South Eastern Australian Climate initiative

Project 2.2.2

Future runoff projections (~2030) for south-eastern Australia

Prepared by
Post DA, Chiew FHS, Vaze J, Teng J, Perraud J-M, Viney NR.

CSIRO Land and Water
Ph: 02 6246 5751
seaci@csiro.au
http://www.seaci.org

Australian Government
Department of Climate Change
Bureau of Meteorology

MURRAY–DARLING BASIN AUTHORITY

State Government Victoria Department of Sustainability and Environment

National Research FLAGSHIPS Water for a Healthy Country

CSIRO

Table of Contents

List of Figures

Summary

This report describes the rainfall-runoff modelling for 0.05° grid cells (~ 5 km x 5 km) across the SEACI (South Eastern Australian Climate Initiative) region and presents the runoff estimates for the historical climate and the likely changes to runoff in ~2030 for the SRES A1B global warming scenario. Daily rainfall and areal potential evapotranspiration (APET) data from 1895–2006 are used for the modelling.

The methods used here and the presentation in this report are very similar to the Murray-Darling Basin Sustainable Yields (MDBSY) Project. However, unlike the MDBSY Project, this study reports on the IPCC SRES A1B global warming scenario. Specifically, this study presents the range of runoff modelling results using climate change projections from 15 global climate models (GCMs) for the IPCC SRES A1B global warming scenario for the SEACI region.

There are three main outputs from this study. The first output is the presentation of runoff estimates for the historical climate and the likely changes to runoff in ~2030 (this report). The second output is the daily rainfall, APET and modelled runoff series across the SEACI region. The third output is parameter values for the SIMHYD and Sacramento lumped conceptual daily rainfall-runoff models for 0.05° grid cells across the SEACI region. The second and third outputs are particularly useful because they can be used to model climate change impacts on runoff for different global warming scenarios and different future periods or to update results as climate change projections improve. The data and models are also useful for other hydrological modelling studies.

The modelling in this study indicates that the mean annual rainfall and runoff, averaged over 1895 to 2006 over the entire SEACI region, are 490 mm and 37 mm respectively. 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 and runoff occurs in the summer-half of the year, and in the south of the SEACI region, most of the rainfall and runoff occurs in the winter-half of the year.

The future climate series for ~2030 is obtained by scaling the historical 1895–2006 daily rainfall and areal PET data using the daily scaling method, informed by the IPCC SRES A1B global warming scenario. The future climate series is then used to drive the rainfall-runoff model (using the same parameter values for modelling the historical climate) to estimate the future runoff (~2030 relative to ~1990).

There is considerable uncertainty in the GCM modelling 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.

The median (best estimate) indicates that future mean annual runoff in the SEACI region in ~2030 relative to ~1990 will be lower, by 0 to 20 percent in the north-east and southern half, and by 10 to 30 percent in Victoria. Averaged across the SEACI region, the median (best estimate) is a 8 percent decrease in mean annual runoff.

The modelled mean annual runoff using the climate change projections from the 15 GCMs range from a 30 percent decrease to a 30 percent increase in the northern half of the SEACI region, 30 percent decrease to 10 percent increase in the southern half of the SEACI region and 50 percent decrease to no change in Victoria. Averaged over the entire SEACI region, the extreme estimates range from a 20 percent decrease to a 6 percent increase in mean annual runoff.

The projected decrease in mean annual runoff in the south of the SEACI region is higher than in the north of the SEACI region because the projected decrease in rainfall is slightly higher in the south, and most of the projected rainfall decrease is in winter when most of the runoff in the south occurs.

1. Methods

1.1 Rainfall-runoff modelling

The rainfall-runoff modelling method adopted provides a consistent way of modelling historical runoff across the SEACI region and 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 entire SEACI region for both current conditions and for 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 south-eastern Australia (referred to hereafter as calibration catchments, see Figure 1). 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.

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 five per cent 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 SEACI region). Almost all the catchments available for model calibration are in the higher runoff areas in the southern and eastern parts of the SEACI region. Runoff estimates are therefore generally good in the southern and eastern parts of the SEACI region, and are comparatively poor elsewhere.

The same set of parameter values are used to model runoff across the SEACI region for both the historical climate and future climate scenarios using 112 years of daily climate inputs described in Section 1.2. 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 (see Chiew *et al.* 2008b for discussion of this complex issue).

The rainfall-runoff model SIMHYD is used because it is simple and has relatively few parameters and, for the purpose of this project, provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire SEACI 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 – as carried out by some agencies – 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. (2008a and 2008b), and for the SEACI region in Chiew et al. (in prep.). The results from these studies indicate that the simulations from the two rainfall-runoff models are relatively similar in the context of the current application.

1.2 Climate scenarios

Daily rainfall and potential evapotranspiration (PET) are required to run the SIMHYD rainfall-runoff model. The climate data and their derivation for the hydrologic scenario modelling across the Murray-Darling Basin (a subset of the SEACI region) are described in detail in Chiew et al. (2008a). A brief summary is given here.

The historical climate (1895-2006) 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 (www.bom.gov.au/averages; Morton, 1983; and Chiew and Leahy, 2003).

The future climate is used to assess the range of likely climate around the year 2030. Fifteen future climate variants, each with 112 years of daily climate sequences, are used. The future climate variants were developed by scaling the 1895 to 2006 climate data to reflect ~2030 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 in 2030 that is 0.9^{o}C higher than the global 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 emission scenarios by 2030 although they diverge after the mid-21st Century.

As the future climate series (A1B scenario) is obtained by scaling the historical daily climate series from 1895 to 2006, the daily climate series for the historical and future climate have the same length of data (112 years) and the same sequence of daily climate. The future climate scenario is therefore not a forecast climate at 2030, but a 112-year daily climate series based on 1895 to 2006 data for projected global temperatures at ~2030 relative to ~1990.

The method used to obtain the future climate series also 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 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 extreme runoff as well as the mean annual runoff.

The methods used here are very similar to the Murray-Darling Basin Sustainable Yields (MDBSY) Project. However, unlike the MDBSY Project, this study reports on the IPCC SRES A1B global warming scenario. Specifically, this study presents the range of runoff modelling results using climate change projections from 15 GCMs for the SRES A1B global warming scenario for the SEACI region.

The method used here is also similar to, but not the same as, the approach used by CSIRO and Australian Bureau of Meteorology (2007) (www.climatechangeinaustralia.gov.au) to provide the climate change projections for Australia. The main difference is the use of 15 GCMs here compared to the CSIRO/BoM study which used all the 23 IPCC 4AR GCMs. The CSIRO/BoM study also used weights to favour the use of GCMs that best reproduce observed historical climate in Australia. The weights in the CSIRO/BoM study vary from 0.3 to 0.7, and the weights of the 15 GCMs used here are all above 0.5. It is likely that further discrimination of the GCMs and using climate change projections from fewer GCMs will give more consistent results, and this is being addressed in other SEACI projects.

2 Modelling results

2.1 Reporting region and calibration catchments

Figure 1 shows the boundary of the SEACI region and the 219 gauged catchments used to calibrate the rainfall-runoff models. Almost all the calibration catchments available for model calibration are in the higher runoff areas in the southern and eastern parts of the SEACI region. Runoff estimates are therefore generally good there and are comparatively poor elsewhere.

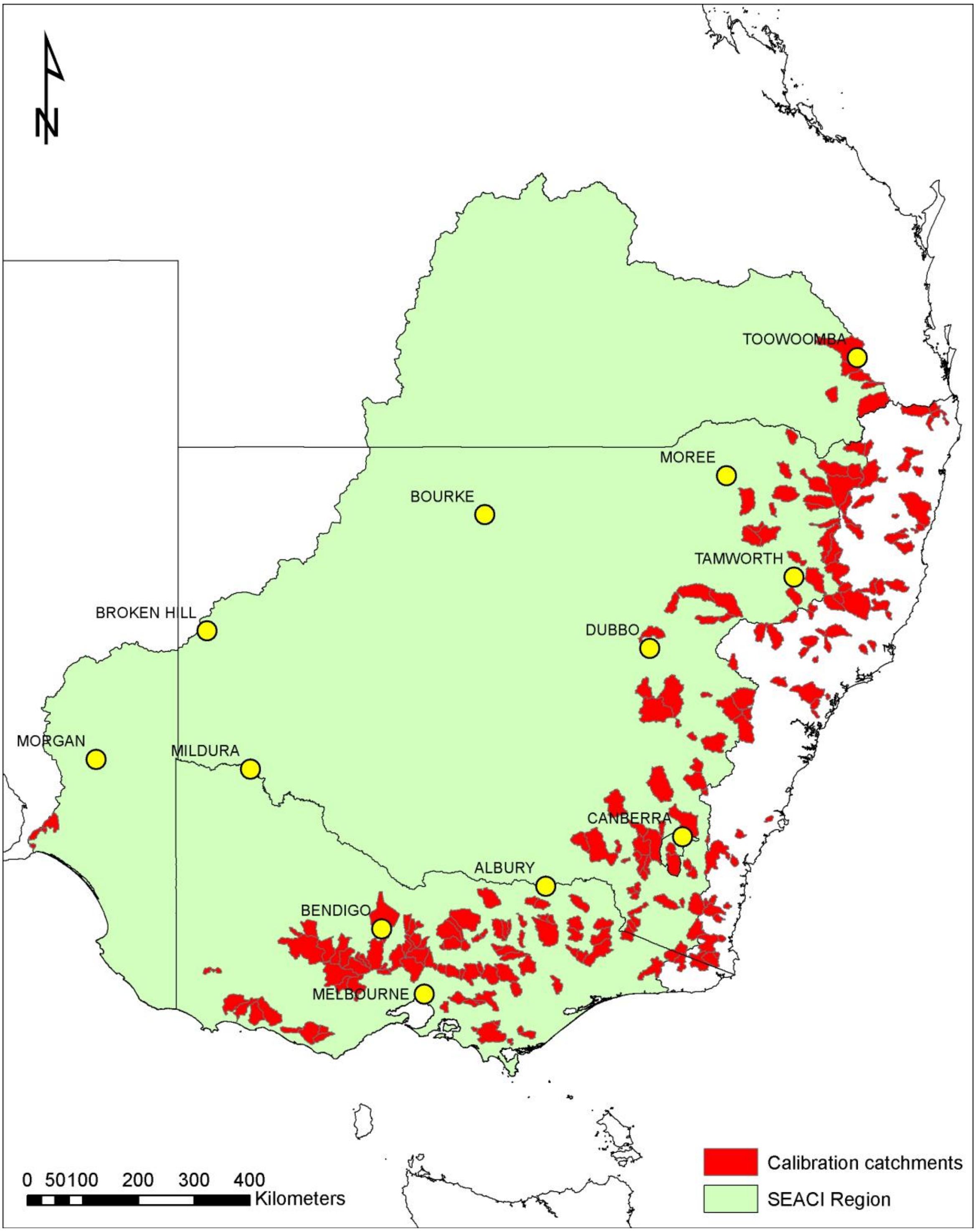

Figure 1. Map showing the SEACI region and calibration catchments.

2.2 Historical rainfall and runoff (1895-2006)

Figure 2, Figure 3, and Figure 4 show the mean annual, summer and winter rainfall, areal potential evapotranspiration (APET) and modelled runoff, averaged over 1895 to 2006. The mean annual rainfall and runoff averaged over the SEACI region are 490 mm and 37 mm respectively.

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 and runoff occurs in the summer-half of the year, and in the south of the SEACI region, most of the rainfall and runoff occurs in the winter-half of the year (see Figure 18).

