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NARCliM1.5 projections over the southern Murray–Darling Basin, Australia

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Abstract: The NSW Department of Planning and Environment (DPE) is undertaking a risk-based methodology to account for climate variability and change in developing its regional water strategies. As part of this process, historical biases and future changes associated with 6 model variants from NARCliM1.5 simulations have been analysed. This paper presents results for two future time windows centered on 2030 and 2070, for scenarios RCP 4.5 and RCP 8.5 for the southern basin region (which includes the Murrumbidgee, Murray and Snowy catchments as well as regions of Victoria and South Australia), focusing on the hydrologically relevant attributes of precipitation.

The evaluation of NARCliM1.5 has been made for model ensemble averages with respect to gauged data in the southern basin for two cases, (1) GCM runs forced with historical greenhouse gas forcings ('historical runs') over the period 1951 to 2005, and (2) reanalysis runs ('evaluation runs') for the period 1979-2013.

The NARCliM1.5 projections were analysed for two 30-year time windows centered on 2030 and 2070 respectively. The range of grid level future changes projected by the NARCliM1.5 ensemble mean are not outside the ranges projected by other sources of climate projections.

- Future simulations show decreases on average in annual total rainfall across the region, with significant variability and where some model configurations show increases. The magnitude of decreases in ensemble average rainfall are higher in the RCP8.5 simulations and increases into the long-term future. There are significant differences between the NARCliM model variants indicating that variability in projections is an important source of uncertainty.
- Seasonal rainfall totals exhibit decreases on average during MAM, JJA, and SON, with the highest magnitude of decreases in SON. The changes in DJF rainfall show mixed patterns (decreases and increases). There are decreases in the number of wet and heavy rainfall days annually and during MAM, JJA, and SON, while the mean rainfall intensity during wet/heavy rainfall days exhibits a mixed pattern of changes (increases and decreases) annually and seasonally.

The NARCliM1.5 dataset can be employed to describe future changes in precipitation in the southern basin and support climate risk assessment.

Keywords: *NARCliM1.5, climate projections*

1. INTRODUCTION

The New South Wales Department of Planning and Environment (DPE) has undertaken a risk-based methodology to account for climate variability and change in developing Regional Water Strategies for multiple basins in New South Wales. This paper documents future changes in the relevant attributes of precipitation over the southern region of the Murray Darling Basin, for selected future time windows from the New South Wales and Australian Capital Territory Regional Climate Modeling version 1.5 (NARCliM1.5) dataset to facilitate the application of the DPE climate risk method.

2. METHOD

2.1. NARCliM1.5 overview

The NARCliM1.5 dataset is a regional climate model simulation dataset that covers south eastern Australia and was used to generate climate projections. This dataset contains four sets of simulations corresponding to past and future time periods, using two different configurations of the Weather Research and Forecasting model that differ in the convective parameterisation scheme used. The evaluation run uses boundary conditions from the ERA Interim reanalysis data for the period 1979 to 2013, while the historical simulations and future projections use boundary forcings from three CMIP5 GCMs, resulting in a total of six ensemble members. These GCMs were selected for their satisfactory performance, independence of model errors, and span of future simulated changes complementary to the GCM spread of the models used for NARCliM1.0 (DPE 2020).

2.2. Spatial domain for comparison

Figure 1 shows the location of the observed gauges used for stochastic data generation in the southern basin, which covers the Murrumbidgee, Murray, Lower Darling, Wimmera-Mallee and Mount Lofty regions. The observed data contains a total of 284 rainfall gauges. The historical and evaluation simulations from NARCliM1.5 are compared with observed data from these gauges to quantify the biases in attributes of precipitation. To assess the robustness of the NARCliM1.5 projections, the changes in annual and seasonal climate variables projected by NARCliM1.5 are compared with available estimates from alternate sources of evidence. The other primary sources of future climate projections used for comparison are Climate Change in Australia (CCIA) Murray Sub-cluster (Timbal et al. 2015) and Loddon Campaspe, Goulburn & Ovens Murray regions from Victoria Climate Projections 2019 (VCP19) (Clarke et al. 2019). In Figure 1, the regions used for reporting future changes by the alternate sources of climate projections are also displayed. The projections from these sources are compared with the range of grid level changes from the NARCliM1.5 ensemble mean data. The dashed boxes indicate the broad area over which the range of changes projected by NARCliM1.5 are summarised for comparison with other projections. The black and red dashed boxes, which include most of the observation rainfall gauges show the data domains used in this study for comparison.

