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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 3.2

REMO climate change simulations with 10km horizontal resolution for case study sites in Southern Italy, the Alps, Southern Norway, and Romania

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

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SUMMARY

Climate change simulations with the regional climate model REMO are performed at a resolution of 10 x 10 km² for three selected regions over Europe: Italy and the Alps, Northern Europe, and Eastern Europe. These climate simulations are delivered to the Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC) in order to be used as boundary conditions for further model simulations performed at a resolution of 3.8 x 3.8 km². Compared to a model with a resolution of 25 x 25 km², the model with 10 x 10 km² grid resolution is shown to simulate more detailed temperature and precipitation patterns associated with regional features such as complex orography. The changes of temperature and precipitation in the simulated future climate are compared to a control climate period. The strongest warming is found in the southern regions in summer and over cold regions in spring and autumn, where the warming is amplified due to the snow-albedo feedback. Precipitation is projected to increase in the cool and moderate regions, but decreases in the warm regions during the warm seasons. The usage of the model output data for simulations on an even more refined grid is expected to improve the ability to simulate even localized heavy precipitation events in regions where rain-induced land slides occur on a regular basis.

Note about contributors

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

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MPG

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CMCC

CONTENTS

1 INTRODUCTION

Extended periods of precipitation and single heavy precipitation events are amongst the main triggers for land slides in Europe. Heavy precipitation events can be associated with synoptic-scale features such as low-pressure systems, but also with regional or even local-scale features such as convection or uplift induced by the orography. Increasing model resolution has an improving influence on the simulation of extreme events over complex orography (e.g. Kunz and Kottmeier 2006; Zängl 2007). In Europe, this is especially important in the Alps (e.g. Frei et al. 2003), but also in the Carpathian Mountains this factor might play a major role. Moreover, a more detailed representation of complex coastlines, such as the western coast of Norway, is expected to have an impact on the accuracy of precipitation simulation. To take into account weather events on a wide range of scales, high resolution climate simulations are necessary. Climate simulations with the regional climate model REMO are performed for the time period 1951 to 2050 at a resolution of 10 x 10 km². The simulations are carried out for three selected regions over Europe: Italy and the Alps, Northern Europe, and Eastern Europe.

For specific studies on particular landslides, for example for the investigation of local high-intensity precipitation events in mountainous regions, even the 10 km resolution of REMO is not sufficient. Therefore, a double nesting procedure is applied in which the non-hydrostatic COSMO-CLM (Rockel et al. 2008) with a target resolution of 3.8 x 3.8 km² is driven by the 10 x 10 km² REMO simulations. For this purpose, the model output of REMO at 10 x 10 km² resolution is passed to the Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC), who perform the COSMO-CLM simulations and analyze heavy precipitation events and their changes at the local scale. Such a high model resolution is expected to improve the ability to simulate even localized heavy precipitation events in regions where rain-induced land slides occur on a regular basis. The shorter grid point distance will be advantageous especially in regions with complex orography. The results from the COSMO-CLM simulations are reported in D3.3.

Task of deliverable D3.2 is to carry out the REMO simulations at 10 x 10 km² resolution, create the boundary data for COSMO-CLM, and deliver the data to CMCC.

In the present report, the setup for the REMO simulations is described in detail. The climatic patterns of temperature and precipitation for the time period 1971-2000 simulated by the REMO model at 25 km resolution and 10 km resolution are compared for the Italy/Alps domain to illustrate how the finer resolution improves the representation of regional details, in particular over a complex orography. Furthermore, the main results from the climate change simulations regarding changes in daily mean temperature and daily precipitation totals are analyzed separately for all seasons in the three simulated domains.

The achievements of the regional climate model simulations are used for detailed case studies in other work packages, such as the preparation of hazard and risk maps, and the investigation of precipitation induced landslides.

2 MODEL DESCRIPTION AND SETUP

2.1 THE REMO MODEL

The regional climate model REMO is a hydrostatic three-dimensional atmospheric circulation model, which dynamically simulates the physically relevant processes in the atmosphere (Jacob, 1997; Jacob, 2001; Jacob et al., 2001; Jacob et al., 2007). Thereby, non-linear interactions are taken into account. Subscale processes which are not resolvable by the model such as the formation of convection, are calculated through physical parameterizations. REMO has been developed based on the Europa Modell of the German Meteorological Service (DWD) (Majewski, 1991; Majewski et al., 1995). The prognostic variables of the model are the horizontal wind components, the surface pressure, the temperature, the specific humidity, and the liquid water content. The physical parameterizations in REMO stem mostly from the global general circulation model ECHAM 4 (Roeckner et al. 1996).

