Climate Change Projections for the Cairngorms

A report for the Cairngorms National Park Authority

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Executive Summary

This report presents observed changes in the climate in the Cairngorms National Park and what four future climate change projections look like.

Key Findings: Observed changes

- Precipitation: There has been an observed change in the mean monthly precipitation amount from the 1960-1989 baseline period. This change has been variable spatially and per month.
- February, June, October and November have experienced an overall increase in precipitation. September has experienced a decrease in precipitation. January, March, May, July, August and December have experienced a mixed spatial pattern of both increases and decreases in precipitation. Decreases have mainly been in the east of the Park.
- Maximum Temperature: There has been an increase in mean monthly maximum temperature in all months except June, and to a lesser spatial extent in October.
- February has experienced the largest increases, by more than 2°C in the eastern part of the Park followed by March. Increases have been mostly 1 to 1.5°C. Analysis indicates an overall uniform increase across the Park, but with some topographical variations in some months, with less or no increases at higher elevations.
- Minimum Temperature: There has been an increase in mean monthly minimum temperature in all months except October and December – but these months have also experienced an increase in some areas of the Park.
- February has experienced the largest increase, by more than 1.5°C. Increases have been less than those for maximum temperature, being mostly 0.5 to 1.0°C. Increases show some topographical variation, with lower increases at higher elevation.
- Reference Evapotranspiration: There has been a noticeable increase in evapotranspiration in March, April and May, but decreased in June, July, August and September in lower elevation areas but increased in high elevation locations. There have been only slight changes (increases and decreases) between October and February.
- Climatic Water Balance (Precipitation – evapotranspiration): The Climatic Water Balance indicates that there have been spatial and temporal shifts in the balance between precipitation input of water and evapotranspiration return to the atmosphere.
- There has been an increase in Climatic Water Balance (more water input) for the majority of the Park in February, June, July, October and November.
- December, January and April have experienced an increase in all areas except the eastern parts of the Park.
- March has experienced both a decrease (less water input) in the eastern half of the Park, and a slight increase in the west.
- August shows a mixed response with some negative decreases in higher elevated areas.
- May and September have experienced an overall decrease in water input, particularly in higher elevated areas. The Park has remained in meteorological water surplus from September through to March.
- Spring and summer months show a spatially varied response in terms of meteorological water surplus or deficit: for May, June and July most of the Park is in deficit, but with indications of some locations shifting from surplus to deficit, most noticeably in May, whilst other locations have shifted from deficit to surplus.

Key Findings: Future Projections

- Precipitation: The four climate projections show similar spatial and temporal patterns of changes in mean monthly precipitation, but with differences in the amounts of changes.
    - 2020-2049: Winter months are likely to see large increases (200 – 300%) in mean monthly precipitation, particularly February, but a decrease in August and September (c. 50 – 100%).
    - 2050-2079: The pattern of wetter winters and drier summers continues.
    - Projected to be large variation in precipitation responses in spring months, with some areas of the Park potentially seeing decreases in precipitation whilst others areas may experience increases.
- Maximum and Minimum Temperature: All areas of the Park are projected to experience increases in mean monthly maximum and minimum temperature. This is variable between the four climate projections in terms of the amount of temperature increase and when in the year these occur.
- Reference Evapotranspiration: All four climate projections indicate an increase in evapotranspiration for March, April and May. Higher elevation areas may experience the most change from the 1960-1989 baseline period. There is a spatially varied response for the summer months, with higher elevation areas potentially experiencing increases in evapotranspiration.
- Climatic Water Balance: All four projections indicate an increase in meteorological water input (positive Climatic Water Balance) for March to May, but varied responses in the summer months and little change for October to January.
    - October to March will see the Park remain in meteorological water surplus.
    - **All four projections indicate risks of large sections of the Park shifting from meteorological water surplus to a deficit between April (large spatial variation) through to September.**

Key Findings: Climate Extreme Indicators

- Number of Consecutive Dry Days (maximum length of a dry spell in any one month (when precipitation is less than 1mm per day):
    - February April, June, August and November have experienced and overall decrease in the number of Consecutive Dry Days. February has decreased by 3 days, whilst in March and September it has increased by 2 days.
    - The future four projections for the 2020-2049 period shows similar spatial and temporal patterns, with February estimated to see further decreases in the number of Consecutive Dry Days, whilst May through to October have increases.
    - There is agreement across the four projections that September is estimated to have a substantial increase in the number of Consecutive Dry Days, by up to 10 days, increasing to 15 in the 2050-2079 period. 2050-2079: there is good agreement that the change of direction in is towards increases between May and October, but decreases between December and February.
- Number of Dry Days (when precipitation is < 1mm): The mean monthly number of Dry Days have both increased in some months, and decreased in others since the 1960-1989 period.
    - February has experienced the largest decrease, by an average of 4 days, mostly in the western half. Increase in April (western half), June, July, October and November (but with some areas also seeing a decrease).
    - March has experienced an increase, of 2 days, across the whole Park. September has experienced the largest increase, covering the whole Park area, of up to 2 more mean monthly number of Dry Days.

    - The future four projections for the 2020-2049 period shows similar spatial and temporal patterns, continuing into the 2050-2079 period, with winter months seeing a decrease in the mean number of Dry Days.
- Heavy Precipitation Days (days when precipitation is ≥ 10mm): The mean has increased in January and February by up to 3 days, April, June and October in most of the Park area, but there has also been both increases and decreases in March, May, July, November and December.
    - August, September and the eastern half or the Park in May have experienced a slight decrease, by 1 day.
    - For the future climate, there is a mixed response between the four projections. February is projected to see an increase, whereas August will see an decrease. This pattern is further continued into the 2050-2079 period.
    - Change direction maps illustrate the extent to which the changes in Heavy Precipitation Days are highly spatially and temporally variable, and this continues into the 2050-2079 period.
    - There is poor agreement between the four projections on the amount of land area experiencing increases, decreases or no change in the mean number of Heavy Precipitation Days

Conclusions:

The Climate in the Cairngorms National Park has already changed since the 1960-1989 period. These changes are spatially and temporally variable, with the winter months becoming both wetter and warmer, whilst summer months have become warmer and but with variable consequences on the amount of water available to enter into soils and aquatic systems. Evapotranspiration has had a variable response, potentially driven by cloud cover impacting the amount of solar radiation reaching ground surfaces.

Future projections indicate that the Park will experience further warming over the coming decades, as well as seasonal and spatial shifts in precipitation distribution. A key finding is that large sections of the Park are likely to experience spring and summer seasons when there is a potential decrease in meteorological water (evapotranspiration > precipitation), meaning that areas that have previous had a meteorological water surplus could experience a deficit in the future. This will increase the risk of drier soils and vegetation, with consequences on ecological functions and fire danger.

Contents

Table of Figures

Acknowledgements:

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We would like to acknowledge the UK Meteorological Office for the use of the gridded observed data and the UKCP18 climate projections. The capability to use the climate data and bias correct it to higher spatial resolution has been developed under the Scottish Government's RESAS Strategic Research Programme 2011-2016 and 2016-2021.

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Introduction

The purpose of this report is to present a series of maps illustrating how the climate in the Cairngorms National Park has changed since 1960 and projected to change in the future based on four different climate change projections. We present information for the mean monthly values for basic climate variables (precipitation, maximum and minimum temperature), and the amount of Reference Evapotranspiration and Climatic Water Balance (precipitation – evapotranspiration) as an indicator of potential changes in water availability. Also presented are three indicators of climate extremes: the number of Consecutive Dry Days; total number of Dry Days and Heavy Rain Days.

The aim is to provide information about how the climate has already changed in the Park and is likely to change further in the future, to aid planning for resilience building and adaptation. The results presented are a subset of a national scale assessment of Scotland's climate trends and future projections (Rivington and Jabloun 2022) and extremes indicators (Rivington et al 2023). An updated summary of these two reports is available here: Summary of climate trends, future projections and extremes in Scotland

We recommend that readers refer to these three reports for full details of the methods, data sources, evaluation, caveats, and guides to interpretation.

Further examples of the Climatic Water Balance and a refined version, the Climatic Water Balance Ratio, is available for the Spey catchment (including application to specific habitats) in Assessment of Natural Capital exposure to current and future meteorological drought (Gagkas et al 2023).

The climate projections used in this report have also be used to assess the impacts of climate change on snow cover in the Cairngorms National Park and on Cairngorm Mountain.

Data and Methods

The observed weather data (1960-2020) used for the historical trends is produced by the UK Meteorological Office. This is a 1km gridded dataset of daily precipitation and temperature data produced by an interpolation method between meteorological stations. See Text Box 1 for important information to aid interpretation of the results.

Text Box 1: Notes on observed data utility

It is important to highlight that the observed baseline data at a 1km resolution (HadUK-Grid dataset[1]) used in this study is produced using a spatial interpolation of data between UK Meteorological Office observation stations. As such the interpolation aims to 'fill the gaps' between observation stations to produce a 1km grid surface across the whole of the UK. Cells with an observation station in can be considered as highly reliable. The data utility for grid cells without an observation station is best in areas with a sufficiently high density of observation stations and uniform topography, but is less so in mountain areas with few stations. The interpolation process does include steps to adjust for distance from the sea and topography, but we recognise that given the diversity of Scotland's topography and concentration of observation stations in lowland areas, there are concerns on how representative the interpolated data is in 1km cells containing remote and or higher mountain areas. Whilst we are confident in the value of the climate trends analysis, we recommend some caution when interpreting results for higher elevation and remote areas.

[1] HadUK-Grid Overview - Met Office

For the future projections we used the UK Climate Projections 2018 (UKCP18) daily data for the RCP8.5 emission pathway (current emissions trajectory). The UKCP18 data is produced by a Regional Climate Model (HadRM3). This is run twelve separate times with variations in the model parameters that result in variations in the model estimates. This is done to capture the range of uncertainty in the parameters and provides a probabilistic range of possible future climate conditions (Figure 1). Each of the 12 model runs is referred to as a projection or an *ensemble member*.

For this report we used four of the 12 projections that represent the spread of possible futures and can be summarised as:

- **Number 4:** 2020-2049 = no change in total annual precipitation, 2.5°C warmer; 2050-2079 = about 6% wetter and 4.5°C warmer.
- **Number 10:** 2020-2049 = about 15% less total annual precipitation and 2°C warmer; 2050-2079 = about 16% less total annual precipitation and 3.5°C warmer.
- **Number 12:** 2020-2049 = about the same amount of mean annual precipitation and 4°C warmer; 2050-2079 = the same amount of mean annual precipitation and 5.5°C warmer. This represents the most extreme projection. It has been included as an illustration of extremes in some years.
- **Number 15:** 2020-2049 = about 5% less mean annual precipitation and 1.2°C warmer; 2050-2079 = about the same mean annual precipitation and 2.5°C warmer.

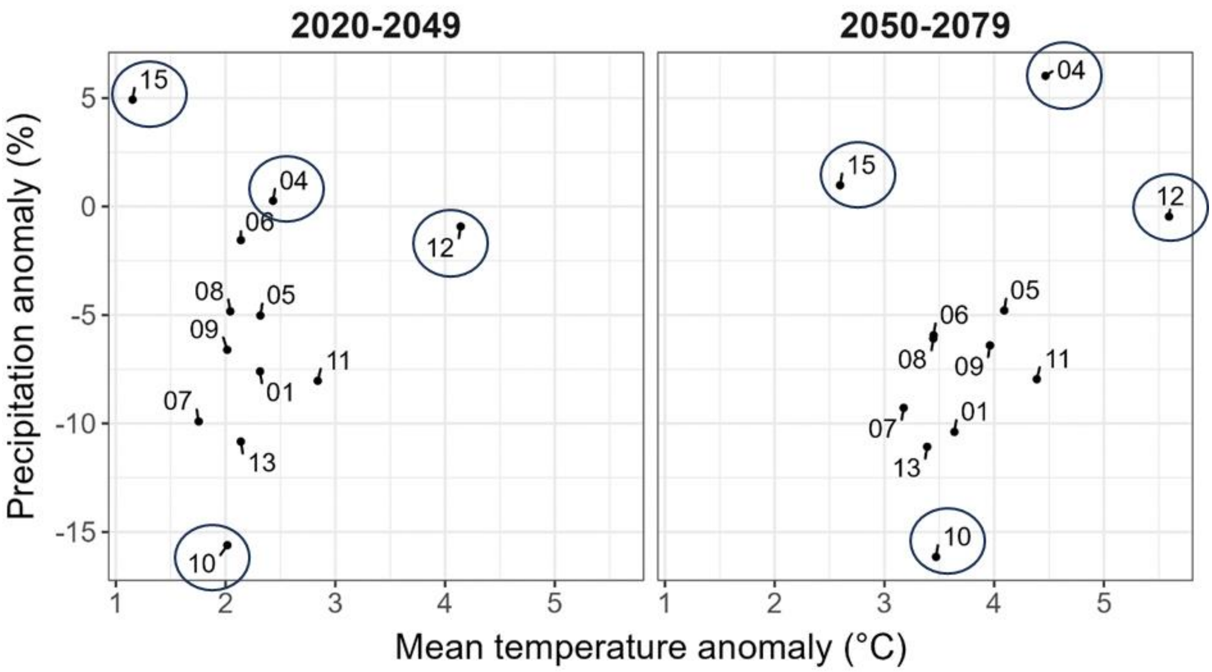


Figure 1. Climate projection anomalies from the 1960-1989 baseline. Circled projections are those used in this study.

Indicator Definitions

Precipitation, Maximum and Minimum Temperature: These are the fundamental daily timestep weather variables used to illustrate trends and changes in the climate. Maximum temperature (°C) is the highest value estimated per day, and minimum the lowest.

Reference Evapotranspiration: This is the amount of water evaporated from plants and soil. The reference ground cover is a uniform grass sward, hence actual evapotranspiration will vary between vegetation and ground surface types.

Climatic Water Balance: This is the difference between precipitation and Reference Evapotranspiration. It is an indicator of the potential for water deficit, when ET_0 is greater than precipitation.

Consecutive Dry Days: The count of the number of Consecutive Dry Days (CDD) is an indication of when water may become limited and drought conditions occur. It is the maximum length of a dry spell in any one month (when precipitation is less than 1mm per day).

Number of Dry Days: This is a count of the number of Dry Days (DD) per month (when precipitation is < 1mm). As with Consecutive Dry Days, this indicator provides information on the potential for increased dry conditions and risks of drought and heat stress.

Number of Heavy Rain Days: This indicator represents days when precipitation may be considered as 'heavy rainfall' – here we consider the threshold as days when precipitation is ≥ 10mm.

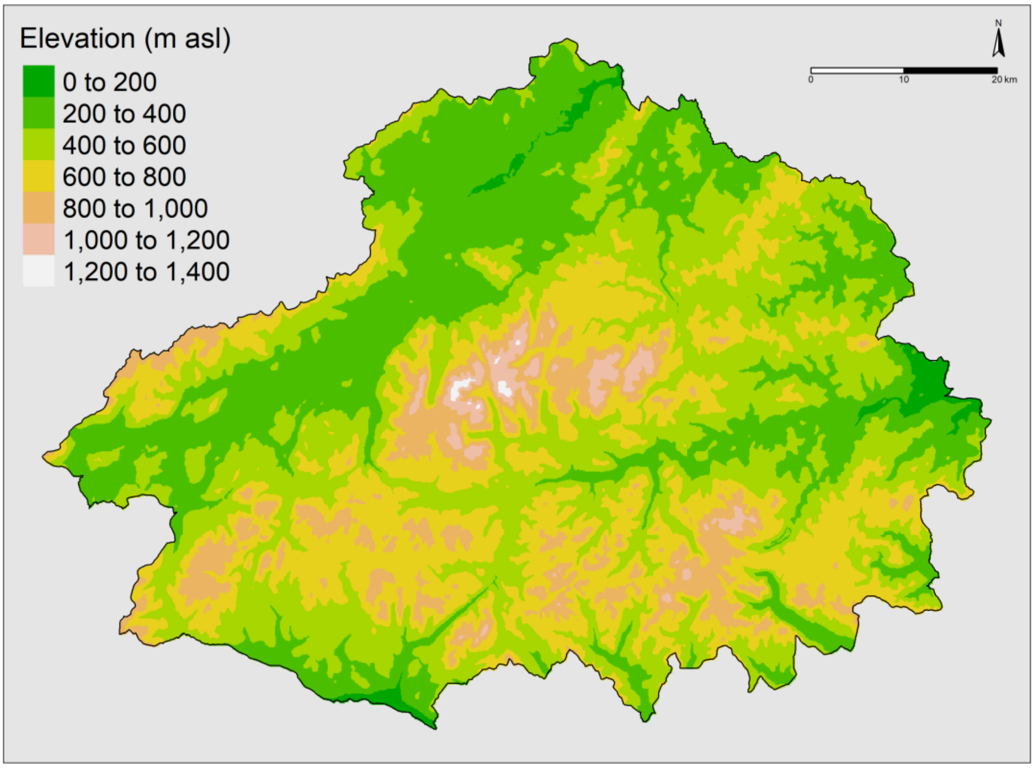


Figure 2. Elevation map for the Cairngorms National Park.

We have included an elevation map (Figure 2) to help interpret the spatial variation of the climate projections summaries.

Results

Observed Precipitation and Temperature trends.

The analysis of temperature and precipitation for the observed and climate model projected future period are shown.

Precipitation:

- There has been an observed change in the mean monthly precipitation amount from the 1960-1989 baseline period. There has been a varied change in precipitation spatially and per month (Figures 4 and 5).
- February, June, October and November have experienced an overall increase in precipitation.
- September has experienced a decrease in precipitation.
- January, March, May, July, August and December have experienced a mixed spatial pattern of both increases and decreases in precipitation.
- Decreases have mainly been in the east of the Park.

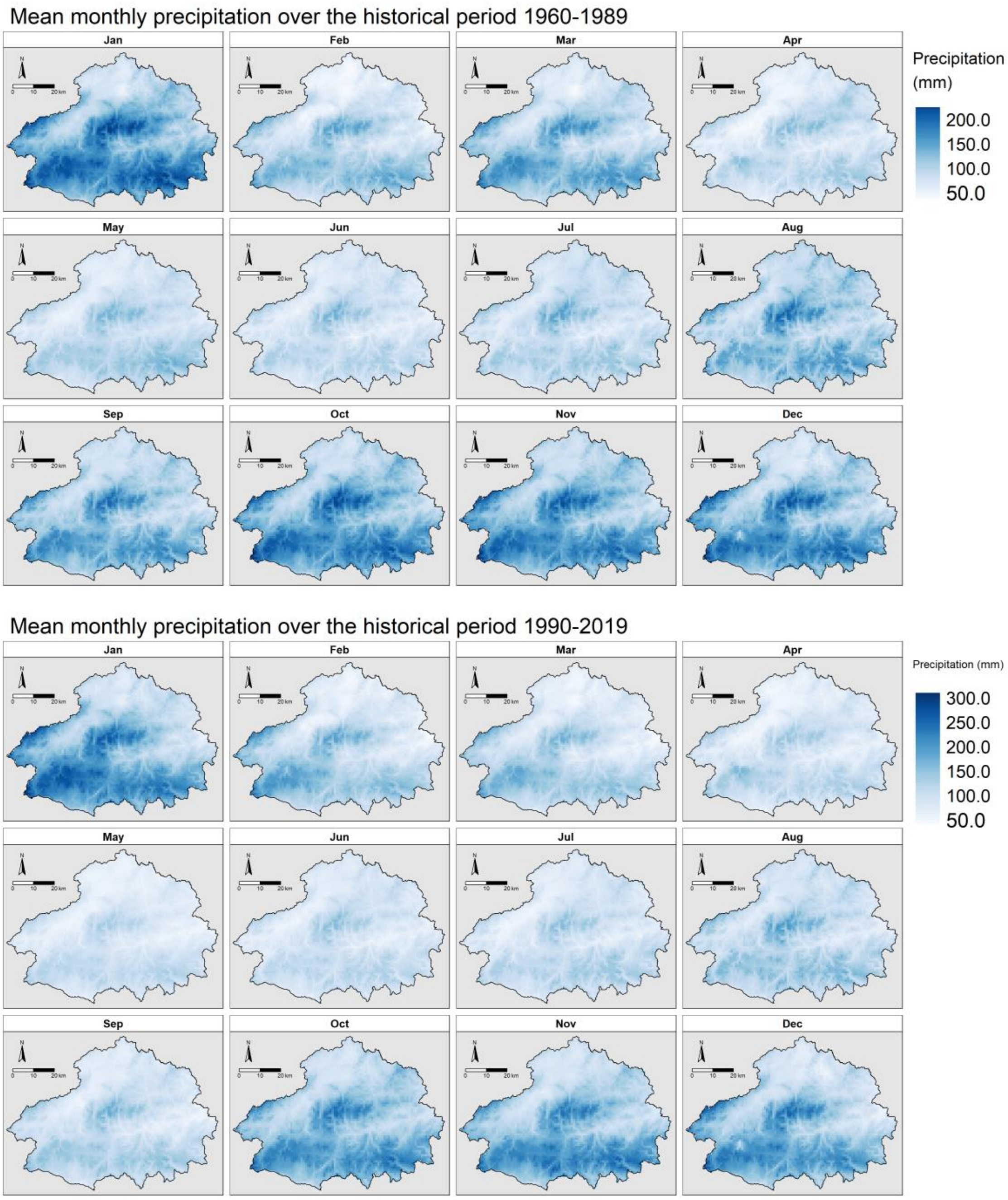


Figure 3. Mean monthly precipitation for the baseline (1960-1989) and recent period (1990-2019).

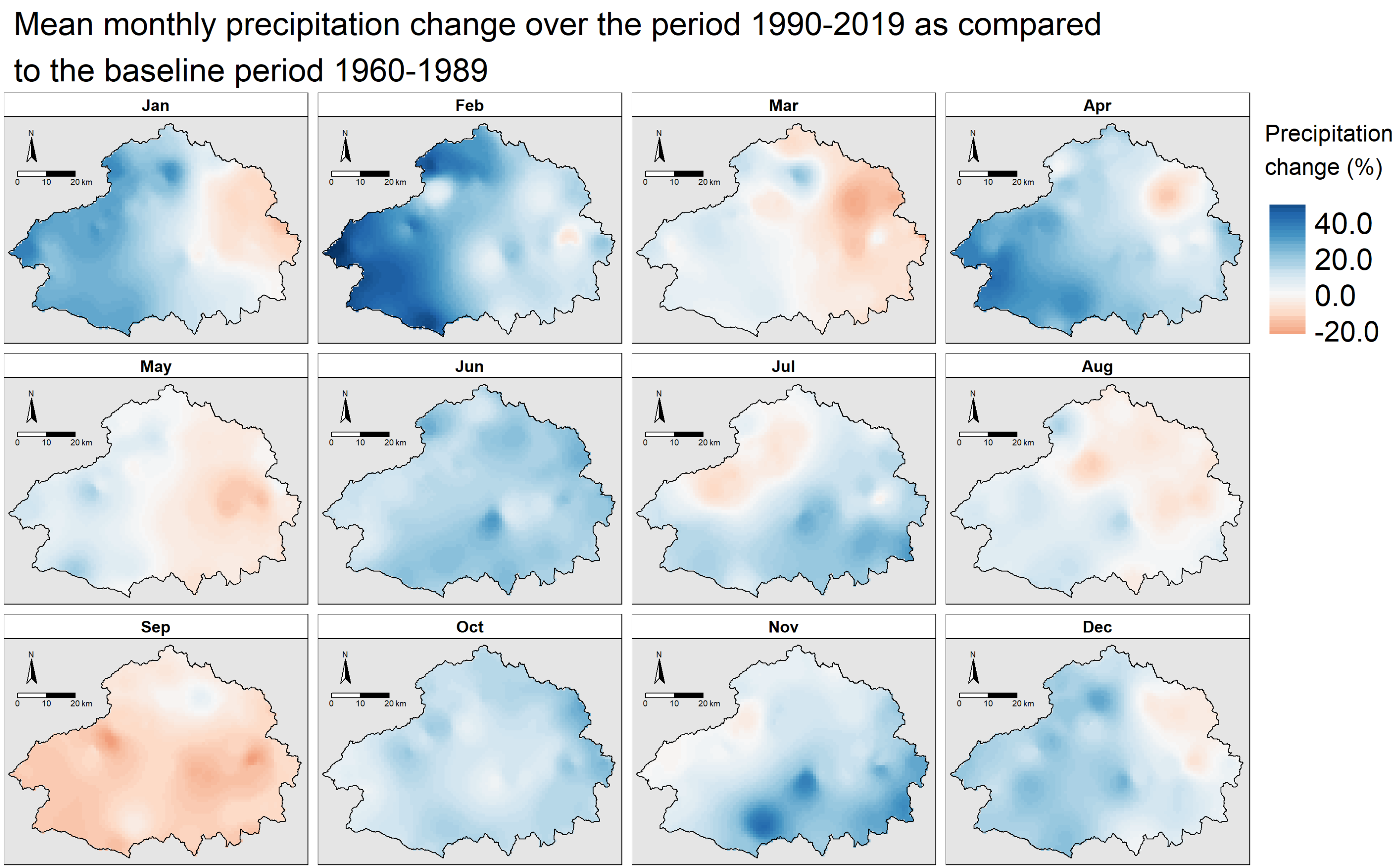


Figure 4. Changes in mean monthly precipitation from 1960-1989 to 1990-2019.