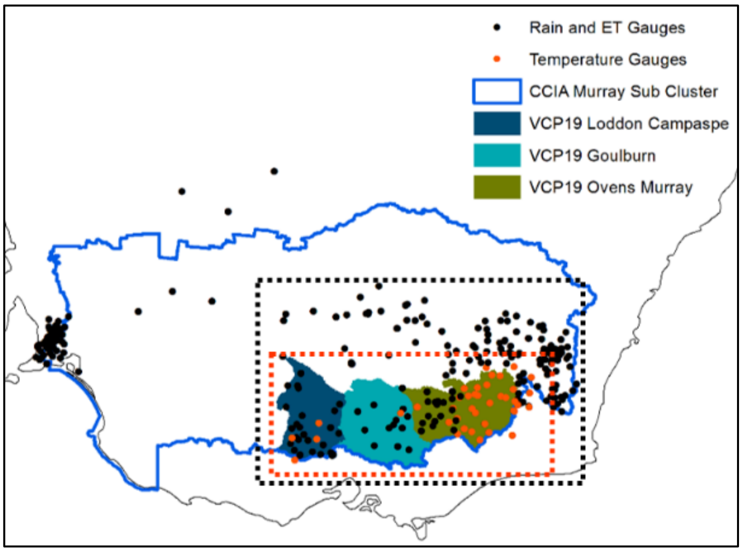

Figure 1. The regions used for reporting future changes by different sources of projections, CCIA and VCP19. This paper summarises the range of grid level future changes from NARCliM1.5 over the black dashed box for rainfall

2.3. Timelines for comparison

Figure 2 provides a comparison of time periods used for calculation of attributes from climate projections. Wherever there is a comparison to attributes from observed timeseries a commensurate time period was used to match the specific projection.

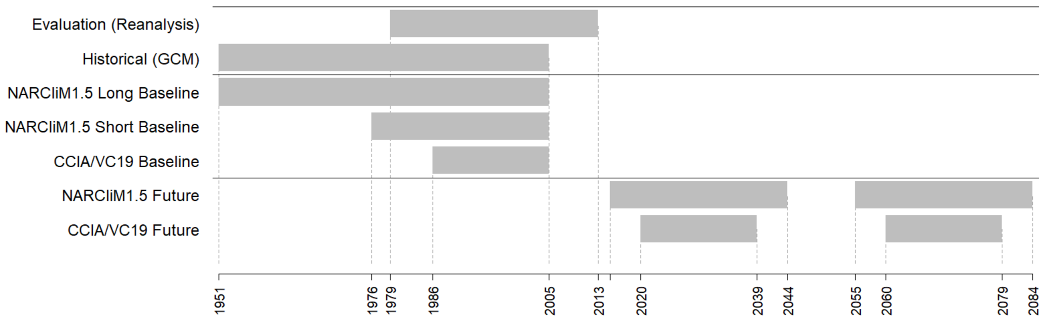

Figure 2. Time periods used for analysis of climate projections

2.4. Climate attributes

The attributes used for the analysis are listed in Table 1. These are hydrologically relevant climate attributes that were used in the pilot assessment to understand the implications of non-stationarity for stochastic generation (Devanand et al. 2020).

