Future climate and runoff projections (~2030)
for New South Wales and Australian Capital Territory

NSW Government
Department of Water & Energy

Publisher

NSW Department of Water and Energy
Level 17, 227 Elizabeth Street
GPO Box 3889
Sydney NSW 2001

T 02 8281 7777 **F** 02 8281 7799

information@dwe.nsw.gov.au

www.dwe.nsw.gov.au

Future climate and runoff projections (~2030) for New South Wales and Australian Capital Territory

June 2008

ISBN 978 0 7347 5894 1

Acknowledgements

Research

We would like to thank the CSIRO MDBSY project team. Andy Pitman (University of New South Wales), Wenju Cai and Janice M Bathols (CSIRO Marine and Atmospheric Research), Neil R Viney and Jenet Austin (CSIRO Land and Water), Andrew Frost (Bureau of Meteorology), Peter Smith and Gregory Summerell (NSW Department of Environment and Climate Change), Andrew Davidson and Richard Beecham (NSW Department of Water and Energy) for useful discussions and suggestions. We thank Department of Water and Energy management for supporting this work, especially David Harriss, Bruce Cooper and Dugald Black. William Young (CSIRO Land and Water) and Jane Gibbs (DWE) reviewed the report.

Authors

Jai Vaze, NSW Department of Water and Energy

Jin Teng, NSW Department of Water and Energy

David Post, CSIRO Land and Water

Francis Chiew, CSIRO Land and water

Jean-Michel Perraud, CSIRO Land and Water

Dewi Kirono, CSIRO Marine and Atmospheric Research

This publication may be cited as:

Vaze J, Teng J, Post D, Chiew F, Perraud J-M, Kirono D, 2008, *Future climate and runoff projections (~2030) for New South Wales and Australian Capital Territory*, NSW Department of Water and Energy, Sydney

DWE 08_133 (web)

Table of contents

List of tables

List of figures

Preface

Warming of the climate system over the past century is very clear and since the mid 20th century most of this warming is due to increases in greenhouse gas concentrations. Global warming will lead to changes in rainfall and runoff and will significantly impact on the regional hydrology. In particular, reduction in rainfall will result in reduced runoff.

Australian natural resources management agencies are aware of the risks of climate change, and many have carried out studies for their systems, ranging from simple climate change impact assessment to detailed system-scale modelling.

The Department of Water and Energy (DWE) is responsible for management of water resources throughout NSW. To effectively manage water resources DWE requires future projections for rainfall and temperature, and an understanding of the impacts of this future climate on runoff and water availability.

The Intergovernmental Panel on Climate Change and the CSIRO Climate Change Projections for Australia released in Nov 2007 are at a Global Climate Model (GCM) scale (roughly around 200 km x 200 km). Currently global climate models (GCMs) are the best available tools for modelling future climate. However, GCMs provide information at a resolution that is too coarse to give results that can be used directly in hydrological modelling. Similarly, the estimates of runoff from GCMs are not applicable at a catchment scale.

This report provides estimates of future climate and runoff across NSW and ACT at a scale which is applicable to hydrological modelling. The results provide a detailed understanding of the impacts of future climate on runoff and water availability across the region. This is the first comprehensive climate change modelling work done in NSW. This study provides a consistent future climate and runoff dataset across NSW and ACT which can be used by all state government agencies and industries to plan for and adapt to the impacts of climate change.

David Harriss
Deputy Director General, Water Management
NSW Department of Water and Energy

Summary

This report describes the rainfall-runoff modelling for 0.05^o grid cells (~ 5 km x 5 km) across New South Wales (NSW) and Australian Capital Territory (ACT) and presents the runoff estimates for the historical climate and the likely changes to runoff in ~2030 for the IPCC 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 similar to and based on the CSIRO Murray-Darling Basin Sustainable Yields (MDBSY) Project and SEACI (South Eastern Australian Climate Initiative). 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 SRES A1B global warming scenario for the whole of NSW and ACT.

There are four 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 NSW and ACT. The third output is parameter values for the SIMHYD and Sacramento lumped conceptual daily rainfall-runoff models for 0.05^o grid cells across NSW and ACT. The fourth output is the comparison of annual and seasonal rainfall from the 15 GCMs with historical SILO rainfall for 1895–2006. 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 fourth output is important because it can form the basis for choosing the most representative GCMs for the region.

The modelling in this study indicates that the mean annual rainfall and runoff, averaged over 1895 to 2006 over entire region, are 516 mm and 55 mm respectively. There is a clear east-west rainfall gradient across the region, where rainfall is highest in the east (mean annual rainfall of more than 1600 mm) and lowest in the west (less than 200 mm). The runoff gradient is much more pronounced than the rainfall gradient, with runoff in the east (mean annual runoff of more than 400 mm) being much higher than elsewhere in the region (less than 5 mm in the western half).

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 models (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 region to global warming. However, the majority of GCMs (9 out of 15) show a decrease in the mean annual rainfall. Most of the GCMs (11 out of 15) indicate that future winter rainfall is likely to be lower across the entire region whereas only 5 of the 15 GCMs indicate a reduction in future summer rainfall across the region.

The median or best estimate indicates that future mean annual runoff in the region in ~2030 relative to ~1990 will be lower by 0 to 20 percent in the southern parts, no change to a slight reduction in the eastern parts and higher by 0 to 20 percent in the northwest corner. Averaged across the entire region, the median or best estimate is a 5 percent decrease in mean annual runoff.

The modelled mean annual runoff using the climate change projections from the 15 GCMs range from a 20 percent decrease to a 20 percent increase in the eastern parts of the region, a 30 percent decrease to a 10 percent increase in the southern parts of the region and a 30 percent decrease to a 30 percent increase in the northwest corner. Averaged over the entire region, the extreme estimates range from a 14 percent decrease to a 10 percent increase in mean annual runoff.

1 Methods

1.1 Rainfall-runoff modelling

The rainfall-runoff modelling method adopted provides a consistent way of modelling historical runoff across the region and assessing the potential impacts of climate change on future runoff.

The lumped conceptual rainfall-runoff models, SIMHYD with a Muskingum routing method and Sacramento are used to estimate daily runoff for 0.05^o grids (~ 5 km x 5 km) across the entire region 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 models are 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-east Australia (referred to hereafter as calibration catchments, see Figure 3). 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.

SIMHYD is a simple lumped conceptual daily rainfall-runoff model with seven parameters (Chiew et al., 2002). Figure 1 shows the model structure of SIMHYD and the equations used to model the rainfall-runoff processes. SIMHYD has been used successfully across Australia for various applications, including the estimation of runoff in the National Land and Water Resources Audit (Peel et al., 2002), the estimation of climate change impact on runoff (Chiew and McMahon, 2002), and in various regionalisation studies (Chiew and Siriwardena, 2005).

A Muskingum routing algorithm with two parameters (K_{MUSK} and X_{MUSK}), as described in Tan et al. (2005), is used to rout the daily runoff simulated by SIMHYD to the catchment outlet. For the application here, X_{MUSK} is set to 0 (therefore routing with a linear storage), and the two relatively insensitive infiltration capacity parameters, COEFF and SQ (see Figure 1), are set to 150 and 2 respectively. There are therefore six parameters in SIMHYD that require optimisation in the application here. The Sacramento model is also a lumped conceptual daily rainfall-runoff model (Burnash et al., 1973), but it is considerably more complex than SIMHYD.

Figure 2 shows the structure of the Sacramento model. The Sacramento model has been used widely, in particular as part of the river system model implementations in New South Wales and Queensland and for flow forecasting worldwide. The Sacramento model has 17 parameters, but in the application here, only 13 parameters are optimised (ADIMP, LZFPM, LZFSM, LZPK, LZSK, LZTWM, PFREE, REXP, SARVA, IZFWM, UZK, UZTWM, ZPERC) plus one unit hydrograph parameter, with the other four parameters set to default values (PCTIM=0, RSERV=0.3, SIDE=0, SSOUT=0).

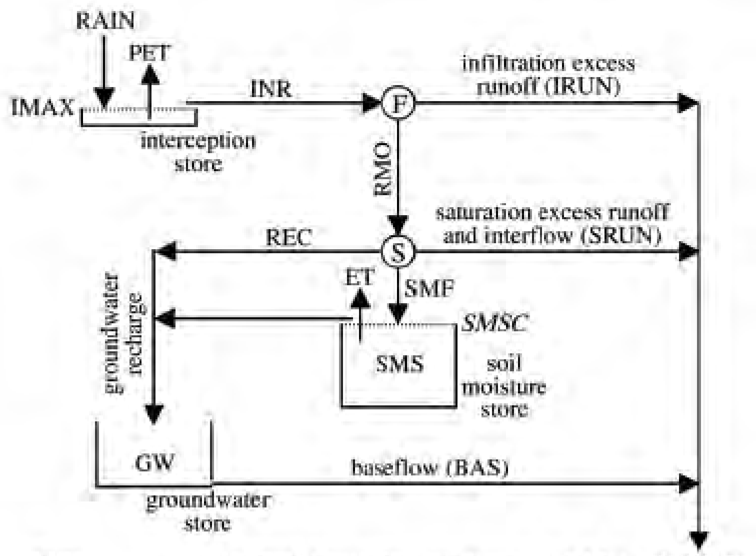
In the model calibration, the six parameters of SIMHYD and 13 parameters of Sacramento are optimised to maximise an objective function that incorporates the Nash-Sutcliffe efficiency of daily runoff together with a constraint to ensure that the total modelled runoff over the calibration period is within 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 region). Almost all the catchments available for model calibration are in the higher runoff areas in the eastern parts of the region. Runoff estimates are therefore generally good in the eastern parts of the region and are comparatively poor elsewhere.

The same set of parameter values are used to model runoff across the whole 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 modelling approach (using SIMHYD and Sacramento models) used for the purpose of this project 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, Sacramento 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.

Figure 1. Structure of SIMHYD rainfall-runoff model

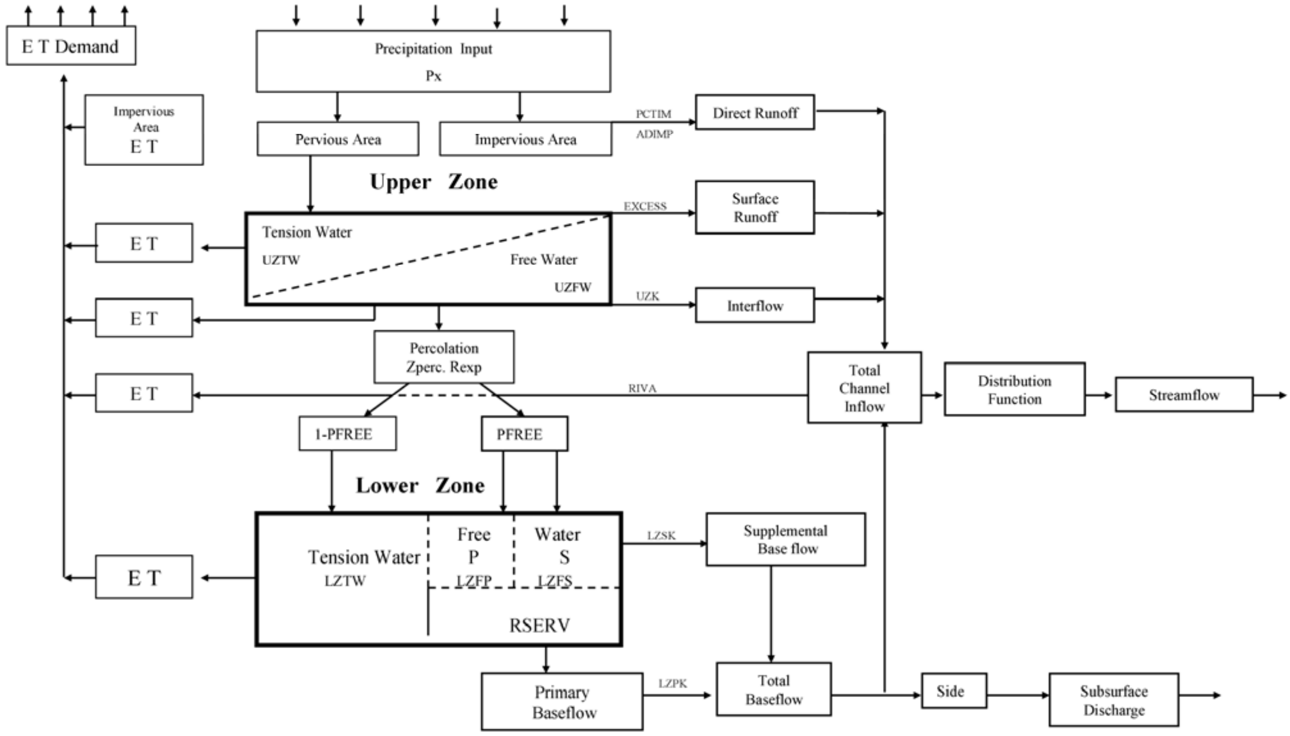


PET	=	areal potential evapotranspiration (input data)
IMAX	=	lesser of {*INSC*, PET}
INT	=	lesser of {IMAX, RAIN}
INR	=	RAIN - INT
RMO	=	lesser of {COEFF exp (-*SQ* x SMS/*SMSC*), INR}
IRUN	=	INR - RMO
SRUN	=	*SUB* x SMS/*SMSC* x RMO
REC	=	*CRAK* x SMS/*SMSC* x (RMO - SRUN)
SMF	=	RMO - SRUN - REC
POT	=	PET - INT
ET	=	lesser of {10 x SMS/*SMSC*, POT}
BAS	=	*K* x GW

Model parameters

INSC	interception store capacity (mm)
COEFF	maximum infiltration loss (mm)
SQ	infiltration loss exponent
SMSC	soil moisture store capacity (mm)
SUB	constant of proportionality in interflow equation
CRAK	constant of proportionality in groundwater recharge equation
K	baseflow linear recession parameter

Figure 2. Structure of Sacramento rainfall-runoff model



ADIMP is the impervious fraction of the catchment;
LZFPM is the free water capacity of the slower draining lower store (mm);
LZFSM is the free water capacity of the faster draining lower store (mm);
LZPK is the drainage rate from the slower draining lower store;
LZSK is the drainage rate from the faster draining lower store;
LZTWM is the tension water storage capacity of the lower store (mm);
PFREE is the proportion of percolated water transferred to the lower store;
REXP is the exponent in the percolation equation;
SARVA is the fraction of the catchment covered by water and riparian vegetation;
UZFWM is the free water capacity of the upper store (mm);
UZK is the lateral drainage rate from the upper store;
UZTWM is the tension water storage capacity of the upper store (mm);
ZPERC is the maximum percolation rate coefficient;
PCTIM is the permanent impervious fraction of catchment draining to channel;
RSERV is the fraction of lower zone free water storage unavailable for transpiration;
SIDE is the channel loss, ratio of unobserved to observed baseflow;
SSOUT is the channel loss, subsurface channel flow.

1.2 Climate scenarios

Daily rainfall and potential evapotranspiration (PET) are required to run the SIMHYD and Sacramento rainfall-runoff models. The methodology used in this study to derive climate data is same as the one used in the CSIRO Murray Darling Basin Sustainable Yields (MDBSY) Project (http://www.csiro.au/MDBSY). The climate data and their derivation for the hydrologic scenario modelling across the Murray-Darling Basin 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°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 CSIRO MDBSY Project. However, unlike the MDBSY Project, this study reports on the IPCC SRES A1B global warming scenario (which is similar to the medium global warming scenario in MDBSY Project). Specifically, this study presents the range of runoff modelling results using climate change projections from 15 GCMs (see Table 1) for the SRES A1B global warming scenario for the region. This is consistent with the work undertaken as part of Theme 2 of the South Eastern Australian Climate Initiative (SEACI) (Post et al., 2008).

