



**A regional climate  
modelling projection  
ensemble experiment  
– NARCIIM**

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# A regional climate modelling projection ensemble experiment – NARCIIM

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Received: 15 August 2013 – Accepted: 12 September 2013 – Published: 25 September 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

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## Abstract

Including the impacts of climate change in decision making and planning processes is a challenge facing many regional governments including the New South Wales (NSW) and Australian Capital Territory (ACT) governments in Australia. NARCIiM (NSW/ACT Regional Climate Modelling project) is a regional climate modelling project that aims to provide a comprehensive and consistent set of climate projections that can be used by all relevant government departments when considering climate change. To maximise end user engagement and ensure outputs are relevant to the planning process, a series of stakeholder workshops were run to define key aspects of the model experiment including spatial resolution, time slices, and output variables. As with all such experiments, practical considerations limit the number of ensembles members that can be simulated such that choices must be made concerning which Global Climate Models (GCMs) to downscale from, and which Regional Climate Models (RCMs) to downscale with. Here a methodology for making these choices is proposed that aims to sample the uncertainty in both GCMs and RCMs, as well as spanning the range of future climate projections present in the full GCM ensemble. The created ensemble provides a more robust view of future regional climate changes.

## 1 Introduction

Global warming is a major international concern and requires a global effort to reduce anthropogenic greenhouse gas concentrations. Nevertheless, as global warming continues adaptation to the inevitable changes in climate will have to be done at regional and local scales. This requires climate projection information at a spatial scale relevant to the system of interest, which is frequently significantly smaller than the resolution of Global Climate Models (GCMs). Dynamic downscaling with Regional Climate Models (RCMs) is one method to address this scale gap. A number of previous projects have produced regional climate projections using RCM ensembles including PRUDENCE

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nity services. This covers many sectors including water resources, biodiversity, infrastructure, health and emergency services. Through a process involving multiple stakeholder workshops, which involved compromise amongst stakeholders from the various sectors, a project design that was achievable within the available compute and data storage resources, was determined. The NARCIIM modelling project is unique within Australia as it's project design has been a bottom up approach, heavily involving end users in the conception and design phases, rather than a top down approach driven mostly by the climate change science community. In the top down approaches, much of the key questions relating to model epochs and climate variable outputs are decided by the climate modellers and then these are presented to the end user community, including other scientists and modellers working on impact science programs as a *fait au complit*. This leads to a disconnect between the end user or adaptation community and the climate modelling community as the outputs are often not relevant to the needs of the adaptation practitioners or if they are it is by chance rather than design. Involving the adaptation community in the project design maximises the chances of developing model outputs that are readily used by this group. Other benefits of early end user involvement are an improved understanding of the climate modelling process and it's limitations and greater sense of ownership and user uptake of the outputs by the end users. The overall project design includes mechanisms for project governance and data distribution. Information about various aspects of the project can be found here (<http://www.ccrcc.unsw.edu.au/NARCIIM/>).

Largely due to the available computing and data storage facilities, the project is limited to a twelve member GCM/RCM ensemble. This will be created by choosing four GCMs and downscaling each of these with three different RCMs. All RCM simulations will be performed at 10 km resolution over NSW/ACT. This high resolution domain will be embedded within a 50 km resolution domain that covers the CORDEX-AustralAsia region (Fig. 1). Choosing this larger domain ensures that a future stage of the project focused on CMIP5 results can take advantage of simulations performed for the CORDEX initiative. The inner domain and resolution is chosen with a particular focus on sim-

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ulations of the east coast climate as this relatively narrow coastal strip, east of the mountains: contains almost half the population of Australia; displays a unique climate response to oceanic modes compared to further inland (Murphy and Timbal, 2008); is generally poorly modelled by GCMs (Suppiah et al., 2007) but is well modelled at 10 km resolution (Evans and McCabe, 2010, 2013); and is strongly influenced by east coast lows which are often small, rapidly developing storm systems (Speer et al., 2009).

Like previous regional climate projection projects, NARCIIM has two main phases.

