Maps of seasonal temperature and precipitation changes for the Mediterranean Basin

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Table of contents

Introduction and scope

Projected changes of key meteorological variables (for example, precipitation and temperature) are not, in terms of magnitude, expected to be consistent throughout the Mediterranean region. Similarly, according to global and regional model projections and due to several climatic feedbacks, these changes will not be uniformly distributed throughout the year. While changes in seasonal temperature and precipitation were also discussed in *Chapter 2* of the First Mediterranean Assessment Report (MAR1), here we present a complementary but more informative assessment that could provide useful information for impact and adaptation studies and also motivate mitigation actions. This is presented in the form of an atlas that includes all the Mediterranean countries, a range of future periods and the two greenhouse gas emission pathways (RCP2.6 and RCP8.5) that were discussed primarily in MAR1.

Data and methods

At the time of writing, the most comprehensive and populated ensemble of regional climate projections, that adequately includes most of the Mediterranean region, is the EURO-CORDEX (Jacob et al. 2020), which is the European initiative of the Coordinated Regional Downscaling Experiment (Giorgi and Gutowski 2015). This set of state-of-the-art regional projections, available in a horizontal resolution of about 12 km is the basis of the present assessment. The full list of experiments taken into account as well as the availability per variable and scenario are presented in *Table 1.*

When assessing future climate change, it is important to specify the reference period to which climate projections are compared, along with future "time slices" of particular interest. In MAR1 and the present atlas, we use 20-year periods. This length is sufficient to smooth part of the high-frequency natural climate variability that may otherwise mask the forced trend, but it is short enough to assume that climate does not change much during the 20 years covered. For the reference period, we chose the last decades of the 20th century (1980-1999). For the future, we kept 20-year time slices in order to sample the same level of internal variability as in the reference period. We divided the 21st century into 20-year time slices with a near-future period (2020-2039), a mid-term period centred in 2050 (2040-2059) and a far-future period close to the end of the 21st century (2080-2099). The mid-21st century period is arguably of particular interest for many stakeholders, especially for mid-term adaptation. The end of the 21st century period is also of interest for stakeholders working on mitigation targets and involved in very long-term planning (e.g., for the design and planning of dams, forests or cities).

In terms of seasons, we use the boreal hemisphere definition for winter (December-February), spring (March-May), summer (June-August) and autumn (September-November), for analysis of both temperature and precipitation. Maps of future projections on an annual basis are discussed in the main text of MAR1 and are therefore not presented here.

For future climate, an important part of the uncertainty is related to the evolution of socio-economic development. To be able to propose future climate projections according to various possible socio-economic and climate policy trajectories, we follow the Representative Concentration Pathways or RCPs, defined in *Box 2.1* of MAR1 (Meinshausen et al. 2011). Here, we focus mostly on two of such pathways which encompass the range of IPCC-AR5, CMIP5 and CORDEX simulations: the 'business as usual' scenario of high emissions (RCP8.5) and a more optimistic pathway closest to meeting the UNFCCC Paris Agreement main targets (RCP2.6). These scenarios have been chosen also due to model projection availability constraints at the regional scale.

GLOBAL MODEL	REGIONAL MODEL	TEMPERATURE AT 2M		PRECIPITATION	
		RCP2.6	RCP8.5	RCP2.6	RCP8.5
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	CLMcom-CCLM4-8-17_v1		•		•
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	CNRM-ALADIN53_v1	•	•		
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	CNRM-ALADIN63_v2	•	•	•	•
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	DMI-HIRHAM5_v2		•		•
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	KNMI-RACMO22E_v2	•	•	•	•
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	RMIB-UGent-ALARO-0_v1	•	•	•	•
CNRM-CERFACS-CNRM-CM5 (r1i1p1)	SMHI-RCA4_v1		•		•
ICHEC-EC-EARTH (r12i1p1)	CLMcom-CCLM4-8-17_v1	•	•	•	•
ICHEC-EC-EARTH (r12i1p1)	DMI-HIRHAM5_v1		•		•
ICHEC-EC-EARTH (r12i1p1)	KNMI-RACMO22E_v1	•	•	•	•
ICHEC-EC-EARTH (r12i1p1)	SMHI-RCA4_v1	•	•	•	•
ICHEC-EC-EARTH (r3i1p1)	KNMI-RACMO22E_v1		•		•
ICHEC-EC-EARTH (r3i1p1)	SMHI-RCA4_v1		•		•
IPSL-IPSL-CM5A-LR (r1i1p1)	GERICS-REMO2015_v1	•		•	
IPSL-IPSL-CM5A-MR (r1i1p1)	SMHI-RCA4_v1		•		•
MOHC-HadGEM2-ES (r1i1p1)	CLMcom-CCLM4-8-17_v1		•		•
MOHC-HadGEM2-ES (r1i1p1)	DMI-HIRHAM5_v1		•		•
MOHC-HadGEM2-ES (r1i1p1)	KNMI-RACMO22E_v2	•	•	•	•
MOHC-HadGEM2-ES (r1i1p1)	SMHI-RCA4_v1	•	•	•	•
MPI-M-MPI-ESM-LR (r1i1p1)	CLMcom-CCLM4-8-17_v1		•		•
MPI-M-MPI-ESM-LR (r1i1p1)	MPI-CSC-REMO2009_v1	•	•	•	•
MPI-M-MPI-ESM-LR (r1i1p1)	SMHI-RCA4_v1	•	•	•	•
NCC-NorESM1-M (r1i1p1)	DMI-HIRHAM5_v2		•		•
NCC-NorESM1-M (r1i1p1)	GERICS-REMO2015_v1		•		•
NCC-NorESM1-M (r1i1p1)	KNMI-RACMO22E_v1		•		
NCC-NorESM1-M (r1i1p1)	SMHI-RCA4_v1	•	•	•	•
NOAA-GFDL-GFDL-ESM2G (r1i1p1)	GERICS-REMO2015_v1	•		•	
	TOTAL	14	25	13	23

Table B.1 | List of EURO-CORDEX experiments taken into account in the presented assessment and availability of variables.