Table 1. List of 15 global climate models used

Global climate model	Modelling group, Country	Horizontal resolution (km)
CCCMA T47	Canadian Climate Centre, Canada	~250
CCCMA T63	Canadian Climate Centre, Canada	~175
CNRM	Meteo-France, France	~175
CSIRO-MK3.0	CSIRO, Australia	~175
GFDL 2.0	Geophysical Fluid, Dynamics Lab, USA	~200
GISS-AOM	NASA/Goddard Institute for Space Studies, USA	~300
IAP	LASG/Institute of Atmospheric Physics, China	~300
INMCM	Institute of Numerical Mathematics, Russia	~400
IPSL	Institut Pierre Simon Laplace, France	~275
MIROC-M	Centre for Climate Research, Japan	~250
MIUB	Meteorological Institute of the University of Bonn, Germany Meteorological Research Institute of KMA, Korea	~400
MPI-ECHAM5	Max Planck Institute for Meteorology DKRZ, Germany	~175
MRI	Meteorological Research Institute, Japan	~250
NCAR-CCSM	National Center for Atmospheric Research, USA	~125
NCAR-PCM1	National Center for Atmospheric Research, USA	~250

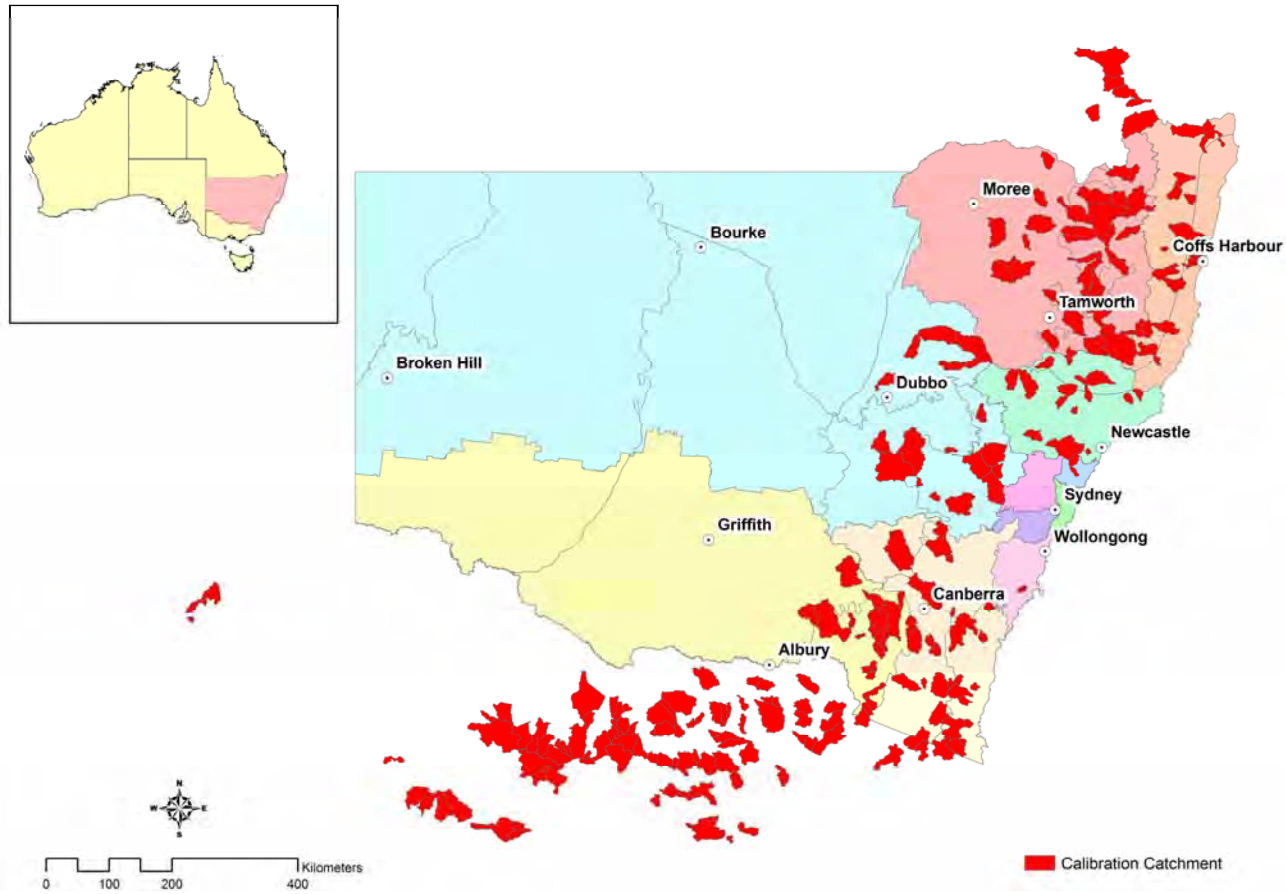
The method used here is also similar to, but not the same as, the approach used by CSIRO and Australian Bureau of Meteorology (2007) (www.climatechangeinaustralia.gov.au) to provide the climate change projections for Australia. The main difference is the use of 15 GCMs here compared to the CSIRO/BoM study which used all the 23 IPCC AR4 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 currently being addressed in some of the SEACI projects.

2 Modelling results

2.1 Reporting region and calibration catchments

Figure 3 shows the boundary for the study area (entire NSW and ACT) 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 eastern parts of the region. Runoff estimates are therefore generally good there and are comparatively poor elsewhere.

Figure 3. Map showing the NSW and ACT region and calibration catchments



2.2 Historical rainfall and runoff (1895–2006)

Figure 3, Figure 4, and Figure 5 compare the mean annual, summer (Dec-Jan-Feb) and winter (Jun-Jul-Aug) rainfall, averaged over 1895 to 2006, simulated by the 15 GCMs with the observed rainfall. Three summary statistics comparing the mean annual, summer and winter GCM simulated rainfall with the observed rainfall are shown on the figures. The statistics summarise the spatial correlation (R), Nash-Sutcliff efficiency (NSE) and the root mean square error (RMSE) between the GCM simulated rainfall and the observed rainfall. There are about 11 to 57 GCM grid cells across the region, and spatial rainfall patterns simulated by the 15 GCMs generally match the observed rainfall pattern, as indicated by the high spatial correlations (R values in the figures).

However, there can be considerable differences between the rainfall values simulated by the GCMs and the observed rainfall. There is a large variability in the annual NSE values comparing the mean annual rainfall simulated by the 15 GCMs and the observed rainfall (2 negative and 13 positive with 7 above 0.5). The seasonal NSE values comparing the mean summer and winter rainfall simulated by the 15 GCMs and the observed rainfall are slightly poorer than the annual statistics (for summer there are 4 negative and 11 positive with 3 above 0.5 and for winter there are 3 negative and 12 positive with 6 above 0.5).

The RMSE comparing the mean annual rainfall simulated by the 15 GCMs and the observed rainfall range from 128 to 423 mm, with a median of 259 mm (mean annual rainfall across the region is 516 mm). The RMSE comparing the mean summer rainfall simulated by the 15 GCMs and the observed rainfall range from 45 to 149 mm, with a median of 113 mm (mean summer rainfall across the region is 154 mm). The difference between the GCM simulated rainfall and observed rainfall is lowest in winter, with RMSE range from 39 to 90 mm, with a median of 53 mm (mean winter rainfall across the region is 117 mm).

The rainfall simulations are compared here because rainfall is the main driver of runoff. A comparative analysis of seasonal and daily rainfall for Australia can be found in Perkins et al. 2007 and for southeast Australia in Teng et al. (in prep). This comparative analysis is carried out partly to investigate whether the GCMs can reproduce the observed historical rainfall and partly to explore whether the results can guide the choice of GCMs for the climate change impact modelling. It is possible that the use of fewer GCMs based on how well they can simulate the historical rainfall could reduce the uncertainty in the modelling results, particularly if the GCMs chosen show consistent future rainfall projections. However, the three statistics used here do not provide a clear threshold to separate the better and poorer GCMs (see also Figure 4, Figure 5, and Figure 6), and for this reason all the 15 GCMs are used in the study.

Figure 7, Figure 8, and Figure 9 show the mean annual, summer and winter rainfall, areal potential evapotranspiration (APET) and modelled runoff for SIMHYD and Sacramento models, averaged over 1895 to 2006. The mean annual rainfall and SIMHYD and Sacramento runoff averaged over the region are 516 mm and 55 mm and 52 mm respectively.

There is a clear east-west rainfall gradient across the region, where rainfall is highest in the east (mean annual rainfall of more than 1600 mm) and lowest in the west (less than 200 mm). The runoff gradient is much more pronounced than the rainfall gradient, with runoff in the east (mean annual runoff of more than 400 mm) being much higher than elsewhere in the region (less than 5 mm in the western half).

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 7, Figure 8, and Figure 9. However these artefacts only affect the very driest parts of the region. Some care therefore needs to be given to the results in the very driest parts of the region. 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.

It is likely that the use of better regionalisation and parameterisation methods can improve the runoff modelling, particularly the daily runoff estimates (e.g., regionalisation based on catchment similarities, weighted ensemble modelling (of simulations from SIMHYD, Sacramento and other models), and constraining model calibrations with other data types like remotely-sensed evapotranspiration or soil moisture). A system-wide optimisation together with the river system models that also use gauged streamflow data in main river channels can also reduce the uncertainty in the runoff estimates.

Figure 7, Figure 8 and Figure 9 clearly show that the mean annual, summer and winter runoff estimated by SIMHYD and Sacramento models is similar. The comparison of results between SIMHYD and Sacramento models 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 also indicate that the simulations from the two rainfall-runoff models are relatively similar.

Figure 4. Observed and GCM simulated mean annual rainfall, averaged over 1895 to 2006

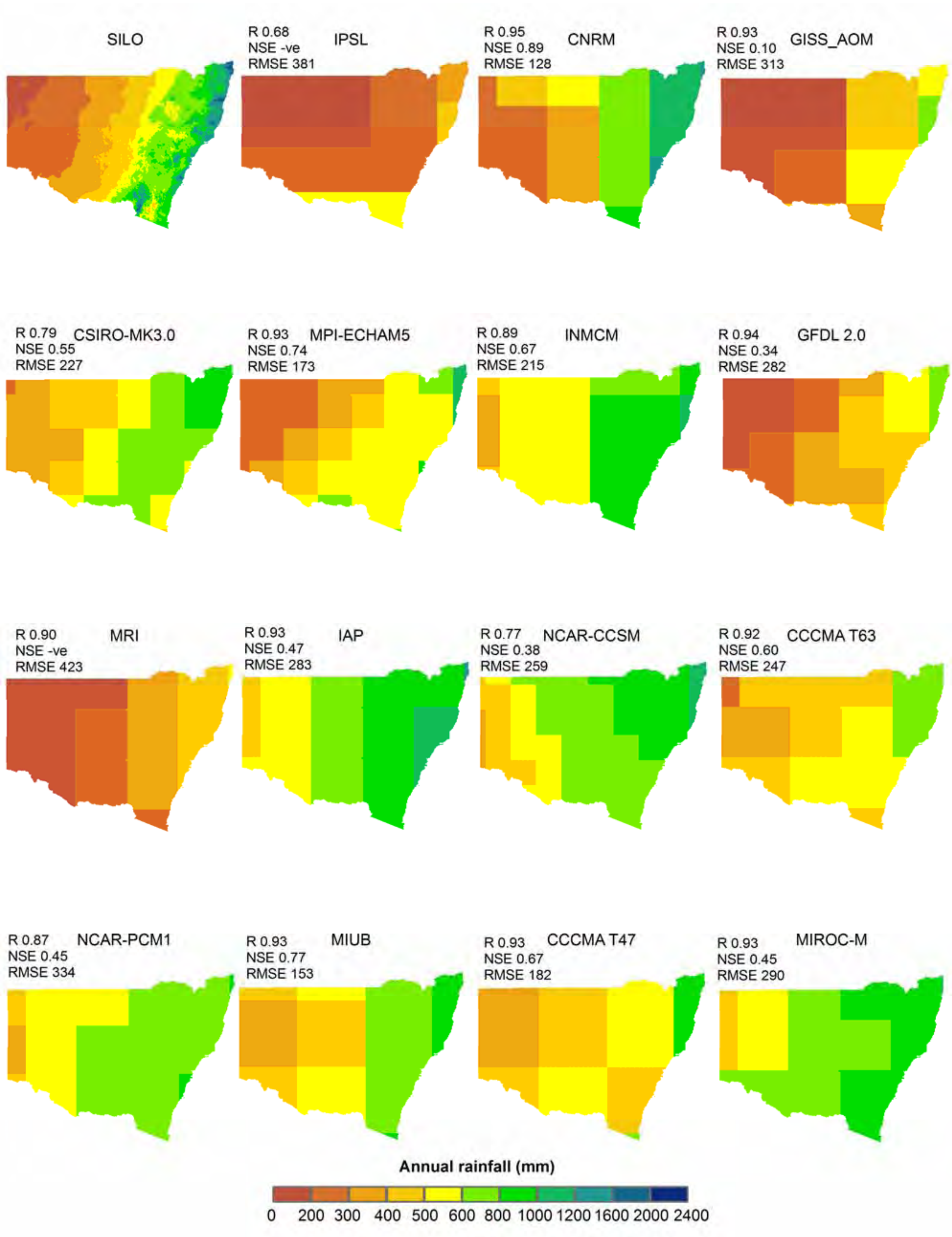


Figure 5. Observed and GCM simulated mean summer (DCF) rainfall, averaged over 1895 to 2006

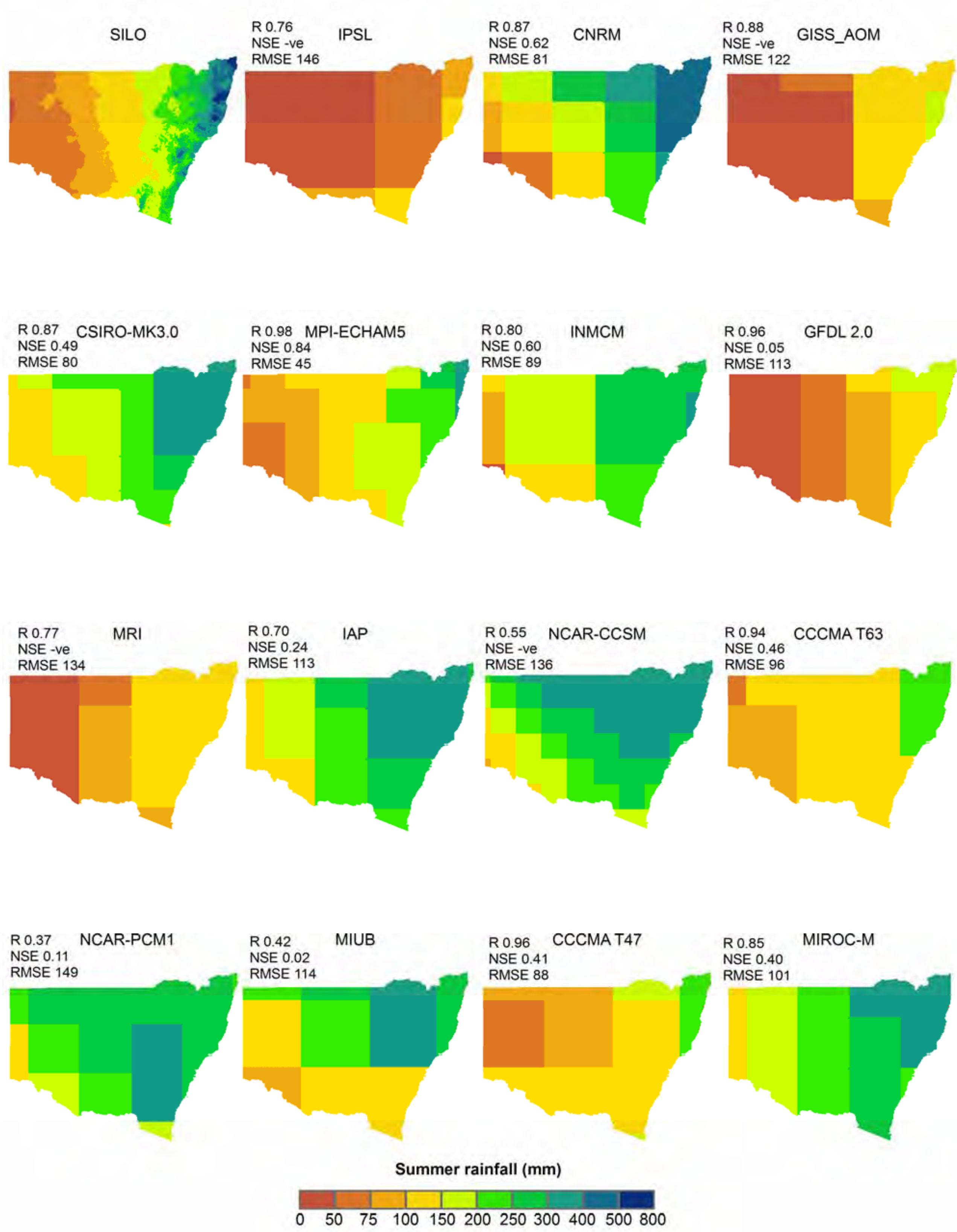


Figure 6. **Observed and GCM simulated mean winter (JJA) rainfall, averaged over 1895 to 2006**

