the radiation. The solar short wave radiation is converted into terrestrial long wave radiation, and radiated back to the lower atmosphere as additional heat. As a consequence, the increase in temperature in colder regions may be enhanced. The changes of precipitation tend to be positive in cooler climate regions, in particular in the mountains. Over Southern and Eastern Europe, precipitation is widely projected to decrease in spring, summer, and autumn.

For the four target regions of WP 3.1, Southern Norway, Romania, Southern Italy, and the Alps, the changes of temperature and precipitation are summarized as follows:

- **Southern Norway:** The temperatures are projected to increase by up to 1 *K* in winter, but stronger during the other seasons. Strongest warming trends up to 2 *K* are found over the mountain massif in autumn, when the ice-albedo feedback plays a role. The precipitation change is strongest in spring along the Norwegian coast line, with up to 30 *%* increase. In winter, negative trends dominate along the coast line, but positive trends are found east of the mountain massif. In summer and autumn, the projected changes are comparatively weak, but tend to be positive in summer and negative in autumn.

- **Romania:** The temperature changes over Romania are strongly characterized by the Carpathian Mountains, which divide the country into the northwestern part with maritime climate, the eastern part where continental climate is prevailing, and the southern part, whose climate is highly influenced by the Mediterranean. In winter and spring, the temperature increase is strongest east of the Carpathian Mountains, with values up to 1.8 *K* in winter. Strong warming trends are associated with the highest mountain peaks, but the temperature increase weakens towards the foothills of the mountains. In summer and autumn, the temperature increase is with up to 2 *K* strongest in the southern part with Mediterranean climate. The precipitation changes are positive in winter and mainly negative during the other seasons. On the upwind side of the mountains, the precipitation increase reaches more than 30 *%* in winter, in Southern Romania, precipitation decreases by up to 30 *%* in summer and autumn.

- **Southern Italy:** The temperature increase until 2050 reaches up to 2 *K* in summer and autumn. Weaker trends are found for winter and spring. Again, the strongest trends are associated with mountains in southern Italy and on Sicily. REMO projects the winter precipitation mainly to increase over the southern part of the Italian peninsula with the largest trends of up to 30 *%* over Calabria. On the other hand, decreasing trends are found over Sicily. In the other seasons, negative trends dominate. In summer, precipitation decreases by more than 30 *%*. Nevertheless, for some grid boxes at the east coast of Sicily and at the gulf of torrent the model suggests increasing precipitation even in summer.

- **The Alps:** The temperature changes in the Alpine region are highly characterized by the topography. In all seasons, the strongest trends are associated with the mountain peaks. In winter this is striking in particular, because the temperature increases only by up to 1.6 *K* over the foothills of the mountains, but by more than 2 *K* in high altitudes. Positive changes of daily precipitation up to 20 *%* dominate in winter and autumn, in particular on the northern side of the Alps. In summer and spring the projected changes are mainly negative. Largest changes of down to –30 *%* are projected on the southern side of the Alps in summer. Over the highest mountains, positive trends are prevalent in all seasons.

3.3 RESULTS OF DELIVERABLE D3.3

Deliverable D3.3 aims to describe the activities related to the execution of regional climate simulations with the non-hydrostatic atmospheric model COSMO-CLM at a grid resolution of 3.8 x 3.8 km^2. Four domains have been chosen, each with a size of 300 x 300 km^2., centred on :

- Nedre Romerike, Norway
- Pizzo d'Alvano, Campania, Italy
- Barcellonette, Department of Alpes-de-Hautes-Provence, France
- Telega, Romania

The points are located inside the four target regions Southern Norway, Southern Italy, the Alps and Romania. Figure 1 illustrates their locations.
For each of the selected locations, the averages of the projected 2-meter temperature and the monthly precipitation are analyzed for the time periods 1971-2000 and 2021-2050. The changes in the future compared to the past are investigated for summer and winter separately. In order to analyze climatic characteristics of extreme precipitation events in the selected regions, the 10-year return levels of daily precipitation have been obtained with an extreme value analysis. Moreover, the changes of heavy precipitation for the simulation period 2021-2050 with respect to 1971-2000 have been analyzed.

The results of D3.3 are summarized in the following. Figure 9 to 12 show the changes in heavy precipitation.

