South Eastern Australian
Climate Initiative

Projected changes in climate and runoff for south-eastern Australia under 1 °C and 2 °C of global warming

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Citation

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Address and contact details:

CSIRO Water for a Healthy Country Flagship

Ph (+61 2) 62465617

Email: seaci@csiro.au

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report presents projected changes in climate and runoff for 1 °C and 2°C of global warming produced as an output of Phase 2 of the South Eastern Australian Climate Initiative (SEACI). It is an update of the information presented in Post et al. (2008). 1 °C of global warming corresponds to the change expected by ~2030 under the A1B emission scenario, while 2 °C of global warming corresponds to ~2070 under the same scenario. As the projections are based on degrees of global warming rather than a specific date, they can be considered to potentially occur earlier under higher emission scenarios and global warming, and later under lower levels.

Daily rainfall and areal potential evapotranspiration (APET) data from 1895–2008 were used for the modelling. The projections were derived from 15 global climate models (GCMs).

The SEACI study region comprises much of south-eastern Australia, but excludes those parts of NSW that are not part of the Murray-Darling Basin (the coastal regions and far north-west). While those areas are not included in the statistics presented in this report, data for all of the catchments across south-eastern Australia (including those outside the SEACI study area) are provided later in this report and are available for download from www.seaci.org.

The mean annual rainfall and runoff, averaged over 1895 to 2008 over south eastern Australia (all statistics are derived over the SEACI study region), are 489 mm and 37 mm respectively. There is a clear east-west rainfall gradient across the region, where rainfall is highest in the southeast (mean annual rainfall of more than 1200 mm) and along the eastern perimeter (800-1000 mm) and lowest in the west (less than 300 mm). The runoff gradient is much more pronounced than the rainfall gradient, with runoff in the southeast corner (mean annual runoff of more than 200 mm) and eastern perimeter (60 to 100 mm) being much higher than elsewhere in the region (less than 10 mm in the western half). In the northern part of the region, most of the rainfall and runoff occurs in the warm season while in the southern part most of the rainfall and runoff occurs in the cool season.

The future climate series for 1 °C and 2°C of global warming were obtained by scaling the historical 1895–2008 daily rainfall and areal PET data using the daily scaling method. This future climate series was then used to drive the SIMHYD rainfall-runoff model (using the parameter values derived by modelling the historical climate) to estimate the future runoff.

There is considerable uncertainty in projected response of rainfall to global warming. However, the majority of GCMs show a decrease in the mean annual rainfall. Most of the GCMs indicate that future winter rainfall is likely to be lower across the entire region. Most of the rainfall and runoff in the southern half of the region occurs in the winter half of the year, and almost all the GCMs indicate less future winter rainfall there.

Projections indicate that future mean annual rainfall under 1 °C of global warming will be lower across the southern half of the region. Averaged across the area south of 33° S, rainfall is projected to decline by between 0 and 9 percent, with a median reduction of 4 percent. This reduction in rainfall would lead to a reduction in areally-averaged runoff of between 2 and 22 percent, with a median estimated reduction of 12 percent.

Across the northern half of the region, projections are less certain, although most GCMs still project a reduction in mean annual rainfall and therefore runoff. Averaged across the area north of 33° S, rainfall is projected to change by between an increase of 4 percent and a decrease of 11 percent, with a median reduction of 3 percent. This change in rainfall would lead to a change in runoff of between an increase of 12 percent and a decrease of 29 percent, with a median estimated reduction of 10 percent.

1. METHODS

1.1 Climate scenarios

The climate data and their derivation for the hydrologic scenario modelling across south-eastern Australia are described in detail in Chiew et al. (2009). A brief summary is given here.

The historical climate (1895-2008) is the baseline against which the future climate is compared. The source of the historical climate data is the 'SILO Data Drill' of the Queensland Department of Natural Resources and Water (www.nrw.qld.gov.au/silo; and Jeffrey et al., 2001). The SILO Data Drill provides surfaces of daily rainfall and other climate data for 0.05^{o} grids across Australia, interpolated from point measurements made by the Australian Bureau of Meteorology. Areal potential evapotranspiration data are calculated from the SILO climate surface using Morton's wet environment evapotranspiration algorithms (Morton, 1983; and Chiew and Leahy, 2003).

Fifteen future climate series, each with 114 years of daily climate sequences were used to derive the projected changes in climate for 1 °C and 2 °C of global warming. These climate series were developed by scaling the 1895 to 2008 climate data to reflect the projected future climate, based on the analyses of 15 global climate models (GCMs) and the IPCC SRES A1B global warming scenario (see IPCC, 2007; and CSIRO and Australian Bureau of Meteorology, 2007). The SRES A1B scenario indicates a global temperature that is 1 °C higher in 2030 and 2 °C higher in 2070 (compared to the global average temperature in 1990). The SRES A1B scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies with a balance across all energy sources (IPCC, 2007). There is little difference in global warming between the different emissions scenarios by 2030 although they do diverge somewhat by 2070. The list of 15 GCMs used and their characteristics are shown in Table 1.

As the future climate series (A1B scenario) is obtained by scaling the historical daily climate series from 1895 to 2008, the daily climate series for the historical and future climate have the same length of data (114 years) and the same sequence of daily climate. The future climate scenario is therefore not a forecast climate at 2030 or 2070, but a 114-year daily climate series based on 1895 to 2008 data for projected global temperatures which are 1 °C and 2°C higher.

The method used to obtain the future climate series takes into account different changes in each of the four seasons as well as changes in the daily rainfall distribution. The consideration of changes in the daily rainfall distribution is important because many GCMs indicate that future extreme rainfall is likely to be more intense, even in some regions where projections indicate a decrease in mean seasonal or annual rainfall. As the high rainfall events generate large volumes of runoff, the use of traditional methods that assume the entire rainfall distribution to change in the same way would lead to an underestimation of the magnitude of extreme runoff events as well as (to a lesser extent) mean annual runoff.

Table 1. List of 15 global climate models used in the current study

Global climate model	Details, modelling group, country	Horizontal resolution (°)
CCCMA_T47	Canadian Climate Centre, Canada	~3.7
CCCMA_T63	Canadian Climate Centre, Canada	~2.8
CNRM	Meteo-France, France	~2.8
CSIRO	Mk 3.0, CSIRO, Australia	~1.9
GFDL	V 2.0, Geophysical Fluid, Dynamics Lab, USA	~2.0
GISS_AOM	NASA/Goddard Institute for Space Studies, USA	~3.0
IAP	LASG/Institute of Atmospheric Physics, China	~2.8
INMCM	Institute of Numerical Mathematics, Russia	~4.0
IPSL	Institute Pierre Simon Laplace, France	~2.5
MIROC	Med Res, Centre for Climate Research, Japan	~2.8
MIUB	Meteorological Institute of the University of Bonn, Germany Meteorological Research Institute of KMA, Korea	~3.7
MPI	Max Planck Institute for Meteorology DKRZ, Germany	~1.9
MRI	Meteorological Research Institute, Japan	~2.8
NCAR_CCSM	National Center for Atmospheric Research, USA	~1.4
NCAR_PCM	National Center for Atmospheric Research, USA	~2.8

1.2 Rainfall-runoff modelling

The rainfall-runoff modelling method adopted provides a consistent way of modelling historical runoff across south-eastern Australia, as well as assessing the potential impacts of climate change on future runoff.

The lumped conceptual rainfall-runoff model, SIMHYD with a Muskingum routing method, is used to estimate daily runoff for 0.05^o grids (~ 5 km x 5 km) across the whole of south-eastern Australia for both current conditions and future climate. The use of 0.05^o grids allows a good representation of the spatial patterns and gradients in rainfall. The rainfall-runoff model is calibrated against 1975 to 2006 streamflow data from 219 small and medium size unregulated gauged catchments (50 km^2 to 2000 km^2) across the region (referred to hereafter as calibration catchments, see Figure 1 for their location). Although unregulated, streamflow in these catchments may reflect low levels of water diversion and will include the effects of historical land use change. The calibration period is a compromise between a shorter period that would better represent current development and a longer period that would better account for climatic variability.

Figure 1 also shows the SEACI study region. It comprises much of south-eastern Australia, but excludes those parts of NSW that are not part of the Murray-Darling Basin (the coastal regions and far north-west). While those areas are not included on the maps presented in this report, data for all of the catchments across south-eastern Australia (including those outside the SEACI study area) are shown in Table 2 and Table 3, and are available for download from www.seaci.org. These catchments are shown in Figure 28.

In the model calibration, the six parameters of SIMHYD are optimised to maximise an objective function that incorporates the Nash-Sutcliffe efficiency of daily runoff together with a constraint to ensure that the total modelled runoff over the calibration period is within 5 percent of the total recorded runoff. The resulting optimised parameter values are therefore identical for all grid cells within a calibration catchment.

The runoff for grid cells that are not within a calibration catchment is modelled using optimised parameter values from the geographically closest grid cell which lies within a calibration catchment. As the parameter values come from calibration against streamflow from 50 to 2000 km^2 catchments, the runoff defined here is different to, and can be much higher than streamflow recorded over very large catchments where there can be significant transmission losses (particularly in the western and north-western parts of the Murray-Darling Basin). Almost all the catchments available for model calibration are in the higher runoff areas in the southern and eastern parts of south-eastern Australia. Runoff estimates are therefore generally good in the southern and eastern parts of the region and are comparatively poorer elsewhere.

The same set of parameter values are used to model runoff across south-eastern Australia for both the historical climate and future climate scenarios using 114 years of daily climate inputs as described above. The future climate scenario simulation therefore does not take into account the effect on forest water use of global warming and enhanced CO_2 concentrations. This effect can be significant, but it is difficult to estimate the net effect because of the compensating positive and negative impact and the complex climate-biosphere-atmosphere interactions and feedbacks. However, Vaze et al. (2010) have shown that this assumption is reasonable, at least for changes in rainfall of up to around 15 percent and in the timeframe considered here (within the 21st century). Beyond that time frame and for higher levels of global warming, these other effects may become important).

The SIMHYD rainfall-runoff model is used because it is simple and has relatively few parameters and provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire region and for assessing the potential impacts of climate change on future runoff. It is possible that in data-rich areas, specific calibration of SIMHYD or more complex rainfall-runoff models based on expert judgement and local knowledge would lead to better model calibration for the specific modelling objectives of the area. The SIMHYD model and the comparison of results with the Sacramento model is described in detail for the Murray-Darling Basin in Chiew et al. (2009). These results indicate that the simulations from the two rainfall-runoff models are relatively similar in the context of producing changes in runoff due to projected changes in rainfall and APET.

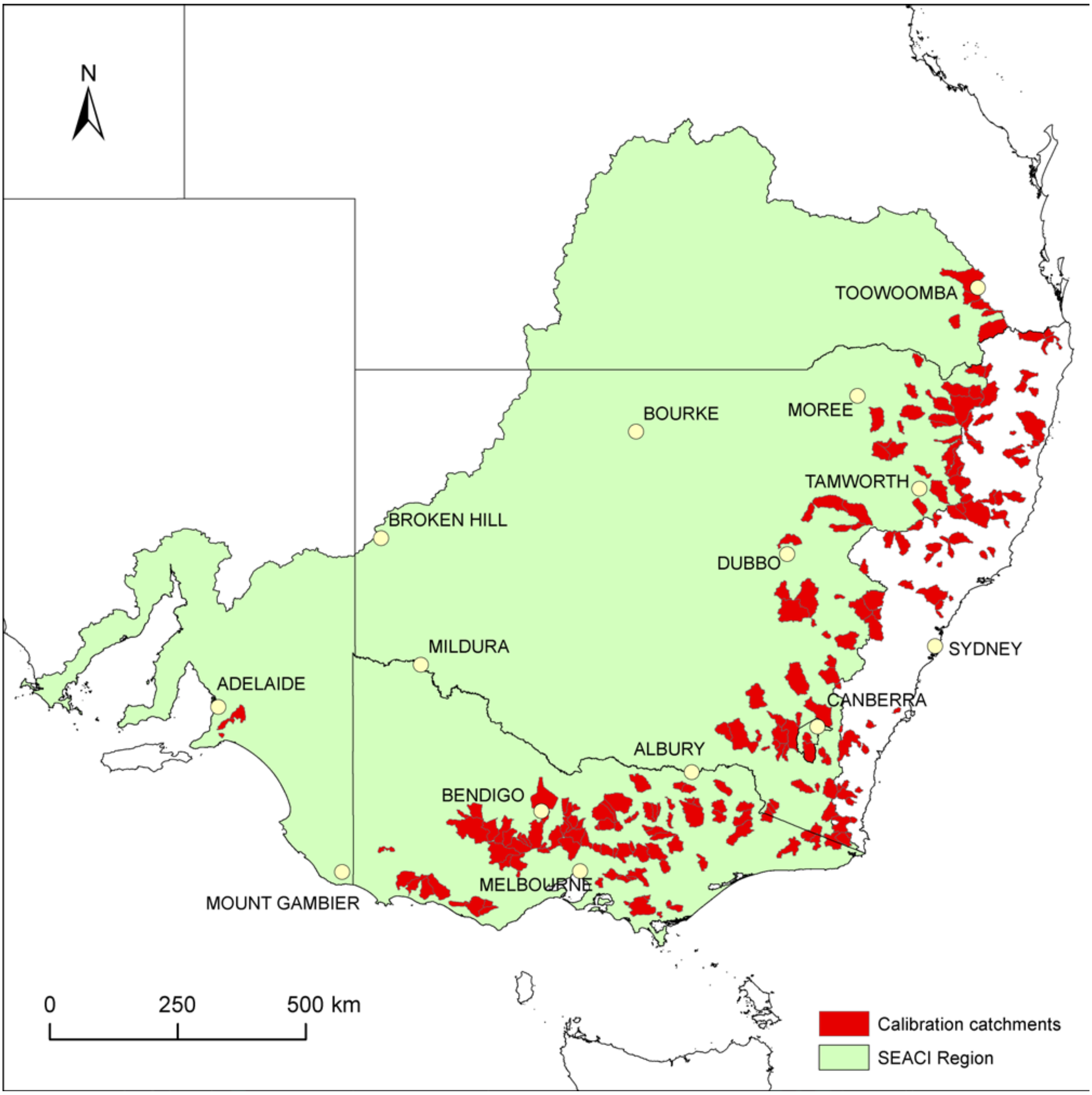

Figure 1. Map showing the SEACI study area, major towns, and calibration catchments in south-eastern Australia

2. RESULTS

2.1 Historical rainfall and runoff (1895-2008)

Figure 2, Figure 3, and Figure 4 show the mean annual and seasonal observed rainfall, potential evapotranspiration and modelled runoff respectively, averaged over the period 1895 to 2008. The mean annual rainfall and runoff averaged over the SEACI study area (as shown in all maps from here on) are 489 mm and 37 mm respectively. Potential evapotranspiration is generally greater than rainfall over most of the region (and the area is thus classified as water limited) with the exception of the far south east, particularly in winter, where some catchments can be energy limited.

There is a clear east-west rainfall gradient across the SEACI region, where rainfall is highest in the southeast (mean annual rainfall of more than 1200 mm) and along the eastern perimeter (800-1000 mm) and lowest in the west (less than 300 mm). The runoff gradient is much more pronounced than the rainfall gradient, with runoff in the southeast corner (mean annual runoff of more than 200 mm) and eastern perimeter (60 to 100 mm) being much higher than elsewhere in the SEACI region (less than 10 mm in the western half). In the north of the SEACI region, most of the rainfall occurs in the warm season, and in the south of the SEACI region, most of the rainfall and runoff occurs in the cool season. Because of the storage of water in soil moisture and snowpacks, runoff across the high-yielding catchments over the south-east peaks in winter and spring, although rainfall is highest in autumn, winter and spring.

Some artefacts of using the closest grid cell within a calibration catchment to produce the parameter values of grid cells in ungauged catchments can be seen as straight lines in the runoff plots in Figure 4. However these artefacts only affect the very driest parts of the region where runoff is less than 25 mm/year. Some care therefore needs to be given to the results in the very driest parts of the basin.