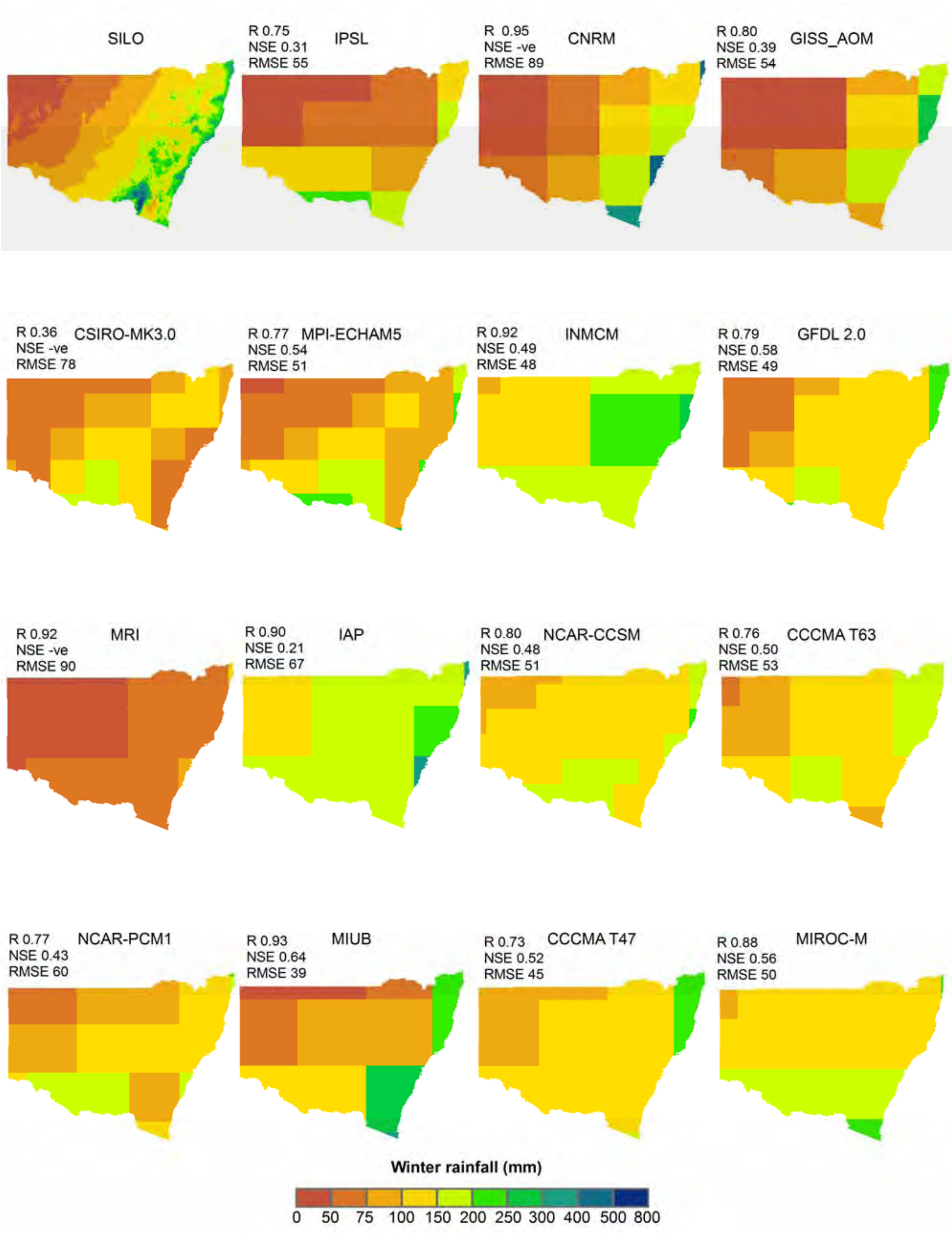


Figure 7. Mean annual rainfall, areal potential evapotranspiration and modelled runoff

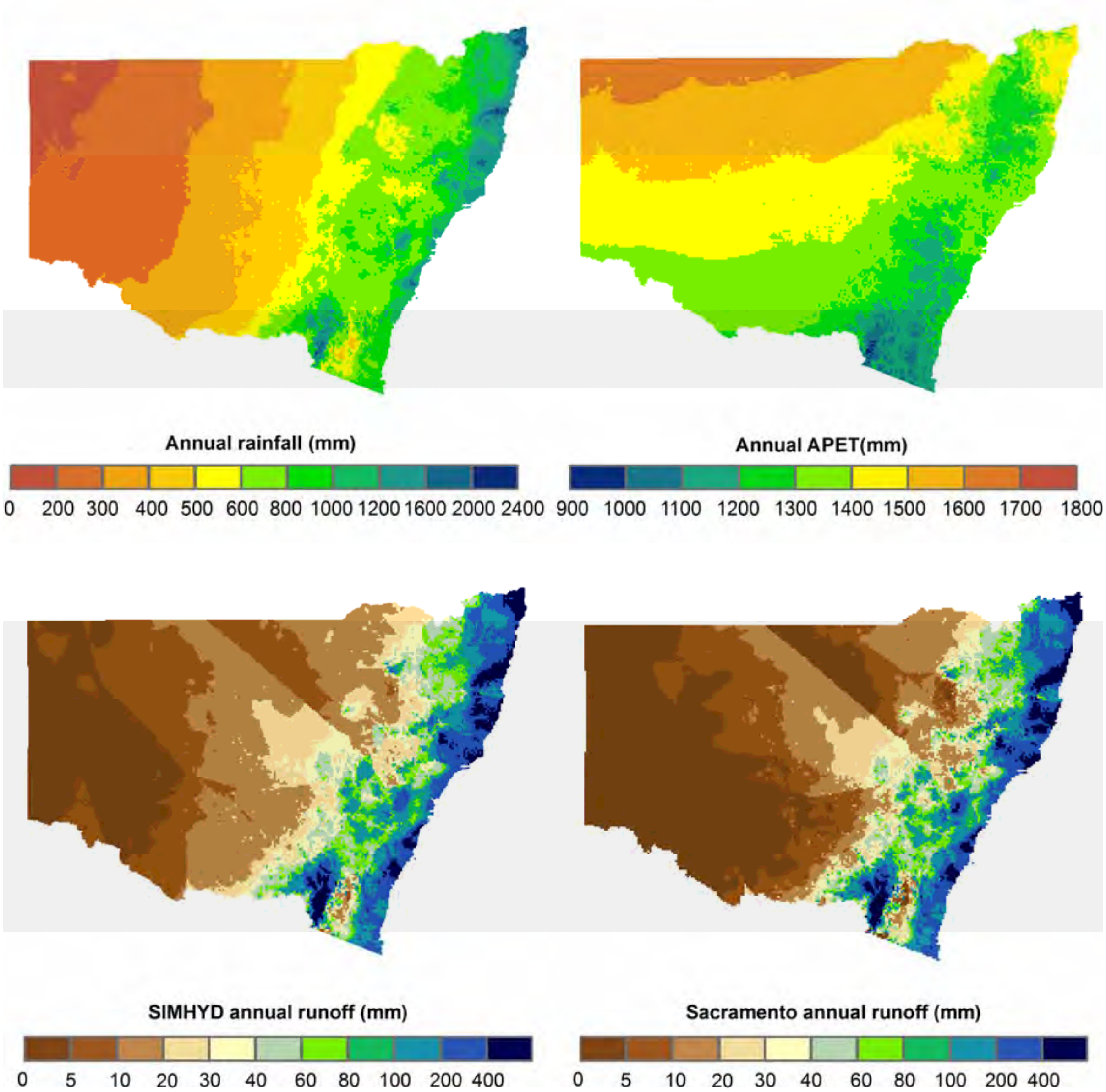


Figure 8. Mean summer (DJF) rainfall, areal potential evapotranspiration and modelled runoff

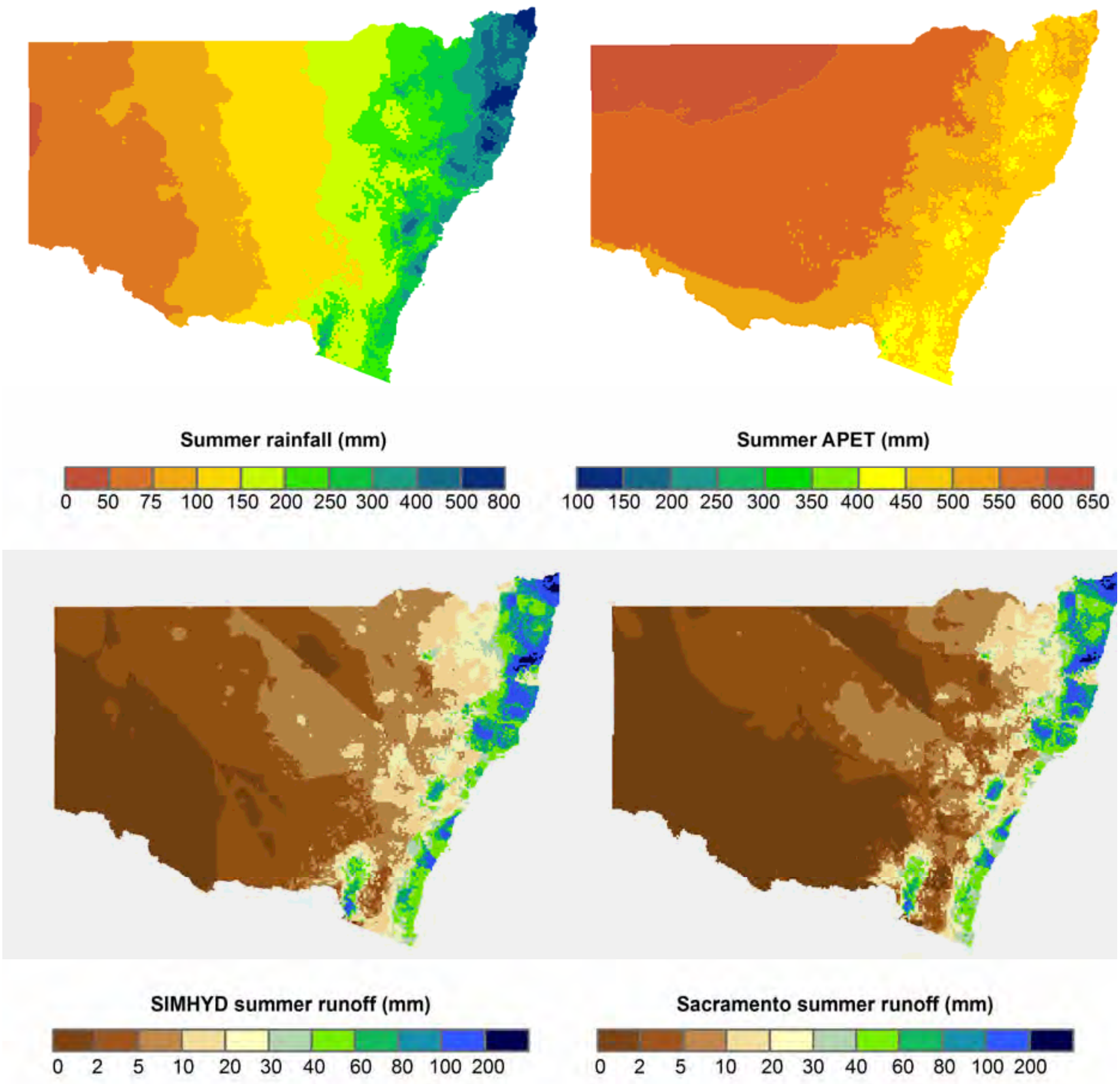
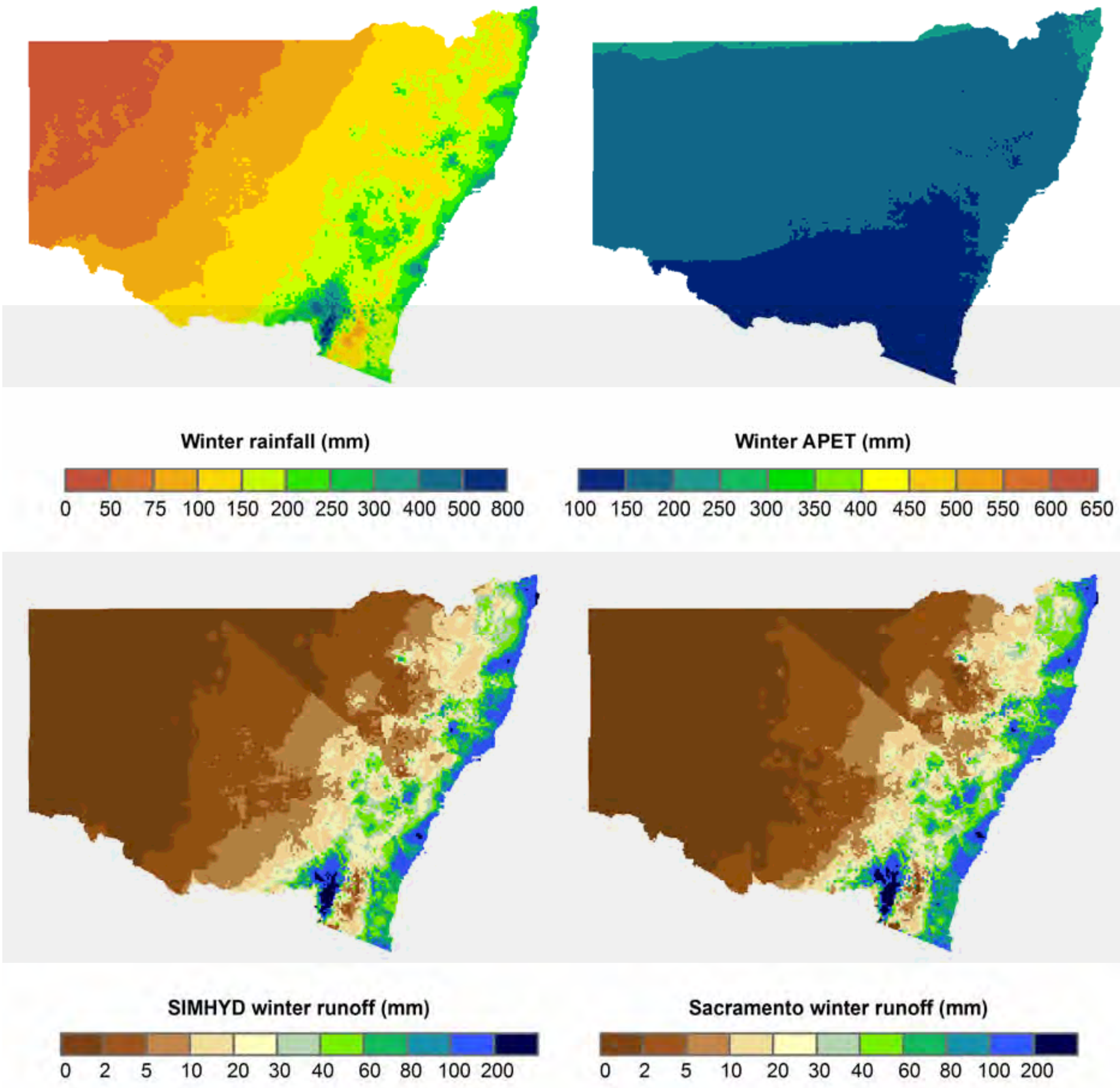


Figure 9. Mean winter (JJA) rainfall, areal potential evapotranspiration and modelled runoff



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

The SIMHYD and Sacramento models were used to simulate future runoff (~ 2030). As discussed earlier for historical runoff, the future runoff estimated by SIMHYD and Sacramento models is similar. The results of future climate impacts on estimated runoff for the SIMHYD model are presented and discussed in this report (as the Sacramento and SIMHYD results are similar, the discussion and conclusions for the SIMHYD results is also applicable to the Sacramento results).

Figure 10, Figure 11 and Figure 12 show the percentage change in mean annual, summer and winter rainfall respectively for ~2030 relative to ~1990 based on the climate change projections from the 15 GCMs for the A1B global warming scenario (see Chiew et al. (2008a) for description of the GCMs). In the figures, GCMs are ranked based on mean annual rainfall (top left to bottom right, driest to wettest) and the same sequence is used to present the results for runoff. Figure 13, Figure 14, and Figure 15 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. Figure 16 shows the number of modelled results that indicate a decrease (or increase) in mean annual, summer and winter rainfall, while Figure 17 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, more than half of the results show a decrease in mean annual rainfall (9 out of 15, Figure 10 and Figure 16) and runoff (9 out of 15, Figure 13 and Figure 17).

The majority of the results indicate that the future summer rainfall and runoff will increase in the region (Figure 11 and Figure 14). The results also indicate that future winter rainfall and runoff is likely to be lower across the region, with more than two-thirds of the results showing a decrease in winter rainfall and runoff (Figure 12 and Figure 15).