Projected temperatures

Winter temperature

Projected winter temperature changes for the Mediterranean are presented in *Figure B1*. For pathway RCP2.6, the EURO-CORDEX multi-model ensemble suggests a relatively mild increase that is not expected to exceed 1°C-2°C for all sub-periods *(Fig. B.1 – left panels)*. Particularly for the middle and late-21st century, the projected winter warming is slightly higher over the eastern part of the Mediterranean. Nevertheless, the regional differences are not so evident. For the business-as-usual RCP8.5, the near-future winter temperature projections are of the same magnitude as the worst-case ones for RCP2.6 *(Fig. B.1 – top right)*. Already by mid-century, winter warming is expected to reach 3°C, with respect to the historical reference, in many parts of the region. This is the case mainly in high-elevation regions, such as the Atlas Mountains, the Alps, Anatolia and parts of the Balkan Peninsula, highlighting that winter warming could be enhanced by positive snow-albedo feedbacks. For the end of the current century *(Fig. B.1 – bottom right)*, warming is projected to intensify and exceed 4°C in most of the region. In the hotspot mountainous areas, this warming is projected to reach 6°C with respect to the reference period.

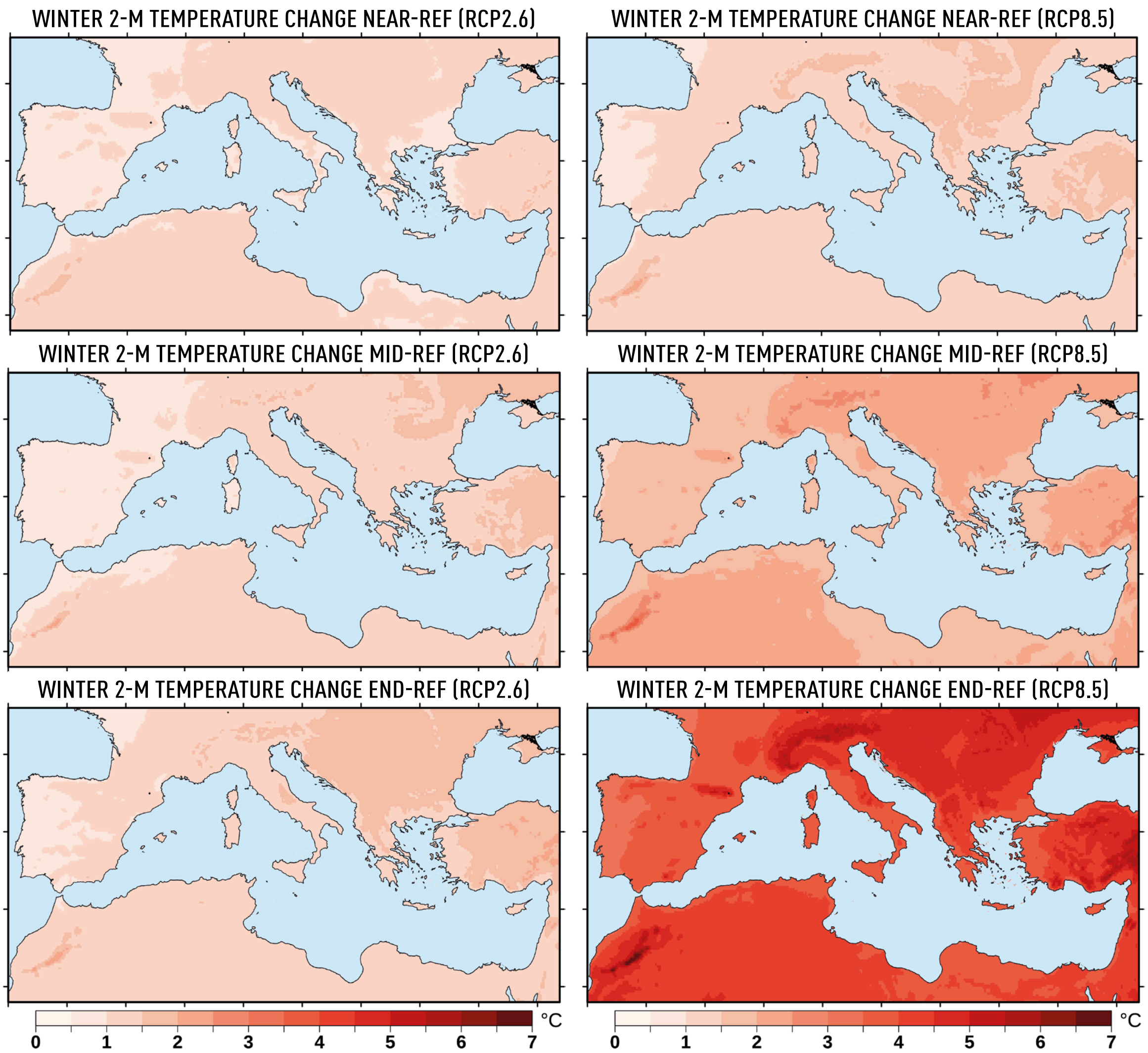

Figure B.1 | **Projected changes in winter (December, January, February) temperatures between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).**

