Projected changes in atmospheric moisture transport contributions associated with climate warming

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Abstract

Global warming and associated changes in atmospheric circulation patterns are expected to alter the hydrological cycle, including the intensity and position of moisture sources. This study presents predicted changes for the middle and end of the 21st century under different climate scenarios for two important extratropical moisture sources: the North Atlantic Ocean (NATL) and Mediterranean Sea (MED). By the end of the century, moisture from the NATL will increase precipitation over eastern North America in winter, western Europe in spring, and northwestern Africa during winter and summer. Moisture from the MED will increase precipitation over the southern and western portions of the Mediterranean continental area. Precipitation associated with the MED will decrease over eastern Europe, while that associated with the NATL will decrease over western Europe and Africa. Precipitation recycling on the Iberian Peninsula will increase in all seasons except winter. Climate change, as simulated by CESM2 thus modifies atmospheric moisture transport, affecting regional hydrological cycles.

Introduction

It is predicted that thermal warming of the atmosphere will exceed the 1.5°C or 2°C targets in the 21st century unless steep reductions in CO_2 and other greenhouse gas emissions are made in the coming decades[1]. The thermodynamic response to a warmed atmosphere per degree of warming is a 6–7% increase in low-level atmospheric water vapour[2], according to the Clausius–Clapeyron relationship[3, 4, 5], and this will have a strengthening impact on moisture transport worldwide[5]. In addition to warming, an increase in mean annual evaporation is expected[5], which will affect the evaporation rates of most oceans[6]. Moisture transport will also increase[2, 7, 8] and so will the vertically integrated water vapour transport (IVT)[9]. This is expected since evaporation will increase from the world's oceans. It has been shown that this effect dominates over circulation changes in the mid-latitudes[10]. For instance, under future warming conditions, the IVT will increase by 30–40% across on current storm tracks over the northern Pacific and Atlantic basins[8]. Changes in the atmospheric circulation patterns will also occur as the planet retains more heat, which will affect the atmospheric water balance at global and regional levels[11].

The net effect of dynamic (circulation) and thermodynamic processes is therefore extremely relevant when analysing future changes in moisture sources for precipitation over a region[12]. It is estimated that continental moisture recycling will decrease by 2–3% per °C globally[13], being systematically higher in the past and lower in the future[14]. However, there will be exceptions: an increase of up to 8% is expected in West Africa and the Iberian Peninsula by the end of the 21st century. This projected decrease in global recycling, coupled with the inherent moisture limitations of the land's surface, implies that the importance of oceans as land moisture sources will increase with warming[15].

It is thus essential to investigate the links between moisture sources and sinks, the role of climate change in modifying atmospheric moisture transport, and how this influences continental precipitation[16]. To our knowledge, previous studies based on Lagrangian approaches have not considered how climate change will alter the location and importance of moisture source regions and the future transport of moisture from such regions to continental areas.

We analysed future changes in the moisture source–sink relationship around the Iberian Peninsula, which is one of the hotspot mid-latitude areas affected by more than one moisture source[6] (Supplementary Fig. 1). This region is optimal for conducting an analysis because its climate is related to moisture from two of the major global oceanic sources[17,18] (Supplementary Fig. 1), the North Atlantic Ocean (NATL) and the Mediterranean Sea (MED), and is affected by strong recycling processes[19] (see Supplementary Section 1.3 for more information). To achieve our aims, we used a Lagrangian model for moisture transport fed by downscaled atmospheric data from the most up-to-date global climate models (CMIP6) under three climate scenarios (SSP2-4.5, SPSS3-7.0, and SPSS5-8.5)[20, 21] (see Data Description in Supplementary Section 1.1). The methodology used is a powerful tool for studying regional climate processes, by providing high-resolution historical and future climate data. It will allow us to gain greater compression of future changes in the moisture source-sink relationship in the study area[22].

The results presented herein, relying on projected climate conditions under a warming atmosphere throughout the 21st century, reveal a general increase in oceanic moisture transport in the North Atlantic latitudes over its surrounding continental areas, an important increase in the recycling processes for the Iberian Peninsula, and a projected decrease in the precipitation contribution from the MED over Eastern Europe and from the NATL for Western Europe.

Results

Future projections for integrated water vapour transport (IVT) in the North Atlantic Ocean

To better frame our assessment of the moisture transport processes, we first characterised the IVT within the extended area of the North Atlantic Ocean for the middle (2049–2053, MC) and end of the 21st century (2096–2100, EC) with respect to the historical (2010–2014) pattern (Supplementary Section 1.4). The differences in the annual IVT field under SSP5-8.5 for the MC show minimal changes in the Atlantic (Supplementary Fig. 7). A latitudinal tripole with a negative signal extends from the tropical zone to mid-latitudes (except for the eastern Caribbean Sea which shows a slight increase), and there is a positive signal toward the south and north of this negative band. This behaviour changes seasonally: in winter, an increase is projected in the band from the Gulf of Mexico to Europe (especially over the coast of the United States (US) and the IP), while a decrease is expected in the Caribbean Sea region; in summer, an increase is evaluated in the tropical region and the east coast of the US, while a decrease in the IVT field is expected in the eastern North Atlantic. Intermediate seasons show transitional patterns: in spring, minimal changes are expected (with the exception of the Caribbean Sea and the Gulf of Mexico, where negative values are projected), and positive values are expected in autumn, mainly in the subtropical regions above 30 °N.

Compared with the MC period, increased moisture transport is expected in most of the North Atlantic during the EC period (Supplementary Fig. 7), with the projected increases in the tropical region and on the US coast being particularly apparent. The maximum IVT values are expected to show a northward shift. These results are in good agreement with previous studies that have projected the poleward shift of subtropical high-pressure areas and the positions of one of the main moisture transport mechanisms: the atmospheric rivers[7]. Minor changes are projected with SSP2-4.5 and SSP3-7.0 (Supplementary Figs. 8,9). A summary of the mean percentage differences with respect to the historical period is presented in Supplementary Table 1. In general, the maximum percentage values follow the Clausius–Clapeyron[3,4,5] relationship, showing an increase of ~ 7% K^{-1}.