The number of GCMs showing an increase in the top 1-percentile (extreme) rainfall is shown in Figure 18 while the number of GCMs showing an increase in the top 1-percentile (extreme) runoff is shown in Figure 19. Comparing Figure 16 with Figure 18 shows that although the mean annual and winter rainfall is projected to decrease, extreme rainfall is likely to increase across the region. 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 17 and Figure 19). 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 17 with Figure 19 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 region are shown in Figure 20, Figure 22, and Figure 24. 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 future mean annual runoff in the region in ~2030 relative to ~1990 will be lower by 0 to 20 percent in the southern parts, no change to a slight reduction in the eastern parts and higher by 0 to 20 percent in the northwest corner. Averaged across the entire region, the median or best estimate is a 5 percent decrease in mean annual runoff. There is considerable uncertainty in the estimates and the modelled mean annual runoff using the climate change projections from the 15 GCMs range from a 20 percent decrease to a 20 percent increase in the eastern parts of the region, a 30 percent decrease to a 10 percent increase in the southern parts of the region and a 30 percent decrease to a 30 percent increase in the northwest corner. Averaged over the entire region, the extreme estimates range from a 14 percent decrease to a 10 percent increase in mean annual runoff.

In terms of change in runoff values (mm), Figure 21 shows decreases in runoff are predicted over the eastern part of the region. The extreme wet estimate shows increasing runoff and the extreme dry scenario shows decreasing runoff. The vast majority of these changes in annual runoff are predicted to occur in winter as can be seen by comparison of Figure 23 with Figure 25.

The mean monthly rainfall and modelled runoff for 12 selected locations (see Figure 3) and the extreme range for the A1B scenario are shown in Figure 26. 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 parts of the region experiences only small amounts of runoff year-round. For almost all of the region, the prediction is for no change in runoff for most months of the year (the median prediction for future climate is similar to the historical climate).

Figure 10. Percentage change in mean annual rainfall across NSW and ACT region (~2030 relative to ~1990) based on climate change projections from 15 GCMs for the medium global warming scenario

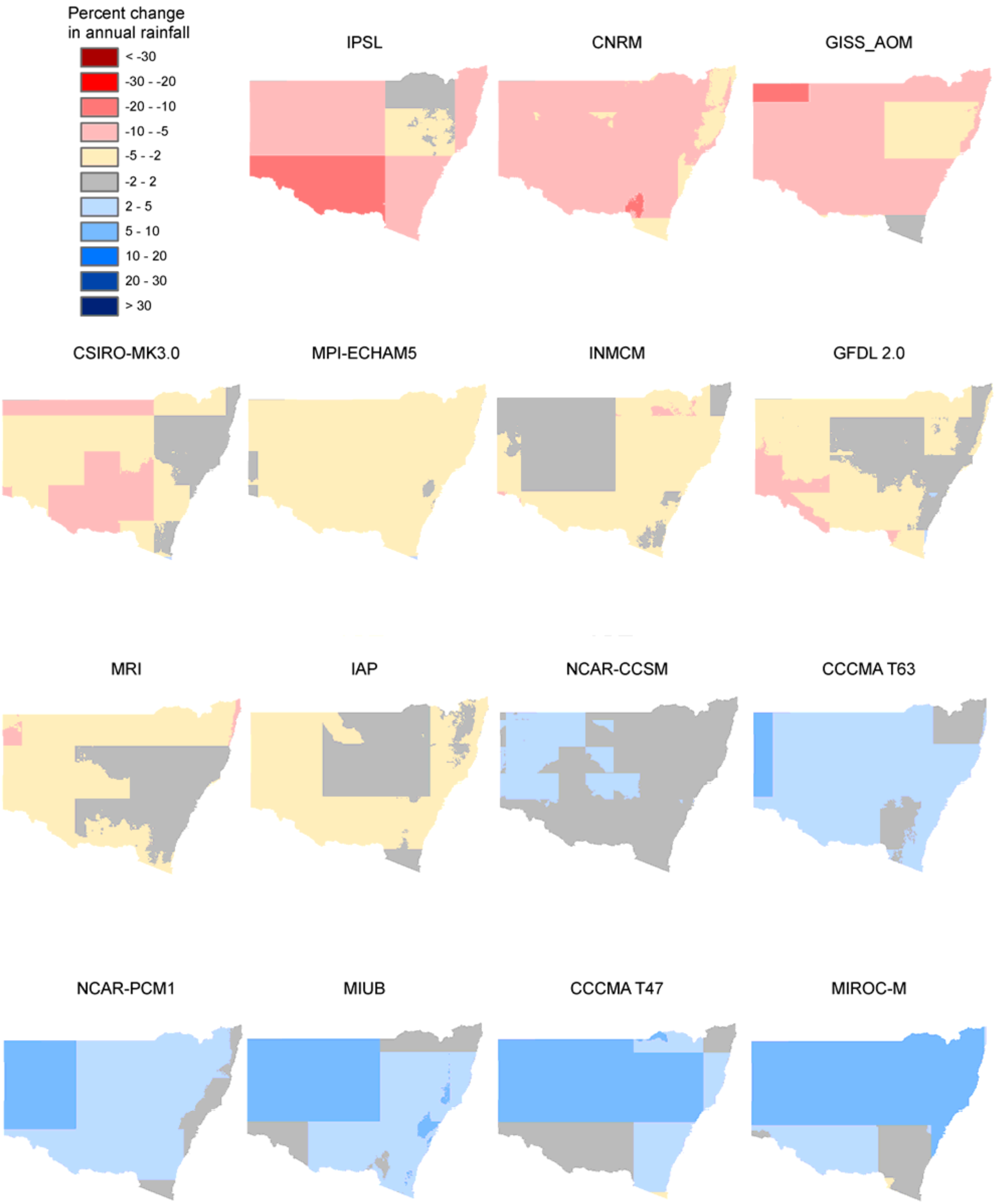


Figure 11. Percentage change in mean summer rainfall across NSW and ACT region (~2030 relative to ~1990) based on climate change projections from 15 GCMs for the medium global warming scenario

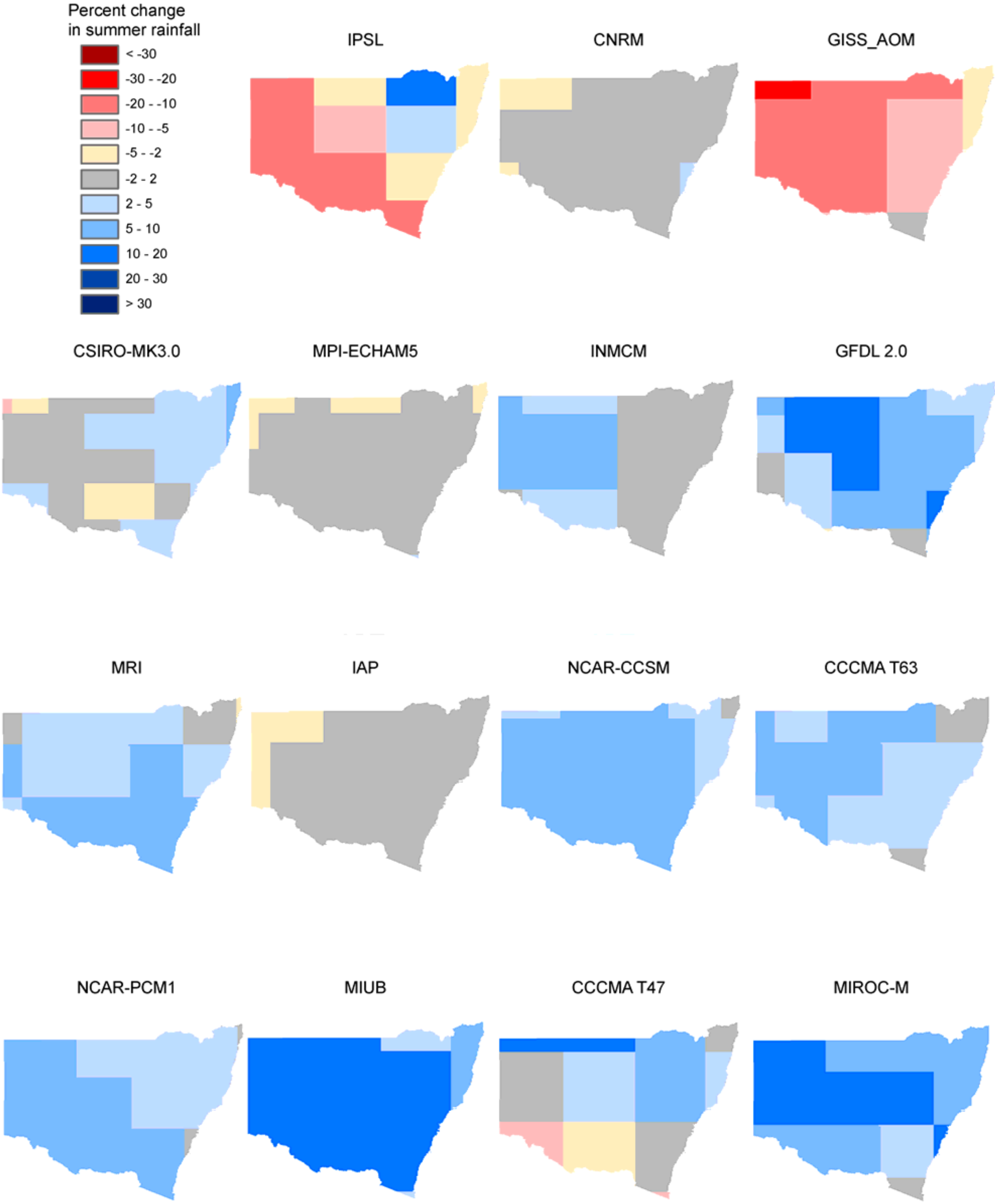


Figure 12. Percentage change in mean winter rainfall across NSW and ACT region (~2030 relative to ~1990) based on climate change projections from 15 GCMs for the medium global warming scenario

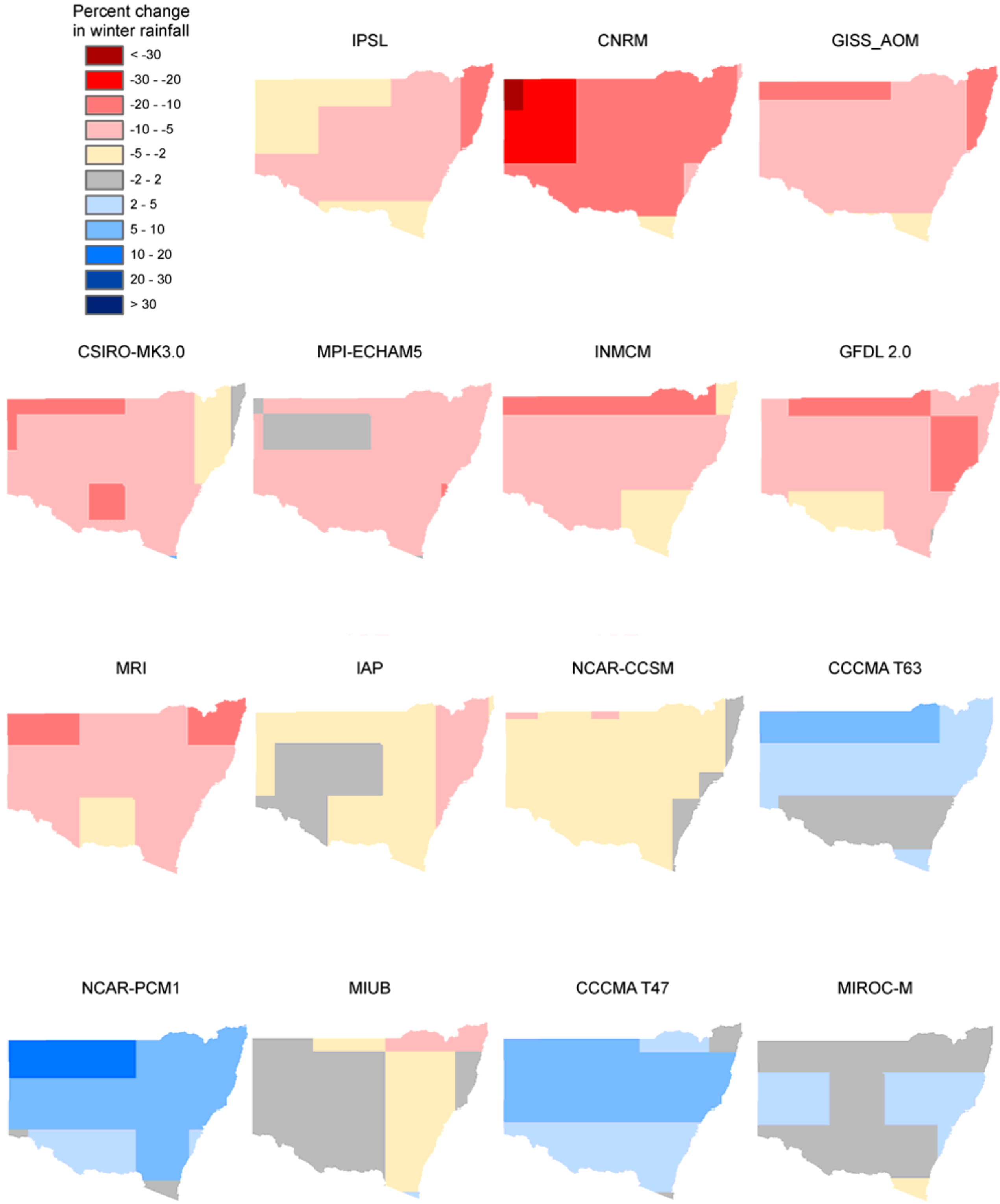


Figure 13. Percentage change in mean annual runoff across NSW and ACT region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario

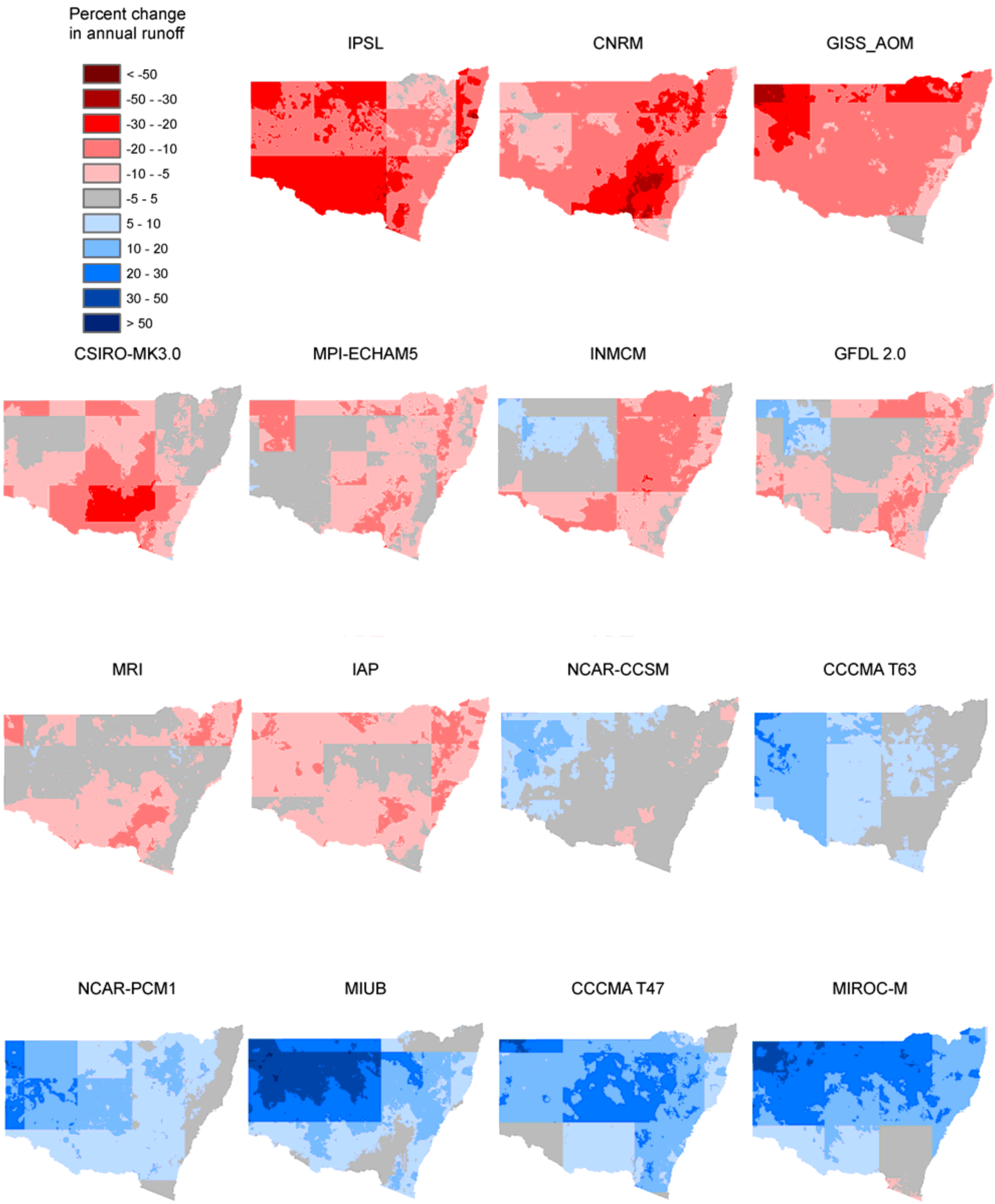


Figure 14. Percentage change in mean summer (DJF) runoff across NSW and ACT region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario