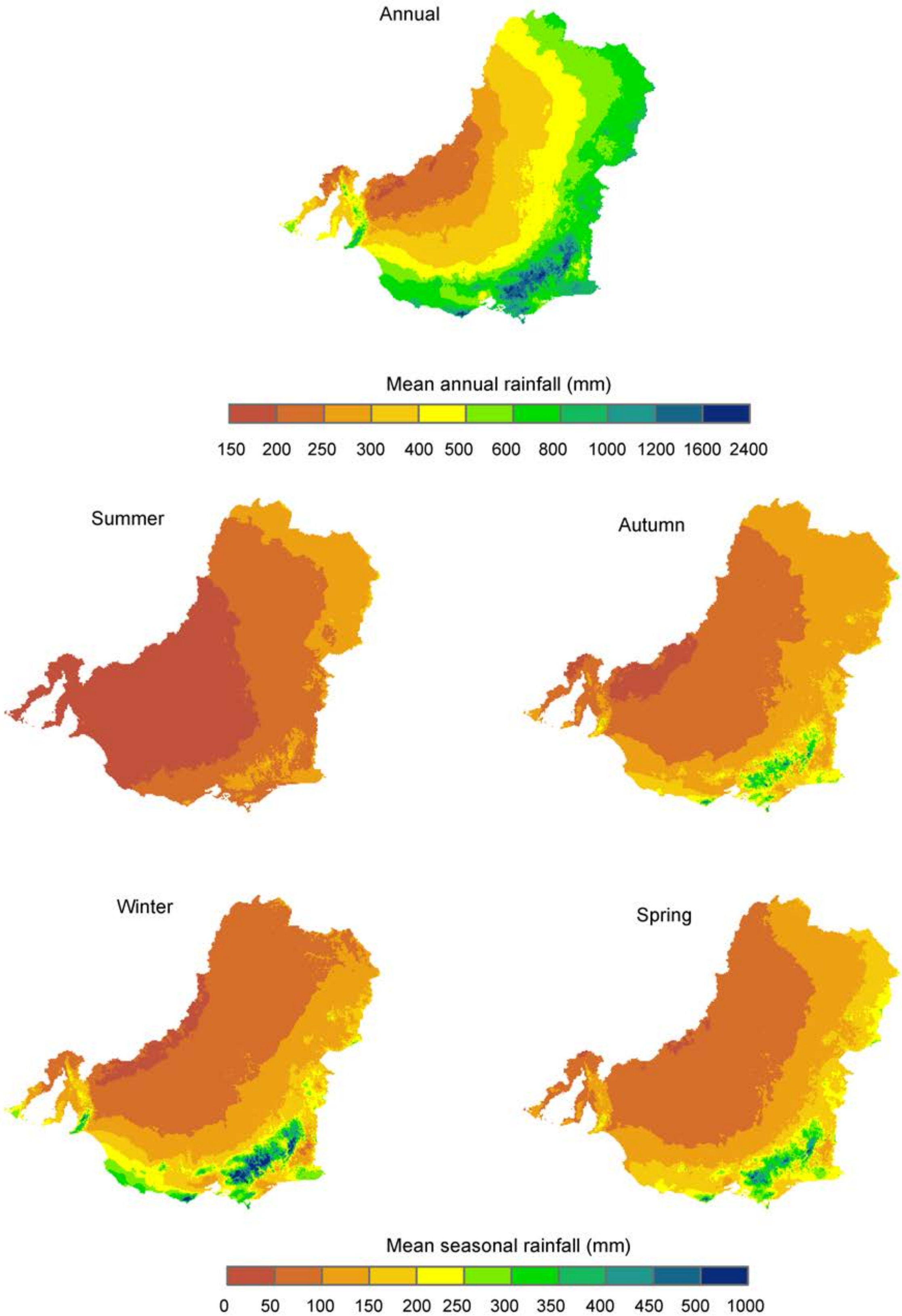

Figure 2. Historical mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall

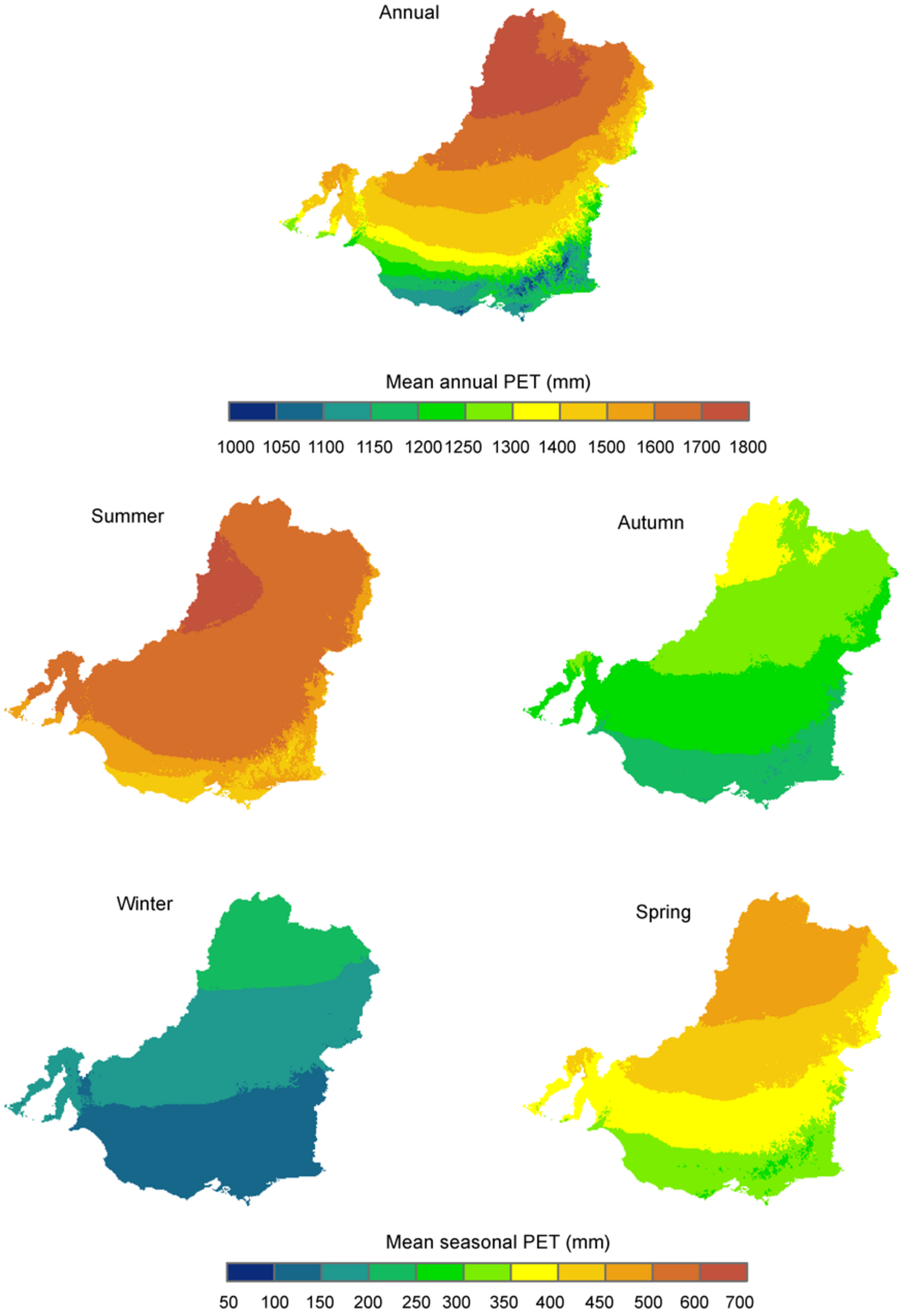

Figure 3. Historical mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) potential evapotranspiration (PET)

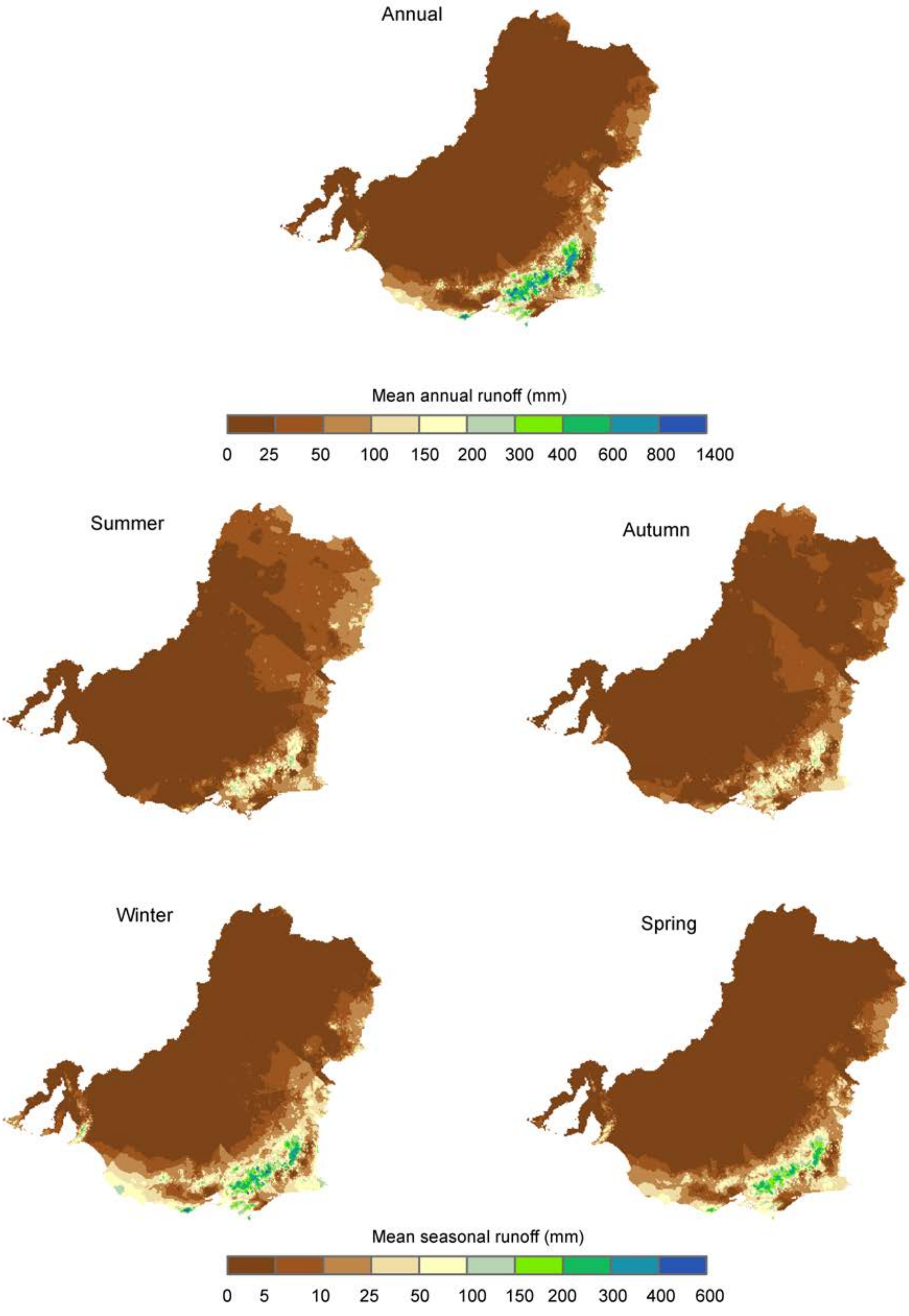

Figure 4. Historical mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff

2.2 Projections of climate and runoff for 1 °C and 2 °C of global warming

Figure 5 and Figure 6 show the percentage change in mean annual and seasonal rainfall for 1 °C and 2 °C of global warming respectively from the 15 GCMs (as shown in Table 1). It will be seen that, averaged across the region, there is a range of projected changes from the 15 GCMs, from a decline in rainfall as projected by the CSIRO model to an increase in rainfall as projected by the MIROC model. Because of the technique used, changes in rainfall for 2 °C of global warming are double those for 1 °C of global warming. The order of GCMs for this and subsequent figures is based on the projected change in mean annual rainfall for 1 °C of global warming from the 15 GCMs averaged across the region.

Figure 7 shows the number of GCMs that indicate a decrease (or increase) in mean annual and seasonal rainfall for 1 °C and 2 °C of global warming. Again, because of the technique used, the results are identical for 1 °C and 2 °C of global warming. It will be seen that although there is a range of projections from an increase in rainfall to a decrease in rainfall, the vast majority of GCMs project a decrease in annual and seasonal rainfall in most seasons (the exception is summer, where GCMs are roughly divided equally between an increase and a decrease in rainfall in the northern half of the region. This trend towards a decrease in rainfall is particularly evident across the southern half of the region where almost all GCMs project a decrease in rainfall, annually and in all four seasons. These results are reiterated at a catchment scale in Table 2 which shows that, for most southern catchments, a vast majority of GCMs project a decrease in mean annual rainfall.

Figure 8 shows that most GCMs project an increase in the 1st percentile of rainfall (representing large rainfall events) across the southern half of the region, but a decrease over the northern half of the region. These projected changes would be expected to produce a smaller reduction in runoff across the southern half of the region compared to the northern half, since more runoff is produced during large rainfall events. However, as seen in subsequent figures, these patterns are barely discernible above the background noise of the projections of overall change in rainfall.

Figure 9 shows the projected change in potential evapotranspiration (PET) under 1 °C of global warming. All of the GCMs project an increase in PET, primarily due to the projected increase in temperature. These projected increases are approximately twice as large for 2 °C of global warming as shown in Figure 10.

Figure 11 and Figure 12 show the absolute change in mean annual and seasonal runoff (in mm depth) for 1 °C and 2 °C of global warming respectively using climate change projections from the 15 GCMs. It will be seen that the projected declines in rainfall across the southern part of the region are having a far greater impact on runoff compared to the projected increases in rainfall from some GCMs across the northern part of the region. For changes in runoff, non-linearities in the rainfall-runoff relationship as well as the secondary impact of increases in APET mean that changes in runoff for 2 °C of global warming are not necessarily double those for 1 °C of global warming (Post et al., 2011). This non-linearity is also reflected in the catchment-scale projected changes in runoff as shown in Table 3.

Figure 13 and Figure 14 show the number of GCMs that indicate a decrease (or increase) in mean annual and seasonal runoff for 1 °C and 2 °C of global warming respectively. As above, unlike for rainfall, there are slight differences between 1 °C and 2 °C of global warming, although these differences are fairly minor. Again, as for rainfall, the vast majority of GCMs project a decrease in annual and seasonal runoff in most seasons. This is particularly true across the southern half of the region where almost all GCMs project a decrease in runoff, annually and in all four seasons. These results are reiterated at a catchment scale in Table 3 which shows that, for most southern catchments, a vast majority of GCMs project a decrease in mean annual runoff.

Figure 15 shows that almost all GCMs project an increase in the number of days per years of zero runoff. That is, even where rainfall is projected to increase, changes in seasonal and daily rainfall amounts, together with non-linearities in the rainfall-runoff relationship combine to increase the number of days of zero runoff. Changes in the characteristics of the runoff regime such as this may have important ecological consequences.

Because it can be difficult for policy makers to interpret and use the results from 15 GCMs, the results from all 15 model results were converted into a probable range of results. This was done by deriving the 10th and 90th percentile projected changes in both rainfall and runoff for each 0.05° grid cell across south-eastern Australia. The 10th percentile was then taken to represent a 'dry' scenario, while the 90th percentile was taken to represent a 'wet' scenario. The 50th percentile was taken to represent the 'median' scenario. Changes in rainfall and runoff for 1 °C of global warming are presented in Figure 16 through Figure 21 for the dry, median and wet scenarios respectively, while those for 2 °C of global warming are presented in Figure 22 through Figure 27. These results are also summarised at a catchment scale in Table 2 and Table 3.

The projections indicate that future mean annual rainfall under 1 °C of global warming will be lower across the southern half of the region. Averaged across the area south of 33° S, rainfall is projected to decline by between 0 and 9 percent, with a median reduction of 4 percent. This reduction in rainfall would lead to a reduction in areally-averaged runoff of between 2 and 22 percent, with a median estimated reduction of 12 percent.

Across the northern half of the region, projections are less certain, although most GCMs still project a reduction in mean annual rainfall and therefore runoff. Averaged across the area north of 33° S, rainfall is projected to change by between an increase of 4 percent and a decrease of 11 percent, with a median reduction of 3 percent. This change in rainfall would lead to a change in runoff of between an increase of 12 percent and a decrease of 29 percent, with a median estimated reduction of 10 percent.

Importantly, it should be noted that even under the wet future scenario, there are still projected decreases in runoff across the important runoff producing areas in the far south-east of the region (for downstream irrigation along the Murray River).

Implications of these projected changes in rainfall and runoff are discussed in CSIRO (2012).