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 2, Figure 3, and 4. However these artefacts only affect the very driest parts of the SEACI region. Some care therefore needs to be given to the results in the very driest parts of the basin. In part however, this problem is alleviated by the fact that we are comparing runoff under future climate with current runoff. As a result if both are slightly over or under-estimated, the effect will cancel out.

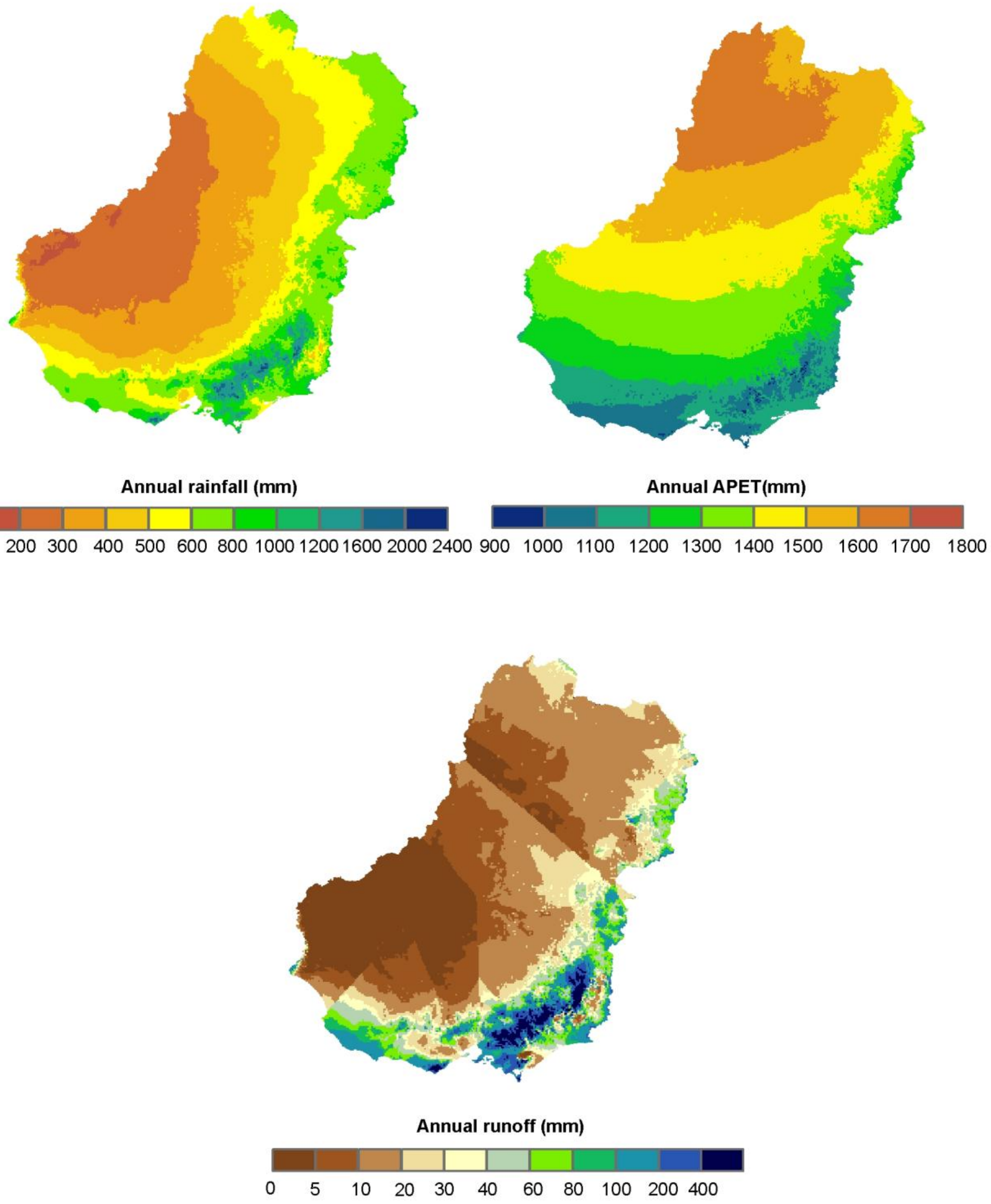

Figure 2. Mean annual rainfall, areal potential evapotranspiration and modelled runoff

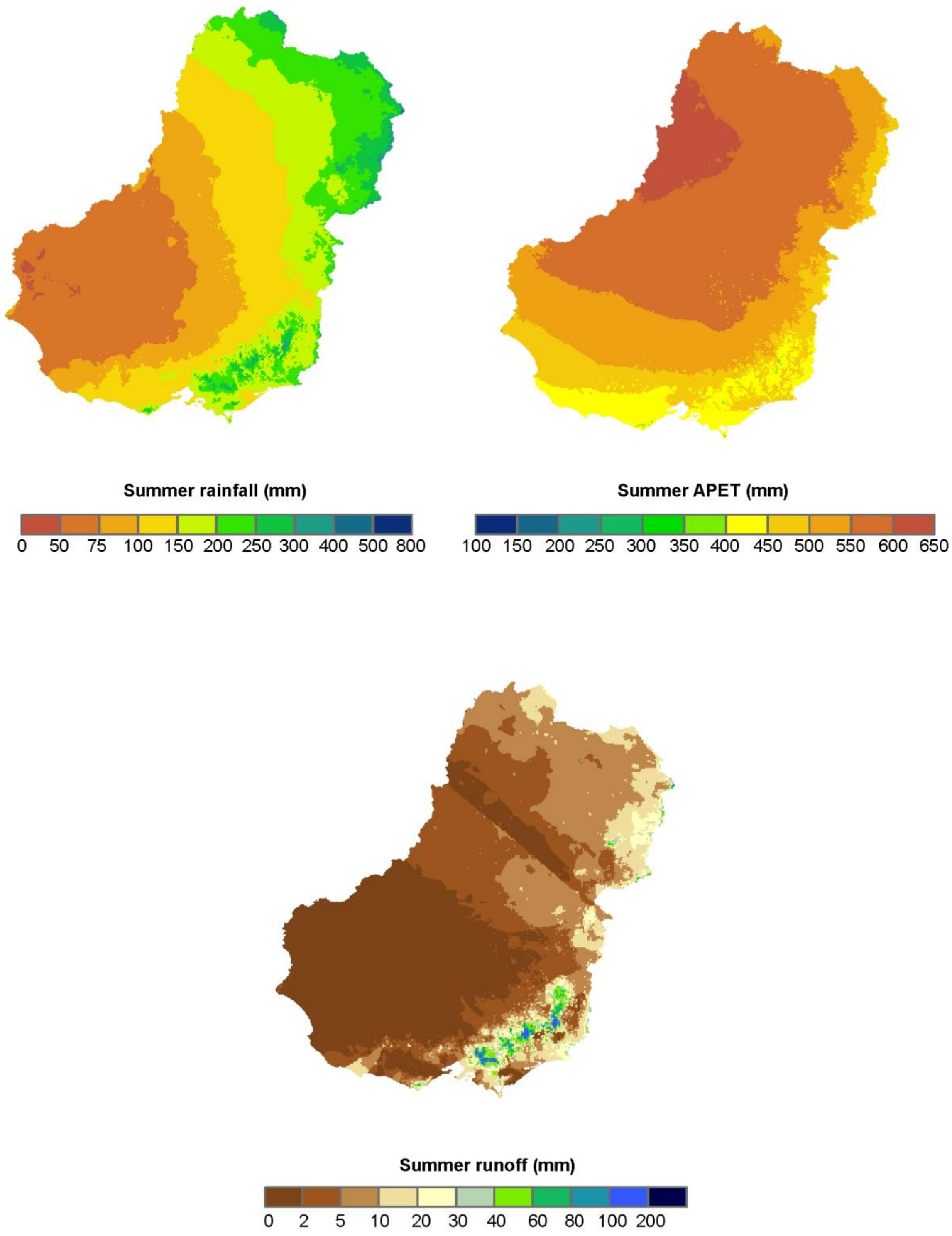

Figure 3. Mean summer (DJF) rainfall, areal potential evapotranspiration and modelled runoff.

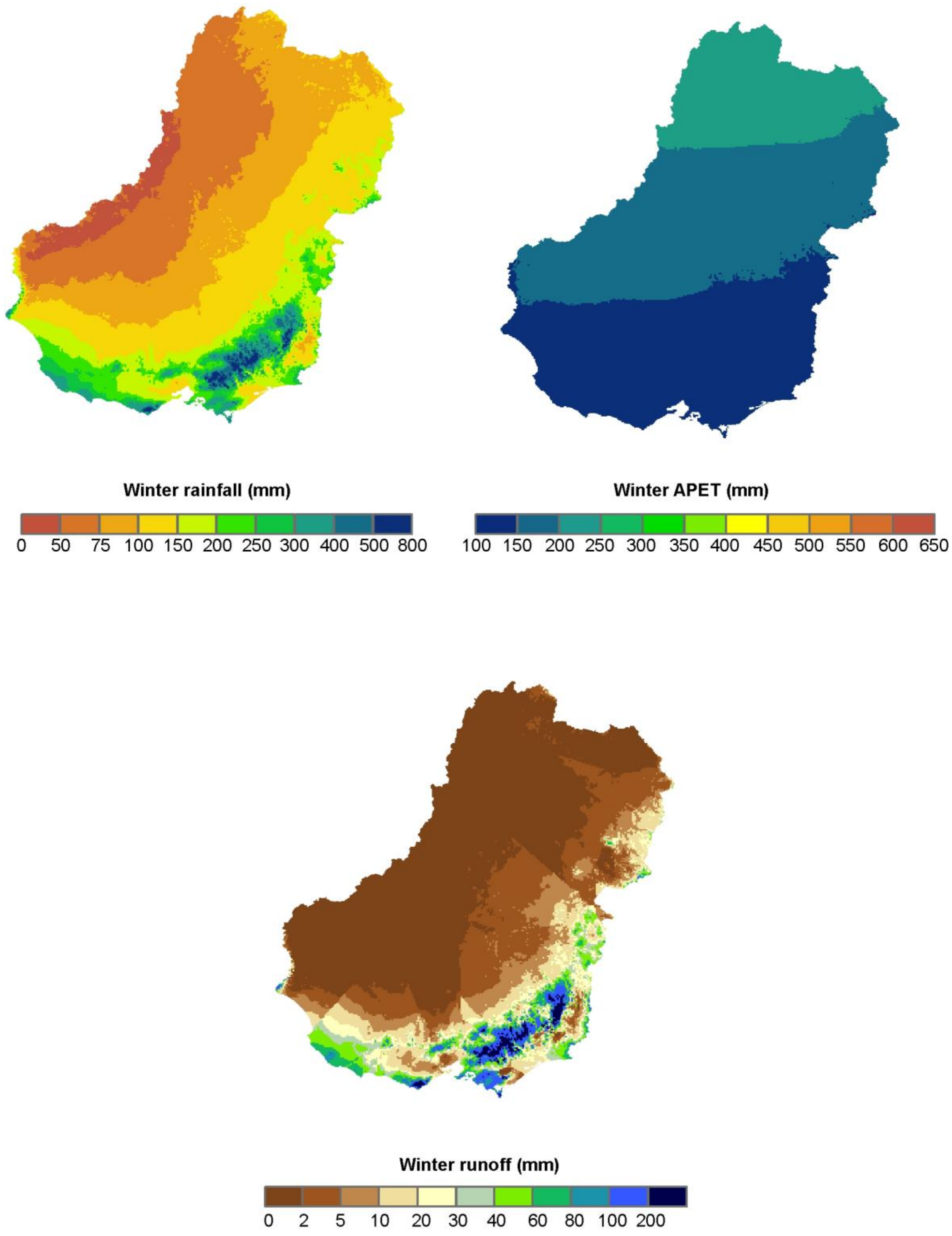

Figure 4. Mean winter (JJA) rainfall, areal potential evapotranspiration and modelled runoff.

