# SA Climate Ready data for South Australia

## A User Guide

Goyder Institute for Water Research
Occasional Paper 14/1

www.goyderinstitute.org

**Goyder Institute for Water Research Technical Report Series ISSN: 2204-0528**

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

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**Citation**
Goyder Institute for Water Research, 2015, *SA Climate Ready data for South Australia - A User Guide,* Goyder Institute for Water Research Occasional Paper No. 15/1, Adelaide, South Australia

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# 1 Introduction

## 1.1 Adapting to climate change

Climate change is occurring as a result of an increase in the concentration of greenhouse gases in the Earth's atmosphere. Recent work by the world's leading scientific body, the Intergovernmental Panel on Climate Change (IPCC 2013a), found that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

Even if the release of greenhouse gases slows in the coming decades, a certain amount of climate change is now inevitable. Preparing for this change is called "adaptation"; that is, taking action so that people, communities, businesses and the environment are able to respond as much as possible to changes in climatic variables like temperature and rainfall.

South Australia has a clear commitment to adapting to climate change. For example, Target 62 of the State Strategic Plan is to: "*Develop regional climate change adaptation plans in all State Government regions by 2016*". This links with a primary goal of the Plan that the State adapt to the long-term physical changes that climate change presents.

## 1.2 Agreed climate projections for South Australia

The Goyder Institute for Water Research (henceforth Goyder Institute) is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, University of Adelaide, and the University of South Australia. In 2011, the Goyder Institute commenced a project to develop an *agreed set of downscaled projections for South Australia*, that is, possible future climates generated at a local scale.

The aim of the climate projections is to provide a common basis on which Government, business and the community in South Australia can develop adaptation plans and undertake more detailed modelling and planning exercises. In addition, the aim of this project was to increase levels of confidence in State Government policy decisions by providing a foundation of reliable scientific evidence about both climate change that accounts for current climate variability and the influence of known climate drivers such as El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole.

Distributions of environmental time series were developed from a suite of agreed downscaled global climate model (GCM) projections for 6 climate variables: rainfall, maximum and minimum temperature, areal potential evapotranspiration, solar radiation, and vapour pressure deficit. Projections of average change in these variables (from a 20 year baseline period 1986 to 2005) were generated for four agreed 20-year time periods, centred on 2030, 2050, 2070, and 2090, annually as well as seasonally for these periods.

The project involved four major tasks:

- Understanding the key drivers of climate change in South Australia (Task 1);
- Selection of GCMs for regional downscaling and projection (Task 2);

- Downscaling and climate change projections for South Australia (Task 3); and
- Development of an application test bed (Task 4).

Reports on outputs from these components are available on the Goyder Institute website at www.goyderinstitute.org.

The *Development of an agreed set of climate change projections for South Australia* project has produced the most comprehensive set of downscaled climate projections data ever available in South Australia. Data is available at the scale of selected individual weather stations across the State. This data has also been summarised at a natural resource management region scale to provide region-scale trend information.

## 1.3 Structure of this User Manual

This User Guide provides information to help users understand how and why to use the climate data produced by the project and learn more about how it has been developed. The Guide is structured to address the following four commonly asked questions:

- What climate projections data is available? (Section 2)
- What are the potential applications of the data? (Section 3)
- How can the data be accessed? (Section 4)
- How should the data be used? (Section 5)

Further information about the project can be found on the Goyder Institute website (www.goyderinstitute.org) or the Enviro Data SA website (https://data.environment.sa.gov.au), where the project data is hosted (further details provided in Section 4).

Much of the detail in this User Guide has been drawn from the Task 3 report:

> Charles SP and Fu G, 2014, *Statistically Downscaled Projections for South Australia,* Goyder Institute for Water Research Technical Report Series No. 15/1, Adelaide, South Australia

This report is available on the Goyder Institute website along with a list of Frequently Asked Questions.

# 2 What climate projections data is available?

## 2.1 Global climate model selection

GCMs are tools used to determine how the climate may change in response to increased atmospheric concentrations of greenhouse gases and changes in aerosol loads and land use. They are complex computer models of the earth-climate system that simulate the inter-relationships between matter and energy and which generate projections of the future climate (Charles and Fu 2014). A projection is distinguished from a prediction because the scenario is based on assumptions about future socioeconomic and technological developments which are irreducibly uncertain (IPCC 2013a).

There are over 40 GCMs used by the IPCC for generating climate projections[1]. GCMs are grouped according to which phase of the *Coupled Model Intercomparison Project* they belong, a standard experimental protocol for studying the output of coupled GCMs. IPCC Assessment Report 4 released in 2007 used the CMIP3 suite of models whereas AR5 used CMIP5 models.