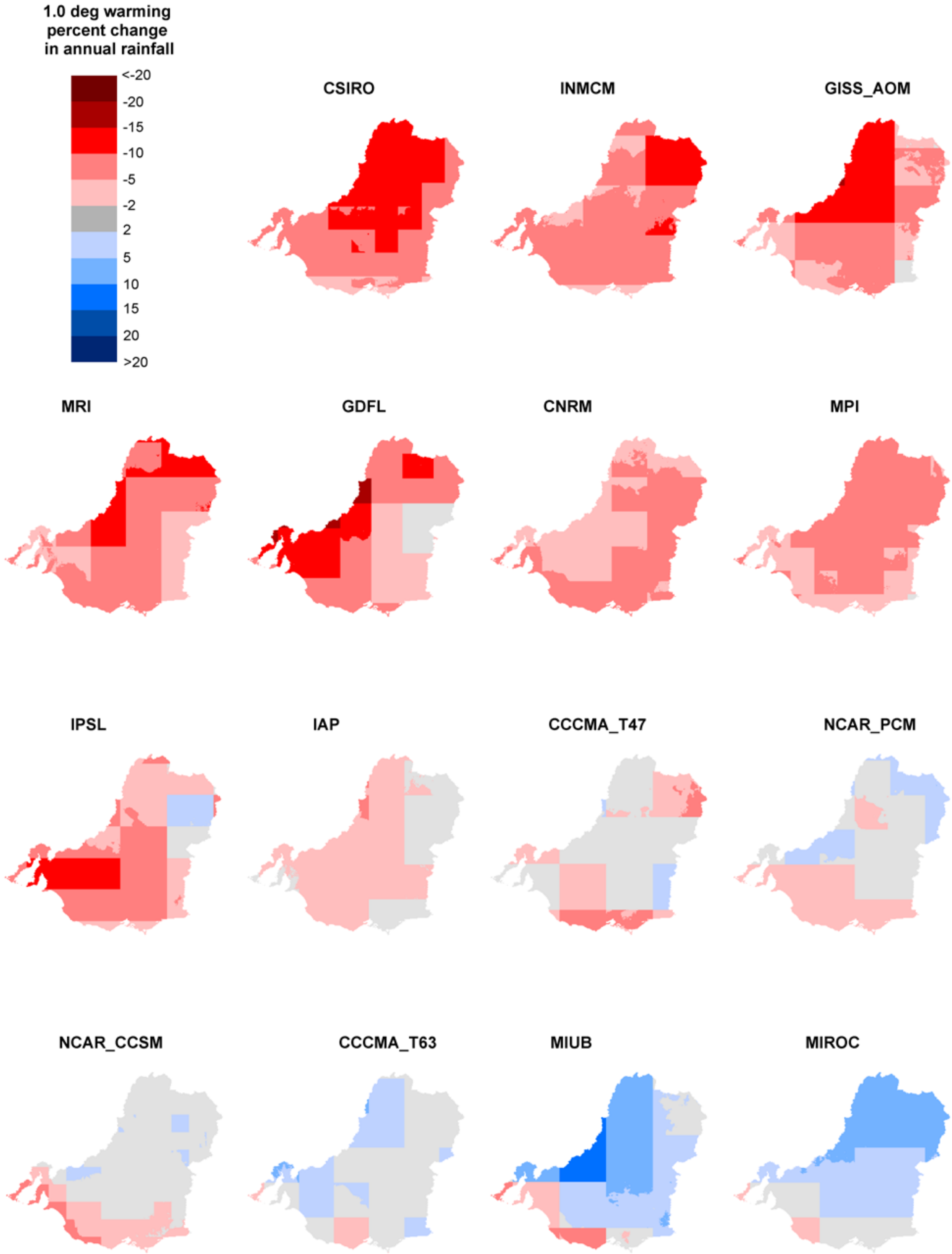

Figure 5. Percentage change in mean annual rainfall under 1 °C of global warming modelled using climate change projections from 15 GCMs

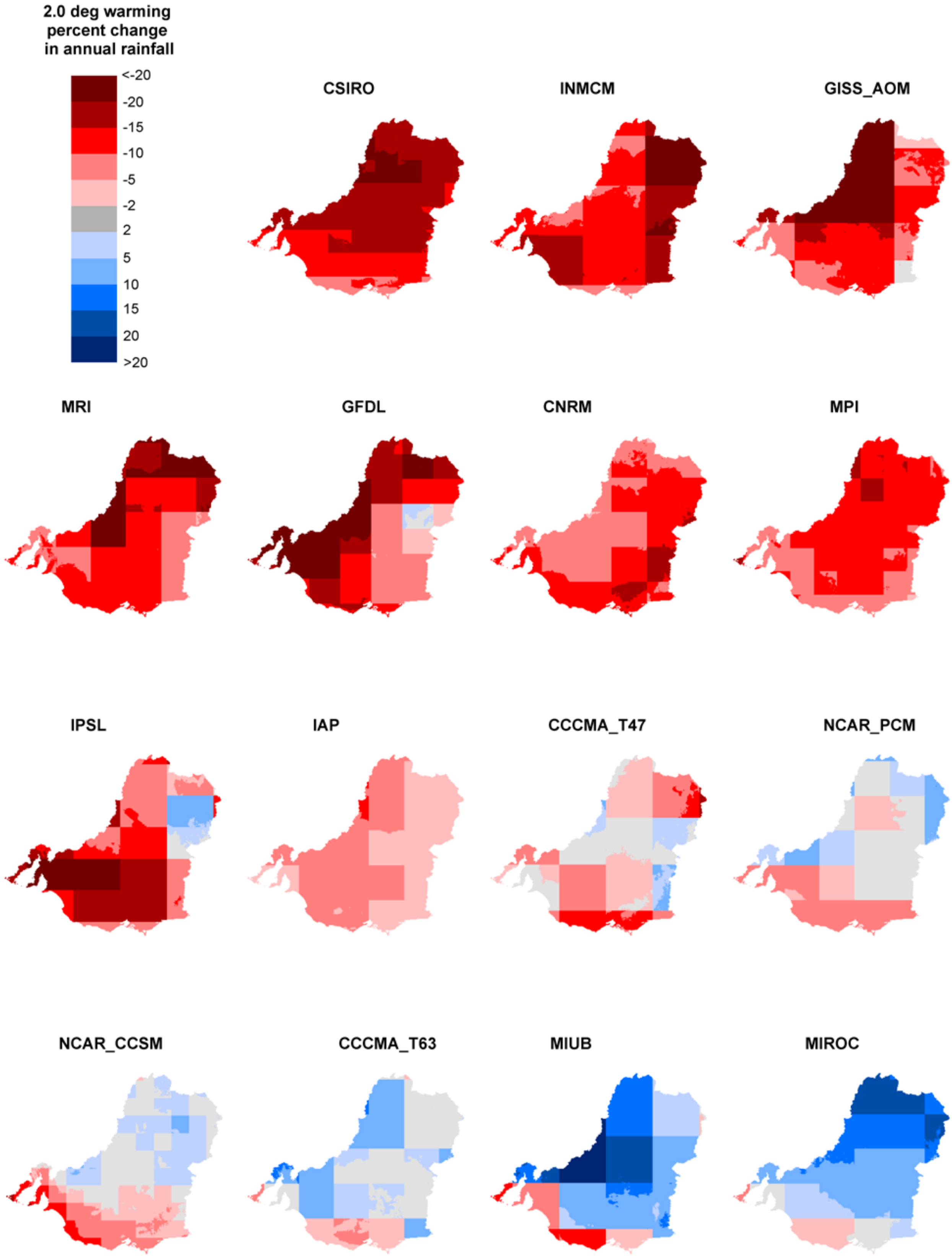

Figure 6. Percentage change in mean annual rainfall under 2 °C of global warming modelled using climate change projections from 15 GCMs

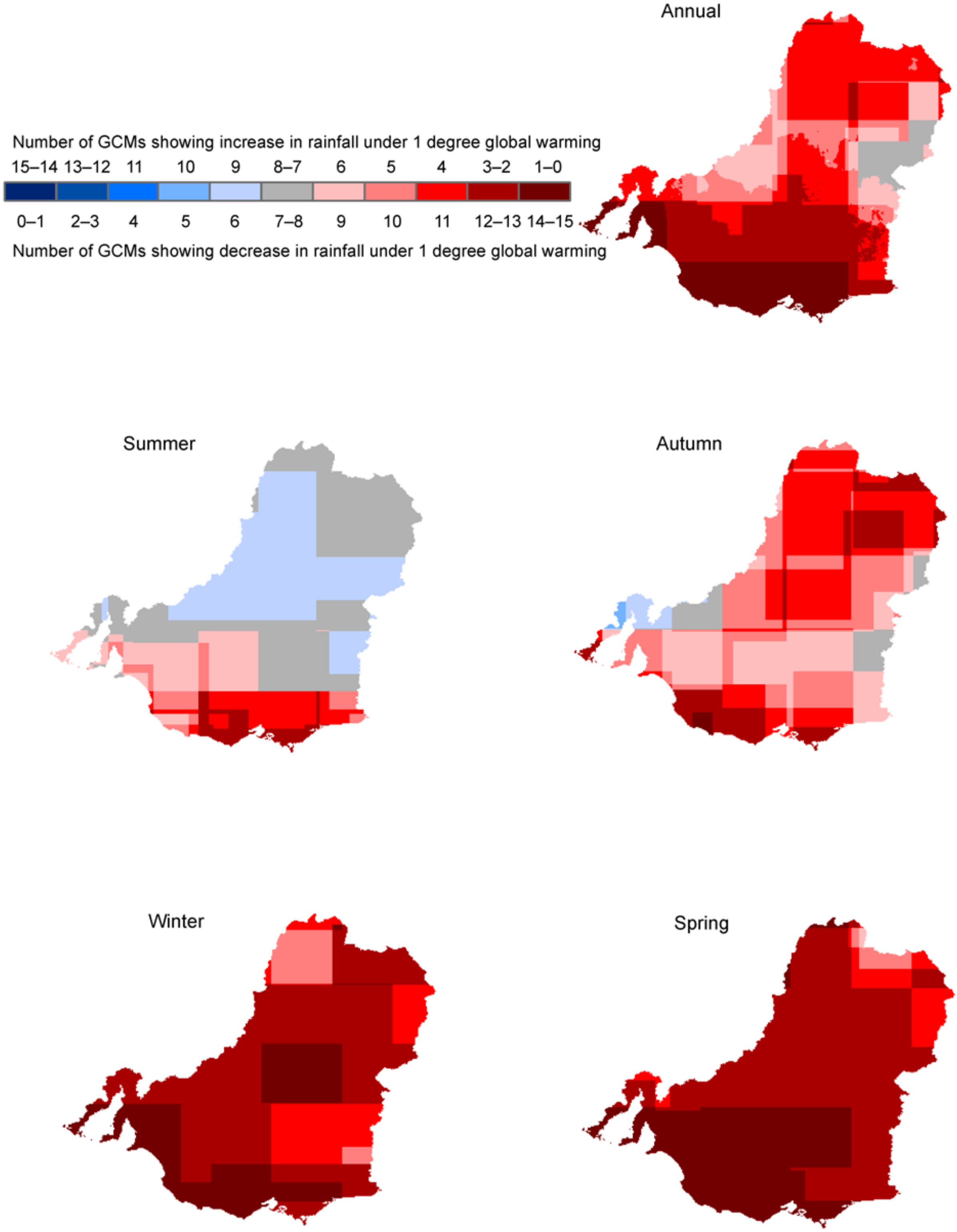

Figure 7. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall under 1 °C and 2 °C of global warming

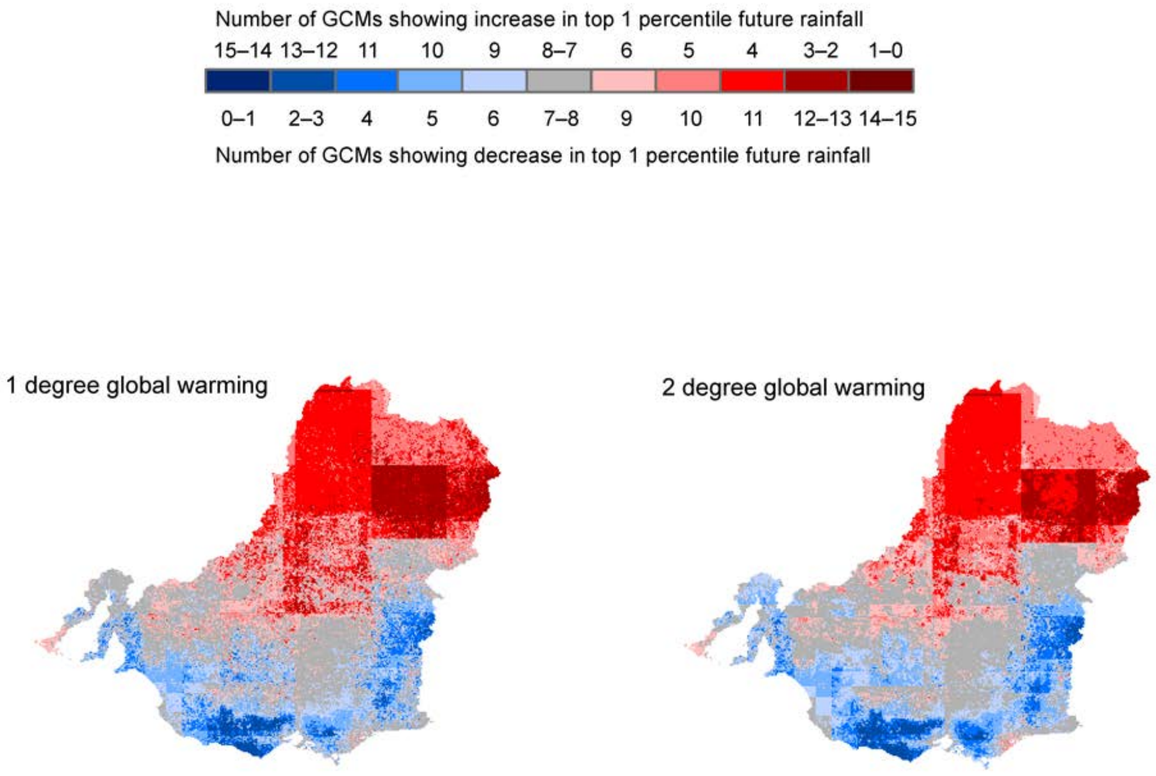

Figure 8. Number of modelling results showing a decrease (or increase) in the top 1-percentile future mean annual rainfall under 1 °C and 2 °C of global warming

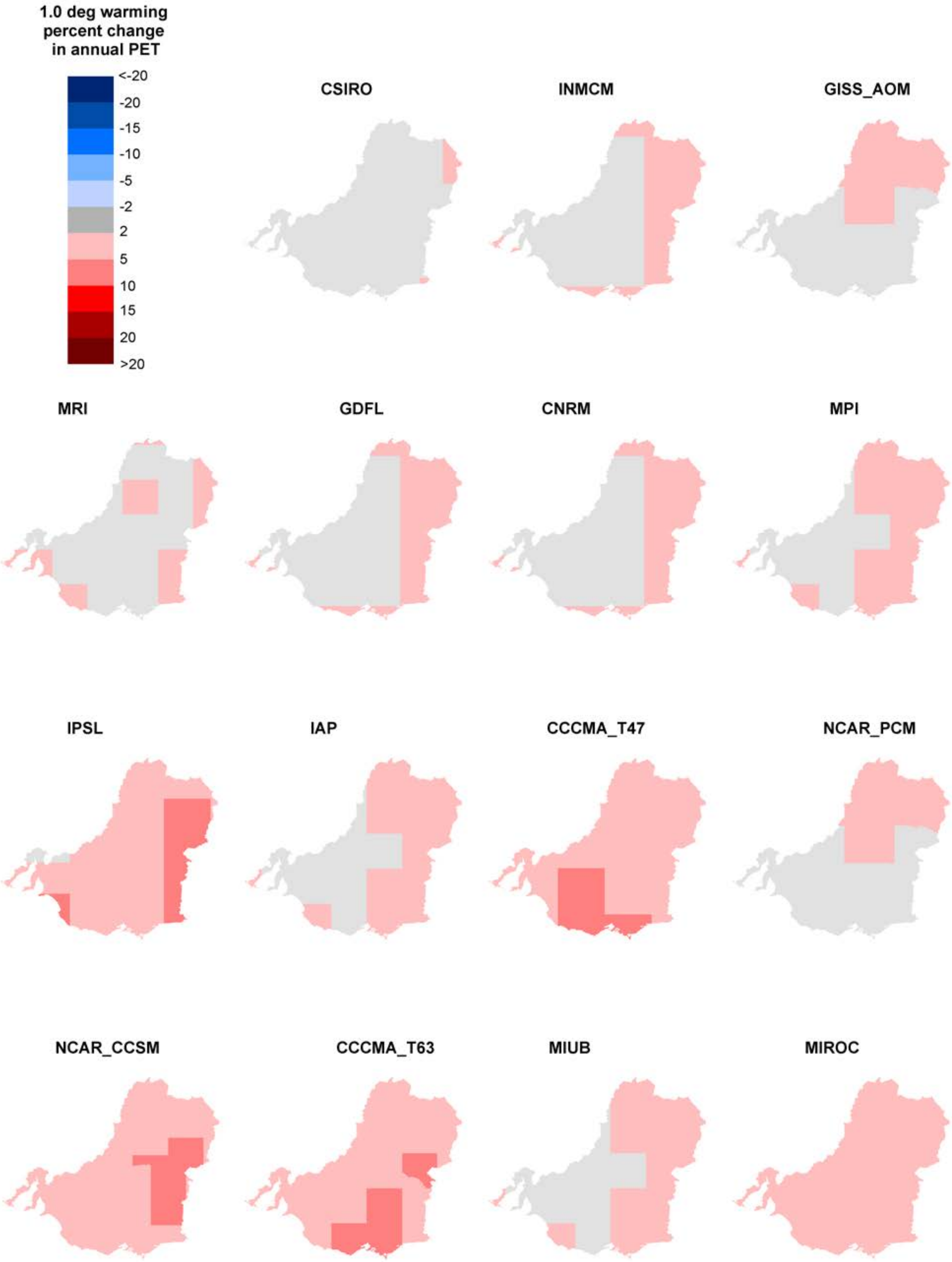

Figure 9. Percent change in annual potential evapotranspiration (PET) under 1 °C of global warming modelled using climate change projections from 15 GCMs

