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SafeLand

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

7th Framework Programme
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Sub-Activity 6.1.3 Natural Hazards

Deliverable 3.1

Overview on and post-processing of available climate change simulations for Europe on a spatial scale of 25km with a special focus on meteorological extreme events

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

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SUMMARY

Extreme precipitation events are expected to change their frequency and intensity in a warmer climate due to alterations in dynamic and thermodynamic processes. We present an extreme-value analysis of projected heavy rainfall in an ensemble of eight high-resolution regional climate model simulations over the European domain. The consideration of several regional climate models that are forced by different global models allows for a robust analysis in terms of inter-simulation agreement. The extreme-value statistical method is based on a model that includes time-dependent parameters. Summer and winter are examined separately. This allows for identifying seasonal characteristics in the patterns of changes and sharpens the understanding of physical processes behind. In winter we see a general trend towards more heavy precipitation events across all analyzed regional climate model simulations. This could partly be explained by an increased amount of vertically integrated water vapour which the atmosphere can hold when air temperatures are rising. For summer, we could find a slight increase of heavy precipitation in Northern Europe and a general decrease in Southern Europe in all regional climate model simulations.

Note about contributors

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

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CMCC

CONTENTS

1 INTRODUCTION

Heavy precipitation events can have a large impact on several regions in Europe as they are often associated with some of the most destroying natural hazards, like, for example, floods in the riverine regions or severe landslides in the mountainous areas. This often results in a threat of human life, property, and infrastructure.

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.

Europe is characterized by a variety of regional factors, such as, for example, the Alps or the Mediterranean Sea, which have a large impact on the regional weather and climate. Therefore the investigation of climatic changes on a regional scale is indispensable and high-resolution regional climate models represent an appropriate tool for this task. For the simulation of heavy precipitation events, regional modelling is of special importance as meso-scale storms and convection are often important features of the strongest rain events. Furthermore, increasing model resolution has an improving influence on the simulation of heavy events over complex orography (e.g. Kunz and Kottmeier 2006; Zängl 2007), which in Europe is especially important in the Alpine region (e.g. Frei et al. 2003)

Due to model inaccuracies which all climate models possess, one single simulation does not allow for assessing the robustness of the results. Therefore, the use of climate model ensembles is an appropriate method to distinguish between possible climate change signals and model-made features. Accordingly, an ensemble of regional climate model simulations is promising also for the investigation of the response of heavy precipitation to changes in the Earth's climate.

This report is structured as follows: In chapter 2, an overview over the different regional climate models is given and the statistical method is described, in chapter 3, the results are presented, and chapter 4 discusses the results and concludes the findings.

2 MODELS AND METHODS

2.1 DESCRIPTION OF THE REGIONAL CLIMATE MODEL ENSEMBLE

To allow for assessing robust changes in heavy precipitation in response to a warming climate, an ensemble of 8 regional climate model (RCM) simulations is used. The simulations, which are all covering the time period from 1961 to 2099, were obtained in the framework of the EU FP6 project ENSEMBLES. All models were run on the whole European domain with the same spatial resolution of about 25 km grid point distance. Regional climate models need lateral boundary forcing data like temperature, wind, surface pressure and moisture and as surface boundary conditions the sea surface temperature and sea ice extent. The boundary data is provided by different general circulation model (GCM) simulations (see Figure 1). The GCM simulations are forced by changing greenhouse gas concentrations according to the A1B scenario of the 4th IPCC Assessment Report. This 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).

The RCMs used in this study are RACMO by the KNMI (Lenderink et al. 2003), RCA by the SMHI (Kjellström et al. 2005) which is used by both SMHI and C4I driven by different boundary conditions, HadRM by the Hadley Centre (Collins et al. 2006), CLM by the ETHZ (Böhm et al. 2006), and REMO by the MPI (Jacob 2001, Jacob et al. 2001).

The ability of regional climate models to represent heavy precipitation is to a large extent affected by its spatial resolution. Processes which occur on smaller scales than actually resolved need to be parameterized using large-scale information. The parameterization schemes are therefore sources of uncertainty in the models. Among all schemes, the one for cumulus cloud convection plays the largest role for the formation of heavy precipitation events. Furthermore, the quality of the driving global model simulation plays a role. Table 1 gives an overview over the regional climate model simulations used here and the global climate models in which the regional models are nested. There are two different versions of the driving global model HadCM3: HadCM3Q0 is the regular version with normal sensitivity and HadCM3Q16 is a version where the model was generated with perturbed physics, which leads to higher sensitivity. A detailed description of the modifications can be found in Collins et al., 2006. The variable here analyzed in more detail is the daily precipitation sum on a grid point basis.