Fifteen CMIP5 global climate models were chosen for this project because they had the necessary variables for use with the chosen downscaling approach (Table 1). Based on research undertaken in Task 2 of the Goyder Institute project, a subset of six GCMs were identified (Table 1) based on their ability to reproduce drivers such as the Indian Ocean Dipole and the El Niño Southern Oscillation. Details of the GCM assessment are summarised in papers by Cai et al. (2014a,b).

GCMs are run using scenarios of greenhouse gas concentrations and aerosols, referred to as Representative Concentration Pathways (RCPs). This is the new description for what the IPCC previously called “emissions scenarios”. This project has used projections for RCP4.5, an intermediate-concentration pathway similar to the B1 emissions scenario from IPCC Assessment Report 4 (AR4), and RCP8.5, a high-concentration pathway similar to the A1FI emissions scenario in IPCC AR4. The RCP numbers refer to the approximate enhanced radiative forcing levels by 2100; that is, an additional 4.5 $W/m^2$ and 8.5 $W/m^2$ of radiative forcing, respectively, corresponding to $CO_2$ levels of approximately 550 ppm and 940 ppm by 2100. For simplicity, hereafter, the phrase “high emissions scenario” will refer to RCP8.5, and “intermediate emissions scenario” will refer to RCP4.5.

## 2.2 Downscaling method

GCMs generate coarse-scale climate change projections at grid resolutions of 150-250 $km^2$. Downscaling is a technique (either dynamical or empirical/statistical) used to generate climate projections at local (point or <10 $km^2$) to regional scales (10 to 100 $km^2$). Such finer-scale data is often required for local-scale planning and for use in modelling where site-specific projections are required.

This project applied a statistical downscaling technique called *Nonhomogeneous Hidden Markov Modeling* (NHMM) to rainfall downscaling. The NHMM simulates daily rainfall at multiple stations, as a function of a discrete set of ‘weather states’ representing spatial patterns of rainfall across the station network. The NHMM has been successfully applied in other studies across southern

[1] A full list of GCMs is provided at http://cmip-pcmdi.llnl.gov/cmip5/availability.html

Australia, particularly for hydrological impact research (Charles et al. 2007, Frost et al. 2011, Fu et al. 2013). The NHMMs were calibrated to the weather stations in each South Australian NRM region. A weather generator was used for downscaling non-rainfall variables, conditional on the weather states and rainfall generated by the NHMM, with the projected changes to 2100 obtained from the GCM grid-scale output for those variables.

## 2.3 What type of data is available?

The Goyder Institute climate projections data provides information on the following climate variables at daily time steps to the year 2100:

- Areal potential evapotranspiration (APET), the daily rate of evapotranspiration that would take place, under the condition of unlimited water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average[2].
- Maximum temperature (Tmax), maximum daily temperature measured in degrees Celsius (°C) ;
- Minimum temperature (Tmin), minimum daily temperature measured in degrees Celsius (°C);
- Rainfall, the daily rainfall recorded in "mm";
- Solar radiation, the amount of solar energy falling on the Earth's surface, measured as the amount of energy received per unit area (MJ/m2)[3]
- Vapour pressure deficit (VPD), the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated, measured as pressure (hPa).[4]

Region scale projections data were generated for 20-year future time periods, relative to a recent 20-year baseline period (1986-2005). The future 20-year periods are centred on: 2030 (2020-2039), 2050 (2040-2059), 2070 (2060-2079), and 2090 (2080-2099). Seasonal averages within the 20-year periods are also available.

Data is available for a varying number of weather stations in each NRM region in the State. A summary of these weather stations by natural resource management region is presented in Table 2.

Climate projections data for each weather station has three sources of variability, which should be considered:

- GCMs, of which 15 were used;
- intermediate and high emissions scenarios (RCP4.5 and RCP8.5);
- realisations of the downscaling model, that is the number of stochastic replicate data sets generated by the downscaling model (NHMM) for a given combination of GCM and emissions scenario, which was 100.