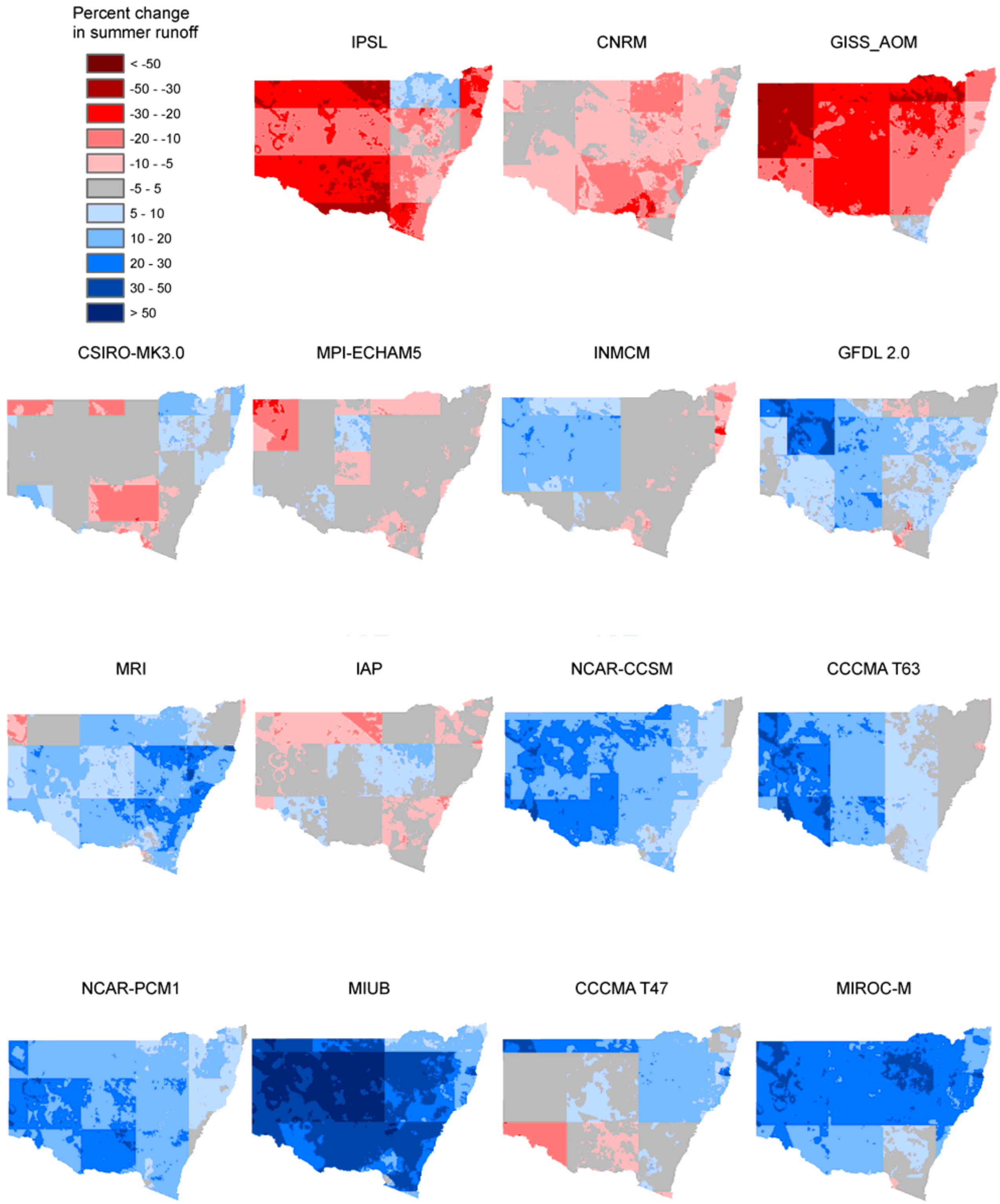


Figure 15. Percentage change in mean winter (JJA) runoff across NSW and ACT region (~2030 relative to ~1990) modelled using climate change projections from 15 GCMs for the medium global warming scenario

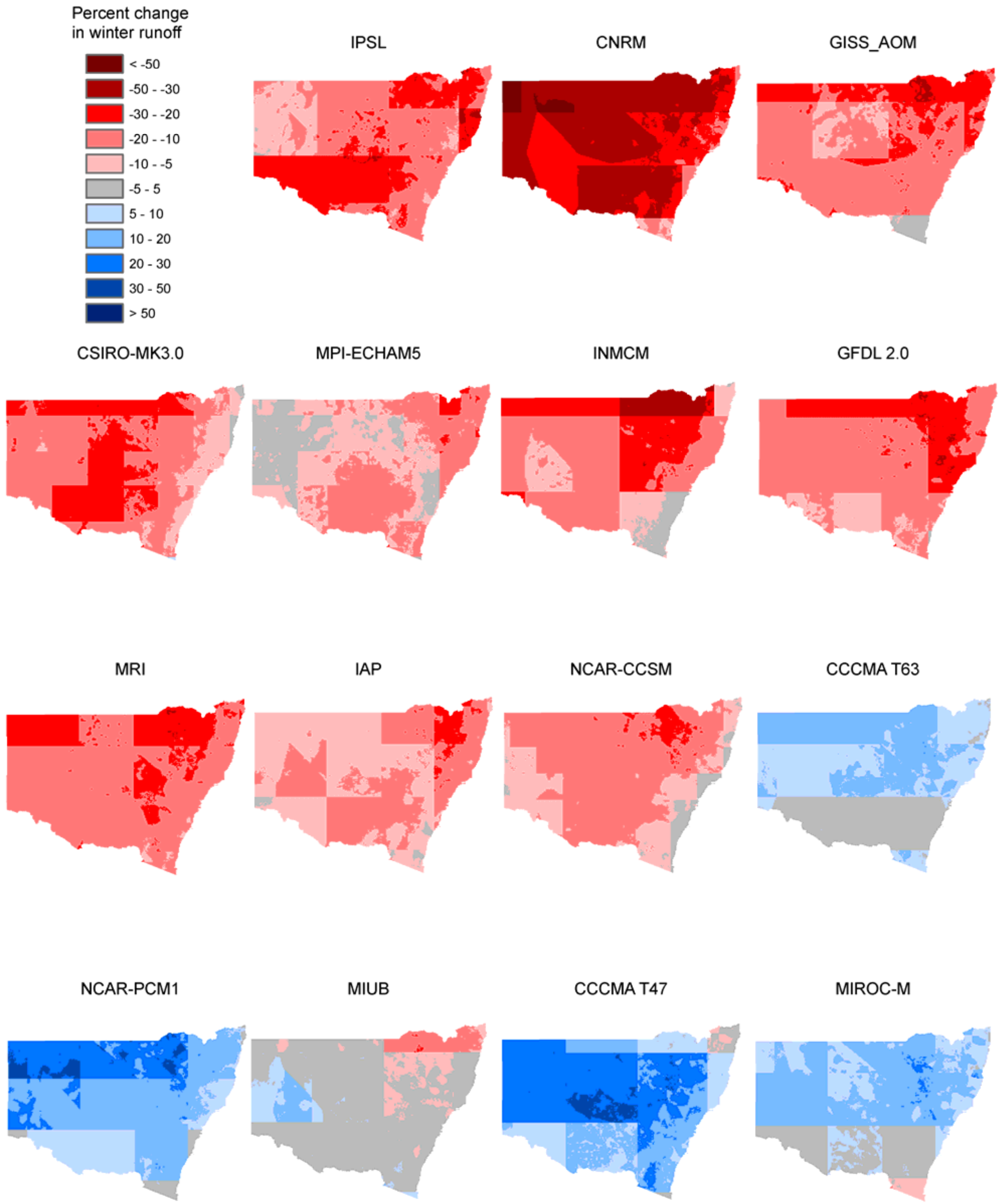


Figure 16: Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF) and winter (JJA) rainfall.

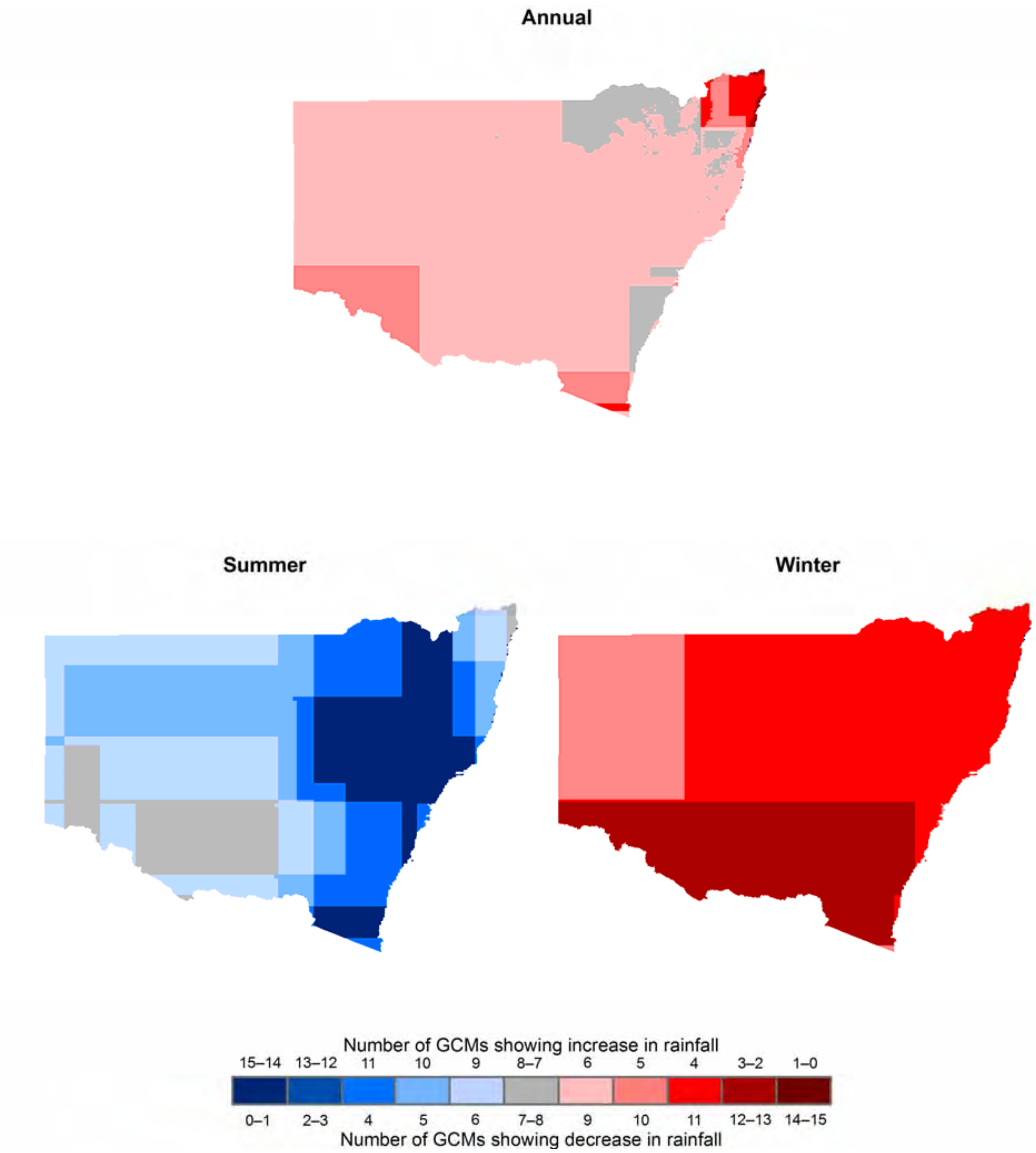


Figure 17. Number of modelling results showing a decrease (or increase) in future mean annual, summer (DJF) and winter (JJA) runoff.

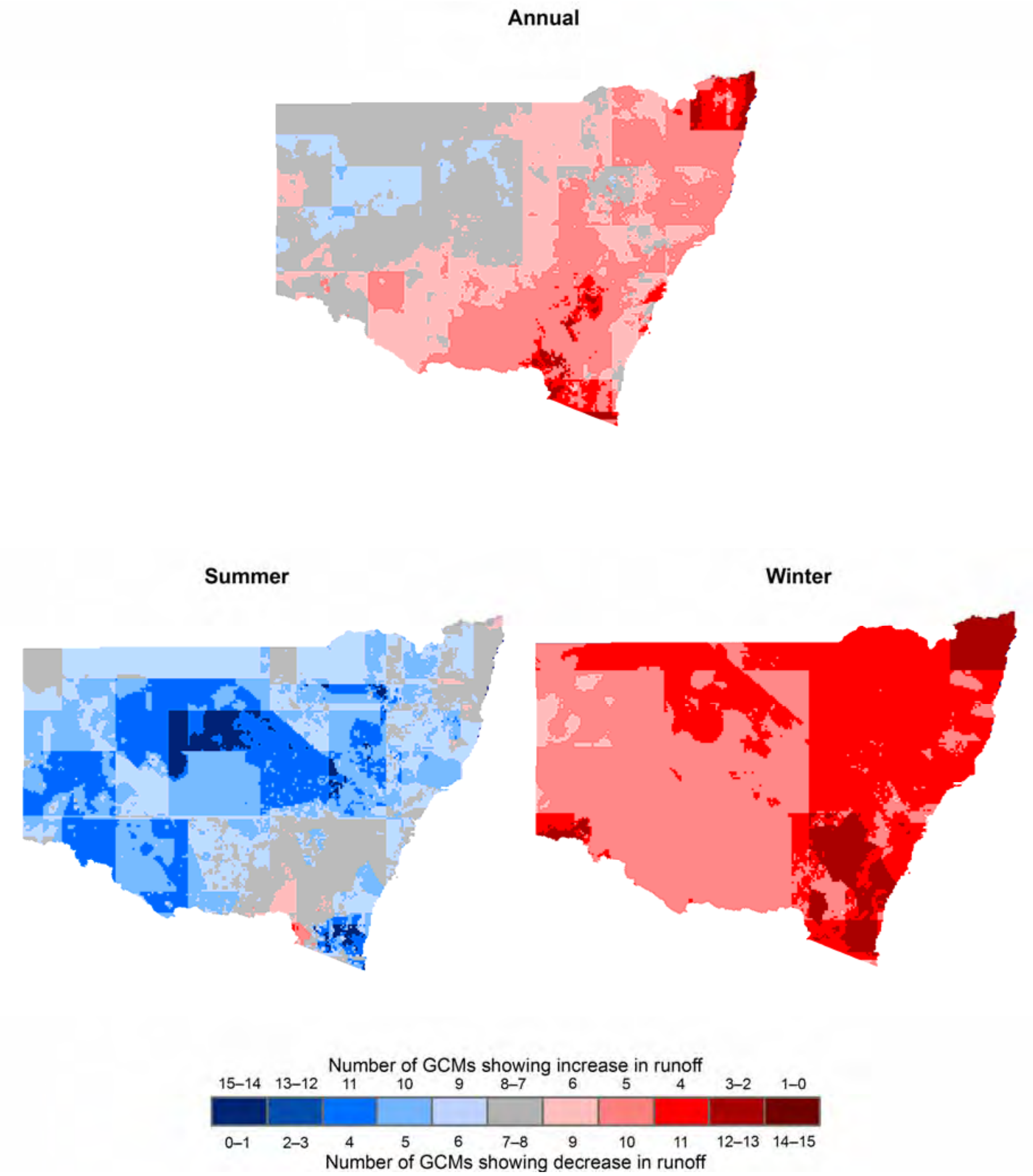


Figure 18: Number of modelling results showing a decrease (or increase) in the top 1-percentile future mean annual, summer (DJF) and winter (JJA) rainfall.

