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Documentation for the use of pattern scaling with particular focus on Europe

D34b_Lot2.1.2.1

European Commission

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Executive Summary

This report documents results from the 34 EURO-CORDEX RCP8.5 simulations present as of today. For a number of European subregions we present patterns describing the regional climate change in relation to the change in global mean temperature. These patterns are derived as the linear fit between regional climate change and change in global mean temperature. This is a commonly used method and can be seen as the standard definition of pattern scaling used in the scientific literature. For the calculation of these patterns the climate change signal was derived for three different time windows (2011-2040, 2041-2070 and 2071-2100) w.r.t. the control climate (1971-2000).

For users of the RCM data these patterns could for instance be used to identify the climate change signal at a certain level of global mean temperature increase (e.g. 1.5, 2 or 3°C). In case information is lacking for some temperature interval, the pattern scaling technique can help in identifying the regional signal by means of linear regression between different warming levels.

The results shows for which change in global mean temperature the regional changes become larger than the model variability around the best fit. For users of C3S data this can help in identifying when a climate change signal becomes significant and emerges out of the noise. The results clearly show that changes in temperature are already significant and clearly outside of the model variability while for precipitation it is clear that this will not happen until several decades or centur(ies) into the future.

At a later stage, when more simulations are available, the method can be applied again to further investigate the robustness of the results. It can also be used to better understand the regional climate change and to what extent it differs from the global. When also different forcing scenarios becomes available it can also be applied for studying to what extent the regional climate change signal is linearly depending on the global forcing.

1. Introduction

This deliverable report D34b_Lot2.1.2.1, D1.2 in PRINCIPLES, describes preliminary results related to the scaling of relevant area-averaged quantities with global temperature. The addition of PRINCIPLES EURO-CORDEX simulations to the already existing EURO-CORDEX multi-model ensemble gives a good foundation for an investigation of the robustness of pattern scaling, here understood as the scaling of climate change patterns with global mean temperature.

In this report we still do not have the entire planned PRINCIPLES ensemble available, and it is therefore not the idea to investigate the exact roles of RCM and GCM choice on deviations from the ensemble mean patterns of change. The aim of this investigation is to see how much spread such patterns exhibit and, conversely, at which level of global warming common patterns of change emerge from the inter-model variations.

European change patterns are calculated from aggregated means over the frequently used PRUDENCE regions (e.g. Christensen and Christensen, 2007. BI: British Isles, SC: Scandinavia, ME: Middle Europe, EA: Eastern Europe, FR: France, AL: Alps, IP: Iberian Peninsula, MD: Mediterranean area). For temperature, the differences between regional means are shown; for precipitation we study the relative difference between regional means.

2. Results and Discussion

We analyse 34 simulations (33 for precipitation) over the CORDEX European 12km areas according to the RCP8.5 emission scenario. Of these, 12 have been performed in the PRINCIPLES project. As PRINCIPLES simulations currently have only been performed for RCP8.5, we will not analyse simulations for other scenarios in this study. The simulations being analysed are listed in Table 1.

In Figs 1-4 we show changes of averaged quantities over the PRUDENCE areas as a function of global warming. Figs 1-2 show regional warming for winter (DJF) and summer (JJA), whereas Figs 3-4 show the relative change in precipitation in percent. Through all points a regression line has been drawn as a dashed line, forced to go through the origin. In Figs 1-2 we also show the identity line to visualize whether regional seasonal warming is larger or smaller than the global average. Both the driving GCM and the RCM is indicated in each symbol: Shape for GCM and colour for RCM. Note that this ensemble includes simulations with both CCLM and WRF in quite different versions with different properties.

It can be seen from these figures, as expected (e.g. Kjellström et al., 2013), that regional temperature shows much less spread around the fitted line than does precipitation as a result of the stronger signal-to-noise ratio for temperature. Still, almost all slopes of regression lines, including those of precipitation, are significantly different from zero as documented in the error bars of Figs 5-6, which show 95% confidence intervals calculated with bootstrapping (1000 re-samplings with replacement). Only JJA precipitation for areas 3 and 4, Middle Europe (ME) and Eastern Europe (EA) do not have a slope line significantly different from 0. This is consistent with the

fact that these two areas span the zero line between increasing summer precipitation to the north and decreasing summer precipitation to the south.

From these two figures, showing the slopes of regression lines through the origin, we see that regional heating differs from the global average in some regions and seasons. Notably, winter warming in northern Europe and summer warming in southern Europe are considerably larger than the global average (Fig. 5). Contrastingly, BI, the British Isles, exhibits less warming than the global average in both seasons. We attribute this to the proximity to the ocean; similarly, the other areas bordering the Atlantic Ocean (every second) show rather low sensitivity in winter compared to the more continental regions further east. In Fig. 6 we recognize the general increase in precipitation in winter except for the Mediterranean region, and the general reduction in summer precipitation except in the northernmost SC domain.

The sum of squared deviations (SSD) from the best-fit line has been calculated for both fields and both seasons. Comparing this with the linear change in global warming allows for the determination of the temperature where the fitted regional signal becomes greater than the square root of the average SSD, in other words, where the signal becomes larger than the inter-model variability around the fitted line. Note that this is not an attribution study, as we are using the slopes determined from the entire period and the entire ensemble; we are merely estimating the global warming where we can expect most models to agree on the sign of the change for each field, season and region. This is illustrated in Fig. 7. We do not show the two situations where the slope is not significant, and we further only show data where the temperature of emergence is below 5 degrees of warming. For half of the regions, localized at intermediate latitudes, we do not see significant summer precipitation change below 5 degrees global warming, as there is a large spread compared to the climate signal causing very high temperatures of emergence. The critical temperatures depicted in Fig. 7 are around 0.5 degrees for regional and seasonal temperature change, around 2 degrees for winter precipitation and roughly 3 degrees for the depicted regions for summer precipitation.