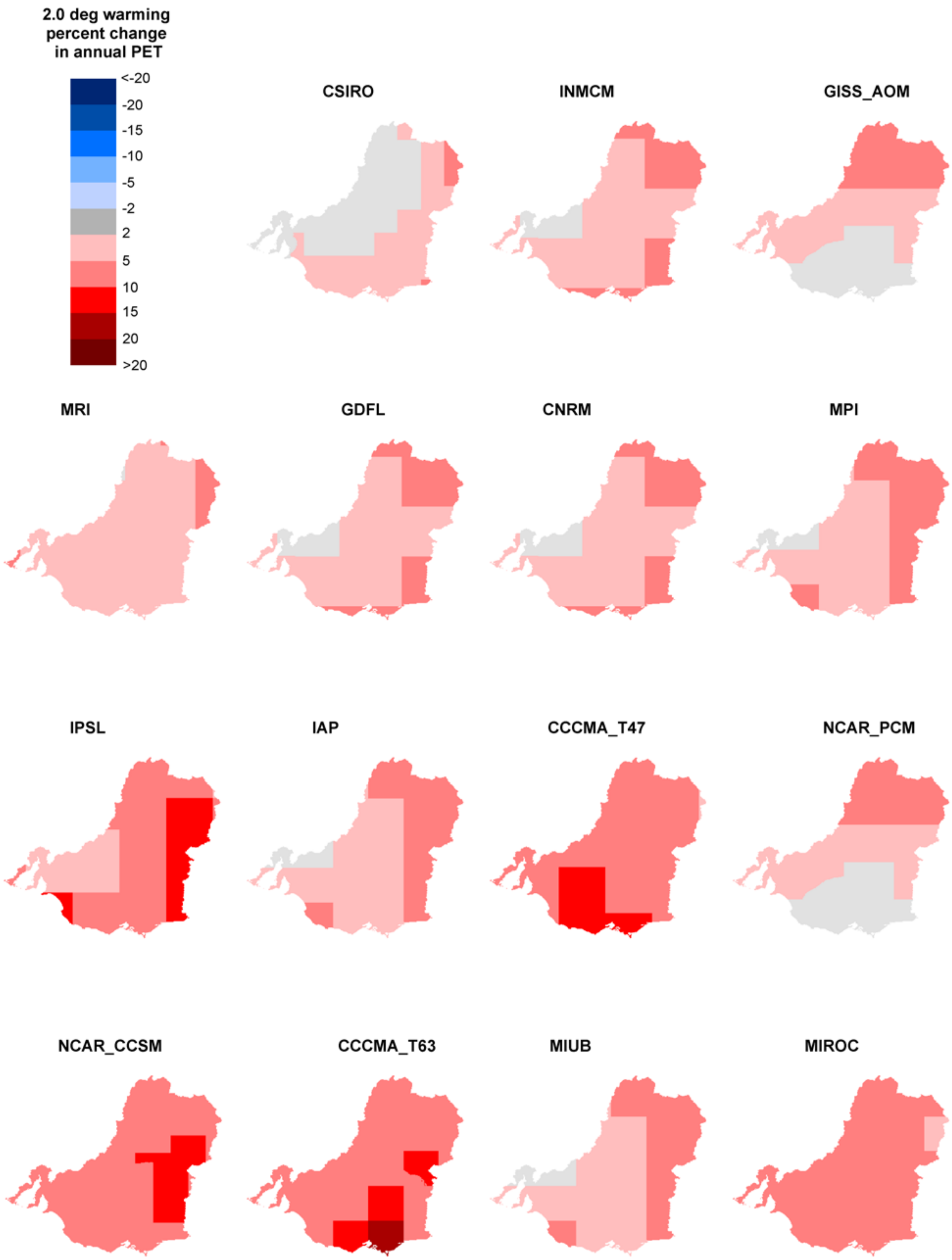

Figure 10. Percent change in annual potential evapotranspiration (PET) under 2 °C of global warming modelled using climate change projections from 15 GCMs

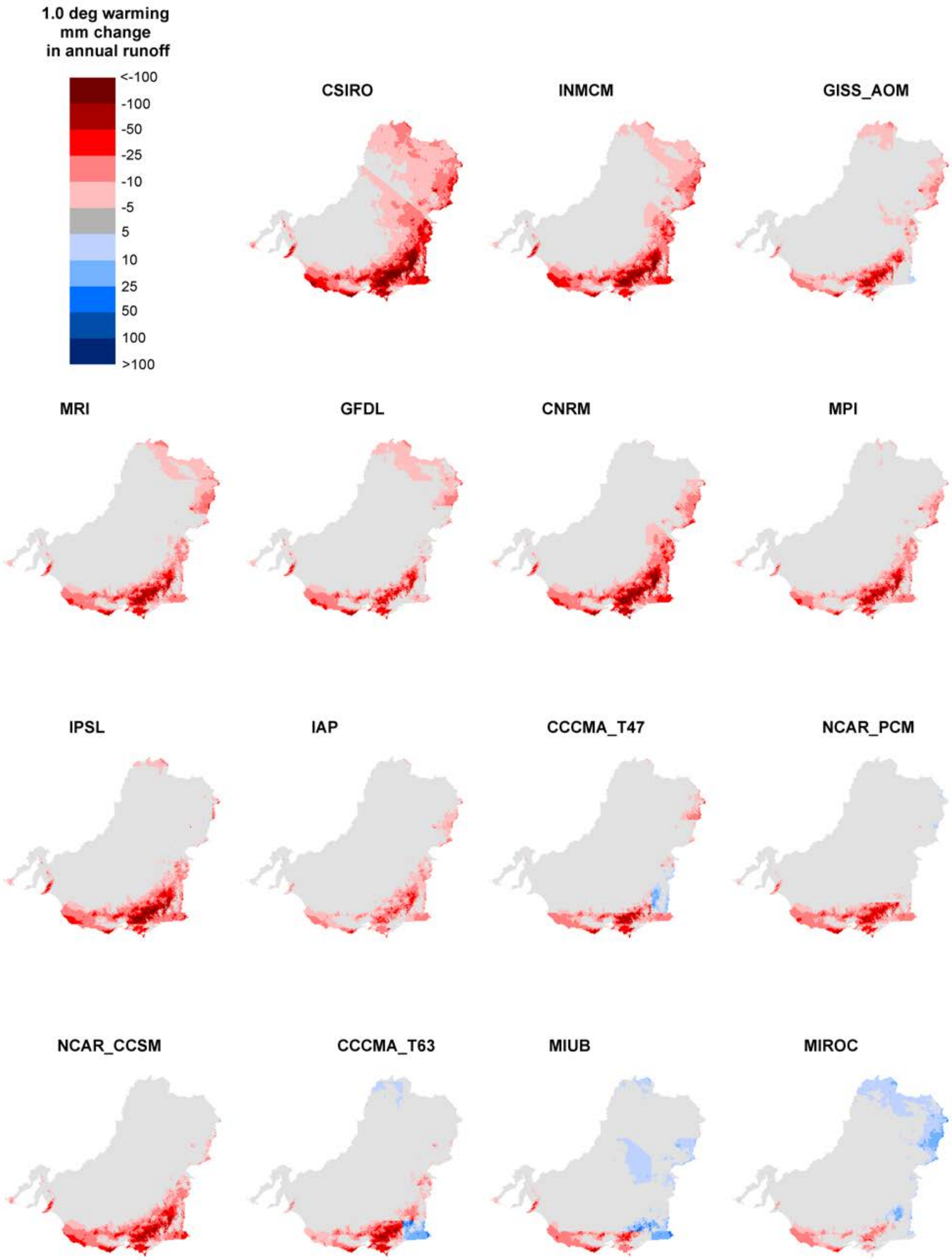

Figure 11. Absolute change in mean annual runoff under 1 °C of global warming modelled using climate change projections from 15 GCMs

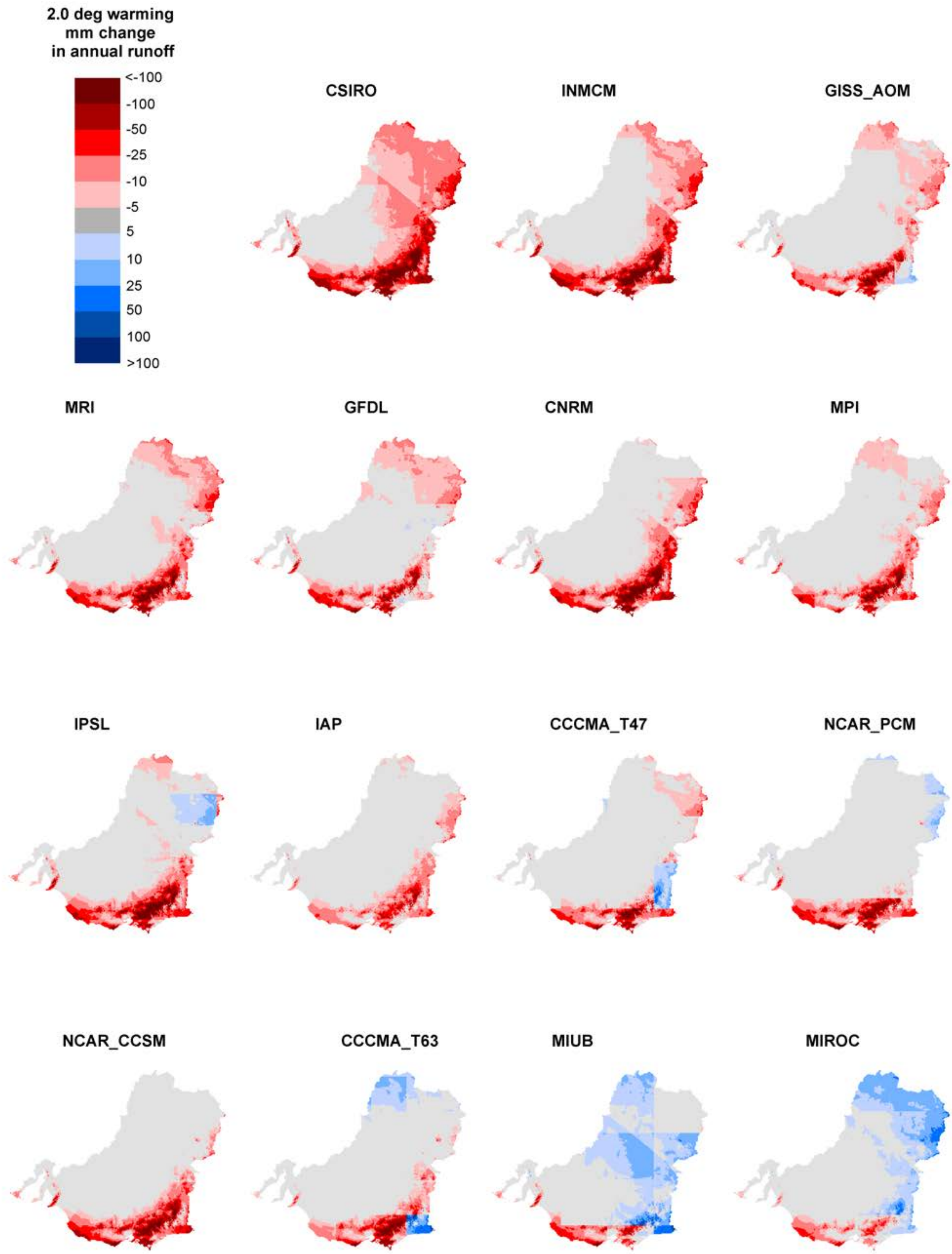

Figure 12: Absolute change in mean annual runoff under 2 °C of global warming modelled using climate change projections from 15 GCMs

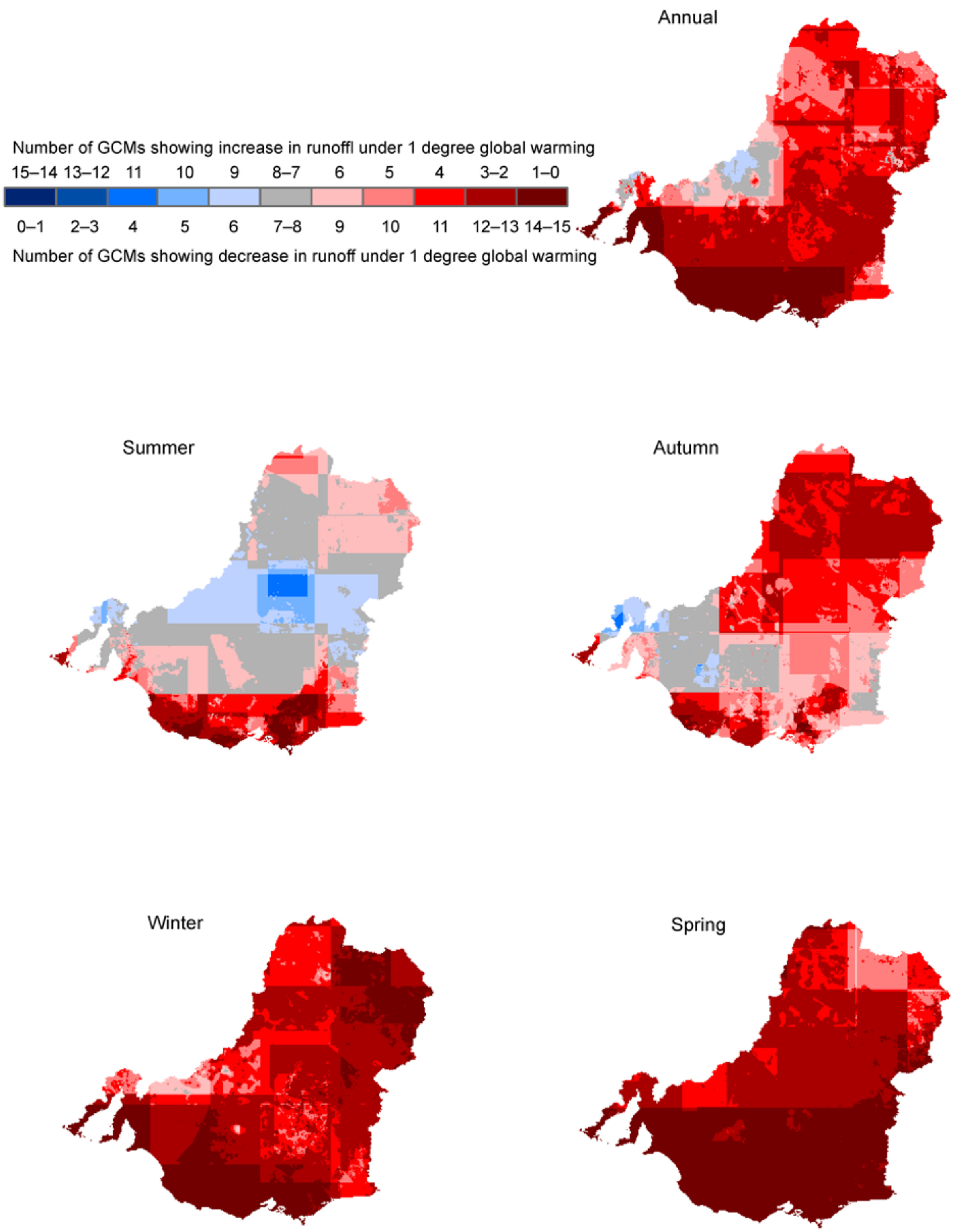

Figure 13. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff under 1 °C of global warming

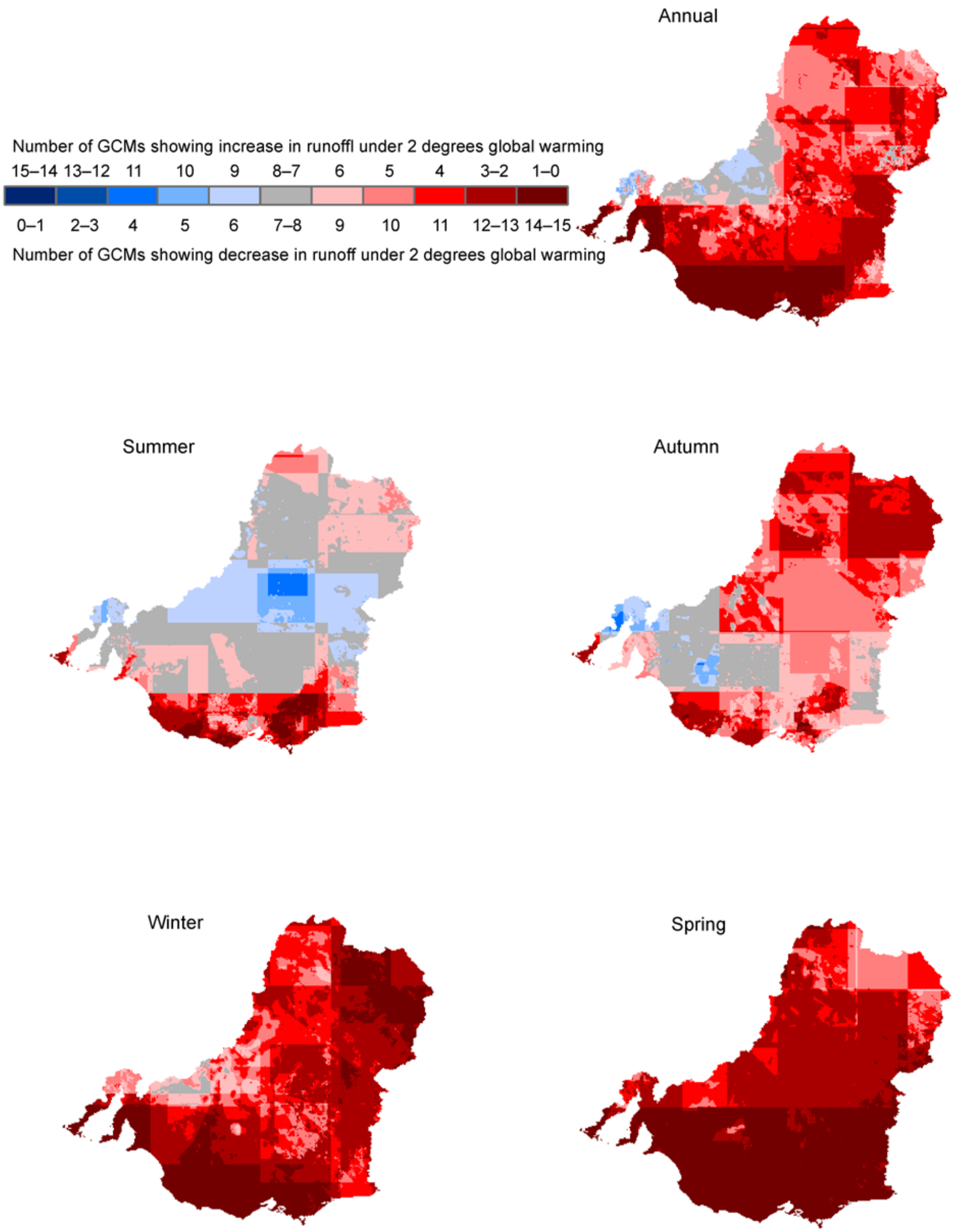

Figure 14. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff under 2 °C of global warming