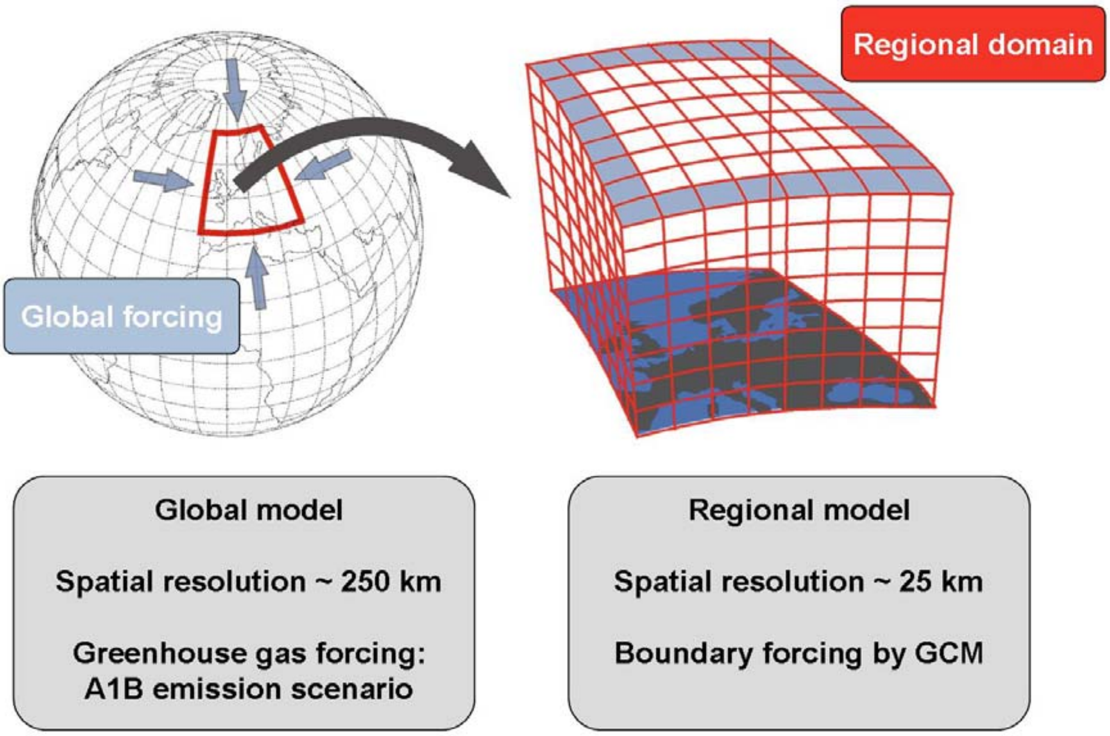

Figure 1: Illustration of the model setup

Notation	RCM	Driving global model
remo	REMO	ECHAM5-r3
remo_ipsl	REMO	IPSL
smhi	RCA	ECHAM5-r3
smhi_bcm	RCA	BCM
knmi	RACMO	ECHAM5-r3
hc	HadRM3Q0	HadCM3Q0
ethz	CLM	HadCM3Q0
c4i	RCA3	HadCM3Q16 (high sensitivity)

Table 1: Regional climate models (RCM) and their driving global climate models.

2.2 STATISTICAL METHOD

Our work focuses on trends in heavy daily precipitation totals. Since heavy weather events are, by definition, rare events, they are more difficult to study than averages and robust conclusions about their statistics and changes cannot be drawn from empiric values. Instead, adequate probability distributions which focus in particular on the rare heavy events have to be fitted to the data. To tackle the problem of estimating the distribution of rare events, special statistical rules apply, which are described by extreme value theory. In the present work we make use of a non-homogeneous Poisson point process approach, which is based on a peaks-over-threshold model. The statistical model is fitted to the occurrence of exceedances over a high threshold (i.e. heavy precipitation events in the context here) and the intensity of the excesses over the threshold. The threshold used in this study is the empiric value of the 95th percentile, i.e. the data value which is exceeded by 5% of the rest of the data.

A major advantage of the Poisson point process method is that time-dependent parameters can easily be established. This fact makes the approach very useful for the investigation of trends in heavy precipitation events. A more detailed description of the Poisson point process and extreme value statistics in general can be found e.g. in Coles, 2001.

From the estimated parameters of the extreme value distribution of daily precipitation events one can finally calculate trends of high percentiles of the distribution, i.e. return values of events with a certain return period. In this study we analyse the trend of the 99th percentile of daily precipitation totals. The 99th percentile of the extreme value distribution refers to an event which occurs once in 100 days. Since we carry out the analysis for winter and summer separately, this is about once per season. Therefore, the trend of the 99th percentile gives an idea how heavy precipitation events with a one-seasonal return period might change in the future. This includes both the frequency and the intensity of heavy precipitation events. To further investigate how the frequency of the events is changing, 30-year running mean values are obtained from the number of the exceedances over the threshold over the whole time period and their linear trends are determined.

3 RESULTS

3.1 CHANGES IN HEAVY AND MEAN PRECIPITATION FROM REGIONAL CLIMATE MODEL SIMULATIONS IN EUROPE

Winter

Figure 2 shows the trend of the 99th percentile of the daily precipitation sums for winter, estimated with the extreme value statistical method described above. The results are displayed separately for each model simulation of the ensemble for the time period from 1961 to 2099. In general we can see a positive trend in heavy precipitation in northern Europe which is indicated in the graphic by green and blue colours. The changes range from 1 to 10 *mm* with strongest values over Scandinavia. Here, an increase of 10 *mm* is equivalent to a 40 *%* higher value of the 99th percentile at the end of the time period compared to the beginning of the time period. In contrast to the positive trends in the major part of Norway, heavy precipitation along the western coast is projected to decrease or stay constant, depending on the simulation. In the graphics this is illustrated by light green or yellow colours. In comparison to northern Europe, the positive trends appear to be weaker in southern Europe. Most of the RCMs suggest that heavy precipitation decreases in the southern parts of the Iberian Peninsula and around the southern Mediterranean Sea, indicated by orange and red colours. In the strongest cases, the 99th percentiles decrease by up to 10 *mm*, which is equivalent to about 35-40 *%*. Besides the differences between northern and southern Europe, positive trends in winter are generally projected to be stronger over the continents than over the oceans. Figure 3 shows the robustness of the results in terms of inter-simulation agreement. Blue areas indicate that the majority of RCM simulations consistently project a positive trend in heavy precipitation, red areas a negative trend. The large-scale pattern of heavy precipitation changes appears to be very consistent across the simulations. 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.

Comparing the trends of the 99th percentile to trends in the mean precipitation (Figure 4), a similar pattern of changes is found. However, the trends in extreme precipitation are much larger in magnitude. Changes in mean precipitation range between -2 *mm* and 2 *mm*, in the graphic indicated by yellow and green colours, respectively. However, if seen in relative terms, these values can mean a change which is larger than for the extremes.