The temporal integration of the model equations in REMO is based on the Leap-Frog scheme with semi-implicit correction and time filtering according to Asselin (1972). A hybrid coordinate system with a terrain following system describes the vertical direction. The horizontal discretization is based on an Arakawa-C-grid in which the values of each variable, except for the wind components, are positioned in the centre of the grid box. The grid box centres are defined on a rotated spherical system with uniform distance in x- and y-direction.

REMO can be driven either by (re)analysis data or with the output of a global climate model. At the beginning of a simulation, the regional model is initialized with global data in the simulated domain, while during the simulation it is driven at its lateral boundaries by transient global data. Temperature, pressure, wind, and humidity are prescribed at the boundaries, while all the remaining variables are directly calculated by REMO at the boundaries and within the simulated domain.

The land and sea surfaces represent the lower boundaries of the model. The land surface is described by its height above sea level, surface properties, roughness, and soil conditions. At each time step, the soil temperature is calculated in five soil layers down to a depth of ten meters. Furthermore, a representative soil moisture is determined.

The model output variables which serve as boundary conditions for the COSMO-CLM simulations by CMCC are listed in Appendix 1.

2.2 SETUP FOR THE SIMULATIONS

REMO is used here at a horizontal resolution of 10 x 10 km², employing 27 vertical levels and covering the time period from 1950 to 2050. REMO as a Limited Area Model needs lateral boundary forcing data like temperature, wind, surface pressure, and moisture, and as surface boundary conditions the temporal variable sea surface temperature and sea ice extent. The high resolution of 10 x 10 km² has been achieved in two steps of refinement, called a double-nesting approach: existing REMO climate simulations from the EU FP 6 project

ENSEMBLES at 25 x 25 km² horizontal resolution have been used as initial and boundary conditions for the 10 x 10 km² simulations. The 25 x 25 km² simulations have been driven by global general circulation model simulations with changing greenhouse gas emissions according to the A1B scenario of the 4th IPCC Assessment Report. The A1B scenario describes a future world with rapid economic growth and population increase until 2050. Furthermore, new and more efficient technologies are assumed to be developed. In the A1B scenario, the energy supply is balanced across non-fossil and fossil sources. For a more detailed description we refer the reader to IPCC, 2001. By nesting the finer into the coarser resolution simulation, the information about changing greenhouse gas concentrations is passed on.

2.3 MODEL DOMAINS

Climate change simulations with changing greenhouse gas concentrations according to the A1B IPCC scenario have been performed for the time period 1950 – 2050. The following three model domains have been considered: Italy and the Alps, Northern Europe, and Eastern Europe. The model domains are displayed in Figure 1. The representation of the model topography in the simulation domains is shown in Figure 2. All domains include large mountainous areas, which play a role for the characteristics of the climate within the regions.