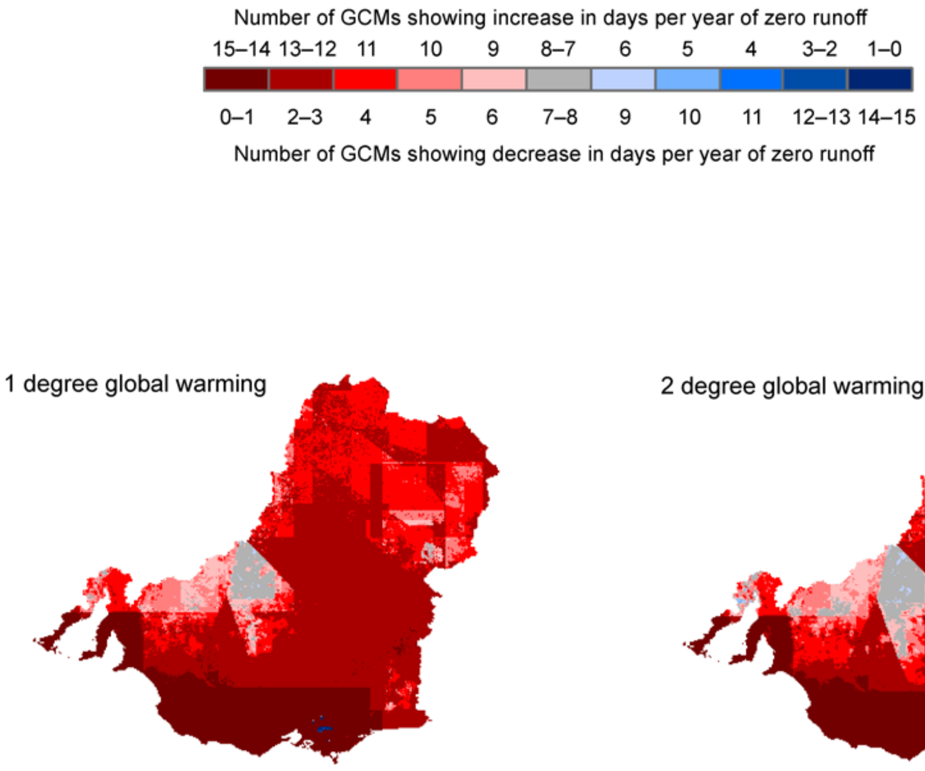

Figure 15. Number of modelling results showing an increase (or decrease) in the number of days per year of zero runoff under 1 °C and under 2 °C of global warming

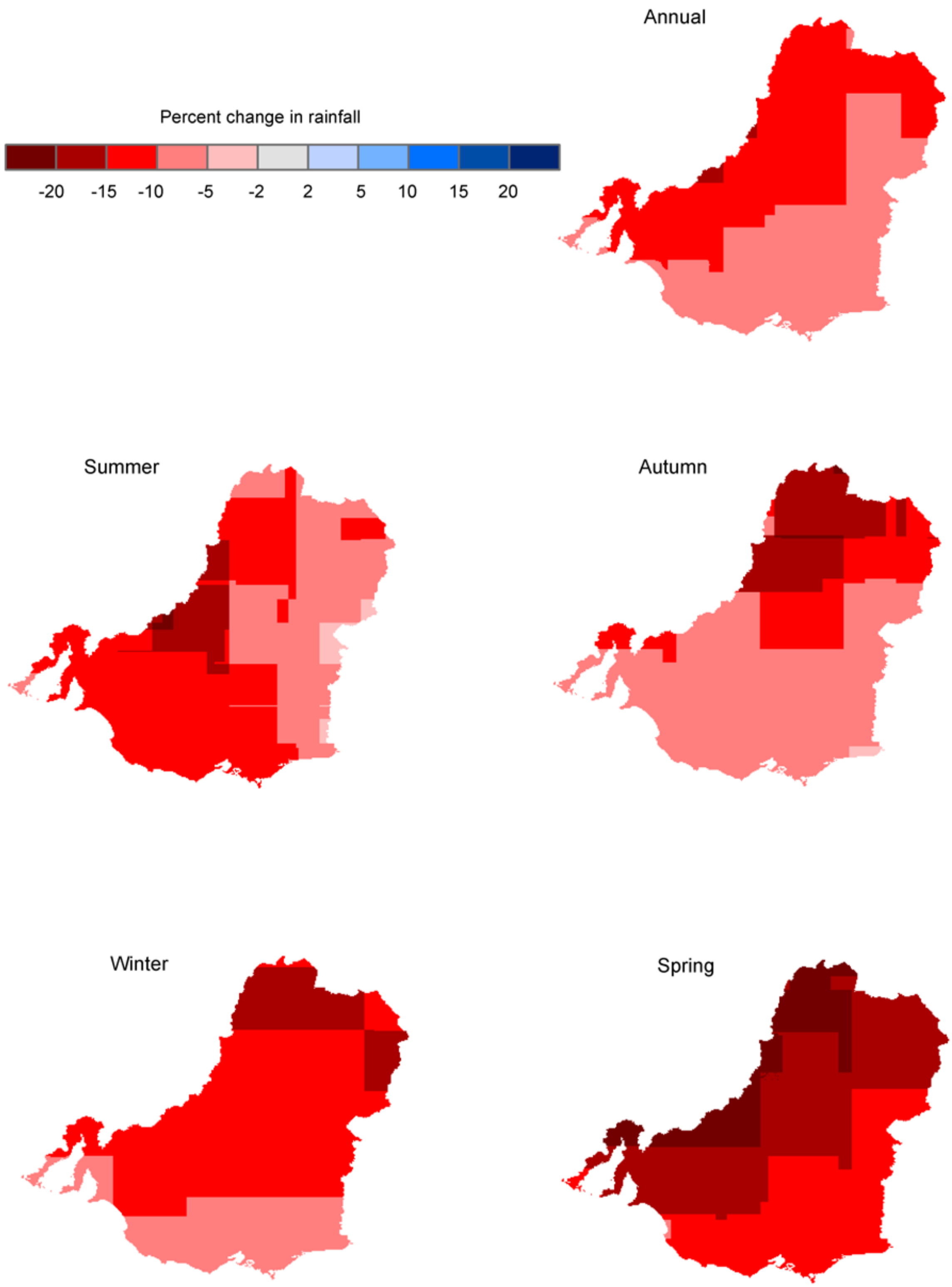

Figure 16. Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 1 °C of global warming for the dry scenario

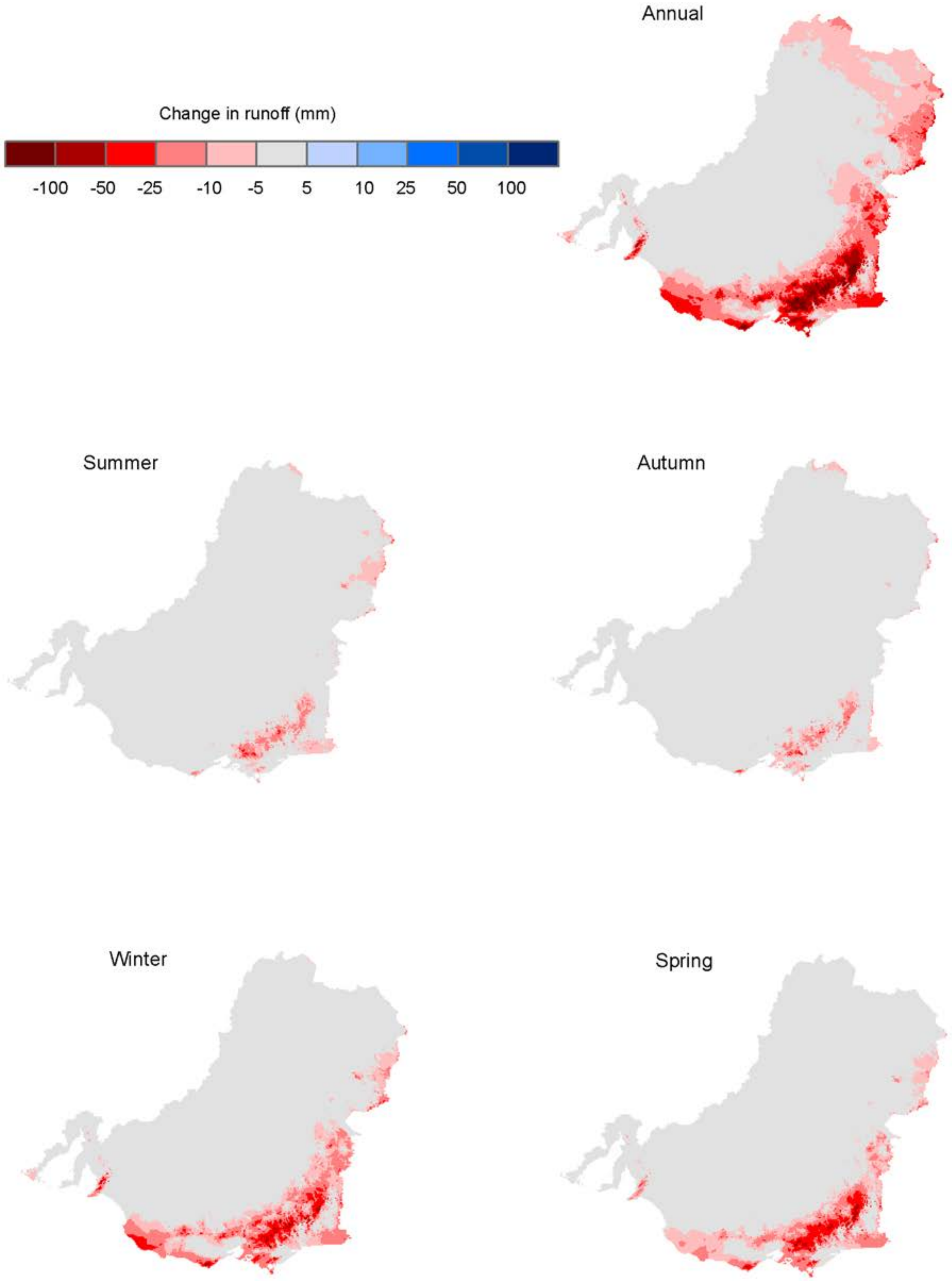

Figure 17. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 1 °C of global warming for the dry scenario

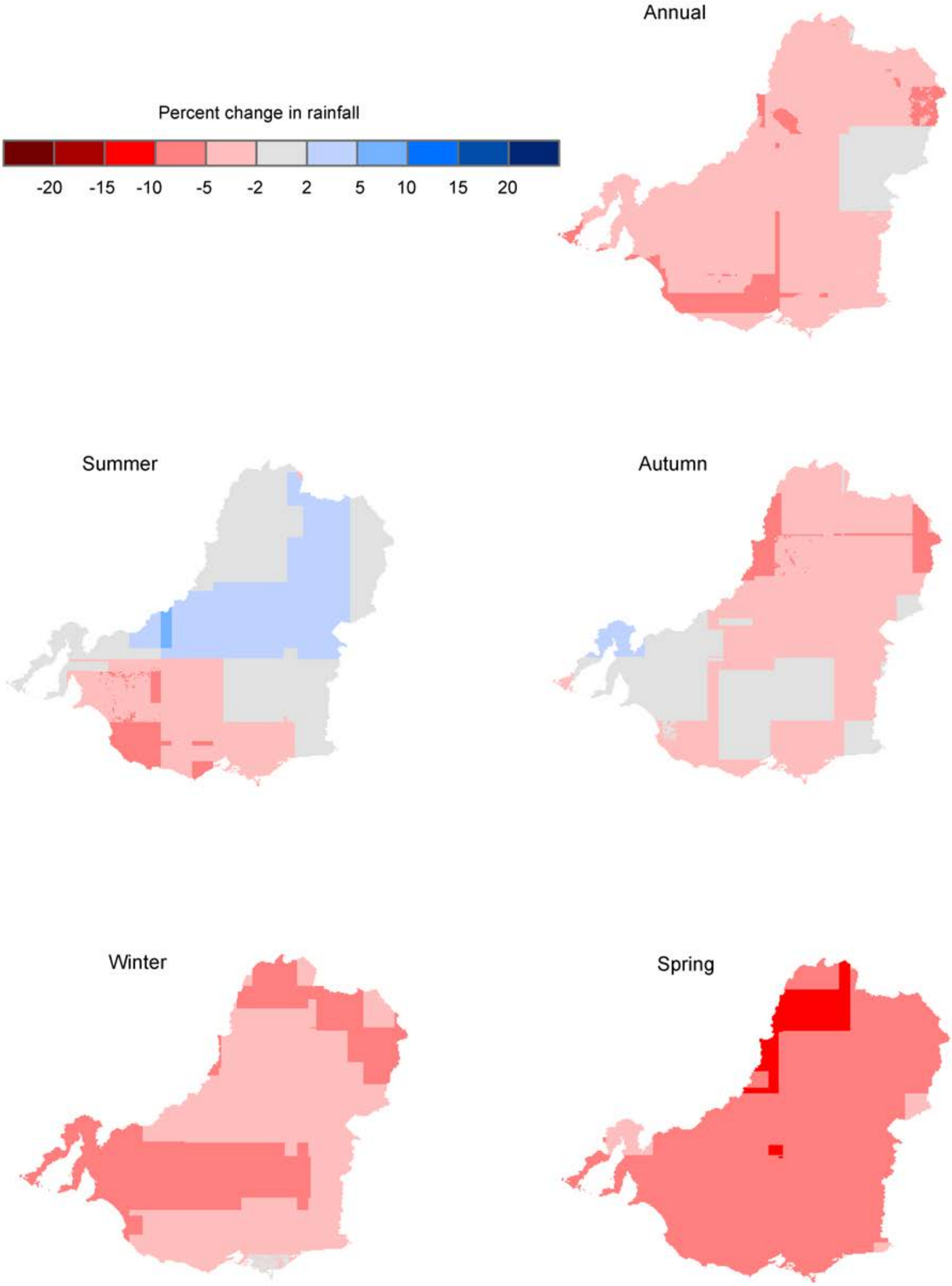

Figure 18. Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 1 °C of global warming for the median scenario

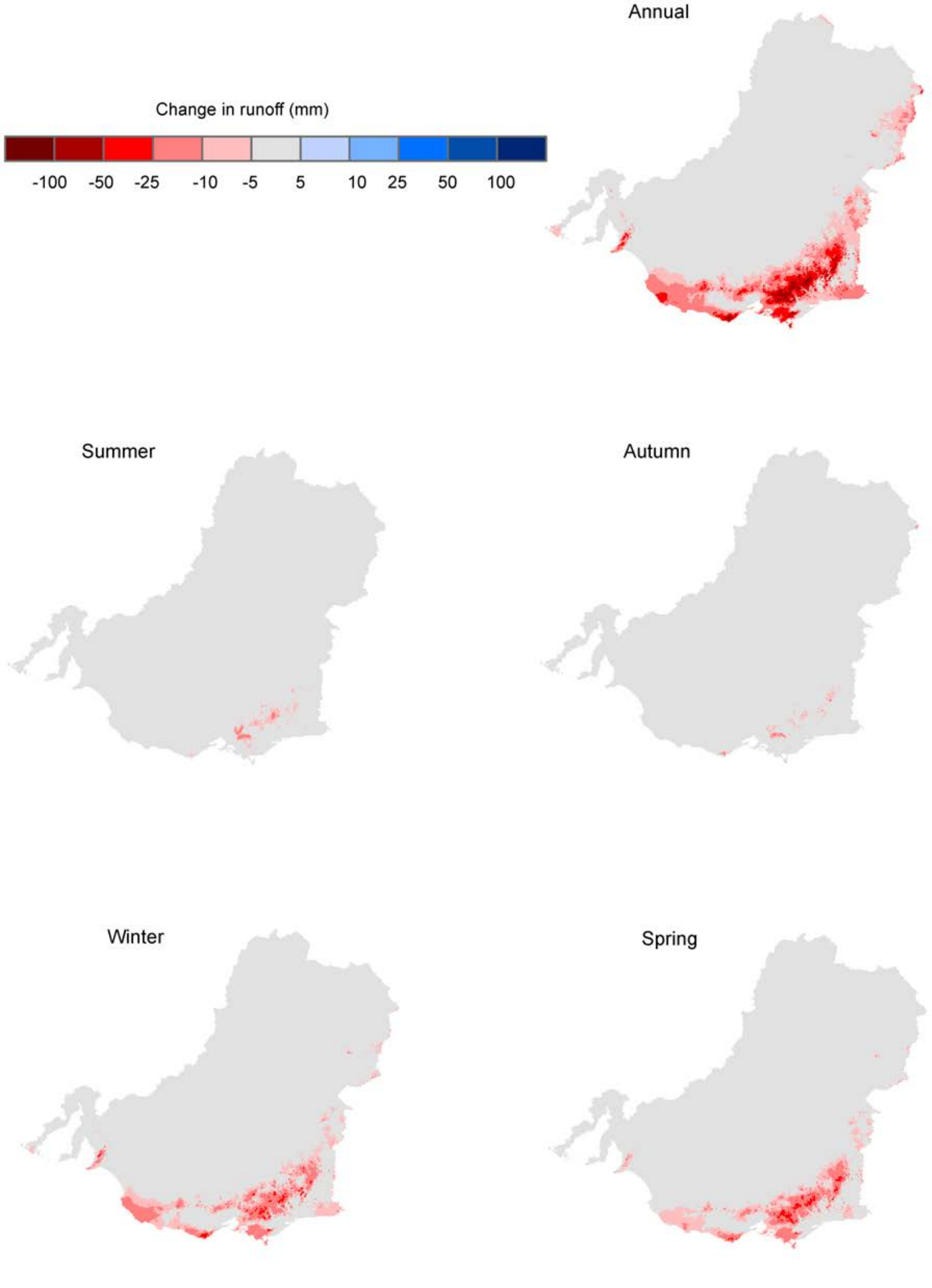

Figure 19. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 1 °C of global warming for the median scenario