In phase one, three RCMs are used to downscale the NCEP/NCAR reanalysis (Kalnay et al., 1996) from 1950 to 2010. This reanalysis was chosen to allow a 60 yr long historical simulation. South-east Australia has experienced strong decadal variability in precipitation over the second half of the 20th century with particularly wet decades in the 1950s and 1970s. These reanalysis driven simulations provide a strong test of the RCMs ability to simulate both these very wet periods and the recent dry period known as the Millennium Drought (Van Dijk et al., 2013). This phase provides an estimate of the RCM quality including any systematic RCM biases.

In phase two, three RCMs will downscale four GCMs in three 20-year time-slices (1990–2010, 2020–2040, 2060–2080). For future projections the SRES A2 emission scenario (IPCC, 2000) will be used. Careful choice of both RCMs and GCMs is required for this small ensemble to adequately sample the model uncertainty, the methodology used to make these decisions is outlined below.

### 2.1 Choosing RCMs

The small number of RCMs chosen to downscale with should span the range of uncertainty present in the full collection of RCMs that are able to simulate the climate in the area of interest well. Thus a two-step RCM selection process is proposed.

1. The full set of RCMs are evaluated over the domain of interest in order to remove from the set any models that are not able to adequately simulate the climate.

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2. From the set of RCMs that perform well a subset is chosen such that each chosen RCM is as independent as possible from the other RCMs.

When evaluating RCMs many subjective choices concerning the variables to be evaluated, the temporal and spatial averaging used, and the statistical measures calculated must be made. Many past studies have evaluated RCM ensembles using many different combinations of the above (e.g. Kjellstrom and Giorgi, 2010 and Mearns et al., 2012) generally finding that no model performs best across all variables and metrics (Kjellstrom et al., 2010). Thus, comprehensive evaluation studies are used here to exclude models that perform consistently poorly across a wide range of variables and metrics, rather than trying to identify a set of best models. This approach is consistent with that adopted in McSweeney et al. (2012) and Overland et al. (2011). The large range in possible evaluations that can be performed, along with the many methods to combine evaluation metrics into a final score, makes it difficult to define a-priori an acceptable performance level. Here a relative performance level is assessed such that any group of models that are significantly worse than the rest of the models will be excluded.

Now that we have a set of RCMs that perform well over our area of interest, we wish to choose a small subset that spans the uncertainty of this larger set. Given that climate models often share code, there is broad recognition that they do not provide independent samples from the model space (Knutti et al., 2010; Pennell and Reichler, 2011). Hence this choice can be rephrased as one in which the most independent models should be chosen from the larger set. Recently Bishop and Abramowitz (2013) proposed a measure that uses the covariance in model errors as the basis for a definition of model dependence. Here we rank the models based on the magnitude of these independence coefficients and choose the top models from this ranking.

## 2.2 Choosing GCMs

Similar to choosing RCMs, the choice of GCMs is made in order to sample the range of uncertainty in the ensemble of GCMs that simulate the climate of the target region well. Since a GCMs ability to simulate the current climate has little relationship with the future climate it projects, an additional criterion is introduced. The GCMs chosen should span the range of projected future change, in order to sample this additional source of uncertainty. That is, a three-step GCM selection process is proposed.

1. The full set of GCMs are evaluated over the domain of interest in order to remove from the set any models that are not able to adequately simulate the climate.
2. The set of GCMs that perform well is then ranked based on a measure of independence.
3. The GCMs are then placed within the future change space and the most independent models that span that space are chosen.

While it is possible to perform evaluation of the GCMs in a similar way to that performed for the RCMs, it is also possible to take advantage of the extensive literature in this regard. Given the plethora of evaluation publications based on CMIP3 (and soon CMIP5) data, a metadata analysis of the literature can provide evidence with which to evaluate the models. When this has been done (e.g. Overland et al., 2011; Smith and Chandler, 2010) it is generally found that it is difficult to identify “best” models. Hence, this evaluation is used to identify those models that are consistently poor performers and remove them from consideration.