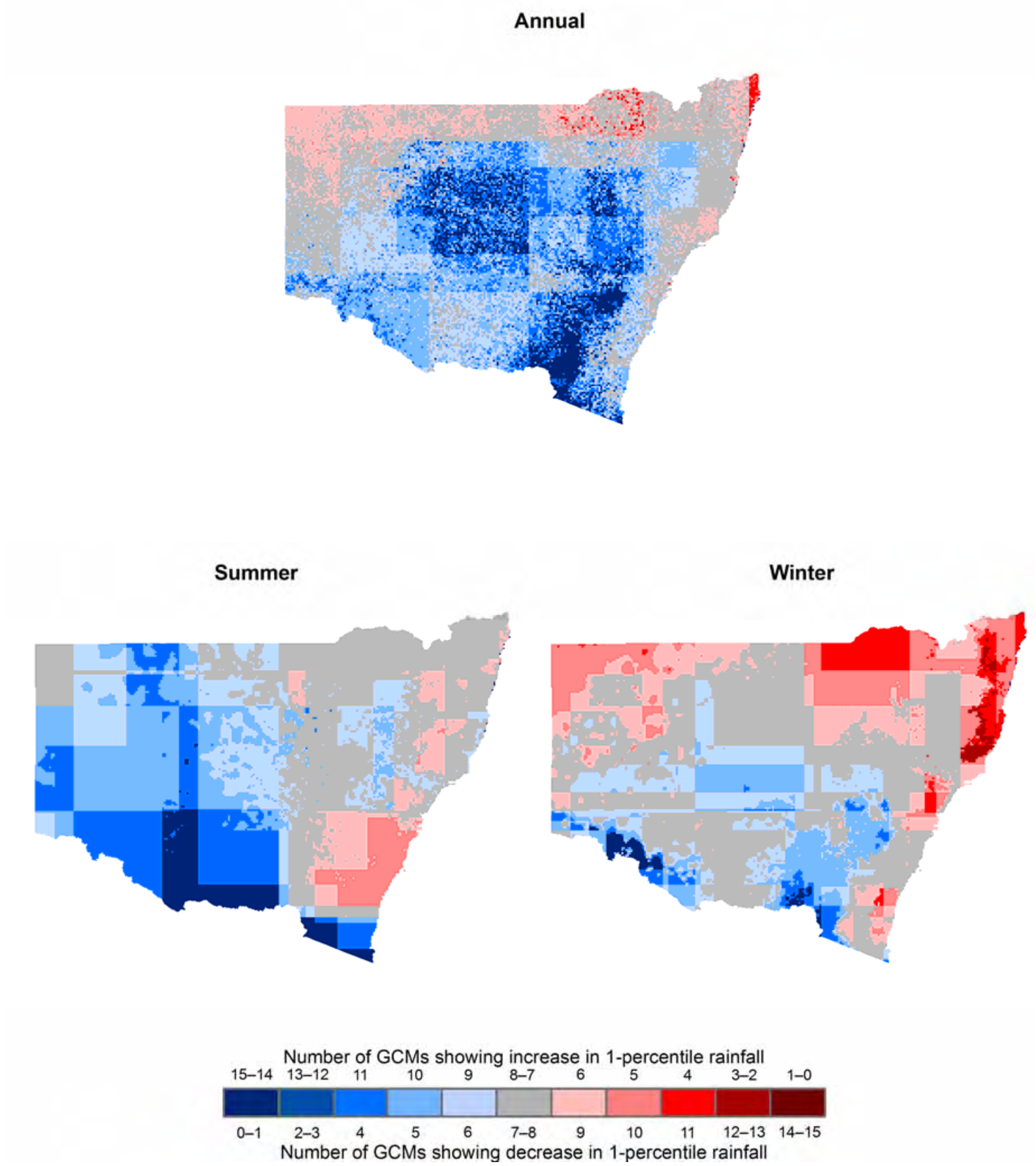


Figure 19: Number of modelling results showing a decrease (or increase) in the top 1-percentile future mean annual, summer (DJF) and winter (JJA) runoff.

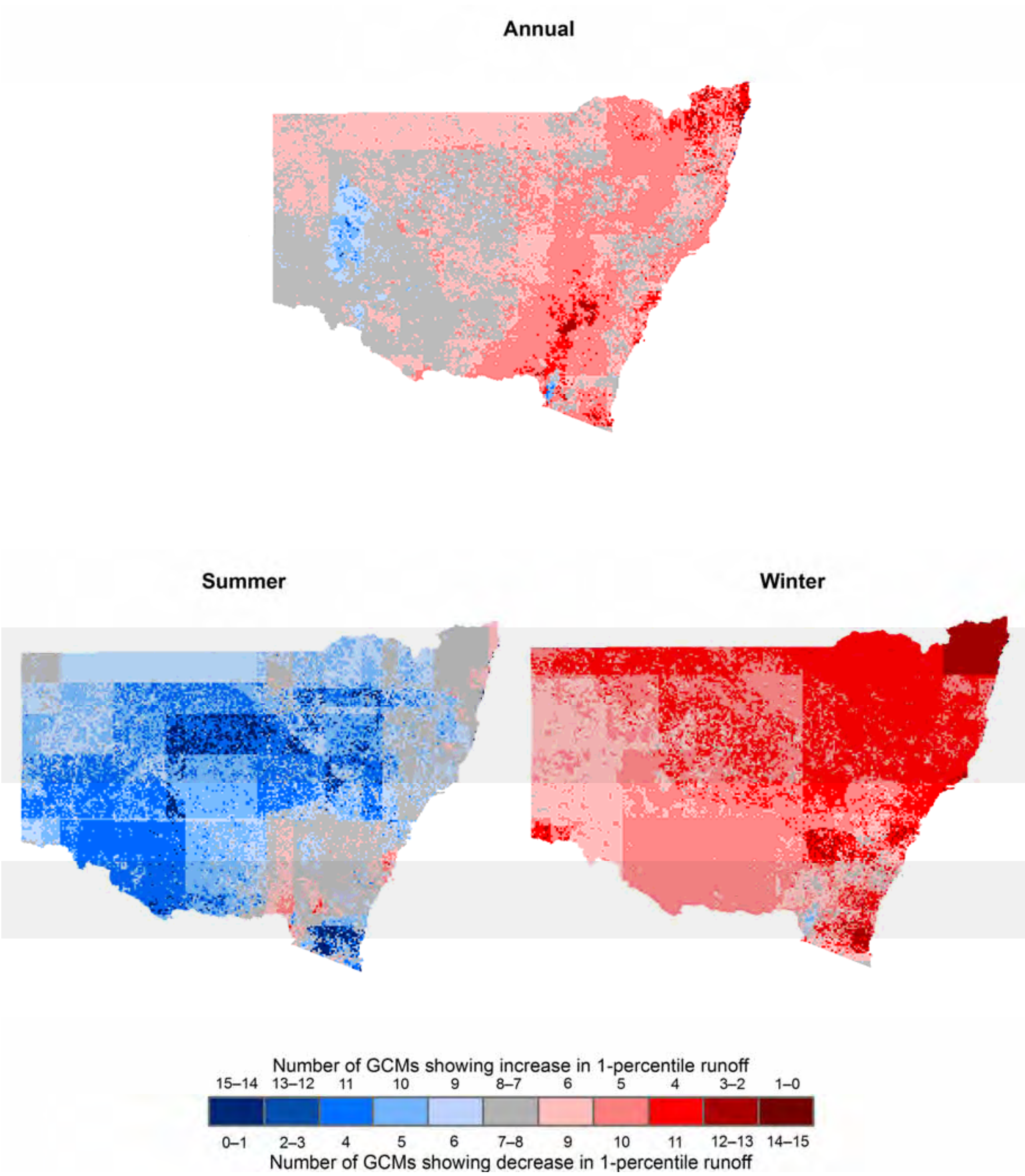


Figure 20. Percentage change in modelled mean annual runoff across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

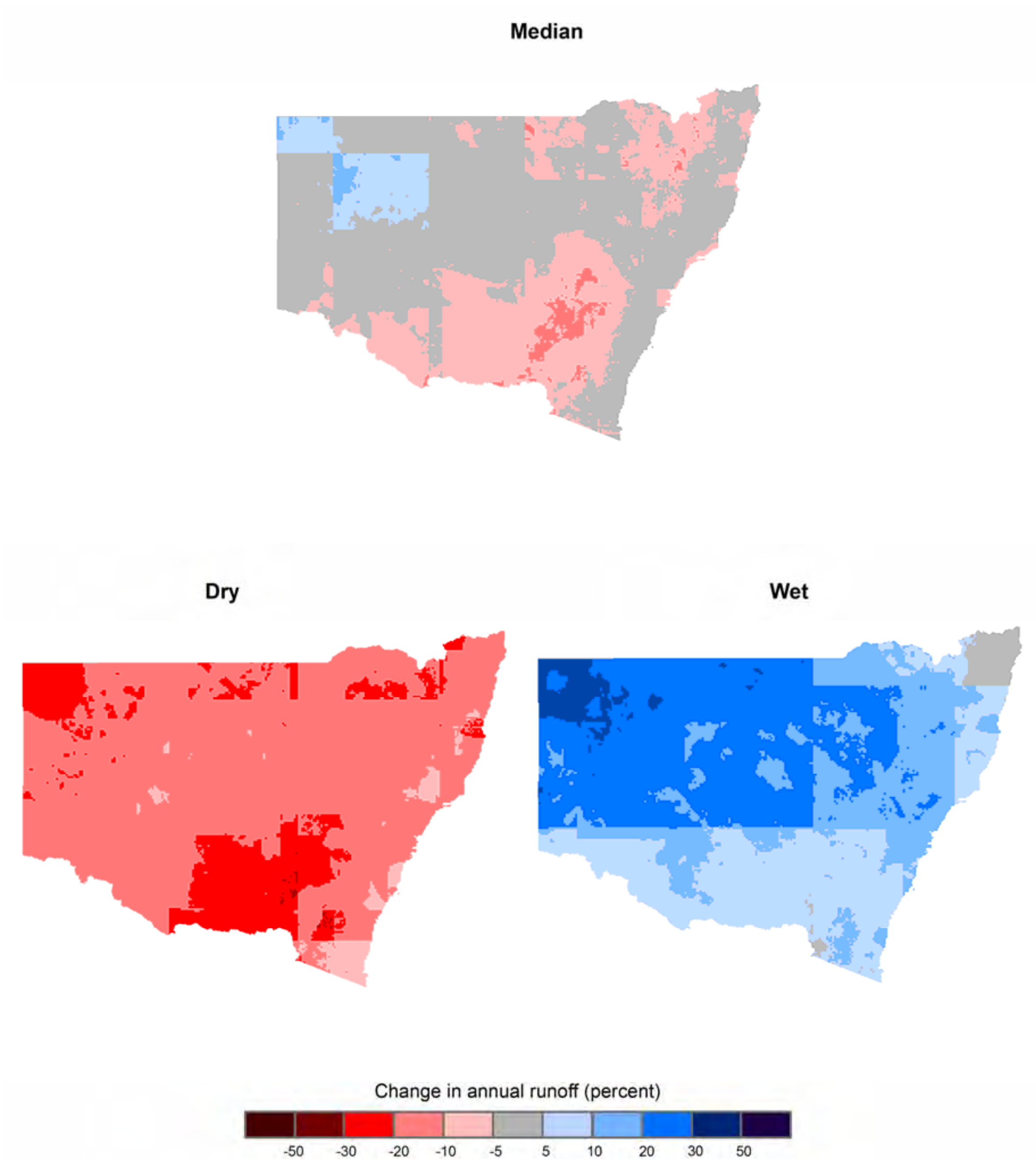


Figure 21. Change in modelled mean annual runoff values (mm) across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

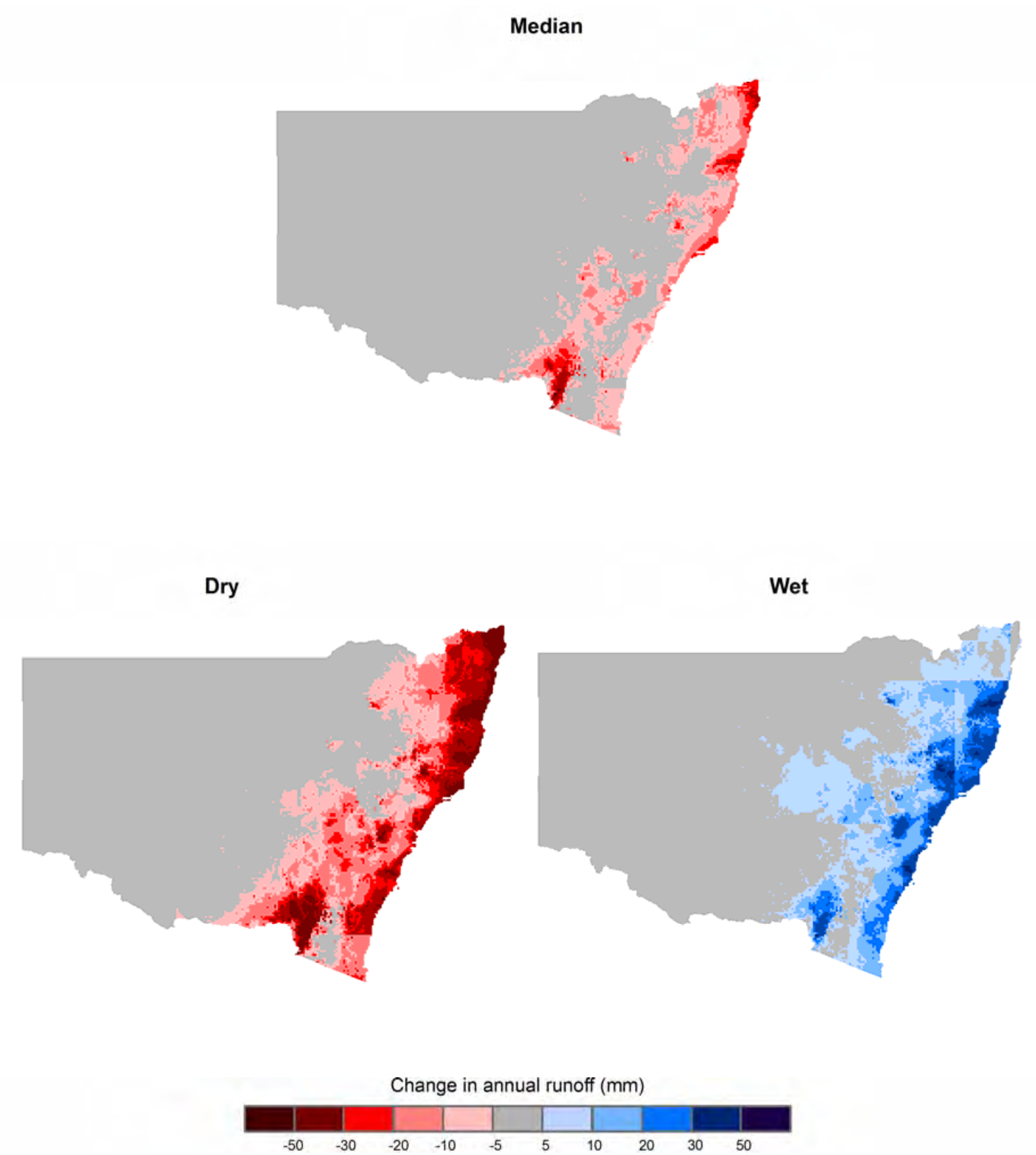


Figure 22. Percentage change in modelled mean summer (DJF) runoff across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

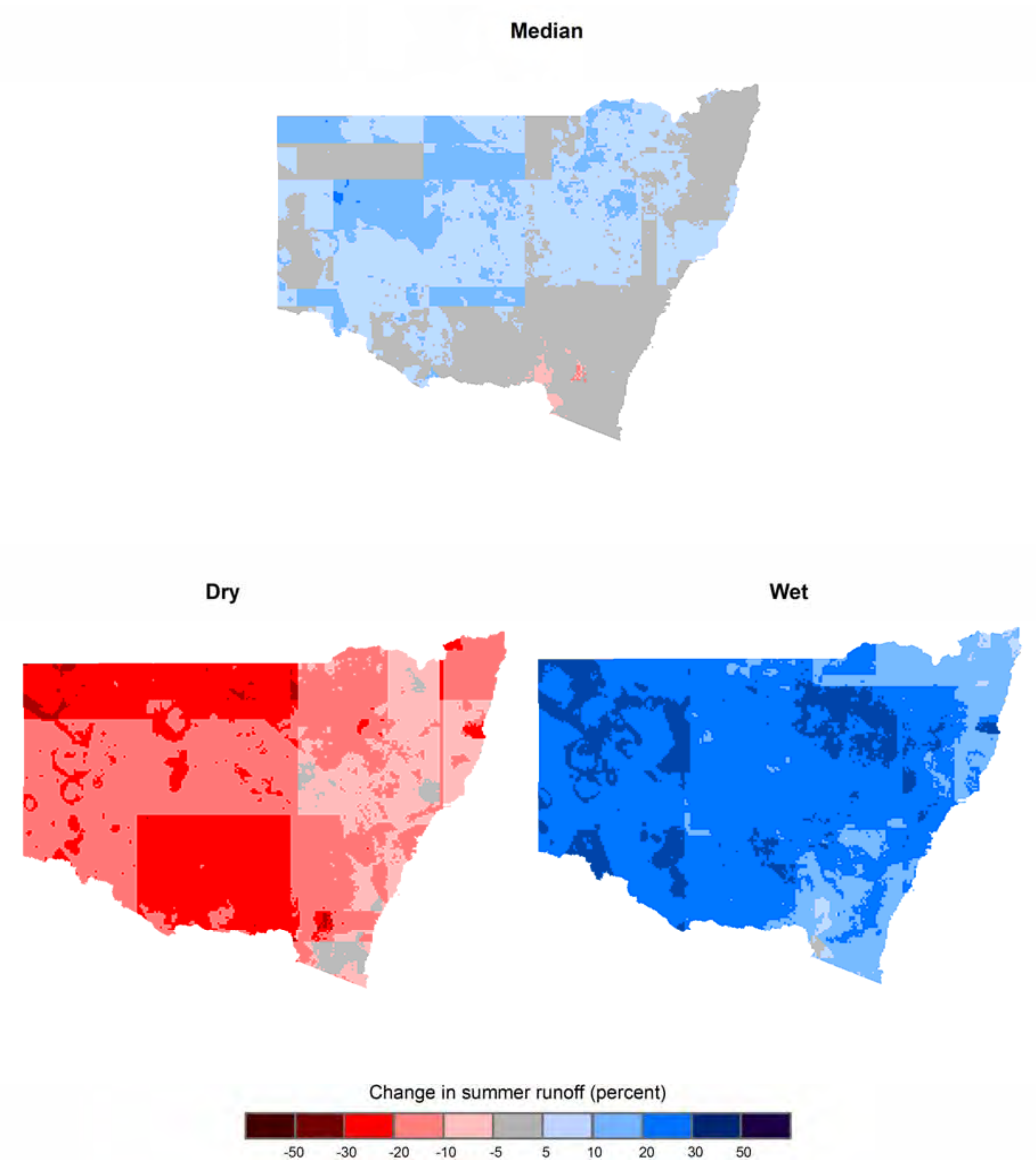


Figure 23. Change in modelled mean summer (DJF) runoff values (mm) across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