2.3 Future rainfall and runoff (SRES A1B emission scenario for 2030)

Figure 5, Figure 6, and Figure 7 show the percentage change in mean annual, summer and winter runoff respectively for ~2030 relative to ~1990 modelled by the SIMHYD rainfall-runoff model using climate change projections from the 15 GCMs for the A1B global warming scenario (see Chiew et al. (2008a) for description of the GCMs). Figure 8 shows the number of modelled results that indicate a decrease (or increase) in mean annual, summer and winter rainfall, while Figure 9 shows the number of modelled results that indicate a decrease (or increase) in mean annual, summer and winter runoff. The results indicate that the potential changes in runoff as a result of global warming can be very significant. However, there are considerable differences in the runoff modelling results using climate change projections from the different GCMs. Nevertheless, the majority of the results show a decrease in mean annual runoff, particularly in the southern half of the SEACI region where more than three-quarters of the results show a decrease in mean annual runoff (Figure 5 and Figure 9).

The majority of the results indicate that the future summer runoff will increase except in the southern-most area of the SEACI region (Figure 6 and Figure 9). The results also indicate that future winter-runoff is likely to be lower across the SEACI region, with more than two-thirds of the results showing a decrease in winter runoff (Figure 7 and Figure 9). As most of the runoff in the southern half of the SEACI region occurs in winter, the decrease in winter runoff translates to a significant decrease in mean annual runoff there.

The number of GCMs showing an increase in the top one-percentile (extreme) rainfall is shown in Figure 10 while the number of GCMs showing an increase in the top one-percentile (extreme) runoff is shown in Figure 11. A comparison of Figure 8 and Figure 10 shows that although the mean annual and winter rainfall is projected to decrease, extreme rainfall is likely to increase, particularly across NSW and Victoria. That is, although the total rainfall has decreased, the extreme rainfall actually increases in most locations and in most seasons. This effect is much less noticeable for runoff (Figure 9 and Figure 11). This is probably because the overall drier antecedent conditions mean that the increase in extreme rainfall does not translate directly to as large an increase in extreme runoff, however comparing Figure 9 with Figure 11 shows that the extreme runoff does not decrease by as much as the total runoff.

The percentage change in runoff resulting from the median or best estimate of the change in mean annual, summer and winter runoff and the extreme range of changes across the SEACI region are shown in Figure 12, Figure 14, and Figure 16. For the median or best estimate, the median result from the A1B global warming scenario is used. For the dry estimate, the second driest result from the A1B global warming scenario is used. For the wet estimate, the second wettest result from the A1B global warming scenario is used.

The median or best estimate indicates that the future mean annual runoff in the SEACI region in ~2030 relative to ~1990 will be lower by 0 to 20 percent in the northeast and southern half, and lower by about 10 to 30 percent over much of Victoria. Averaged across the entire SEACI region, the median or best estimate is a 8 per cent decrease in mean annual runoff. There is considerable uncertainty in the estimates, with the dry and wet estimates in the northern half of the SEACI region ranging from a 30 per cent decrease to a 30 per cent increase in mean annual runoff. In the southern half of the SEACI region, the extreme estimates range from a 30 per cent decrease to a 10 per cent increase in mean annual runoff, and in Victoria, the extreme estimates range from a decrease in mean annual runoff of up to 50 per cent to little change in mean annual runoff (Figure 12). Averaged across the entire SEACI region the extreme estimates range from a 20 per cent decrease to a six per cent increase in mean annual runoff.

In terms of absolute change in runoff, Figure 13 shows that large decreases in runoff are predicted over the southern and eastern parts of the region. Even the extreme wet estimate only shows relatively small areas of increasing runoff, whereas the extreme dry scenario shows large areas of significantly lower runoff. The vast majority of these changes in annual runoff are predicted to occur in winter as can be seen by comparison of Figure 15 with Figure 17.

The mean monthly rainfall and modelled runoff for 12 selected locations (see Figure 1) and the extreme range for the A1B scenario are shown in Figure 18. The lower and upper bounds are determined for each month separately, with the second driest monthly result from the A1B global warming scenario used to define the lower bound and the second wettest result from the A1B global warming scenario used to define the upper bound. For locations in the north, most of the rainfall and runoff occurs in the summer-half of the year, and for locations in the south most of the rainfall and runoff occurs in the winter-half of the year. The western half of the SEACI region experiences only small amounts of runoff year-round. For close to all of the SEACI region, the prediction is for less runoff for most months of the year (the median prediction for future climate is less than the historical climate). This is particularly true in winter in southern parts of the region.

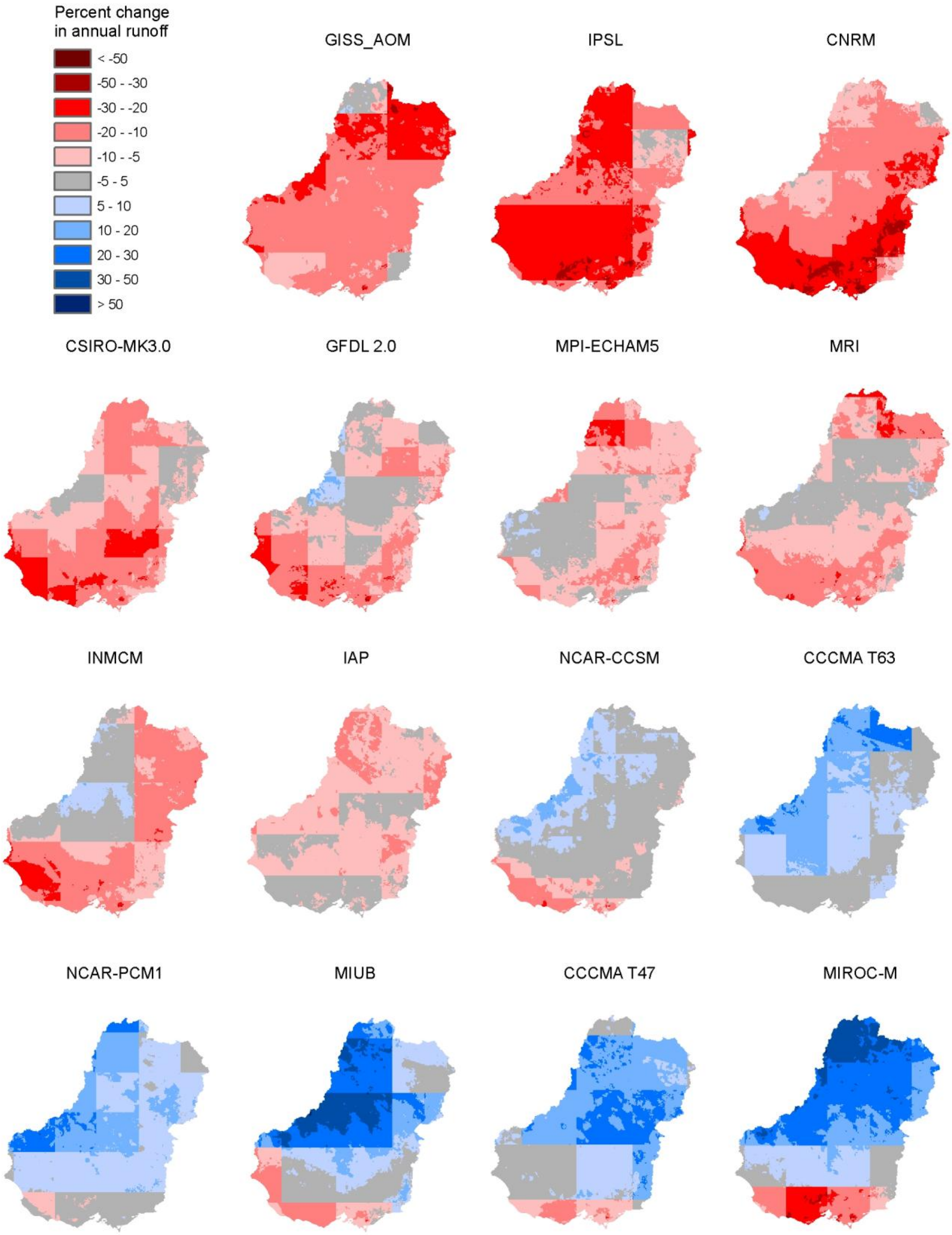

Figure 5. Percentage change in mean annual runoff across the SEACI region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario.

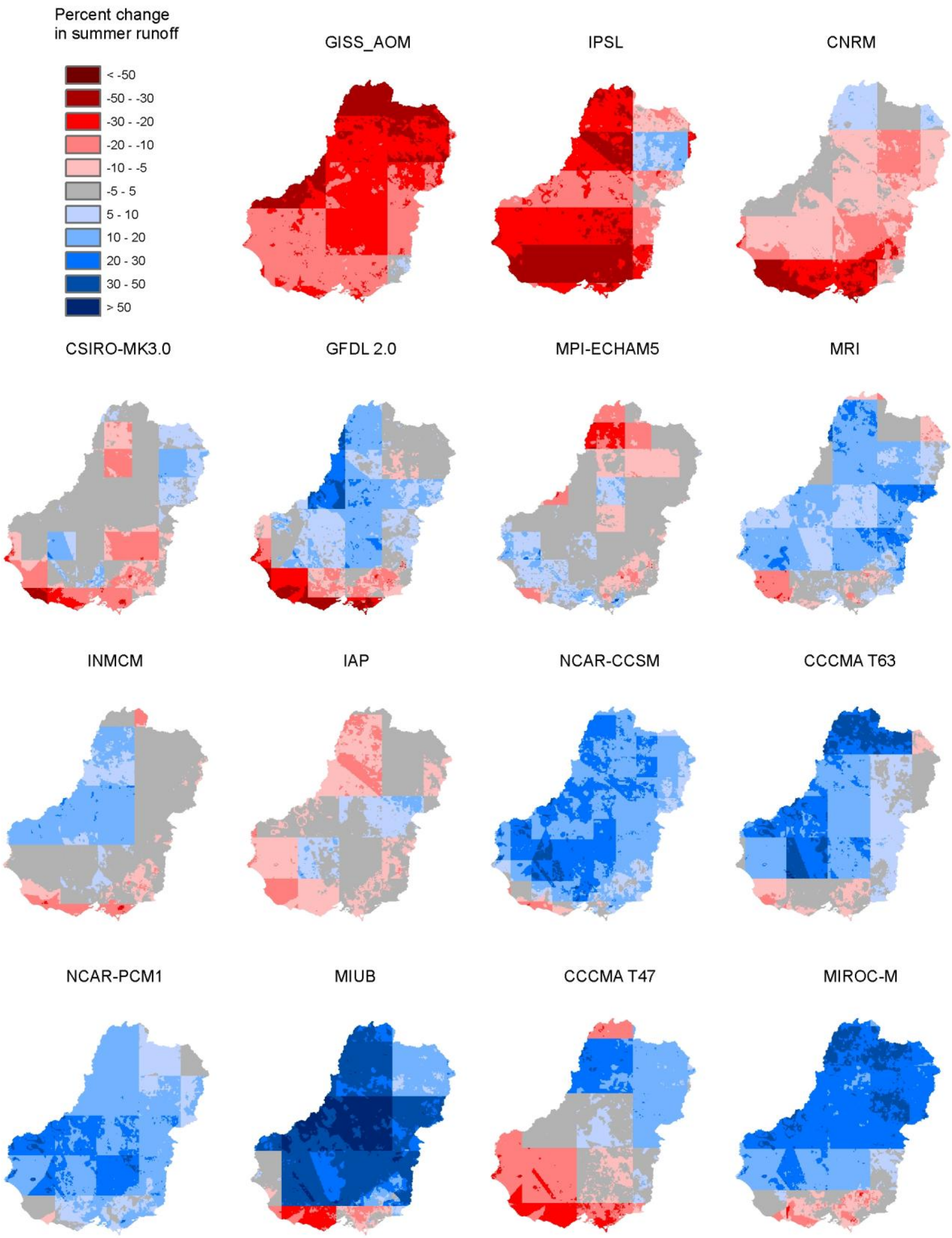

Figure 6. Percentage change in mean summer (DJF) runoff across the SEACI region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario.