[2] http://www.bom.gov.au/climate/averages/climatology/gridded-data-info/metadata/md_ave_et_1961-90.shtml
[3] http://www.bom.gov.au/climate/austmaps/solar-radiation-glossary.shtml
[4] http://www.bom.gov.au/water/awid/id-569.shtml

**Table 1. Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate models and institutions.**

| GLOBAL CLIMATE MODEL | INSTITUTION | INSTITUTION ID |
|---|---|---|
| ACCESS1.0* <br> ACCESS1.3* | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia | CSIRO-BOM |
| BCC-CSM1.1(m) | Beijing Climate Center, China Meteorological Administration, China | BCC |
| CanESM2# | Canadian Centre for Climate Modelling and Analysis, Canada | CCCMA |
| CNRM-CM5# | Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique, France | CNRM-CERFACS |
| CSIRO-Mk3.6.0* | Commonwealth Scientific and Industrial Research Organisation in collaboration with Queensland Climate Change Centre of Excellence, Australia | CSIRO-QCCCE |
| GFDL-ESM2G <br> GFDL-ESM2M# | NOAA Geophysical Fluid Dynamics Laboratory, USA | NOAA GFDL |
| INM-CM4* | Institute of Numerical Mathematics, Russia | INM |
| IPSL-CM5A-LR * <br> IPSL-CM5B-LR# | Institut Pierre-Simon Laplace, France | IPSL |
| MIROC-ESM* | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan | MIROC |
| MIROC5# | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan | MIROC |
| MRI-CGCM3# | Meteorological Research Institute, Japan | MRI |
| NorESM1-M | Norwegian Climate Centre, Norway | NCC |

# = ensemble of six better performing GCMs
* = ensemble of six poorer performing GCMs
Performance of the GCM's is based on their ability to reproduce drivers of relevance to South Australian climate.

**Table 2. List of weather stations by natural resource management region for which climate projection data is available in South Australia.**

| Region | Weather station name |
|---|---|
| Adelaide and Mount Lofty Ranges | Adelaide Airport, Adelaide (Dry Creek Saltworks), Adelaide (Hope Valley Reservoir), Adelaide (Kent Town), Aldgate, Cherry Gardens, Cudlee Creek (Millbrook), Edinburgh RAAF, Hamley Bridge (Linwood), Happy Valley Reservoir, Hermitage Upper, Hindmarsh Valley (Fernbrook), Hindmarsh Valley (Springmount), Kapunda (Hamilton), Kersbrook (Mabenjo), Longwood, Mount Bold Reservoir, Myponga Reservoir, Normanville, Parawa (Sharon), Port Parham, Rosedale (Turretfield Research Centre), St Kitts, Victor Harbor (Rivington Grange), Williamstown (Glen Gillian), Williamstown (South Para Reservoir) |
| Eyre Peninsula | Buckleboo (Hi-View), Butler (Moody Vale), Butler Tanks (North Parnda), Ceduna (Goode), Ceduna (Maltee), Ceduna (Uworra), Ceduna Amo, Cleve (Ningana), Cleve (Pineview), Cowell (Winter Springs), Cummins (Glenreath), Darke Peak, Elliston, Karcultaby, Kimba (Cortlinye), Kimba (Melaleuca), Koongawa (Retawon), Kyancutta, Mt Wedge (Mount Wedge), Murdinga (Mungala), Nundroo, Port Lincoln (Westmere), Streaky Bay, Tumby Bay (Warratta Vale), Warramboo, Wirrulla (Pimbena), Yeelana (Brooker) |
| Kangaroo Island | American River, Cape Willoughby, Murrays Lagoon (Bayside), Kingscote (Karinga), Smith Bay (Smiths Bay), Parndana (Pioneer Bend), Flinders Chase (Rocky River), Rocky River (Brookland Park), Murrays Lagoon (Hawks Nest), Parndana (Turkey Lane). |
| Northern and Yorke | Belton (Shadow Vale), Morchard (The Rocks), Melrose (Para Gums), Hawker (Wilson), Cradock (Yednalue), Yongala, Carrieton (Glenroy Estate), Brinkworth (Bungaree), Snowtown (Condowie), Clare (Hill River), Koolunga, Mount Templeton (Glenalbyn), Port Pirie Zinifex, Hallett (Old Canowie), Huddleston (Willow Ponds), Clare (Calcannia), Manoora (Cooinda), Snowtown (Banyula), Crystal Brook Section 299, Balaklava (Wanappe), Boowillia, Apoinga (Wilivere), Maitland, Maitland (Weetulta), Ardrossan (Winulta), Arthurton (Lowandale), Riverton (Leaward), Eudunda (Moondah) |
| South Australian Arid Lands | Woomera Aerodrome, Coober Pedy, Glendambo (Coondambo), Kondoolka, Woomera (Mahanewo), Tarcoola (Mulgathing), Nonning, Roxby Downs (Parakylia Station), Woomera (South Gap Stn), Todmorden, The Twins Station, Yardea, Andamooka, Marree (Farina), Innamincka Station, Oodnadatta (Macumba), Marree, Muloorina Station (Muloorina Homestead), Blinman (Narrina), Parachilna (Motpena), Arkaroola, Roopena, Maralinga*, Whyalla (Moola), Hawker (Holowilena), Erudina, Manna Hill, Mutooroo, Yunta (Paratoo), Mooleulooloo, Birdsville Police Station.<br><br>* Located in the adjacent Alinytjara Wilurara NRM region. |
| South Australian Murray-Darling Basin | Burra (Woolgangi), Burra (Worlds End), Whyte-Yarcowie (Gum Park), , Harrogate, Kanmantoo, Mount Barker, Rockleigh (Black Heath), Hartley (Pine , Ill), Renmark Irrigation, Loxton (Pyap), Duffield Ramco, Paringa Lock V, Eudunda, Murray Bridge, Robertstown, Murray Bridge (Tepko), Nildottie, Tailem Bend (River Downs), Blanchetown Lock 1, Wellington (Brinkley South), Milang (Navarino), Purnong (Claypans), Kulkami, Lowaldie (Carrawar Stud), Bowhill, New Well (Marfield), Pinnaroo (Kombali), Caliph, Lameroo, Lameroo (Artlaringa) |
| South East | Keith, Wirrega (Taunton), Meningie (Naranga), Bordertown (Inglewood), Tintinara (Colebatch Downs), Coonalpyn (Alpyn Downs), Keith (Mandurama), Ki Ki (Moorilla), Tintinara (Richards), Kingston Se (Keilira Station), Lake Leake , Kooeeyong), Padthaway (Marcollat), Mount Gambier Aero, Robe, Tantanoola, Bordertown (Yacca Vale), Policemans Point, Bordertown (Beeama Section 48), Naracoorte (Bettws-Y-Coed), Salt Creek (Pitlochry Outstation 1), Mount , Chank (Jethia), Lucindale (Greenvale), Wrattonbully (Joeville), Avenue (Downer) |

