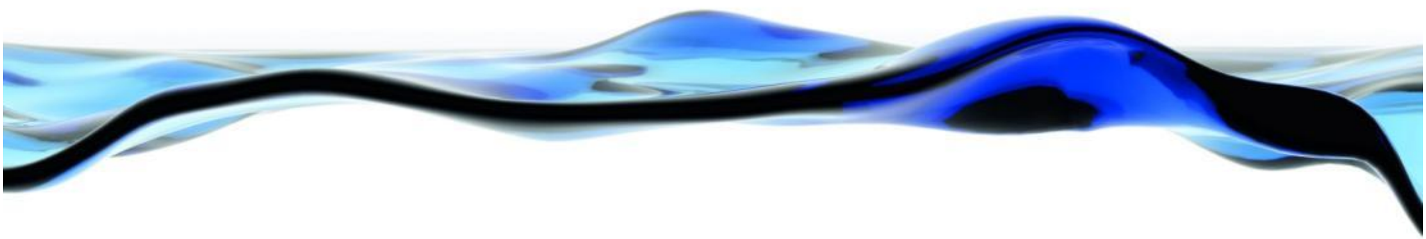
Application of downscaled climate data for South Australia using the cropping simulation model APSIM

Peter Hayman and Bronya Alexander



Goyder Institute for Water Research
Technical Report 15/2

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

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The following Associate organisations contributed to this report:

Enquires should be addressed to: Goyder Institute for Water Research
Level 1, Torrens Building
220 Victoria Square, Adelaide, SA, 5000
tel: 08-8303 8952
e-mail: enquiries@goyderinstitute.org

Citation

Hayman PT and Alexander BM, 2015, *Application of downscaled climated data for South Australia using the cropping simulation model APSIM: Sub report from SARDI Climate Applications,* Goyder Institute for Water Research Technical Report Series No. 15/2, Adelaide, South Australia.

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Executive Summary

As part of the Goyder Institute funded project "An agreed set of climate projections for South Australia", SARDI Climate Applications was involved with Task 4 "Development of an application test bed". To test the downscaled data, the agricultural model APSIM (Agricultural Production Systems sIMulator) was applied.

Key findings from this experience are as follows:

1. Including an application test bed as a subprogram within this project on consistent climate change projections is worthwhile. Applied research conducted in parallel with data production enables a two way flow of information between the data providers and data users.
2. SARDI Climate Applications benefited from the engagement with climate science and interdisciplinary work with hydrologists.
3. The cropping simulation model APSIM can be run with the data generated by the Goyder Institute Project "An agreed set of climate projections for South Australia", henceforth referred to as the Goyder Institute Project. It follows that similar application models will also be able to use the data.
4. Compared to climate files that the applications community normally works with, the projection data from the Goyder Institute Project is substantial (100 ensembles for 94 years from 2006 to 2100) for each GCM. This data set presents data challenges, many of which have been solved during the life of the project. Skills in using the modelling program R will benefit SARDI Climate Applications.
5. It is likely that many in the application community will seek to subsample the large amount of climate data. This is partly due to the processing time required for 9400 yearly simulations for each climate model and projection pathway. The main reason is that adaptation research involves the use of many options such as fertiliser rates, or choice of crop and variety.
6. We found that there was no simple approach to subsampling ensembles by identifying a dry (10^{th} percentile), mid-range (50^{th} percentile) and wet (90^{th} percentile). We also found that taking a year in the future and running the 100 ensembles was problematic as some years have almost all ensembles wetter or drier than the average.
7. In the short term at least, the main users of Goyder Institute Project climate information will be hydrologists assessing the impact of climate change on surface water flows.

Glossary

ACCESS	Australian Community Climate and Earth-System Simulator
APSIM	Agricultural Production Systems sIMulator
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEWNR	Department for Environment, Water and Natural Resources
ECHAM	A Global Climate Model developed by the Max Planck Institute for Meteorology
GCM	Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory
GSR	Growing Season Rainfall (rain from April to October)
MRI	Meteorological Research Institute (Japan)
N	Nitrogen
QDPI	Queensland Department of Primary Industries
RCP	Representative Concentration Pathways
SARDI	South Australian Research and Development Institute
SILO	Specialised Information for Land Owners
Tmax	Maximum temperature
Tmin	Minimum temperature

Background – SARDI Climate Applications role in the applications test bed and why the simulation model APSIM was used.