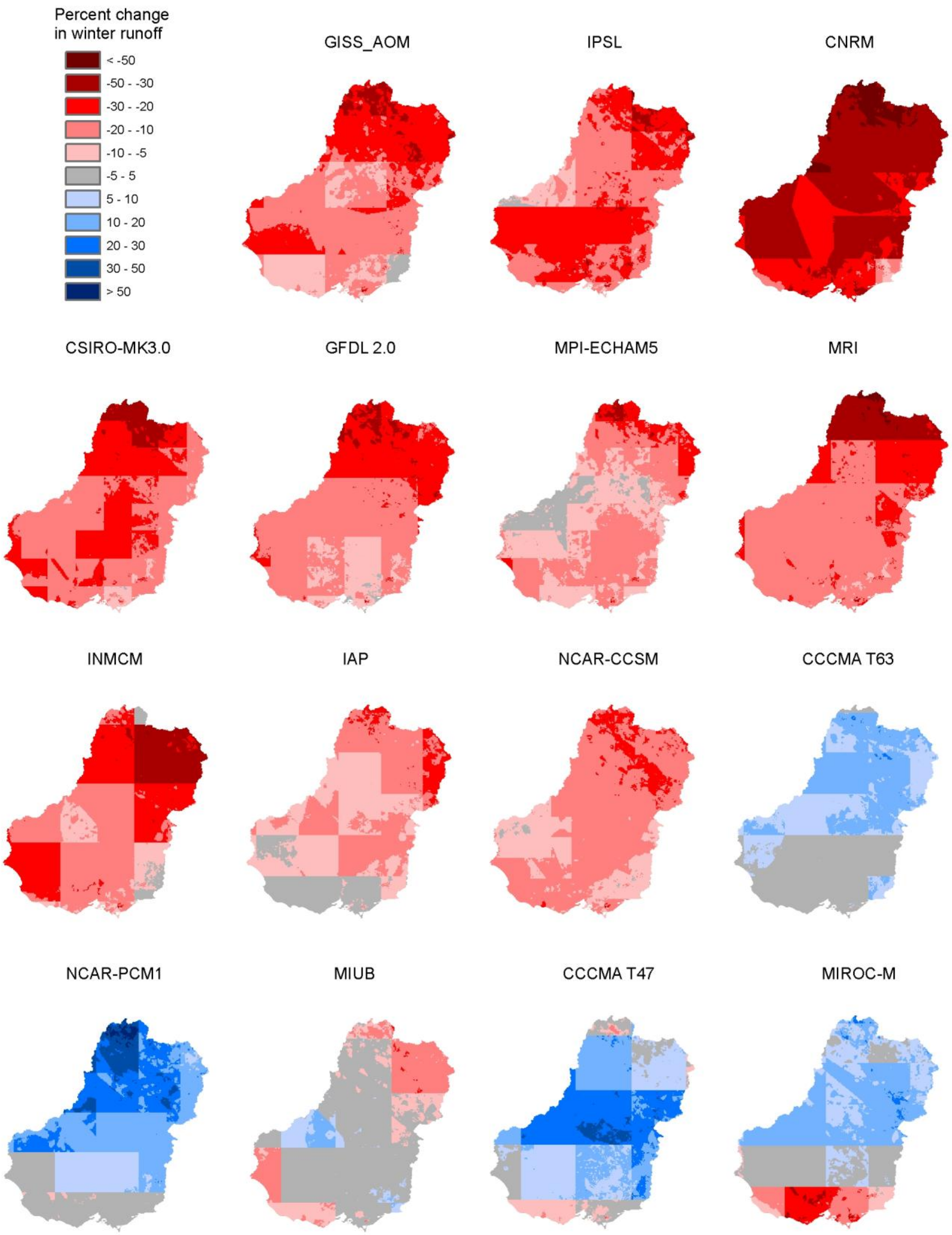

Figure 7. Percentage change in mean winter (JJA) runoff across the SEACI region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario.

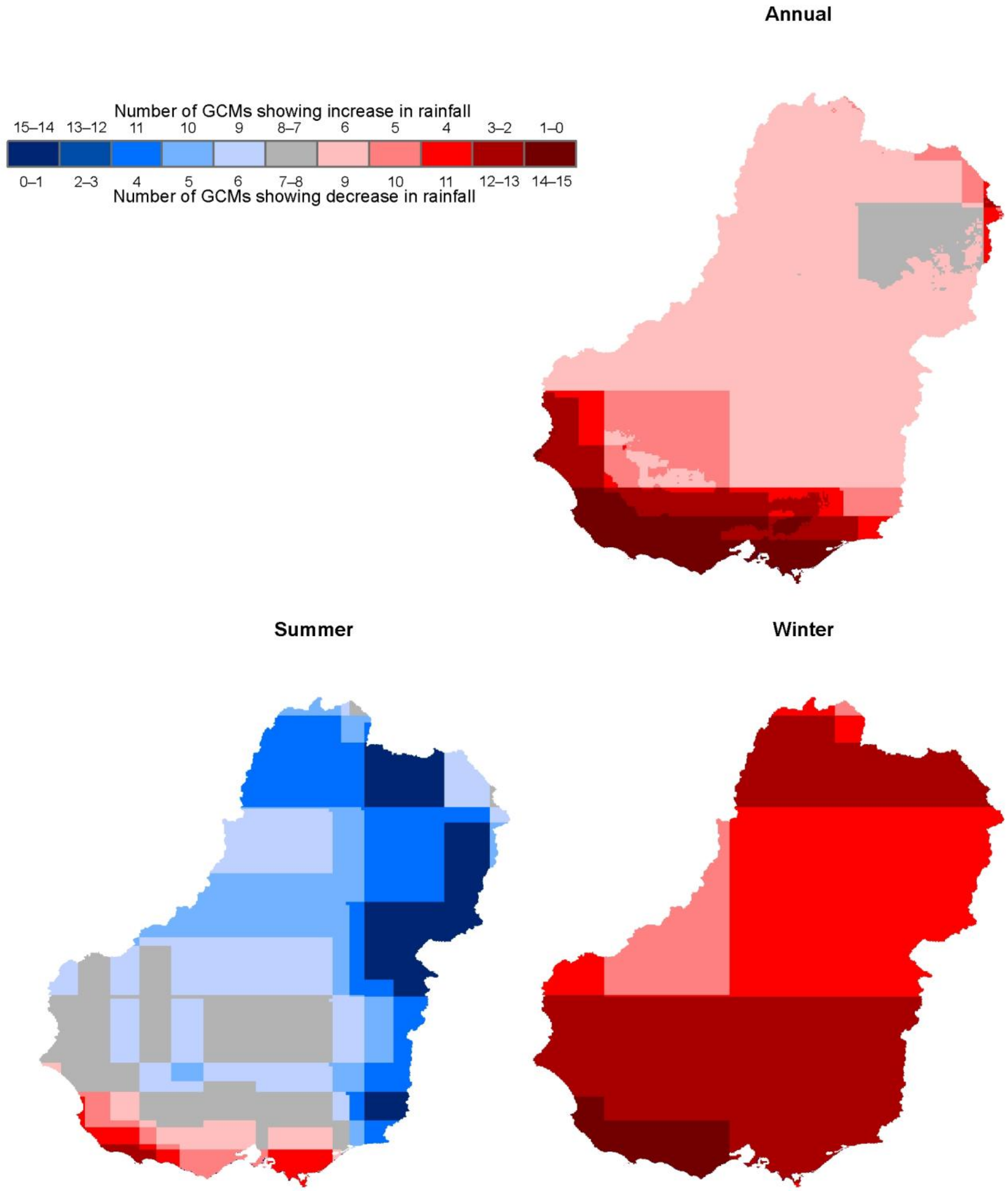

Figure 8. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF) and winter (JJA) rainfall.

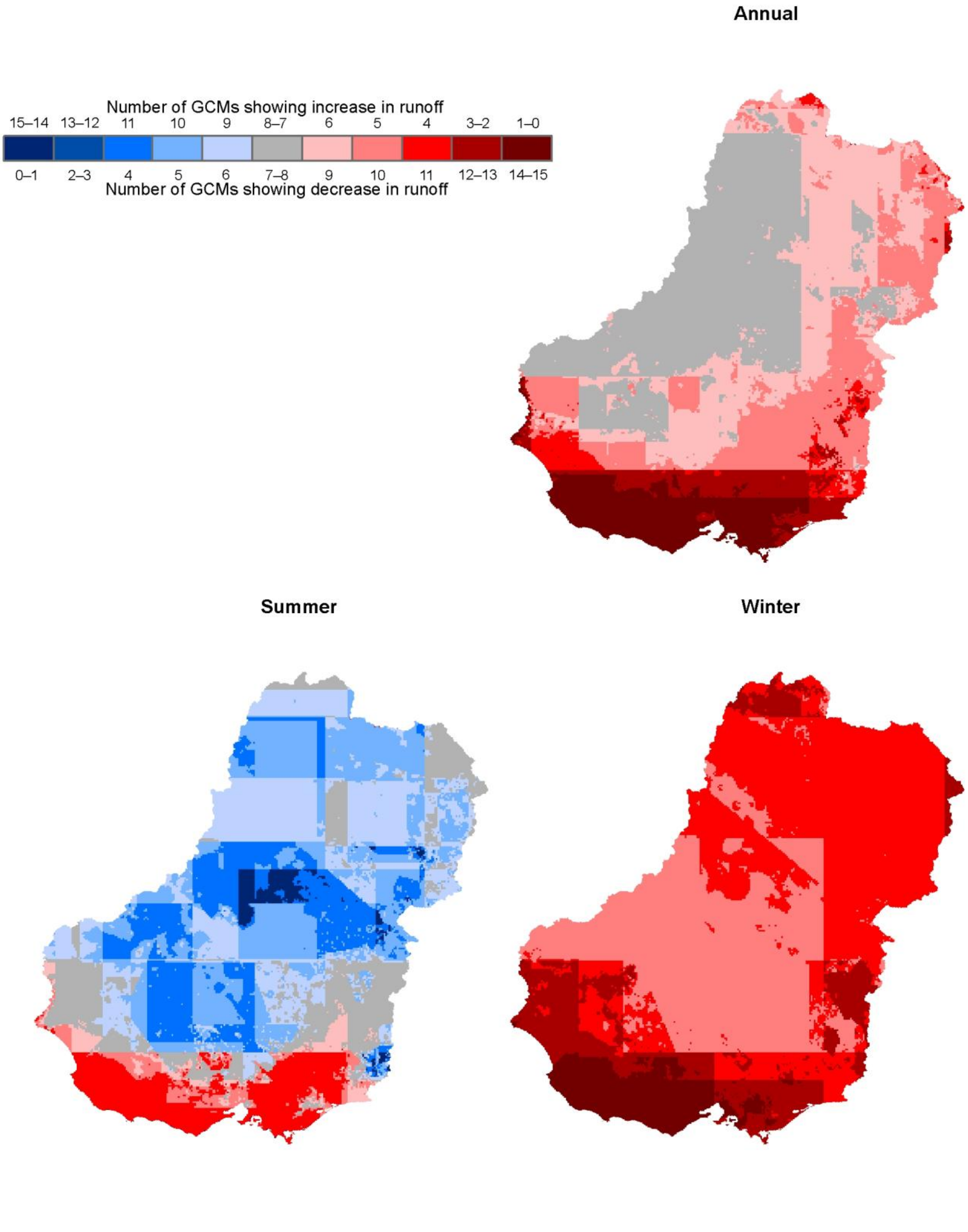

Figure 9. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF) and winter (JJA) runoff.