## 2.4 How does the Goyder data differ from other sources?

Various climate change projections data exists for South Australia. Some of this data was generated for past projects using superceded emissions scenarios and GCMs (e.g. Climate Change in Australia, CSIRO-BoM 2007), whereas other data sets such as from the 2015 Climate Change in Australia project are using updated approaches (refer to www.climatechangeinaustralia.gov.au). The Goyder Institute climate projections data may differ from other available data in four main ways:

- First, the Goyder Institute's data differs from earlier climate change projections as it is based on the most recent suite of CMIP5 GCMs and emissions scenarios. Previous climate projections data for South Australia was generated using the previous group of CMIP3 models, which were the basis of IPCC Assessment Report 4.

- Second, compared to other recent projections (and those soon to be released), the Goyder Institute project used a different subset of CMIP5 GCMs for generating climate projections. Task 2 of the Goyder Institute climate projections project conducted research specifically to determine which GCMs were best suited to developing projections for South Australia.

- Third, the approach to downscaling used in the Goyder Institute project is likely to differ from other projects, with the NHMM station-based technique selected for the Goyder Institute projections because it has been successfully applied in various studies across southern Australia, particularly for application in hydrological impact research (Charles and Fu 2014).

- Summary projections of change in the weather variables of rainfall, temperature and PET are made for SA NRM regions, rather than the large scale areas of other climate projection projects.

# 3 What are the potential applications of the data?

There are various potential uses of the Goyder Institute's climate projections data, with flexibility in application possible due to the local and aggregated spatial scales at which the data is available. At the local, weather station scale, the data may be applied for:

- climate change impact modelling studies, commonly in hydrological disciplines, but also in agriculture and infrastructure planning;
- understanding the future climate that infrastructure may be exposed to at a given locality;
- generating site-specific heatwave and bushfire risk metrics; and
- quantitative risk assessment for many sectors.

The aggregation and summary of this local-scale data to the larger scale of the South Australian NRM regions provides suitable data for use in adaptation planning and climate risk and vulnerability assessments. Data at this regional scale provides trends, or patterns, in the direction of change in climate variables such as temperature or rainfall.

Examples of existing applications of the Goyder Institute's climate projections data are listed below. A case study for each of these examples is available from the Goyder Institute website (www.goyderinstitute.org).

**1. How will climate change affect flows into reservoirs in regional South Australia?**

*Project: Impact of climate change on the surface water resources of the Kangaroo Island natural resources management region*

To assess the impact of projected changes in climate on the surface water resources of Kangaroo Island, rainfall and potential evapotranspiration information for an intermediate and high emissions future were incorporated into a rainfall-runoff model for Middle River. Using the Goyder Institute climate projections data the project considered runoff projections to 2100.