Changes in moisture sources for the Iberian Peninsula

The backward Lagrangian approach was used to evaluate future changes in the moisture sources for the IP, our target region (see Methods). The moisture sources during the historical period for CESM2 (Fig. 1, left column) show known seasonal variations[19], with a greater contribution in winter from the NATL source reaching as far as the Gulf of Mexico, and predominant influences from the moisture recycling processes (PRPs) and the MED in summer and spring. Annually, the PRPs provide the greatest contributions.

A general and progressive intensification in the moisture sources is found in all seasons for the MC and EC periods under the more extreme future scenario, SSP5-8.5 (Fig. 1). In the MC, this is most pronounced for PRPs in spring and summer. However, decreases in the contributions from the western Mediterranean Sea are expected, principally in summer, with lower values in winter and autumn, and from the PRPs in winter over the entire IP and in summer over the eastern IP. In the EC, positive changes continue to intensify, highlighting the expected increase in PRPs over most of the IP (and the surrounding European continental areas) in spring and summer, which results in a very strong signal for the whole year (Fig. 1f,i,o). Positive changes are also projected from the Mediterranean Sea, except in winter when decreases in PRPs remain (Fig. 1c). However, a greater contribution from the North Atlantic is projected for winter, with a positive signal extending from the Caribbean Sea that is more notable over the Central Atlantic.

With respect to the intermediate SSP2-4.5 and SSP3-7.0 scenarios (Supplementary Figs. 10, 11), the mean projected moisture pattern rises gradually until reaching that of the SSP5-8.5 scenario. The moisture pattern distributions and their signs are similar to those of SSP5-8.5; however, the PRPs in the MC are projected to decrease (increase) during spring (summer) under the SSP2-4.5 but increase (decrease) under SSP3-7.0 and SSP5-8.5.

Figure 1. Future changes in moisture source fields for the Iberian Peninsula under SSP5-8.5. Moisture sources fields ($E - P > 0$) for the IP in the historical reference period (2010–2014) and differences under

the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053, MC, and 2096–2100, EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

Changes in precipitation contribution from oceanic moisture sources

The forward trajectories from the oceanic moisture sources (NATL and MED) were tracked to evaluate future changes in their precipitation contributions (PCs) over the surrounding continental areas (see Methods section). PCs is defined as the precipitation contribution of each moisture source over a given area. For the MED, the historical PC pattern shows that it provides a similar contribution over the continent adjacent to both the north and east of the MED basin in the boreal cold season (Fig. 2a, m). In the warm season, the PC moves westward and has a greater effect during spring on Europe and during summer on Africa (Fig. 2e,i). This result agrees with that of previous studies[17,18].

The PC projections under SSP5-8.5 in the MC (Fig. 2, central column) are positive mainly over central Europe and northern Africa in autumn and spring, respectively. However, a PC reduction is expected in spring (summer) over central Europe (central Africa). In addition, a positive PC is expected over western and central Europe during summer. This full pattern continues to increase in value and sign toward the end of the century, mainly in summer and autumn. Both seasons show maximum PC increases from the MED over the IP, Alps, and Italian Peninsula. During all seasons, increases in PC are expected in North Africa, with the exception of eastern North Africa in summer, where a reduction is expected. The changes in PC from the MED using the other SSPs (shown in Supplementary Figs. 12, 13) are generally similar to (but slightly less than) those obtained using SSP5-8.5.

Figure 2. Future changes in moisture sinks from the Mediterranean source under SSP5-8.5. Moisture sinks fields (|E −P| < 0) for the MED source for the historical reference period (2010–2014) and differences under the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053, MC, and 2096–2100, EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn, and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

The PC contribution from the NATL source during the historical period (Fig. 3, left column) is the highest over the continents on both sides of the basin (southern North America, Europe, and northern Africa) during winter and autumn, but this high contribution continues only over North America in spring, where it expands southward to Central America. The PC is lower in Europe. In summer, the maximum PC occurs in tropical regions and to the eastern region of North America (to a lesser extent).

Under the SSP5-8.5 scenario, the overall projections in the MC and EC (Fig. 3, central and right columns) show that the PC generally increases (more wet days in the future[1], but there are important decreases, mainly over the ocean. The projected patterns of change are similar, but the values increase in intensity toward the EC, especially during winter (Fig. 3c). Furthermore, the increase in PC is expected to shift toward higher latitudes, leading to negative values at lower latitudes[23,24]. This behaviour could also explain the projected increased PC in summer and autumn over southeast North America[25], and the generalised decrease in autumn over the African coast[26] and the southwest IP[2,27]. The results under the SSP2-4.5 and SSP3-7.0 scenarios in the MC and EC (Supplementary Figs. 14, 15) are similar to those previously reported, but with lower increases or decreases.

Figure 3. Future changes in moisture sinks from the North Atlantic source under SSP5-8.5. Moisture sink fields (|E –P| < 0) for the NATL source for the historical reference period (2010–2014) and differences under the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053 MC and 2096–2100 EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn, and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

Discussion

The hydrological cycle is projected to increase in intensity under climate change[28]. We found a general increase in moisture reaching continental areas in the extratropical North Atlantic and Mediterranean belts.