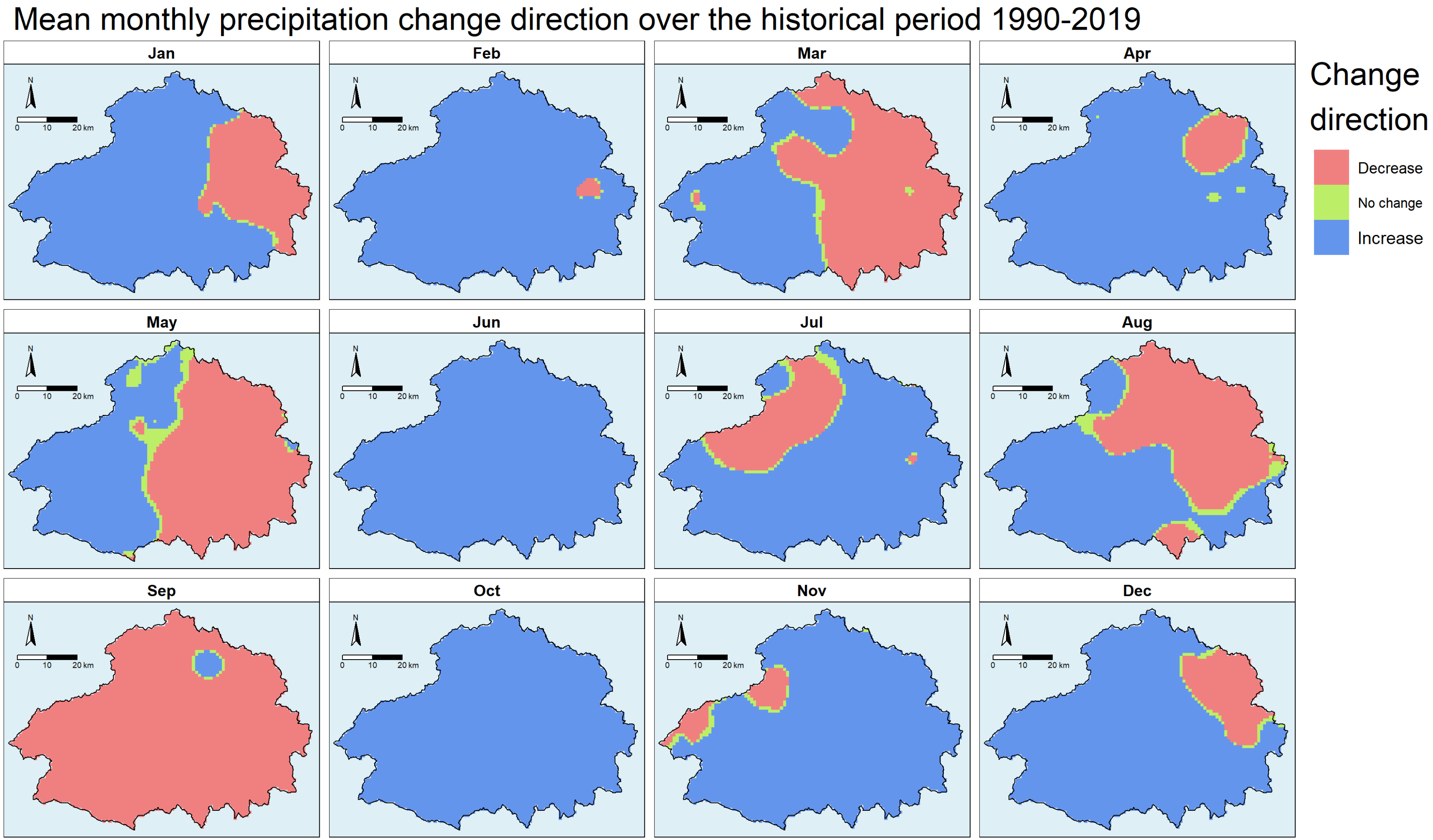


Figure 5. Mean monthly precipitation change direction from 1960-1989 to 1990-2019

Maximum Temperature

- There has been an increase in mean monthly maximum temperature in all months except June, and to a lesser spatial extent in October (Figure 7).
- February has experienced the largest increases, by more than 2°C in the eastern part of the Park followed by March.
- Increases have been mostly 1 to 1.5°C.
- Analysis indicates an overall uniform increase across the Park, but with some topographical variations in some months, with less or no increases at higher elevations.

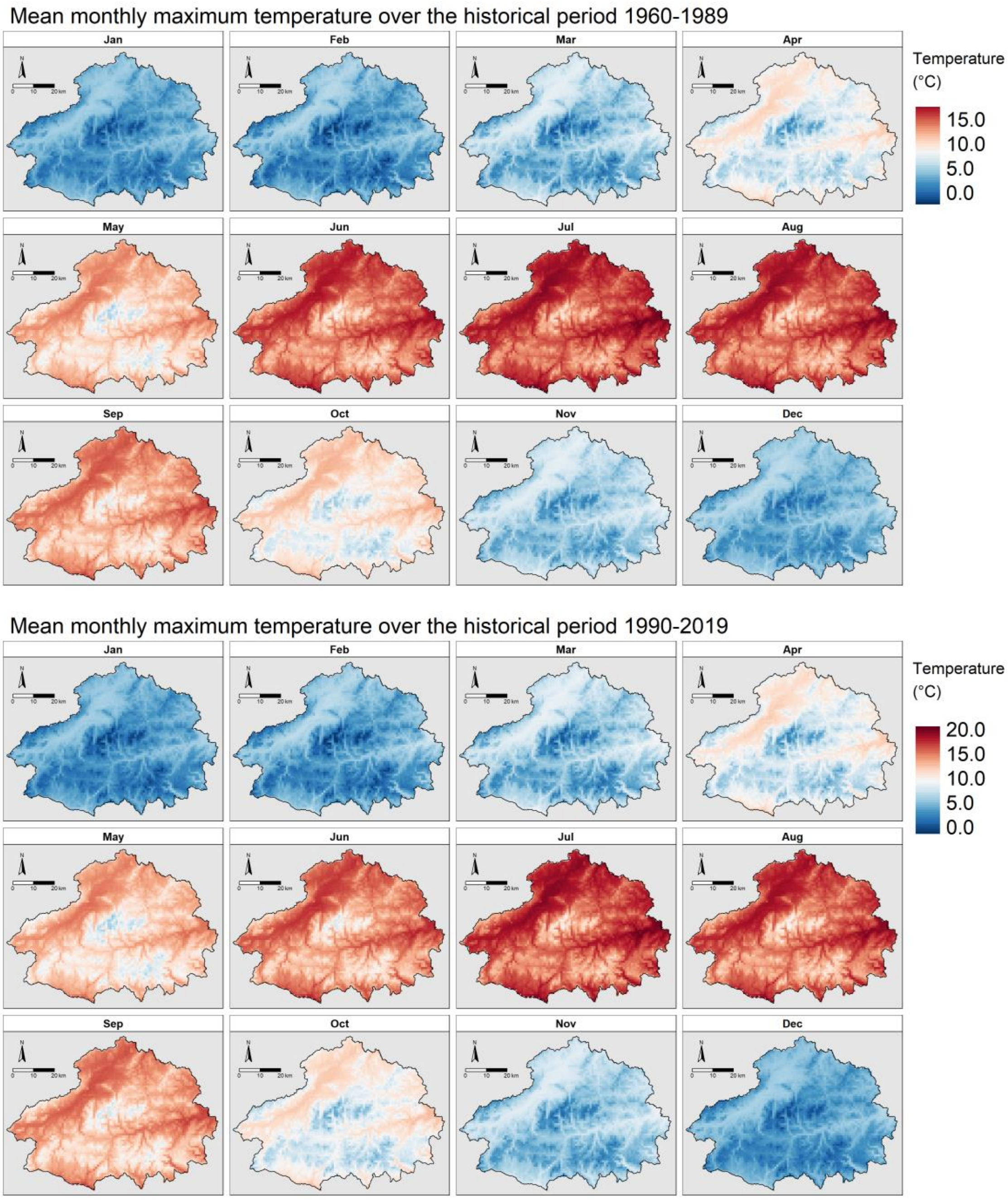


Figure 6. Mean monthly maximum temperature for the baseline (1960-1989) and recent period (1990-2019).

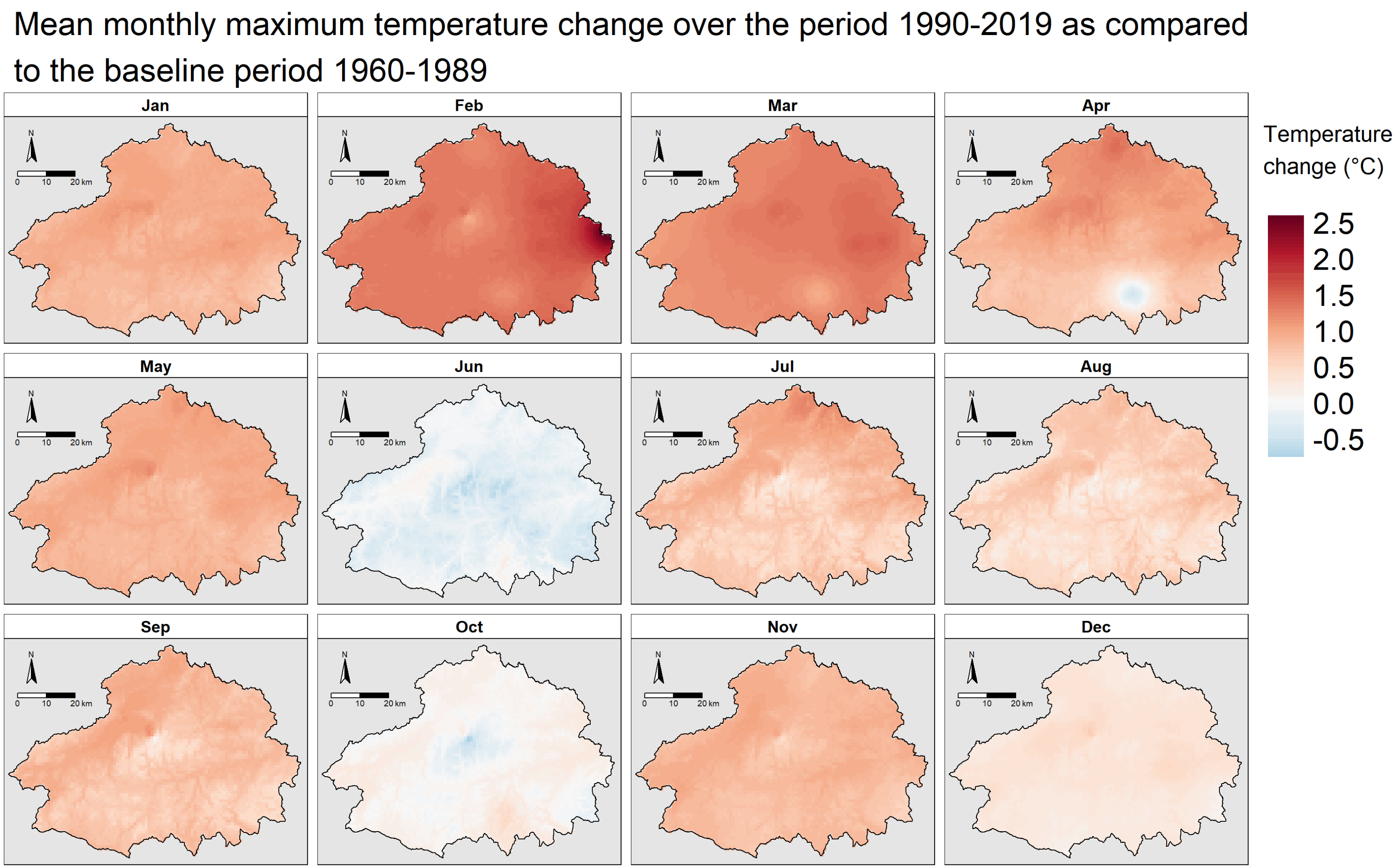


Figure 7. Changes in mean monthly maximum temperature from 1960-1989 to 1990-2019. .

Minimum Temperature

- There has been an increase in mean monthly minimum temperature in all months except October and December – but these months have also experienced an increase in some areas of the Park.
- February has experienced the largest increase, by more than 1.5°C.
- Increases have been less than those for maximum temperature, being mostly 0.5 to 1.0°C.
- Increases show some topographical variation, with lower increases at higher elevation.

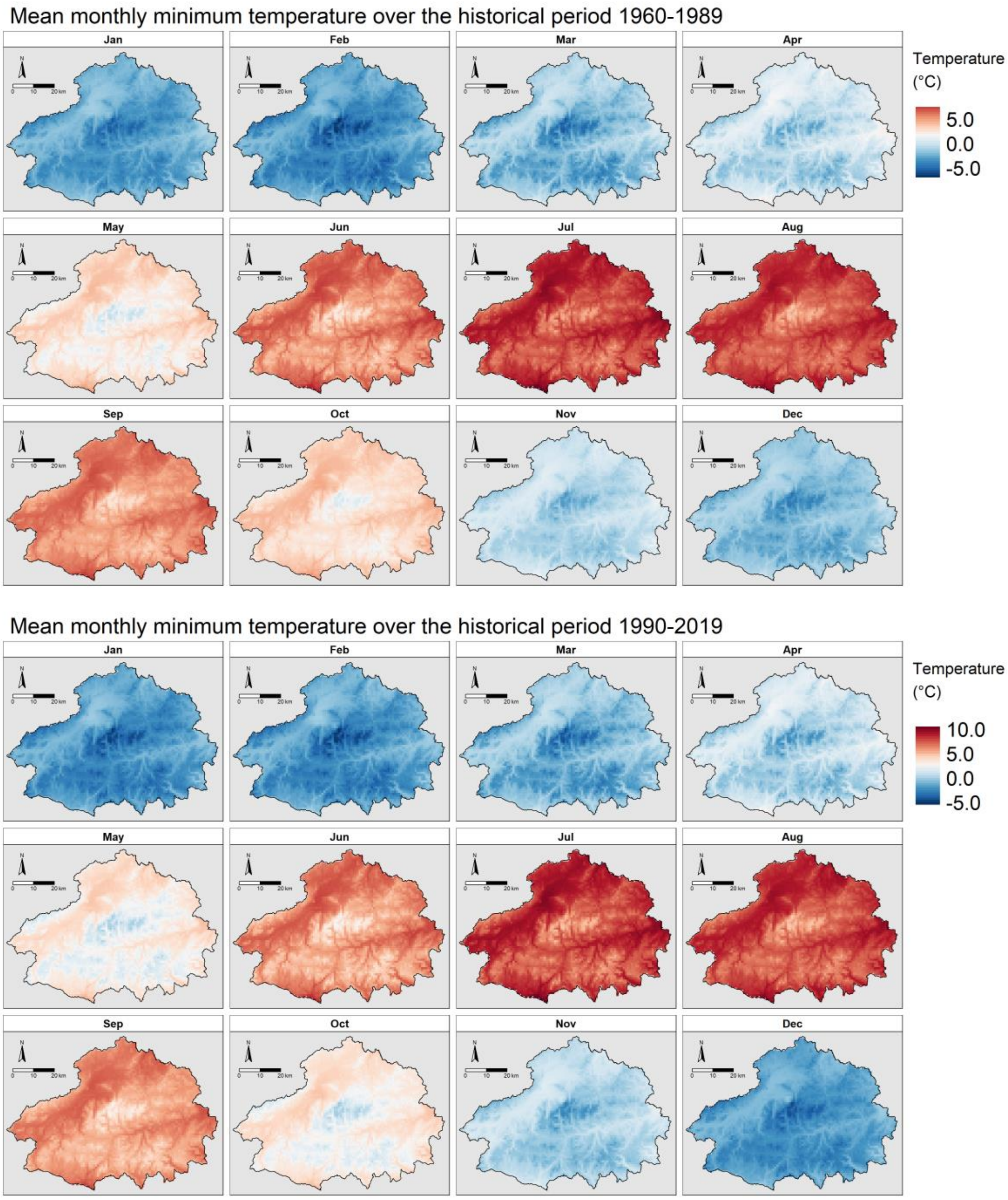


Figure 8. Mean monthly minimum temperature for the baseline (1960-1989) and recent period (1990-2019).

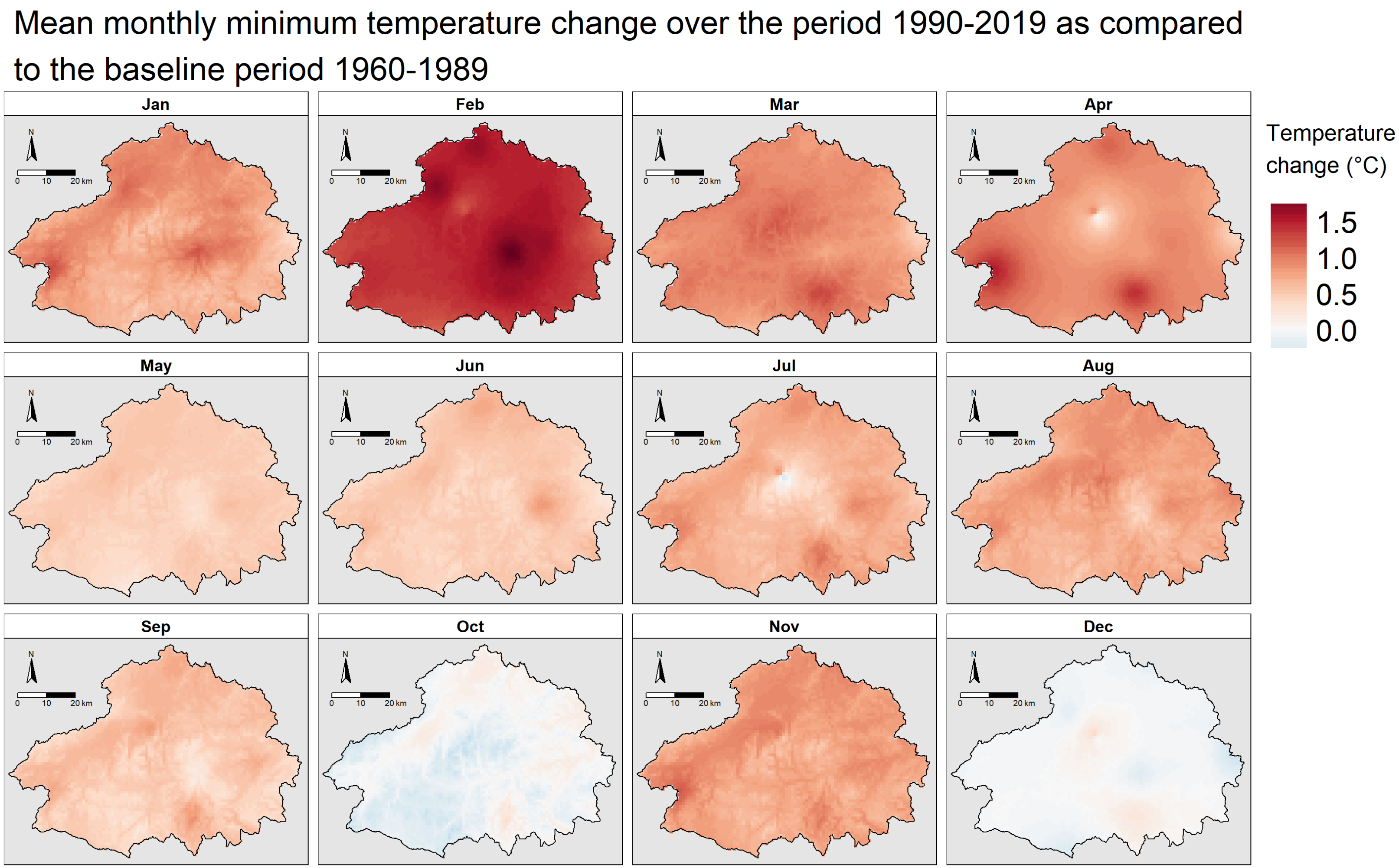


Figure 9. Changes in mean monthly minimum temperature from 1960-1989 to 1990-2019.

Reference Evapotranspiration

- There has been a noticeable increase in evapotranspiration in March, April and May (Figure 11).
- Evapotranspiration has decreased in June, July, August and September in lower elevation areas but increased in high elevation locations.
- There has been only slight changes (increases and decreases) between October and February.

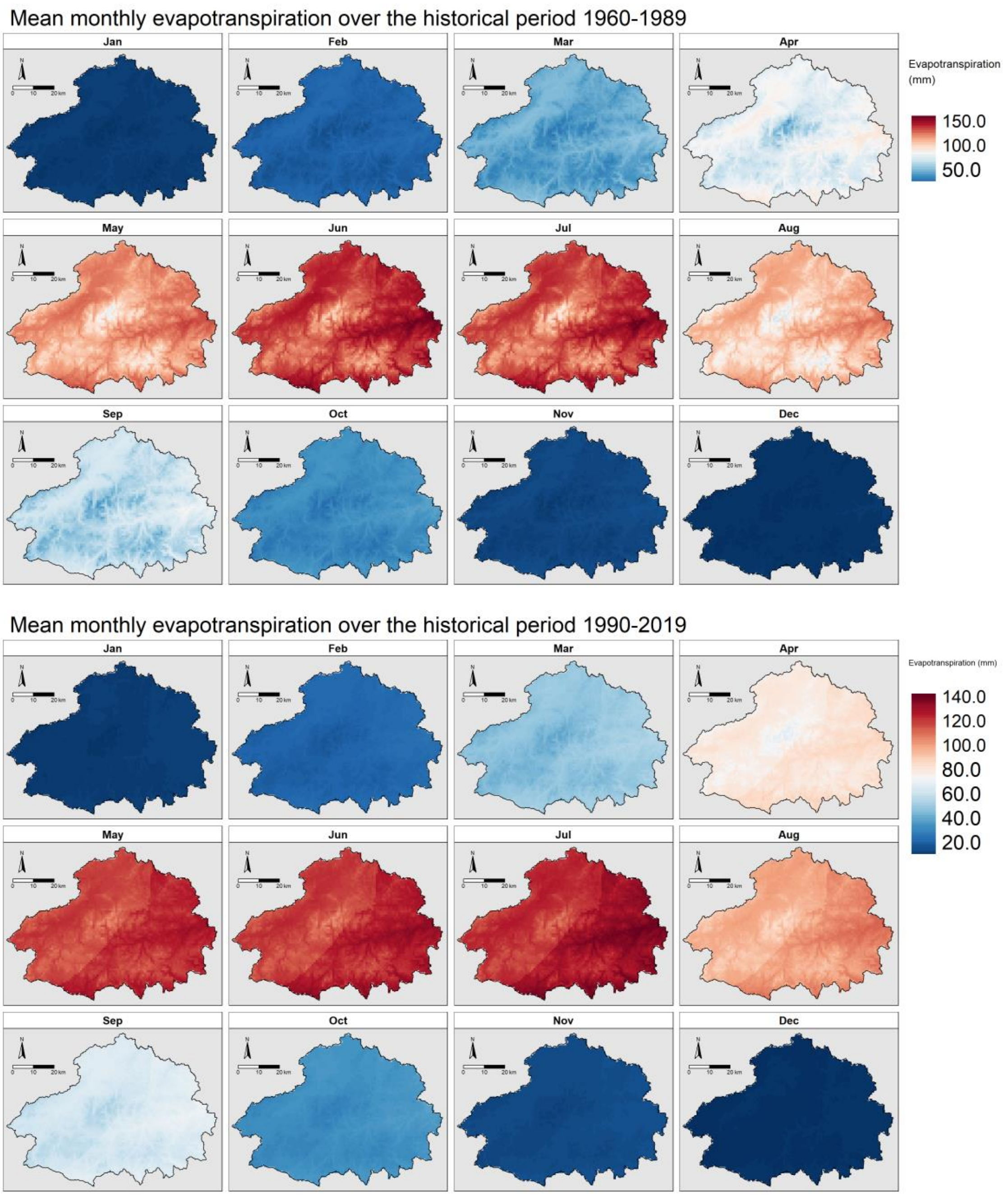


Figure 10. Mean monthly Reference Evapotranspiration for the baseline (1960-1989) and recent period (1990-2019).