Several issues must be overcome in order to combine literature studies into one overall score for a GCM: some studies provide a binary pass/fail outcome based on their internal criteria, while others provide continuous measures; and many published studies use only a subset of the full GCM ensemble. Here we address these issues through the introduction of a fractional demerit score, such that the lower the score,

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### 3.1 RCM selection

Within a project such as CORDEX, the RCM evaluation could be performed directly on the reanalysis driven simulations to choose a subset with which to perform the transient GCM driven simulations. Within NARCIIM the available compute resources required the evaluation to be performed using much shorter simulations, and the time constraints limited the number of separate modelling systems that could be implemented. Previous work has shown that the range in the multi-model ensemble can be reproduced within perturbed physics ensembles (Collins et al., 2006). Here the RCM choice is based on a multi-physics ensemble built using the Weather Research and Forecasting (WRF) modelling system (Skamarock et al., 2008). This system facilitates the use of many RCMs by allowing all model physical parametrisations to be changed and hence many structurally different RCMs can be built. Due to computational limitations, the RCM performance and independence was evaluated based on a series of representative event simulations rather than using multi-year simulations.

By limiting the evaluation period to a series of representative events for the region, a much larger set of RCMs can be tested. In this case an ensemble of 36 RCMs was created by using various parametrisations for the Cumulus convection scheme, the cloud microphysics scheme, the radiation schemes and the Planetary Boundary Layer (PBL) scheme. Each of these RCMs was used to simulate a set of 8 representative storms (Evans et al., 2012; Ji et al., 2013) that cover the various relevant storm types for this region discussed in the literature (Shand et al., 2010; Speer et al., 2009). In each case a two week period is simulated centred around the peak of the event. Subsequent analysis then includes pre and post-event climate as well as the event itself.

Evaluation was performed against daily precipitation, minimum and maximum temperature from the Bureau of Meteorology's (BoMs) Australian Water Availability Project (BAWAP – Jones et al., 2009). Evaluation was also performed against the mean sea level pressure and the 10 m winds obtained from BoMs MesoLAPS analysis (Puri et al., 1998). The metrics used for the ranking are the bias, root mean square error (RMSE),

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of independence between them. The role of performance in the measure can also be seen in the SURFERS case where none of the models that produced large overestimates of precipitation after the observed peak, were chosen. While the models chosen are a compromise across all events, they are still able to sample much of the range of behaviour in the full ensemble for each event.

### 3.2 GCM selection

In CORDEX the ensemble from which GCMs are selected is the CMIP5 ensemble. For NARCIIM the CMIP3 ensemble is used. Many studies have evaluated the performance of CMIP3 GCMs over south-east Australia using different variables and metrics. Here we build on the meta-analysis of Smith and Chandler (2010). First, more recent evaluations over Australia, not covered in Smith and Chandler (2010), are added to the analysis for a total of 11 studies (see Table 1). Of these studies four provided a pass/fail assessment of the GCMs, while the rest provided continuous measures. Then a fractional demerit score was calculated to indicate the models over-all performance. The lower the fractional demerit the better the performance. Here, six GCMs score 0.5 or higher and are removed from further analysis.

As for the RCMs, the remaining GCMs are then ranked based on their level of model independence using the measure of Bishop and Abramowitz (2013). In this case the independence coefficient is calculated separately for mean temperature and precipitation and then averaged.

The final step requires placing the GCMs within a future climate change space. Such a space could be defined using any combination of climate variables. Here we define the future climate space using the change in mean temperature in Kelvin, and the percent change in mean precipitation. Figure 4 shows the location of the GCMs within this future climate space, numbered by their independence rank order. Four groupings of GCMs can be seen within this space: top left; top right; centre left; and bottom right. It is desirable then to choose one GCM from each of these groupings that has the highest independence ranking. In this case the models to choose would be the models ranked

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est. This identification should be relatively robust to the individual measures used in a comprehensive evaluation.

The field of model independence is a relatively new and growing area of research. While the coefficient of Bishop and Abramowitz (2013) is used here as a metric to determine the relative independence of models within an ensemble, other methods are likely to be developed in the coming years and may also be used within this context.

The future climate change projected by the GCMs is given here by the projected change in temperature and precipitation. This choice was made as these two climate variables were the most sought after by project stakeholders. In practice any climate variables could be used. Including the possibility of using a higher dimensional space (more than two climate variables). Probably the most subjective aspect of the methodology presented here is the choice of models from this future climate change space. Future development of this methodology will include objective methods for making this choice. This may include the application of 2-D clustering techniques to identify clusters from which to choose models, or applying kernel smoothing techniques where the future climate change uncertainty is derived from the inter-annual variability.

Combining the model choice methodology described here with the “sparse matrix” of GCM and RCM combinations used in previous regional climate modelling projects, will result in a climate projection ensemble that more robustly samples the uncertainty space associated with regional climate projections, given limited computational and data storage resources.