For the IP, the percentage changes in contributions from the moisture sources under the different scenarios show that general increases are expected with increases in radiative forcing. An increase in the contribution from the recycling process was found, mainly at the end of the century (Fig. 4a). Percentage increases ranging from 60–90% were projected in spring, summer, autumn, and annually, whereas in winter the PRPs were found to decrease in both periods with respect to the historical period. Our results show that the oceanic moisture contribution will increase in the 21st century (Fig. 4b, c). In particular, the contribution from the MED will reach 40–60% in spring and autumn, and 30% annually; however, a considerable reduction in the moisture contribution for precipitation from this source (up to 20%) is projected for the MC in summer, whereas increases of up to 20% or more are projected for the EC. In addition, the contribution from the MED is projected to decrease in winter, although its contribution compared to historical patterns is insignificant. From the NATL source, there are considerable increases in all scenarios and periods, with maximum percentages corresponding to the EC and winter (~ 70%), and the lowest increment projected for summer. The remaining seasons show values increasing from 20–40%. All these strong changes corroborate the assumption that with a decrease in the recycling ratios, there will be increases in the importance of oceans as moisture sources to land with global warming[15].

Figure 4. **Future moisture contribution changes for the Iberian Peninsula.** Percentage values of future moisture contribution changes corresponding to the: NATL, IP, and MED. The periods are JFM, AMJ, JAS, OND, and ANNUAL and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of century, respectively.

The sources of moisture for precipitation from the MED and NATL will undergo changes in the future climate, and their moisture sinks will undergo associated precipitation pattern changes[29]. The results of this study show that there will be increases from both sources (Figs. 5, 6) but the seasonal regional impacts will differ. For example, the results for all SSPs show a considerable increase in precipitation over the IP from the MED moisture source (Fig. 5) in summer (also in Fig. 4), with increases from 70–110% (maximum values were found for the EC), which shows that the MED will continue to be the main precipitation source for the region in summer[30]. In addition, the projected increases will continue in autumn. However, the role of the MED as a precipitation source throughout the 21st century will decrease considerably during winter, with maximum values occurring in the MC[31]. In spring, the changes projected for the MC and EC are not homogeneous. For instance, for Western Europe (EUwest, Fig. 5), the highest percentage changes in the contribution for precipitation from the MED at the EC are projected to occur in winter and autumn (~ 50%) but higher values will occur in the MC during summer[1]. This projected seasonal sharpening of precipitation has been noted across other Mediterranean climates[32]. However, Eastern Europe (EUeast, Fig. 5) will suffer a decreased precipitation (reduction of 20–50%) associated with the MED source, although SSP2-4.5 and SSP3-7.0 project increases during summer (~ 20–50%). Finally, positive percentage increases are projected for North Africa (Fig. 5d); these will mostly occur at the EC and range from 25–50%, and the projected values are higher for SSP5-8.5. Overall, there will be greater contributions from the MED moisture source to continental precipitation in the middle and end of the 21st century over the southern and western surrounding areas, but the contribution will decrease over eastern Europe[33–36]. This result may be associated with the projected latitudinal displacement of storm trajectories in the future climate[24].

Figure 5. **Future changes in precipitation contribution associated with the Mediterranean source.** Percentage projected future changes in precipitation contribution over: EUwest, EUeast, Africa, and IP associated with the MED source. The periods are JFM, AMJ, JAS, OND, and ANNUAL, and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of the century, respectively.

The NATL source supports moisture for precipitation along the eastern and western coasts of the North Atlantic basin[17,19] (Fig. 6). On the eastern Atlantic coastlines, the projected changes from Africa to the British Isles differ in percentage and sign, probably associated with the poleward shifts of the general circulation[1,24,37]. For the British Isles, the maximum increases are projected at the EC during winter and spring, with values ranging from 60–90%, while increases or decreases not exceeding 20% are projected for the other seasons. Descending latitudinally, the greatest changes in the EUwest area will occur in spring, where changes from 80–100% are expected in the mid-to late century, but there will be minimal changes in the other seasons. In contrast, the Iberian Peninsula will receive less precipitation from the NATL source, mainly at the EC, although a slight increase will occur in the MC in spring and autumn. These results show that although the source of the NATL will intensify in the future and provide more moisture to the IP (Fig. 6), it will not positively contribute to the final amount of precipitation over the IP. Moisture from the NATL source may not necessarily precipitate if the appropriate conditions are absent, such as favourable moisture convergence, forcing for vertical ascent, and instability[38]. This will be a consequence of the poleward shift of the storm tracks and the upward expansion of the midlatitude baroclinic regions[39]. For the west coast of Africa, a general increment ranging from 40–100% is projected in winter and summer at the EC (Fig. 6). Finally, over the continent along the western North Atlantic basin, the results show a future contribution reaching 200% in terms of percentage changes in winter, and approximate increases of 50% in autumn. This behaviour in the precipitation contribution from the NATL source to its sink areas agrees with the projections of the poleward movement[1] of the general circulation[23,24]. Therefore, these regions, mainly Europe, will receive a reduced contribution from NATL source, which will have an impact on the precipitation regime and a reduction in rainfall, as previously reported for the Mediterranean area[40], especially in IP during autumn and mainly at the EC[7]. This behaviour may be due to the possible extension of stable and dry summer conditions and a decoupling between moisture availability and dynamic forcing[7], but it could also be the product of a circulation that relates to the mean displacement of the humidity corridors and the associated atmospheric rivers toward the poles[7].

Figure 6. **Future changes in precipitation contributions from the North Atlantic source.** Percentage future changes in the precipitation contribution over: BI, EUwest, IP, WAfrica, and NAMeast associated with the NATL source. The periods are JFM, AMJ, JAS, OND, and ANNUAL and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of the century, respectively.

This study makes a significant contribution to the hydrological cycle research because no previous studies based on Lagrangian approaches have considered how climate change will alter the location and importance of moisture source regions or the future transport of moisture in the north Atlantic area. These results show that climate change has a major influence on moisture transport around the Atlantic Ocean, which will result in changes in the rainfall availability within several regions; this could result in water stress, particularly in southern Europe.