Spring temperature

The projected changes during boreal spring are presented in *Fig. B.2*. Under pathway RCP2.6 and for near-future and mid-century, the projected spring warming is somehow higher than during the winter season. For southern Mediterranean regions, such as the Maghreb, this warming will reach 2.5°C-3°C. By the end of the century, the warming is not projected to exceed 2°C in most of the Mediterranean, with the exception of Anatolia. As expected, under the business-as-usual pathway *(Fig. B.2 – right panels)*, the spring warming is projected to follow the same spatial patterns. The EURO-CORDEX ensemble suggests warming between 4°C and 5°C, with higher values in North Africa and the mountainous regions of the Mediterranean.

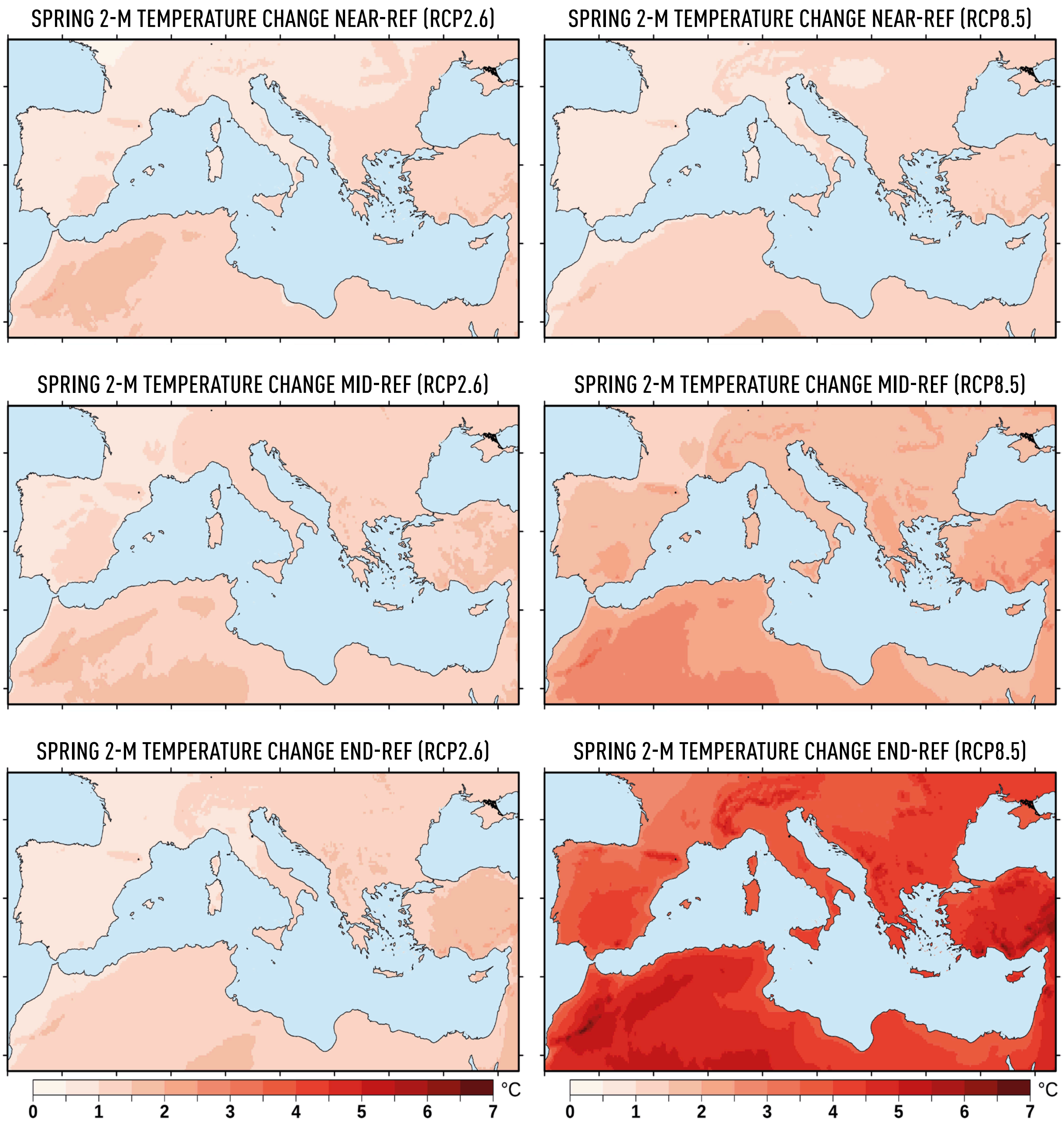

Figure B.2 | Projected changes in spring (March, April, May) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).