Positive trends in the 99th percentile imply that an event which occurs about once per season will on average be stronger, negative trends that it will be weaker. Nevertheless, changes in the 99th percentile of daily precipitation totals include changes in both the frequency and the intensity of heavy precipitation events. These two characteristics are not distinguishable from the extreme-value statistical method that has been used. Yet, regarding the consequences which heavy precipitation events may have, it is of high importance to investigate whether they might occur more frequently in the future. Therefore, we analyse the trends in the number of simulated precipitation events which exceed a high threshold. The choice of the threshold is a trade-off: it has to be high enough in order to analyze heavy precipitation

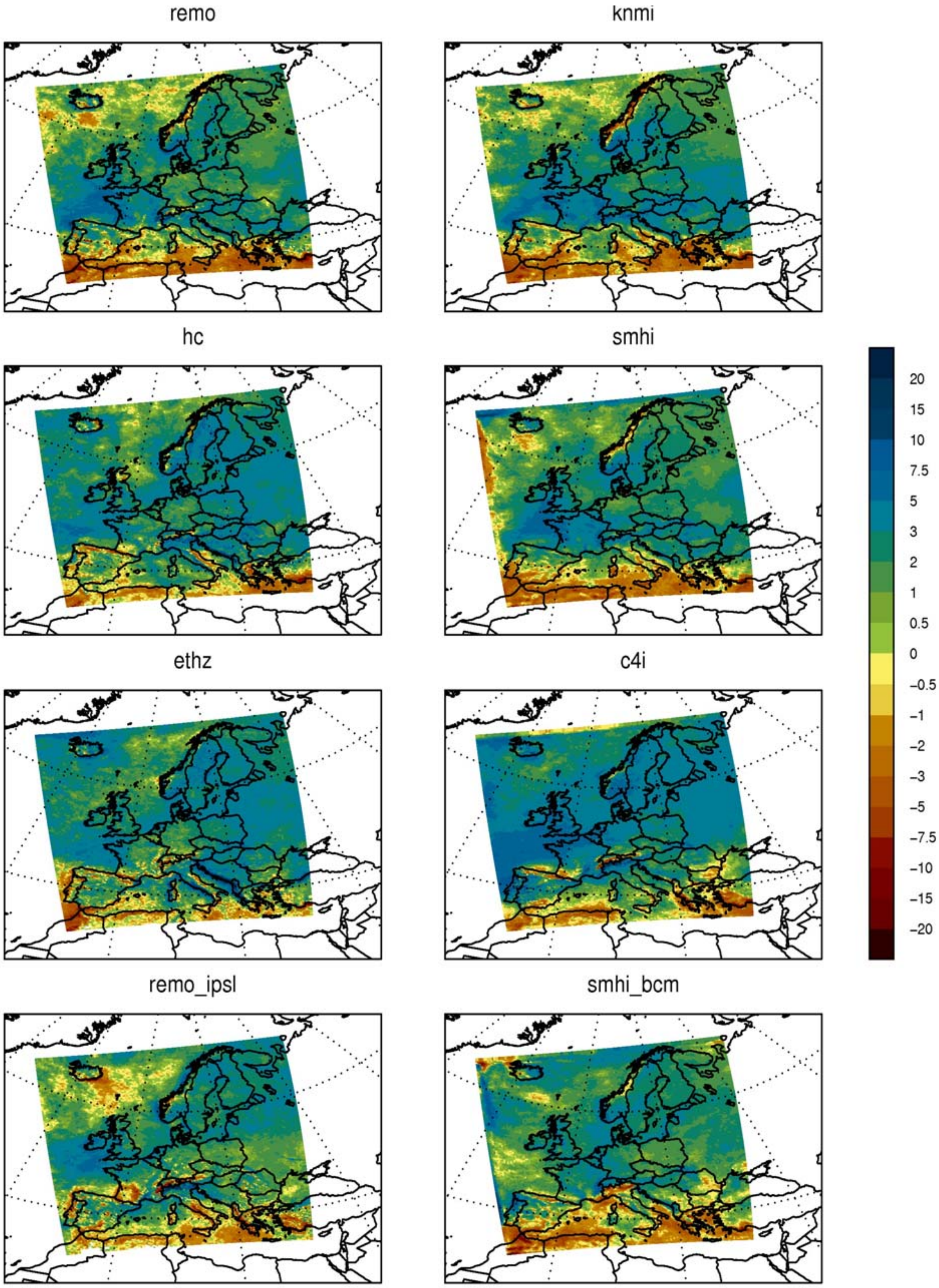

Figure 2: Trend of the 99th percentile of the extreme value distribution of daily precipitation sum in mm for 1961-2099 in winter (DJF).