Methods

Data employed

The available outputs of the climate model Community Earth System Model Version 2 (CESM2)[41], from Phase 6 of the Coupled Model Intercomparison Project (CMIP6), were dynamically downscaled. Specifically, Weather Research and Forecasting (WRF-ARW) model in its version 3.8.1[42] was used to downscaled CESM2 data (see Supplementary Section 1.2). Three climate projections corresponding to the shared socioeconomic pathways (SSPs) (SSP2-4.5, SSP3-7.0, and SSP5-8.5) were also used to analyse the different ranges of future forcing pathways to 2100 (see Supplementary Section 1.1), and 5-year periods were compared spanning the historical period 2010–2014 and the intervals 2049–2053 (for the mid-century: MC) and 2096–2100 (for the end-century: EC). ERA5[43] reanalysis data were also used to evaluate the results for the historical period.

Identification of moisture sources and sinks

To estimate the moisture sources and sinks, a Lagrangian methodology was applied to follow the changes in the specific moisture content (q) over time (t, every 6 h) along the tracks described by each atmospheric particle that the atmosphere was divided into. According to a previous study[45], these changes can be calculated by

$$(e-p)=m\left(\frac{dq}{dt}\right),$$

1

where m is the mass of the particle, and the difference between e and p considers the increase or decrease in the water vapour ratio along the trajectory. Once the individual trajectories of all plots have been calculated, the total surface freshwater flux in each grid cell can be calculated by summing the contributions of all particles traversing a grid area (A) at a given time. The total budget was calculated as follows,

$$(E-P)=\frac{\sum_{k=1}^{N}(e-p)_k}{A}$$

2

,

where E represents evaporation, P is precipitation, and N is the total number of particles over the grid area. For this analysis, the particle trajectories were followed for 10 days, the considered average residence time of water vapour particles in the atmosphere [46–48], and the final computed E-P fields were considered as integrated values during this period.

Moisture particles can be tracked backward (forward) in time from a given region to track their direction and determine their sources (sinks)[45,49]. In a backward experiment, the moisture source of a region is defined as an area in which evaporation dominates over precipitation (i.e. absolute positive values of (E-P), |E-P|>0), and in a forward mode projection, air masses with a net loss of moisture are detected to determine areas that are moisture sinks (i.e. areas where precipitation dominates over evaporation, |E-P|<0).

The moisture field patterns were evaluated using a different dataset, periods and statigraphs (see Supplementary Section 1.4.).

Assessment of projected changes

Climate change signals were determined as the difference between the (E-P) fields obtained in 5-year intervals for the MC and EC periods (2049–2053 and 2096–2100, respectively), and the historical reference period 2010–2014.

As the Lagrangian model uses dynamically downscaled CESM2 data (WRF-CESM2), we first conducted simulations using ERA5 data in the historical period (see Supplementary Figs. 2–6). Simulations were then conducted using the FLEXPART-WRFv3.3.2 dispersion model[50] to study moisture changes, and the experiments were forced with WRF-CESM2 outputs every 6 h (herein FLEX-CESM2). According to the distribution of the atmospheric mass, the simulation domain (covering 100 °W to 40 °E and from 15 °S to 57 °N, see Supplementary Fig. 1) was homogeneously divided into 2 million air parcels (or particles), which were subsequently advected forward in time for the entire study period. Finally, to obtain the (E-P) fields for comparison, the moisture sources and sinks for the target regions selected in this study (NATL, MED and IP) were identified and computed (Supplementary Section 1).

Limitations of this study

The results presented in this research present the limitation of using a single climate model as a forcer because the results could vary depending on the GCM used.

Data availability

ERA5 reanalysis data can be obtained from https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels-monthly-means?tab=form and CESM2 model data from https://esgf-data.dkrz.de/search/cmip6-dkrz/. The WRF-ARW outputs are available upon request to the corresponding author.

Code availability

Code that supports the findings of this study is available upon reasonable request from the corresponding author.

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Declarations

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Author contributions

L.G. and R.N. designed the study; J.C.F-A. and A.P-A. performed the research; J.C.F-A., A.P-A., and S.R-E. analyzed the data; J.C.F-A. and R.N. wrote the paper; L.G., R.N., J.C.F-A., S.R-E., A.P-A. review the paper.