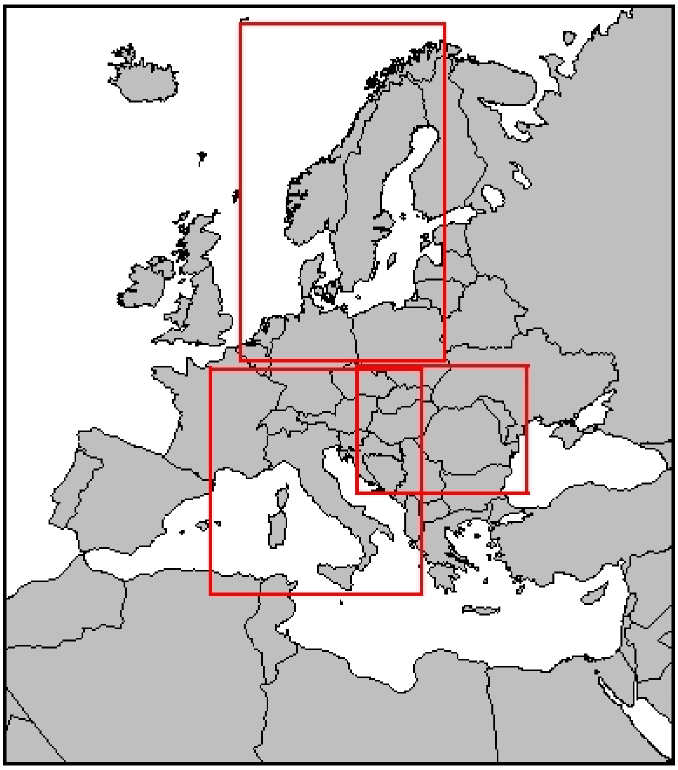

Figure 1: Illustration of the model domains

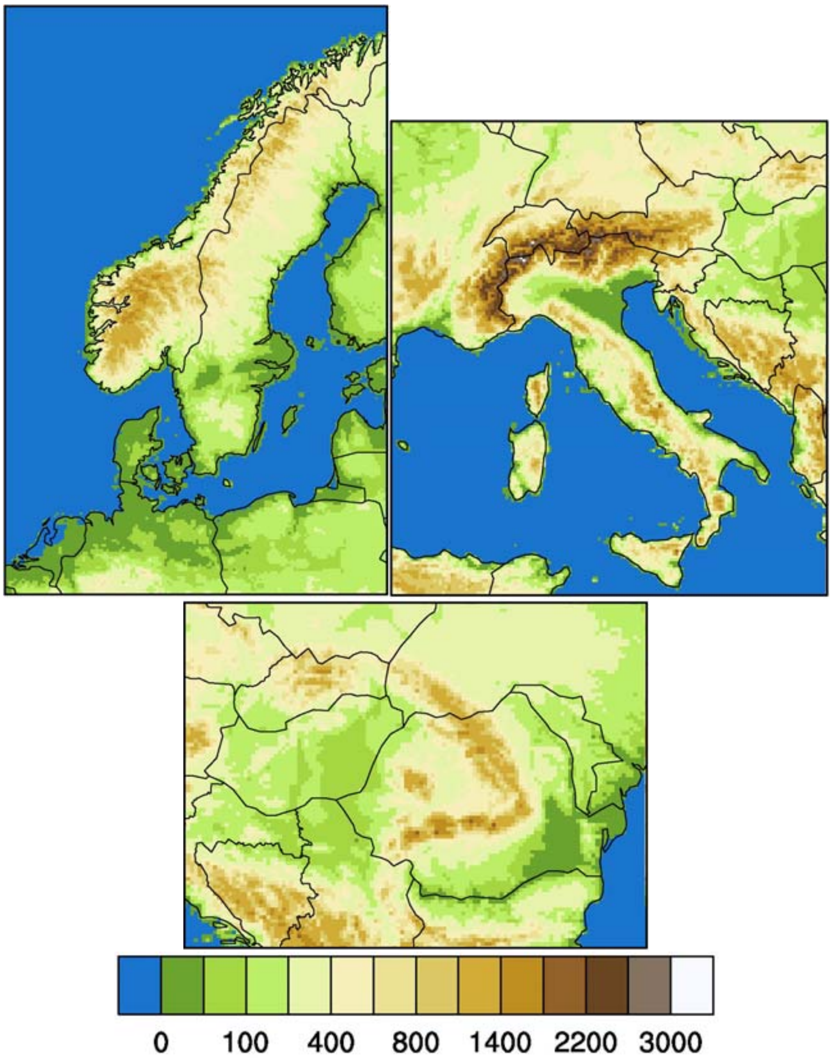

Figure 2: Topography in meters above sea level as it is represented in the model, for Northern Europe (top left), Italy and the Alps (top right), and Eastern Europe (bottom).

3 RESULTS

3.1 COMPARISON OF CLIMATIC PATTERNS AT DIFFERENT MODEL RESOLUTION

Figure 3 and Figure 4 show the mean temperature and mean daily precipitation patterns for the time period 1971 to 2000 in the Italy/Alps domain in the driving REMO simulation with 25 x 25 km² resolution and in the simulation with 10 x 10 km² resolution. The increase in resolution remarkably improves the representation of the climatic variables, especially over the Alps. In particular the precipitation pattern (Figure 4) shows more regional features, which are associated with orographic effects of the mountain peaks and valleys in the Alps and the Apennine Mountains. The precipitation pattern typically changes at the coast lines, where the cool and moist oceanic air reaches the dry and hot land, inducing convection. These coastline effects at the western coasts of Italy and at the eastern side of the Adriatic Sea appear to be represented more accurately in the 10 x 10 km² simulation.