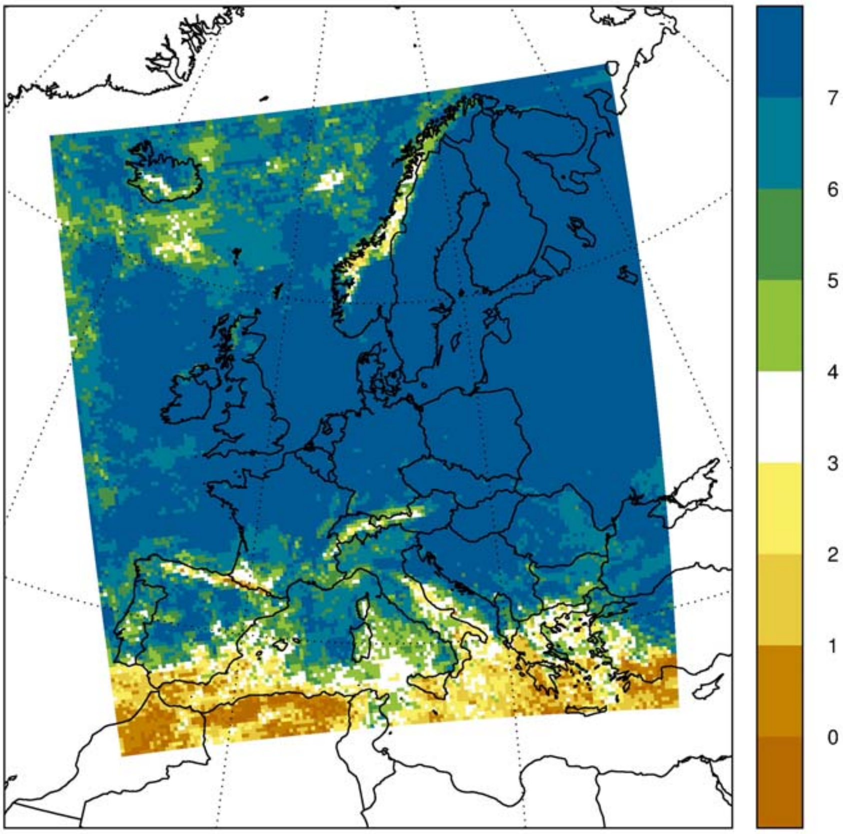

Figure 3: Number of models which agree on a positive change in the 99th percentile of daily precipitation for winter (DJF).

events and not too high in order to investigate a large enough data base. These conditions are fulfilled for the empiric 95th percentile. The changes in the number of exceedances over this threshold are investigated for the time period 1961 to 2099. The results can be interpreted as changes in the potential for heavy precipitation. As we can see from the patterns in Figure 5, the changes in the number of the exceedances show similar tendencies as the trends in the 99th percentile of the extreme value distribution. In winter, the increase in the number of heavy precipitation events in northern Europe appears to be even more robust throughout the models than the trend of the 99th percentile. In large parts of Scandinavia, the Baltic Sea, and Northeast Europe, the whole ensemble of RCMs projects more than a doubling in the number of exceedances over the 95th percentile. On the other hand, in the southernmost regions of Europe, the models simulate a climate where the number of precipitation events stronger than the 95th percentile decreases by up to 50% by the end of this century.

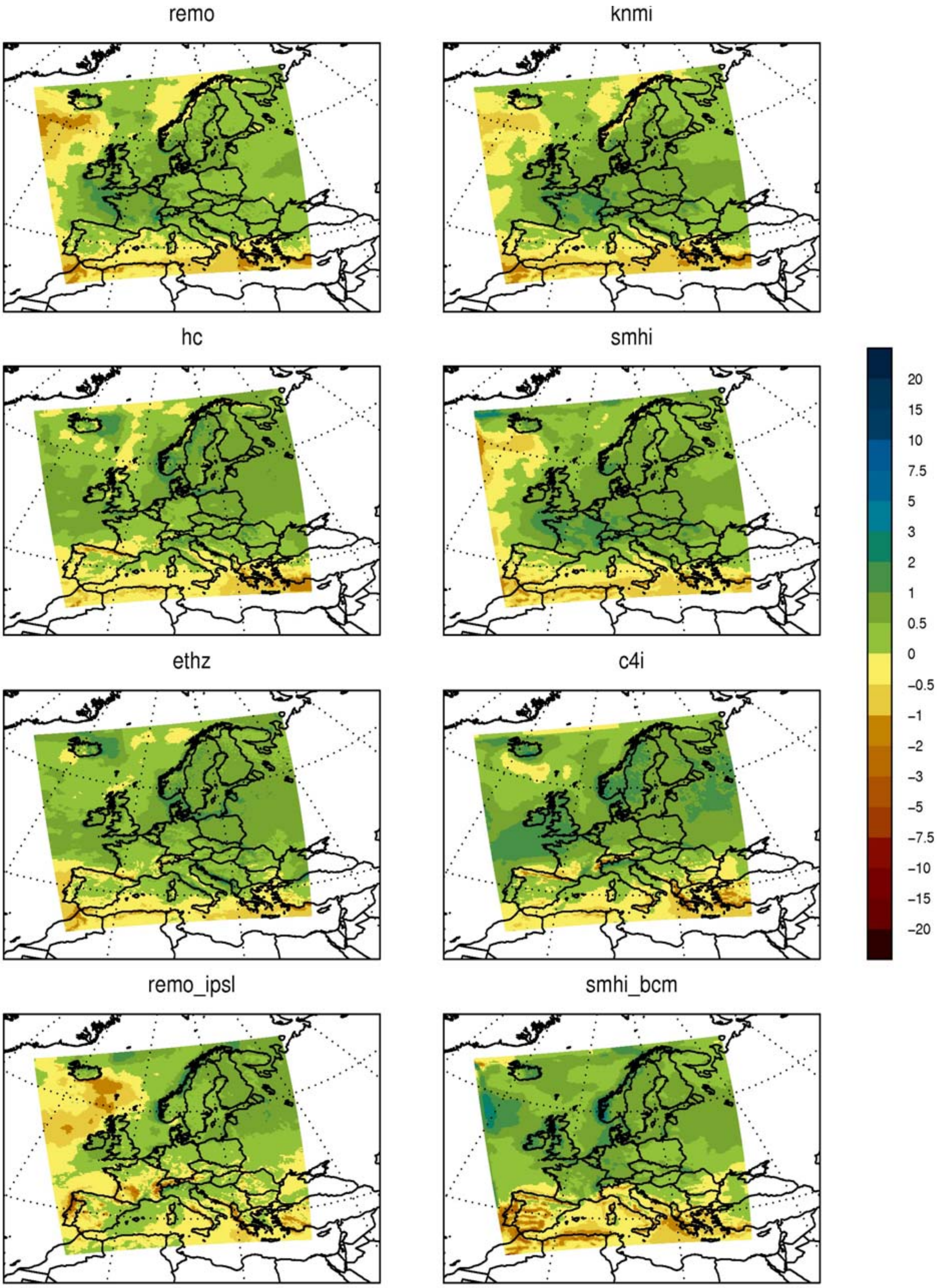

Figure 4: Trend of the mean daily precipitation sum in mm for 1961-2099 in winter (DJF).