The project found that annual rainfall is projected to decrease in the future, with the high emissions scenario projecting a greater reduction. Potential evapotranspiration is also expected to increase. Overall, the percentage decrease in runoff is projected to be proportionally greater than the percentage decrease in rainfall.

**2. How will climate change affect investment decisions in water treatment infrastructure?**

*Project: Impact of climate change on reservoir water quality (Development of an application test bed)*

Using downscaled temperature, rainfall, radiation and vapour pressure data, SA Water was able to pilot approaches for using existing reservoir models to better understand the impacts of climate change on water quality. Data included climate projections for intermediate and high emissions scenarios (RCP4.5 and RCP8.5).

The pilot produced a new data set for use by SA Water, which will be applied to reservoir water quality models as part of integrated modelling schemes, consisting of coupled catchment and reservoir models to evaluate the direct versus indirect impacts to water quality resulting from climate change.

**3. How will climate change affect our groundwater dependent wetlands?**

*Project: Predicting the impacts of climate change on groundwater dependent ecosystems*

A risk assessment framework was used to identify the risk of climate change to Middlepoint Swamp, a groundwater dependent ecosystem in the Lower South East region of South Australia. The study investigated the effects of historic groundwater level decline and the predicted impacts of additional climate induced groundwater decline, using a range of 'best' and 'worst' case climate scenarios to 2030.

The project found that by 2030, the maximum surface water level in Middlepoint Swamp is predicted to fall by up to 1 m under the high emissions scenario (for the GCM "ESM 2M"), almost completely drying the wetland.

**4. How will climate change affect the design of major infrastructure works?**

*Project: Investigation into climate change impacts on groundwater levels to assist development of the construction brief for the Torrens Road to River Torrens Infrastructure project*

The project used models to convert rainfall information into estimates of the depth to groundwater at the construction site. Using climate projection data for intermediate and high emissions scenarios, the project compared historical with projected changes in depth to groundwater for the period 2015 to 2090.

The project found that groundwater levels are projected to decline for all scenarios considered at the site. Under the intermediate emissions scenario by about 2055, 90% of all model outputs showed groundwater levels would be below observed water levels. The implications of this analysis are that the project can proceed with a low chance that future climate change will increase water levels in a way that could damage this long lived piece of transport infrastructure.

**5. How will climate change affect the amount of water flowing into our reservoirs?**

*Project: Impacts of climate change on surface water in the Onkaparinga Catchment*

Using the climate projections data for intermediate and high emissions scenarios, flow for three sub-catchments was projected (Scott Creek, Echunga Creek and Houlgrave Weir) across four future time horizons (2016 to 2045, 2036 to 2065, 2056 to 2085 and 2071 to 2100).

The project found that the best (median) estimate of the change in average flows is a decline of 14% for the period 2016-2045 and 37% for 2071-2100. The projected trend indicates a reduction in flow. This information combined with the detailed weather station data will assist the evaluation of security of supply into the future and options to identify appropriate management responses.

# 4 How can the data be accessed?

## 4.1 Where to access the data

The climate projections data are available as summarised written documents, as well as data files of daily projections of climate variables, through the Enviro Data SA website (see Section 4.2).

The written documents that contain summary level data are:

- the Task 3 Final Report titled "*Statistically Downscaled Projections for South Australia*", which provides a detailed summary of projections against the six climate variables considered in the project for each natural resource management region in South Australia. This report is 20 MB in size.

- regional summary brochures, which contain trend information for rainfall and maximum and minimum temperatures for each natural resource management region in South Australia.

Summary level data is available for all of the South Australian NRM regions, except the *Alinytjara Wilurara* NRM region because it had only one weather station included in the analysis. Analyses interested in this region should consider the results for the South Australian Arid Lands NRM region, which has 31 weather stations with a broad spatial representation.

These documents are available from the Goyder Institute website at http://goyderinstitute.org

## 4.2 Enviro Data SA

Enviro Data SA is a website providing access to data and information relating to the science and monitoring of South Australia's environment and natural resources. It is maintained by the South Australian Department of Environment, Water and Natural Resources and can be accessed at:

http://data.environment.sa.gov.au

The specific part of the Enviro Data SA site dedicated to accessing the Goyder Institute's climate projections data can be accessed at:

https://data.environment.sa.gov.au/Climate

Users are required to select the data they wish to download using filtering options, such as weather stations on a map of South Australia, or by using drop down boxes which provide options of selecting data by:

- natural resource management region;
- global climate model; or
- representative concentration pathway (herein referred to emissions scenarios).