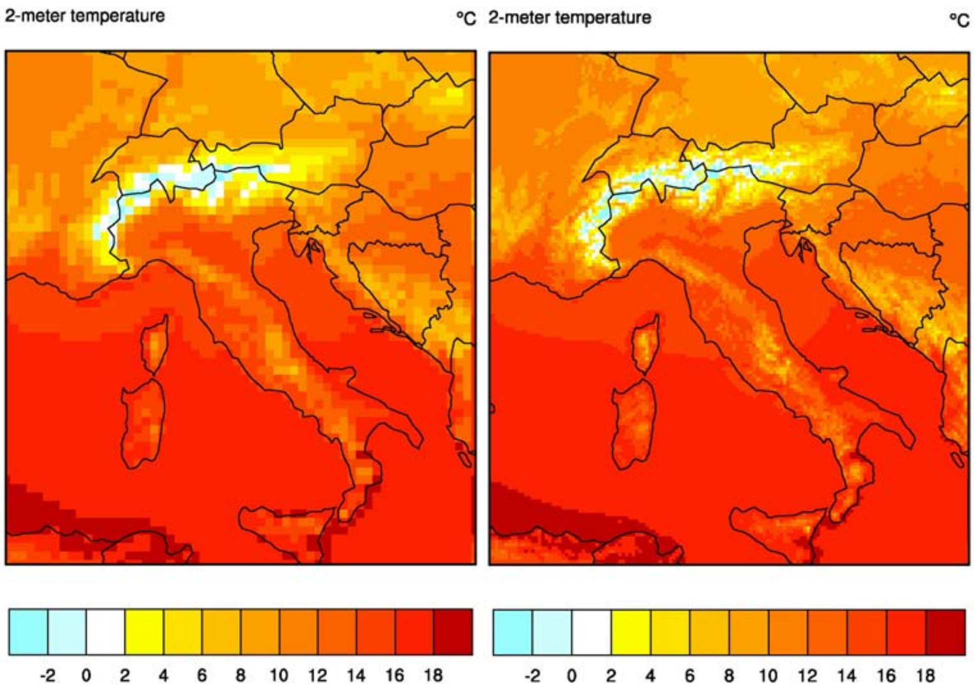

Figure 3: Mean temperature in °C for the time period 1971-2000 over the Italy&Alps-domain, simulated by REMO at 25 x 25 km² resolution (left) and 10 x 10 km² resolution (right).

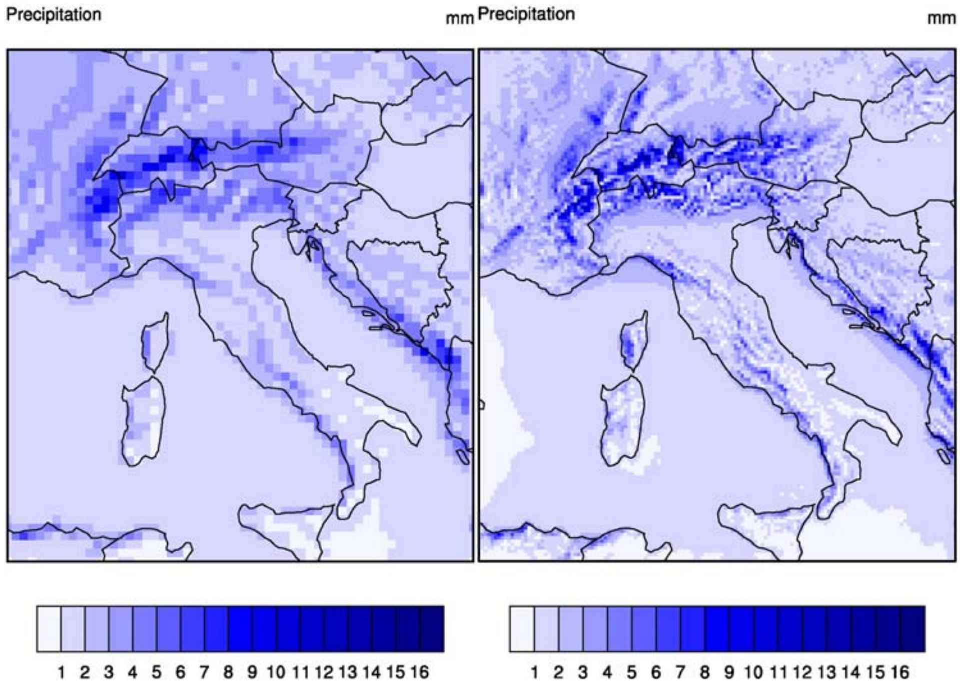

Figure 4: Mean daily precipitation in mm for the time period 1971-2000 over the Italy&Alps-domain, simulated by REMO at 25 x 25 km² resolution (left) and 10 x 10 km² resolution (right).