Summer temperature

As discussed in MAR1, the projected summer temperature increase in the Mediterranean region, mainly in the South, is particularly high. This is the case mostly for RCP8.5 *(Fig. B.3 – right panels)*. By mid-century, summer warming will likely exceed 3°C in many parts of the region. The late-21st century RCP8.5 projections suggest that this warming will further intensify and locally exceed levels of 6°C-6.5°C. This is expected mainly for southern latitudes and regions such as the Maghreb, the Iberian Peninsula and Anatolia, as well as the Alps. Soil-atmosphere interactions have been found to play a role in this summer warming amplification (e.g., Zittis et al. 2014). In contrast, under the more moderate RCP2.6 pathway, summer temperature changes will likely be less than 2°C throughout the Mediterranean *(Fig. B.3 – left panels)*.

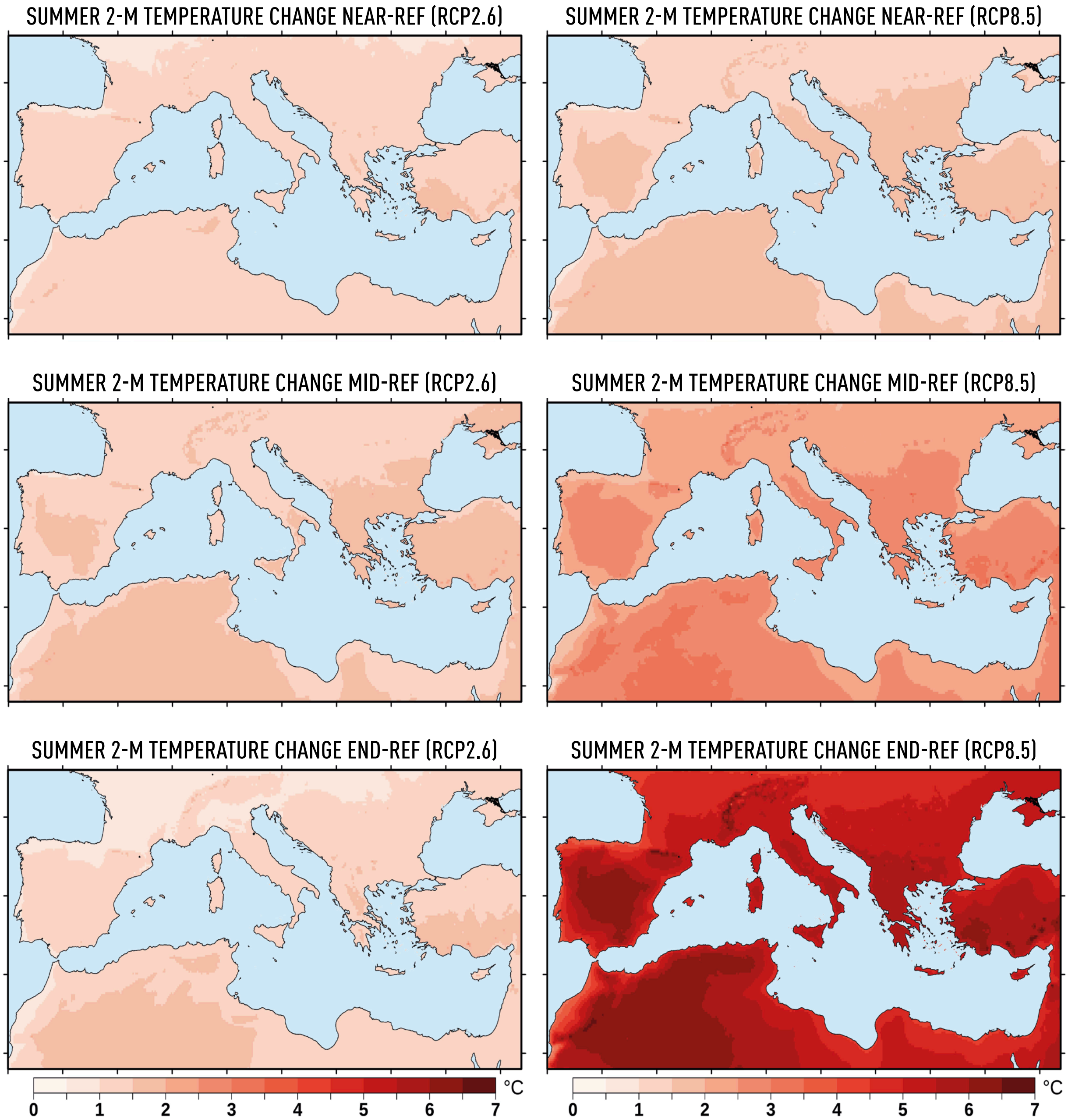

Figure B.3 | Projected changes in summer (June, July, August) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).

Autumn temperature

Maps of projected changes for the transitional season of autumn are presented in *Fig. B.4.* The spatial patterns are very similar to those for the summer season, however, the magnitude of warming is lower. For RCP2.6, future changes range between 1°C and 1.5°C for all future periods *(Fig. B.4 – left panels)*. The only exception is the western part of the Mediterranean and middle century projections that are expected to be somehow higher (up to 2°C). Under the high-emission pathway *(Fig. B.4 – right panels)*, the near future changes are comparable to those for RCP2.6, while the middle century projections indicate that the autumn warming, with respect to the reference period, is not expected to exceed 3°C. The end-of-century projections under RCP8.5 indicate further warming of up to 5°C-6°C, expected mainly for the southern Mediterranean (for example, the Maghreb, the Iberian Peninsula and Anatolia), as well as the Alps.