*Acknowledgements.* This work was made possible by funding from the NSW Office of Environment and Heritage backed NSW/ACT Regional Climate Modelling (NARCIIM) Project, NSW Environmental Trust for the ESCCI-ECL project, and the Australian Research Council as part of the Future Fellowship FT110100576 and Linkage project LP120200777. This work was supported by an award under the Merit Allocation Scheme on the NCI National Facility at the ANU.

## GMDD

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**Table 1.** The model configuration for the three most independent RCMs.

NARCIIM Ensemble member	Planetary boundary layer physics/ Surface layer physics	Cumulus physics	Micro-physics	Shortwave/ Longwave radiation physics
R1	MYJ/Eta similarity	KF	WDM 5 class	Dudhia/RRTM
R2	MYJ/Eta similarity	BMJ	WDM 5 class	Dudhia/RRTM
R3	YSU/MM5 similarity	KF	WDM 5 class	CAM/CAM

MYJ is the Mellor-Yamada-Janjic Planetary Boundary Layer (PBL) scheme; YSU is the Yonsei University PBL scheme; KF is the Kain-Fristch cumulus scheme; BMJ is the Betts-Miller-Janjic cumulus scheme; WDM5 is the WRF Double Moment 5 class microphysics scheme; RRTM is the Rapid Radiative Transfer scheme; and CAM is the CCSM Atmospheric Model radiation scheme.

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**Table 2.** Summary of CMIP GCM assessments.

Assessment region		Australia							MDB		SE Australia		
Model	Fractional Demerit	A	B	C	D	E	F	G	H	I	J	K	
UKMO-HadCM3	0	0	Yes	6	608							179	
CSIRO-Mk3.5	0						5	1				207	
GFDL-CM2.1	0.111	0	Yes	2	672	Yes			No	Yes	0.72	184	
GFDL-CM2.0	0.125	0	Yes	2	671	Yes			No	Yes		252	
MIROC3.2 (hires)	0.125	0	Yes	7	608		12	9	Yes			201	
CSIRO-Mk3.0	0.182	1	No	7	601	Yes	1	2	Yes	No	0.73	214	
UKMO-HadGEM1	0.2	0	No	2	674							163	
ECHAM5/MPI	0.222	0	Yes	1	700	Yes			No	No	0.79	173	
MIUB-ECHO-G	0.222	0	No	4	632	Yes			Yes	No	0.78	174	
INM-CM3.0	0.222	1	No	7	627		9	11		Yes		0.75	192
NCAR CCSM3	0.273	0	No	2	677	No	4	6	No			0.68	245
CNRM-CM3	0.286	0	No	4	542					No		0.73	196
FGOALS-G1.0	0.3	2	No	2	639	No	8	4	Yes			0.66	251
MIROC3.2 (medres)	0.364	2	Yes	7	608	Yes	11	3	Yes	No	0.6	255	
CCCM3.1(T63)	0.375	1		10	478		2	7	No		0.72	241	
MRI-CGCM2.3.3	0.455	1	No	3	601	No	10	12	Yes	Yes	0.41	437	
CCCM3.1(T47)	0.455	1	No	8	518	No	3	10	Yes	No	0.77	186	
GISS-ER	0.5	0	No	8	515	Yes	6	5	No	No		238	
BCCR-BCM2.0	0.5	5		5	590	Yes			No			485	
GISS-AOM	0.667	1	No	8	564	No	7	13	Yes		0.6	326	
IPSL-CM4	0.8	2	No	14	505	No	13	8	Yes		0.48	394	
NCAR PCM	0.833	3	No	11	506						0.64	309	
GISS-EH	1	5	No	14	304		14	14				487	

A: number of rainfall criteria failed (Smith and Chandler, 2010), B: satisfied ENSO criteria (Min et al., 2005; van Oldenborgh et al., 2005), C: demerit points based on criteria for rainfall, temperature and MSLP (Suppiah et al., 2007), D: M-statistic representing goodness of fit at simulating rainfall, temperature and MSLP over Australia (Watterson, 2008), E: satisfied criteria for daily rainfall over Australia (Perkins et al., 2007), F: order of model based on the total skill scores for each rainfall metric (Kirono et al., 2010), G: order of model based on the total skill scores for each of rainfall and PET metric (Kirono et al., 2010), H: satisfied criteria for daily rainfall over MDB region (Maxino et al., 2008), I: satisfied criteria for MSLP over MDB region (Charles et al., 2013), J: combination of RMSE of mean annual rainfall across south-east Australia and mean NSE (rainfall > 1 mm) comparing GCM-simulated and observed daily rainfall distribution with equal weights (Vaze et al., 2011), K: RMSE of mean annual rainfall over south-east Australia (Chiew et al., 2009).