A list of weather stations is provided, with a sub-set of weather stations presented based on the selected combination of the above parameters. Users are provided with all 100 realisations of the model output for the combination of parameters selected. This is because the realisations are not ordered by (for example) whether they are the dry or wet, warmer or cooler, end of model outputs and hence users need to assess the range across the replicates when applying the data.

Individual data files are in text file format (.txt) and file names take the form of:

> NRM region and total number of weather stations.GCM name.concentration pathway.weather station ID number.realisation number.

For example:

> al27.canesm2.his.16001.001

where:

- *al27* = an abbreviation for South Australian Arid Lands which has 27 weather stations;
- *canesm2* = the name of the GCM (see list of names in Table 1);
- *his* = an abbreviation indicating the historic climate scenario has been used, as opposed to r45 (RCP4.5) or r85 (RCP8.5);
- *16001* = the individual weather station ID number; and
- *001* = the specific realisation number representing this combination of weather station, GCM and emissions scenario (ranges from 001-100).

Files are space delimited and can be viewed in Wordpad or opened in spreadsheet software, such as Excel.

Users requiring a large number of data files that exceed download capacity on their own IT system should contact the Help desk (Section 4.4) to determine if other arrangements can be made.

Users interested in bulk download of data are directed to the following CSIRO website, which provides for download of all data for a given natural resource management region:

https://data.csiro.au/dap/landingpage?pid=csiro:10408&v=1&d=true

Data can be downloaded at no cost and is for non-commercial uses only. However, terms and conditions of use must be accepted prior to downloading data sets.

Users can obtain support to understand how to use and apply the data through the Enviro Data contact page.

# 5 How should the data be used?

## 5.1 Do you need regional trends or site specific daily data?

Users of the climate change data provided by the Goyder Institute are likely to need different elements of the data provided, depending on their application.

Two types of climate change information are provided:

**A. Mean amounts of projected change in the variables of rainfall, temperature and PET for each NRM region**

These provide the projected amounts of change in rainfall, temperature and PET for each region according to an average of the projections of the selected GCMs, averaged across all the weather stations in the region that have been used for downscaling. These regional summaries indicate the average amount of change (in each weather variable) that is incorporated in the downscaled climate datasets for the weather stations in a region. These data will be essential for regional climate change adaptation planning in South Australia and for NRM planning that incorporates consideration of climate change at the regional scale.

**B. Multiple time series datasets of projected values of weather variables, downscaled to individual weather stations in daily time steps, provided as multiple text files**

These datasets are intended for use in numerical modelling and statistical analyses where variations in climate variables on a daily (or greater) timescale are influential on the model outcome. The datasets are useful for climate change impact modelling studies, commonly in hydrological disciplines, but also in agriculture and infrastructure planning and quantitative risk assessment for many sectors. Typically, users of these datasets will be skilled in numerical modelling, data processing and/or statistical analysis.

User should note that detailed climate projection datasets such as these are not forecasts of an exact sequence of events in the future. Rather, they are a set of synthetic climate data that are statistically realistic but include projected change in the climate. These datasets can be used to explore what future conditions may look like in a climate sense, and explore the impacts of that projected change.

For regional climate change adaptation planning purposes, the regionally summarised climate change projections provided in the regional summary brochures (www.goyderinstitute.org) and in the Goyder Institute project's final downscaled projections report (Charles and Fu 2014) provide the most appropriate information source and are recommended for use wherever possible for climate change adaptation planning in South Australia. These reports provide summaries of the change projected by the suite of selected GCMs, for each of the projected climate variables, averaged across the weather stations within each South Australian NRM region.

For location-specific modelling of climate impacts, such as for prediction of impacts on runoff in a particular reservoir catchment, or predictions of changes in heatwave frequency and characteristics for a particular city, the downscaled future climate time series datasets are provided for 200 weather stations in South Australia.

## 5.2 RCPs and 'historic' scenarios – what do they mean and how should they be used?

The RCP4.5 and RCP8.5 scenarios are representative of increases in atmospheric greenhouse gas concentrations through the 21st century that result in global radiative forcings in 2100 of 4.5 W/m2 and 8.5 W/m2 respectively corresponding to $CO_2$ levels of approximately550 ppm and 940 ppm by 2100. The downscaled datasets for these scenarios represent individual GCM projections of climate at each weather station under the change in global climate that is projected by the GCM with the respective concentration pathway (and corresponding radiative forcing) applied.

The downscaled datasets for the historic (filename suffix 'his') scenario represent individual GCM recreations of climate at each weather station from 1961 to 2005 under the GCM's historical climate of that period (i.e. they do not replicate the sequences of the observed historical record).