3.2 TEMPERATURE AND PRECIPITATION CHANGES

From the simulated time series at each grid point of the domain we have selected the period 1971 to 2000, which can be regarded as representative of the present climate and the period 2021 to 2050 which can be regarded as representative the future climate. The mean temperature and mean daily precipitation totals are calculated for both time slices. By subtracting the mean of the present climate from the mean of the future climate, the change is determined. Changes in the mean 2-meter temperature are given in absolute terms, changes in the mean daily precipitation sum in relative (percentage) terms. The four seasons winter (DJF), spring (MAM), summer (JJA) and autumn (SON) are analyzed separately.

3.2.1 Northern Europe

Figure 5 (left) shows the mean change of the 2-meter temperature in the northern European domain. In winter, spring, and autumn one can recognize many regional details associated with the Norwegian mountain massifs. In summer on the other hand, the temperature change is more uniformly distributed over Northern Europe. In spring and autumn the temperature increase is stronger over the mountains. This is likely due to an earlier onset of snow melt and a later onset of snow build-up, which result in reduced values of the albedo during these seasons. Hence, the amount of solar energy absorbed is increased, which causes a stronger warming of the lower atmosphere. During the winter season, the high albedo of the snow-covered mountains reduces the warming of the lower atmosphere.

The changes in daily precipitation totals for the northern European domains are illustrated in Figure 5 (right). The pattern of precipitation changes is less uniform than for temperature. Instead a lot of regional details appear. In winter, the model projects precipitation to increase in an area extending from the foothills of the southern Norwegian mountains to Sweden and the Baltic Sea. On the other hand, decreasing precipitation totals are projected at the Norwegian coast line. In spring and autumn, the mountains and the western Norwegian coast line feature positive trends in precipitation. In summer, the trends over the land masses are rather weak. Instead, strong positive trends appear over the Baltic Sea, The temperature change indicates that this might be due to an increased gradient in temperatures over land and over water. This leads to a decrease in the atmospheric stability in summer, which can result in more convective rainfall.