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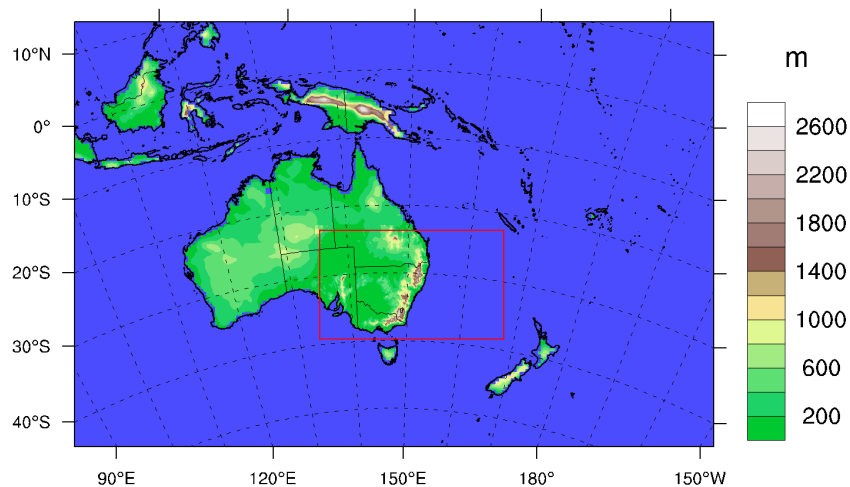
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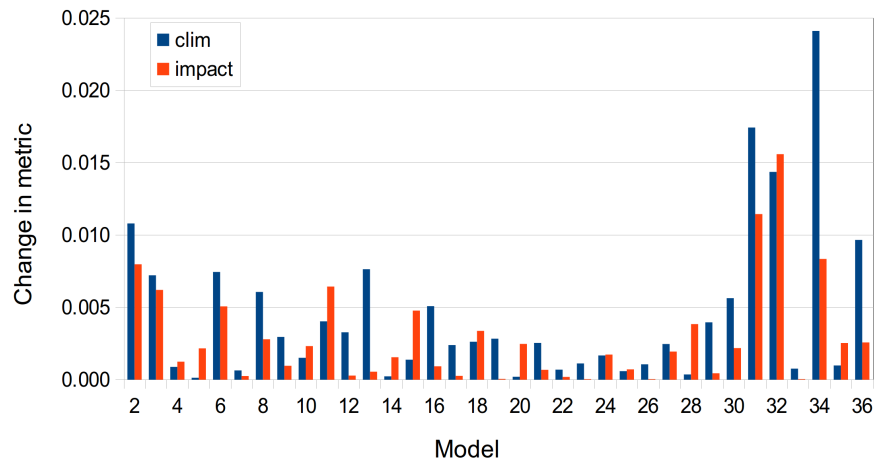
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**Fig. 1.** Topographic map showing the outer and inner (in red) NARCIIM model domain and state borders. New South Wales is just to the left of centre of the inner domain.

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**Fig. 2.** Change in the overall RCM evaluation metrics between neighbouring models ordered from the best model (left) to the worst model (right).