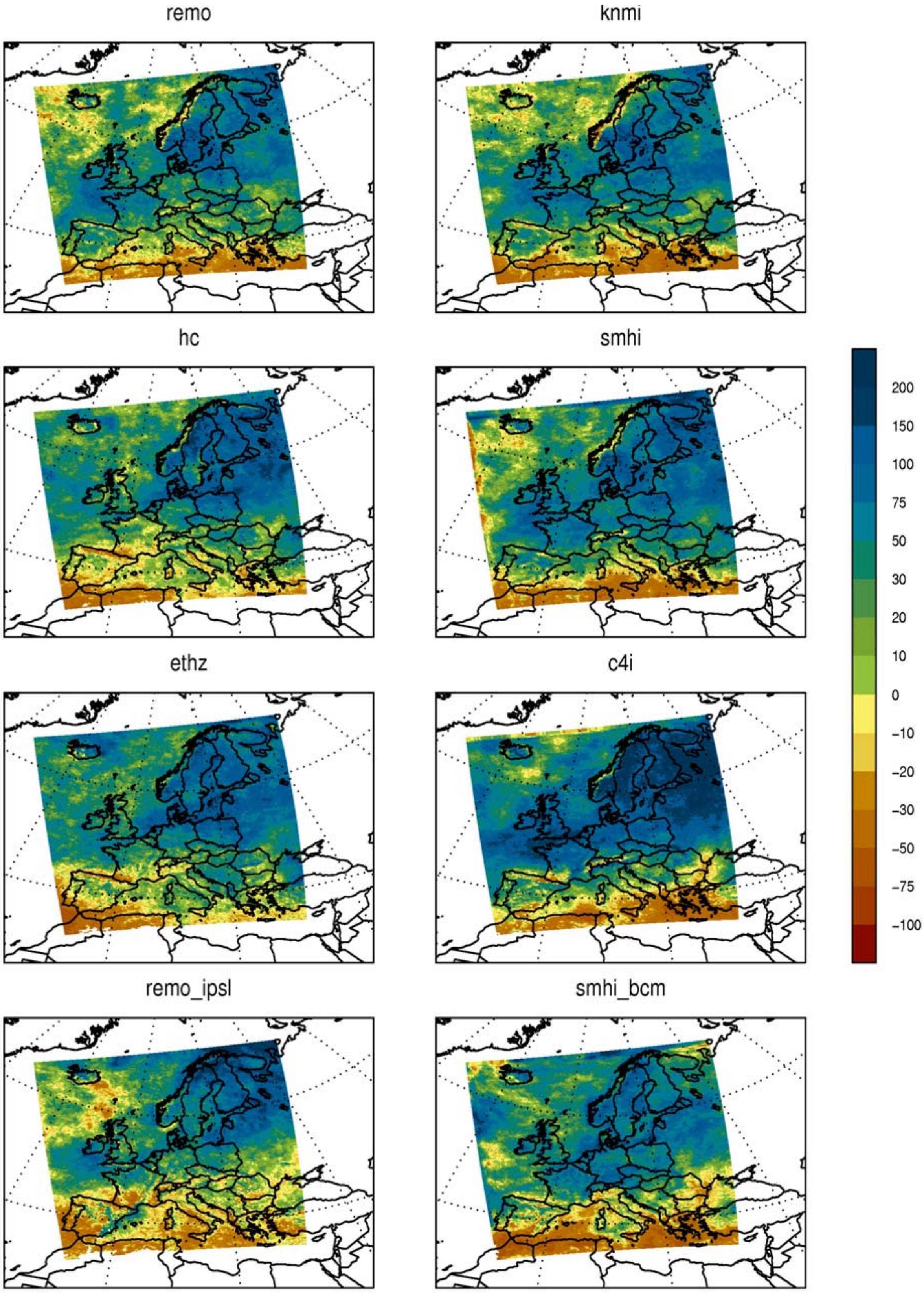

Figure 5: Relative trend of the number of exceedances over the 95th percentile of daily precipitation sum per 30-year running period in % for 1961-2099 for winter (DJF).

Summer

In summer, the ensemble of regional climate simulations projects a very different response of heavy precipitation on the changing climate: Changes in the 99th percentile of daily precipitation (Figure 6) appear to be positive over northern Europe, indicated by green and blue colours. As for winter, the magnitudes of the trends range from 1 to 10 *mm*. However, the extent of the area with positive trends is not consistent throughout the ensemble. On the other hand, all simulations agree on negative trends in heavy precipitation over southern Europe and parts of central Europe, indicated by the orange and red colours in Figure 6. The 99th percentile is projected to decrease by up to 15 *mm* in some southern European areas. In relative terms this is equivalent to more than a 30 *%* decrease from the beginning to the end of the time period. The Alps appear as a boundary between positive trends on their northern side and negative trends on their southern side. It is striking that the area with negative trends extends beyond the southwest coasts to the Atlantic Ocean. Over land, heavy summer precipitation events often have a very local and convective nature and changes might be due to a decreased local availability of water. This is not an issue over the ocean, which indicates that changes in the dynamics of the atmosphere may alter the probability for heavy precipitation here.

Despite this widespread tendency for decreasing trends in heavy precipitation over the southern parts of Europe, some models project increasing trends in small areas over and around the southern Mediterranean Sea, for example south of Sardinia.

Figure 7 shows that the results are most robust in terms of inter-simulation agreement over Scandinavia and southern Europe. This is illustrated by dark blue and red colours in the graphic. Largest inconsistencies, indicated by light colours, are found in the transition zone between positive trends in the North and negative trends in the South. Although the whole ensemble shows the same tendencies over large parts of Europe, there are some differences in the magnitudes of the trends. The RCMs driven by the general circulation model ECHAM5/MPI-OM show a weaker positive trend in northern Europe in winter and a stronger negative trend in southern Europe in summer compared to the RCM simulations driven by HadCM3Q0, HadCM3Q16 and IPSL (see Table 1).