- **Nedre Romerike:** Strong temperature increases (up to 3.2 *K*) are expected in winter, and between 1 and 2 *K* in summer, over the whole area. A general increase of precipitation is projected by COSMO-CLM in winter; in summer the western part of the domain shows a reduction, while the eastern part shows a slight increase of precipitation. The analysis of the 10-year return levels of daily precipitation shows that in the model simulation the strongest events occur in the north-west part of the domain, without significant differences between the two seasons. Figure 9 shows the projected changes of the 10-year return levels for the period 2021-2050 with respect to 1971-2000, for winter (left) and summer (right): similar patterns are obtained for both seasons, with a general increase of extreme events, which is strongest in the western part of the domain, where the strongest precipitation events are simulated.

- **Pizzo d'Alvano:** An increase of temperature of about 1 *K* is projected in winter over the whole region, reaching 1.5 *K* in the north-east part of the domain. In winter, strong increases of precipitation are expected in the area of Pizzo d'Alvano, while in summer slight reductions are expected over the whole domain. The largest intensities of extreme precipitation events are found in winter in the area of Pizzo d'Alvano (central part of the domain), but strong events are projected also in large parts of the simulated domain. Figure 10 shows the changes of the 10-year return levels for the period 2021-2050 with respect to 1971-2000, for winter (left) and summer (right): in the future period (winter), increases of the intensity of extreme events are projected in the north west part of the domain and along the western coastline, whereas minor decreasing trends are found elsewhere. A similar behaviour is simulated in summer.

- **Barcellonette:** Significant increases of temperature of up to 3 *K* are registered in both seasons, but especially in winter. An increase of precipitation of about 25 *mm/month* is expected in winter in the area of Barcellonette, and in small regions in both the seasons; small reductions are registered in wide parts of the domains in summer. In winter the largest intensities of extreme events are simulated in the south-west part of the domain, while in summer strong events are observed only on the boundaries. Figure 11 shows the changes of the 10-year return levels for the period 2021-2050 with respect to 1971-2000, for winter (left) and summer (right): the trends are low in general, but characterized in winter by a slight reduction of heavy precipitation events in the south-west part of the domain and a slight increase in the south-east part of the domain. Since these coincide with a maximum and a minimum in the simulated 10-year return levels during the period 1971-2000, this might indicate a shift of heavy precipitation events to the east. In summer, the picture is similar: positive changes are projected where heavy precipitation has a minimum and negative where it has a maximum.

- **Telega:** A general increase of temperature of about 1.5 *K* is expected over the whole domain, for both seasons. In winter, an average increase in precipitation of about 25 *mm* is expected in the area of Telega. At some grid points changes of up to 70 *mm* are projected. A general significant reduction of monthly precipitation amounts is expected in summer. Heavy precipitation events with largest intensities have been simulated in the central part of the domain both in winter and in summer. Figure 12 shows the changes of the 10-year return levels for the period 2021-2050 with respect to 1971-2000, for winter (left) and summer (right): a similar pattern of changes is expected for both seasons. Increasing trends occur mainly in the north-west of the domain with the magnitude of changes being higher in winter than in summer. In the south-east part of the domain, where the occurrence of heavy precipitation events is rare, no significant trends are found in either of the seasons.

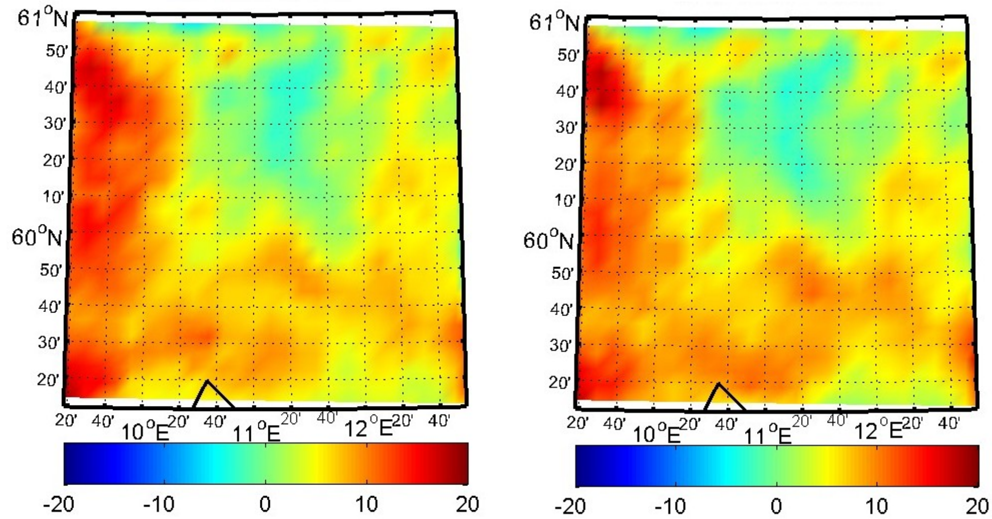

Figure 9: Change of 10-year return levels of precipitation (mm/day) in the Nedre Romerike region, Norway: values on the period 2021-2050 minus values on the period 1971-2000 for winter (left) and summer (right).