Because the downscaled projections of future climate are affected by both the GCM and the NHMM downscaling process, any study that compares results of modelling with synthetic climate data with the results of modelling of current or historic climate conditions must use historic climate data that is derived from the same GCM and NHMM downscaling process.  It would not be an appropriate comparison if results of future climate scenario modelling were compared with results from models using actual historic data from the same location.

## 5.3 Time periods of downscaled datasets

1. Downscaled climate projection datasets cover the period from 2006 to 2100, inclusive.
2. The downscaled historical datasets cover the period from 1961 to 2005, inclusive.

The historical downscaled data is a NHMM downscaling of GCM simulations of the historical period (1961 – 2005) at the individual weather station.

## 5.4 Baselines

The downscaled historical datasets for each weather station/GCM combination provide an appropriate baseline against which to compare the intermediate emissions (RCP 4.5) and high emissions (RCP8.5) downscaled datasets for the same weather station/GCM combination. The time period represented by the downscaled historic datasets is from 1961 to 2005, inclusive. This is longer than, but includes, both the IPCC AR5 baseline period, which is from 1986 to 2005, and the earlier IPCC baseline period of 1961 - 1990.

## 5.5 Columns definitions in downscaled datasets

The downscaled data sets are provided as space-delimited text files with ten columns of data and one row for each day. The columns of data in the downscaled data files are in the following order:

**Year, Month, Day, Weather State, Rainfall (mm), Tmax (°C), Tmin (°C), Solar Radiation (MJ/m$^2$), Vapour Pressure Deficit (hPa), Potential Evapotranspiration (mm).**

Column headings are not included in the data files to ease automated data entry in modelling applications.

The PET data provided are values of areal potential evapotranspiration, calculated from the preceding downscaled variables in each data row according to the formula of Morton (1983).

## 5.6 How to select which RCPs and GCMs to use for your application

A combination of 15 GCMs, two concentration pathways and 100 realisation of each results in 3000 future climate time series for each weather station. Many users may find this an unwieldy number of climate datasets to process through a model or on which to undertake statistical analysis and may wish to select a subset of either GCMs, RCPs or realisations to work with.

**Whether to use one or two RCPs?**

The RCP4.5 and RCP8.5 scenarios represent, respectively, reasonable lower and upper bounds of greenhouse gas concentration pathways for the 21$^{st}$ century. In view of the factors that introduce a range of uncertainty into projections of future climate, it is common in climate impact studies to select two scenarios which may be considered 'bookends' to the range of possible outcomes. The RCP4.5 and RCP8.5 scenarios represent reasonable bookends to the likely pathways of atmospheric greenhouse gas concentrations. Hence an approach that considers the future impacts of both of these scenarios may be adopted in many cases. By adopting this approach, modelling or statistical analysis results can demonstrate the range of future climate impact outcomes that are possible while future greenhouse gas concentrations remain uncertain.

Some users may choose to reduce the number of scenarios to be dealt with by only considering only one RCP. This is a valid approach, providing the RCP adopted and the uncertainty in whether it will be realised in future are clearly articulated. RCP4.5 and RCP8.5 do not start to diverge significantly until after 2020. For impact studies that project no further into the future than 2030, use of only the RCP8.5 scenario may be considered a reasonable and precautionary approach.

**Which GCMs to select?**

The Goyder Institute climate change project selected GCMs from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012) These CMIP5 GCMs were used in the most recent IPCC AR5 report (IPCC, 2013). Fifteen GCMs were selected on the basis that they had all the variables available to produce the atmospheric predictors required for input to the calibrated NHMM downscaling process. Their names and host institutions are listed in Table 1.

The fifteen selected GCMs provide a range of projections of future climate. There are risks inherent in selecting individual GCMs from this group for climate change impact studies, since it is not possible to identify which is likely to provide a more accurate projection of the future climate.

To enable comparison of projections from GCMs assessed as better performing, in terms of their ability to simulate the large-scale processes of relevance to South Australian climate drivers, the Goyder Institute project assessed a set of CMIP5 GCMs that included 12 of the 15 GCMs available for downscaling. Based on this assessment it was possible to classify the 12 into a subset of six better and six poorer performing GCMs, based on their ability to reproduce drivers of relevance to South Australian climate. These subsets are identified in Table 1. Details of the GCM assessment are summarised in Cai et. al. (2014a,b).