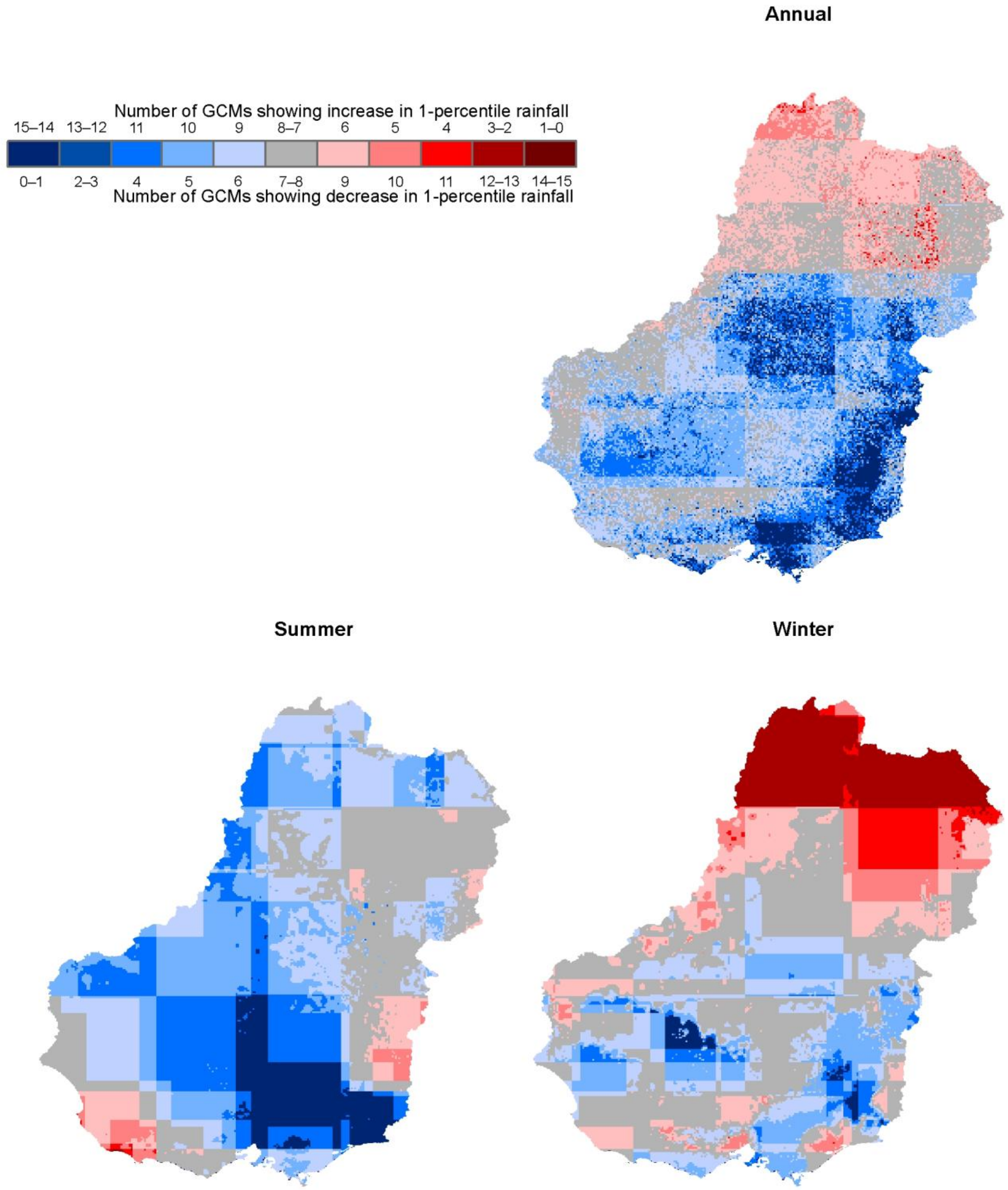

Figure 10. Number of modelling results showing a decrease (or increase) in the top one-percentile future mean annual, summer (DJF) and winter (JJA) rainfall.

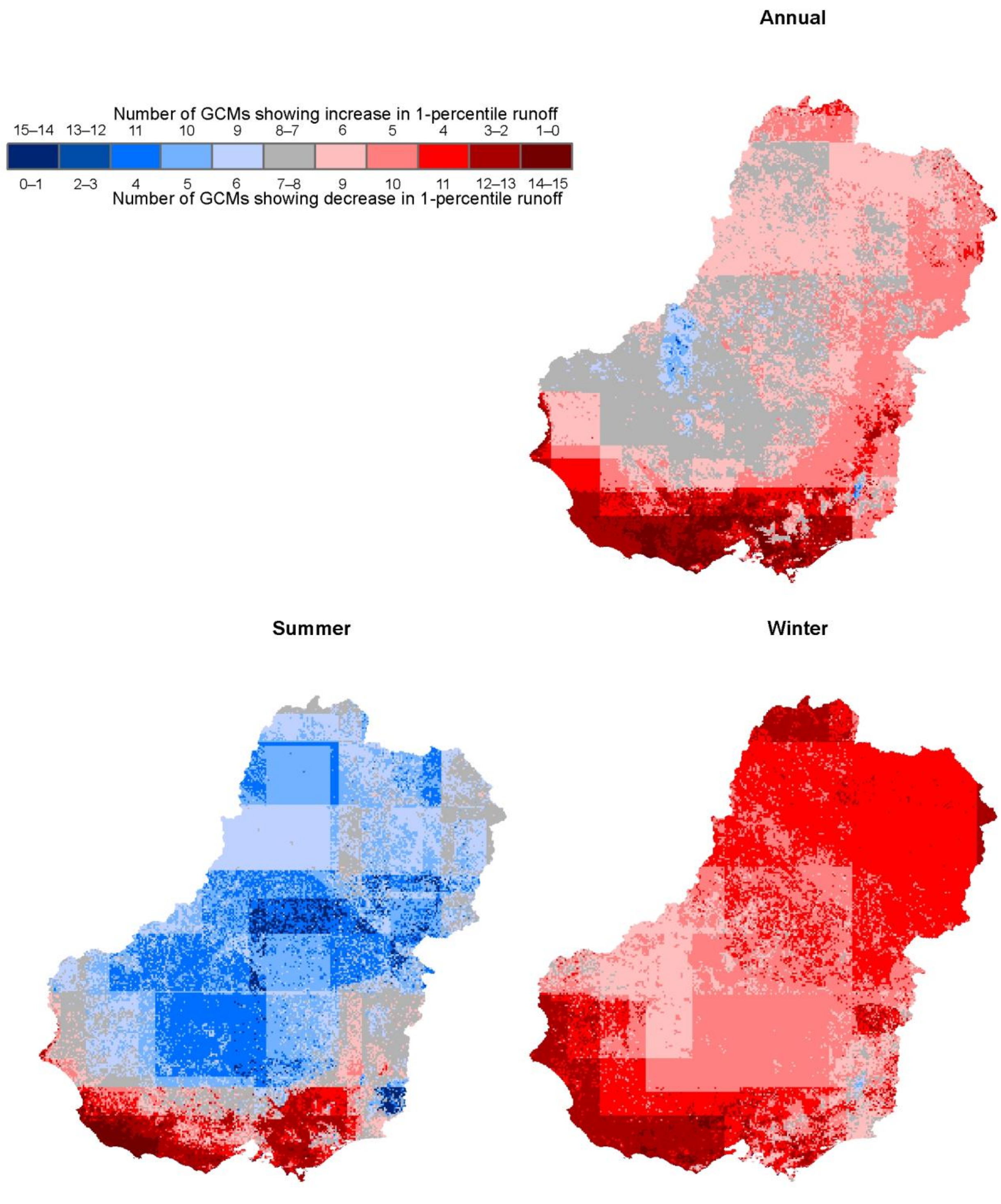

Figure 11. Number of modelling results showing a decrease (or increase) in the top one-percentile future mean annual, summer (DJF) and winter (JJA) runoff.

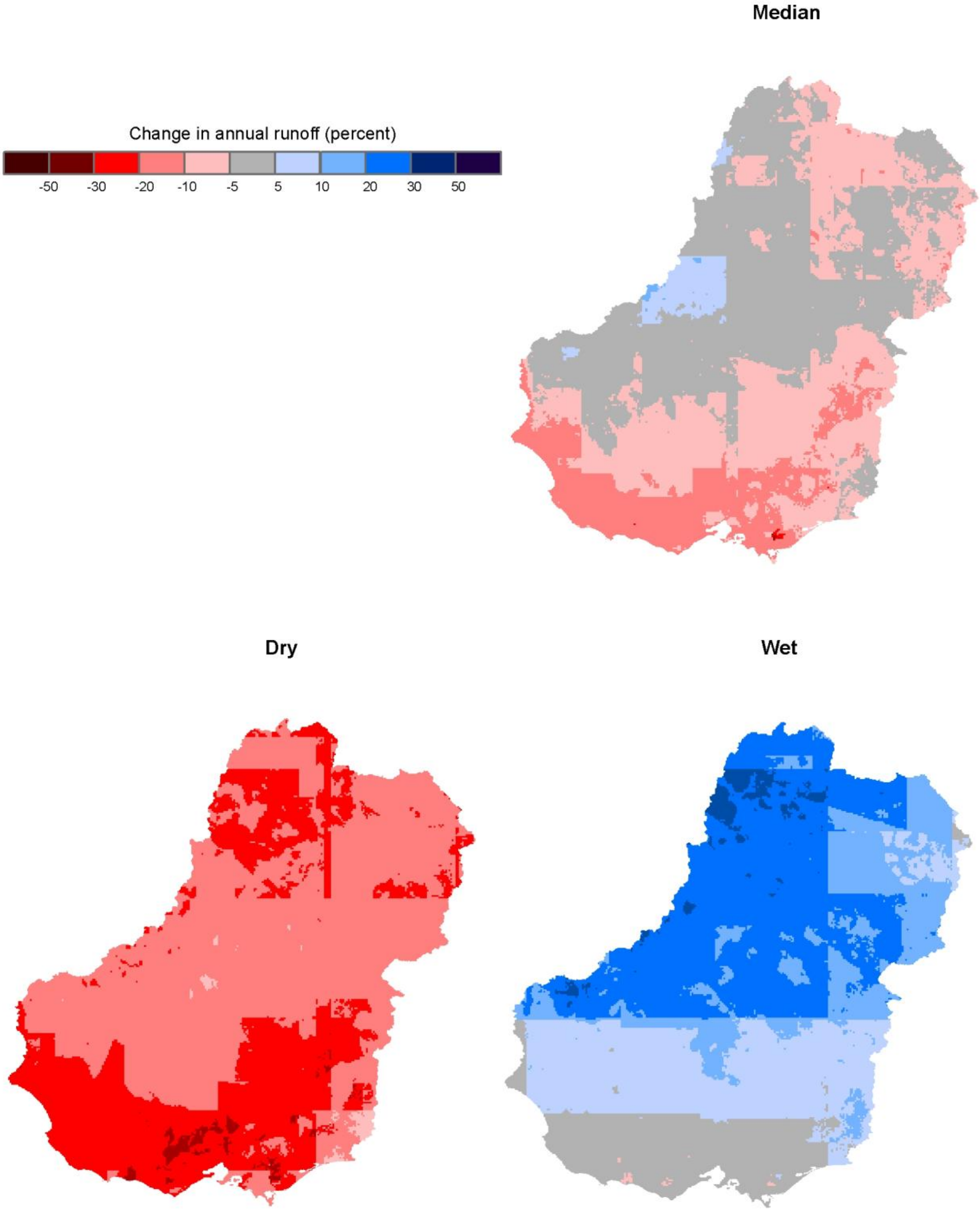

Figure 12. Percentage change in modelled mean annual runoff across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