In designing the larger project on "Agreed set of climate change projections for South Australia" Task 4 was the development of an applications test bed (Figure 1).

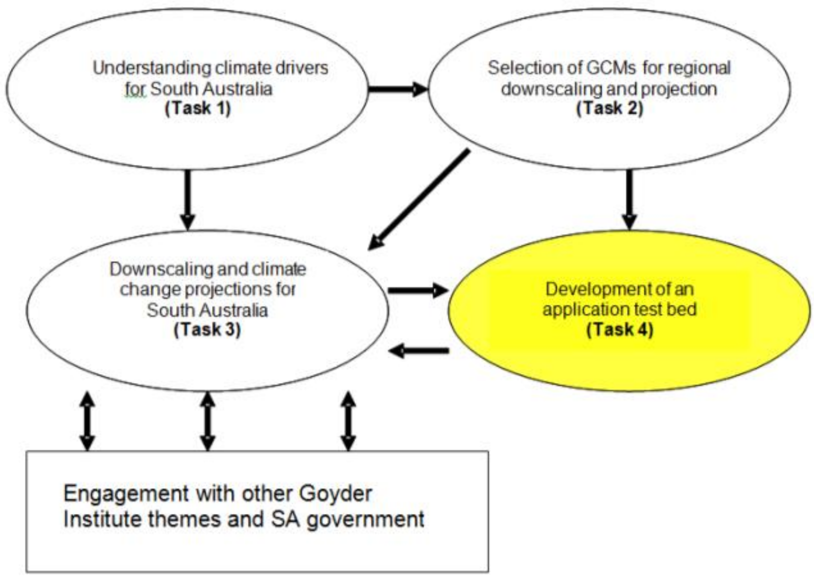


Figure 1: Graphic from proposal representing relationship of Task 4 to other parts of the project.

The purpose of the test bed was to ensure that the downscaled output from Task 3 was in an appropriate format for hydrological models commonly used by technical specialists in state government. SARDI Climate Application's role was to ensure compatibility between climate files from the Goyder Institute Project and the daily time step simulation model APSIM. This funded 15% of a research officer in climate risk, Bronya Alexander, and SARDI contributed 5% of Peter Hayman's time. The primary role of Task 4 was to ensure compatibility with existing applications rather than develop new applications or even conduct research on management of future changes in climate. In other words, the focus was the first stage of impact modelling rather than the complexities of adaptation to climate change.

We chose to use APSIM because it is the most widely used crop model in South Australia. As a daily time step model, it is representative of other models used in farming systems including CERES Wheat, Grassgro, DairyMOD, SGS pasture model, GRASP and AusFARM. Furthermore, the climate file that is used as an input for APSIM is in the standard format where rows are days and columns are climate parameters (rain, max temp, min temp, radiation etc). This format is similar for most agricultural models, but is also used by the climate applications community for spreadsheets or programs of varying complexity to calculate agro-climatic indices such as the number of wet days, heat units, growing degree days, chill units and thermal heat stress for cattle. The key point is that most agricultural applications are run at single point locations whereas many hydrological models have a spatial component.

APSIM is a point-based crop simulation model which uses climate data to simulate a daily soil water balance, daily crop growth and partitioning into harvestable yield. It was initially developed in Qld by CSIRO and QDPI but has been validated for use in the southern Australian grains belt (eg Sadras et al. 2003; Yunasa et al. 2004; and Whitbread and Hancock 2008; Hayman et al. 2010) and previously used for studies on climate variability (Hayman et al. 2010) and climate change in the region (Reyenga et al. 2001, Howden et al. 2001, Luo et al. 2005; Alexander et al. 2008). Within SA state government funded projects, APSIM has been used for policy on ground cover for erosion cover within DEWNR (Liddicoat et al 2012), NRM planning (Meyer et al 2013), identifying Goyder's Line (Nidumolu et al 2012), and valuing PIRSA's project on soil modification New Horizons. APSIM has been used in all states of Australia and in Africa, India and throughout Asia.

As outlined in Figure 2, APSIM requires detailed input for four areas: Soil properties; Starting conditions such as soil moisture, organic matter etc; Agronomic management including sowing rules, fertiliser application etc; and daily climate data. Crop growth is simulated for each day from sowing through to maturity for every year that climate data is provided

There are numerous output variables relating to soil water balance and crop growth, partitioning and yield. Analyses of simulated crop yields such as wheat are common after running the model with multiple years of climate data. It can also be run using projected climate data from global circulation models (Figure 3). APSIM is useful for analysing moisture budget variables including soil evaporation, transpiration, runoff and drainage, and can be run with or without a crop growing in the soil.