Table 1. Attributes of hydro-climatic variables used for the analyses

Attribute	Definition
Total Rainfall	Total annual and seasonal (DJF, MAM, JJA & SON) rainfall (mm)
Wet Day Rainfall	Mean annual and seasonal wet day (P >= 1 mm) rainfall (mm/day)
Number of Wet Days	Annual and seasonal number of wet days (P >= 1mm) (days)
Heavy Day Rainfall	Annual and seasonal heavy day (P >= 10 mm) rainfall (mm/day)
Number of Heavy Rain Day	Mean annual and seasonal heavy day (P >= 10 mm) rainfall (mm/day)
Mean Dry-Spell Duration	Annual mean number of consecutive days with rainfall < 1 mm (days)
Max. Dry-Spell Duration	Annual maximum number of consecutive days with rainfall < 1 mm (days)
Extreme Intensity	Annual mean rainfall during days with rainfall > the 95th percentile (mm/day)

3. RESULTS

3.1. Comparison of NARCLIM1.5 future projections

Figure 3 provides an illustration of changes in the ensemble mean of the future simulations for the 2030 window, showing decreases in annual total rainfall across the region for RCP4.5 and RCP8.5 scenarios. Table A.1 further examines the range of future changes in the rainfall across the wider range of attributes.

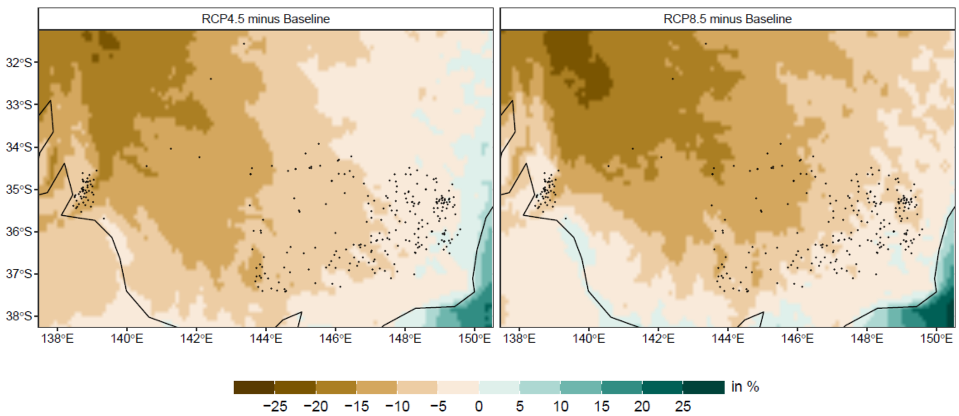

Figure 3. Changes in rainfall ensemble mean annual total rainfall: 2030 window minus baseline

Rainfall: From Table A.1 the ensemble mean of the future simulations shows decreases in annual total rainfall across the region. Spatially, the magnitudes range from -10% to 0% (-15% to 0%) in the RCP4.5 (RCP8.5) runs for a future 30-year window centred on the year 2030. For a future window centred on 2070, the magnitude of decreases is higher and range from -20% to 0% (-30% to 0%) in the RCP4.5 (RCP8.5) runs. Most ensemble members exhibit decreases in annual totals in the long term. Seasonal rainfall totals exhibit decreases during MAM, JJA, and SON, with the highest magnitude of decreases in SON. The ranges of the magnitude of changes during SON are RCP4.5: -20% to 0%; RCP8.5: -30% to 0% for the 2030 window; and RCP4.5: -30% to 0%; RCP8.5: -40% to -10% for the 2070 window. The decreases in spring rainfall are consistent in sign across most of the ensemble members. The changes during MAM and JJA show mixed signs between the ensemble members in the short term (2030 window). In the longer term (2070 window), the decreases in MAM rainfall are consistent in sign in most of the ensemble members; the changes in JJA rainfall are of mixed signs between the ensemble members. The changes in DJF rainfall show mixed patterns (decreases and increases) in both the short and long terms. The number of wet and heavy rainfall days in the ensemble mean shows decreases annually as well as during MAM, JJA, and SON. The decreases during SON are larger in magnitude and consistent in sign between most of the ensemble members for both the short and long terms. The long-term decreases in wet and heavy rainfall days annually are also consistent between the ensemble members. During DJF, the number of wet and heavy rainfall days shows mixed patterns (both increases and decreases) in the short and long-terms. The mean rainfall intensity during wet/heavy rainfall days exhibits mixed patterns of changes (increases and decreases) annually and seasonally. The length of dry spell durations shows positive changes in both the near term and long term. The sign of changes is more consistent between the ensemble members in the long term. Considering an alternate shorter historical baseline of 30 years (1976 to 2005) for the calculation of future changes, the sign/range of changes in the ensemble mean is generally consistent with the changes estimated using the full historical baseline, except for a few attributes. The attributes that show some differences are the number of heavy rainfall days, and some of the seasonal totals.