As for winter, the changes in the mean precipitation over Europe are much weaker than for the extremes in absolute terms (Figure 8). Yet, the areas coloured in green and yellow show that the tendencies point to the same direction almost everywhere. An exception are a few spots located in particular over central Europe where mean precipitation slightly decreases but heavy precipitation increases. This is for example the case over Ireland, over France, and over Germany in some of the simulations. In central and southern Europe, the average precipitation is projected to weaken by up to 3 *mm*. Over the dry southern European land masses this can mean that precipitation is reduced by over 60 *%*.

In summer, we also find negative trends in the frequency of heavy precipitation events over southern Europe (Figure 9). Over the Atlantic Ocean west of the southern European continent, the number of events exceeding the 95th percentile changes by up to 70%. Only in the northernmost part of Scandinavia and along its western coast, significant positive trends can be identified. As for the 99th percentile of the extreme value distribution, one can recognize a clear line through Central Europe that divides a part with almost no changes north of it from negative changes in the south. In regions where the frequency of heavy precipitation events increases but the 99th percentile decreases, heavy precipitation events might occur less often, but with higher intensities. This appears to be the case for some grid boxes over Europe, but in general, changes in the intensities seem to play a minor role.

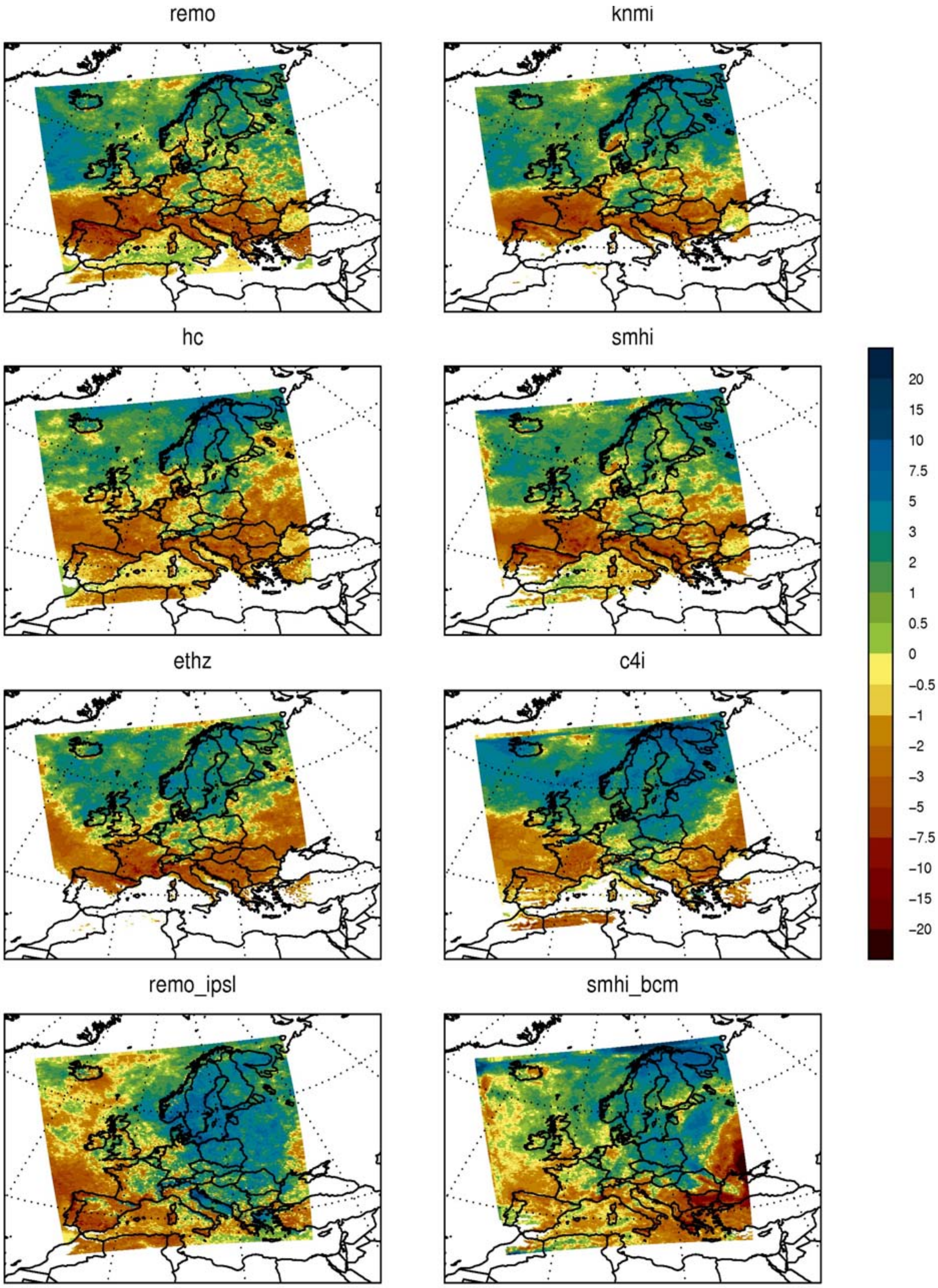

Figure 6: Trend of the 99th percentile of the extreme value distribution of daily precipitation sum in mm for 1961-2099 in summer (JJA).