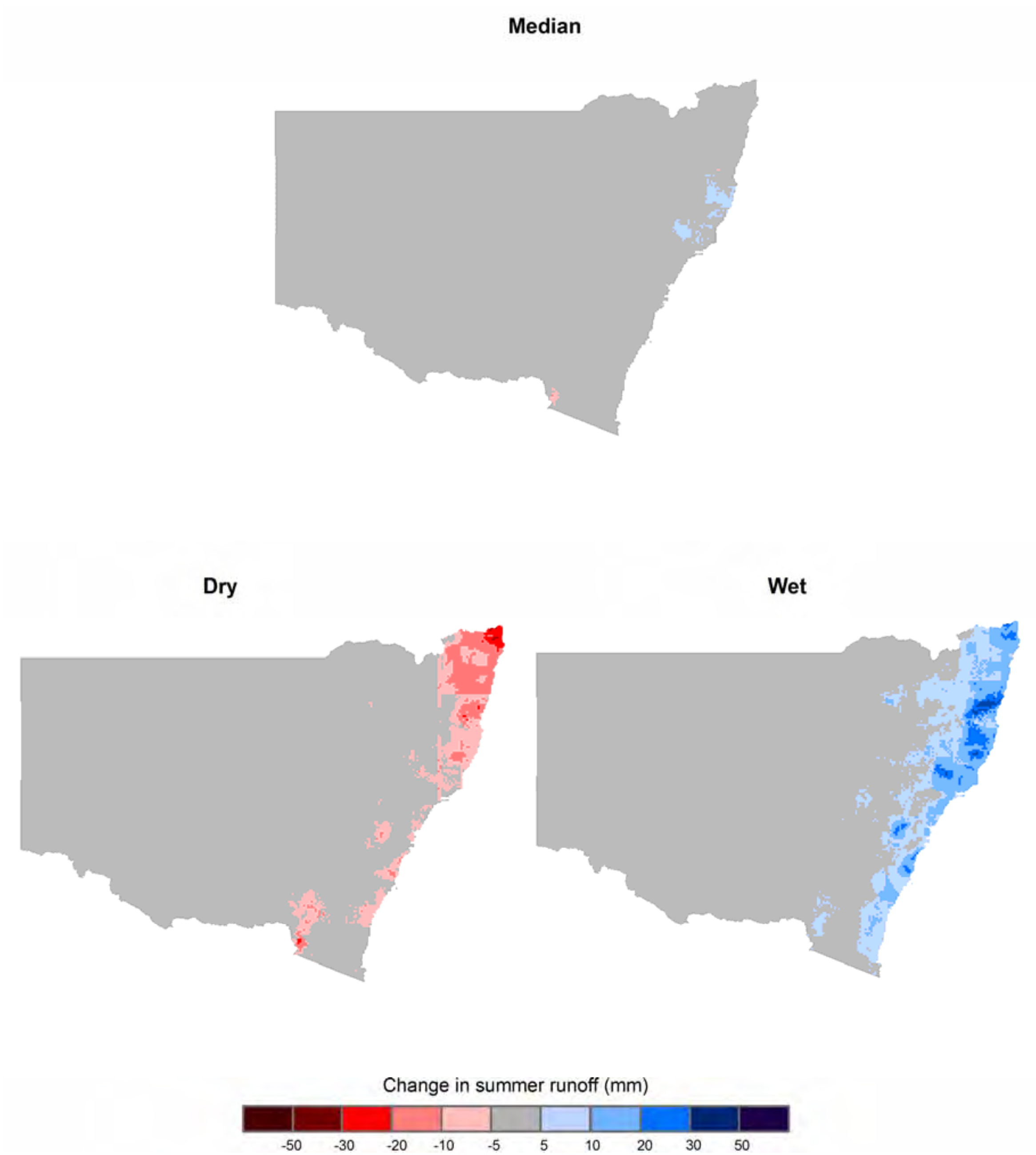


Figure 24. Percentage change in modelled mean winter (JJA) runoff across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

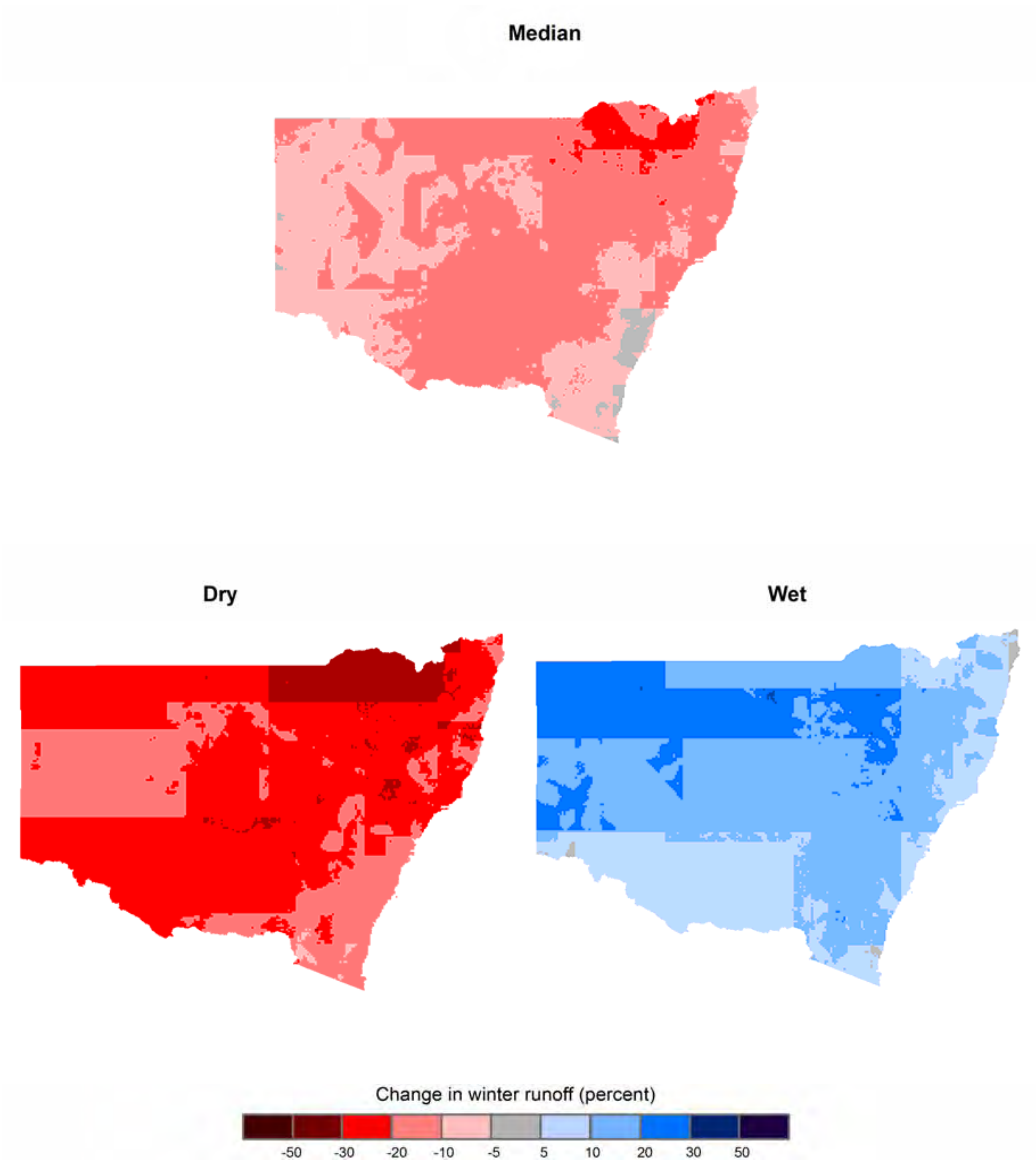


Figure 25. Change in modelled mean winter (JJA) runoff values (mm) across NSW and ACT region (~2030 relative to ~1990) for the median or best estimate and the dry and wet scenarios

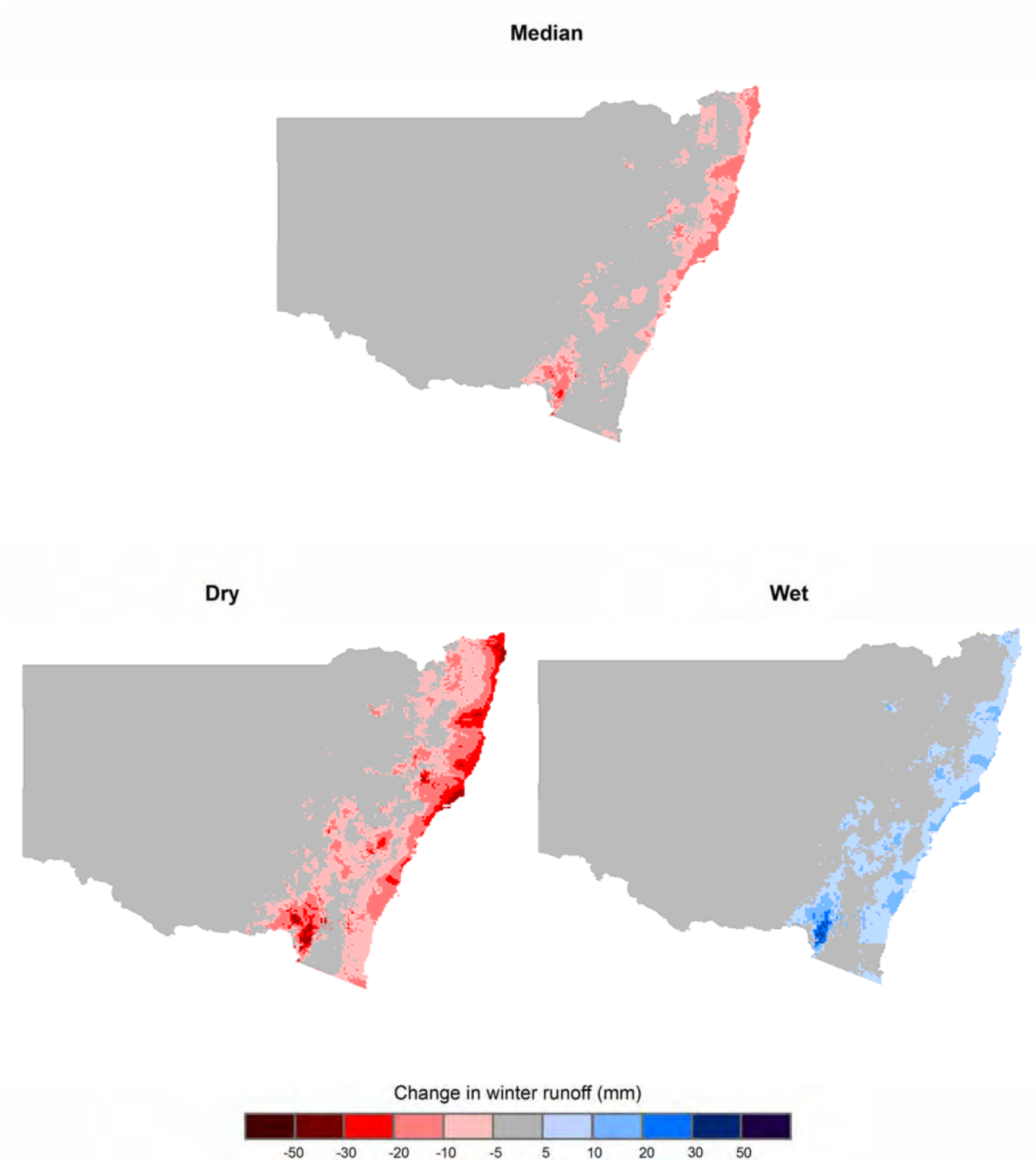
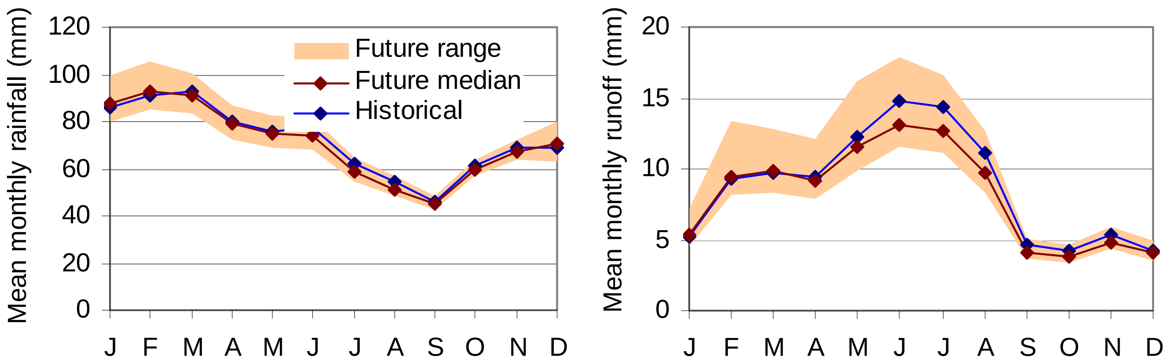
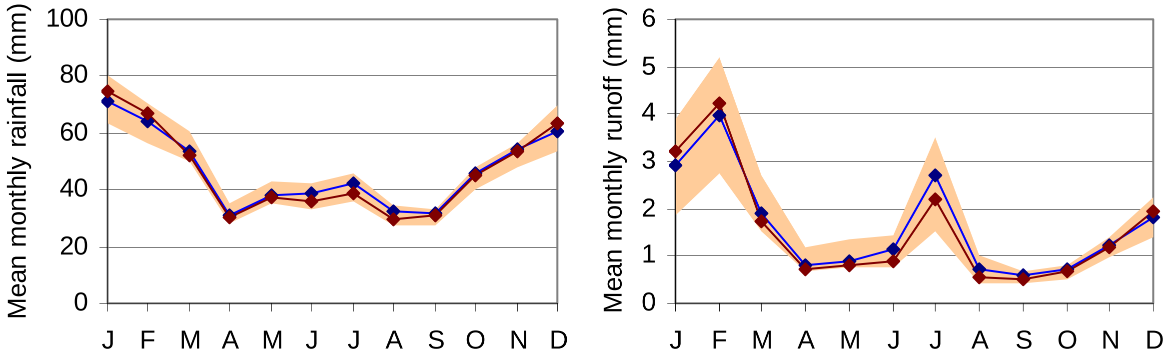


Figure 26: Mean monthly modelled runoff for 12 selected locations (see Figure 3) for the historical climate and the range and median predictions for future (A1B) climate.