3.2. Comparison of future projections with other sources

The range of grid-level future changes projected by the NARCliM1.5 ensemble mean is compared with estimates from CCIA and VCP19 (Table A.2). The results show that the changes in annual and seasonal total rainfall projected by NARCliM1.5 are within the bounds projected by the alternate sources. The higher decline in SON totals and the mixed sign in DJF totals are consistent between the different datasets.

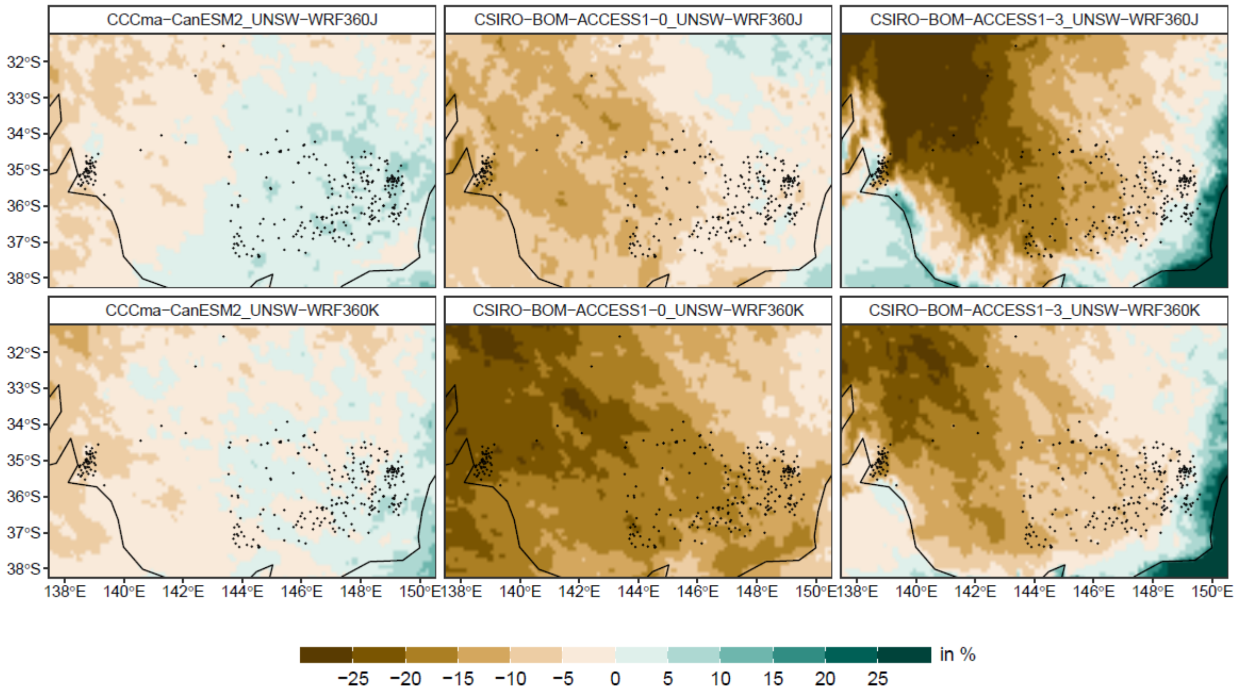

Figure 4. Changes in rainfall annual total rainfall per model configuration: 2030 window minus baseline