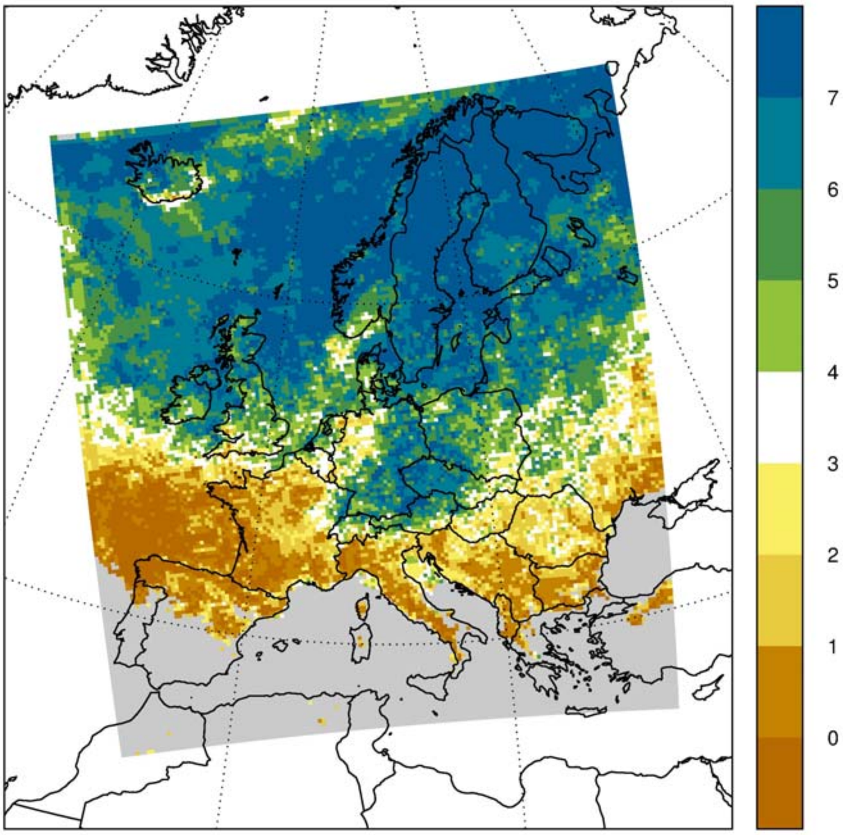

Figure 7: Number of models which agree on a positive change in the 99th percentile of daily precipitation for summer (JJA).

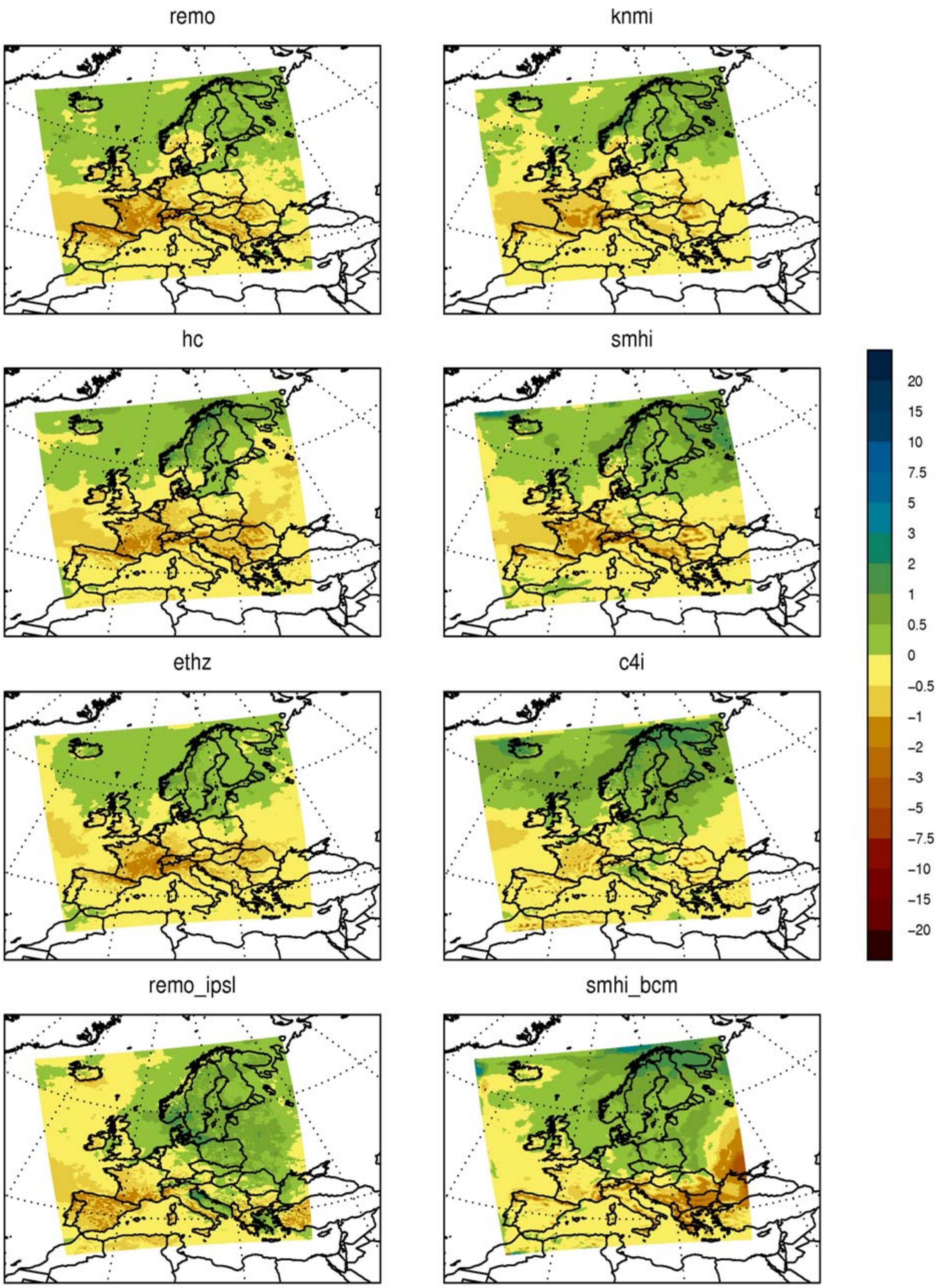

Figure 8: Trend of the mean daily precipitation sum in mm for 1961-2099 in summer (JJA).