Table 1. Euro-CORDEX simulations under study. 12 of the 34 simulations have been produced in the PRINCIPLES project. PRINCIPLES simulations are indicated in boldface. Fields with more than one simulation refer to different GCM ensemble members except for MOHC-HadGEM2-ES-WRF, where two different RCM versions were used on the same GCM simulation. The simulation IPSL-CM5A-WRF has not been included in the precipitation analysis due to a post processing error.

| RCP8.5	RCA4	CCLM	REMO	RACMO	HIRHAM	ALADIN	RegCM	WRF
MOHC-HadGEM2-ES	1	1	1	1	**1**		**1**	1+**1**
ICHEC-EC-EARTH	1+**1**	1	1	2+**1**	1+**2**			
CNRM-CERFACS-CNRM-CM5				**1**		**1**		
NCC-NorESM1-M	**1**		**1**		1			
MPI-M-MPI-ESM-LR	1	1	2					1
IPSL-IPSL-CM5A-MR	1							**1**
CCCma-CanESM2		1	1					
MIROC-MIROC5		1	1					
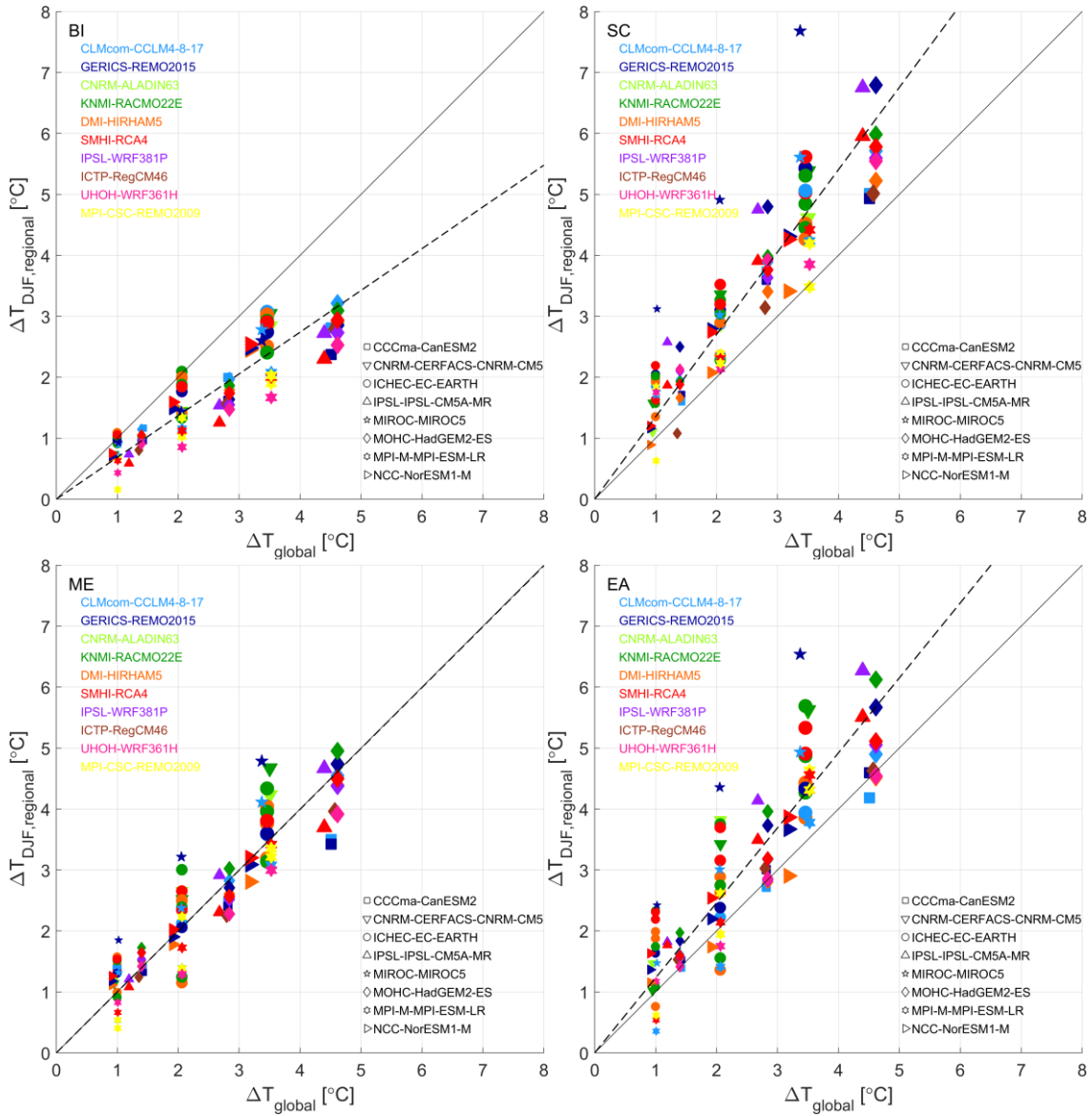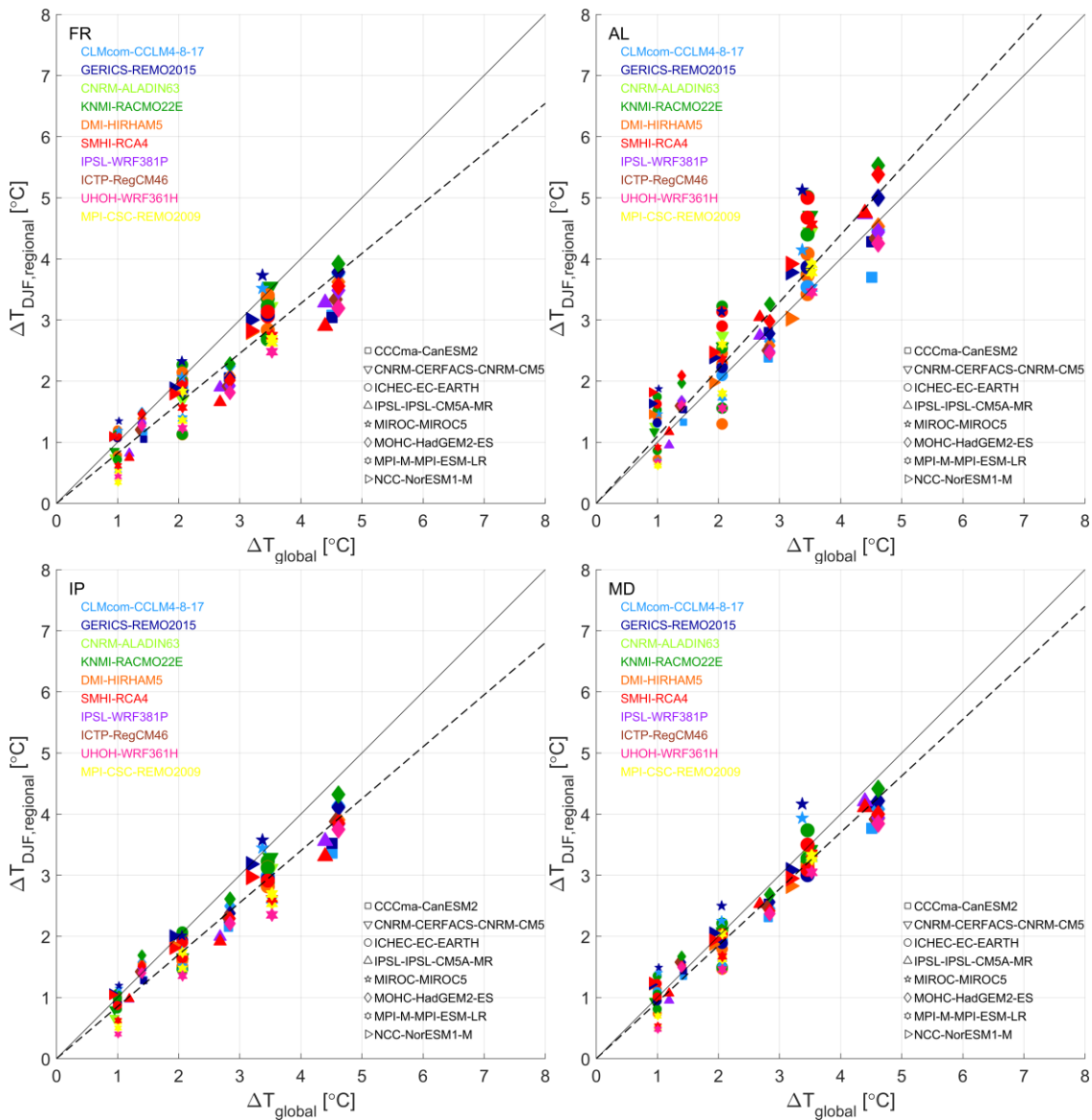
Figure 1. DJF warming for Euro-CORDEX simulations relative to 1971-2000. Small symbols: 2011-2040, medium-size symbols: 2041-2070, large symbols: 2071-2100. The symbol illustrates the driving GCM according to the legend, the colour shows the