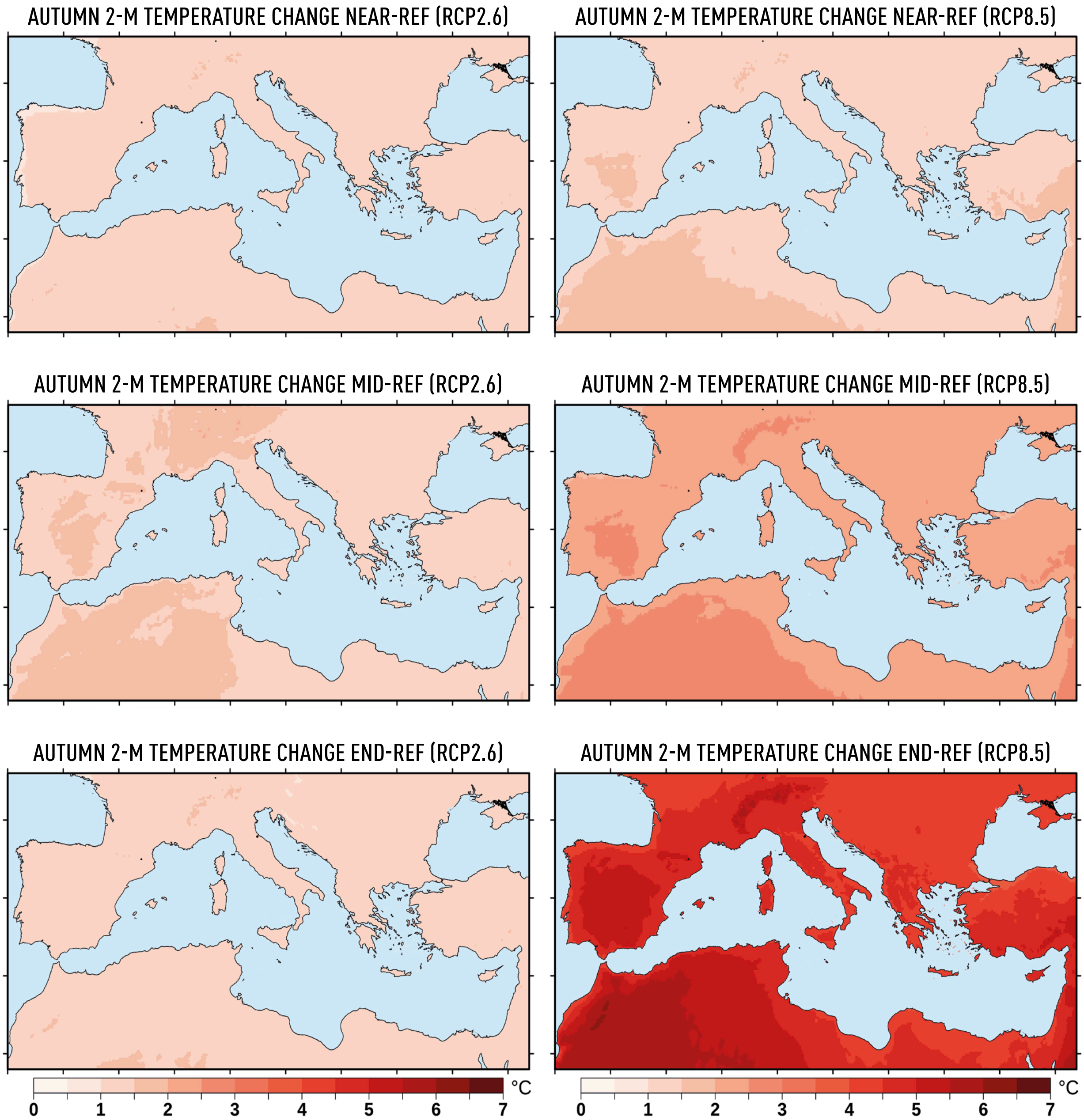

Figure B.4 | **Projected changes in autumn (September, October, November) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).**

Precipitation

Winter precipitation

Projected changes for boreal winter (December, January and February) precipitation are presented in *Fig. B.5* as percentage differences from the historical reference period. Under both emission pathways, and all future periods a North-South gradient of the climate change signal is evident. For southern Europe and the northern Mediterranean territories, winter precipitation is expected to change slightly or increase up to 10%-30%. In contrast, for the drier southern parts of the region, winter precipitation, which is more critical for replenishing water resources, is projected to decrease between 20% and 50%. For the Maghreb region, which is a hotspot of drying, the projected winter precipitation decrease could even exceed 60%. The projected changes are higher for the end of the current century and this is likely the case for both pathways under investigation.