Competing interests

The authors declare no competing interests

Figures

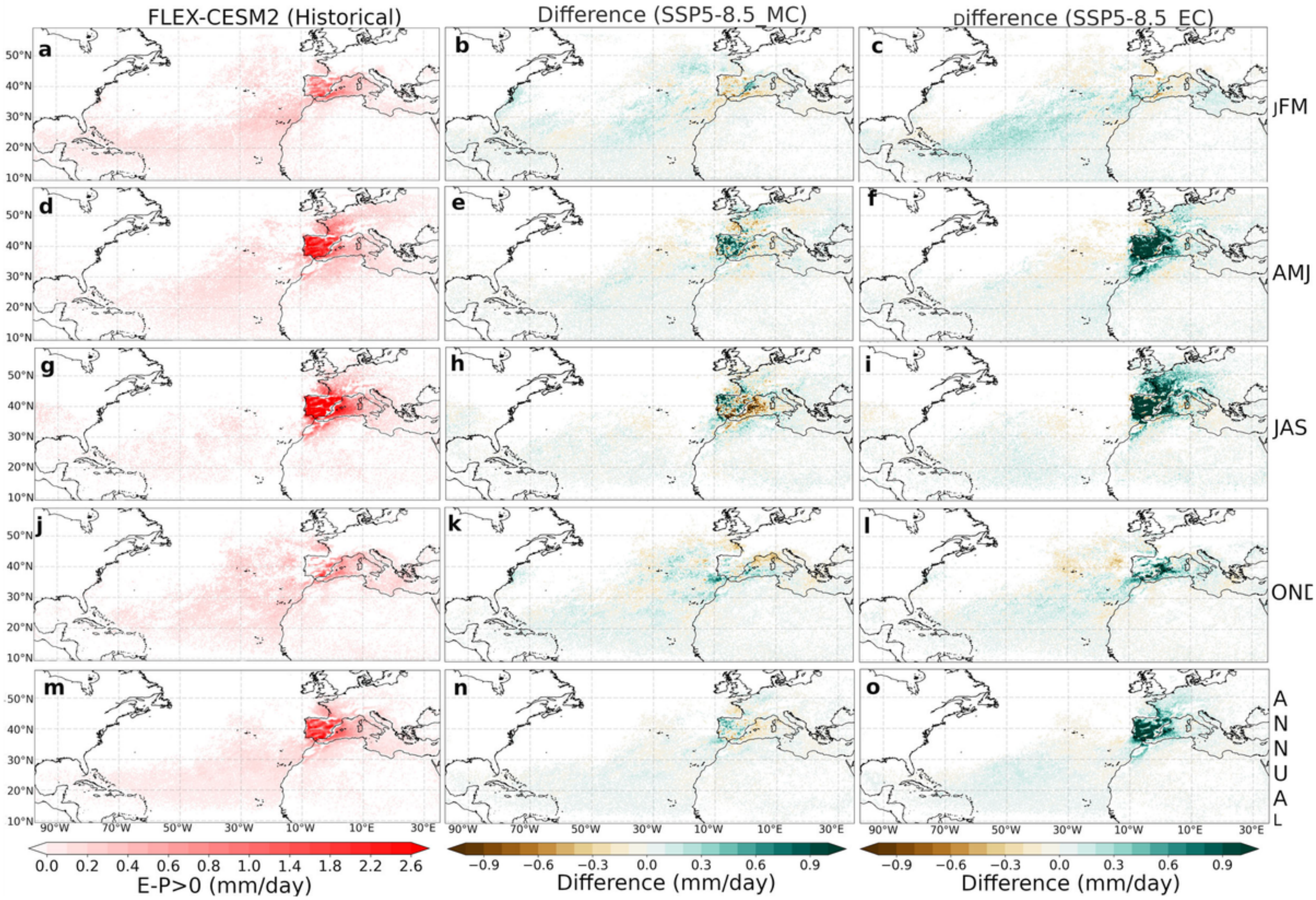

Figure 1

Future changes in moisture source fields for the Iberian Peninsula under SSP5-8.5. Moisture sources fields (E –P > 0) for the IP in the historical reference period (2010–2014) and differences under the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053, MC, and 2096–2100, EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