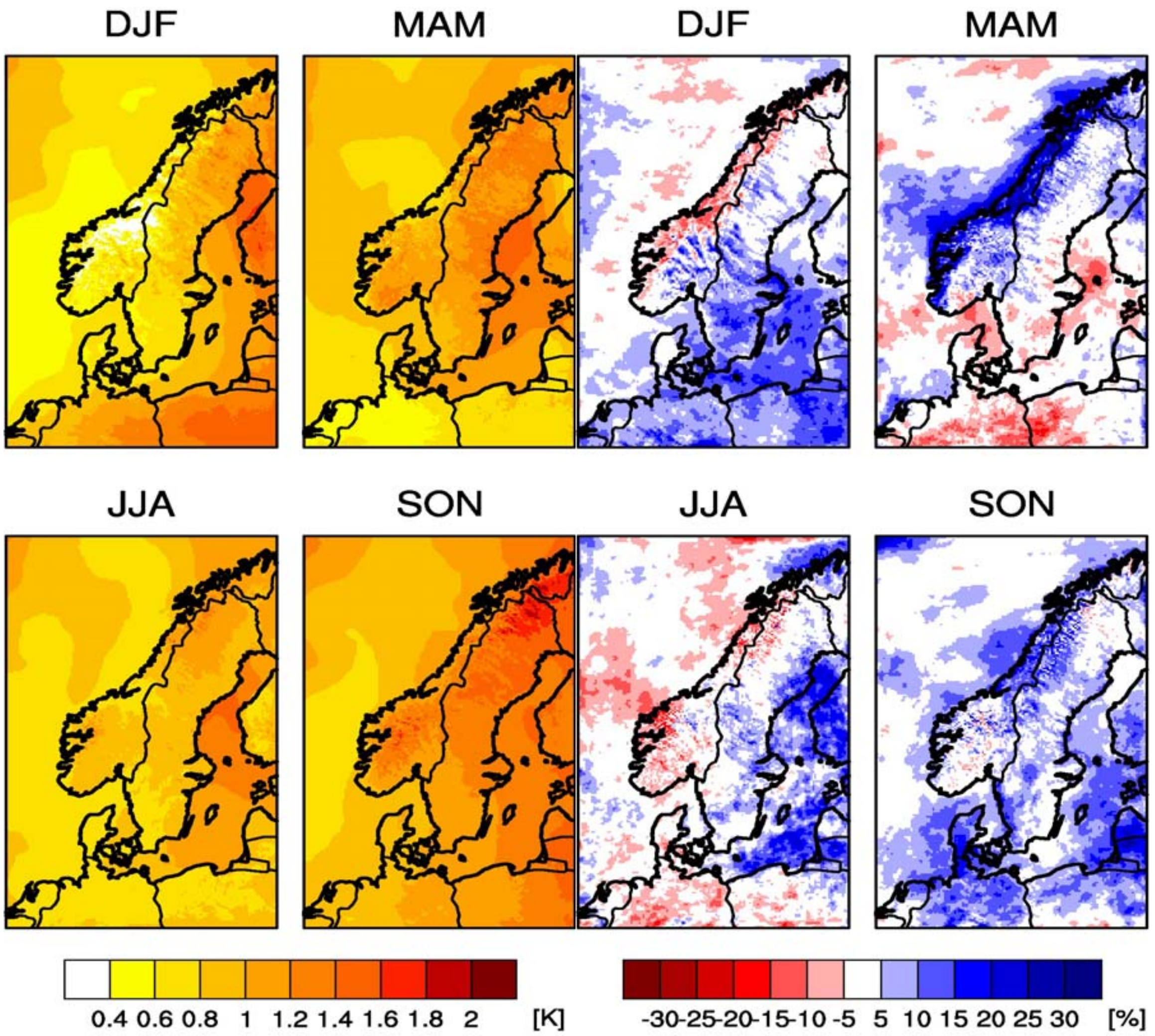

Figure 5: Mean temperature change in K (left) and mean precipitation change in % (right) over Northern Europe from 2021-2050 compared to 1971-2000 for the A1B emission scenario.