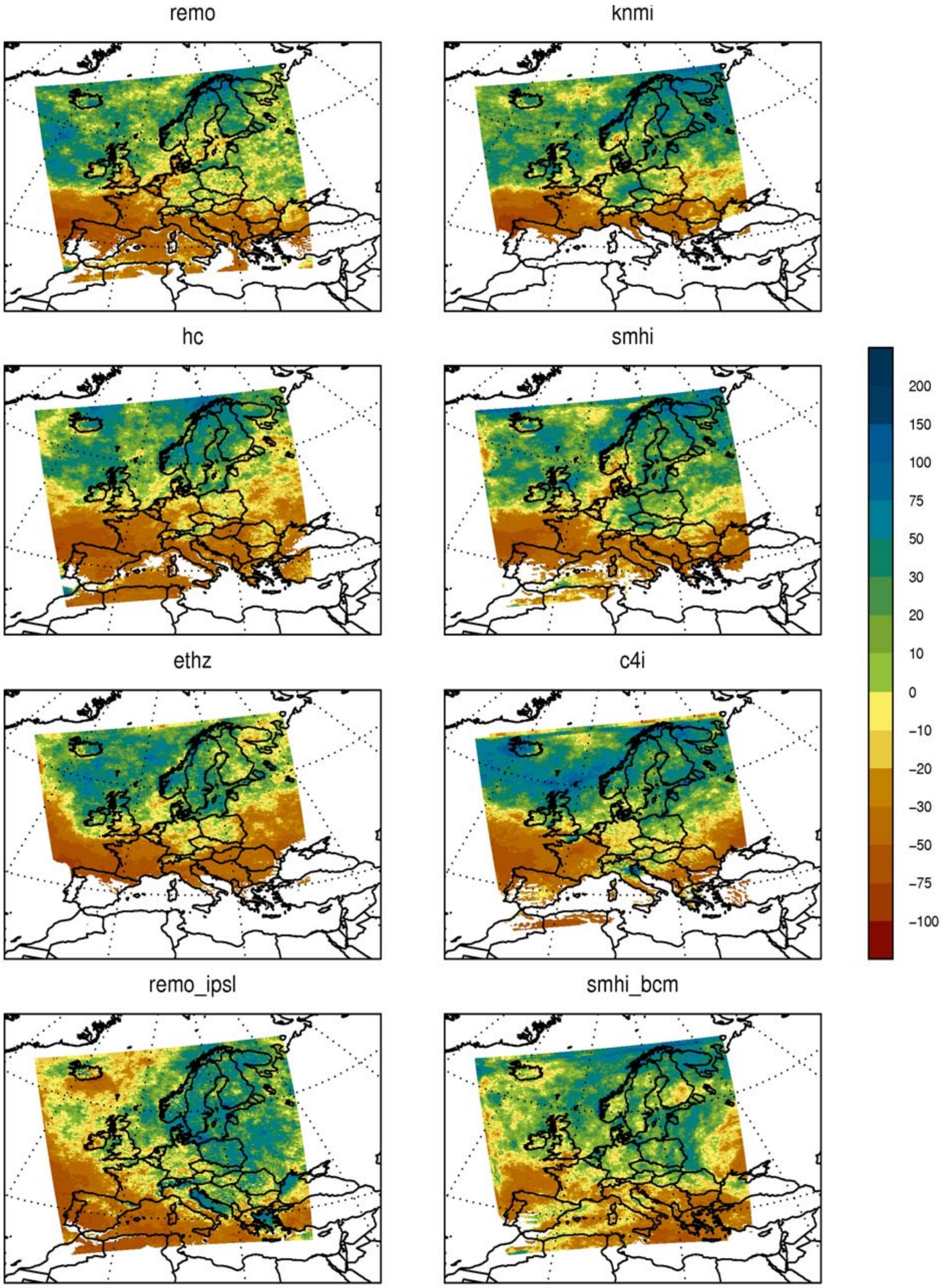

Figure 9: Relative trend of the number of exceedances over the 95th percentile of daily precipitation sum per 30-year running period in % for 1961-2099 for summer (JJA).

4 DISCUSSION AND CONCLUSIONS

Thanks to the high spatial resolution of 25 x 25 km², the RCMs are able to simulate regional scale processes and are therefore believed to represent heavy precipitation in a more realistic manner than global climate models. Processes which take place on scales smaller than the RCM resolution have to be parameterized and may cause uncertainties. Another source of uncertainty can be the driving global model, which influences the large-scale dynamics in the regional climate model. 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.

For the given scenario, the ensemble of regional climate model simulation projects robust trends in heavy precipitation over Europe. The robustness of the results gives confidence that heavy precipitation is likely to change in the simulated way:

In winter we find a general increase in heavy precipitation almost over entire Europe. This trend can partly be attributed to an increased amount of water vapour in the atmosphere. In a warmer climate the saturation pressure of water changes according to the Clausius-Clapeyron equation and as a consequence the atmosphere can collect more moisture until it is saturated. The investigation of changes in the number of precipitation events with amounts above a high threshold shows that heavy events might occur more often in the future. Changes in the intensities of extreme events seem to play a minor role.

The negative trends which are projected over central and southern Europe in summer are contradictory to what would be expected from the Clausius-Clapeyron relation. Further investigations have shown that the probability for saturation decreases in these regions. Over the land masses this might be due to a limited availability of water for evaporation because of hotter and therefore drier surface conditions. Interestingly, the decreasing trends in heavy precipitation extend over the Atlantic Ocean as well, although the availability of water is infinite over the sea. This fact indicates that changes in the large-scale dynamics of the atmosphere may be an explanation for changes in the occurrence of heavy precipitation events. Despite the general decrease in heavy precipitation over southern Europe in summer, some simulations project positive trends for small areas in the southern Mediterranean region. Since the frequency of precipitation events above a high threshold decreases in the same regions, the intensity needs to increase accordingly.

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