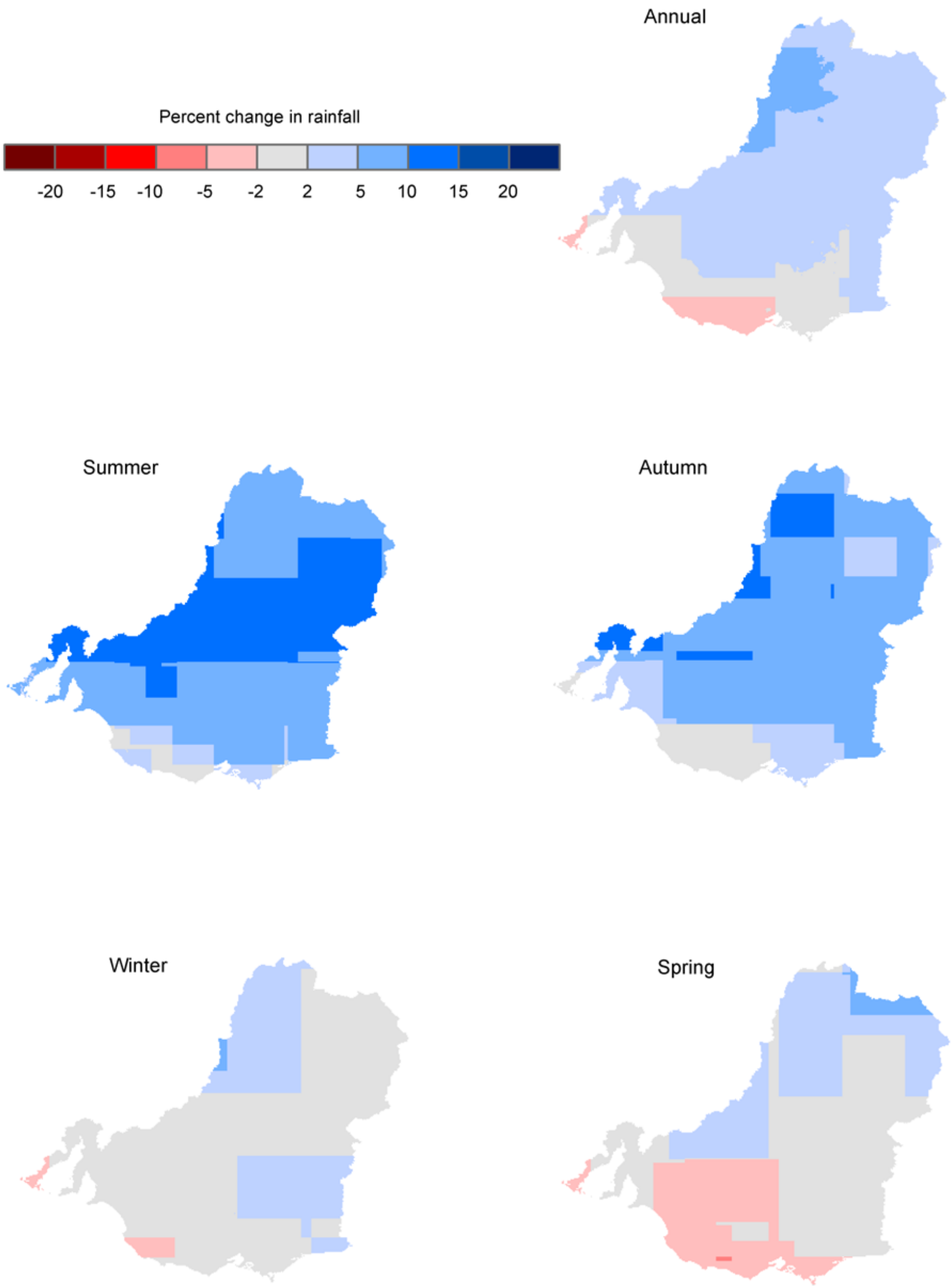

Figure 20. Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 1 °C of global warming for the wet scenario

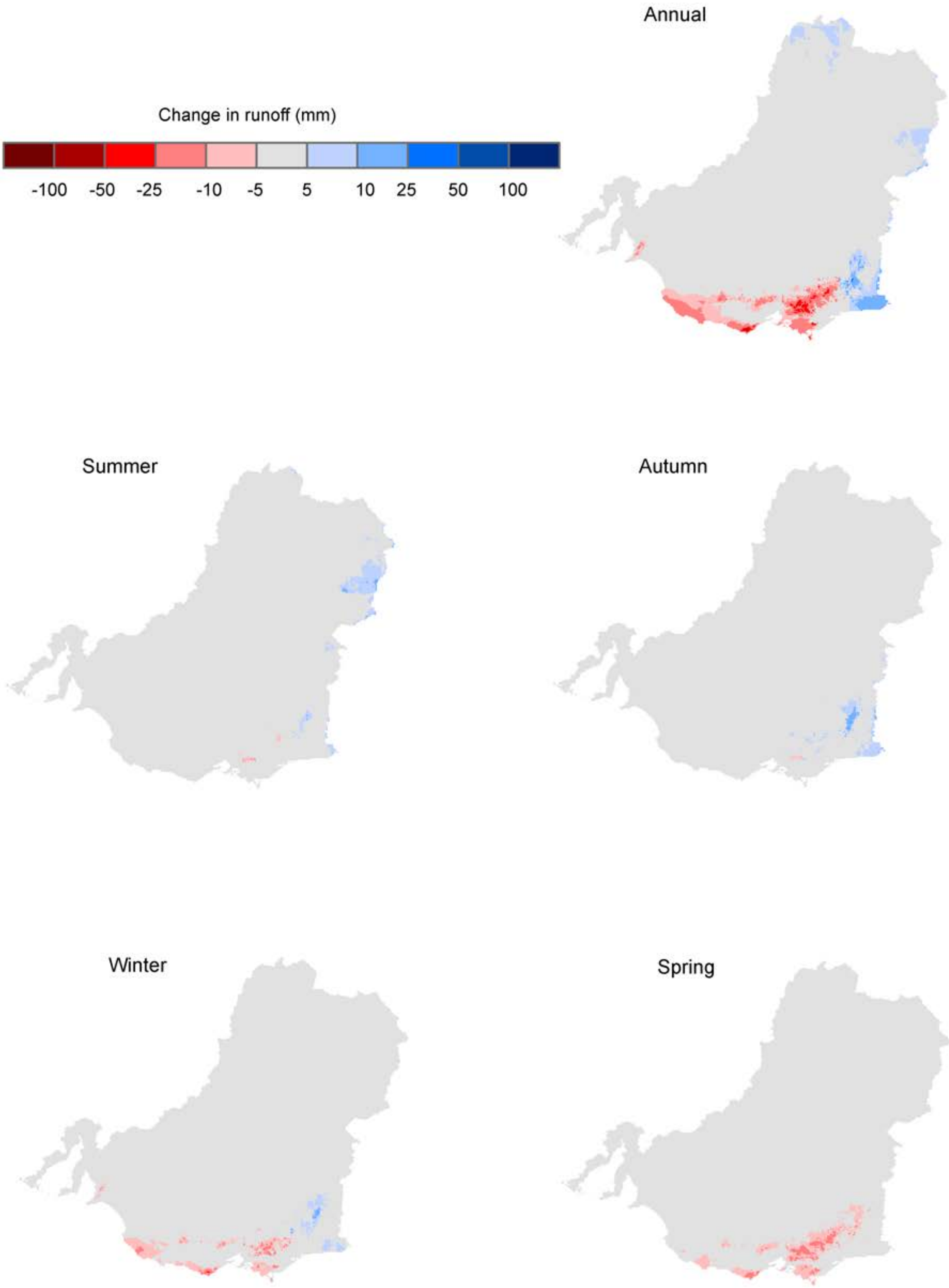

Figure 21. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 1 °C of global warming for the wet scenario

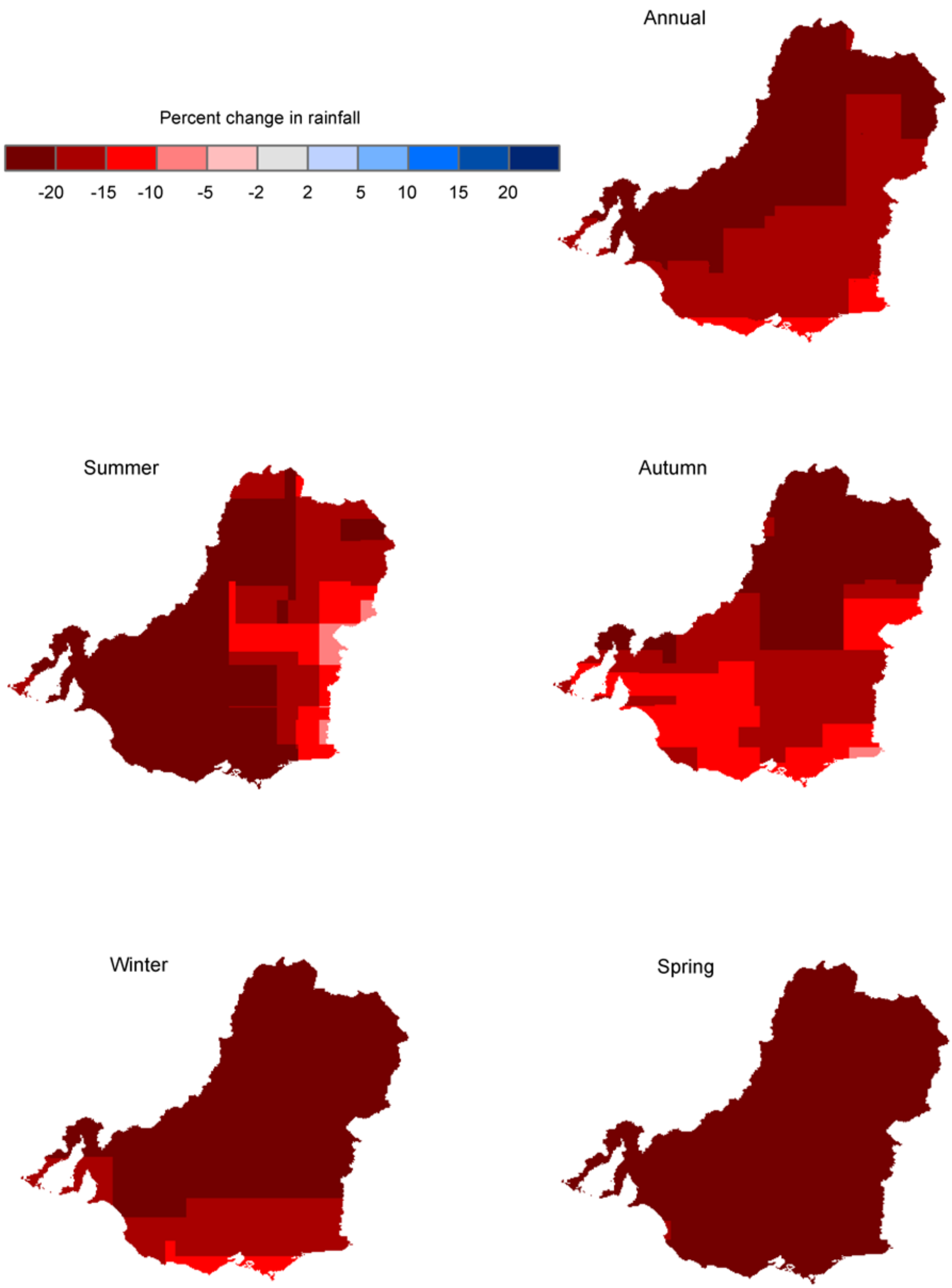

Figure 22 Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 2 °C of global warming for the dry scenario

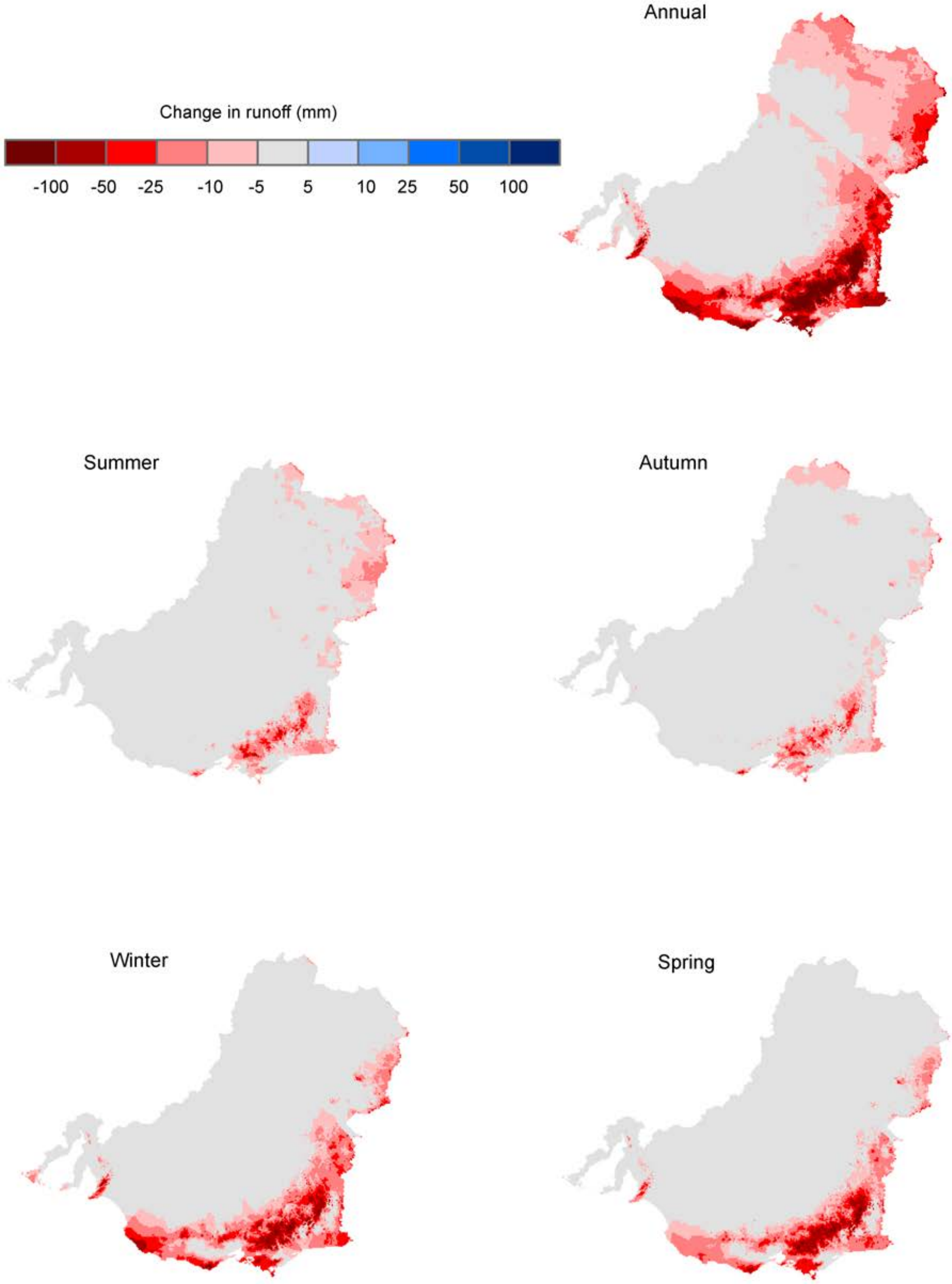

Figure 23. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 2 °C of global warming for the dry scenario