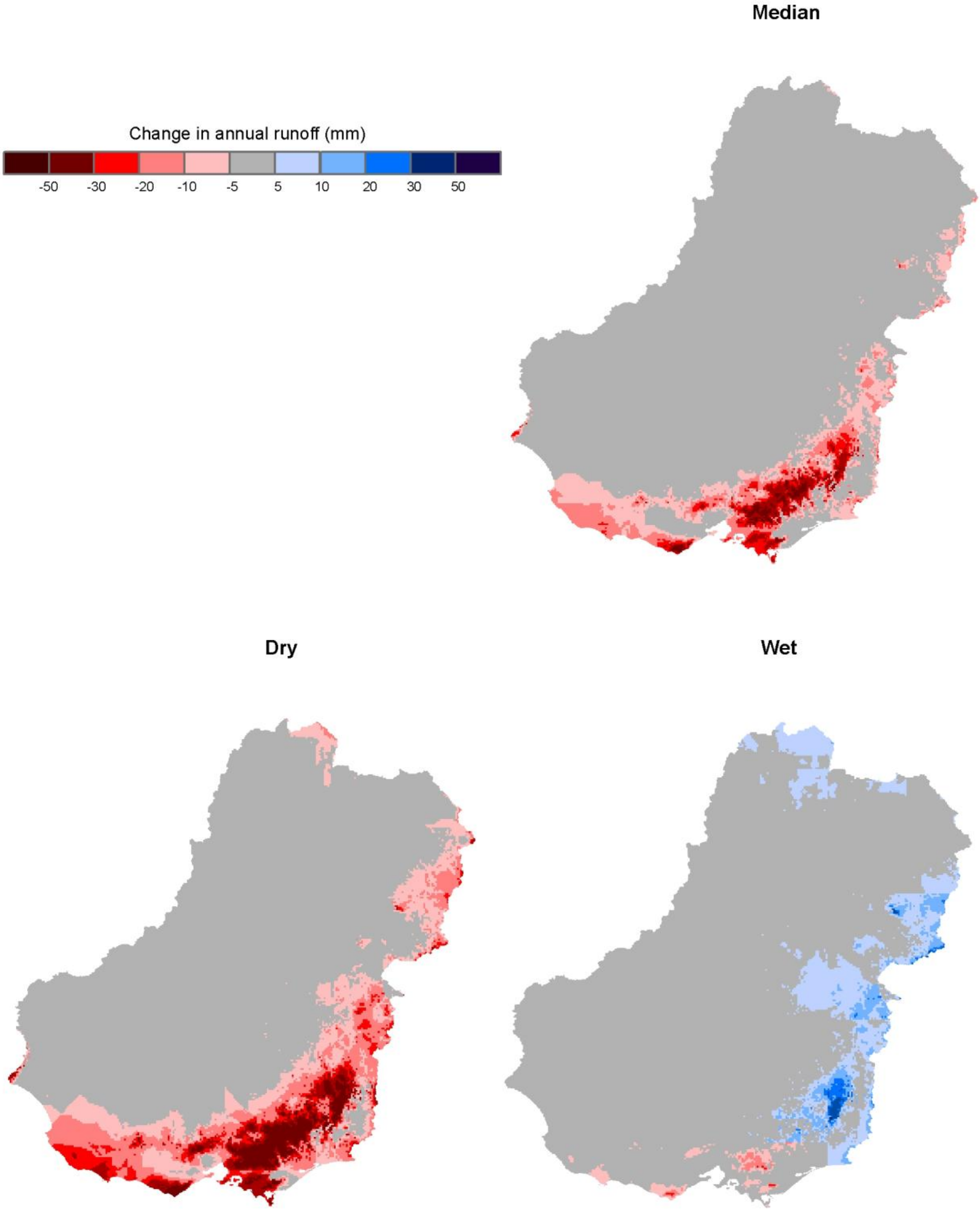

Figure 13. Absolute change in modelled mean annual runoff (mm) across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

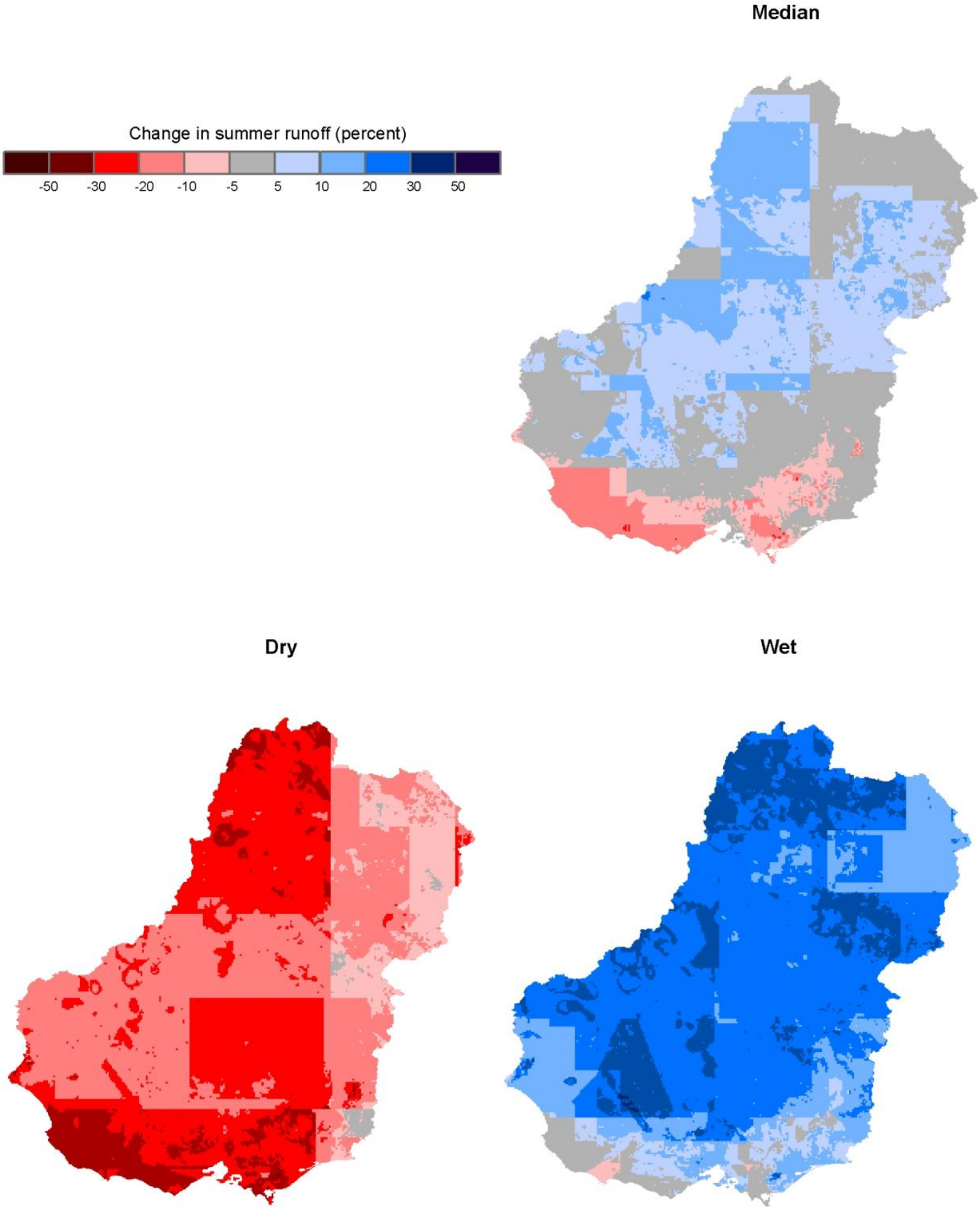

Figure 14. Percentage change in modelled mean summer (DJF) runoff across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

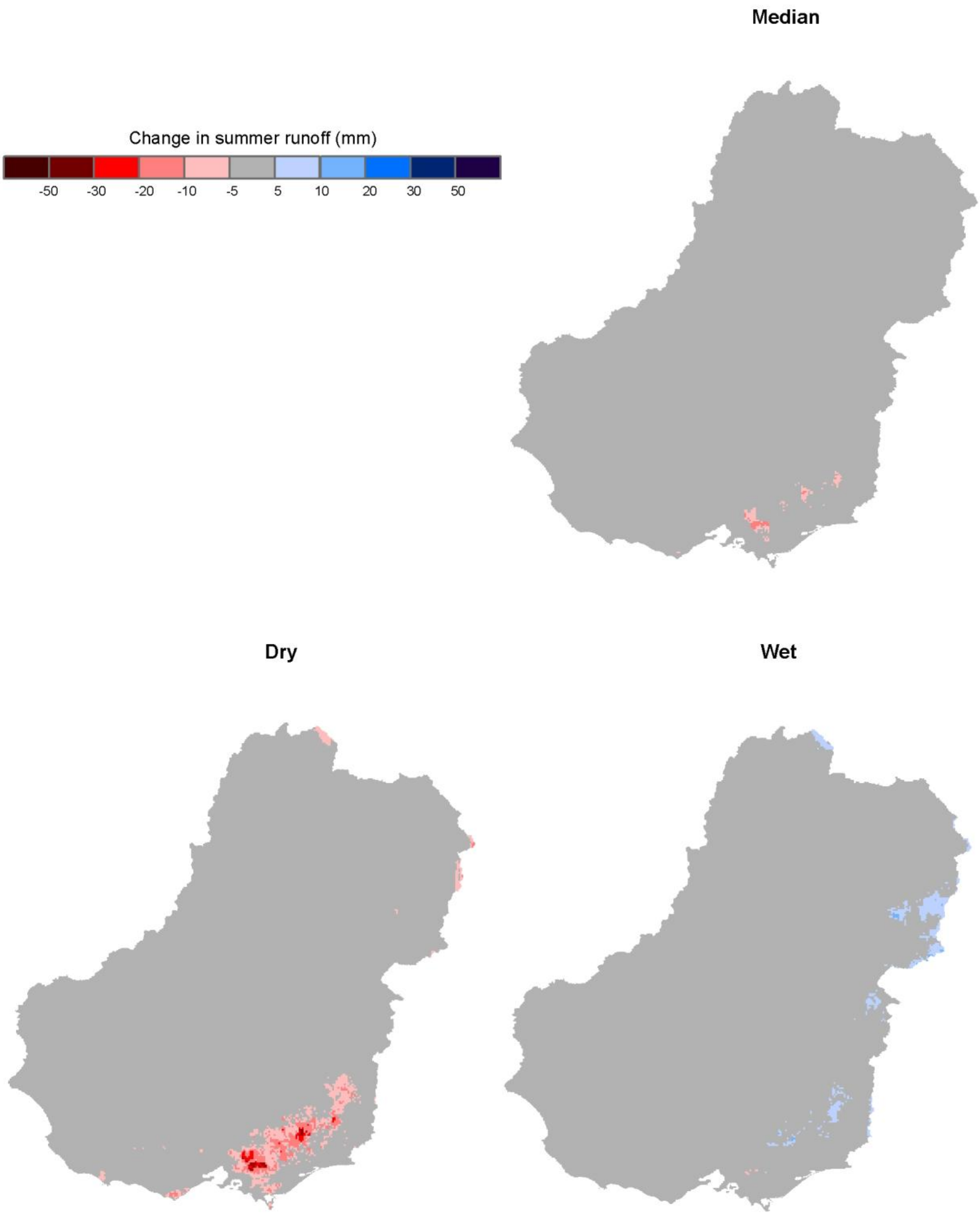

Figure 15. Absolute change in modelled mean summer (DJF) runoff (mm) across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