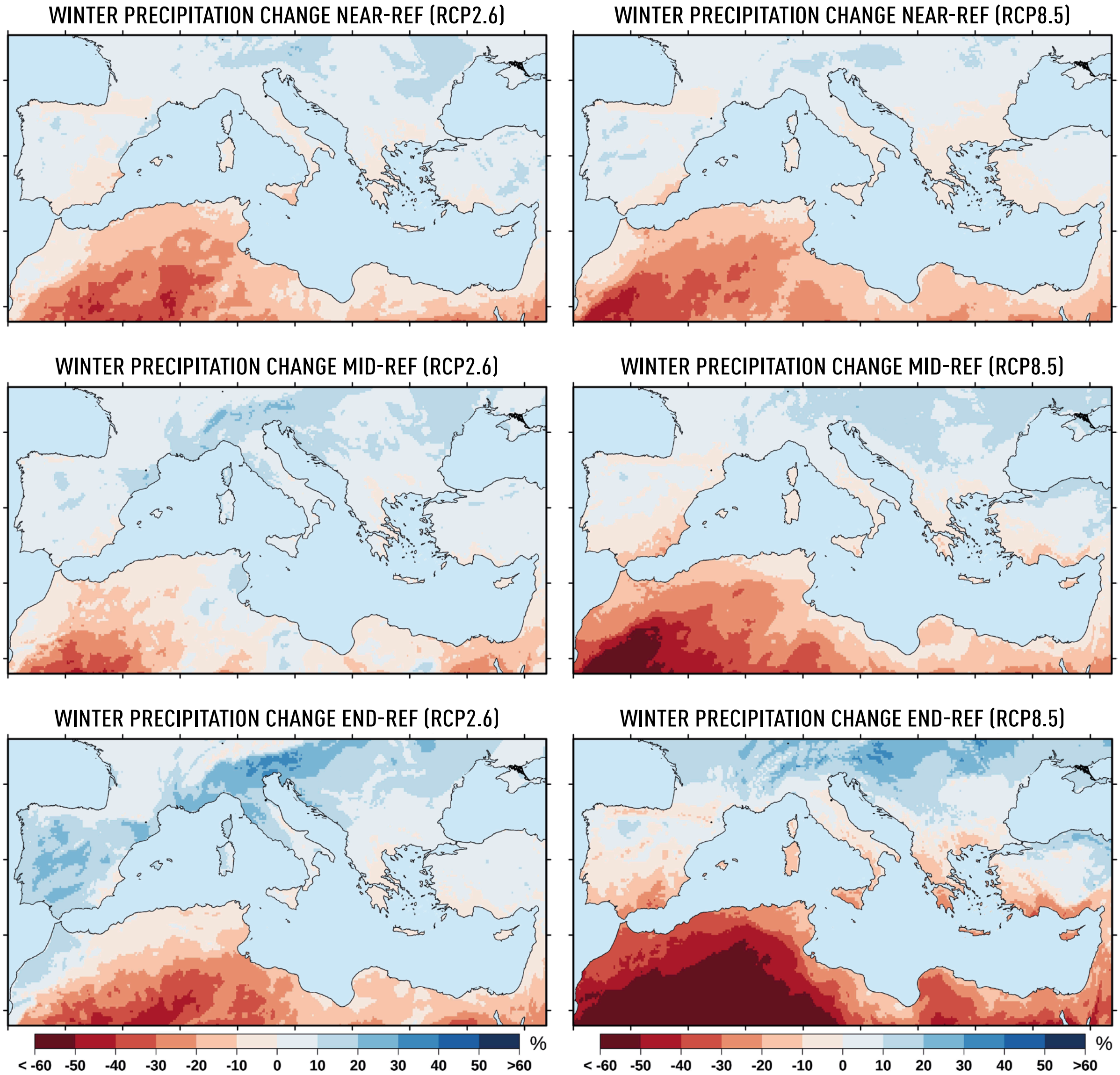

Figure B.5 | Projected changes in winter (December, January, February) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).

Spring precipitation

For spring (March to May) precipitation changes, the North-South gradient is still evident, however, this pattern is less pronounced *(Fig. B.6)*. Noteworthy, for the next two decades (i.e., the near future sub-period), the projected changes are higher for RCP2.6, indicating that even under low-emission pathways, global warming could introduce changes with high impact at regional scales. This is the case mainly for the Maghreb region *(Fig. B.6 – top panels)*. For the mid-21st century, the EURO-CORDEX ensemble suggests similar changes for both pathways. Small changes are expected for southern Europe, while for North Africa, a decrease of 10%-30% in spring precipitation is expected. Under RCP8.5, seasonal drying is expected to intensify towards the end of the century.