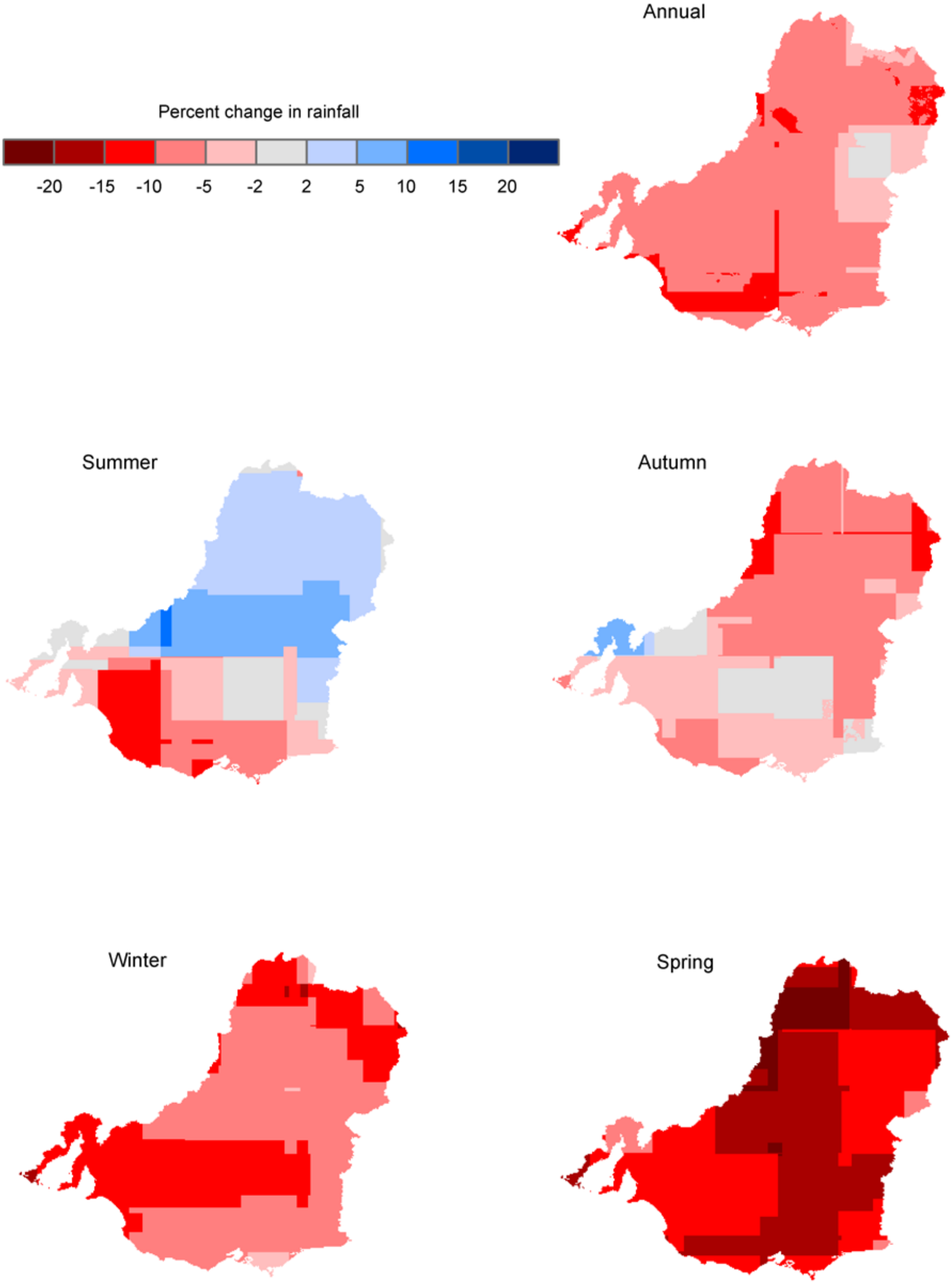

Figure 24. Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 2 °C of global warming for the median scenario

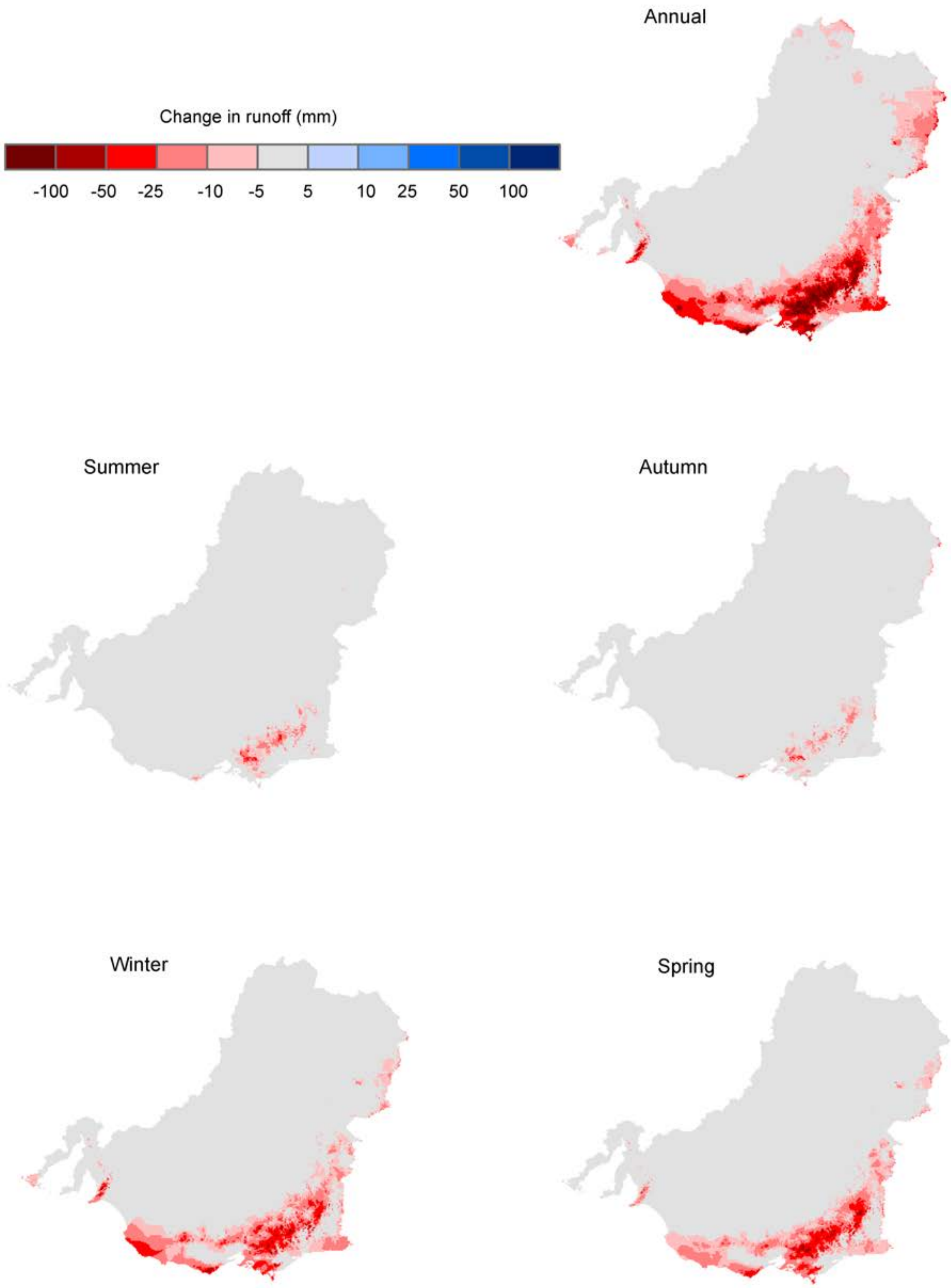

Figure 25. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 2 °C of global warming for the median scenario

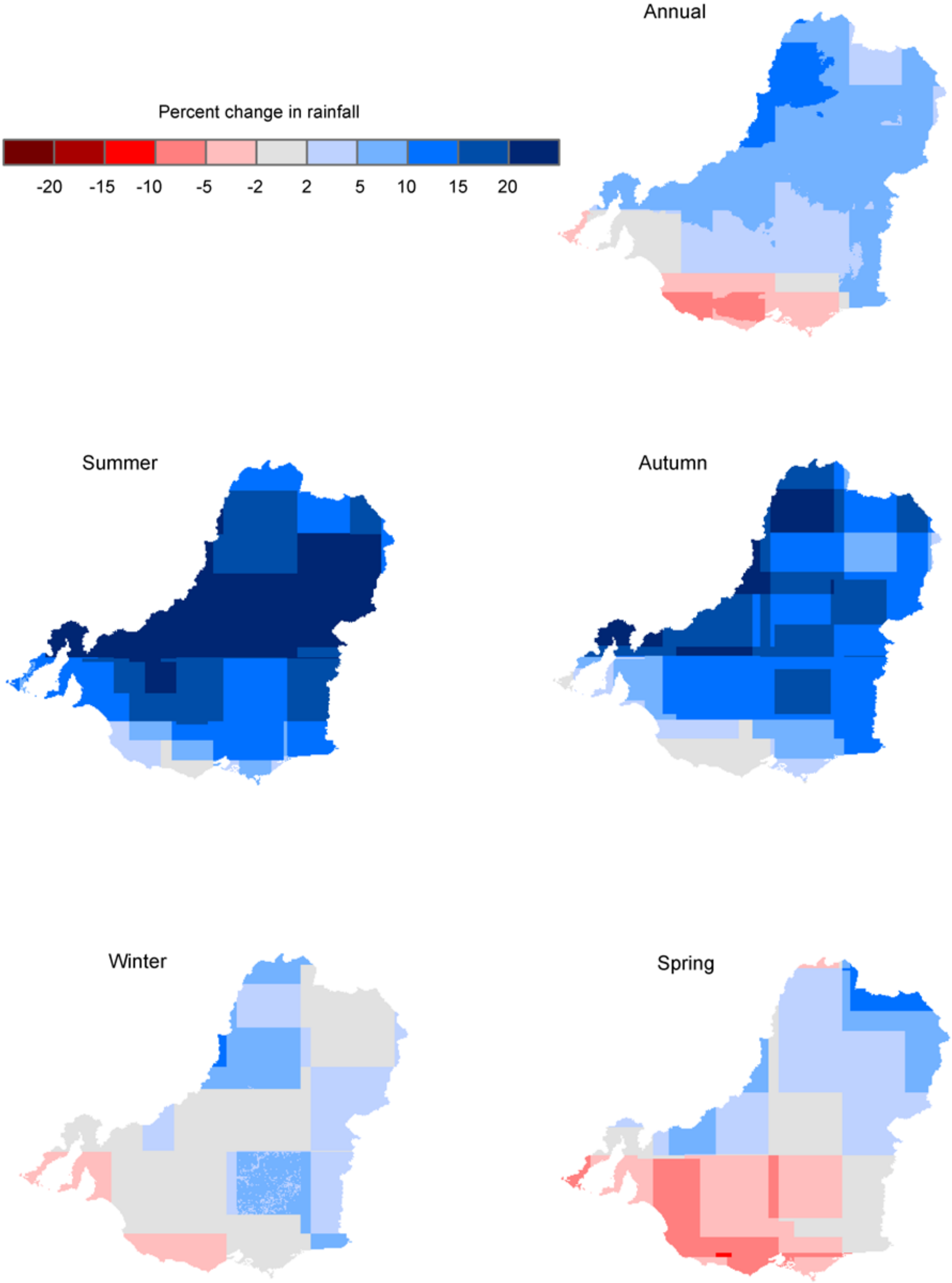

Figure 26. Percentage change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall across the SEACI region under 2 °C of global warming for the wet scenario

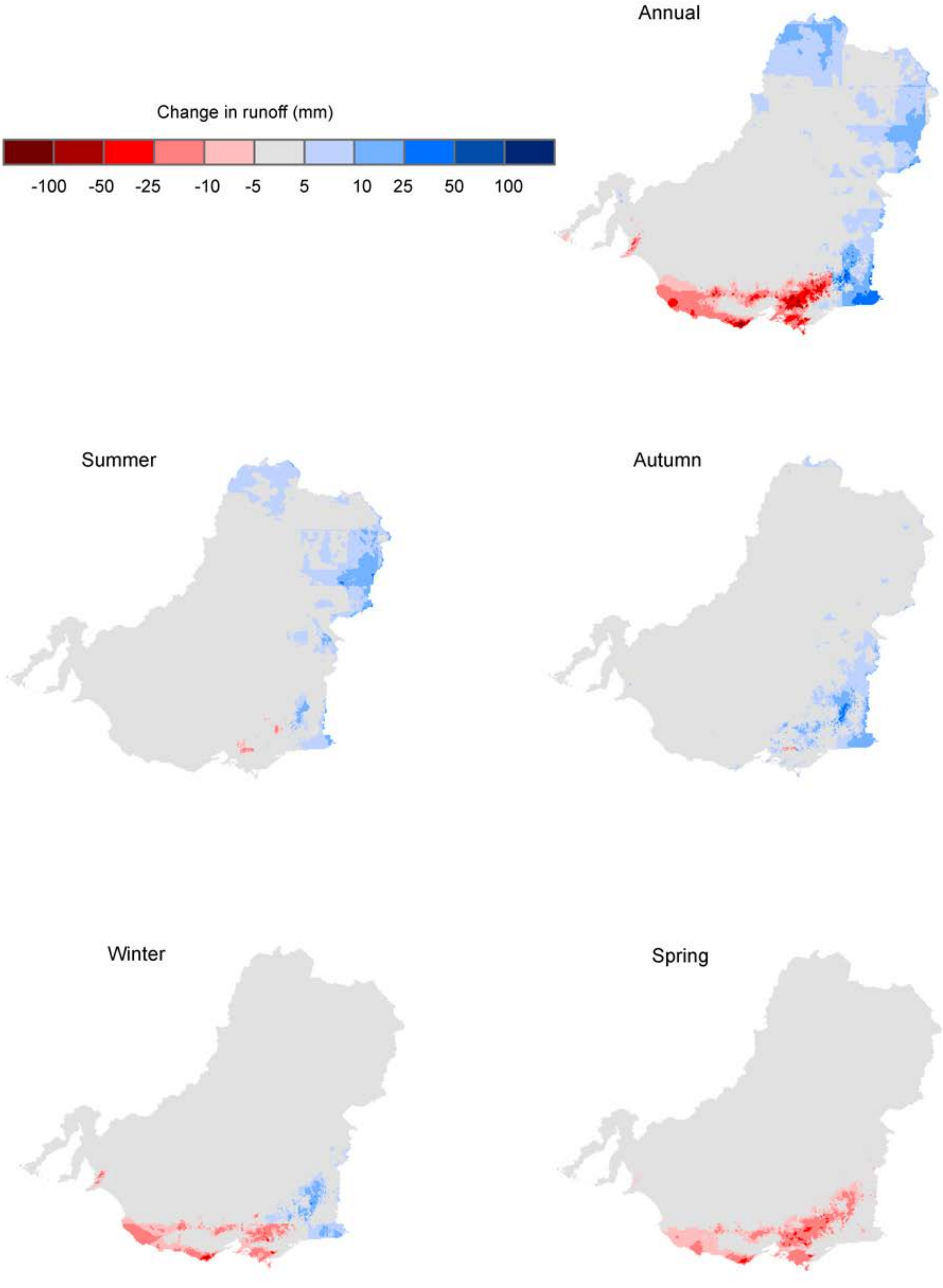

Figure 27. Absolute change in modelled mean annual, summer (DJF), autumn (MAM), winter (JJA) and spring (SON) runoff (mm) across the SEACI region under 2 °C of global warming for the wet scenario

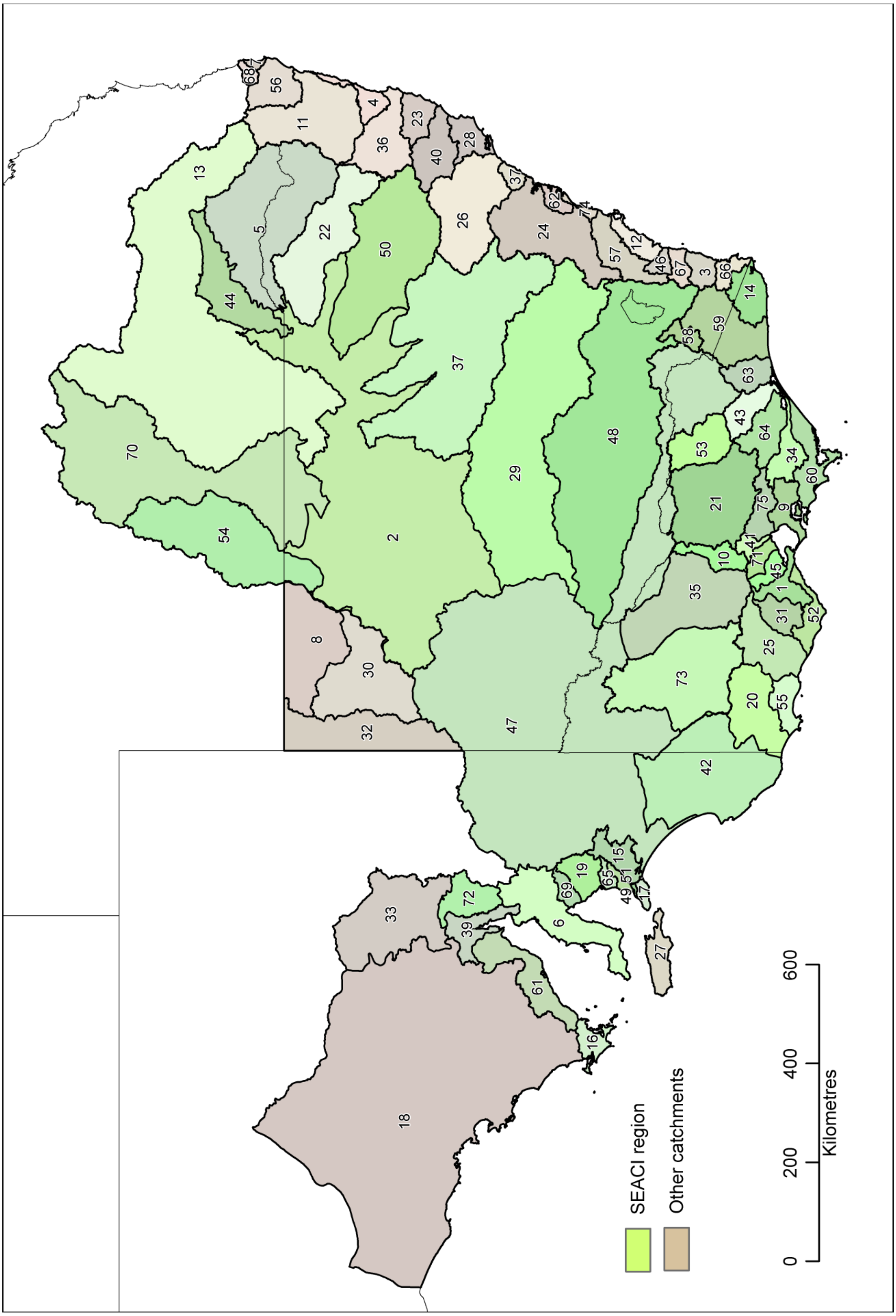

Figure 28. Location of catchments for which summary information is provided in Tables 2 and 3