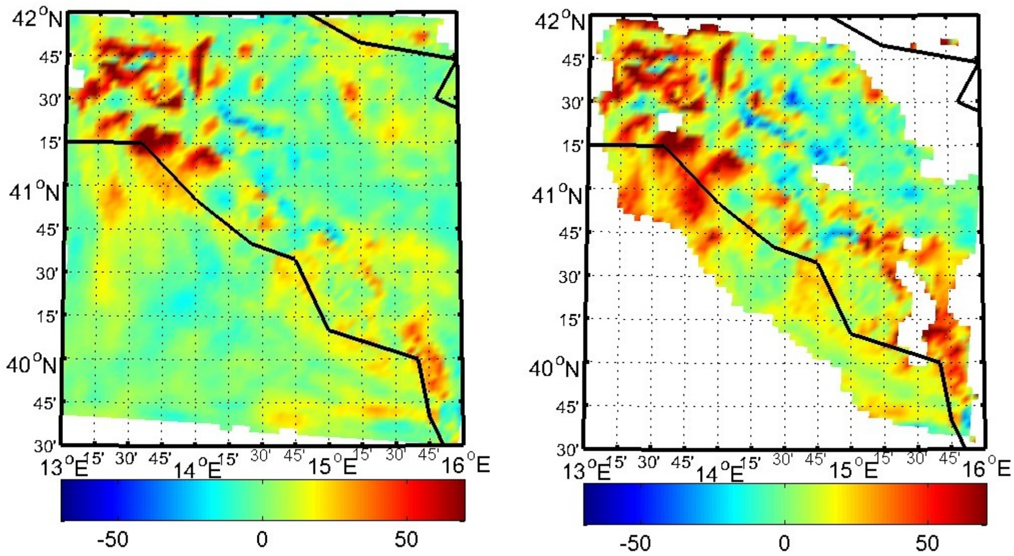

Figure 10: Change of 10-year return levels of precipitation (mm/day) in the Pizzo d'Alvano region, Italy: values on the period 2021-2050 minus values on the period 1971-2000 for winter (left) and summer (right).

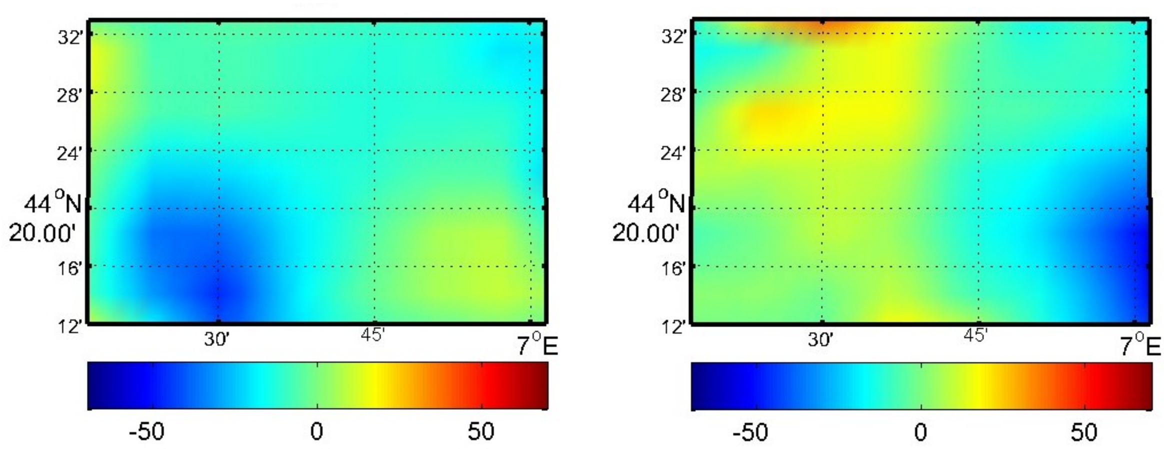

Figure 11: Change of 10-year return levels of precipitation (mm/day) in the Barcellonette region, France: values on the period 2021-2050 minus values on the period 1971-2000 for winter (left) and summer (right).