4. DISCUSSION

Given the large number of comparisons, discussion to this point has primarily been summarised according to ensemble mean performance with variations between models available in the accompanying appendices. Nonetheless, there are significant differences for precipitation between the model variants. For example, Figure 4 shows changes in the annual total rainfall as a difference from the 1951–2005 baseline for the 2030 time window for each model variant (Figure 3 previously showed the corresponding ensemble mean). Whereas the ensemble mean showed a mild decrease on average, some model instances show projected increases to the rainfall (top-left panel) while others show more significant drying than the ensemble mean (top right panel). Given that hydrological models typically amplify the impact of climate inputs, variability in the model configurations is likely to be an important factor to quantify in subsequent studies and more informative that only used a constructed average. Furthermore to this point, the average of a function output is not the same as the function evaluated based on an averaged input, especially for non-linear models such as with streamflow production. Lastly, the spatial 'gradient' of an ensemble mean is an abstracted pattern rather than a pattern derived from a physically coherent simulation (as with an individual model configuration). For these reasons it is recommended that a method of scaling is applied individually to each model rather than based on a single ensemble average.

5. CONCLUSION

This paper has analysed future changes of a range of key climate attributes from NARCliM1.5 projections across the southern region of the Murray-Darling Basin, encompassing Murrumbidgee, Murray and Snowy catchments as well as regions of Victoria and South Australia. Quantitative analysis was conducted for a set of six model configurations according to different time periods and climate scenarios as well as qualitative analysis for other published studies. The range of grid level future changes projected by the NARCliM1.5 ensemble mean are generally within the ranges projected by other sources of climate projections. The ensemble mean of the future simulations shows decreases in annual total rainfall across the region. The magnitude of decreases is higher in the RCP8.5 simulations and increases into the long-term future. Seasonal rainfall totals exhibit decreases during MAM, JJA, and SON, with the highest magnitude of decreases in SON. The decreases in spring rainfall are consistent in sign across most of the ensemble members. The changes in DJF rainfall show mixed patterns (decreases and increases). There are decreases in the number of wet and heavy rainfall days annual and during MAM, JJA, and SON, while the mean rainfall intensity during wet/heavy rainfall days exhibits a mixed pattern of changes (increases and decreases) annually and seasonally. Thus the changes in rainfall totals appear to be primarily associated with a decrease in the frequency of rainfall events.

ACKNOWLEDGEMENTS

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APPENDIX A

Table A.1 The range of future changes in precipitation attributes (in percentage) from NARCliM1.5. The estimates are the grid-level changes in the ensemble mean with respect to the full historical baseline (1951 to 2005) over the area marked by black dashed box in Figure 2. The shading indicates attributes/seasons that exhibit differences if a shorter historical baseline of 30 years is used for the calculation.