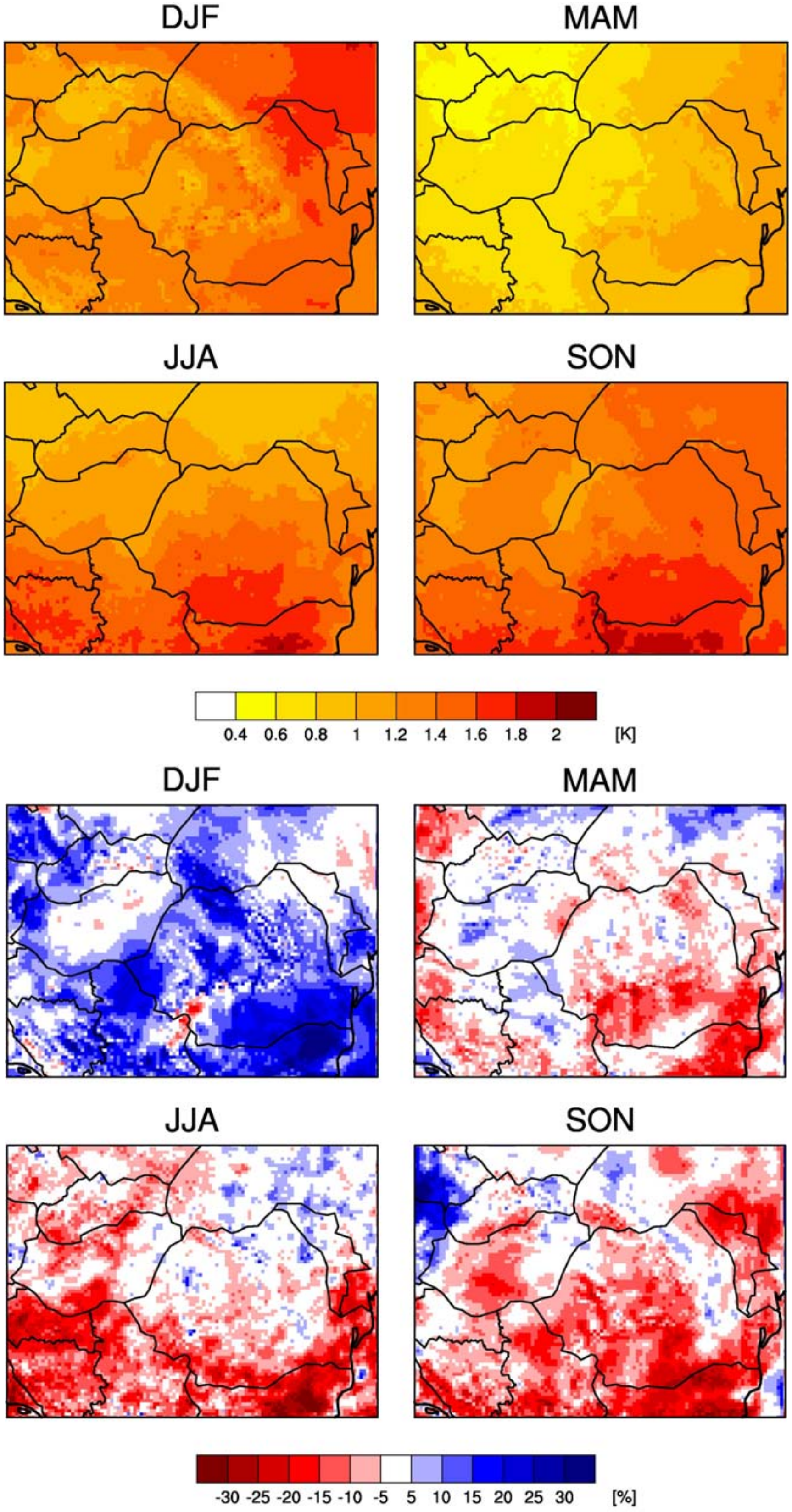

Figure 6: Mean temperature change in K (top) and mean precipitation change in % (bottom) over Eastern Europe from 2021-2050 compared to 1971-2000 for the A1B emission scenario.

3.2.2 Eastern Europe

Figure 6 (left) shows the temperature change in the climate change simulation for the eastern European domain. In winter and spring, the Carpathian Mountains appear as a border between stronger warming east of them and weaker warming further west. As for the Norwegian mountain chains, the warming is damped over the Carpathians in winter. In contrast to northern Europe, the mountains do not play such a large role for the temperature changes in spring and autumn. The largest values of warming are found for summer and autumn in the southern part of the domain. These regions are highly influenced by the climate in the Mediterranean region, which becomes hotter and drier.

The precipitation change in the eastern European domain (Figure 6, right) is positive for winter with regional details over the Carpathian Mountains. During the other seasons, the model projects a negative trend in precipitation, which depends on the temperature trend, indicating that the warmer temperatures dry out the soil and less water is available for evaporation. In winter on the other hand, the increased temperatures lead to a higher atmospheric water holding capacity and therefore more water is transported to this region from the Mediterranean Sea.

3.2.3 Italy and Alps

Figure 7 shows the temperature change for the Italy/Alps domain. The changes are more moderate in winter and spring compared to summer and autumn. A stronger regional warming over the mountain chains is visible in all seasons. As for northern Europe this is most likely caused by changes in the timing of snow melt and snow build-up as well as by a decrease in the overall snow coverage in the Alps. In summer the model simulates a strong increase in temperature over the entire Italian peninsula, with largest changes above 2 K in southern Italy.

In winter the changes in precipitation (Figure 7, right) are rather weak over the Italian peninsula, but positive trends dominate at the Adriatic coast lines and north of the Alps. In spring, summer, and autumn, negative trends are in particular found over the Italian peninsula and Sicily. Nevertheless, the mountainous regions tend to feature positive trends.