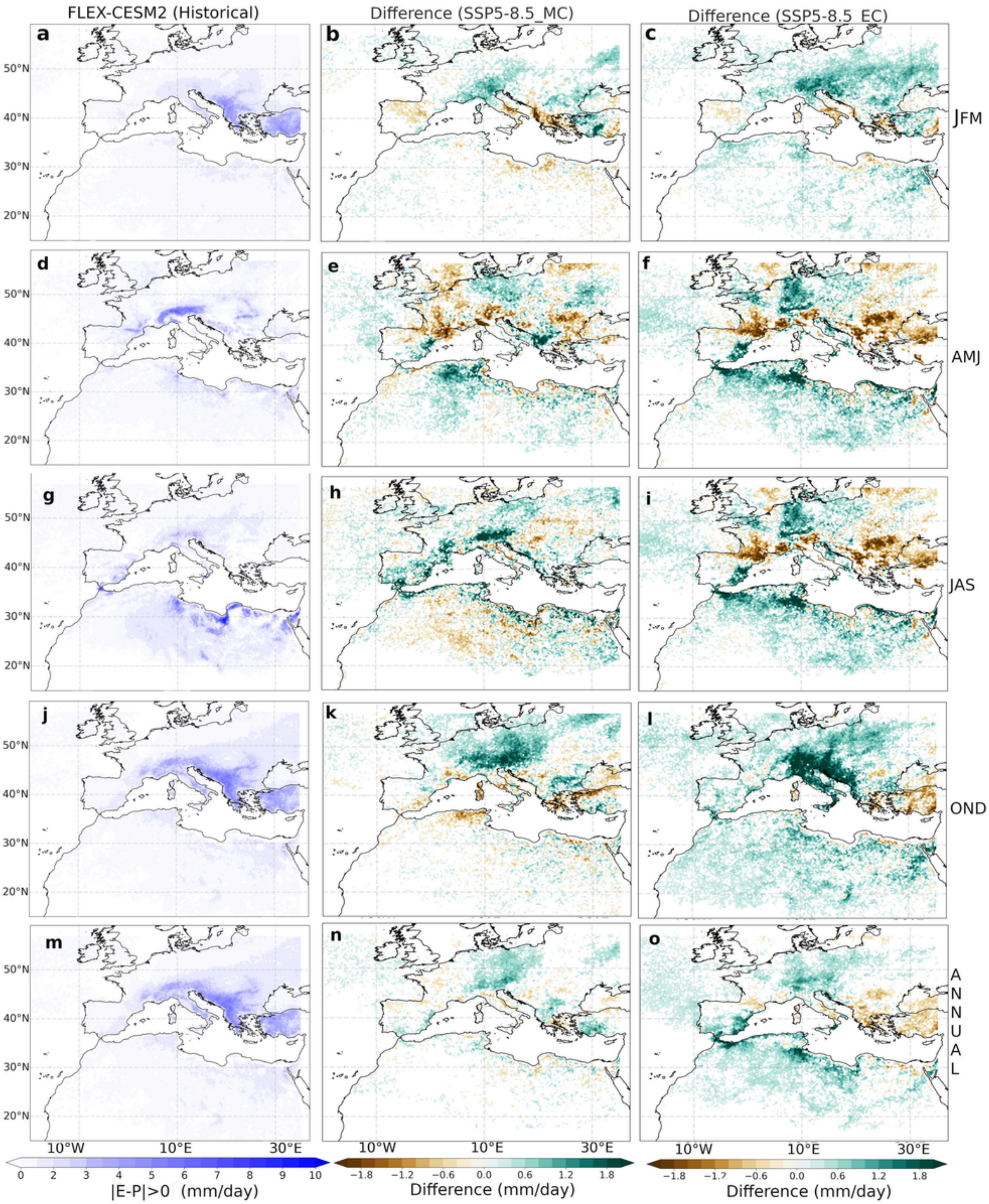

Figure 2

Future changes in moisture sinks from the Mediterranean source under SSP5-8.5. Moisture sinks fields (|E−P| < 0) for the MED source for the historical reference period (2010–2014) and differences under the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053, MC, and 2096–2100, EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn, and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

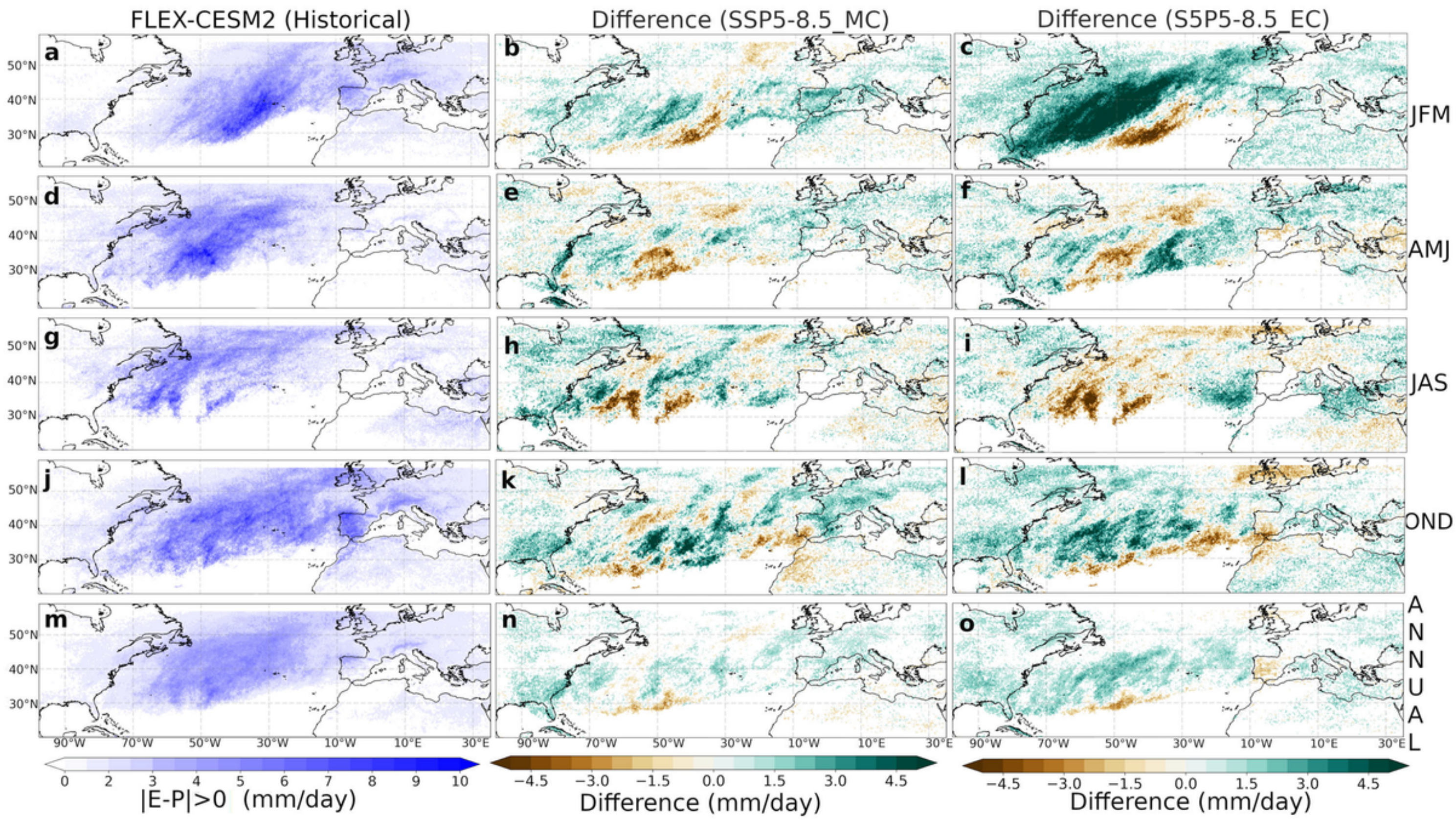

Figure 3

Future changes in moisture sinks from the North Atlantic source under SSP5-8.5. Moisture sink fields (|E −P| < 0) for the NATL source for the historical reference period (2010–2014) and differences under the SSP5-8.5 scenario for the mid- and end 21st century (2049–2053 MC and 2096–2100 EC, respectively) expressed in mm day^{-1}. The fields displayed from top to bottom correspond to winter, spring, summer, autumn, and annual periods (JFM, AMJ, JAS, OND, and ANNUAL).