Attribute	Season	Short term (2015 to 2044) (%)		Long term (2055 to 2084) (%)		Description of the spatial patterns of changes in short term	Description of the spatial patterns in the long term (if different from the short-term changes)
		Ensemble mean changes RCP4.5	Ensemble mean changes RCP8.5	Ensemble mean changes RCP4.5	Ensemble mean changes RCP8.5		
Totals (mm)	Annual	-10 to 0	-15 to 0	-20 to 0	-30 to 0	Decreases across the region with is a spatial gradient in the magnitude of percentage changes from south-east (lower) to north-west (higher) areas of the region.	same
	MAM	-10 to 10	-20 to 0	-20 to 0	-30 to 0	Similar to the annual totals, there are decreases across the region. There is a spatial gradient in the percentage of changes from south-east (lower) to north-west (higher).	same
	JJA	-10 to 0	-10 to 10	-20 to 0	-30 to 10	Mixed. Primarily decrease in RCP4.5. The mixed pattern is more prominent in RCP8.5. There is a north (higher) - south (lower) gradient in the spatial pattern of changes.	Decreases with north (higher)-south (lower) gradient in the pattern of changes.
	SON	-20 to 0	-30 to 0	-30 to 0	-40 to -10	Decreases across the region	same
	DJF	-15 to 15	-15 to 15	-20 to 20	-20 to 20	East/west pattern of decrease/increase	same
No. of wet days (days)	Annual	-10 to 0	-10 to 0	-20 to 0	-10 to -30	Decrease. South-east (lower) to north-west (higher) spatial gradient in the magnitude of changes, similar to the annual total.	same
	MAM	-10 to 0	-15 to 0	-20 to 10	-30 to 0	Decrease. South-east to north-west gradient in spatial pattern.	same
	JJA	-10 to 0	-10 to 5	-20 to 0	-20 to 0	Mixed positive/negative signals, especially in RCP8.5.	Decreases with north (higher)-south (lower) gradient in the pattern of changes.
	SON	-20 to 0	-20 to 0	-30 to -10	-10 to -40	Decreases across the region	same
	DJF	-15 to 10	-10 to 5	-20 to 10	-20 to 10	East/west pattern of increase/decrease similar to the seasonal total.	same
No. of heavy days (days)	Annual	-20 to 0	-20 to 0	-20 to 0	-30 to 0	Decrease. South-east (lower)-north west (higher) pattern in the magnitude of changes	same
	MAM	-10 to 0	-20 to 0	-30 to 0	-30 to 0	Predominantly decreasing.	Decrease. South-east (lower)-north west (higher) pattern in the magnitude of changes
	JJA	-20 to 0	-20 to 20	-25 to 0	-25 to +25	Mixed signals in RCP8.5	Predominantly decreases
	SON	-30 to 0	-30 to 0	-40 to 0	-40 to -20	Changes are prominent. Most grid points show changes of at least -10%	Changes are prominent. Most grid points show changes of at least -20%
	DJF	-20 to +20	-20 to +20	-20 to +20	-20 to +20	East/west pattern of changes similar to the seasonal total	same
Wet day rain	Annual	-3 to +3	-6 to +3	-5 to 10	-5 to 10	Mixed pattern of minor increases/decreases	same
	MAM	-5 to +10	-10 to +5	-15 to +5	-10 to +5	Mixed spatial pattern of increases/decreases	same
	JJA	-5 to +5	-10 to 10	-10 to 10	-10 to 10	Mixed spatial pattern of increases/decreases	same

Attribute	Season	Short term (2015 to 2044) (%)		Long term (2055 to 2084) (%)		Description of the spatial patterns of changes in short term	Description of the spatial patterns in the long term (if different from the short-term changes)
		Ensemble mean changes RCP4.5	Ensemble mean changes RCP8.5	Ensemble mean changes RCP4.5	Ensemble mean changes RCP8.5		
intensity (mm/day)	SON	-6 to 3	-9 to 3	-10 to 10	-15 to 5	RCP 4.5 shows mixed pattern, RCP 8.5 primarily decreases.	same
	DJF	0 to +10	-5 to +10	-5 to +10	-10 to +10	Mixed pattern; predominantly increases in RCP4.5	same
Heavy day rain intensity (mm/day)	Annual	0 to +5	-2.5 to +5	-3 to +9	-3 to +9	RCP 4.5 shows increases, mixed patterns in RCP 8.5	Primarily increases across the region, more spatially coherent in the RCP4.5 run
	MAM	-5 to +10	-5 to +5	-10 to +15	-10 to +15	Mixed pattern	same
	JJA	-5 to 5	-5 to 10	-5 to +10	-5 to +15	Mixed pattern	Mixed in RCP4.5; primarily increases in RCP8.5
	SON	-7.5 to +7.5	-7.5 to 7.5	-5 to +15	-5 to +10	Mixed pattern	same
	DJF	0 to +10	0 to +10	0 to +15	-5 to 15	Mixed pattern; more increases than decreases	same
Extreme intensity (mm/day)	Annual	-5 to +10	-5 to +10	-5 to +10	-5 to +15	Mixed pattern; more increases than decreases	same
Dry spell duration (days)	Annual	0 to +5	0 to +5	0 to 20	0 to 40	Increases across the region	Increases across the region; the magnitude increases in south-east to north-west
	Annual	0 to +7.5	0 to +7.5	0 to +10	0 to +15	Increases across the region	Increases across the region; highest in the south-east.