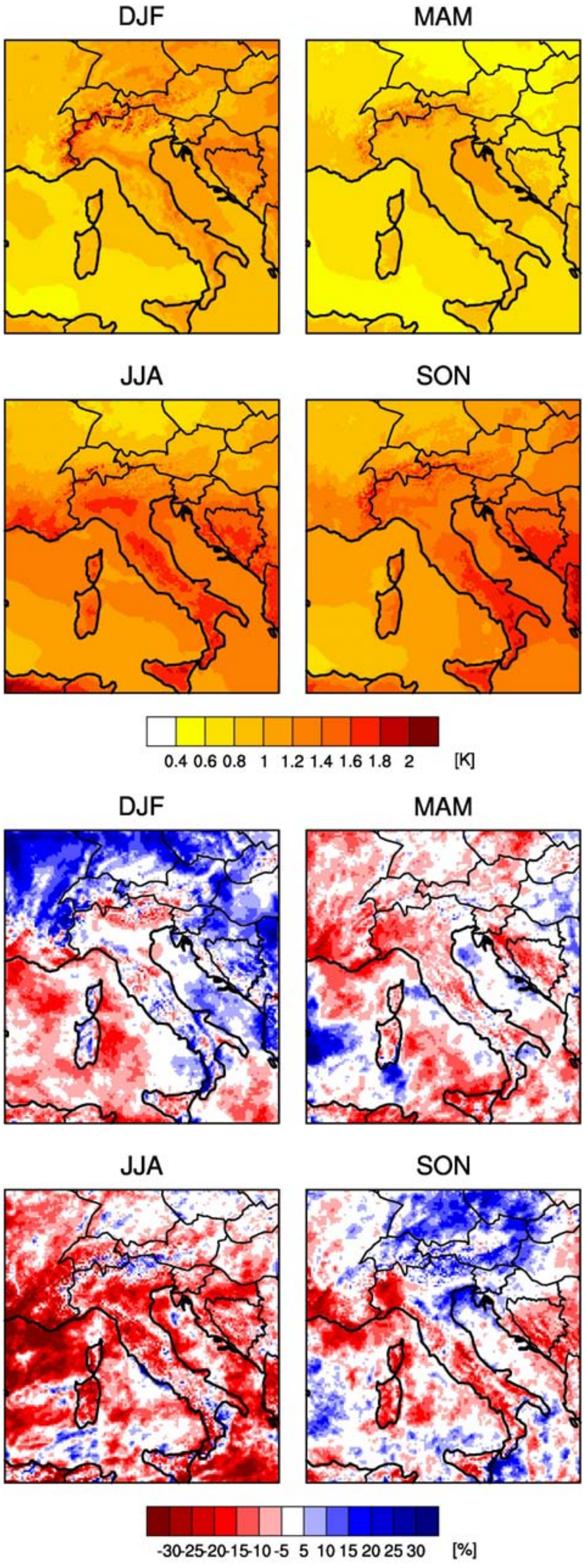

Figure 7: Mean temperature change in K (top) and mean precipitation change in % (bottom) over Italy and the Alps from 2021-2050 compared to 1971-2000 for the A1B emission scenario.

4 CONCLUSIONS

The simulations described in this report are characterized by a high resolution (10 x 10 km²) and are therefore able to represent regional details such as orographic rainfall patterns more accurately than simulations at coarser resolution The climate change simulations, which are based on the A1B IPCC scenario for changing greenhouse gas emissions, have highlighted considerable changes of temperature and precipitation between the time periods 2021-2050 and 1971-2000. The model projects the 2-meter temperature to increase in each domain, but the magnitude of increase depends on various factors, such as orography and decreased albedo due to snow melt. One has to take into account that temperature trends in regional climate models could be overestimated in certain regions due to an underestimation of soil moisture and, hence, evapotranspiration. This might in particular be relevant for the Mediterranean region and for Eastern Europe (Seneviratne et al., 2006). 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. In regional climate models the simulation of precipitation is divided into a large-scale scheme, which includes precipitation produced by dynamic systems such as cyclones or frontal systems, and a convective scheme, which describes clouds and precipitation induced by convective processes. Since convective processes are not resolved by the model resolution, they have to be parameterized, which leads to model uncertainty. Therefore, the representation of precipitation can be uncertain in regions and seasons where convective processes play a large role, such as in southern and Eastern Europe in summer and autumn. However, the results from D3.1 indicate that the general decrease in precipitation over these regions appears to be a robust feature across an ensemble of regional climate models. Despite the tendency towards more dry conditions in southern Europe in the future, there is evidence that in some regions, heavy precipitation events might increase. This is consistent with the findings by Christensen and Christensen, 2004.

5 USAGE OF THE RESULTS BY CMCC

A more detailed study of climatic changes at specific test sites in Europe has been performed by the Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC) with the non-hydrostatic regional model COSMO-CLM at a resolution of 3.8 x 3.8 km². The results are reported in D3.3. In a nesting procedure COSMO-CLM is driven by the 10 x 10 km² REMO simulations. COSMO-CLM receives the boundary information of REMO at a 6-hourly time step. In this way, a physically consistent simulation of meso- to local-scale climatic features, for example, local precipitation extremes and other landslide triggering events, is possible. A list of the variables which are passed to COSMO-CLM, is given in Appendix 1. The results of the very high resolution simulations can then be linked to geo-mechanical models used for high resolution case studies in other work packages.

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APPENDIX 1

List of REMO variables delivered to CMCC as forcing data for the COSMO-CLM simulations:

Surface temperature (water)
Surface temperature (ice)
Surface geopotential (orography)
Temperature (at model levels)
U-component of the wind
V-component of the wind
Specific humidity
Surface pressure
Surface temperature (mean over grid box)
Soil wetness
Soil depth
Liquid water content
Soil temperature (down to 4.134 m)
Land-sea mask
Soil temperature (down to 9.834 m)
Skin reservoir content
Soil temperature (down to 0.065 m)
Soil temperature (down to 0.319 m)
Soil temperature (down to 1.232 m)
Sea ice cover
Field capacity of the soil