Users of the downscaled datasets for modelling and statistical studies are advised to apply the projections of a number of GCMs to ensure that the range and uncertainty among the projects of differing GCMs is represented and conveyed in the resulting products. The six better performing GCMs identified by the Goyder Institute project may for many users be a suitably small number of GCMs to convey a justifiable range of climate change projections for South Australia.

Users needing to sub-select GCMs further may also take a bookending approach to GCM selection. In this, the two or more GCMs that provide the least and most amount of temperature and/or rainfall change for the location of interest would be selected. This process should be undertaken with care for a number of reasons:

- The GCM that projects the most or least amount of change for one location may not do so for another location. Similarly for differing time periods, a GCM that projects the most or least amount of change for one time period (such as 2030-2050) may not do so for another time period (such as 2070-2070).
- A GCM may project an amount of change that is significantly different to the projections of the majority of the group of 15 GCMs. This will not be apparent unless the changes projected by the whole group for the location of interest are assessed to determine the spread of their differing projections.
- A GCM that projects the most or least amount of change in temperature may not be the same as the GCM that projects the most or least amount of change in rainfall.
- The GCMs that project the highest/lowest values for one variable (whether it be annual average rainfall, annual maximum rainfall and so on) will not necessarily lead to the highest/lowest values in the outcomes of a model they are applied to. For example, the downscaled data from a GCM that projects the greatest reduction in rainfall may not result in the greatest reduction in runoff when the projections of a number of GCMs are applied to a hydrological catchment runoff model.

The CSIRO 'Climate Futures' analysis method[5] provides a means that allows an analysis of the spread of change in both rainfall and temperature projected for a location by a group of GCMs. This method entails plotting the mean change projected by the individual GCMs for a given location and time horizon, with the temperature and rainfall variables plotted on axes of a single scatter graph. The resulting graph illustrates the relative spread of the projected changes in rainfall and temperature among the group of GCMs. From this graph, the GCMs that project, for example, the warmest-driest and coolest-wettest future climates can be selected for use in modelling and statistical applications. The cautions listed above should be carefully considered if this approach to GCM selection is taken.

[5] http://www.climatechangeinaustralia.gov.au

## 5.7 Why are there 100 'realisations' of future climate?

As noted above, the downscaled daily climate projection datasets such are not forecasts of an exact sequence of events in the future. Rather, they are a set of synthetic climate data that are statistically realistic but include projected change in the climate. Within the downscaled climate projections datasets, for each combination of GCM and emissions scenario there are 100 realisations of rainfall from 2006-2100. This multiple dataset approach is necessary when statistically downscaled daily time series of climate variables are provided. This is because each projection is only one possible realisation of the future outcome of temperature, rainfall, etc. under the climate conditions that are projected by the GCM and downscaled to represent the weather patterns of the individual location; they are not a prediction of what will happen. Repeating the statistical downscaling process 100 times for each GCM/emissions scenario combination provides a group of projections that represent the range of possible daily weather outcomes within the projected future climate.

Each of these groups of 100 realisations is based on the same GCM projection of climate, hence they each have similar decadal-scale trends. However, within each GCM/emissions scenario combination, there is a broad spread of future climate projections. Within each group of 100, users might take an average of the outcomes of the modelling or statistical process they apply the group of 100 datasets to, or might select, for example, the 10$^{th}$ wettest, 10$^{th}$ driest and median, climate realisations the of the impact projections resulting from these.

# 6 Glossary

**Areal potential evapotranspiration (APET)** - The evapotranspiration that would take place, under the condition of unlimited water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average[6].

**Climate model** - A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity; that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved.

**CMIP** – Refers to the *Coupled Model Intercomparison Project,* a standard experimental protocol for studying the output of coupled global climate models. Phases of the project are represented by using a number next to the CMIP acronym (e.g. CMIP5 refers to the CMIP Phase 5 group of models).

**Downscaling** – A method that derives local -to regional -scale (10 to 100 $km^2$) information from larger-scale climate models or data analyses. Two main methods exist: dynamical downscaling and empirical/statistical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution, or high-resolution global models. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables.

**Solar radiation** - The amount of solar energy falling on the Earth's surface, measured as the amount of energy (joules) received per unit area ($m^2$).[7]

**Vapour Pressure Deficit (VPD)** – The difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated.[8]

**Representative Concentration Pathways -** Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover. Herein, they are referred to as emissions scenarios for simplicity.

[6] http://www.bom.gov.au/climate/averages/climatology/gridded-data-info/metadata/md_ave_et_1961-90.shtml
[7] http://www.bom.gov.au/climate/austmaps/solar-radiation-glossary.shtml
[8] http://www.bom.gov.au/water/awid/id-569.shtml

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The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.