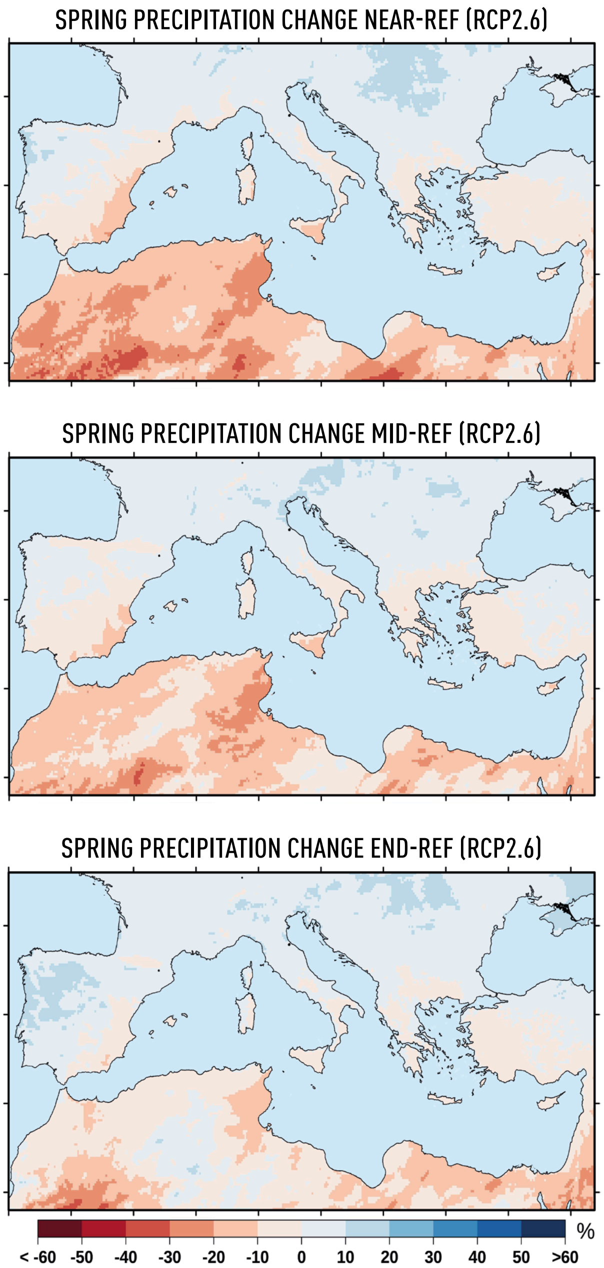

Figure B.6 | **Projected changes in spring (March, April, May) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).**

Summer precipitation

The projected precipitation changes of the summer season are presented in *Fig. B.7.* For the northern Mediterranean and southern Europe, the projected changes are relatively mild and were found to range between ±10%. For parts of the southern Mediterranean, a precipitation increase is projected, however, this is not always significant in actual precipitation amounts since summer precipitation is limited (not shown). This increase, that varies in magnitude between the different pathways and time periods, is likely related to a northward expansion of the inter-tropical convergence zone (Evans 2010). A strong summer precipitation decline is evident only for the end of the current century and the RCP8.5 pathway *(Fig. B.7 – bottom right).* This is apparent for most of the Mediterranean and southern Europe.

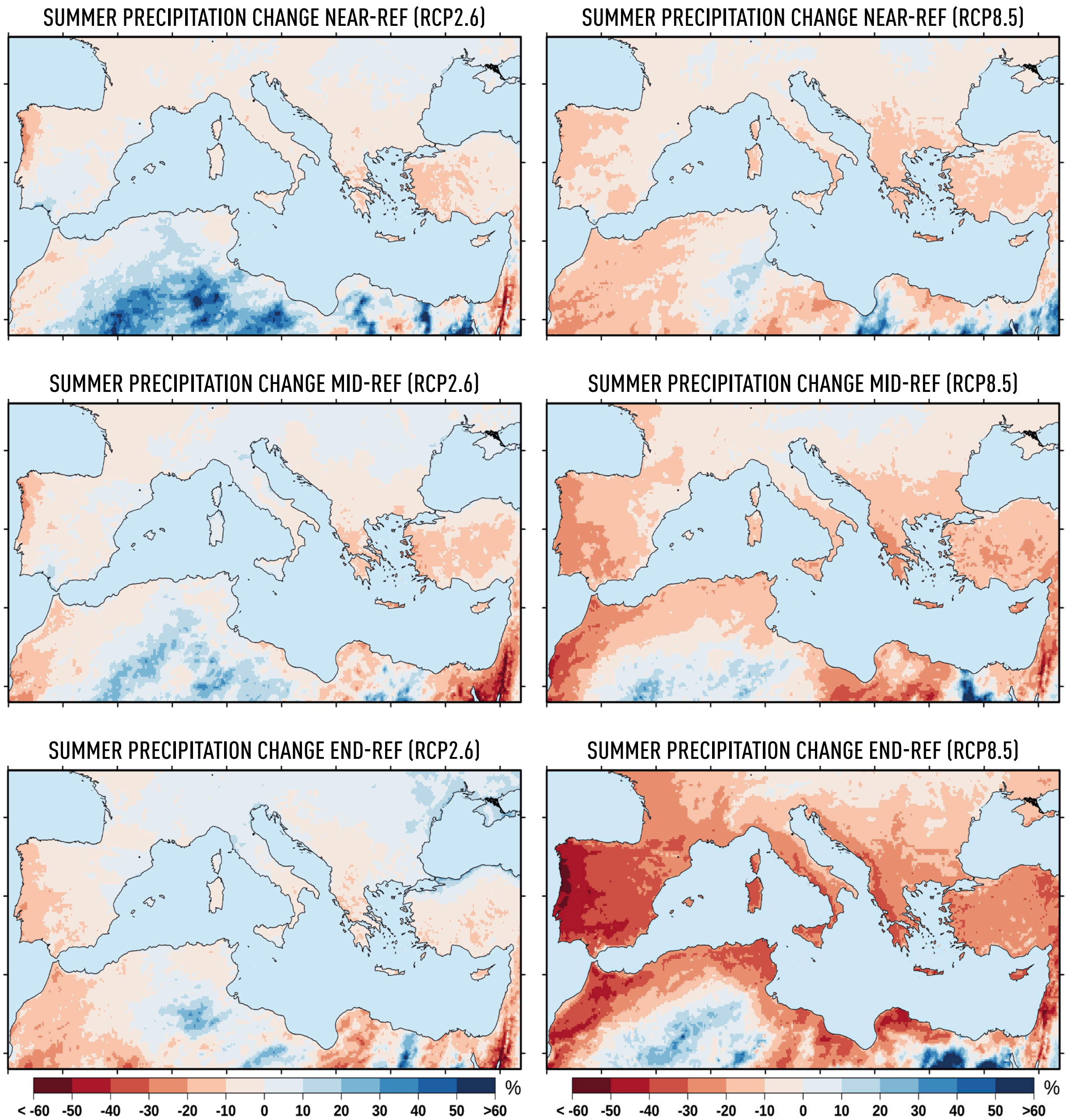

Figure B.7 | **Projected changes in summer (June, July, August) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).**