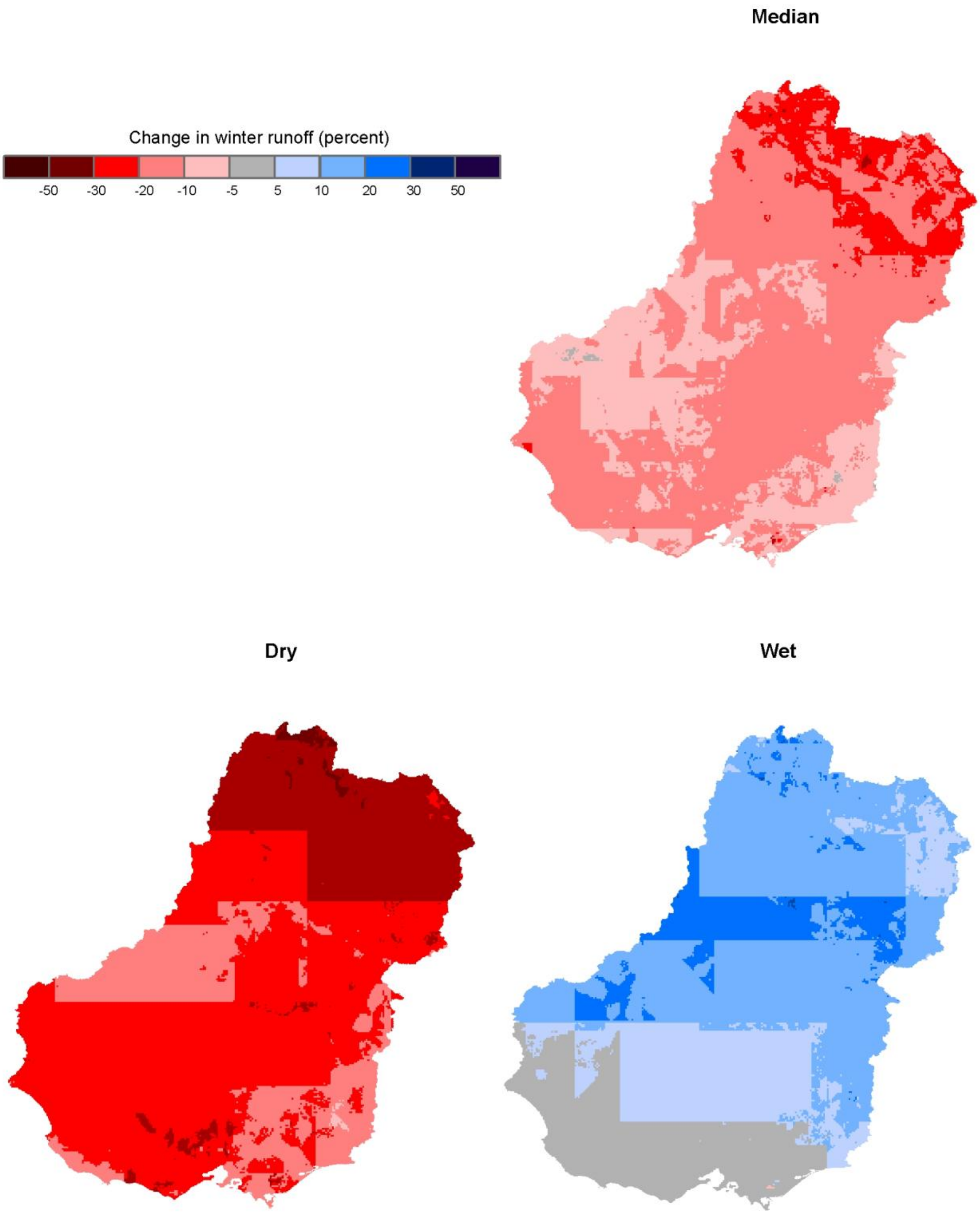

Figure 16. Percentage change in modelled mean winter (JJA) runoff across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

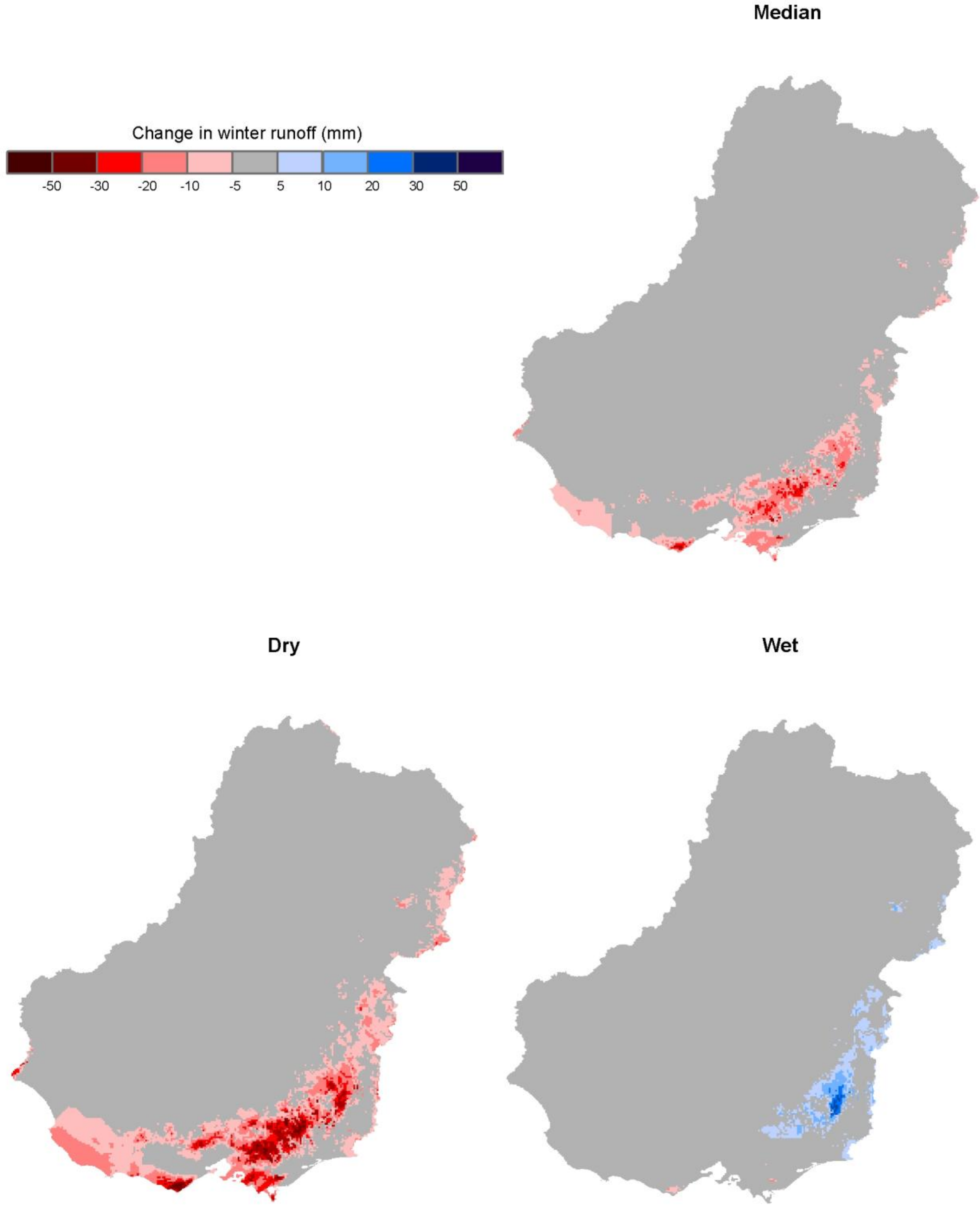

Figure 17. Absolute change in modelled mean winter (JJA) runoff (mm) across the SEACI region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios.

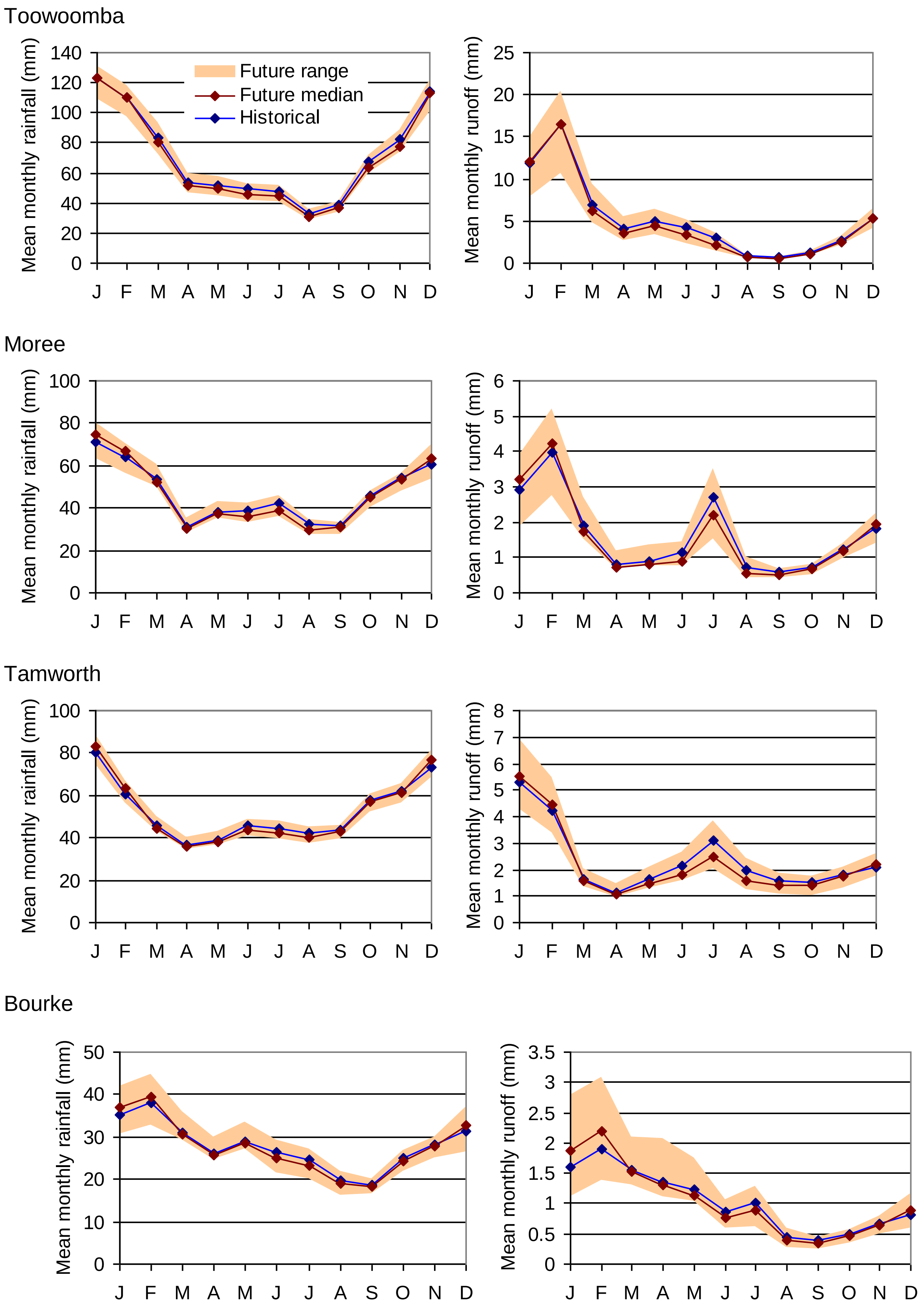

Figure 18. Mean monthly modelled runoff for 12 selected locations (see Figure 1) for the historical climate and the range and median predictions for future (A1B) climate.