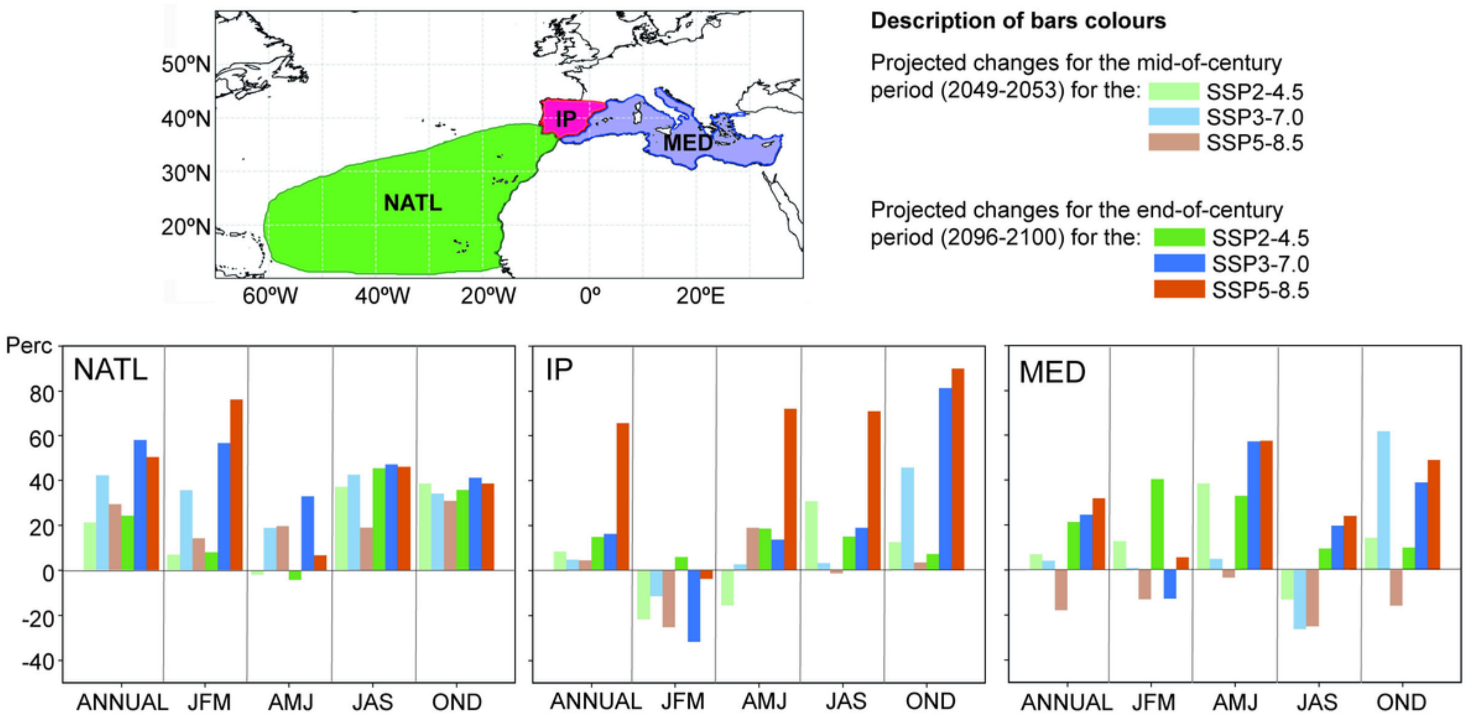

Figure 4

Future moisture contribution changes for the Iberian Peninsula. Percentage values of future moisture contribution changes corresponding to the: NATL, IP, and MED. The periods are JFM, AMJ, JAS, OND, and ANNUAL and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of century, respectively.