RCM. A total of 34 RCP8.5 simulations have been investigated, as listed in Table 1. The diagrams are labelled at the top left with abbreviations denoting region, BI: British Isles, SC: Scandinavia, ME: Middle Europe, EA: Eastern Europe, FR: France, AL: Alps, IP: Iberian Peninsula, MD: Mediterranean area.
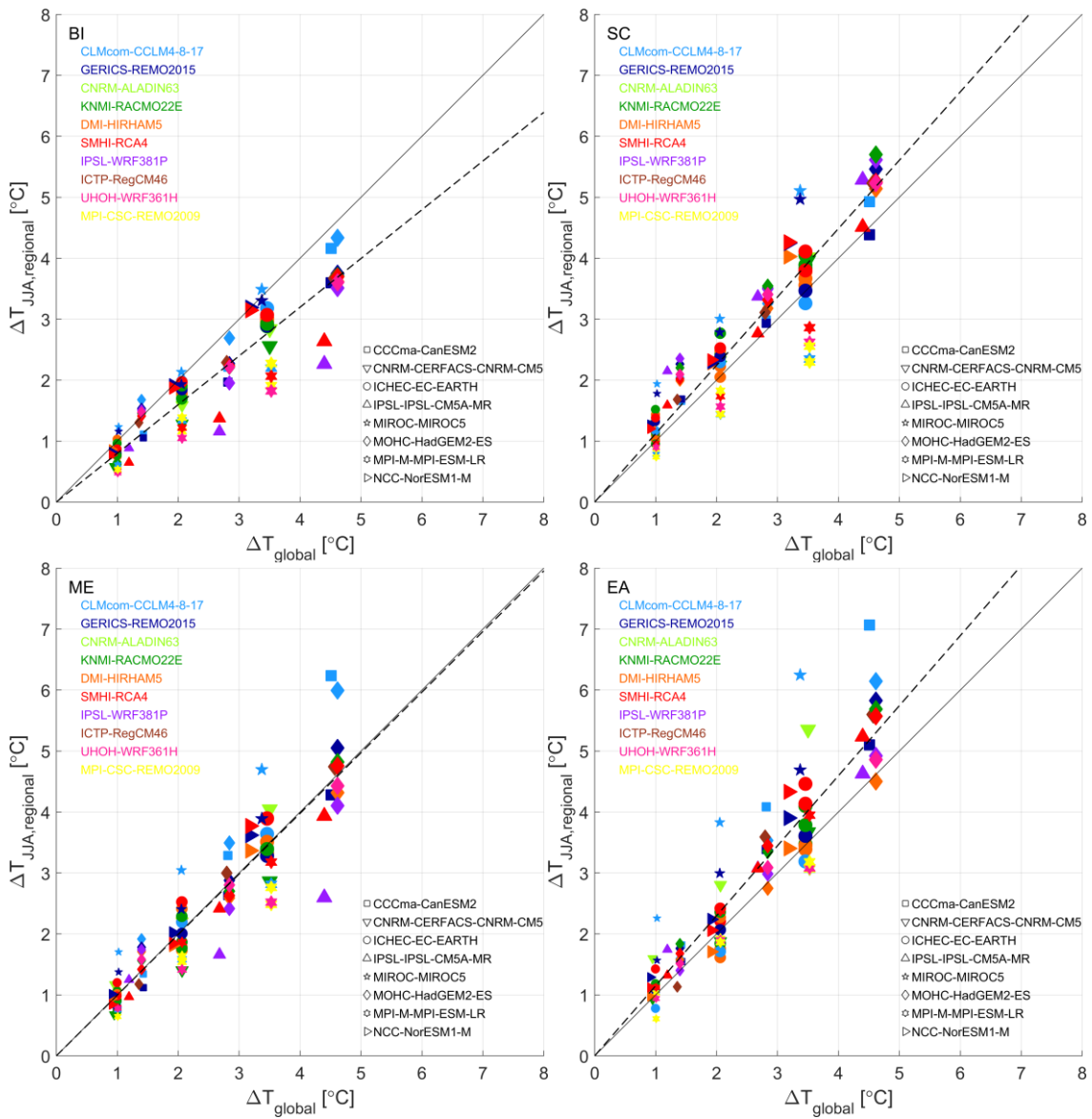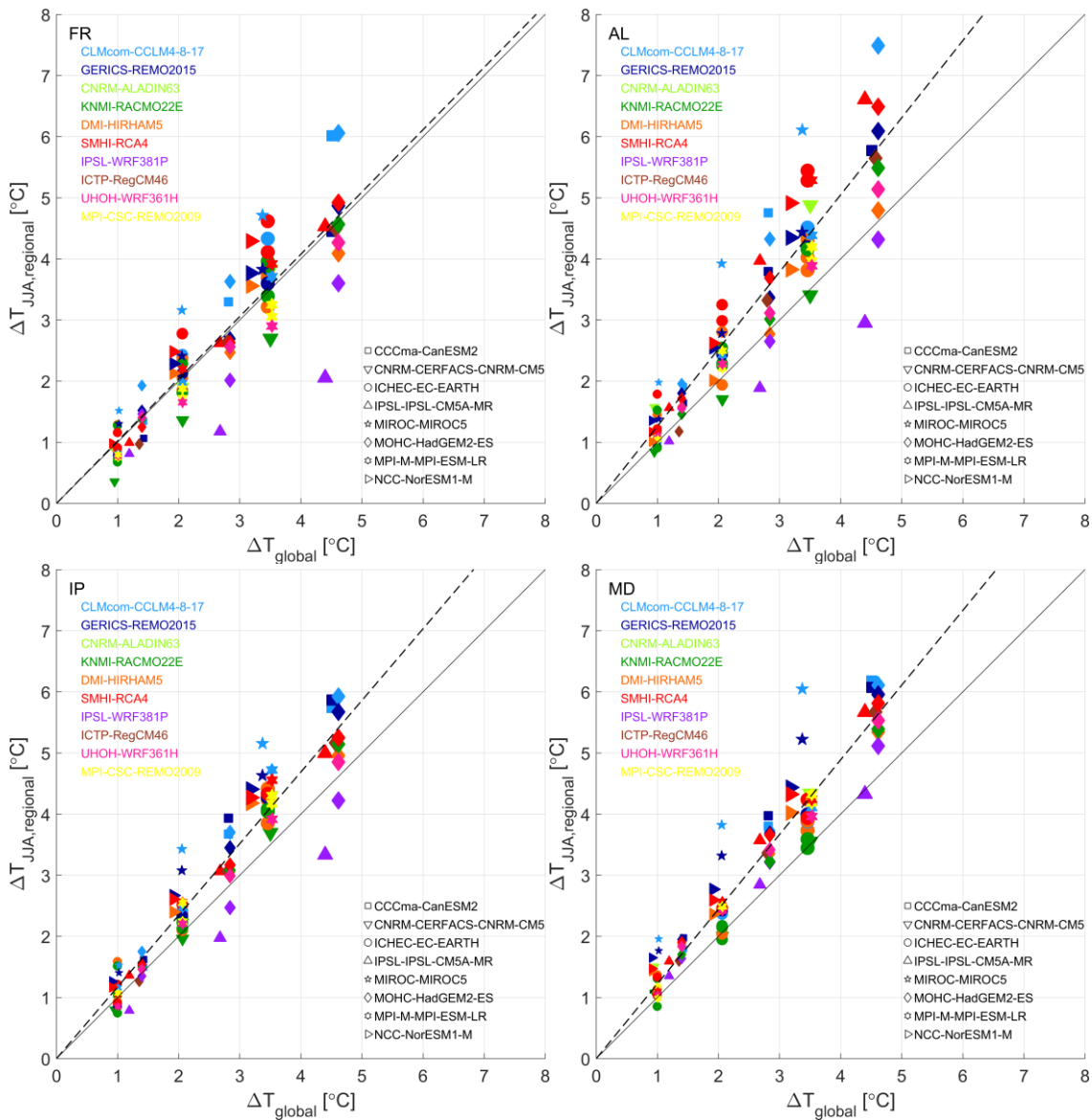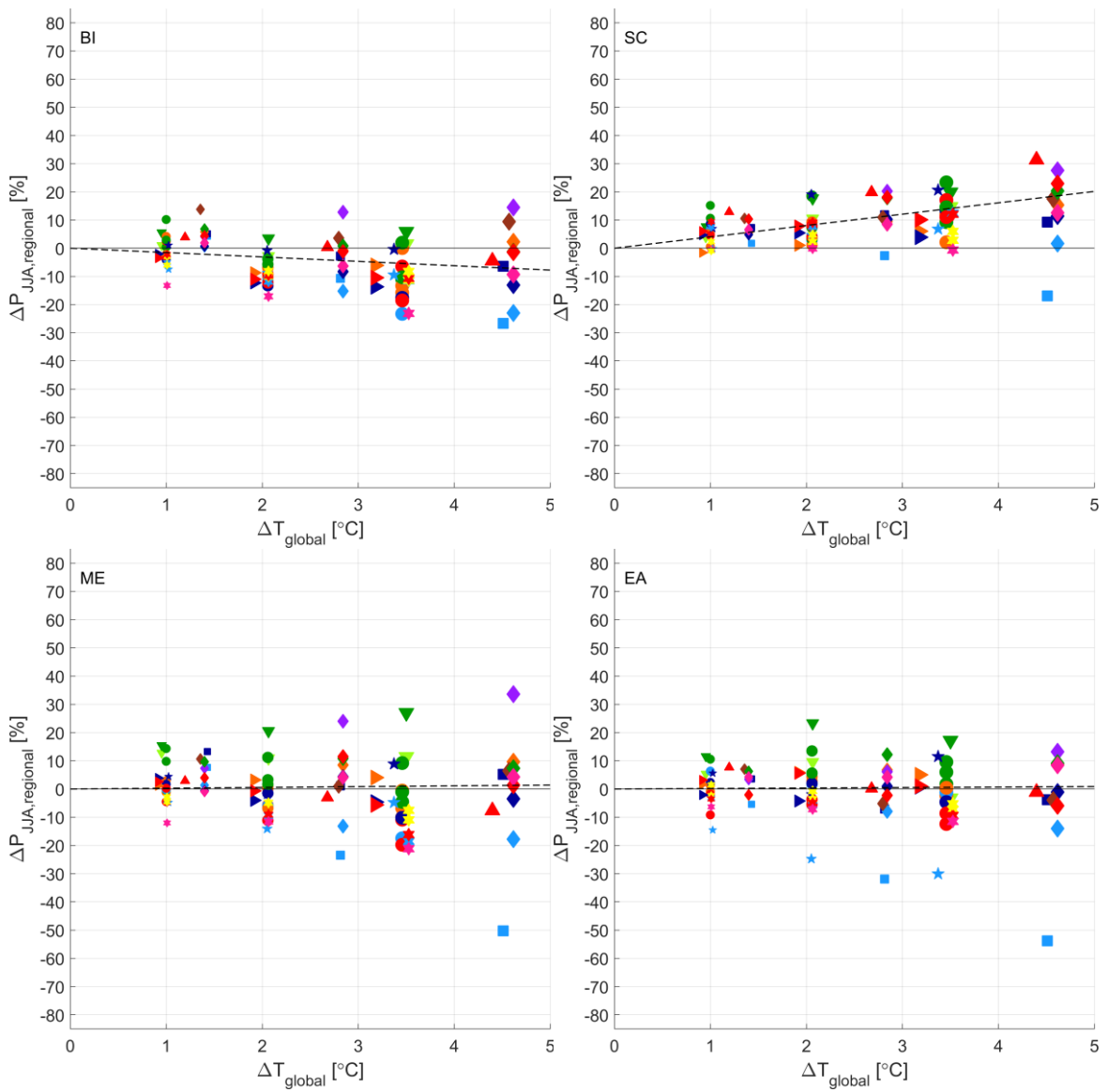
Figure 2. JJA warming for Euro-CORDEX simulations relative to 1971-2000. Small symbols: 2011-2040, medium-size symbols: 2041-2070, large