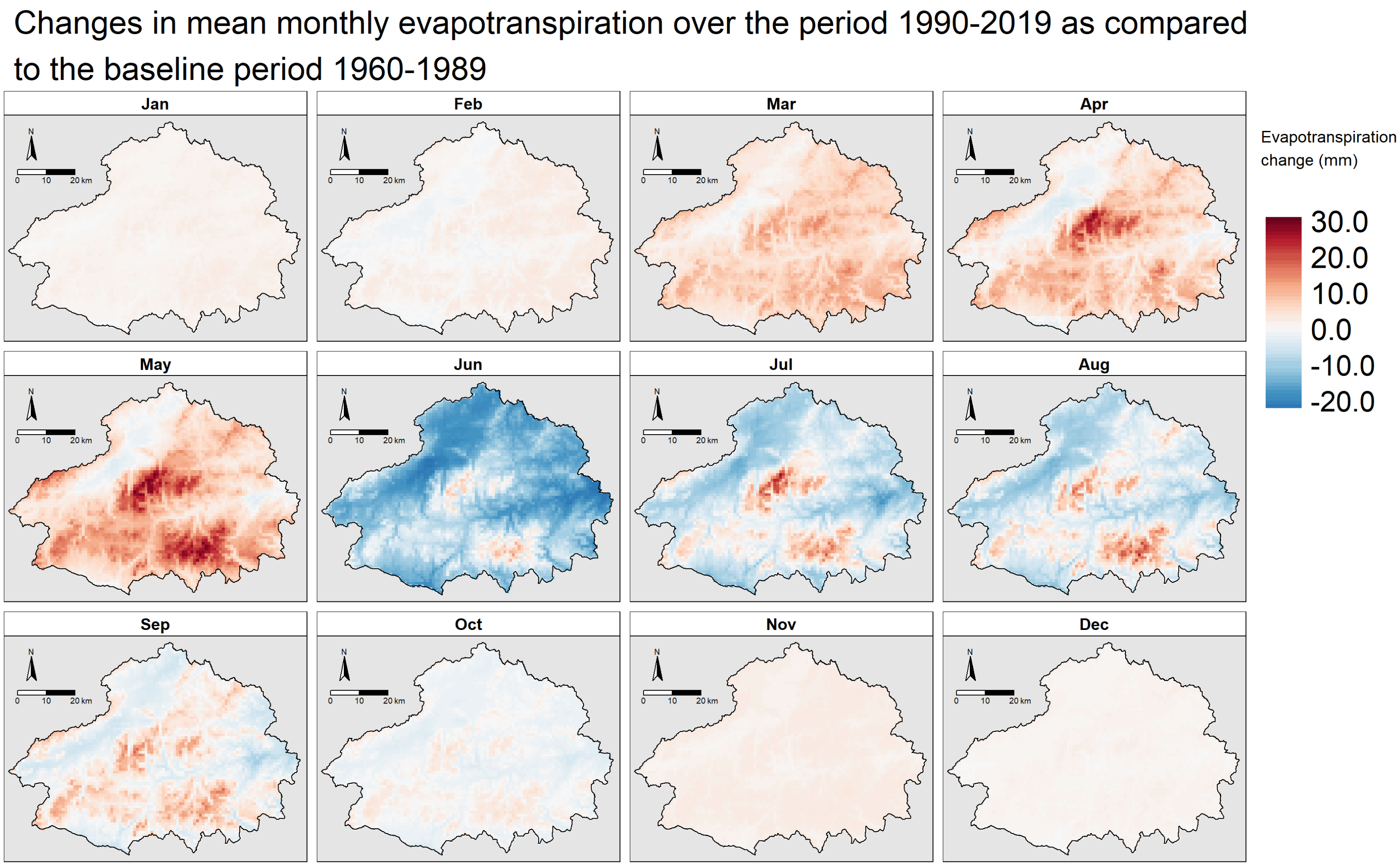


Figure 11. Changes in mean monthly Reference Evapotranspiration from 1960-1989 to 1990-2019.

Climatic Water Balance

- The Climatic Water Balance indicates that there have been spatial and temporal shifts in the balance between precipitation input of water and evapotranspiration return to the atmosphere (Figures 13a and 13b).
- There has been an increase in Climatic Water Balance (more water input) for the majority of the Park in February, June, July, October and November.
- December, January and April have experienced an increase in all areas except the eastern parts of the Park.
- March has experienced both a decrease (less water input) in the eastern half of the Park, and a slight increase in the west.
- August shows a mixed response with some negative decreases in higher elevated areas.
- May and September have experienced an overall decrease in water input, particularly in higher elevated areas.
- The Park has remained in meteorological water surplus from September through to March.
- Spring and summer months show a spatially varied response in terms of meteorological water surplus or deficit: for May, June and July most of the Park is in deficit, but with indications of some locations shifting from surplus to deficit, most noticeably in May, whilst other locations have shifted from deficit to surplus.

Notes on interpreting the Climatic Water Balance:

1. Negative CWB (evapotranspiration > precipitation), indicates that there is less meteorological water input. Conversely, positive CWB (precipitation > evapotranspiration) indicates more meteorological water input.
2. For the change direction maps (e.g. Figure 13b), this information is presented as shifts in meteorological water input surplus to deficit (dark red), deficit to surplus (dark blue), remaining in surplus (light blue) and remaining in deficit (light red).
3. A surplus to deficit change does not mean there is a water deficit in soils, but instead means there is less water input. However, surplus to deficit (dark red) areas indicate locations at potentially greater risk of drying soils.
4. Results are presented as mean monthly values from 30 year periods, meaning that extremes in annual variations are obscured. There will have been annual variation, hence in some years the CWB values (positive or negative) will be larger or smaller. In terms of impacts on the environment and people, the more extremes in this variation will likely be the most significant.

Examples:

May: Figure 12 shows the Park to be mostly in negative CWB (red) except higher elevation locations. Figure 13a shows that the central and eastern part of the Park, there has been a decrease in CWB (red), particularly in the higher elevation locations, but also an increase (blue) in the western side. The change in direction map (Figure 13b) shows that the majority of the Park remains in meteorological water deficit (light red), or in surplus (light blue). However, some of the higher elevation areas are estimated to have experienced a shift from surplus to deficit (dark red). This means that where previously meteorological water was in surplus (P > E, 1960-1989 period) it now in deficit (E > P), which will likely have consequences on biotic systems and hydrology, especially in more extreme years (note 4 above).

September: Figure 12 shows there is a more positive CWB (blue), mostly in the higher elevation areas, but lower positive values in lower locations. In Figure 13a, we see that there has been a reduction (negative) in the CWB in the higher elevation areas (red), but little or no change in the lowland areas, and even a slight increase in the north of the Park. This results in most of the Park remaining in meteorological water surplus (light blue), meaning that although the total amount of water input has decreased in these areas since the 1960-1989 baseline period, overall meteorological water input is still positive (precipitation greater than evapotranspiration).

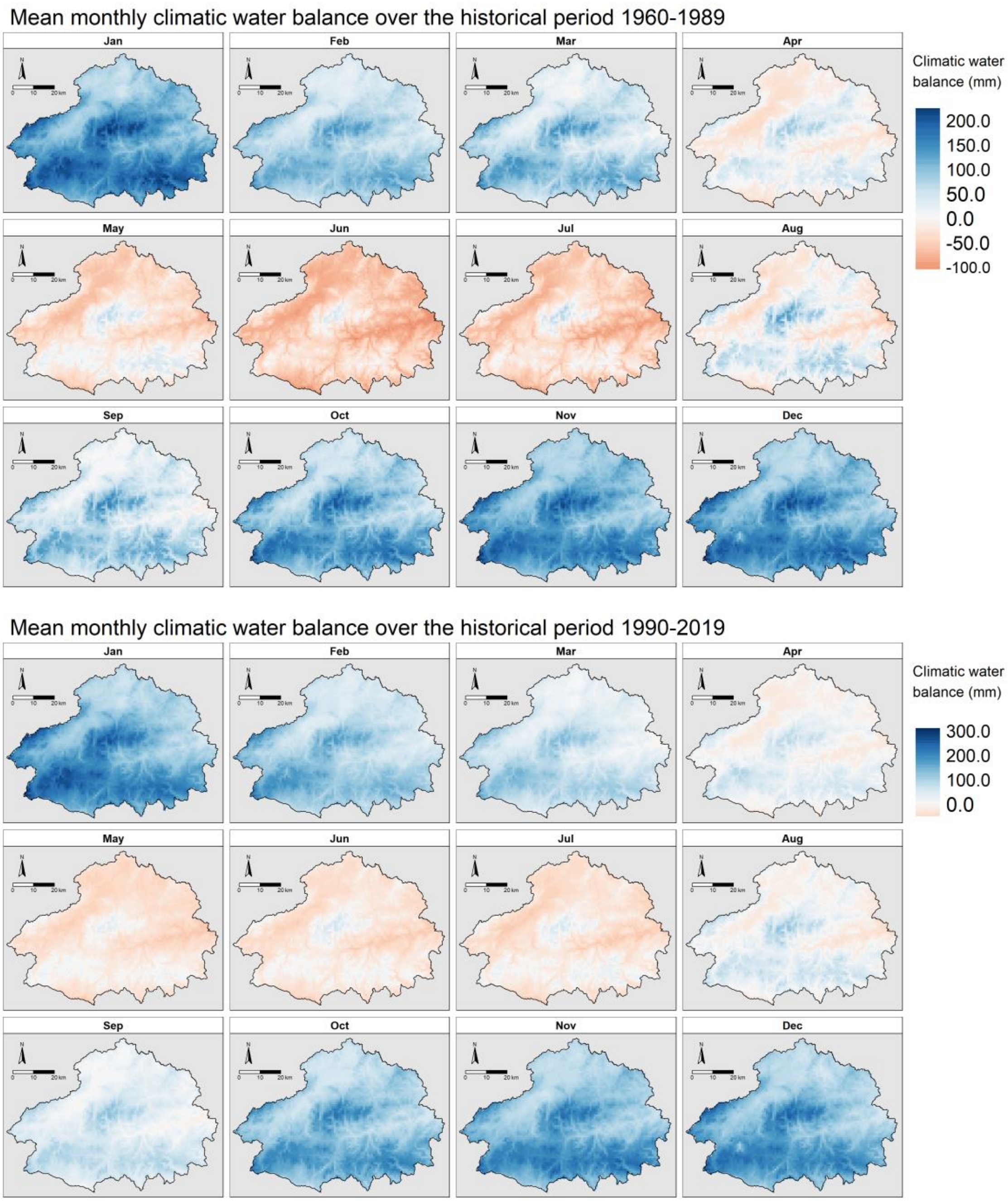


Figure 12. Mean monthly Climatic Water Balance for the baseline (1960-1989) and recent period (1990-2019.

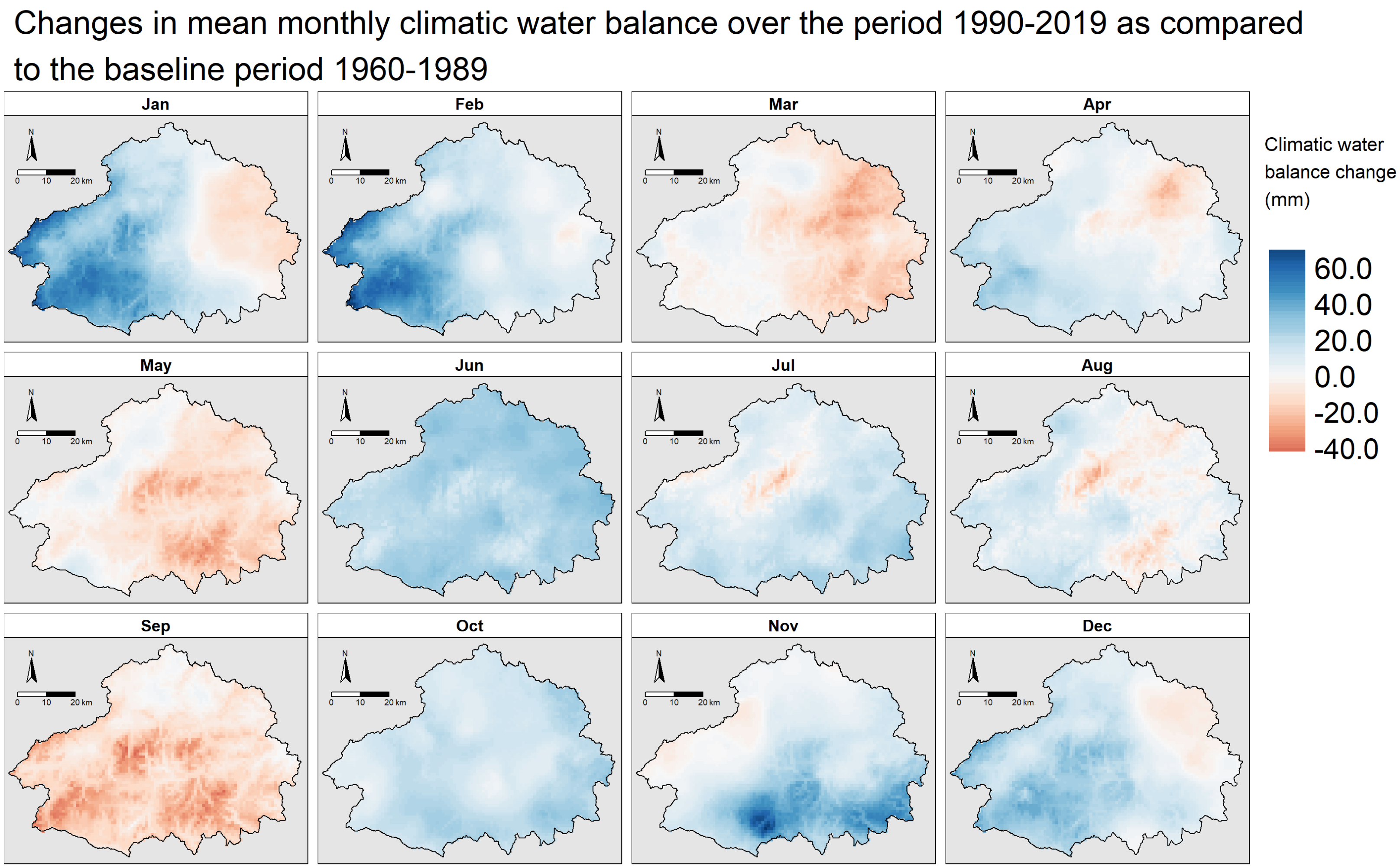


Figure 13a. Changes in mean monthly Climatic Water Balance from 1960-1989 to 1990-2019

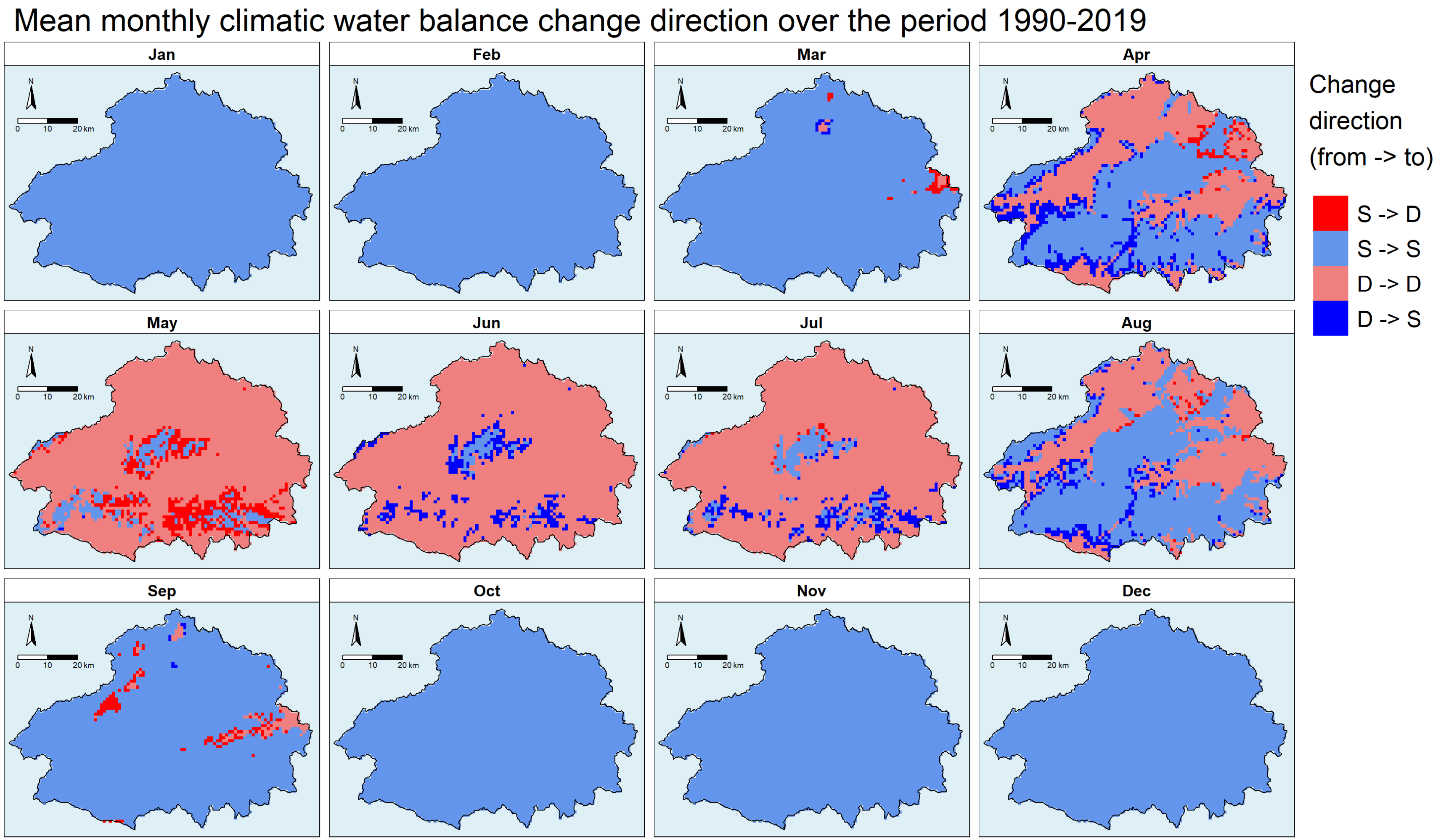


Figure 13b. Direction of change in mean monthly Climatic Water Balance from the 1960-1989 baseline to 1990-2019. S= Surplus, D = Deficit.

Climate Projections

This section presents the results of mapping analysis of the four climate projections. Maps shown are for changes in the climate variables and extreme indicators for four climate projections over two time periods, 2020-2049 and 2050-2079 compared to the 1960-1989 baseline.

Precipitation

- The four climate projections show similar spatial and temporal patterns of changes in mean monthly precipitation, but with differences in the amounts of changes (Figures 14 and 15).
- 2020-2049: Winter months are likely to see large increases (200 – 300%) in mean monthly precipitation, particularly February, but a decrease in August and September (c. 50 – 100%).
- 2050-2079: The pattern of wetter winters and drier summers continues.
- There is projected to be large variation in precipitation responses in spring months, with some areas of the Park potentially seeing decreases in precipitation whilst others areas may experience increases.

Maximum Temperature

- All areas of the Park are projected to experience increases in mean monthly maximum temperature. This is variable between the four climate projections in terms of the amount of temperature increase and when in the year these occur.
- Example: The projection with the lowest overall temperature increase (number 15, c. 1.2°C overall increase, Figure 1) for the 2020-2049 period indicates May, July, August and September to experience increases in meant monthly maximum temperature of 2-3°C (Figure 16).

Minimum Temperature

- All areas of the park are projected to experience increases in mean monthly minimum temperature. This is variable between the four climate projections in terms of the amount of temperature increase and when in the year these occur.
- An exception is that under one projection, December minimum temperature may decrease.
- Example: The projection with an overall c. 2°C temperature increase (number 10, Figure 1) for the 2020-2049 period indicates that there is potential for more warming in the winter than summer months.

Reference Evapotranspiration

- All four climate projections indicate an increase in evapotranspiration for March, April and May. Higher elevation areas may experience the most change from the 1960-1989 baseline period.
- There is a spatially varied response for the summer months, with higher elevation areas potentially experiencing increases in evapotranspiration.
- Example: The projection with an overall c. 2.5°C temperature increase (number 4, Figure 1) for the 2020-2049 period indicates March, April and May are estimated to see increases in evapotranspiration of up to 60mm in higher elevation locations (Figure 20), increasing to include March through to September when there is a further increase in evapotranspiration (up to 80mm in May) forth 2050-2079 period.

Climatic Water Balance

- All four projections indicate an increase in meteorological water input (positive Climatic Water Balance) for March to May, but varied responses in the summer months and little change for October to January (Figure 22).

- Example: The projection with an overall c. 2°C temperature increase (number 10, Figure 1) for the 2020-2049 period indicates that the Climatic Water Balance to be positive (precipitation > evapotranspiration) for all months, except in the north-west section of the Park between June and September, when there is a decrease (E > P) (Figure 22). Similar responses are also seen for projections 4 and 15 for the 2050-2079 period (Figure 23).
- The change direction for the Climatic Water Balance (Figures 24 and 25) indicate that from October to March will see the Park remain in meteorological water surplus.
- All four projections indicate risks of large sections of the Park shifting from meteorological water surplus to a deficit between April (large spatial variation) through to September.
- Example: The projection with the lowest overall temperature increase (number 15, c. 1.2°C overall increase, Figure 1) for the 2020-2049 period indicates in May higher elevation areas in the central and southern parts of the Park may experience a shift from meteorological water surplus to a deficit. This becomes more pronounced in August (Figure 24) and increases in the period 2050-2079 to include most of the Park area in September as well (Figure 25).

Climate Extreme Indicators: Observed trends and future projections.

This section presents the mapping of trends in the historical periods (1960-1989 to 1990-2019) and two future periods (2020-2049, 2050-2079) for the four climate projection changes from the 1960-1989 baseline.

Number of Consecutive Dry Days

The count of the number of Consecutive Dry Days (CDD) is an indication of when water may become limited and drought conditions occur. It is the maximum length of a dry spell in any one month (when precipitation is less than 1mm per day).

- There has been spatial and temporal variation in the changes to the number of Consecutive Dry Days (Figure 27).
- February April, June, August and November have experienced and overall decrease in the number of Consecutive Dry Days.
- The number of Consecutive Dry Days in February has decreased by 3 days, whilst in March and September it has increased by 2 days.
- The future four projections for the 2020-2049 period shows similar spatial and temporal patterns, with February estimated to see further decreases in the number of Consecutive Dry Days, whilst May through to October have increases.
- There is agreement across the four projections (Figure 29) that September is estimated to have a substantial increase in the number of Consecutive Dry Days, by up to 10 days (Figure 28), increasing to 15 in the 2050-2079 period (Figure 30).
- For the 2050-2079 period there is good agreement between the four projections that the change of direction in the number of Consecutive Dry Days is towards increases between May and October, but decreases between December and February.

Number of Dry Days

This is a count of the number of Dry Days (DD) per month (when precipitation is < 1mm). As with Consecutive Dry Days, this indicator provides information on the potential for increased dry conditions and risks of drought, fires and heat stress.

- The mean monthly number of Dry Days have both increased in some months and decreased in others. This is also spatially variable (Figure 34).
- February has experienced the largest decrease in the number of Dry Days, cover the entire Park area, by an average of 4 days, mostly in the western half. Increase have also been seen in April (western half), June, July, October and November (but with some areas also seeing a decrease).
- March has experienced an increase, of 2 days, across the whole Park.
- September has experienced the largest increase, covering the whole Park area, of up to 2 more mean monthly number of Dry Days.
- The future four projections for the 2020-2049 period shows similar spatial and temporal patterns (Figure 35), continuing into the 2050-2079 period (Figure 37), with winter months seeing a decrease in the mean number of Dry Days.
- Example: For the projection with an overall similar amount of mean annual total precipitation but higher temperature increase (number 12, Figure 1), September is projected to see a decrease in the number of dry days of up to 15 days (Figure 35). Conversely, in February there may be an increase by as much as 5-10 days.
- The change direction maps show large spatial variations in some months (as may be expected from precipitation-based indicators) but there is good agreement across the four projections that there is likely to be increases in the number of Dry Days in August, September and October (Figure 36). Other months have good agreement for some parts of the Park, e.g. the southern half in May and June. In the period 2050-2079, the land area experiencing increases in the number of Dry Days increases (Figure 39)

Heavy Precipitation Days

This indicator represents days when precipitation may be considered as 'heavy rainfall' – here we consider the threshold as days when precipitation is ≥ 10mm.

- The mean number of Heavy Precipitation Days has increased in January and February by up to 3 days, April, June and October in most of the Park area (Figure 41), but there has also been both increases and decreases in March, May, July, November and December.
- August, September and the eastern half or the Park in May have experienced a slight decrease, by 1 day.
- For the future climate, there is a mixed response between the four projections. February is projected to see an increase, whereas August will see a decrease (Figure 42 – note that unfortunately the colour scheme here is counter-intuitive, with red indicating more Heavy Precipitation Days, blue means fewer). This pattern is further continued into the 2050-2079 period (Figure 44).
- The change direction maps illustrate the extent to which the changes in mean monthly number of Heavy Precipitation Days (Figure 43) are highly spatially and temporally variable, and this continues into the 2050-2079 period (Figure 45).
- There is poor agreement between the four projections on the amount of land area experiencing increases, decreases or no change in the mean number of Heavy Precipitation Days (Figure 46).