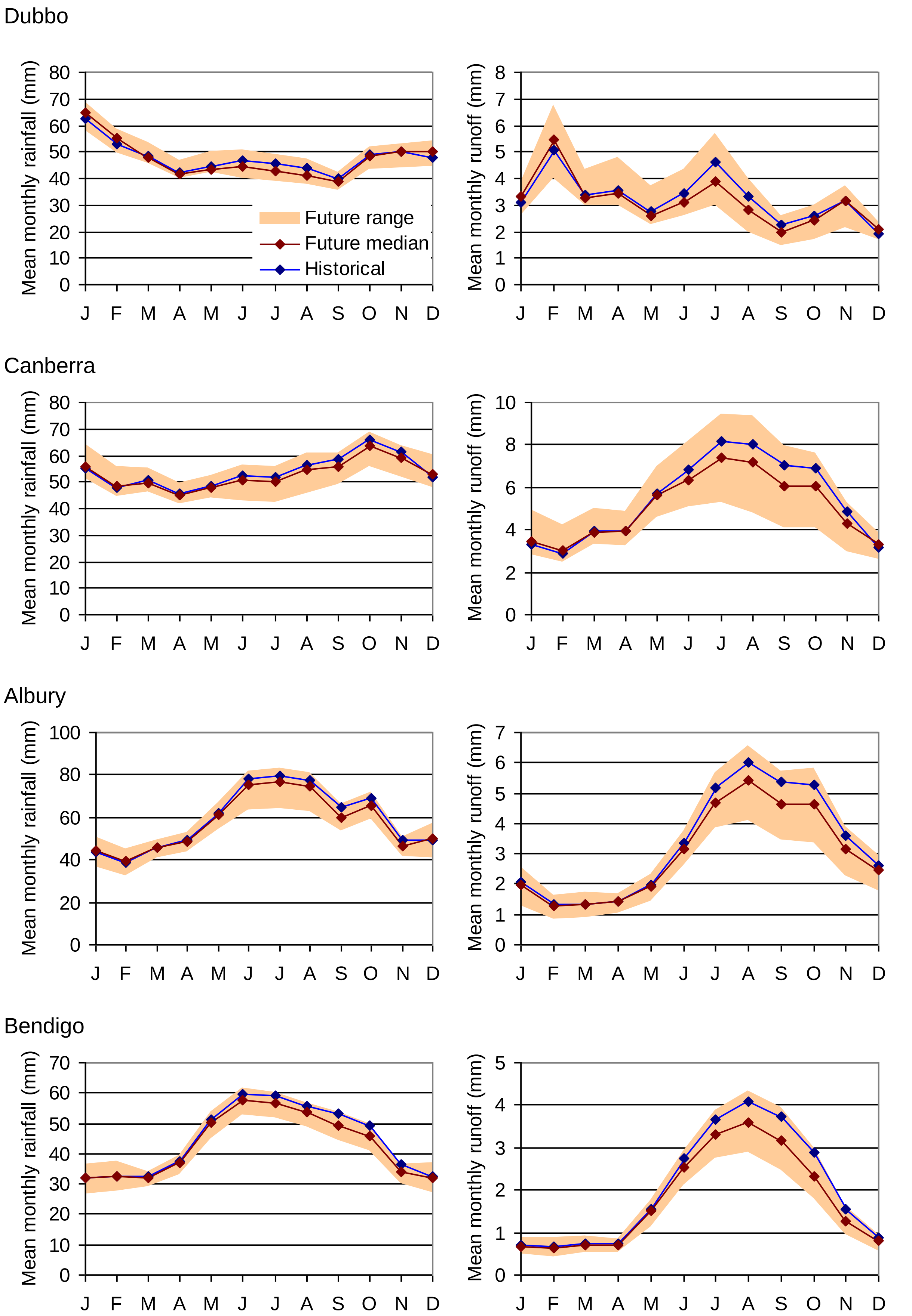

Figure 18 (cont'd). Mean monthly modelled runoff for 12 selected locations (see Figure 1) for the historical climate and the range and median predictions for future (A1B) climate.

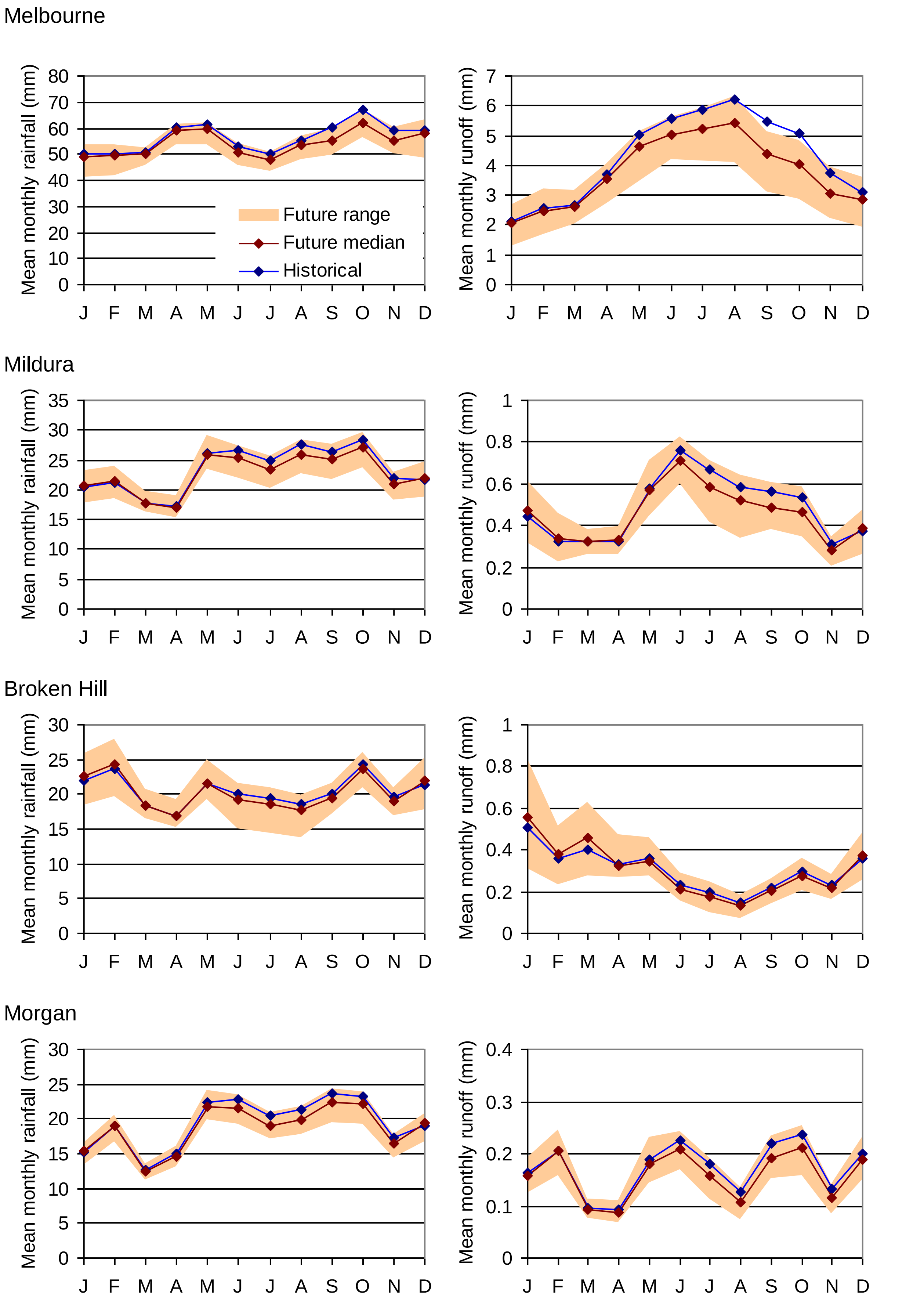

Figure 18 (cont.): Mean monthly modelled runoff for 12 selected locations (see Figure 1) for the historical climate and the range and median predictions for future (A1B) climate.

3 Conclusions

This study has examined the potential impacts of climate change on runoff generation in the SEACI region. The climate change examined was that predicted by the A1B scenario of the IPCC. The global warming by ~2030 relative to ~1990 in the IPCC SRES A1B greenhouse gas emission scenario is 0.9°C, while the mean annual APET in ~2030 relative to ~1990 will increase by two to four per cent.

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.

The median (best estimate) indicates that future mean annual runoff in the SEACI region in ~2030 relative to ~1990 will be lower, by zero to 20 percent in the north-east and southern half, and by 10 to 30 per cent in Victoria. Averaged across the SEACI region, the median (best estimate) is an eight per cent decrease in mean annual runoff.

The modelled mean annual runoff using the climate change projections from the 15 GCMs range from a 30 per cent decrease to a 30 per cent increase in the northern half of the SEACI region, 30 per cent decrease to 10 per cent increase in the southern half of the SEACI region and 50 per cent decrease to no change in Victoria. Averaged over the entire SEACI region, the extreme estimates range from a 20 per cent decrease to a 6 per cent increase in mean annual runoff.

4 References

Chiew FHS and Leahy C (2003). Comparison of evapotranspiration variables in Evapotranspiration Maps of Australia with commonly used evapotranspiration variables. Australian Journal of Water Resources 7, 1-11.

Chiew FHS, Teng J, Kirono D, Frost A, Bathols J, Vaze J, Viney N, Young W, Hennessy K and Cai W (2008a). Climate data for hydrologic scenario modelling across the Murray-Darling Basin. A report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia.

Chiew FHS, Vaze J, Viney N, Jordan P, Perraud J-M, Zhang L, Teng J, Young W, Arancibia J, Morden R, Freebairn A, Austin J, Hill P, Wiesenfeld C, and Murphy R (2008b). Rainfall-runoff modelling across the Murray-Darling Basin. A report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia.

Chiew FHS, Vaze J, Viney N, Perraud J-M, Teng J, and Post DA (2008c). Modelling runoff and climate change impact on runoff in 178 catchments in the Murray-Darling Basin using Sacramento and SIMHYD rainfall-runoff models. Water Down Under, 15-17 April 2008, Adelaide, Australia.

Chiew FHS, Post DA, Teng J, Vaze J and Perraud J-M (In prep.) Modelling climate change impact on runoff in southeast Australia. Journal Paper, In Preparation.

CSIRO and Australian Bureau of Meteorology (2007) Climate change in Australia. Technical report, www.climatechangeinaustralia.gov.au.

IPCC (2007). Climate Change 2007: The Physical Basis. Contributions of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press (www.ipcc.ch).

Jeffrey SJ, Carter JO, Moodie KB and Beswick AR (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environmental Modelling and Software 16, 309-330.

Morton FI (1983). Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology 66, 1-76.