symbols: 2071-2100. The symbol illustrates the driving GCM according to the legend, the colour shows the RCM. A total of 34 RCP8.5 simulations have been investigated, as listed in Table 1. The diagrams are labelled at the top left with abbreviations denoting region, BI: British Isles, SC: Scandinavia, ME: Middle Europe, EA: Eastern Europe, FR: France, AL: Alps, IP: Iberian Peninsula, MD: Mediterranean area.
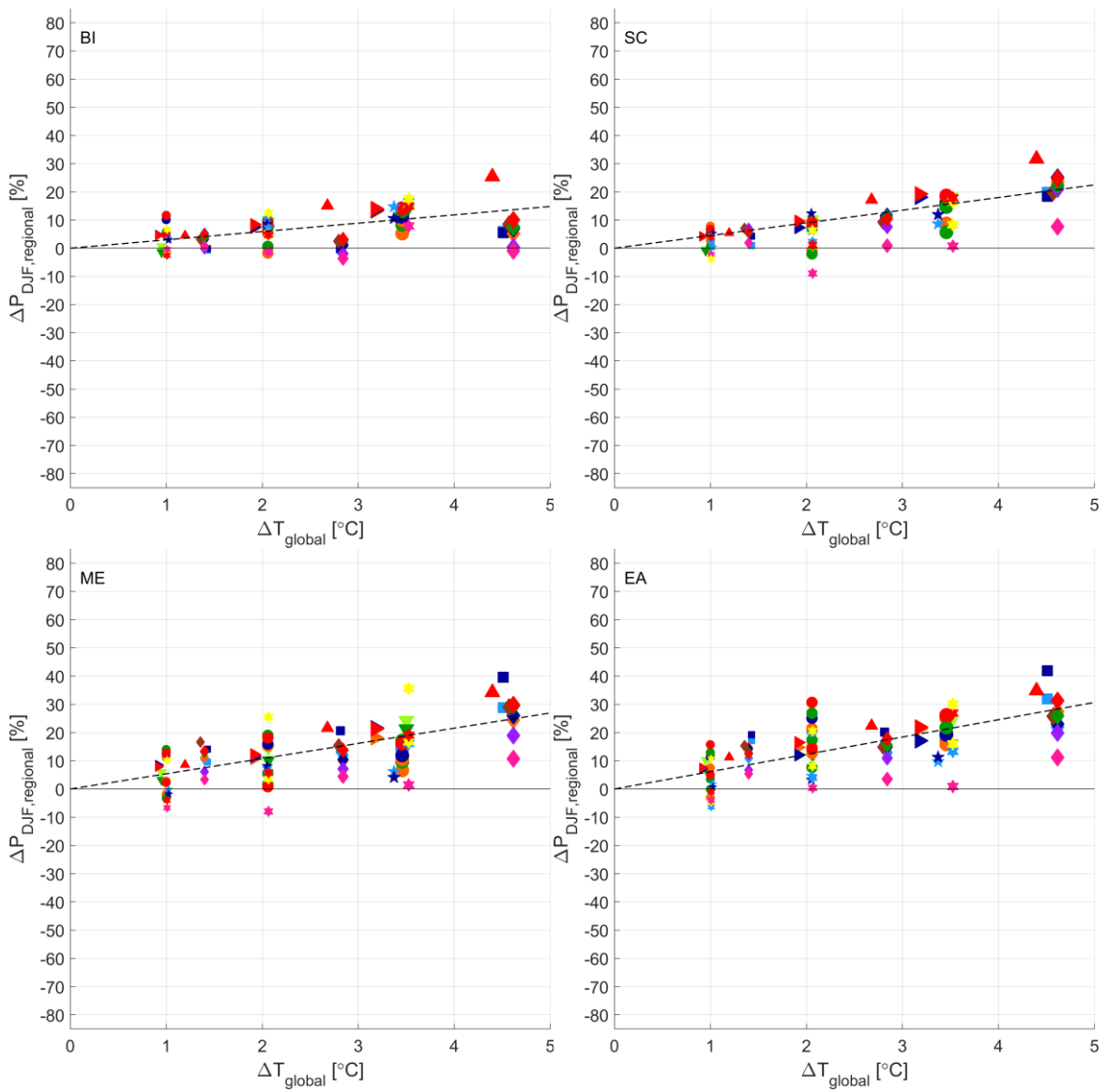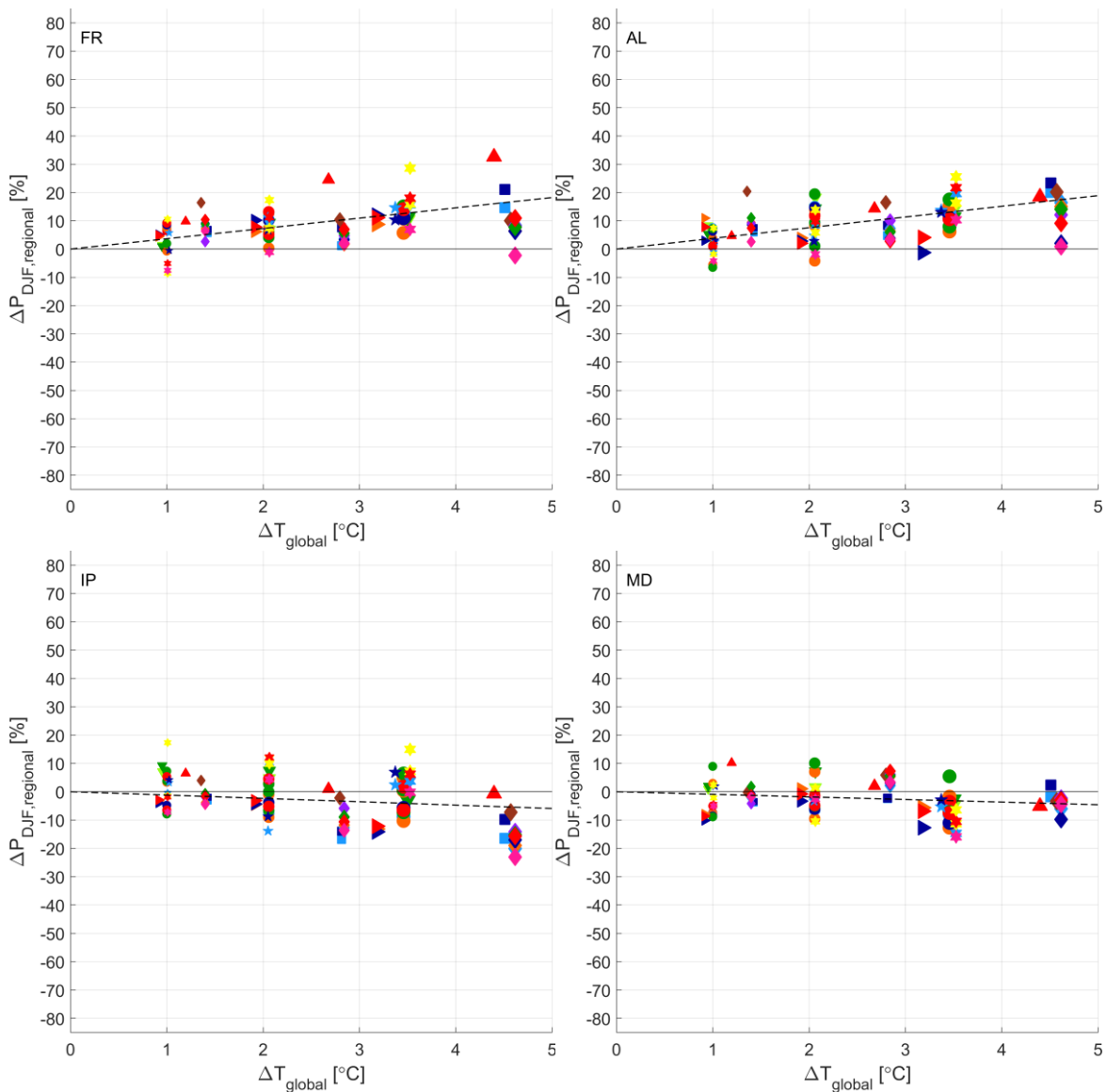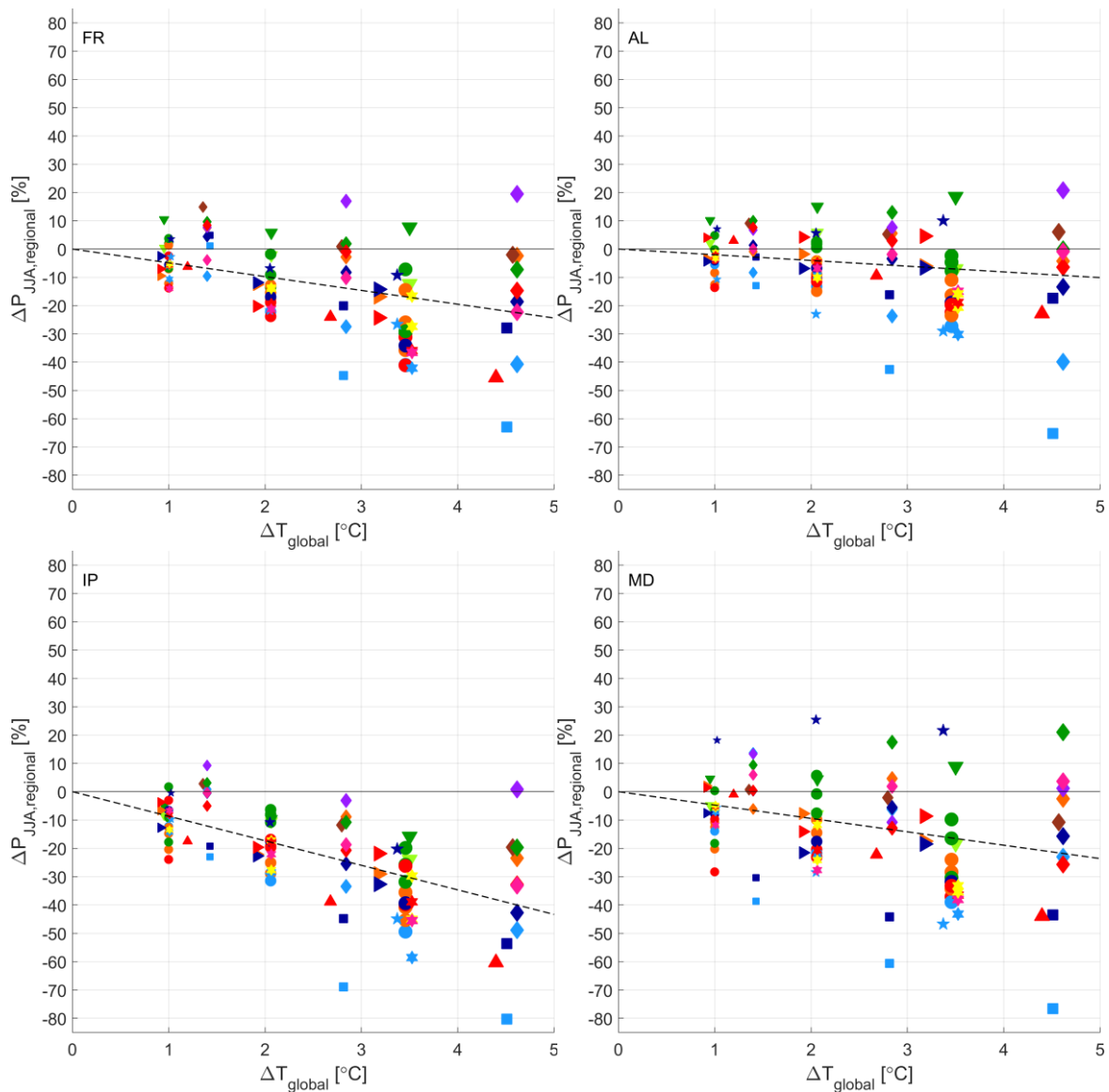
Figure 3. DJF relative precipitation change in per cent for Euro-CORDEX relative to 1971-2000. Small symbols: 2011-2040, medium-size symbols: 2041-2070, large symbols: 2071-2100. The symbol illustrates the driving GCM according to the legend, the colour shows the RCM. A total of 33 RCP8.5 simulations have been investigated, as listed in Table 1. The diagrams are labelled at the top left with abbreviations denoting region, BI: British Isles, SC: Scandinavia, ME: Middle Europe, EA: Eastern Europe, FR: France, AL: Alps, IP: Iberian Peninsula, MD: Mediterranean area.