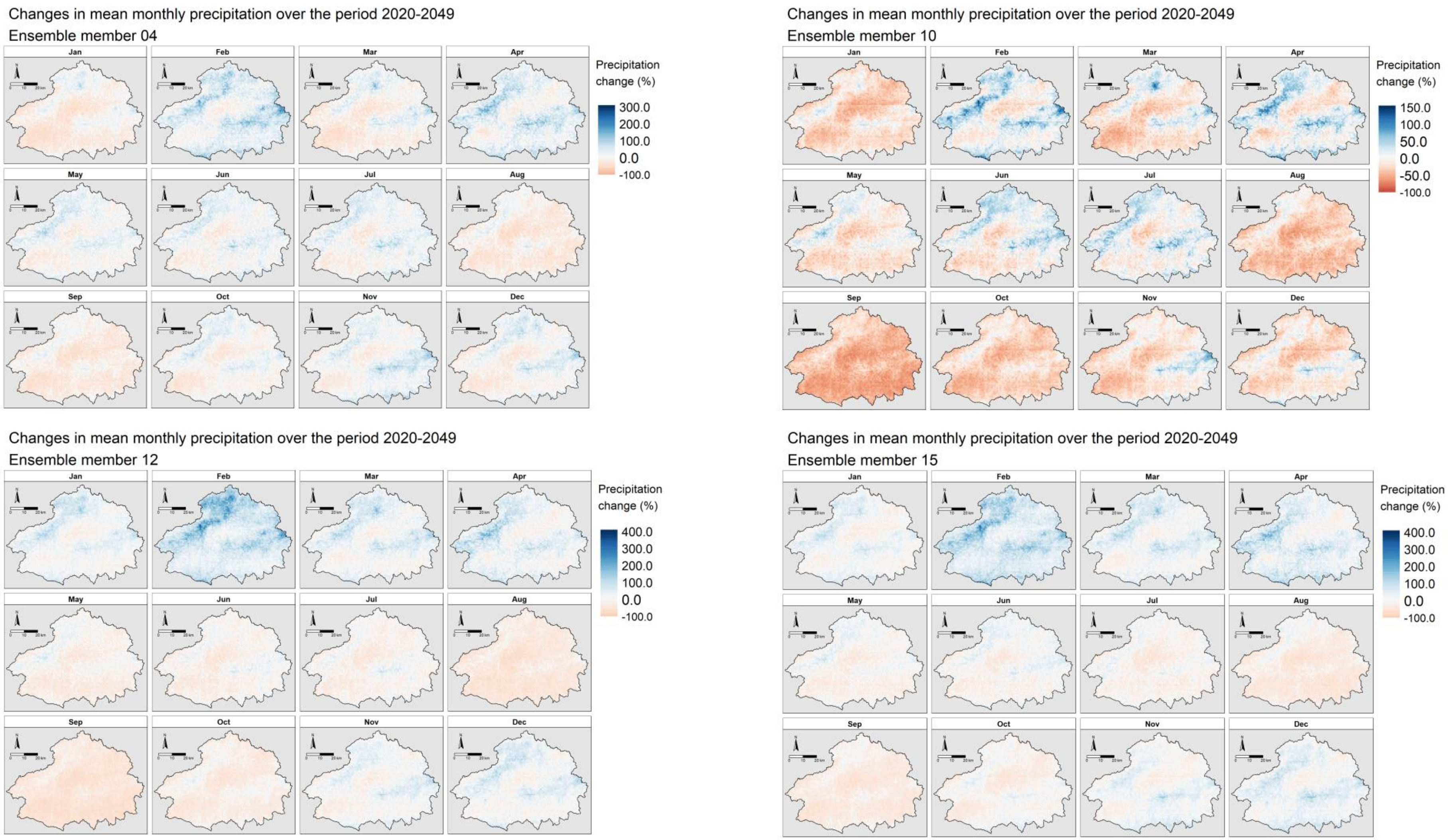


Figure 14. Changes in projected mean monthly precipitation for the period 2020-2049. Note differences in scales means it is not possible to directly compare between projections.

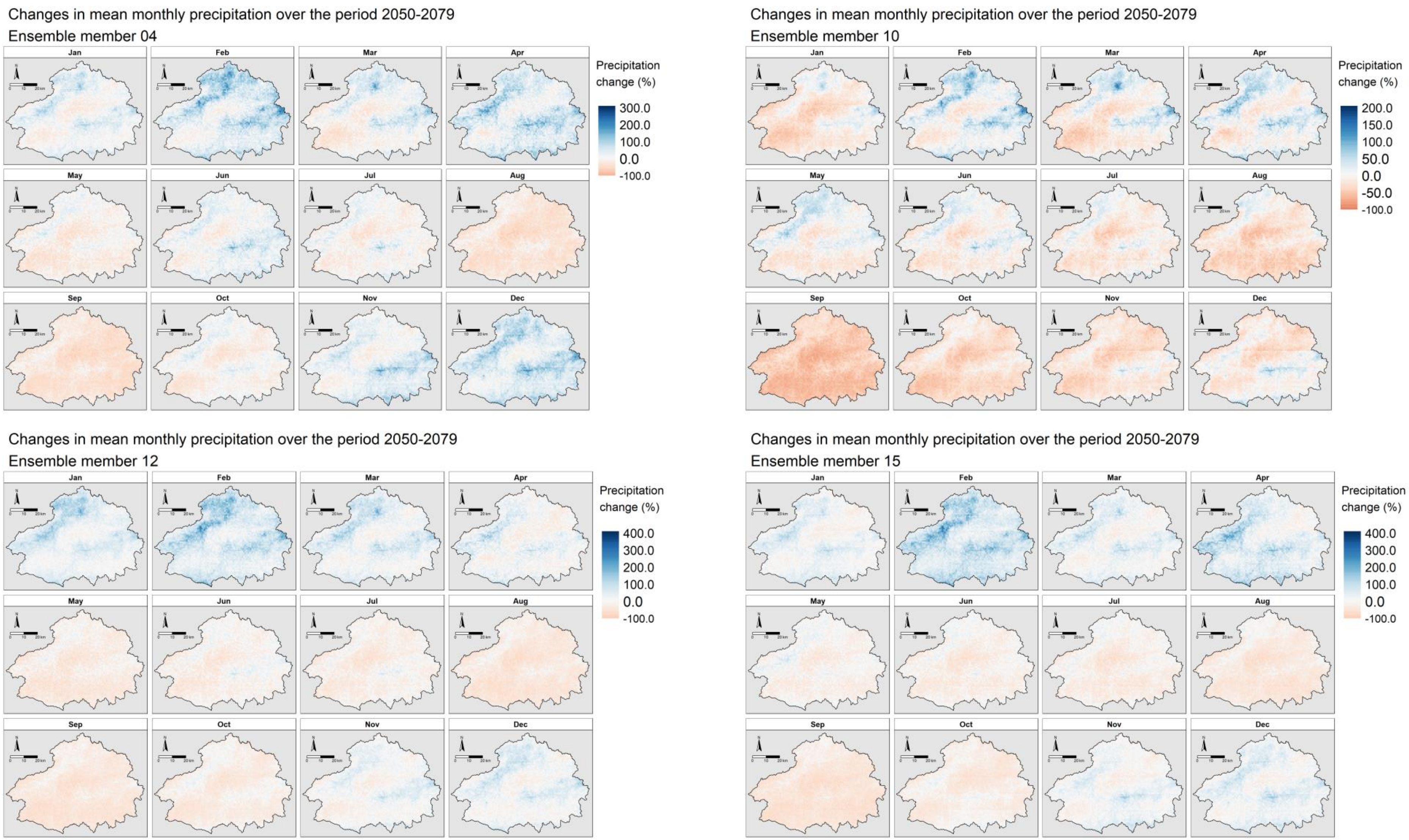


Figure 15. Changes in mean monthly precipitation for the period 2050-2079. Note differences in scales means it is not possible to directly compare between projections.

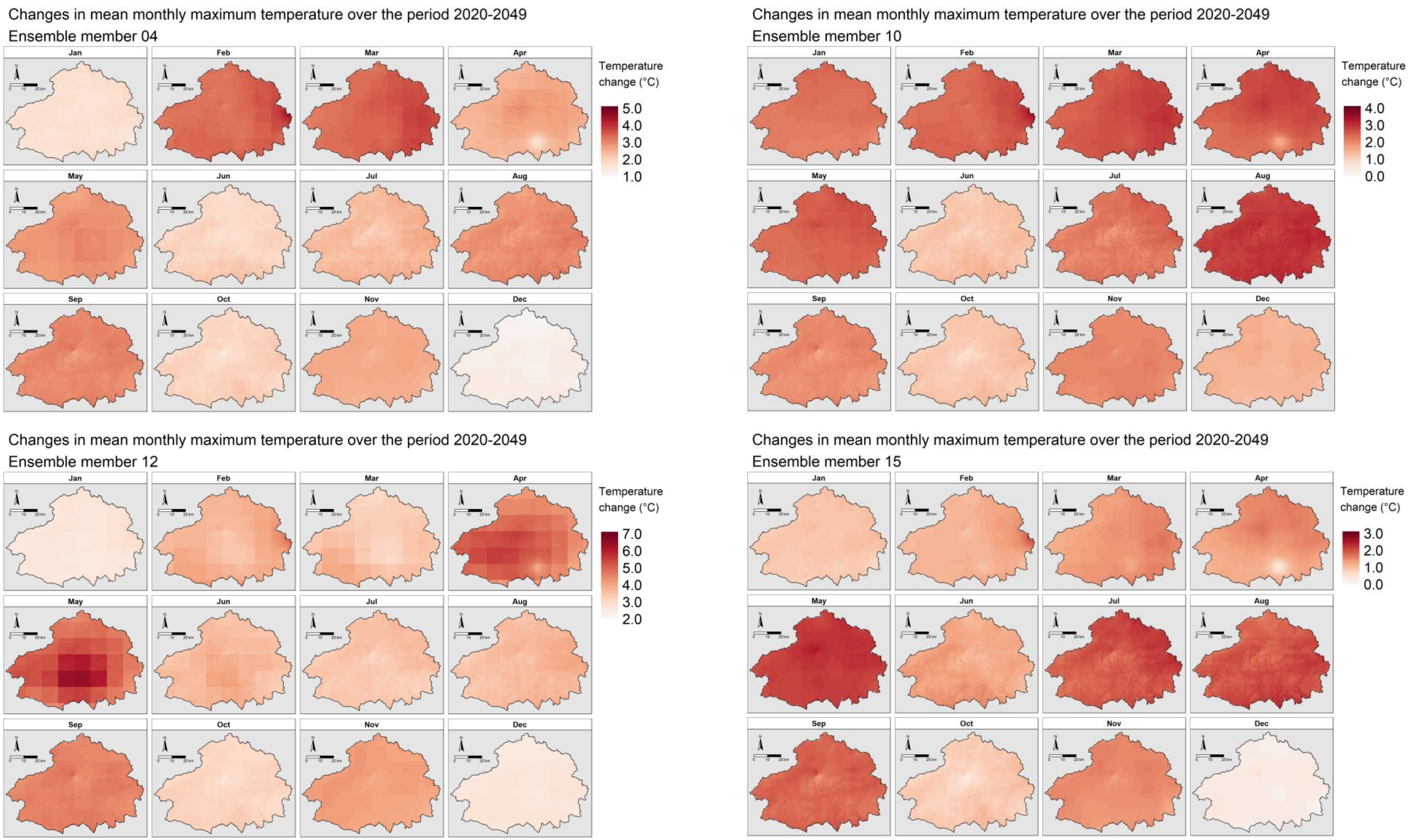


Figure 16 .Changes in projected mean monthly maximum temperature for the period 2020-2049. Note differences in scales means it is not possible to directly compare between projections.

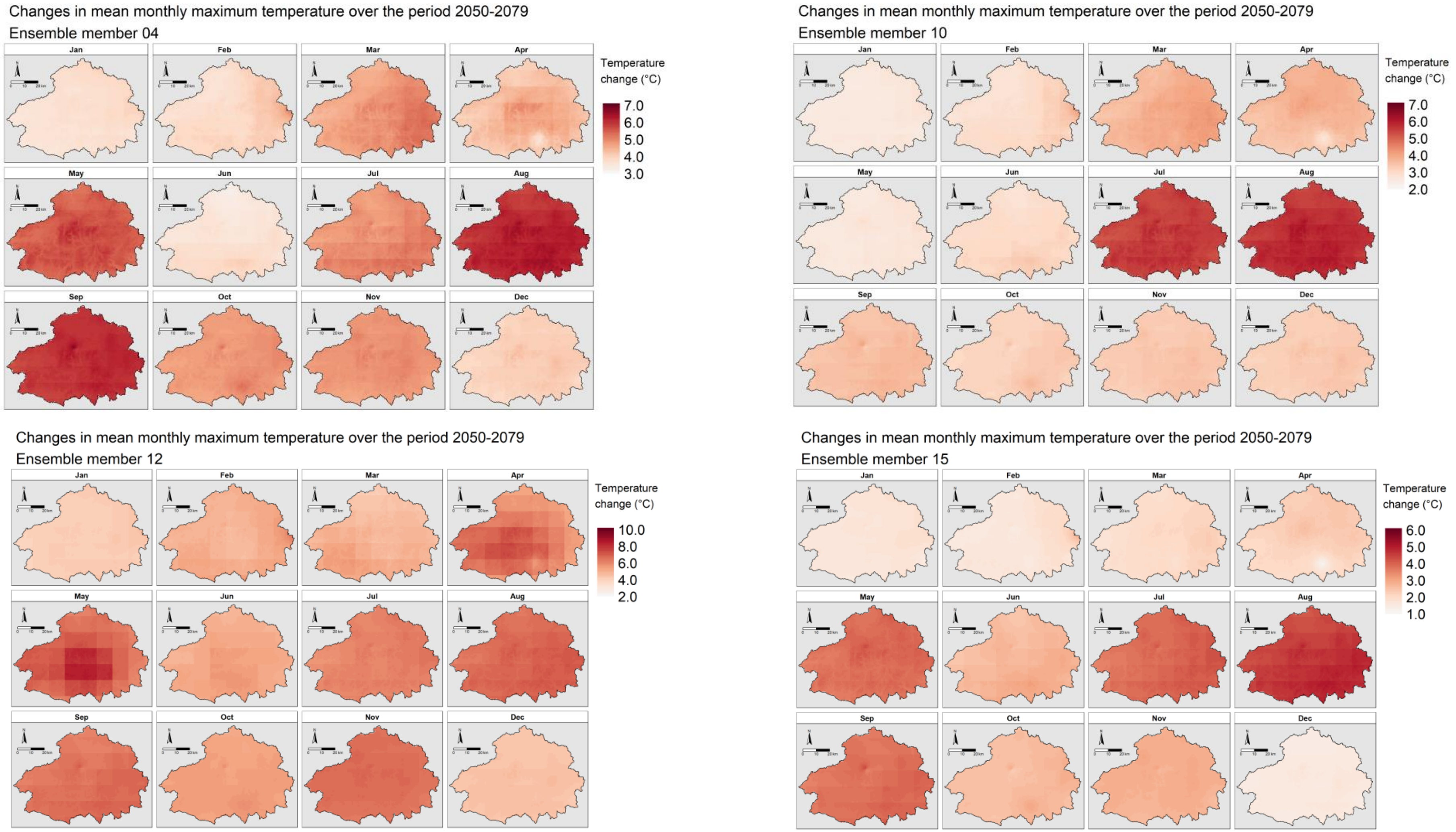


Figure 17. Changes in projected mean monthly maximum temperature for the period 2050-2079. Note differences in scales means it is not possible to directly compare between projections.

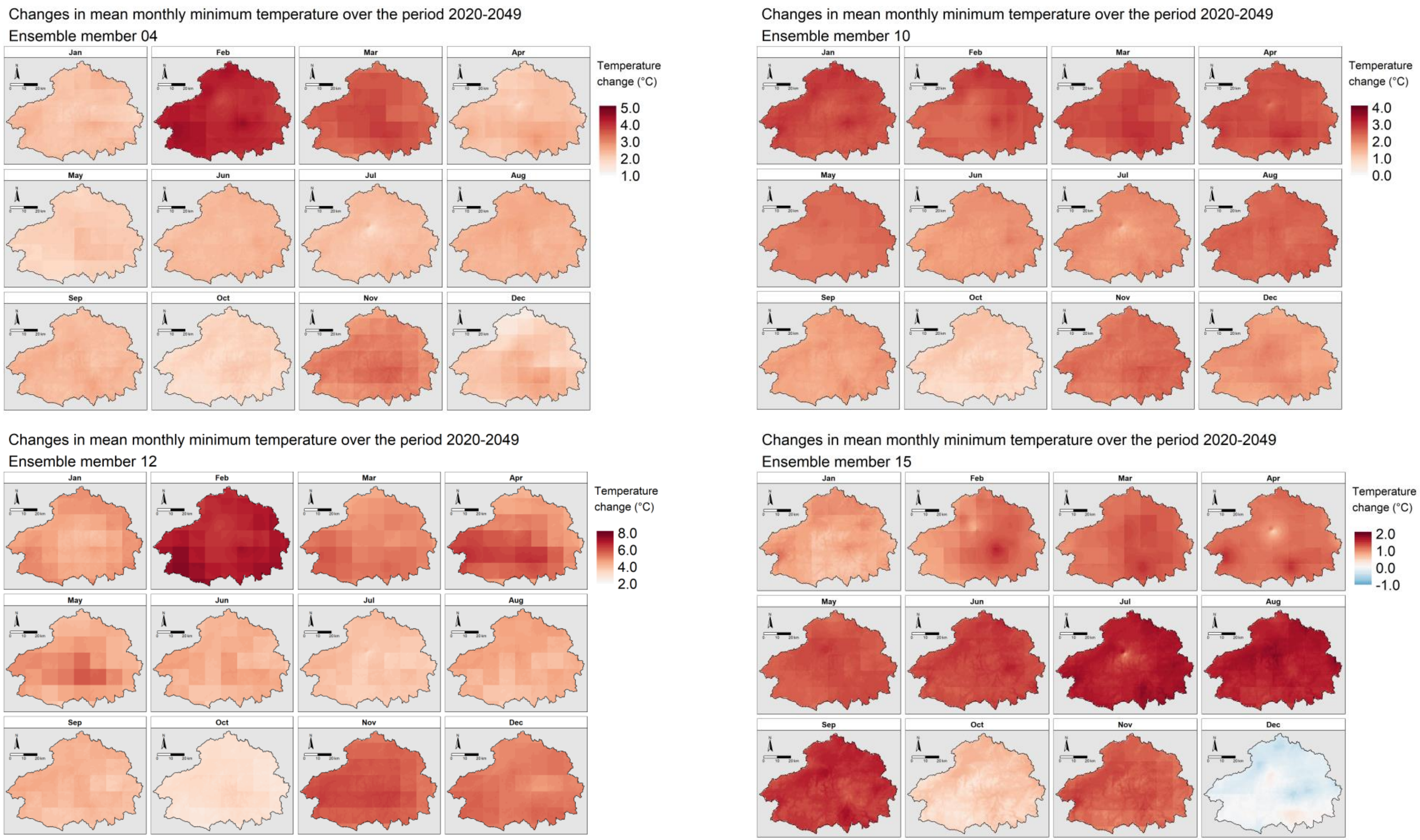


Figure 18. Changes in projected mean monthly minimum temperature for the period 2020-2049. Note differences in scales means it is not possible to directly compare between projections.

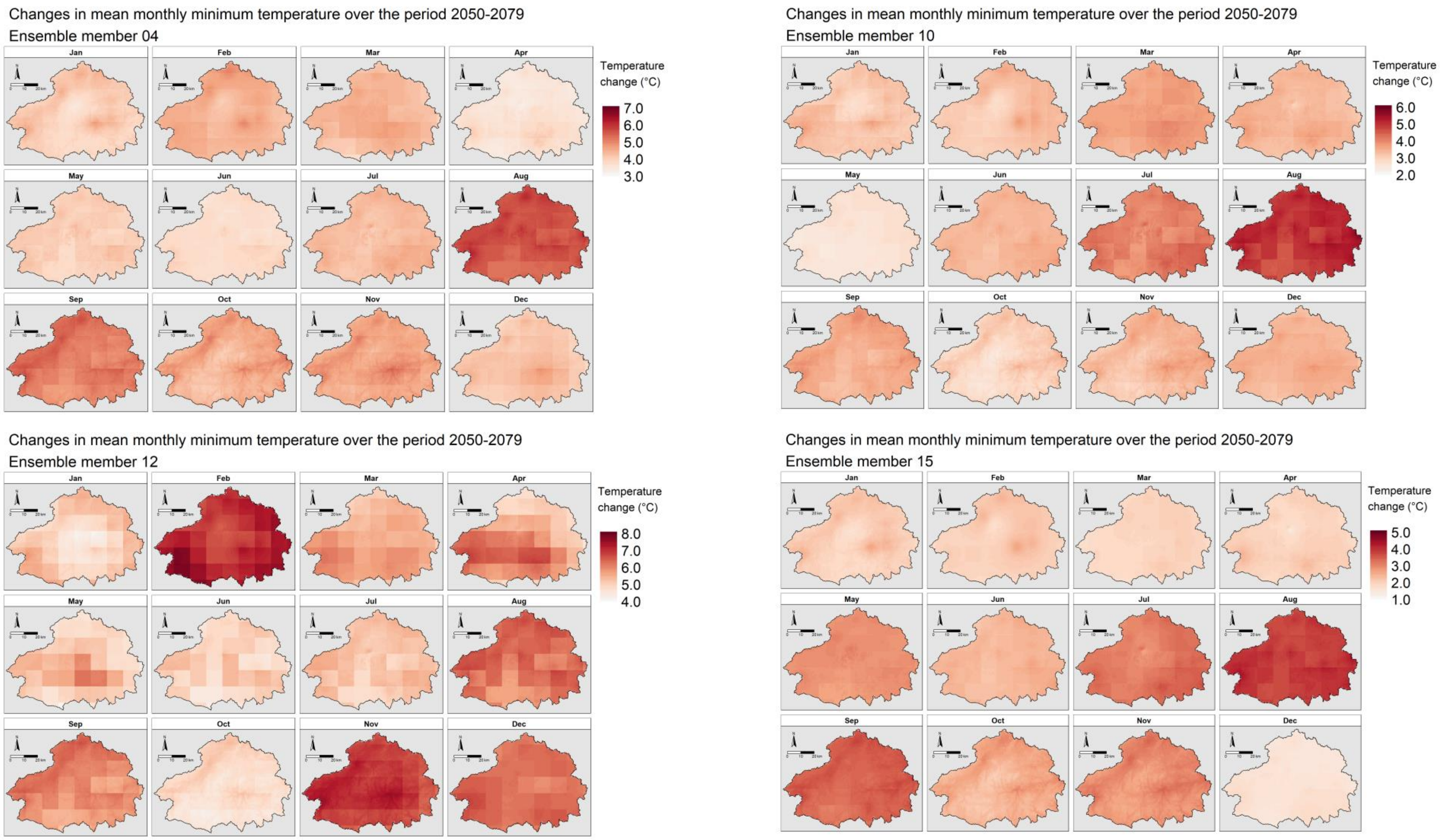


Figure 19. Changes in projected mean monthly minimum temperature for the period 2050-2079. Note differences in scales means it is not possible to directly compare between projections.

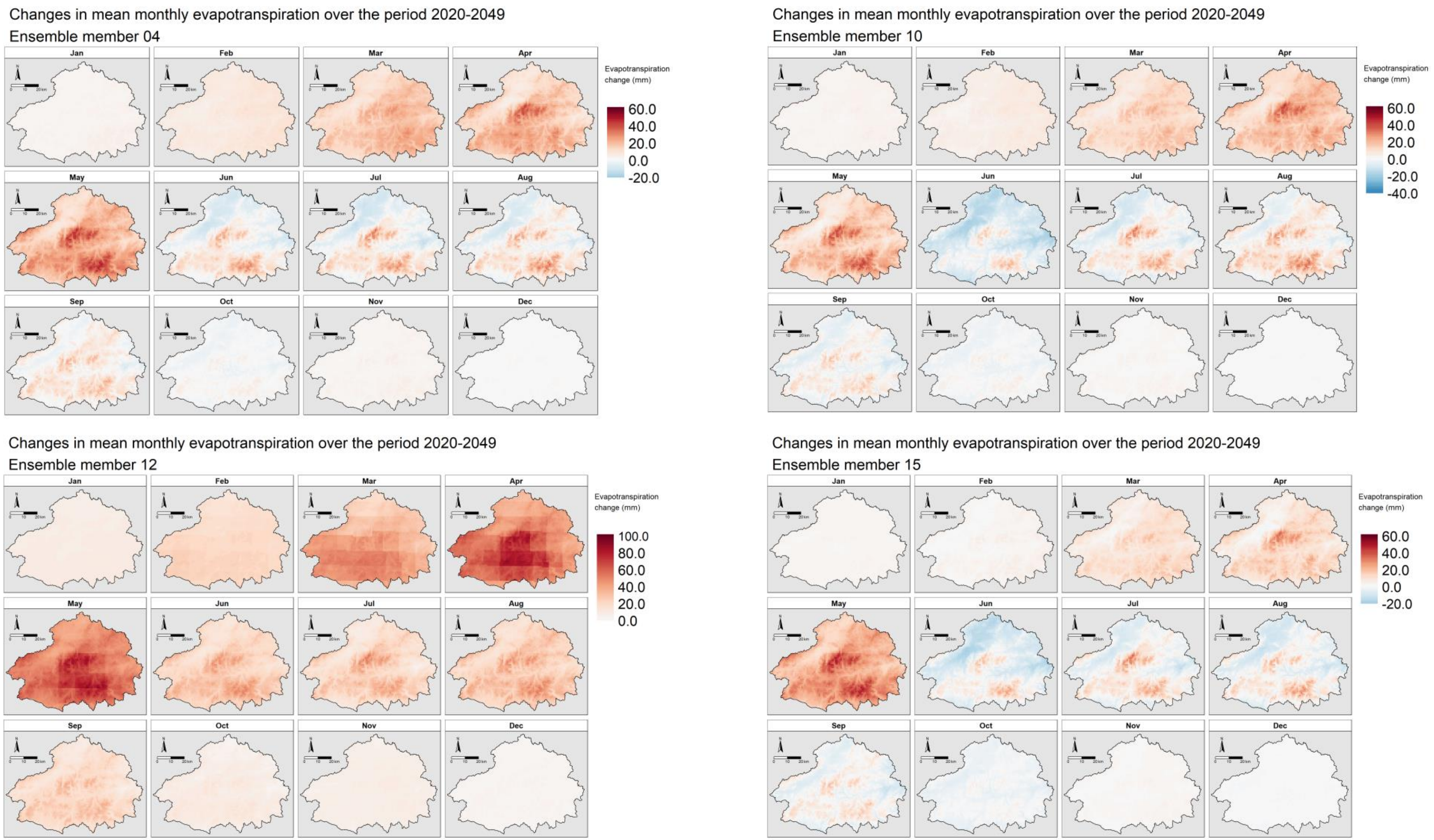


Figure 20. Changes in projected mean monthly Reference Evapotranspiration for the period 2020-2049. Note differences in scales means it is not possible to directly compare between projections.