Autumn precipitation

For the northern Mediterranean, the projected change in autumn precipitation is limited (±10%). For other regions (e.g., Southwest Mediterranean), the future change signal is not consistent between the two pathways. For the Maghreb, precipitation increases (10%-30%) have been projected under RCP2.6 *(Fig. B.8 – left panels).* On the contrary under RCP8.5, this region is projected to be subject to strong drying trends (up to 40%-50%), particularly towards the end of the current century *(Fig. B.8 – right panels).*

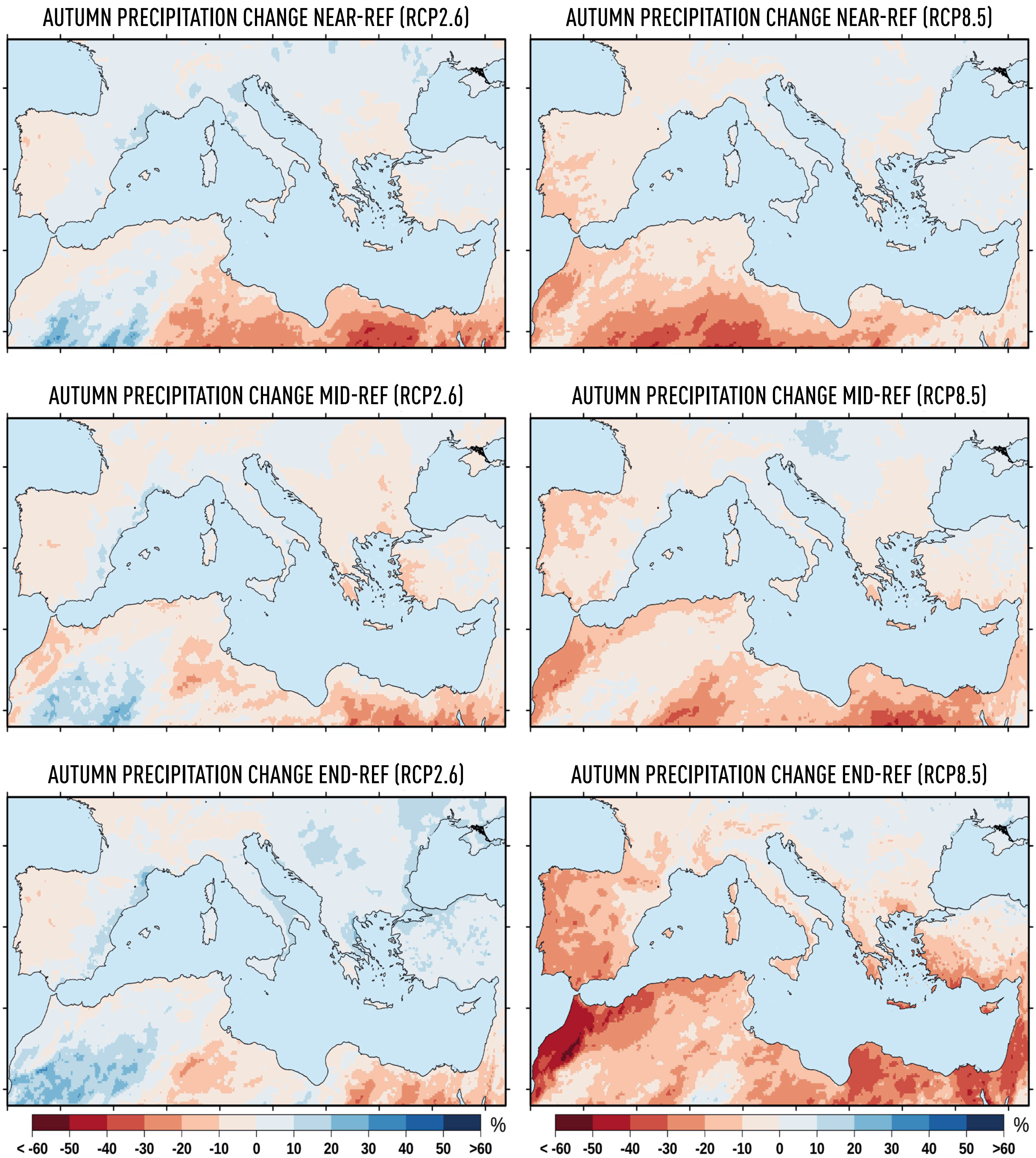

Figure B.8 | Projected changes in autumn (September, October, November) precipitation between the recent past reference period (REF: 1980-1999) and three future sub-periods (NEAR: 2020-2039, MID: 2040-2059, END: 2080-2099), based on the ensemble mean results of the EURO-CORDEX high-resolution simulations for pathways RCP2.6 (left panels) and RCP8.5 (right panels).

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