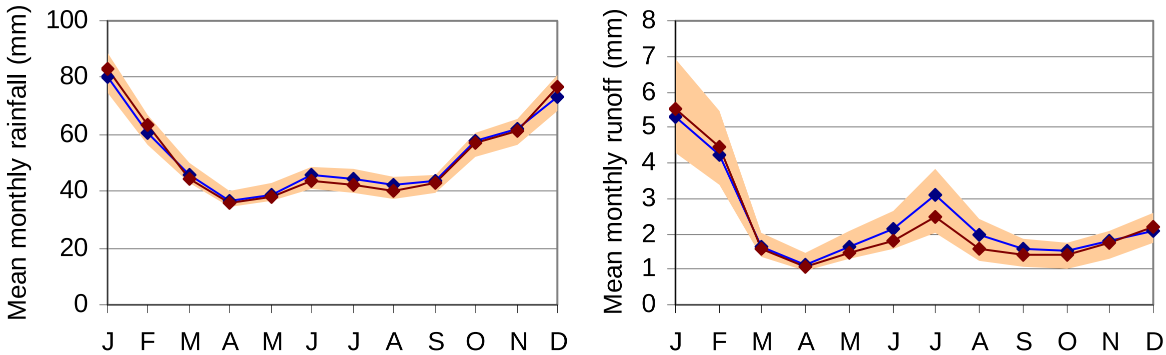
Sydney



Moree



Tamworth



Bourke

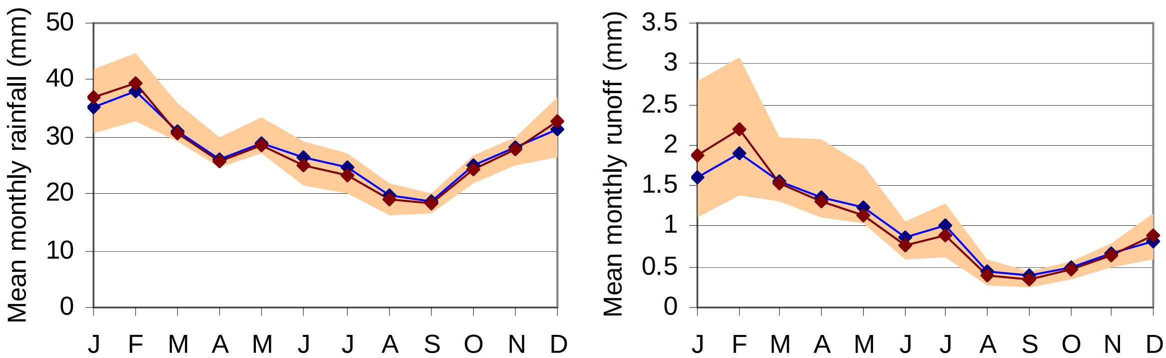
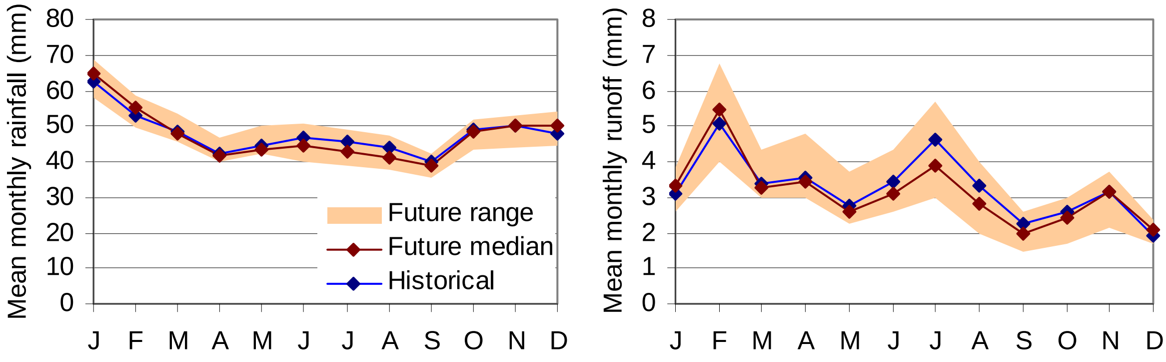
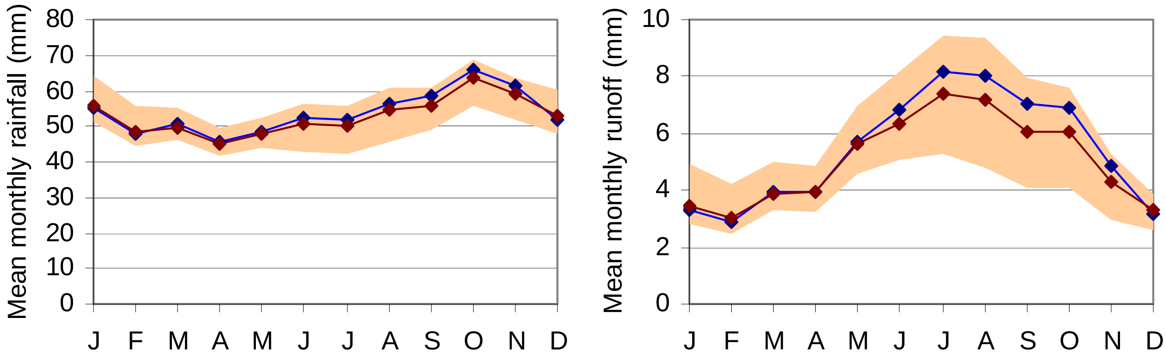


Figure 26 (cont.): Mean monthly modelled runoff for 12 selected locations (see Figure 3) for the historical climate and the range and median predictions for future (A1B) climate.

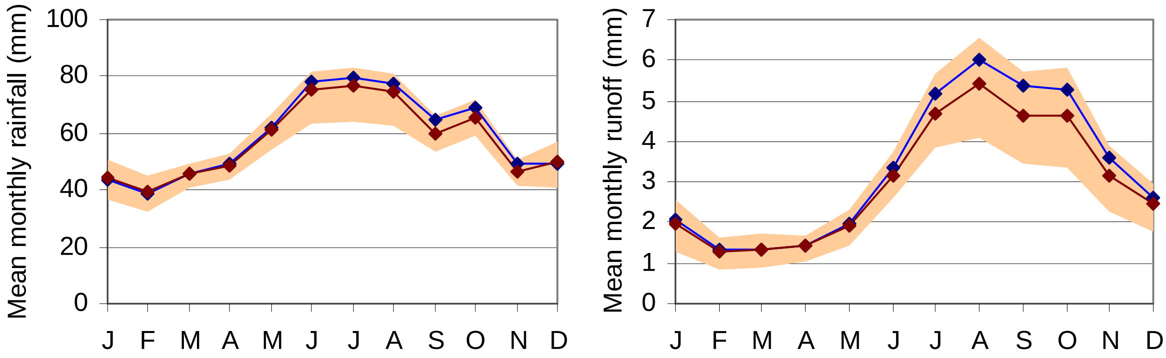
Dubbo



Canberra



Albury



Newcastle

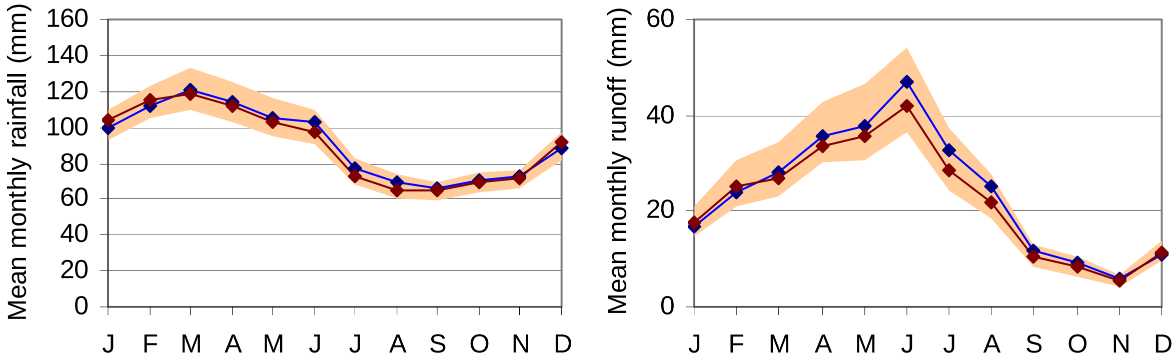
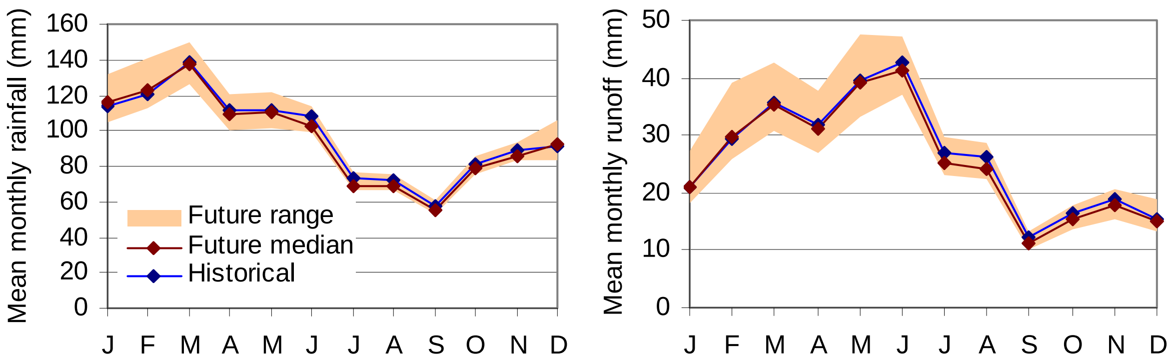
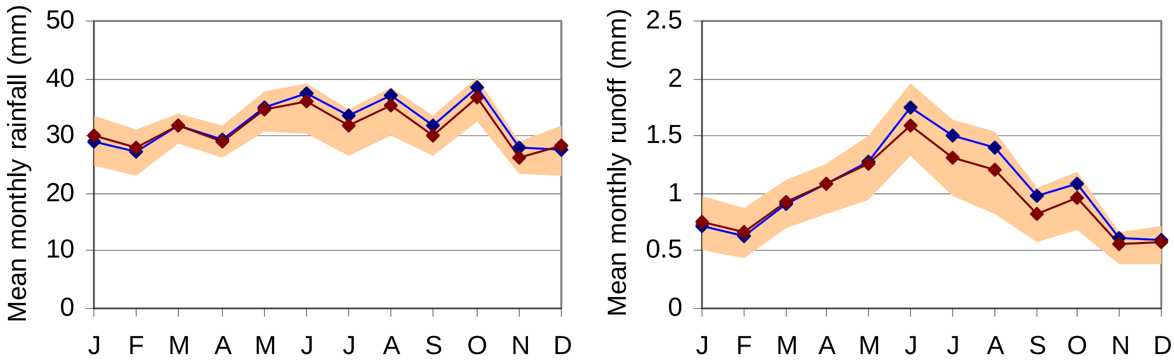


Figure 26 (cont.): Mean monthly modelled runoff for 12 selected locations (see Figure 3) for the historical climate and the range and median predictions for future (A1B) climate.

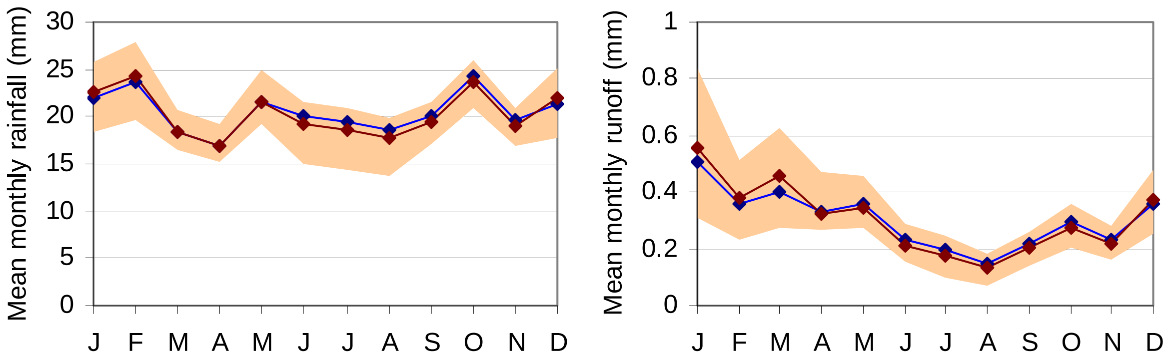
Wollongong



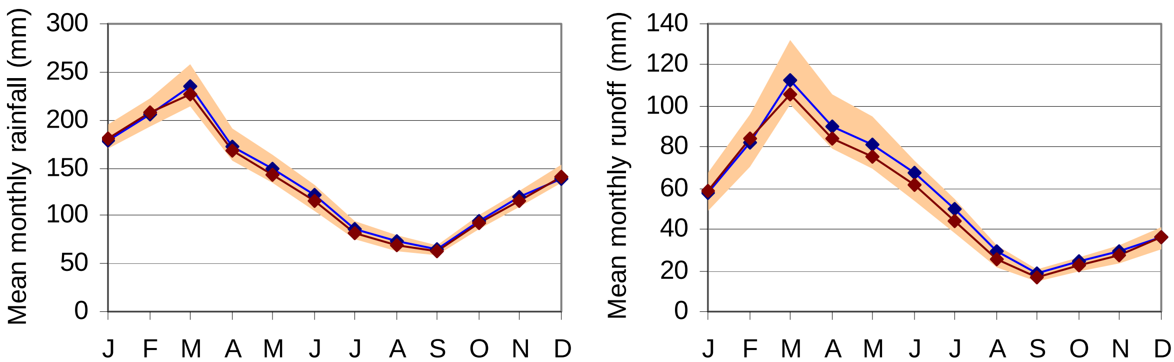
Griffith



Broken Hill



Coffs Harbour



3 Conclusions

This study has examined the potential impacts of climate change on runoff generation in NSW and ACT. 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 $^{\circ}$C, while the mean annual APET in ~2030 relative to ~1990 would increase by 2 to 4 percent.

There is considerable uncertainty in the GCM modelling of rainfall response in NSW and ACT to global warming. However, the majority of GCMs (9 out of 15) show a decrease in the mean annual rainfall. Most of the GCMs (11 out of 15) indicate that future winter rainfall is likely to be lower across the entire region whereas only 5 of the 15 GCMs indicate a reduction in future summer rainfall across the region.

The median or best estimate indicates that future mean annual runoff in NSW and ACT in ~2030 relative to ~1990 will be lower by 0 to 20 percent in the southern parts, no change to a slight reduction in the eastern parts and higher by 0 to 20 percent in the northwest corner. Averaged across the entire region, the median or best estimate is a 5 percent decrease in mean annual runoff.

There is considerable uncertainty in the estimates and the modelled mean annual runoff using the climate change projections from the 15 GCMs range from a 20 percent decrease to a 20 percent increase in the eastern parts of the region, a 30 percent decrease to a 10 percent increase in the southern parts of the region and a 30 percent decrease to a 30 percent increase in the northwest corner. Averaged over the entire region, the extreme estimates range from a 14 percent decrease to a 10 percent increase in mean annual runoff.

References

Burnash RJC, Ferral RL and McGuire RA (1973) A generalised streamflow simulation system – conceptual modelling for digital computers. U.S. Department of Commerce, National Weather Service and State of California, Department of Water Resources.

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 and McMahon TA (2002) Modelling the impacts of climate change on Australian streamflow. Hydrological Processes 16, 1235–1245.

Chiew FHS and Siriwardena L (2005) Estimation of SIMHYD parameter values for application ungauged catchments. Congress on Modelling and Simulation (MODSIM 2005), Melbourne, December 2005, pp. 2883–2889.

Chiew FHS, Peel MC and Western AW (2002) Application and testing of the simple rainfall-runoff model SIMHYD. In: Mathematical Models of Small Watershed Hydrology and Applications (Editors: VP Singh and DK Frevert), Water Resources Publication, Littleton, Colorado, pp. 335–367.

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.

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.

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.

Peel MC, Chiew, FHS, Western AW and McMahon TA (2000) Extension of unimpaired monthly streamflow data and regionalisation of parameter values to estimate streamflow in ungauged catchments. National Land and Water Resources Audit. In: http://audit.ea.gov.au/anra/water/docs/national/streamflow/streamflow.pdf.

Perkins, S. E., A. J. Pittman, N. J. Holbrook and J. McAneney, 2007. Evaluation of the AR4 climate models' simulated daily maximum temperature, minimum temperature and precipitation over Australia using probability density functions. J. Climate, 20, 4356- 4376.

Post DA, Chiew FHS, Vaze J, Teng J, Perraud J-M, and Viney NR. 2008. Future Runoff Projections (~2030) for Southeast Australia: A SEACI Report. CSIRO Land and Water, Australia.

Tan KS, Chiew FHS, Grayson RB, Scanlon PJ and Siriwardena L (2005) Calibration of a daily rainfall-runoff model to estimate high daily flows. Congress on Modelling and Simulation (MODSIM 2005), Melbourne, December 2005, pp. 2960–2966.

Teng J, Vaze J, and Chiew FHS (In prep.) Assessing GCM capability to simulate annual, seasonal and daily rainfall across southeast Australia. Journal Paper, In Preparation.