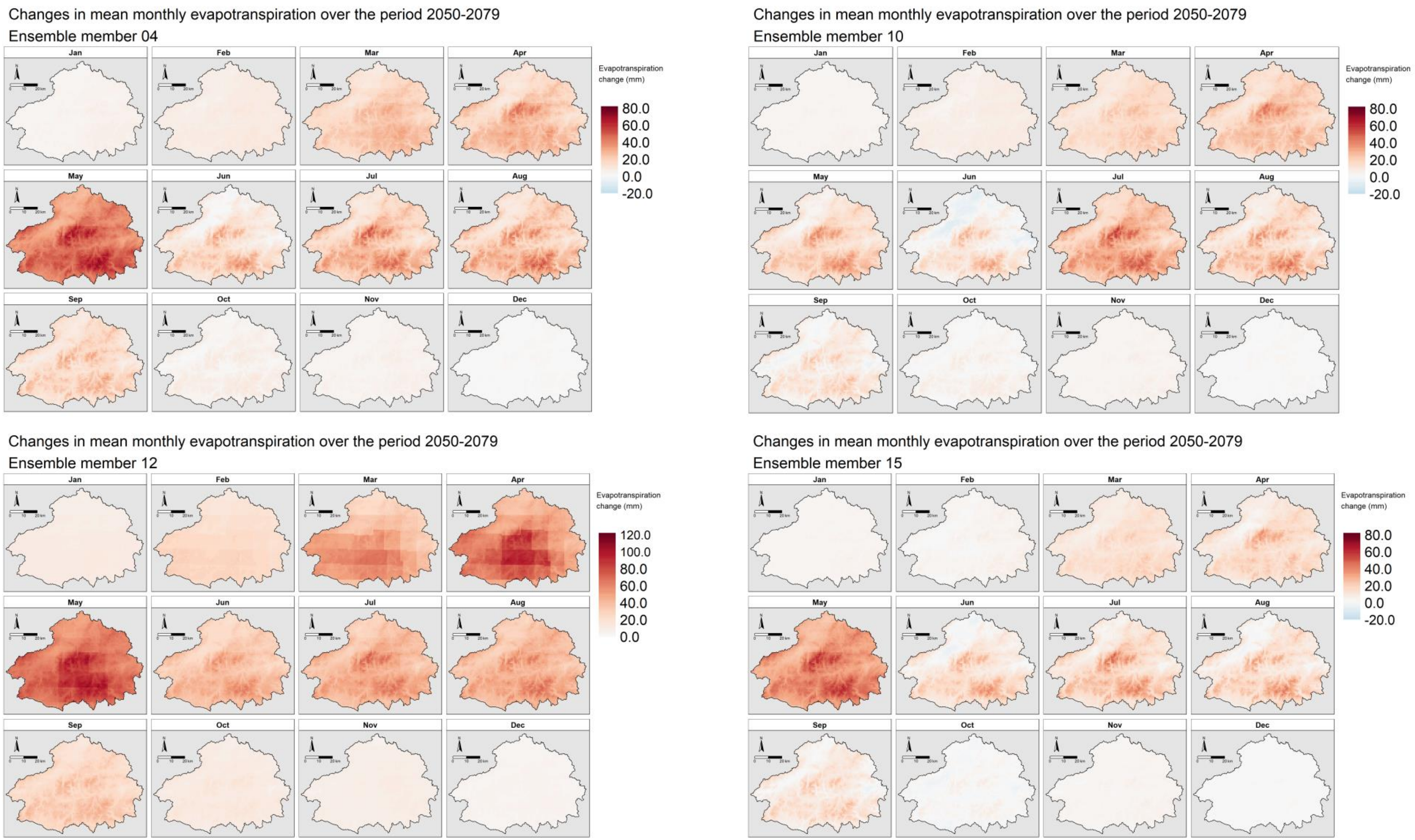


Figure 21. Changes in projected mean monthly Reference Evapotranspiration for the period 2050-2079. Note differences in scales means it is not possible to directly compare between projections.

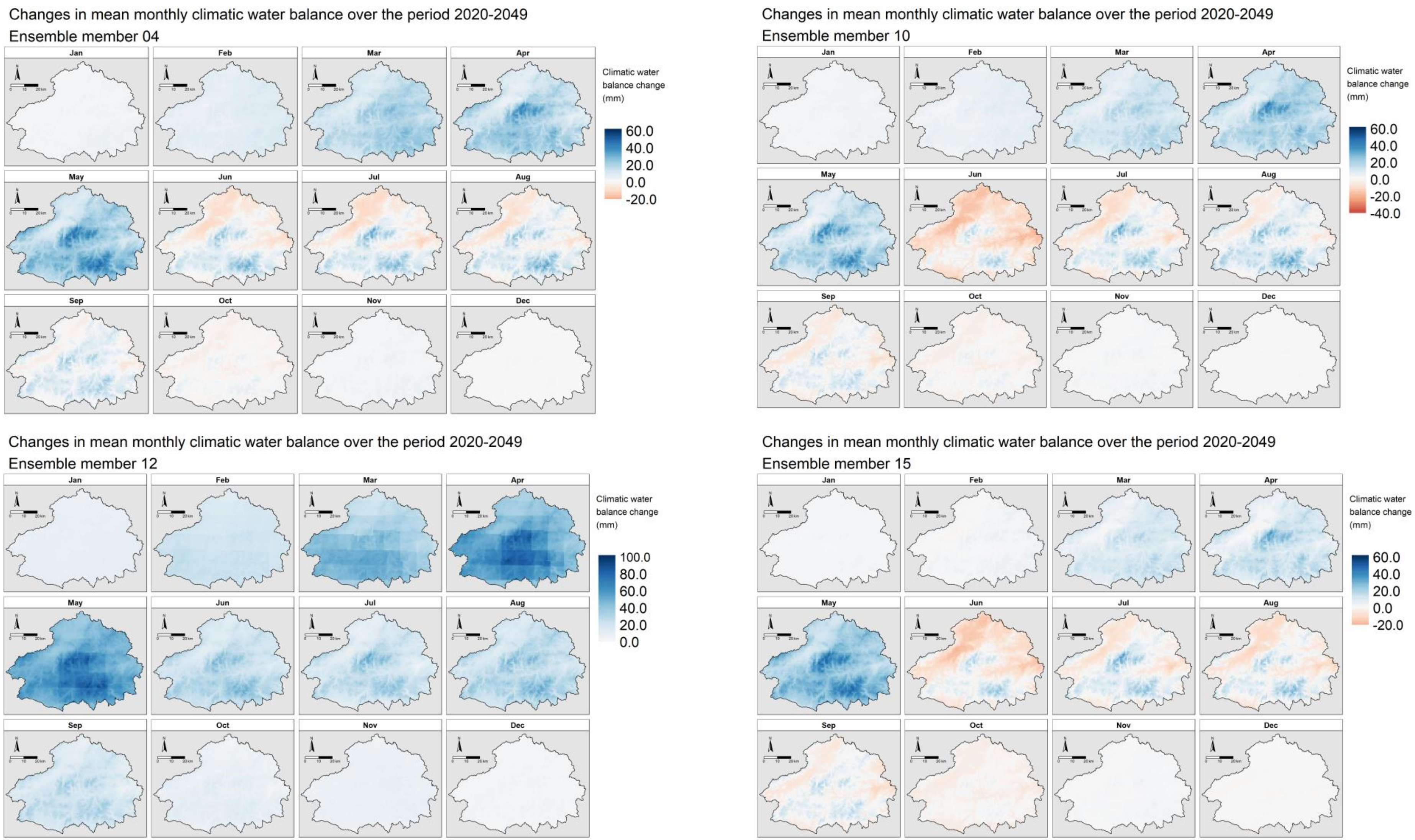


Figure 22. Changes in projected mean monthly Climatic Water Balance for the period 2020-2049. Note differences in scales means it is not possible to directly compare between projections.

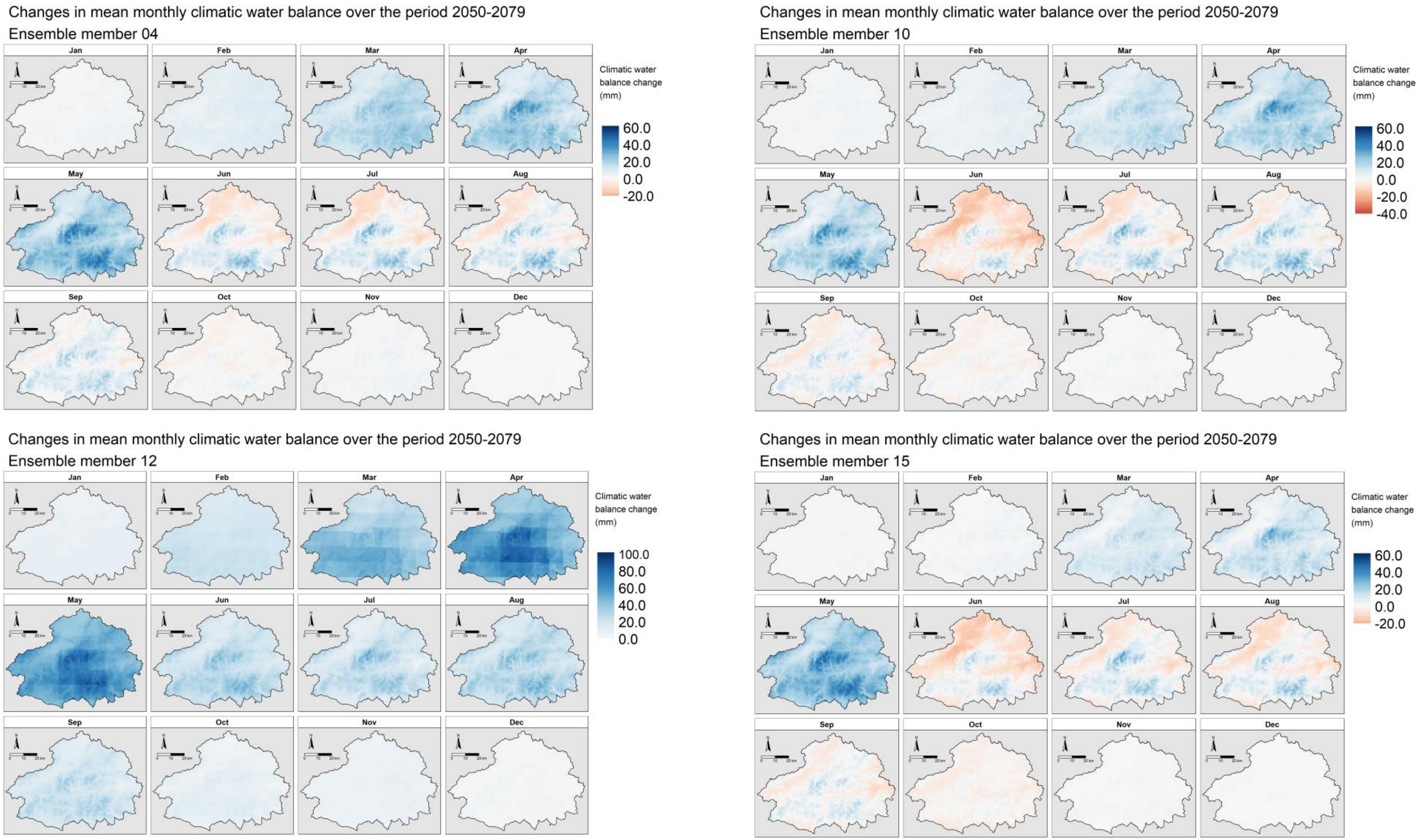


Figure 23. Changes in projected mean monthly Climatic Water Balance for the period 2050-2079. Note differences in scales means it is not possible to directly compare between projections.

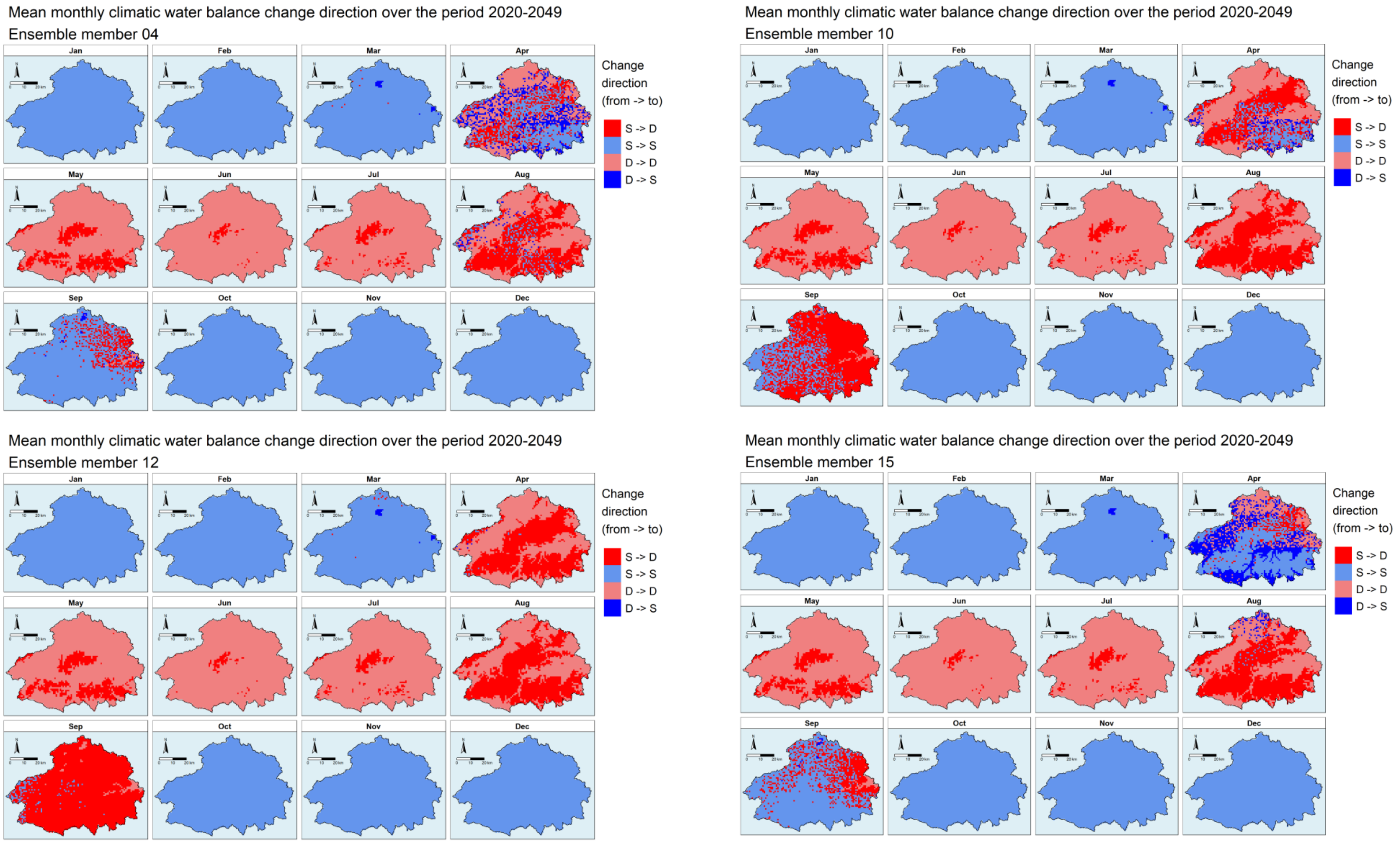


Figure 24. Changes direction in projected mean monthly Climatic Water Balance for the period 2020-2049. S= Surplus; D= Deficit.

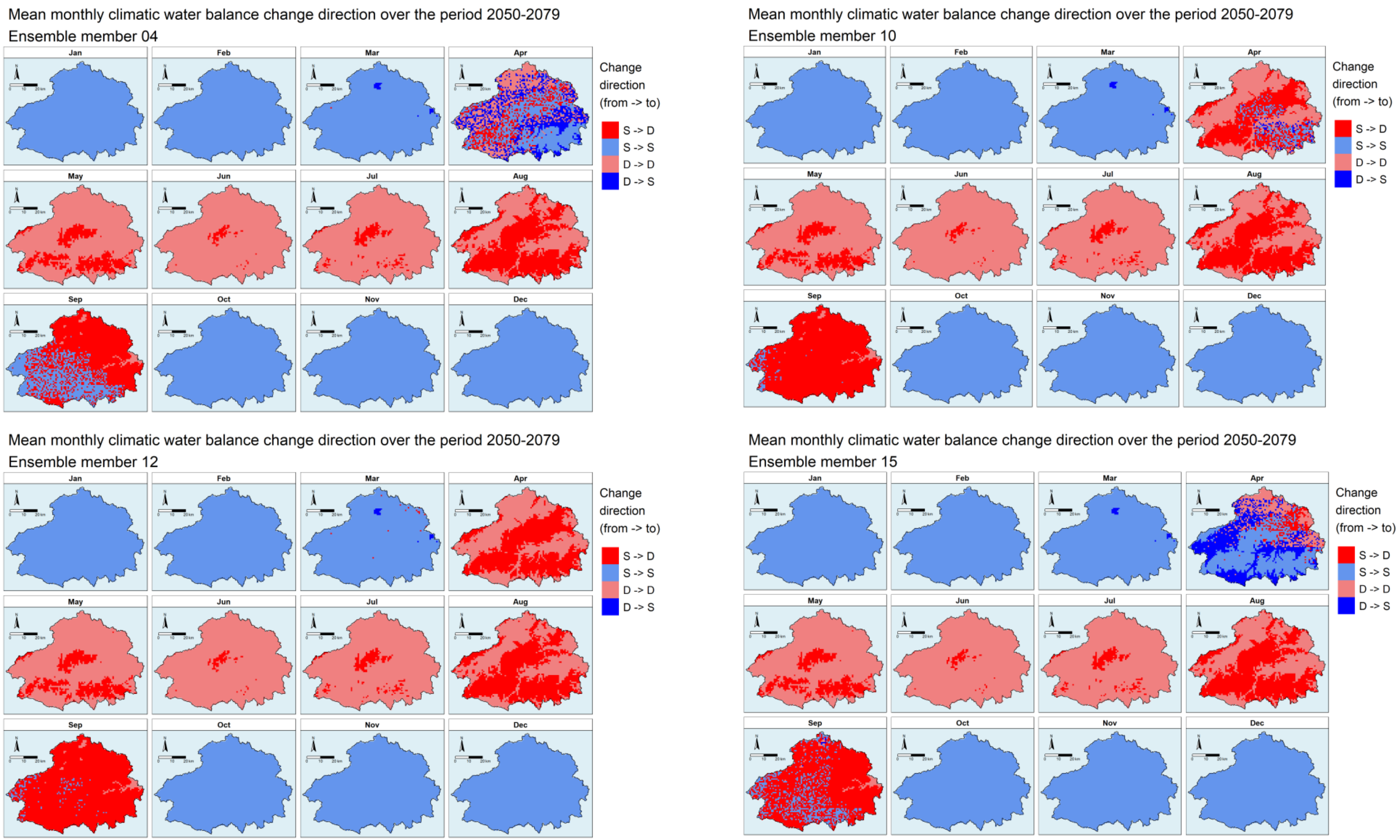


Figure 25. Changes direction in projected mean monthly Climatic Water Balance for the period 2050-2079. S= Surplus; D= Deficit.

Climate Extremes Indicators

Number of Consecutive Dry Days

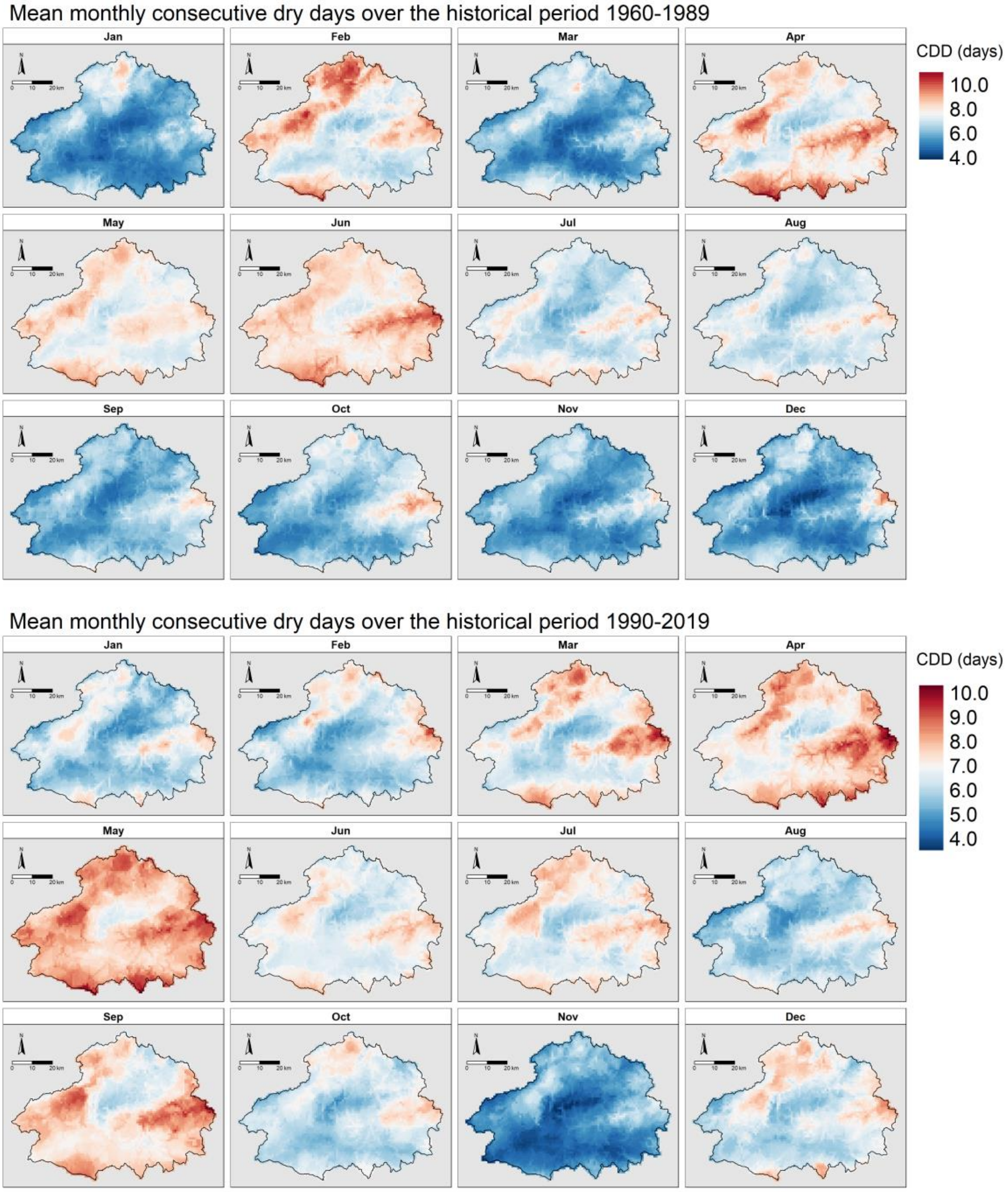


Figure 26. Observed mean monthly number of Consecutive Dry Days for the periods 1960-1989 (top) and 1990-2019 (bottom)

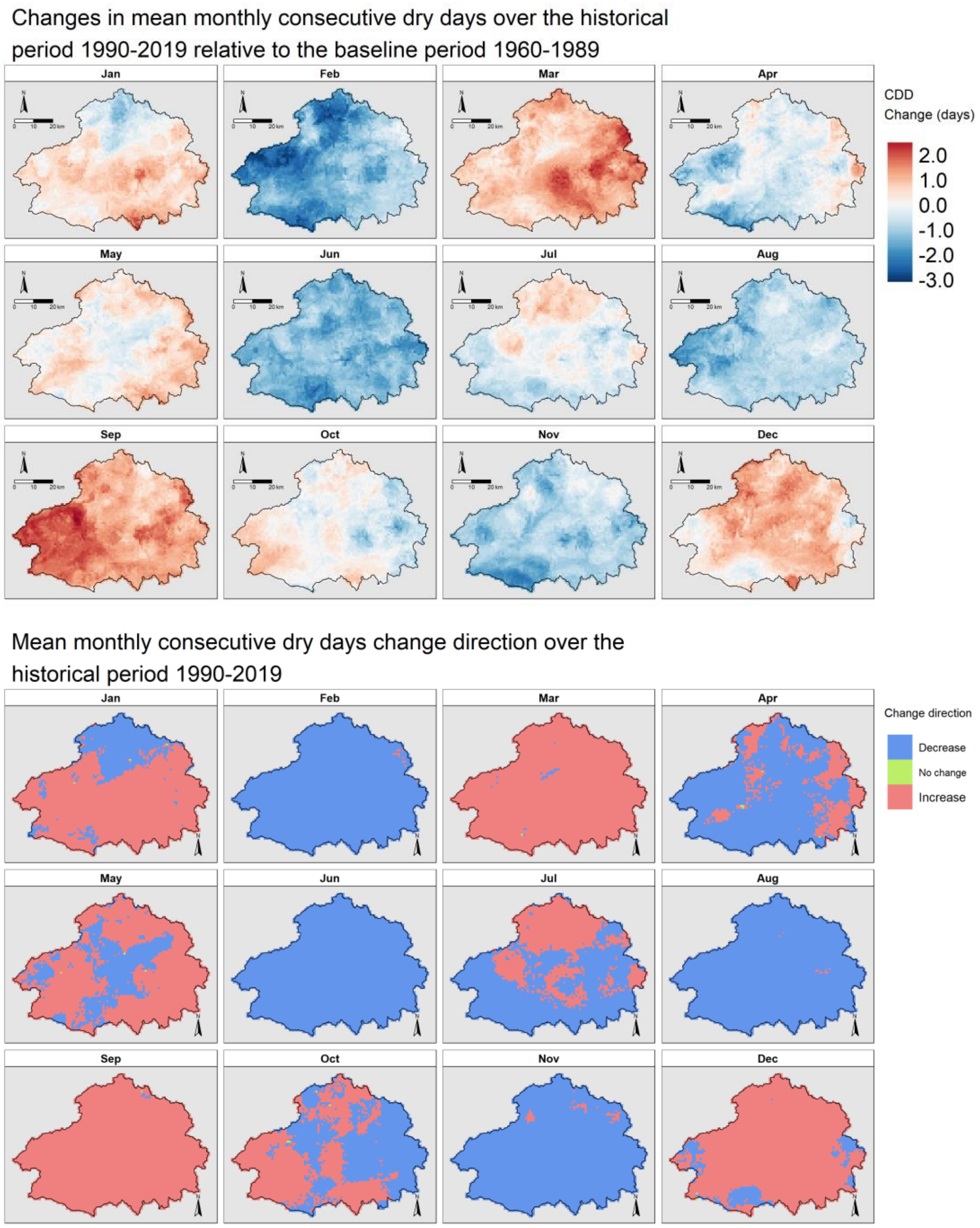


Figure 27. Change in the mean monthly number of Consecutive Dry Days between the periods 1960-1989 (baseline) and 1990-2019 (top) and the change direction from the baseline to 1990-2019 (bottom)