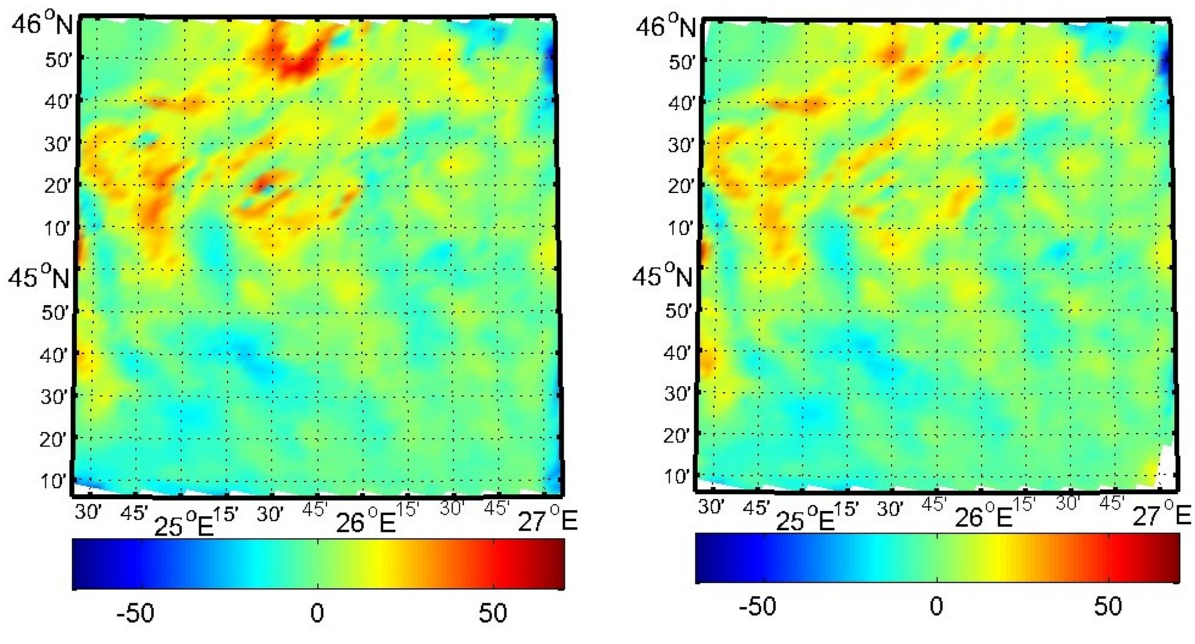

Figure 12: Change of 10-year return levels of precipitation (mm/day) in the Telega region, Romania: values on the period 2021-2050 minus values on the period 1971-2000 for winter (left) and summer (right).

4 DISCUSSION AND CONCLUSIONS

In the SafeLand work package W3.1, climate change scenarios for selected regions in Europe have been investigated with focus on meteorological extreme events. Expected future climate conditions have been simulated with regional climate models at different scales. The trends in the climate variables are forced by the chosen scenario for changing greenhouse gas emissions. In this study, the moderate A1B IPCC scenario is selected. The main findings from the deliverables of WP 3.1 are summarized in chapter 3. Analyses of changes in heavy precipitation events have been carried out in D3.1 and D3.3 with focus on the target regions Southern Norway, Southern Italy, the Alps, and Romania. D3.1 focuses on trends in heavy precipitation over larger regions for the time period 1961 to 2099. D3.3 analyses simulated heavy precipitation events on the local scale and investigates their changes by comparing the time period 2021-2050 to the time period 1971-2000. Due to the different time periods and different analysis methods, the results from D3.1 and D3.3 may differ. The changes in heavy precipitation until 2099 might be more pronounced compared to the changes until 2050 only.

Both the analyses from D3.1 and D3.3 show mainly positive trends of heavy precipitation in winter. Strong changes are particularly found in mountainous regions, where the impact on land slides may be large. The summer trends in Northern Europe are generally weaker than the winter trends. In warm and rather dry regions, such as the Pizzo d’Alvano domain, which is located in Campania in southwestern Italy, or the Telega domain in Romania, the average summer precipitation is projected to decrease. In other words, dry regions tend to become even drier. For extreme events on the other hand, increasing trends are found for some of these regions, in pareticular in the high-resolution COSMO-CLM simulation. This indicates that especially the typical convective events in summer may occur with higher probability. For regions where the average precipitation decreases and the soil dries, the drainage of the soil is reduced and consequently the occurrence of heavy precipitation events may have strong impacts, such as flooding. On the other hand, regions which already possess a moist climate, such as Southern Norway, tend to become even wetter on average and also in the extremes.

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