Table 2. Summary of projected impacts of climate change on rainfall for all catchments in south-eastern Australia

				1 degree of global warming			2 degrees of global warming		
ID	Catchment	Historical rainfall (mm)	# of GCMs (out of 15) projecting a decrease in future rainfall	Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
1	Barwon River	645	15	-8%	-5%	-3%	-15%	-10%	-5%
2	Barwon-Darling	328	10	-11%	-4%	4%	-23%	-7%	8%
3	Bega River	863	11	-7%	-2%	4%	-13%	-5%	8%
4	Bellinger River	1463	10	-9%	-3%	2%	-17%	-5%	5%
5	Border Rivers	641	10	-11%	-5%	3%	-21%	-10%	6%
6	Broughton River	412	14	-11%	-5%	0%	-23%	-9%	1%
7	Brunswick River	1779	12	-10%	-5%	2%	-19%	-10%	4%
8	Bulloo River	206	9	-18%	-5%	5%	-36%	-9%	11%
9	Bunyip River	877	15	-7%	-4%	-2%	-15%	-9%	-3%
10	Campaspe	591	14	-8%	-5%	-1%	-16%	-11%	-3%
11	Clarence River	1070	10	-10%	-4%	2%	-19%	-8%	4%
12	Clyde River-Jervis Bay	1076	11	-7%	-3%	4%	-15%	-6%	7%
13	Condamine-Balonne	519	11	-12%	-4%	4%	-23%	-8%	7%
14	East Gippsland	956	12	-7%	-3%	3%	-14%	-6%	6%
15	Eastern Mt Lofty Ranges	464	14	-11%	-4%	0%	-22%	-9%	-1%
16	Eyre Peninsula	489	15	-9%	-6%	-2%	-18%	-11%	-4%
17	Fleurieu Peninsula	674	15	-10%	-5%	-1%	-20%	-11%	-1%
18	Gairdner	219	13	-12%	-5%	0%	-24%	-9%	0%
19	Gawler River	472	15	-11%	-4%	-1%	-22%	-8%	-1%
20	Glenelg River	684	15	-9%	-5%	-3%	-17%	-10%	-5%
21	Goulburn-Broken	761	14	-8%	-4%	-1%	-16%	-9%	-2%
22	Gwydir	644	10	-10%	-3%	3%	-20%	-6%	6%
23	Hastings River	1355	10	-8%	-2%	3%	-16%	-4%	6%
24	Hawkesbury River	870	9	-8%	-2%	4%	-16%	-5%	8%
25	Hopkins River	639	15	-8%	-5%	-3%	-16%	-10%	-5%
26	Hunter River	770	8	-9%	-2%	4%	-17%	-4%	7%
27	Kangaroo Island	597	15	-9%	-6%	-1%	-18%	-12%	-1%
28	Karuah River	1225	9	-9%	-2%	3%	-17%	-5%	5%
29	Lachlan	460	11	-9%	-3%	3%	-18%	-6%	5%
30	Lake Bancannia	201	9	-16%	-4%	5%	-32%	-8%	10%
31	Lake Corangamite	627	15	-8%	-5%	-3%	-15%	-10%	-5%
32	Lake Frome	170	9	-17%	-4%	5%	-35%	-8%	11%
33	Lake Torrens	183	10	-14%	-4%	5%	-27%	-8%	10%
34	Latrobe River	982	15	-7%	-5%	-2%	-15%	-9%	-3%
35	Loddon-Avoca	429	13	-8%	-5%	0%	-16%	-10%	-1%
36	Macleay River	969	9	-8%	-2%	3%	-17%	-4%	6%
37	Macquarie-Castlereagh	544	9	-9%	-1%	3%	-19%	-3%	6%
38	Macquarie-Tuggerah Lakes	1137	9	-9%	-2%	4%	-17%	-5%	8%

Table 2 (cont) Summary of projected impacts of climate change on rainfall for all catchments in south-eastern Australia

				1 degree of global warming			2 degrees of global warming		
ID	Catchment	Historical rainfall (mm)	# of GCMs (out of 15) projecting a decrease in future rainfall	Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
39	Mambray Coast	280	11	-12%	-4%	4%	-24%	-8%	8%
40	Manning River	1091	10	-8%	-2%	3%	-16%	-4%	7%
41	Maribyrnong River	676	15	-8%	-5%	-2%	-16%	-11%	-4%
42	Millicent Coast	553	14	-9%	-5%	-1%	-18%	-10%	-3%
43	Mitchell River	969	15	-8%	-4%	-1%	-16%	-9%	-3%
44	Moonie	528	11	-11%	-5%	3%	-22%	-10%	6%
45	Moorabool River	602	15	-8%	-5%	-3%	-17%	-11%	-5%
46	Moruya River	900	11	-7%	-2%	4%	-15%	-5%	7%
47	Murray	340	11	-11%	-4%	2%	-21%	-8%	4%
48	Murrumbidgee	529	12	-8%	-4%	2%	-17%	-7%	5%
49	Myponga River	691	15	-11%	-4%	-1%	-21%	-9%	-1%
50	Namoi	634	8	-9%	-1%	3%	-17%	-2%	7%
51	Onkaparinga River	700	15	-11%	-4%	-1%	-21%	-9%	-1%
52	Otway Coast	1002	15	-7%	-5%	-2%	-14%	-9%	-5%
53	Ovens	1000	14	-8%	-4%	0%	-16%	-8%	0%
54	Paroo	312	10	-13%	-4%	6%	-26%	-9%	11%
55	Portland Coast	761	15	-7%	-5%	-3%	-14%	-10%	-5%
56	Richmond River	1272	11	-9%	-5%	2%	-19%	-9%	4%
57	Shoalhaven River	892	10	-7%	-3%	4%	-15%	-6%	7%
58	Snowy Mtns Scheme	1068	11	-8%	-3%	3%	-16%	-6%	5%
59	Snowy River	774	11	-7%	-3%	3%	-14%	-6%	6%
60	South Gippsland	892	15	-7%	-4%	-2%	-14%	-9%	-3%
61	Spencer Gulf	290	13	-11%	-4%	1%	-23%	-9%	2%
62	Sydney Coast-Georges River	1017	10	-7%	-2%	5%	-15%	-5%	9%
63	Tambo River	790	13	-9%	-4%	0%	-17%	-8%	1%
64	Thomson River	926	15	-8%	-5%	-2%	-16%	-9%	-3%
65	Torrens River	664	15	-11%	-4%	-1%	-21%	-8%	-1%
66	Towamba River	876	11	-7%	-3%	4%	-13%	-6%	7%
67	Tuross River	893	10	-7%	-2%	4%	-14%	-4%	8%
68	Tweed River	1712	12	-9%	-5%	2%	-19%	-9%	4%
69	Wakefield River	415	15	-11%	-4%	0%	-23%	-8%	-1%
70	Warrego	426	11	-12%	-4%	5%	-24%	-8%	10%
71	Werribee River	613	15	-8%	-6%	-2%	-17%	-11%	-4%
72	Willochra Creek	303	11	-12%	-4%	4%	-24%	-9%	8%
73	Wimmera	403	13	-9%	-5%	0%	-18%	-9%	0%
74	Wollongong Coast	1250	10	-7%	-2%	5%	-13%	-5%	9%
75	Yarra River	1030	15	-8%	-5%	-2%	-16%	-9%	-3%
	SEACI region	**489**	**11**	**-10%**	**-4%**	**2%**	**-20%**	**-8%**	**4%**

Table 3. Summary of projected impacts of climate change on runoff for all catchments in south-eastern Australia

				1 degree of global warming			2 degrees of global warming		
ID	Catchment	Historical runoff (mm)	# of GCMs (out of 15) projecting a decrease in future runoff	Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
1	Barwon River	52	15	-22%	-16%	-8%	-38%	-29%	-14%
2	Barwon-Darling	9	10	-25%	-8%	13%	-38%	-12%	30%
3	Bega River	211	10	-14%	-6%	9%	-26%	-10%	18%
4	Bellinger River	434	12	-20%	-9%	3%	-37%	-17%	5%
5	Border Rivers	32	11	-30%	-14%	7%	-52%	-25%	22%
6	Broughton River	10	14	-28%	-15%	-2%	-47%	-26%	-2%
7	Brunswick River	659	13	-20%	-11%	1%	-38%	-21%	2%
8	Bulloo River	5	9	-36%	-7%	26%	-57%	-4%	58%
9	Bunyip River	156	15	-21%	-14%	-6%	-37%	-25%	-9%
10	Campaspe	63	14	-27%	-16%	-7%	-46%	-28%	-12%
11	Clarence River	223	12	-21%	-11%	3%	-38%	-20%	6%
12	Clyde River-Jervis Bay	351	12	-15%	-5%	6%	-28%	-8%	12%
13	Condamine-Balonne	16	11	-33%	-13%	14%	-54%	-21%	31%
14	East Gippsland	196	11	-18%	-8%	7%	-33%	-14%	15%
15	Eastern Mt Lofty Ranges	29	14	-30%	-16%	-5%	-51%	-29%	-9%
16	Eyre Peninsula	23	15	-28%	-22%	-9%	-48%	-38%	-16%
17	Fleurieu Peninsula	73	15	-23%	-15%	-4%	-42%	-25%	-7%
18	Gairdner	3	11	-25%	-11%	1%	-42%	-17%	7%
19	Gawler River	18	14	-31%	-17%	-6%	-52%	-31%	-11%
20	Glenelg River	81	15	-28%	-19%	-10%	-48%	-34%	-18%
21	Goulburn-Broken	153	14	-21%	-12%	-4%	-38%	-23%	-7%
22	Gwydir	37	11	-28%	-10%	9%	-48%	-17%	24%
23	Hastings River	416	11	-19%	-6%	3%	-35%	-12%	6%
24	Hawkesbury River	135	11	-20%	-6%	8%	-36%	-10%	17%
25	Hopkins River	40	15	-30%	-21%	-11%	-50%	-36%	-19%
26	Hunter River	92	11	-22%	-6%	7%	-40%	-10%	15%
27	Kangaroo Island	52	15	-22%	-17%	-5%	-40%	-28%	-9%
28	Karuah River	367	12	-21%	-9%	2%	-39%	-16%	5%
29	Lachlan	24	12	-26%	-11%	5%	-43%	-18%	12%
30	Lake Bancannia	4	8	-35%	0%	25%	-52%	2%	54%
31	Lake Corangamite	34	15	-25%	-18%	-9%	-43%	-32%	-17%
32	Lake Frome	3	8	-37%	1%	30%	-58%	4%	62%
33	Lake Torrens	2	8	-26%	-2%	18%	-44%	-1%	45%
34	Latrobe River	181	15	-21%	-14%	-6%	-37%	-25%	-9%
35	Loddon-Avoca	18	13	-28%	-17%	-7%	-47%	-30%	-12%
36	Macleay River	171	11	-20%	-7%	5%	-37%	-13%	10%
37	Macquarie-Castlereagh	33	12	-25%	-8%	5%	-42%	-12%	13%
38	Macquarie-Tuggerah Lakes	271	11	-22%	-6%	6%	-41%	-10%	13%

Table 3 (cont) Summary of projected impacts of climate change on runoff for all catchments in south-eastern Australia

				1 degree of global warming			2 degrees of global warming		
ID	Catchment	Historical runoff (mm)	# of GCMs (out of 15) projecting a decrease in future runoff	Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
39	Mambray Coast	5	9	-25%	-8%	14%	-42%	-10%	33%
40	Manning River	250	11	-20%	-7%	5%	-37%	-12%	10%
41	Maribyrnong River	68	15	-27%	-17%	-7%	-47%	-29%	-12%
42	Millicent Coast	48	14	-30%	-19%	-9%	-50%	-34%	-16%
43	Mitchell River	219	14	-20%	-12%	-4%	-35%	-22%	-6%
44	Moonie	16	11	-32%	-12%	9%	-53%	-20%	24%
45	Moorabool River	54	15	-24%	-16%	-8%	-41%	-28%	-13%
46	Moruya River	223	12	-16%	-5%	7%	-30%	-9%	14%
47	Murray	24	11	-21%	-10%	1%	-38%	-19%	4%
48	Murrumbidgee	51	12	-22%	-10%	3%	-39%	-17%	8%
49	Myponga River	82	15	-26%	-14%	-5%	-46%	-26%	-9%
50	Namoi	28	11	-27%	-7%	10%	-46%	-11%	23%
51	Onkaparinga River	97	14	-29%	-16%	-6%	-50%	-30%	-10%
52	Otway Coast	215	15	-19%	-14%	-8%	-34%	-27%	-14%
53	Ovens	224	14	-21%	-12%	-3%	-38%	-22%	-5%
54	Paroo	8	10	-32%	-13%	27%	-51%	-20%	61%
55	Portland Coast	98	15	-22%	-16%	-9%	-40%	-29%	-17%
56	Richmond River	350	12	-20%	-11%	1%	-38%	-21%	2%
57	Shoalhaven River	237	12	-16%	-5%	7%	-30%	-9%	13%
58	Snowy Mtns Scheme	363	12	-17%	-7%	2%	-32%	-13%	5%
59	Snowy River	106	11	-19%	-8%	7%	-34%	-15%	15%
60	South Gippsland	155	14	-20%	-13%	-6%	-36%	-24%	-10%
61	Spencer Gulf	4	11	-26%	-12%	3%	-43%	-19%	11%
62	Sydney Coast-Georges River	182	12	-20%	-7%	9%	-36%	-13%	19%
63	Tambo River	74	12	-24%	-12%	2%	-41%	-21%	5%
64	Thomson River	203	14	-19%	-12%	-3%	-35%	-22%	-5%
65	Torrens River	90	14	-28%	-16%	-6%	-49%	-29%	-10%
66	Towamba River	199	10	-16%	-7%	8%	-29%	-12%	17%
67	Tuross River	226	10	-15%	-5%	7%	-28%	-8%	15%
68	Tweed River	630	13	-19%	-11%	1%	-36%	-20%	2%
69	Wakefield River	11	14	-31%	-17%	-6%	-51%	-29%	-9%
70	Warrego	13	11	-33%	-13%	24%	-52%	-24%	52%
71	Werribee River	45	14	-25%	-16%	-6%	-43%	-27%	-11%
72	Willochra Creek	6	10	-23%	-8%	12%	-40%	-10%	29%
73	Wimmera	17	13	-29%	-18%	-6%	-49%	-31%	-11%
74	Wollongong Coast	342	12	-15%	-6%	8%	-29%	-11%	17%
75	Yarra River	239	15	-21%	-13%	-5%	-38%	-24%	-9%
	SEACI region	**37**	**12**	**-24%**	**-12%**	**1%**	**-41%**	**-21%**	**5%**

3. CONCLUSIONS

This study has examined the potential impacts of climate change on climate and runoff across south-eastern Australia. The climate change examined was that produced by 1 °C and 2 °C of global warming, corresponding to ~2030 and ~2070 under the A1B emission scenario.

There is considerable uncertainty in the GCM simulations of rainfall response in the SEACI region to global warming. However, the majority of GCMs show a decrease in the mean annual rainfall. Most of the GCMs indicate that future winter rainfall is likely to be lower across the entire SEACI region. Most of the rainfall and runoff in the southern half of the SEACI region occurs in the winter half of the year, and almost all the GCMs indicate less future winter rainfall there.

Projections indicate that future mean annual rainfall under 1 °C of global warming will be lower across the southern half of the region. Averaged across the area south of 33° S, rainfall is projected to decline by between 0 and 9 percent, with a median reduction of 4 percent. This reduction in rainfall would lead to a reduction in areally-averaged runoff of between 2 and 22 percent, with a median estimated reduction of 12 percent.

Across the northern half of the region, projections are less certain, although most GCMs still project a reduction in mean annual rainfall and therefore runoff. Averaged across the area north of 33° S, rainfall is projected to change by between an increase of 4 percent and a decrease of 11 percent, with a median reduction of 3 percent. This change in rainfall would lead to a change in runoff of between an increase of 12 percent and a decrease of 29 percent, with a median estimated reduction of 10 percent.

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For more information:

Email **seaci@csiro.au**
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