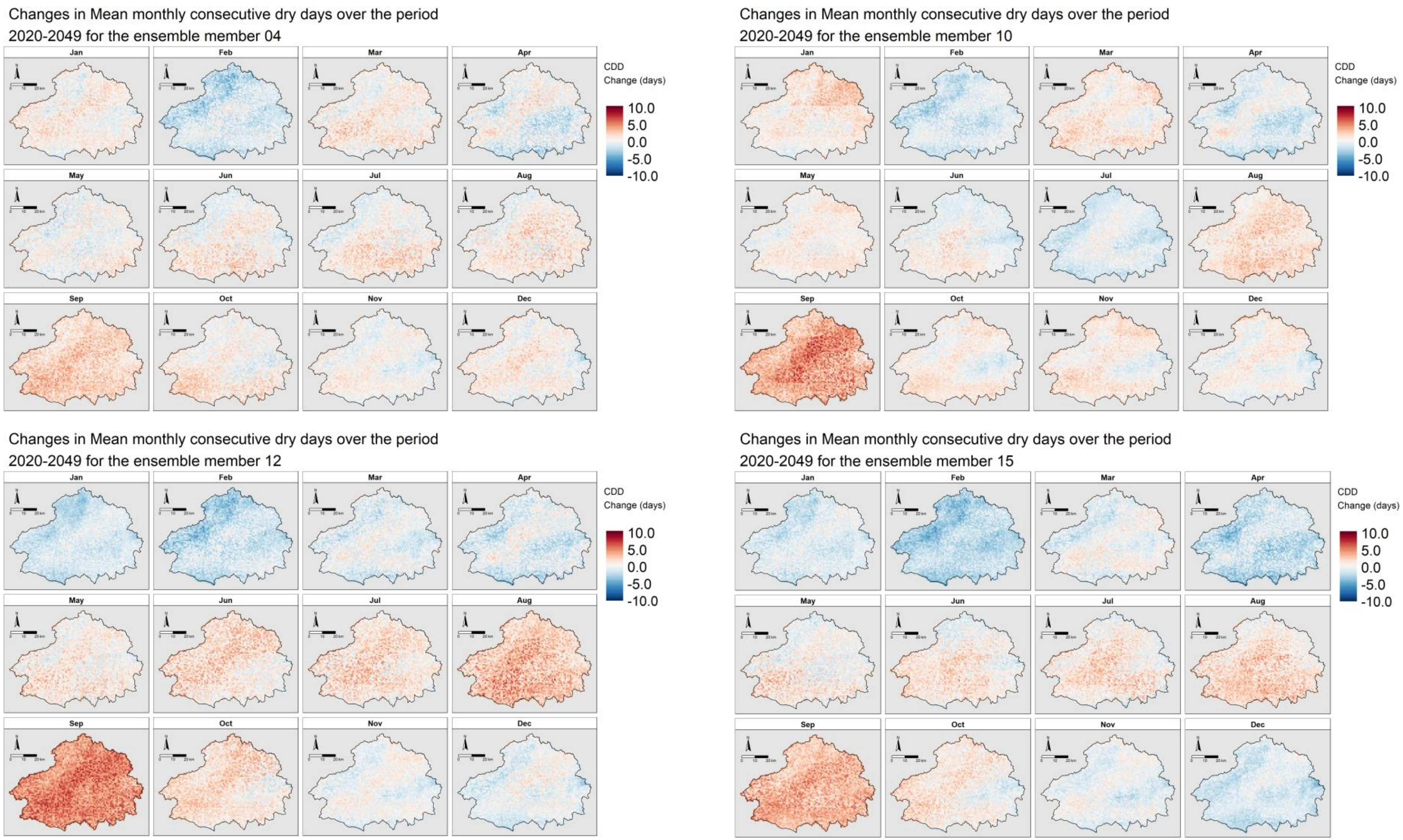


Figure 28. Projected change in the mean monthly number of Consecutive Dry Days for the future period 2020-2049.

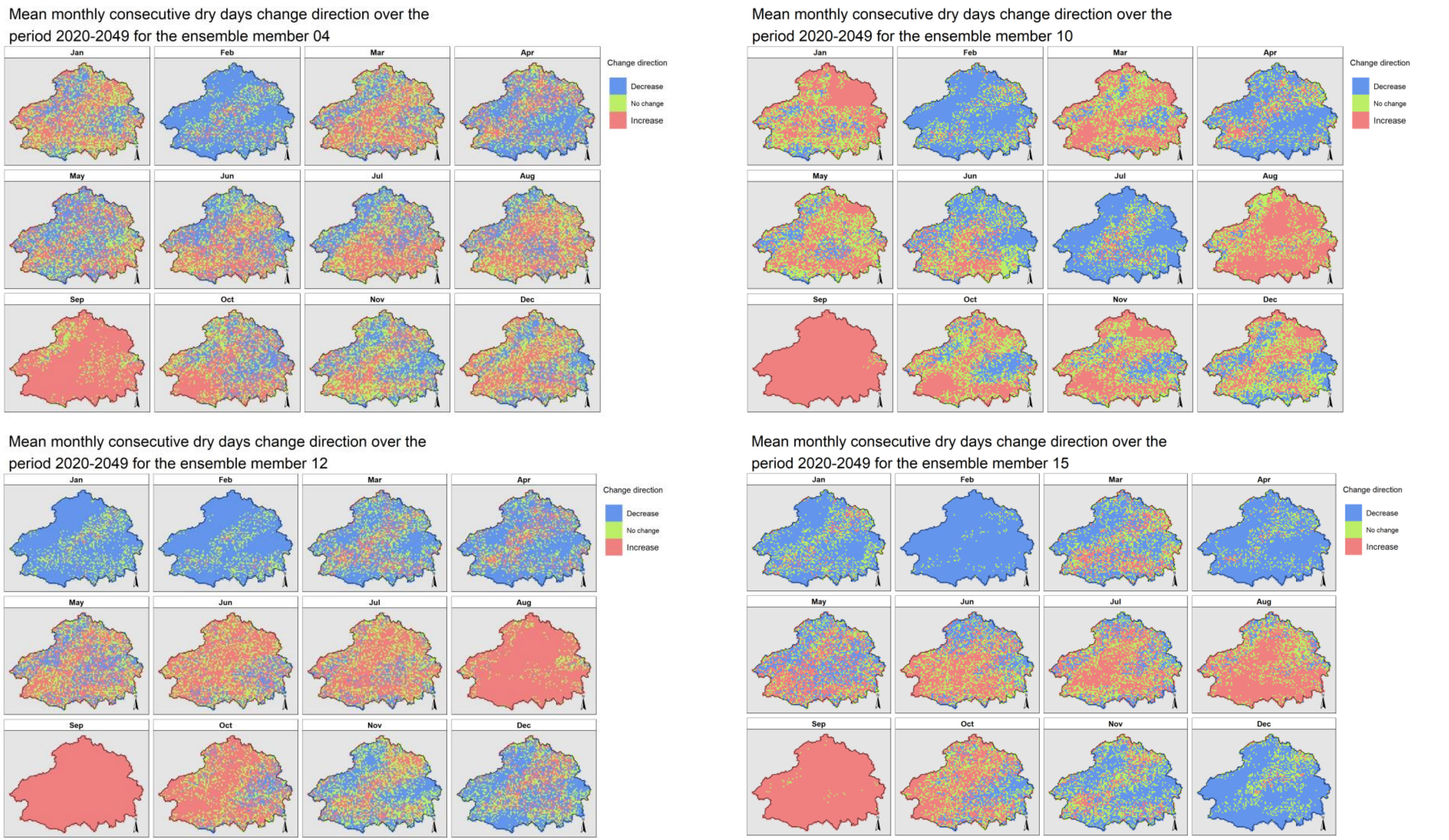


Figure 29. Projected change in direction of the mean monthly number of Consecutive Dry Days for the future period 2020-2049 from the 1960-189 baseline.

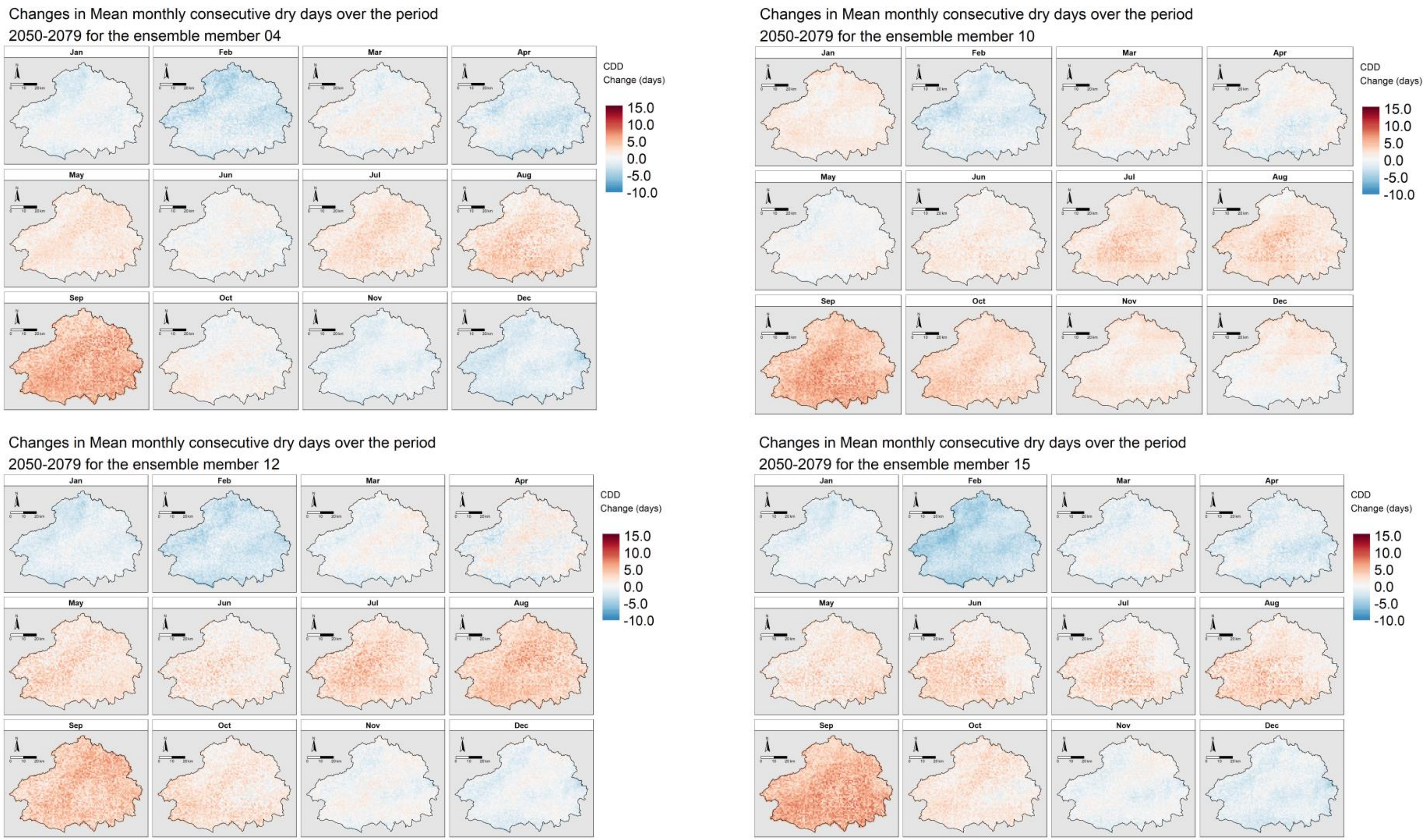


Figure 30. Projected change in the mean monthly number of Consecutive Dry Days for the future period 2050-2079.

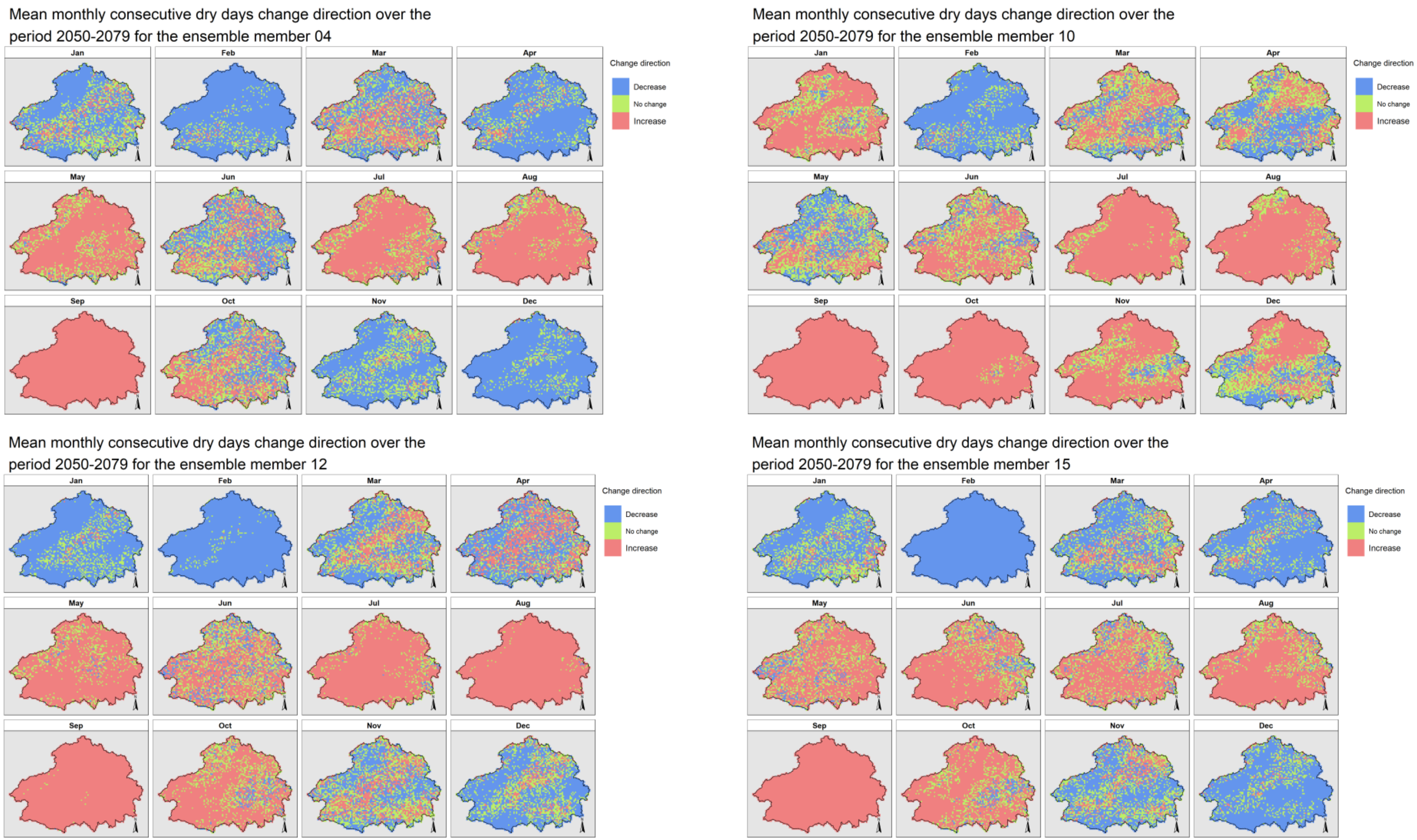


Figure 31. Projected change in direction of the mean monthly number of Consecutive Dry Days for the future period 2050-2079 from the 1960-189 baseline.

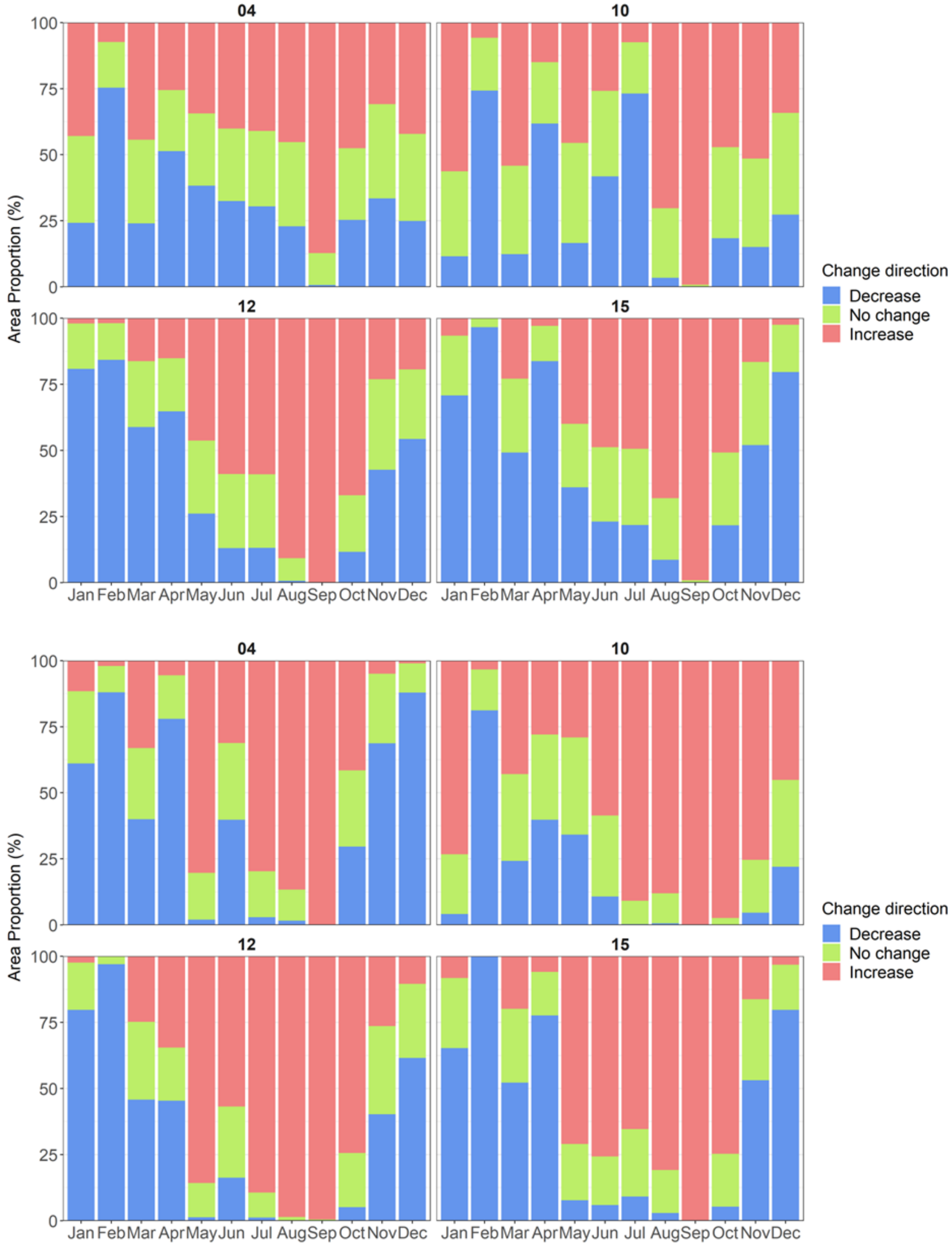


Figure 32. Cairngorms National Park land area proportion (%) for the mean monthly number of Consecutive Dry Days for the future periods 2020-2049 and 2050-2079 from the 1960-189 baseline.

Number of Dry Days

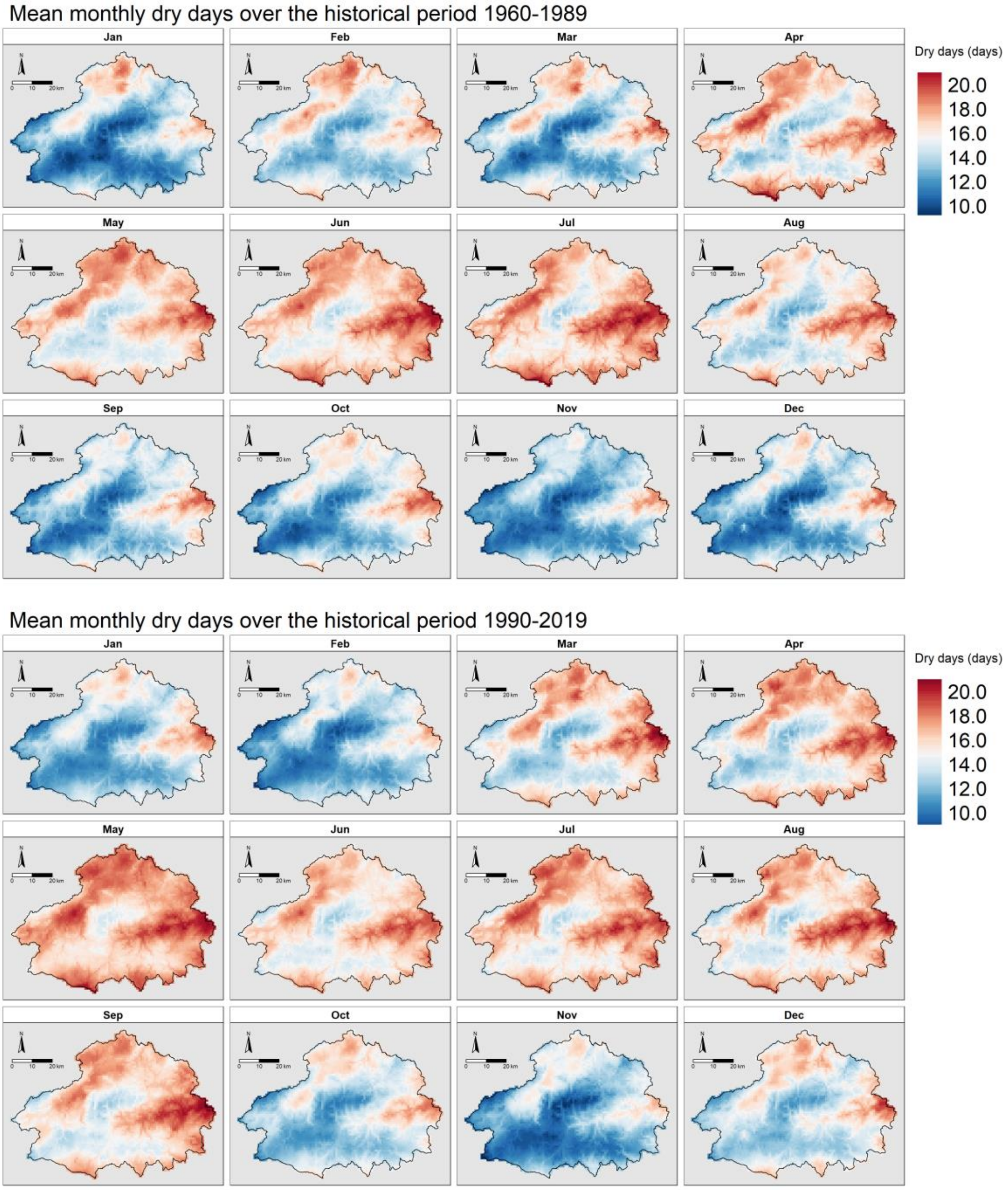


Figure 33. Observed mean monthly number of Dry Days for the periods 1960-1989 (top) and 1990-2019 (bottom)