Figure 4. JJA relative precipitation change in per cent for Euro-CORDEX simulations relative to 1971-2000. Small symbols: 2011-2040, medium-size symbols: 2041-2070, large symbols: 2071-2100. The symbol illustrates the driving GCM according to the legend, the colour shows the RCM. A total of 33 RCP8.5 simulations have been investigated, as listed in Table 1. The diagrams are labelled at the top left with abbreviations denoting region, BI: British Isles, SC: Scandinavia, ME: Middle Europe, EA: Eastern Europe, FR: France, AL: Alps, IP: Iberian Peninsula, MD: Mediterranean area.
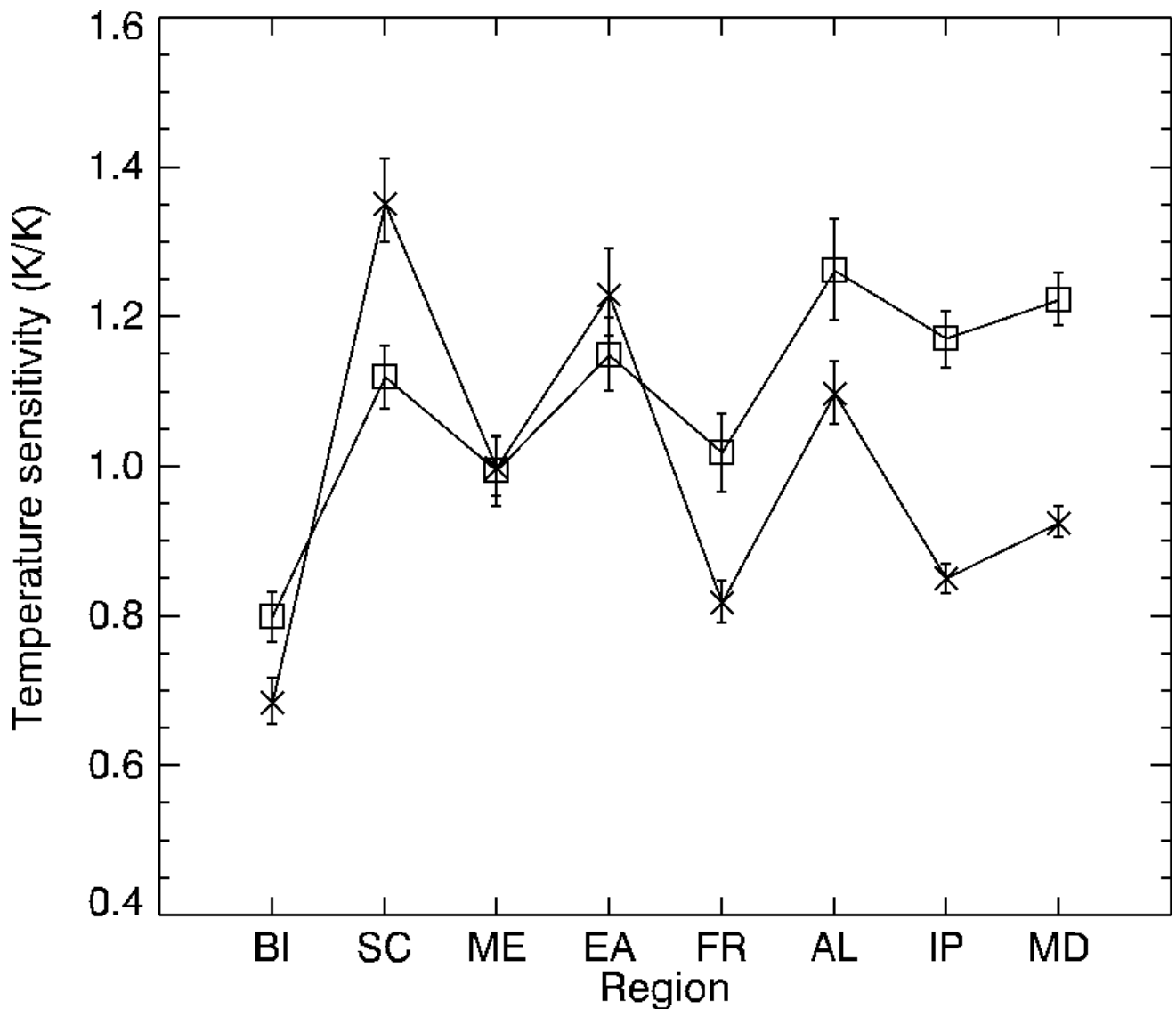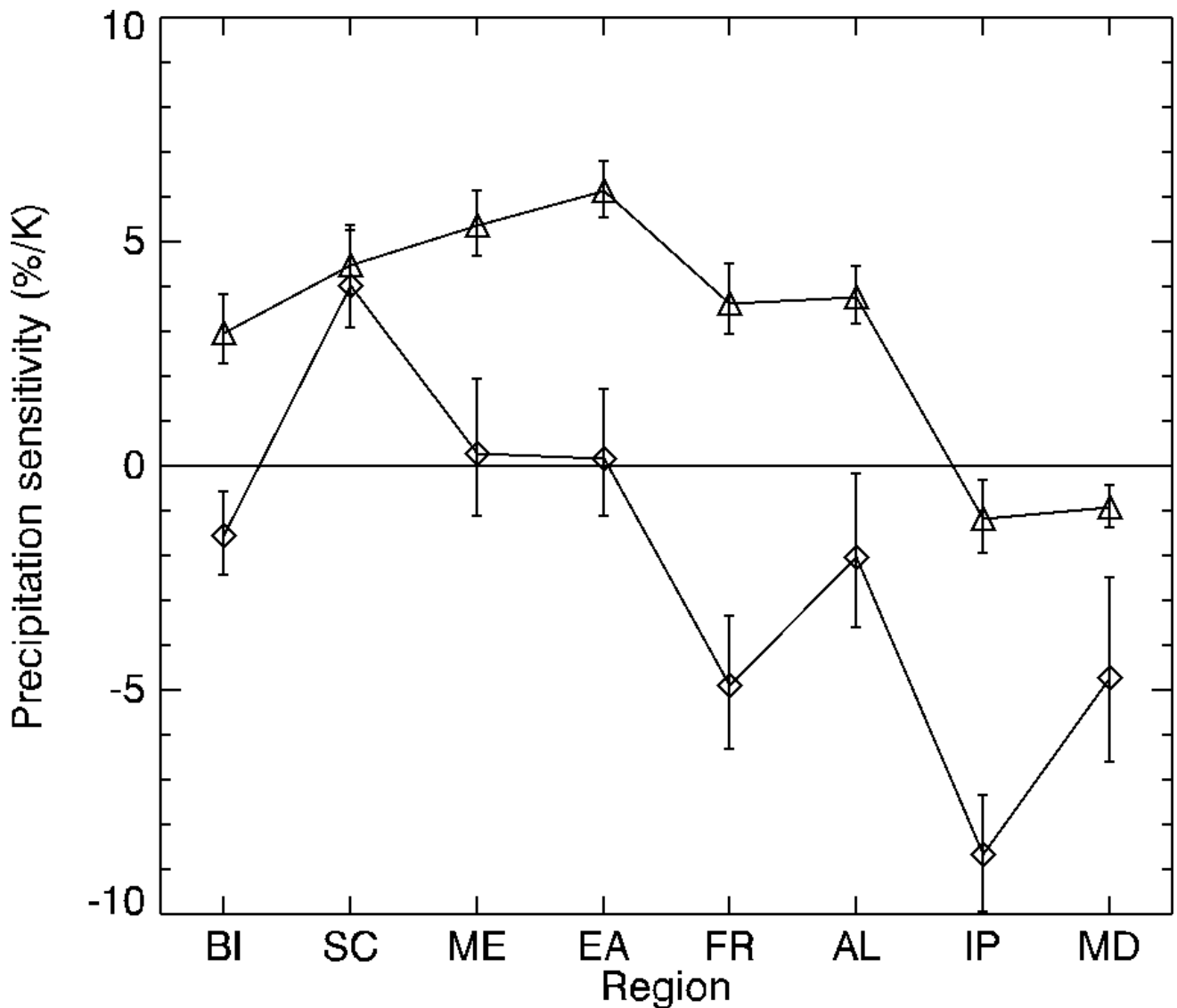
Figure 5. Regional warming per degree of global warming as calculated from Figs 1 and 2. Squares: Summer; Crosses: Winter. Regions are shown in the same quasi-geographical sequence as in Figs 1-4. Error bars indicate the 95% confidence interval of the regression slopes as calculated with a 1000 member bootstrap. The regions are: (BI) British Isles, (SC) Scandinavia, (ME) Middle Europe, (EA) Eastern Europe, (FR) France, (AL) Alps, (IP) Iberian Peninsula, (MD) Mediterranean area.