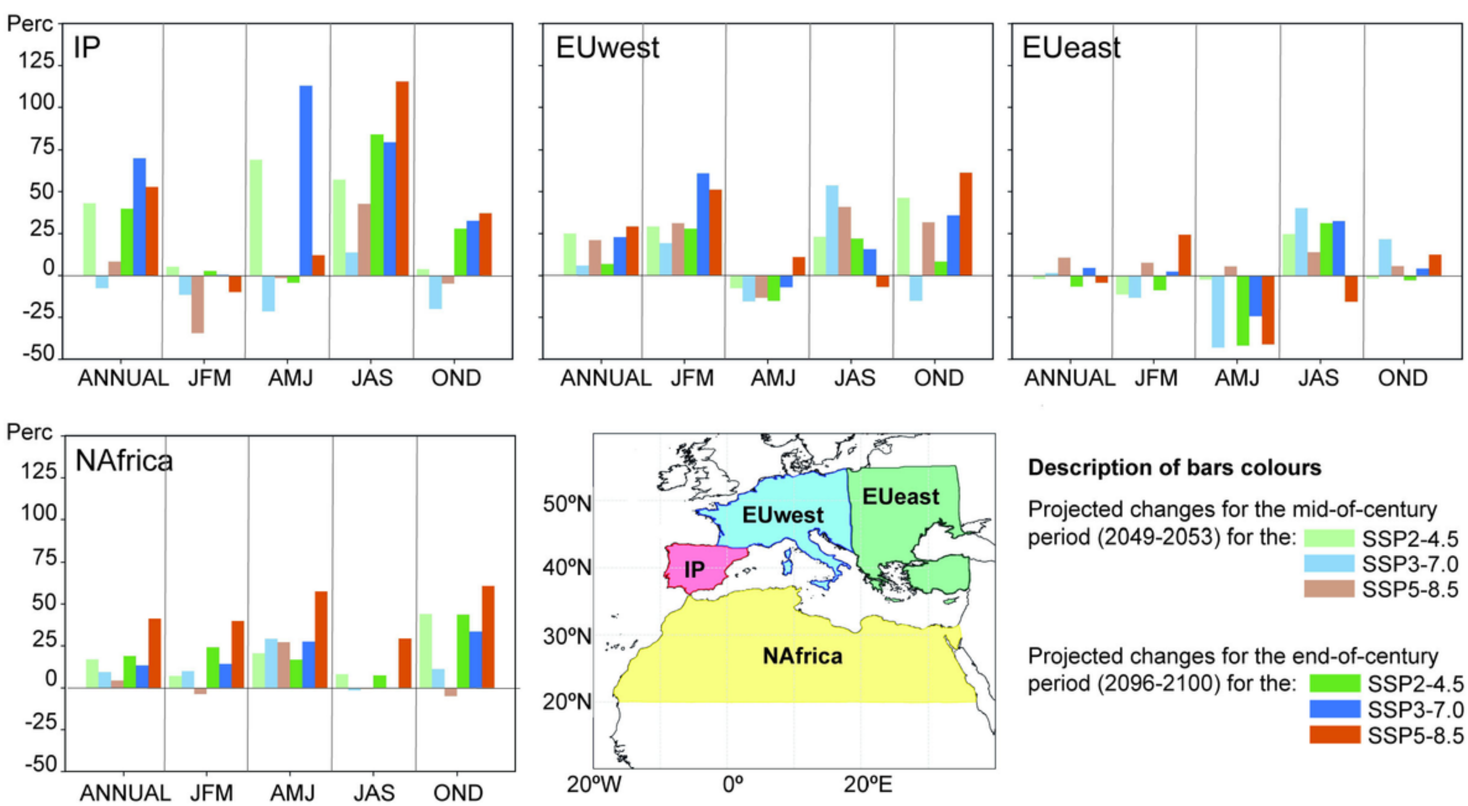

Figure 5

Future changes in precipitation contribution associated with the Mediterranean source. Percentage projected future changes in precipitation contribution over: EUwest, EUeast, Africa, and IP associated with the MED source. The periods are JFM, AMJ, JAS, OND, and ANNUAL, and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of the century, respectively.

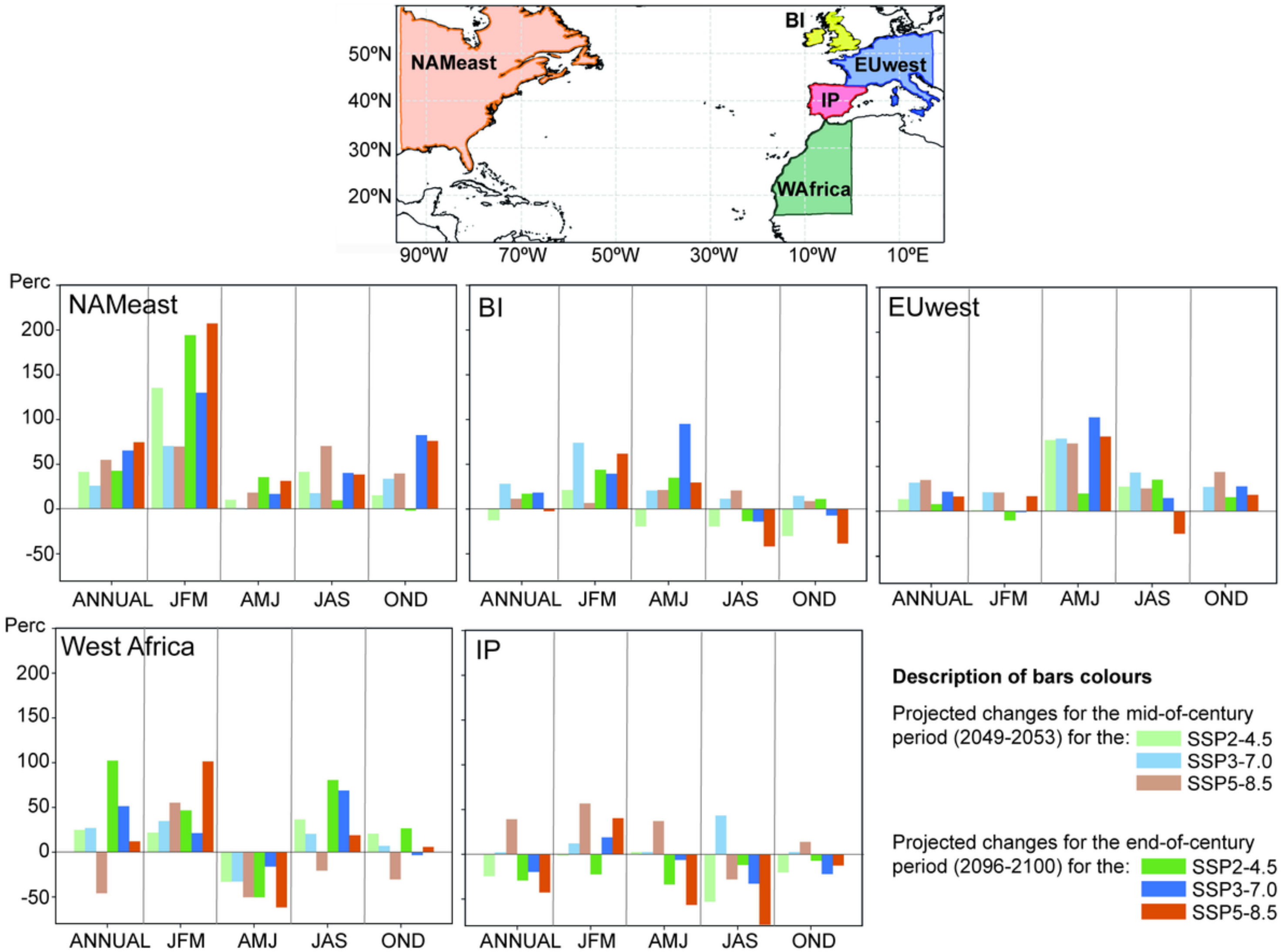

Figure 6

Future changes in precipitation contributions from the North Atlantic source. Percentage future changes in the precipitation contribution over: BI, EUwest, IP, WAfrica, and NAMeast associated with the NATL source. The periods are JFM, AMJ, JAS, OND, and ANNUAL and the SSPs are the SSP2-4.5, SSP3-7.0, and SSP5-8.5. The red and blue colours correspond to the mid- and end of the century, respectively.

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