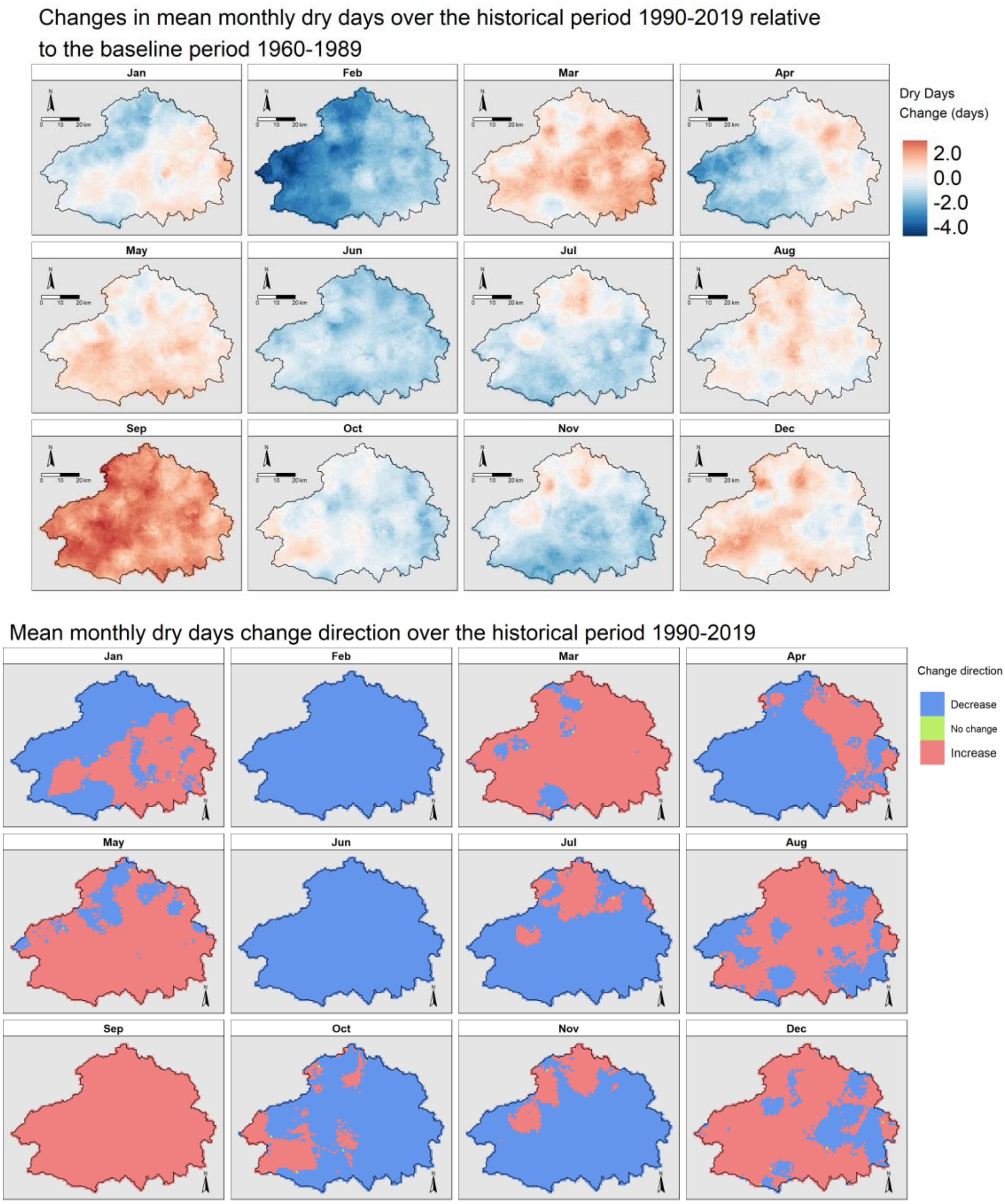


Figure 34. Change in the mean monthly number of Dry Days between the periods 1960-1989 (baseline) and 1990-2019 (top) and the change direction from the baseline to 1990-2019 (bottom)

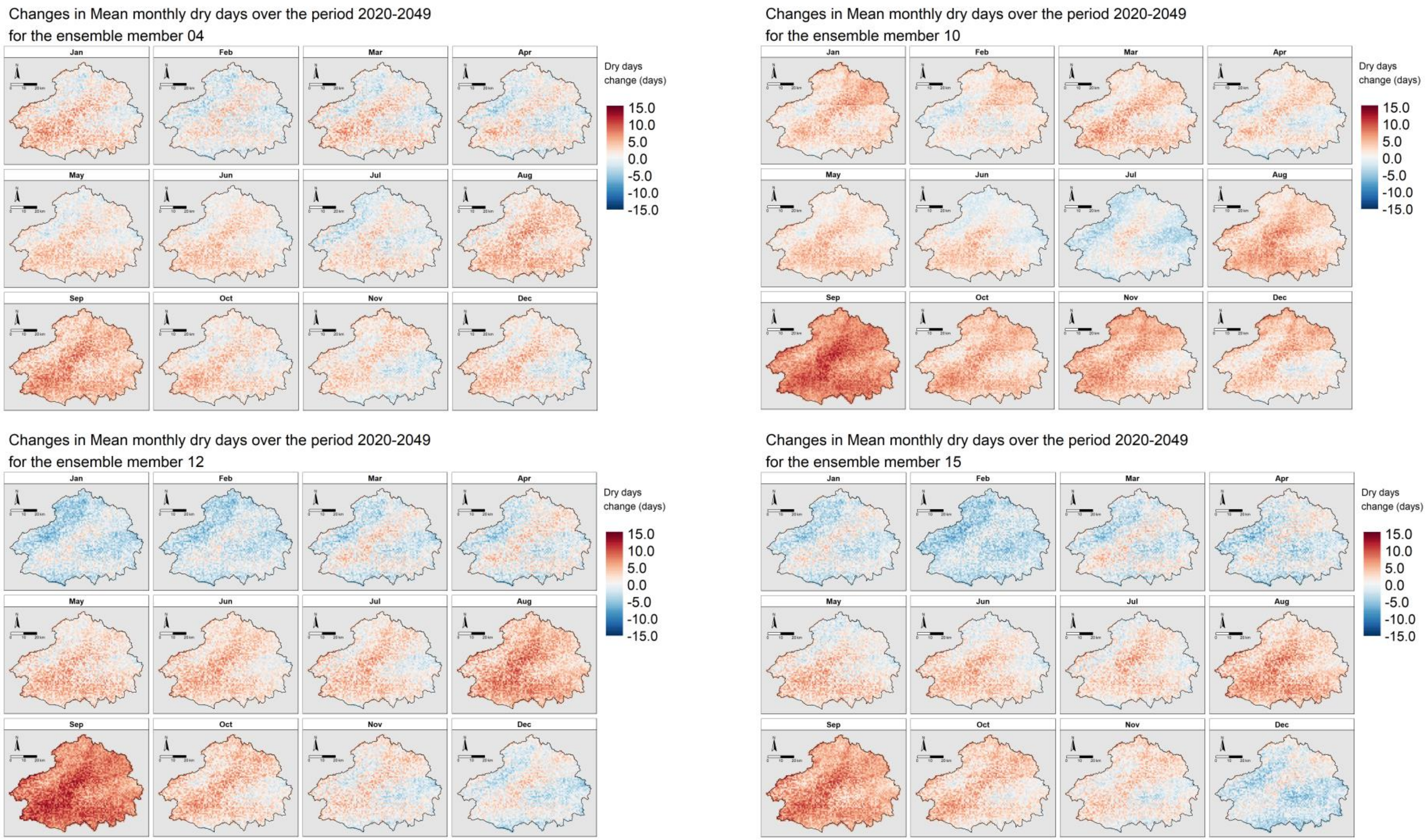


Figure 35. Projected change in the mean monthly number of Dry Days for the future period 2020-2049.

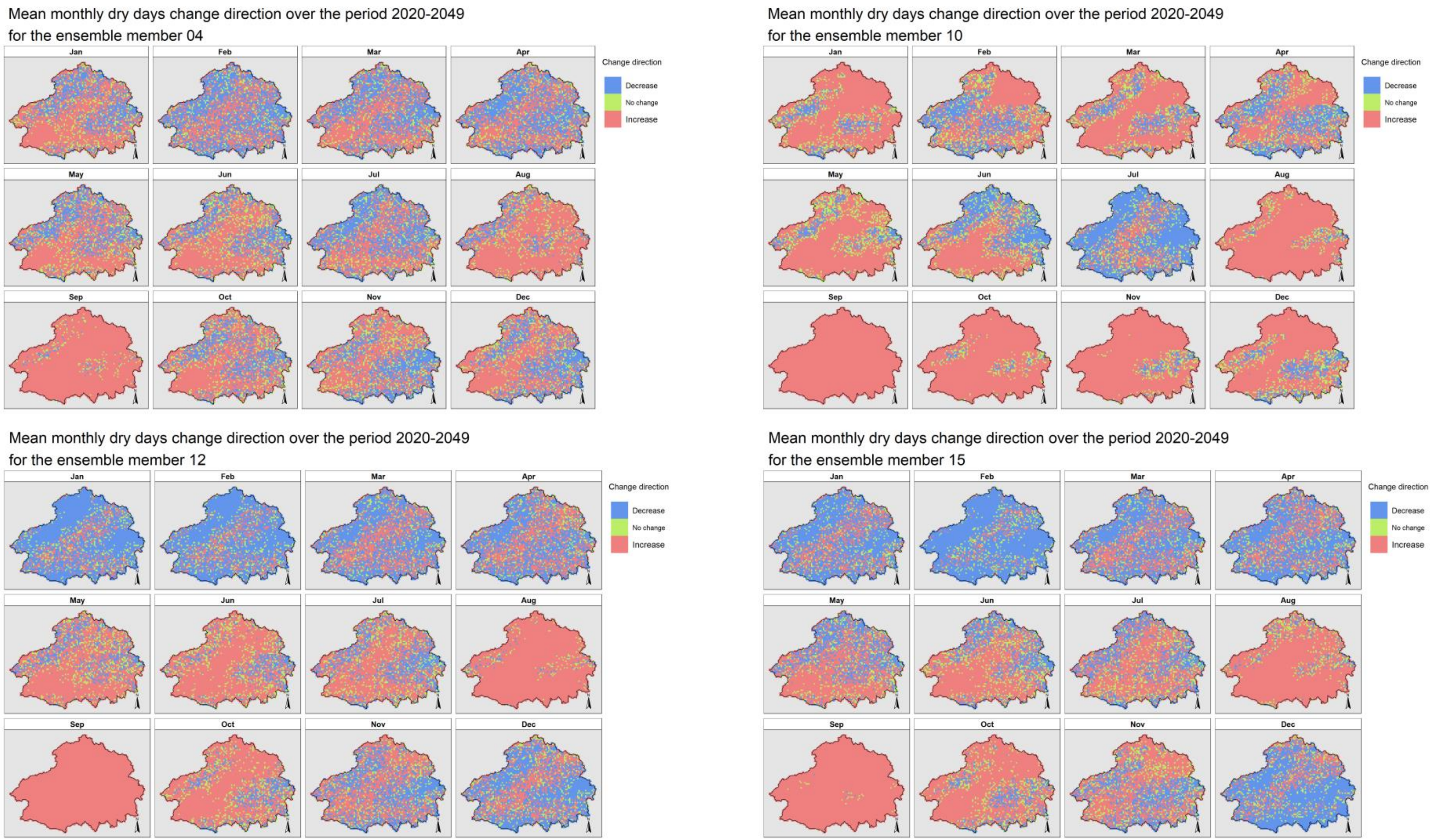


Figure 36. Projected change in direction of the mean monthly number of Dry Days for the future period 2020-2049 from the 1960-189 baseline.

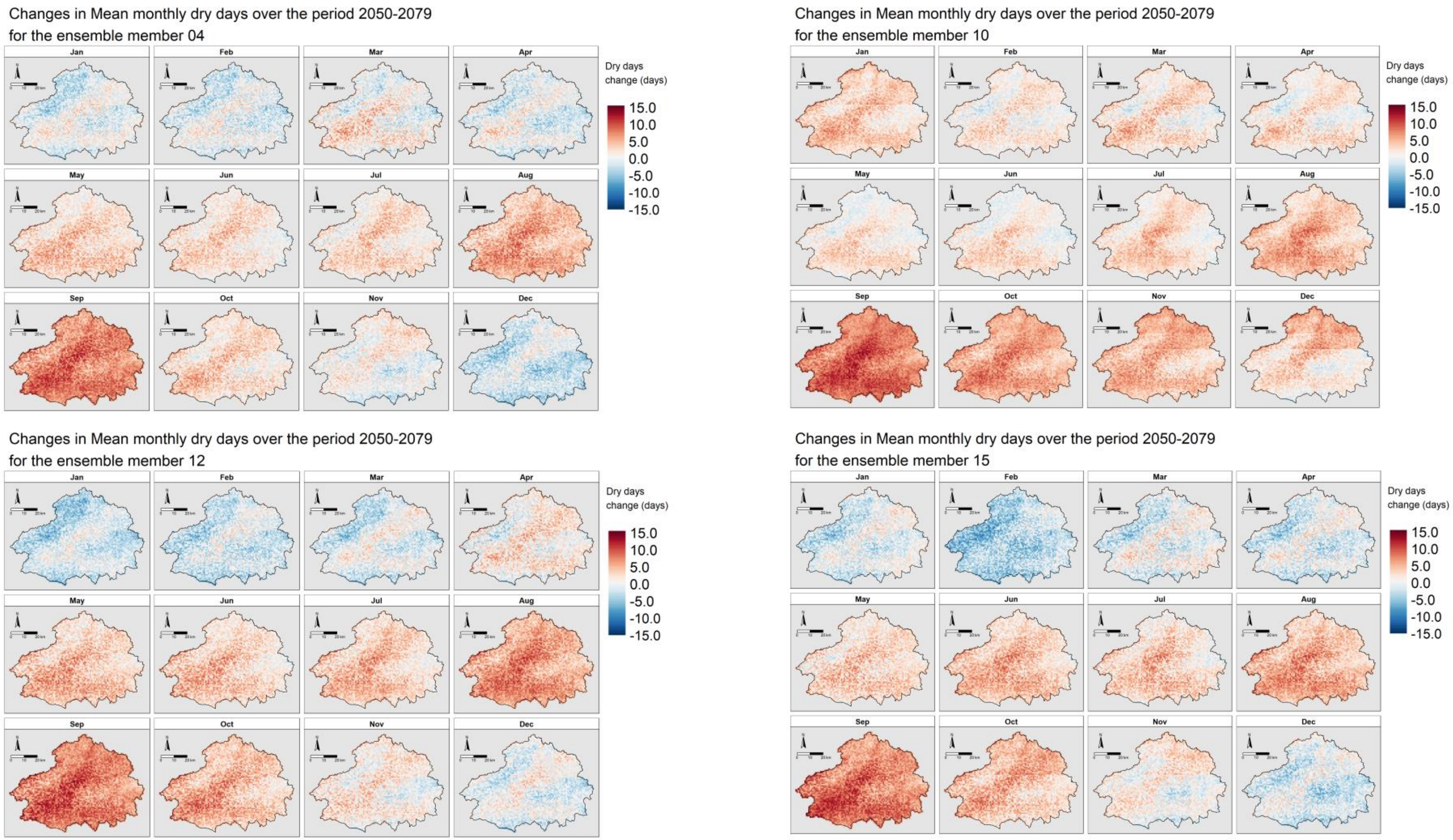


Figure 37. Projected change in the mean monthly number of Dry Days for the future period 2050-2079.

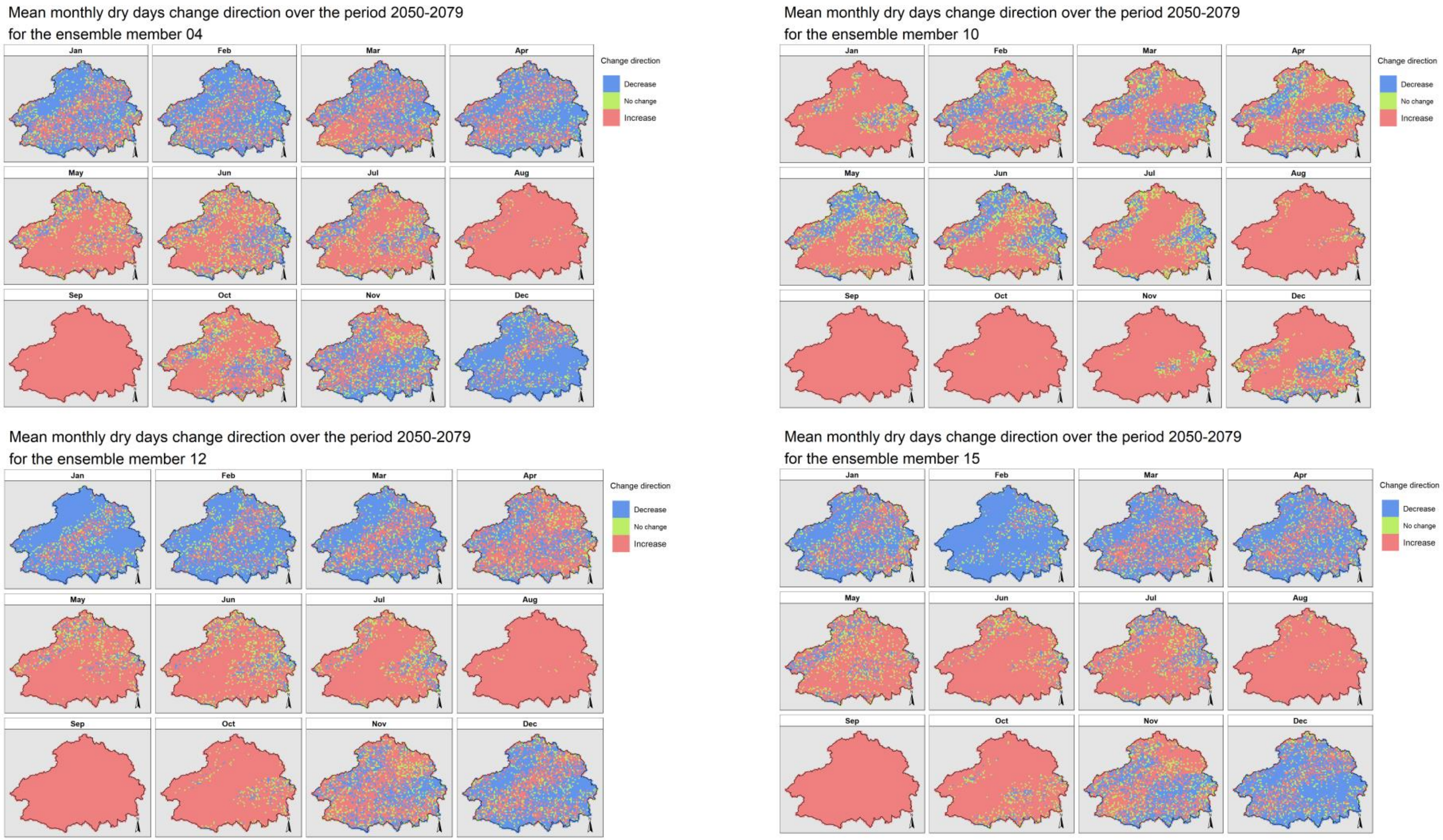


Figure 38. Projected change in direction of the mean monthly number of Dry Days for the future period 2050-2079 from the 1960-189 baseline.

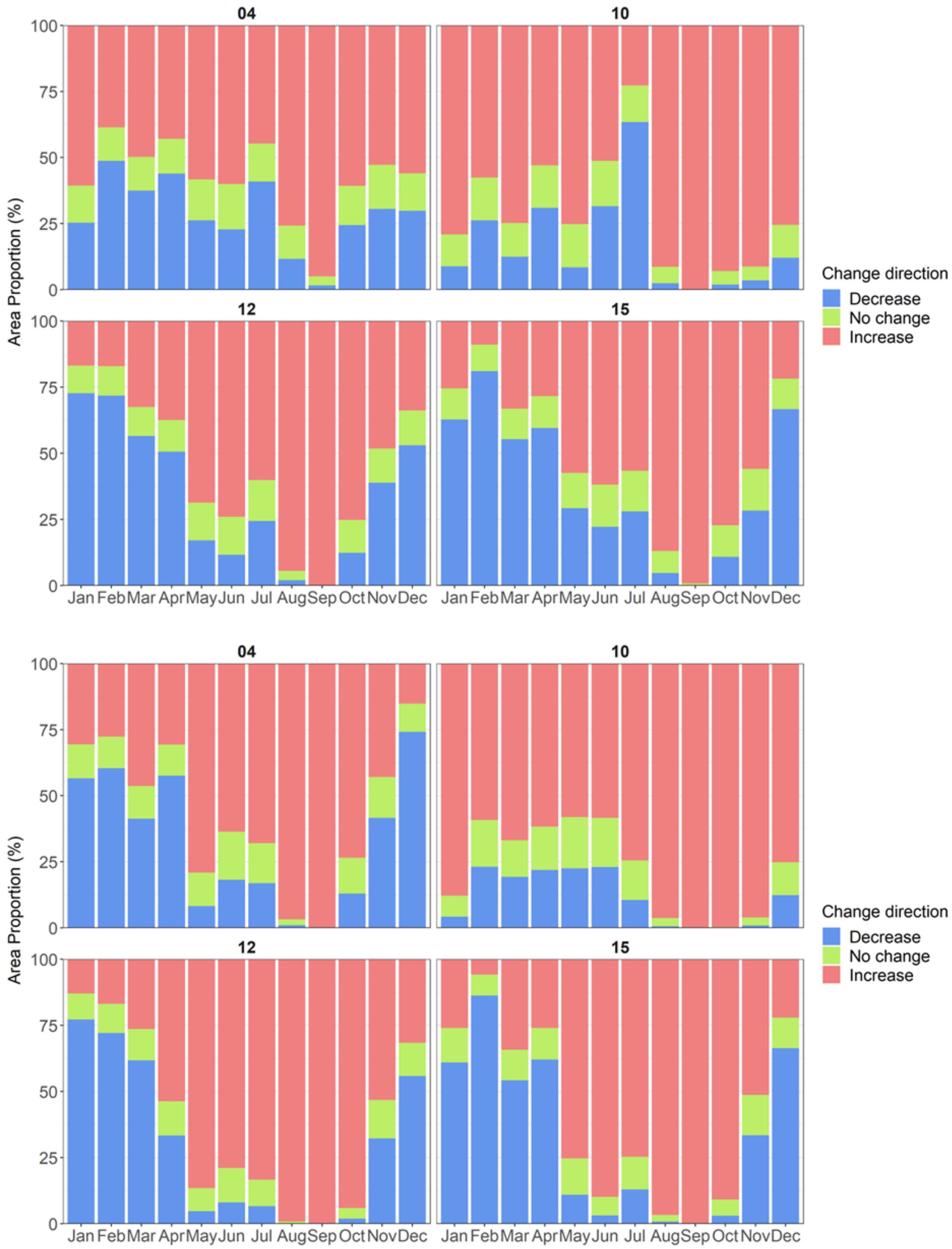
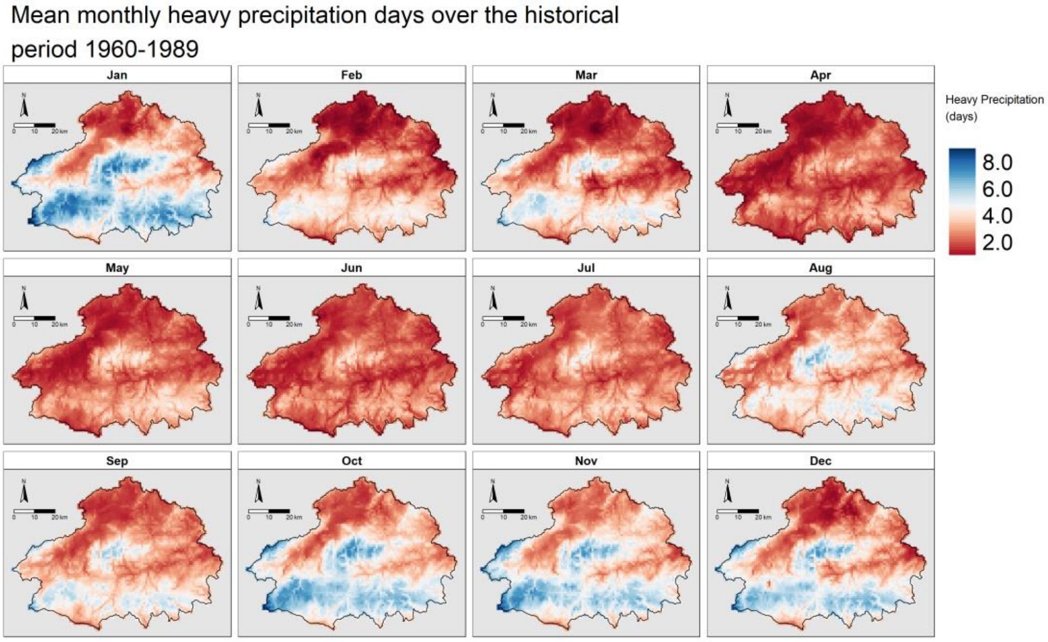


Figure 39. Cairngorms National Park land area proportion (%) for the mean monthly number of Dry Days for the future periods 2020-2049 and 2050-2079 from the 1960-189 baseline.