Figure 6. Regional relative precipitation change per degree of global warming as calculated from Figs 3 and 4. Diamonds: Summer; Triangles: Winter. Regions are shown in the same quasi-geographical sequence as in Figs 1-4. Error bars indicate the 95% confidence interval of the regression slopes as calculated with a 1000 member bootstrap. The regions are: (BI) British Isles, (SC) Scandinavia, (ME) Middle Europe, (EA) Eastern Europe, (FR) France, (AL) Alps, (IP) Iberian Peninsula, (MD) Mediterranean area.
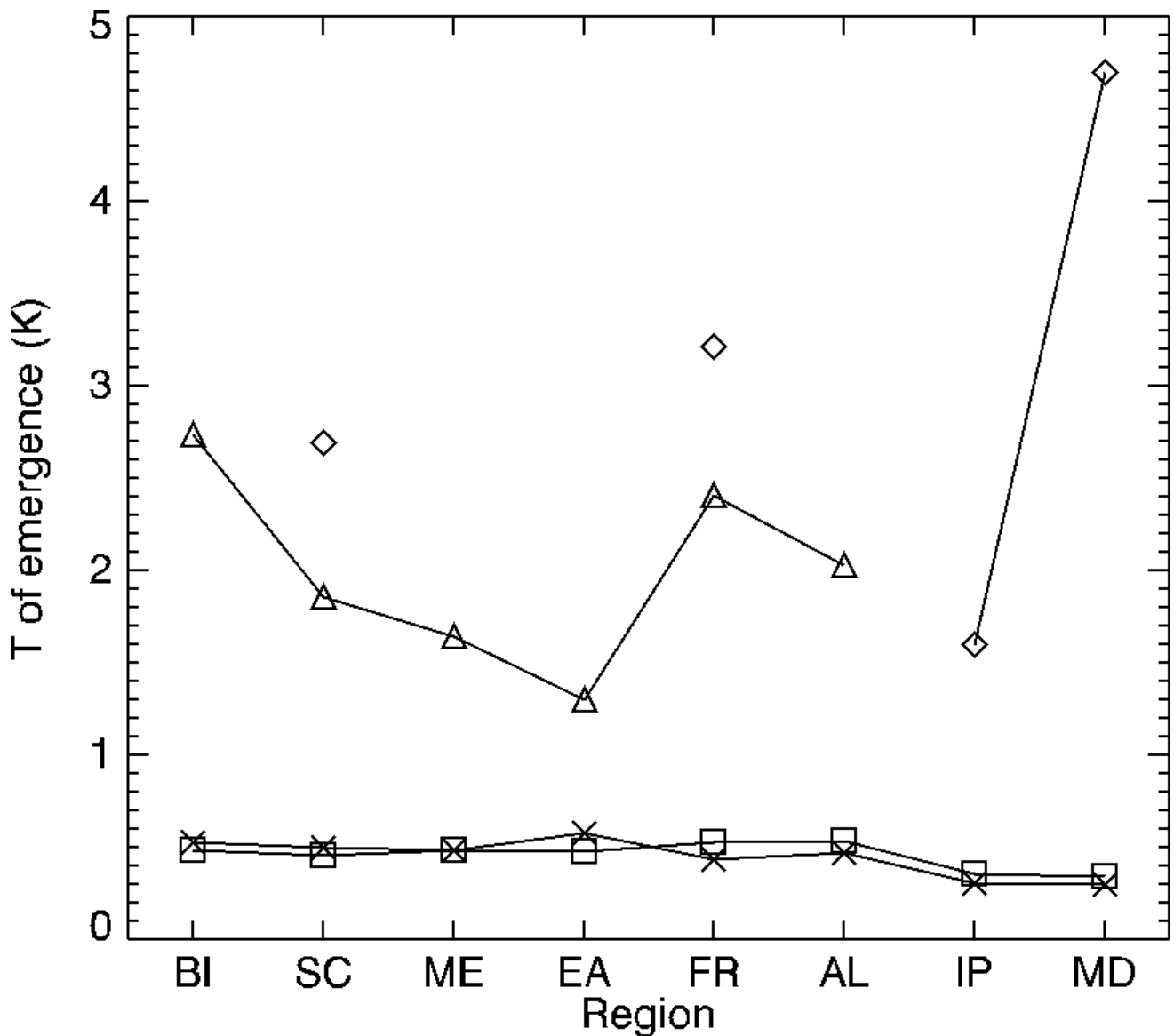
Figure 7. For each region, the global warming where regional change according to the linear relationship exceeds the model variability around the best fit line, i.e., a measure of the global warming where the specific regional climate signal emerges from inter-model variability. Only points with emergence temperature below 5 degrees are shown. Squares: Summer temperature; Crosses: Winter temperature; Diamonds: Summer precipitation; Triangles: Winter precipitation. The regions are: (BI) British Isles, (SC) Scandinavia, (ME) Middle Europe, (EA) Eastern Europe, (FR) France, (AL) Alps, (IP) Iberian Peninsula, (MD) Mediterranean area.

References

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