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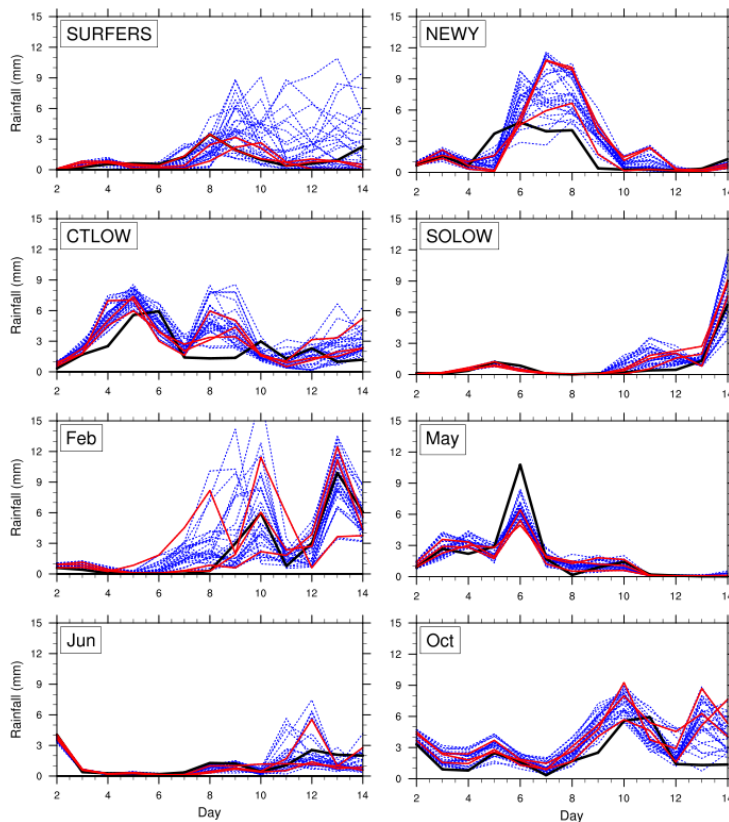
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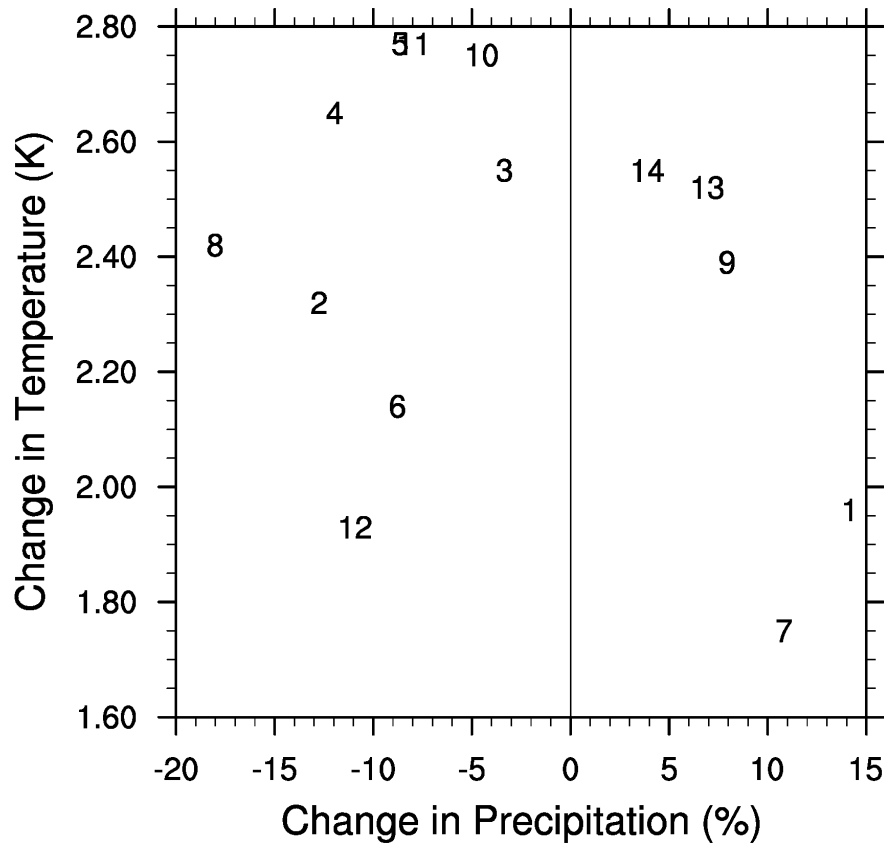
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**Fig. 3.** Daily precipitation time series for each of the eight test periods. Observations are shown in black. All ensemble members retained after the performance evaluation are shown with blue dotted lines. The three members chosen using the independence measure are shown in red.

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**Fig. 4.** Future change space for the CMIP3 GCMs that performed adequately and had the necessary data available, numbered by their independence rank. The change is between the mean of 1990–2009 and the mean of 2060–2079.

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