Heavy Precipitation Days



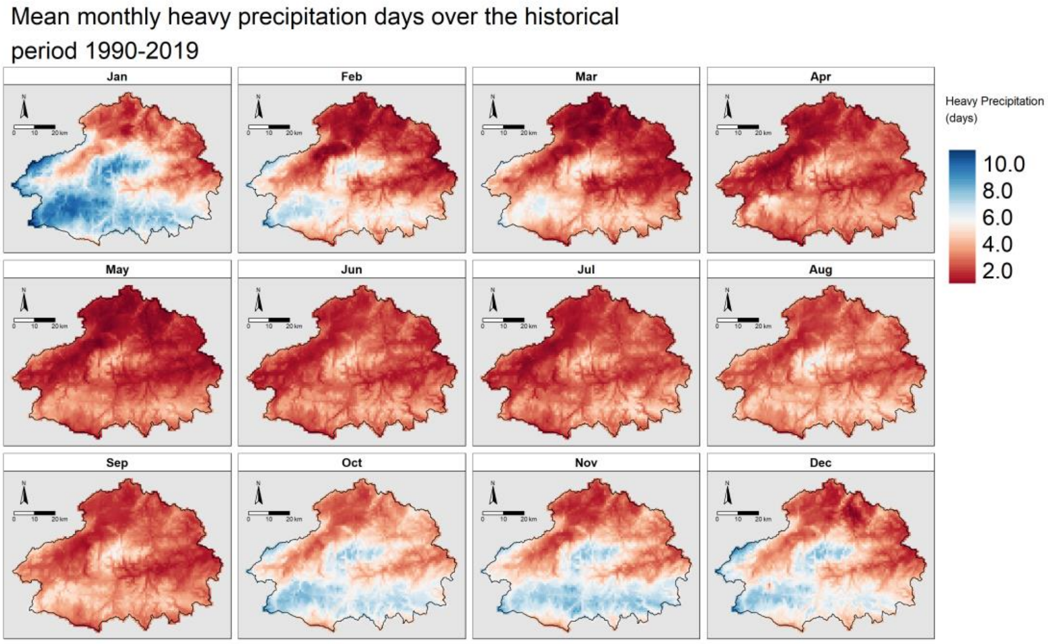


Figure 40. Observed mean monthly number of Heavy Rain Days for the periods 1960-1989 (top) and 1990-2019 (bottom). Note differences in scales means it is not possible to directly compare between periods.

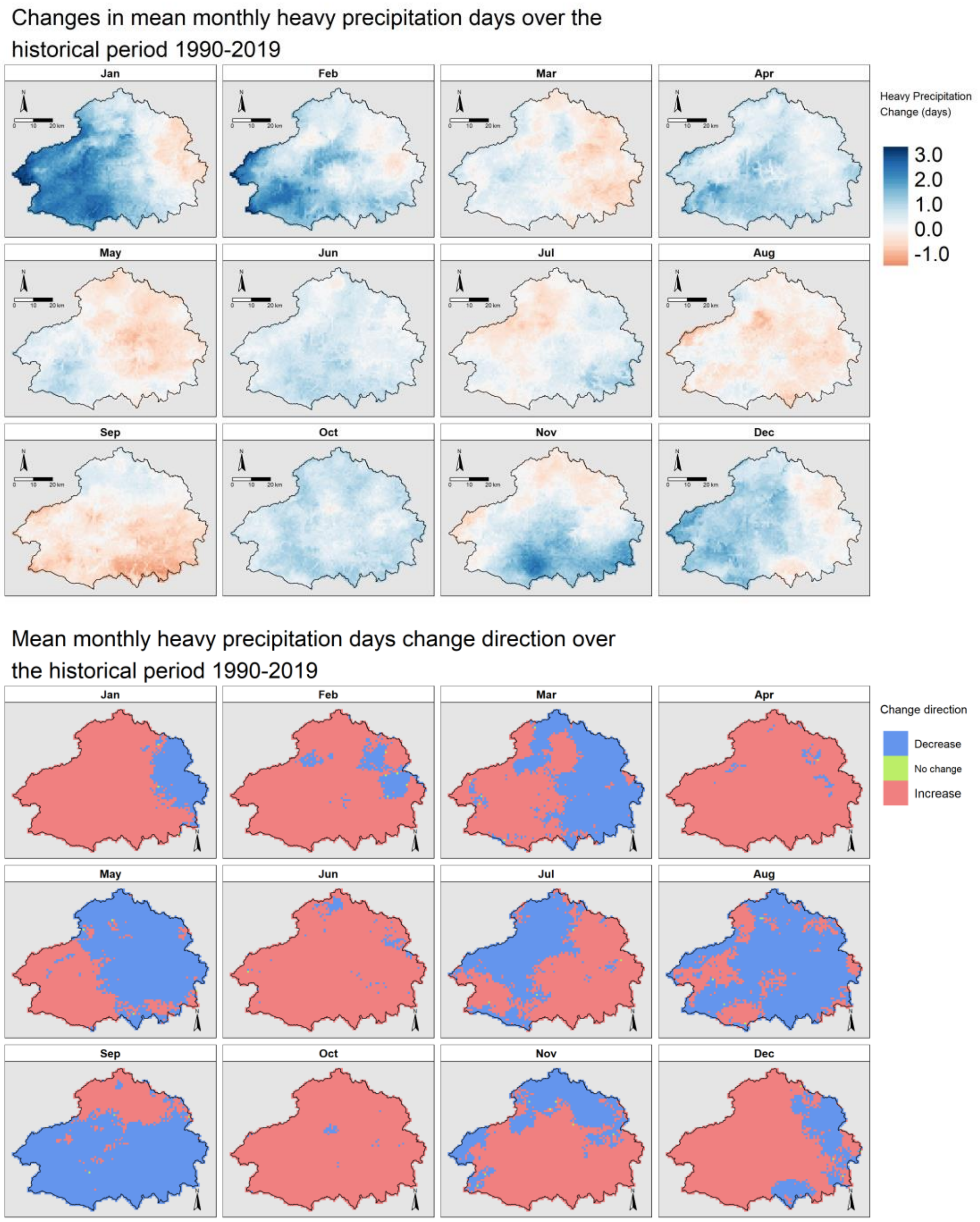


Figure 41. Change in the mean monthly number of Heavy Rain Days between the periods 1960-1989 (baseline) and 1990-2019 (top) and the change direction from the baseline to 1990-2019 (bottom)

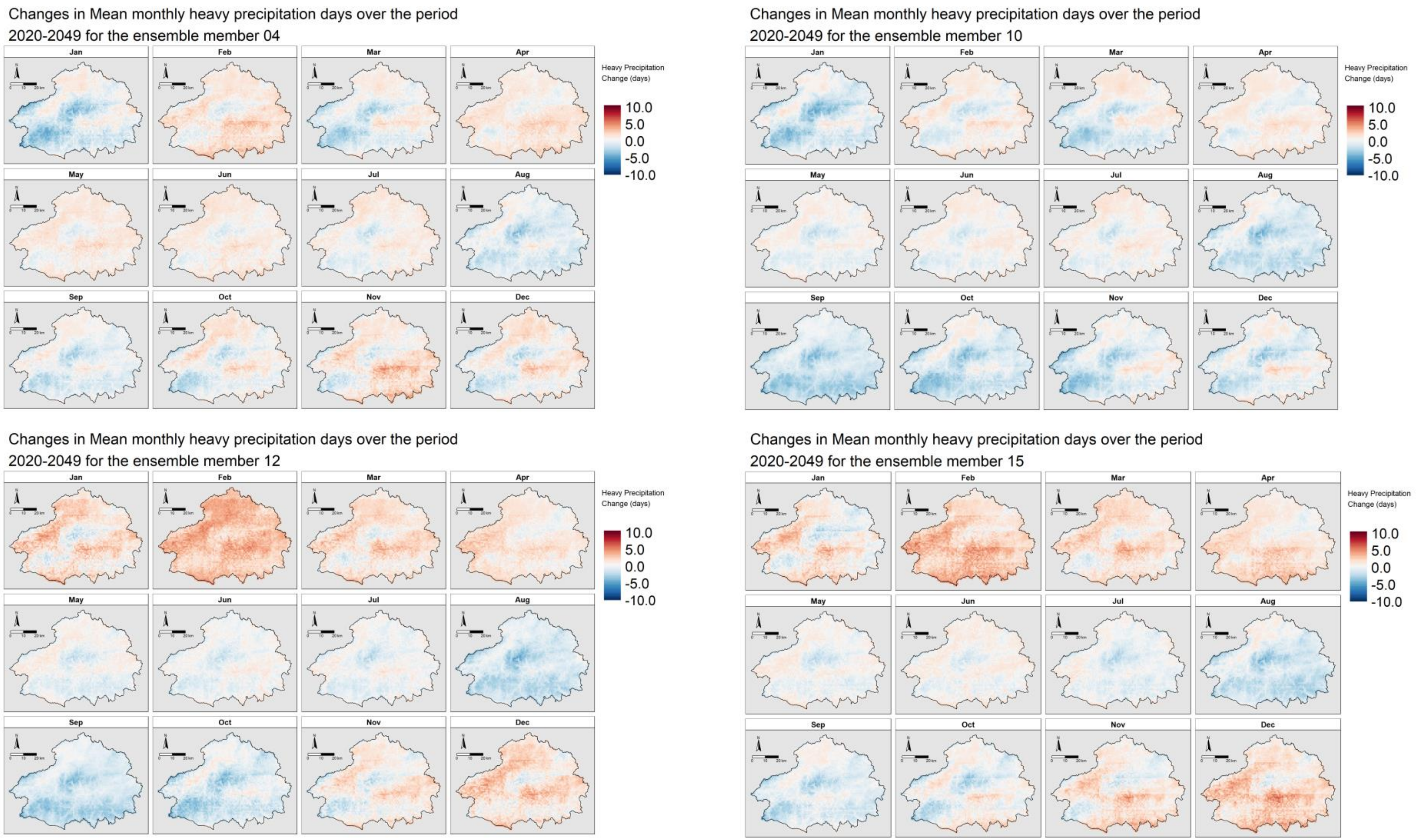


Figure 42. Projected change in the mean monthly number of Heavy Days for the future period 2020-2049.

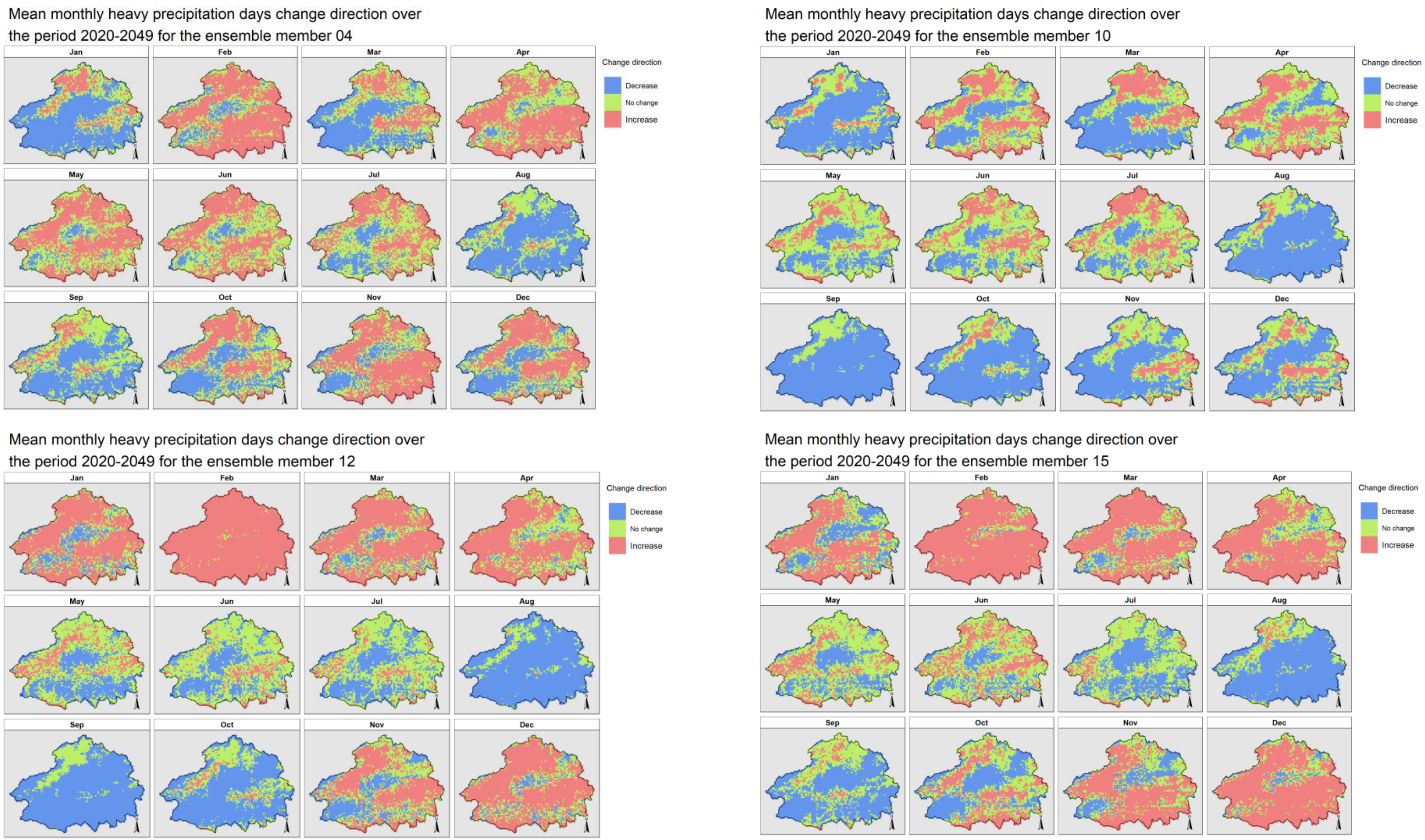


Figure 43. Projected change in direction of the mean monthly number of Heavy Rain Days for the future period 2020-2049 from the 1960-189 baseline.

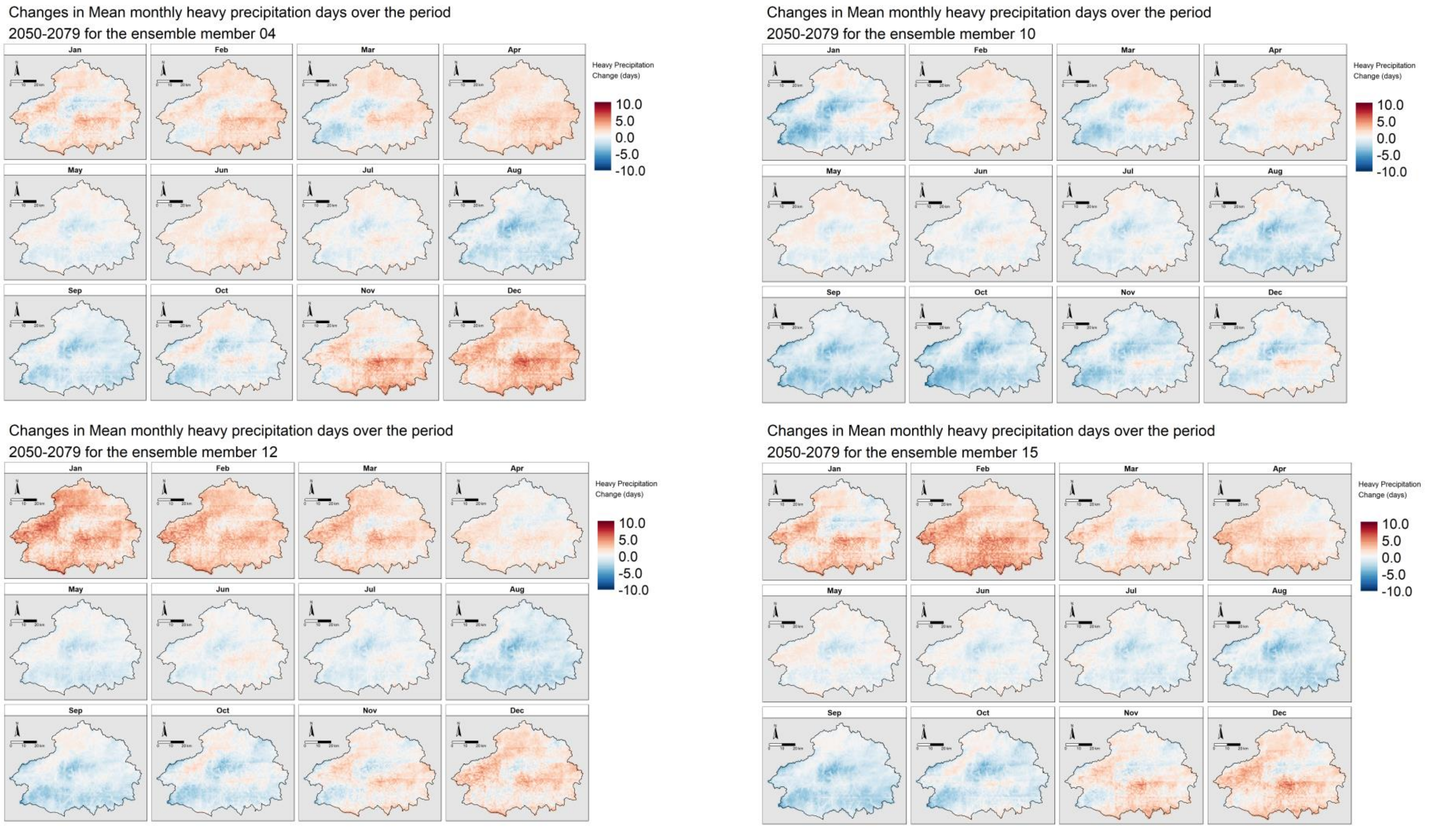


Figure 44. Projected change in the mean monthly number of Heavy Days for the future period 2050-2079.

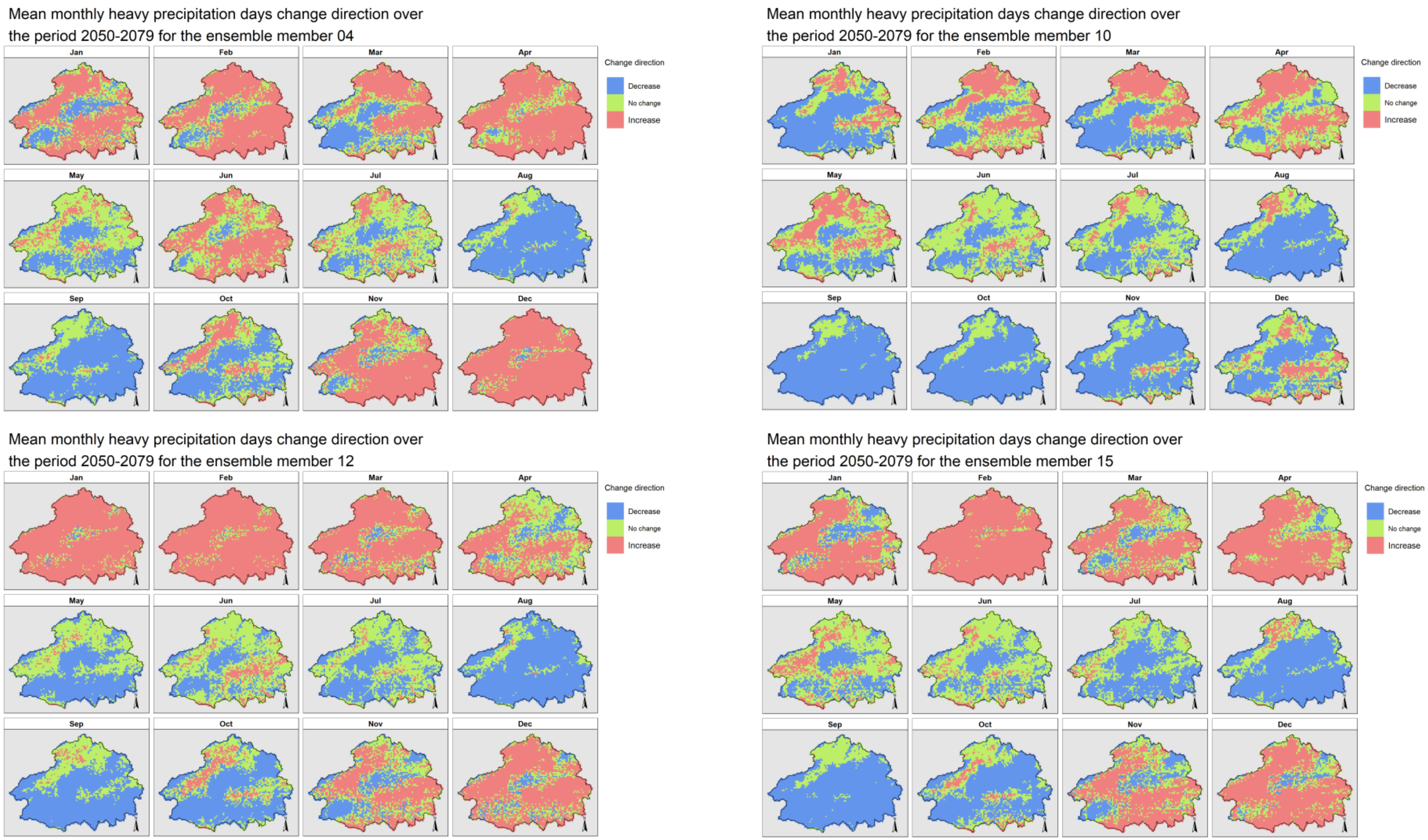


Figure 45. Projected change in direction of the mean monthly number of Heavy Rain Days for the future period 2050-2079 from the 1960-189 baseline.

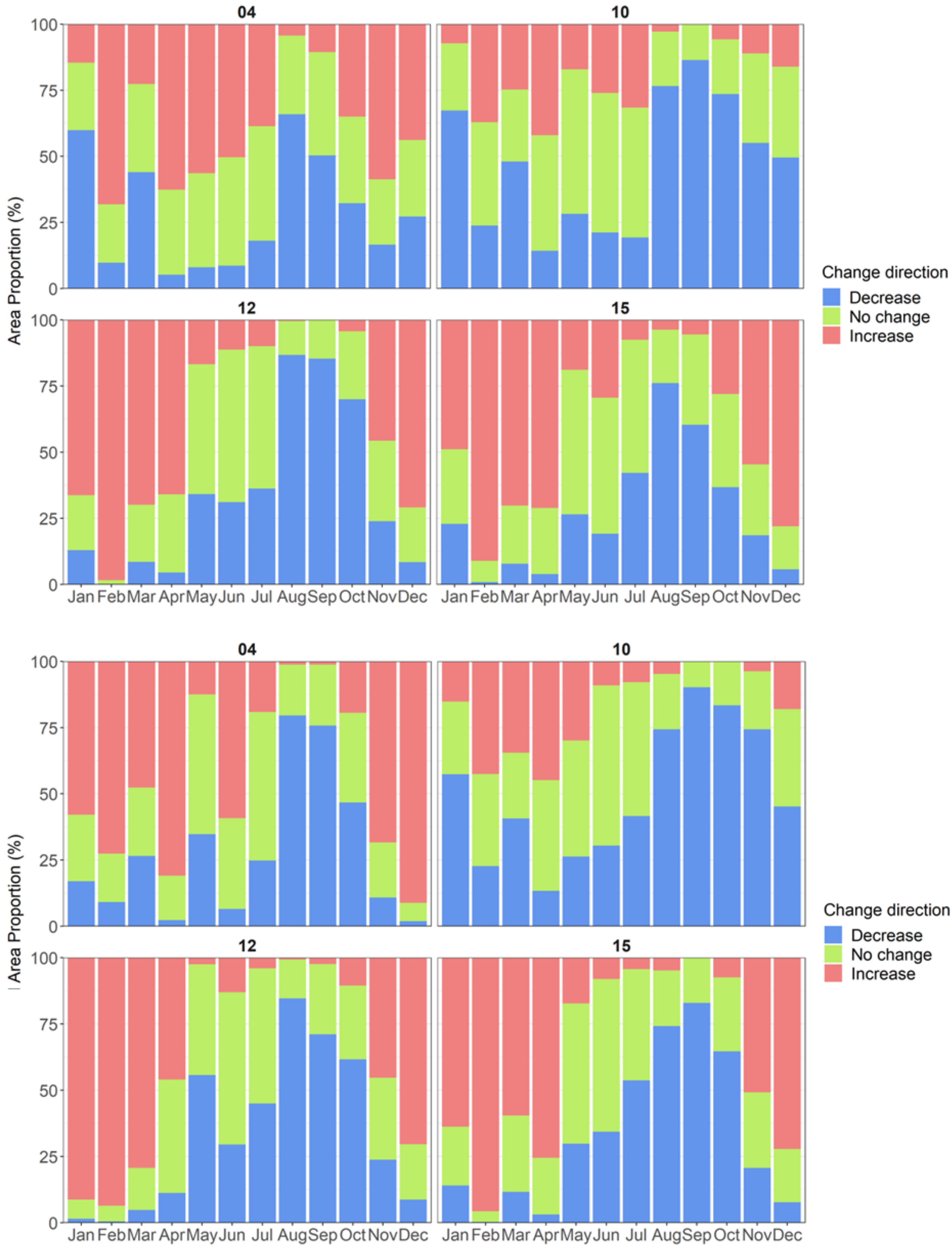


Figure 46. Cairngorms National Park land area proportion (%) for the mean monthly number of Dry Days for the future periods 2020-2049 and 2050-2079 from the 1960-189 baseline.

References

Rivington M, Jabloun M (2022) Climate Trends and Future Projections in Scotland. Deliverable D2.1a for the Project D5-2 Climate Change Impacts on Natural Capital. The James Hutton Institute, Aberdeen. Scotland. DOI: 10.5281/zenodo.7657945
https://zenodo.org/record/7657945#.Y_OwnSbP2Uk

Climate Trends and Future Projections in Scotland

Rivington M, Jabloun M, Gimona A, Martino S, Aitkenhead M, Glendell M, Gagkas Z (2022) Climate Extremes in Scotland. Deliverable D2.1b for the Project D5-2 Climate Change Impacts on Natural Capital. The James Hutton Institute, Aberdeen. Scotland. DOI: 10.5281/zenodo.7699842

Climate Extremes in Scotland

The James Hutton Institute