The attribute-time periods during with the range of future changes calculated using a shorter 30-year historical baseline are different from these ranges by more than 5%

Table A.2. The future changes projected by NARCliM1.5 compared to projections from other sources

Variable	Time period	Season	CCIA Median (10%, 90 %)		VCP19 Median (10th perc, 90th perc)						NARCliM1.5		Comments
			Murray cluster		Loddon Campaspe	Goulburn	Ovens Murray	Loddon Campaspe	Goulburn	Ovens Murray	Range of changes in the ensemble mean		
			RCP4.5	RCP8.5	RCP4.5			RCP8.5			RCP4.5	RCP8.5	
Total rainfall changes (%)	Near term (2030s)	Annual	-2 (-9 to 5)	-1 (-11 to 5)	-4 (-10 to 6)	-4 (-12 to 4)	-6 (-12 to 4)	-10 (-16 to 4)	-9 (-16 to 3)	-11 (-18 to 3)	-10 to 0	-15 to 0	The NARCliM1.5 changes are within the bounds indicated by the alternate sources. The higher decline in SON totals and the mixed sign in DJF totals are consistent with the alternate sources.
		MAM	-1 (-24 to 12)	-1 (-21 to 12)	-3 (-19 to 23)	-4 (-21 to 21)	-6 (-19 to 16)	-3 (-21 to 13)	-6 (-21 to 13)	-4 (-24 to 13)	-10 to 10	-20 to 0	
		JJA	-3 (-15 to 8)	-5 (-17 to 7)	-8 (-18 to 10)	-7 (-18 to 10)	-9 (-18 to 10)	-10 (-19 to 7)	-10 (-17 to 7)	-12 (-21 to 7)	-10 to 0	-10 to 10	
		SON	-3 (-16 to 12)	-6 (-17 to 7)	-6 (-14 to 24)	-8 (-17 to 13)	-9 (-20 to 4)	-15 (-18 to 7)	-15 (-20 to 7)	-18 (-23 to 7)	-20 to 0	-30 to 0	
		DJF	0(-15 to 13)	1 (-9 to 16)	-3 (-11 to 14)	-3 (-11 to 15)	-5 (-13 to 12)	-11 (-23 to 18)	-2 (-25 to 18)	-2 (-20 to 14)	-15 to 15	-15 to 15	
	Long term (2070s)	Annual	-4 (-18 to 8)	-4 (-22 to 8)	-8 (-21 to 5)	-8 (-21 to 5)	-10 (-21 to 5)	-11 (-25 to 5)	-12 (-28 to 5)	-15 (-28 to 5)	-20 to 0	-30 to 0	
		MAM	-4 (-19 to 20)	-4 (-25 to 19)	-5 (-30 to 16)	-8 (-32 to 16)	-9 (-32 to 16)	-12 (-30 to 17)	-17 (-33 to 17)	-17 (-36 to 17)	-20 to 0	-30 to 0	
		JJA	-4 (-22 to 7)	-8 (-25 to 2)	-7 (-20 to 8)	-7 (-19 to 8)	-9 (-21 to 8)	-20 (-31 to 5)	-20 (-30 to 5)	-24 (-31 to 5)	-20 to 0	-30 to 10	
		SON	-5 (-28 to 7)	-8 (-32 to 8)	-14 (-28 to 4)	-13 (-28 to 4)	-15 (-28 to 4)	-12 (-41 to 6)	-15 (-41 to 6)	-19 (-41 to 6)	-30 to 0	-40 to -10	
		DJF	2 (-19 to 13)	4 (-16 to 24)	5 (-20 to 27)	7 (-20 to 27)	3 (-20 to 19)	-2 (-22 to 29)	2 (-22 to 29)	9 (-22 to 29)	-20 to 20	-20 to 20	