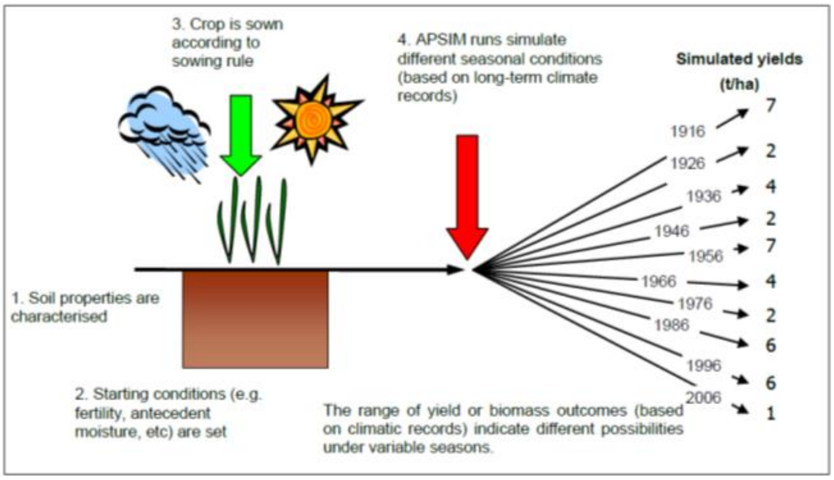


Figure 2: Overview of the APSIM crop simulation model (adapted by Craig Liddicoat Rural Solutions South Australia from http://www.bcg.org.au/cb_pages/what_is_yield_prophet.php)

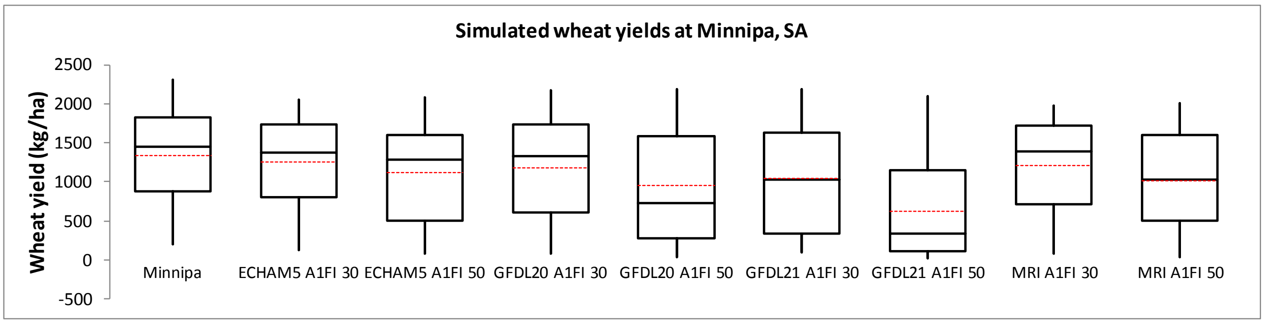


Figure 3: Example analysis of simulated wheat yields using APSIM for Minnipa, South Australia. Boxplots have been determined using a range of different climate projections data, including four global models (ECHAM5, MRI, GFDL2.0 and GFDL2.1), two forecast periods (2030 and 2050) and the A1FI emissions scenario, along with yields determined using the historical climate record.

In this study we have used one representative concentration pathway (RCP) 8.5 for two Global Climate Models; GFDL and ACCESS. The models are described under Objective 2 in this report. The choice of appropriate global climate models for SA was the responsibility of Task 2 (see Figure 1). This project focussed on applying GCMs to crop models. Because the method used to generate ensembles from the host GCM was the same for all GCMs, the actual GCMs used are not important to the findings of this report.

Objectives

1. **To identify and solve data challenges of using climate files from the Goyder Institute Project to run APSIM and similar models.**
2. **To conduct a preliminary investigation of the Goyder Institute Project climate files for impact of climate change on wheat cropping in Snowtown.**
3. **To report on the challenges and opportunities for the use of downscaled climate change data from the Goyder Institute Project in agricultural applications in SA.**

Objective 1: To identify and solve data challenges of using climate files from the Goyder Institute Project to run APSIM and similar models.

The first question for compatibility involves access to relevant daily climate data. A common problem is that a crop model requires radiation and/or daily evaporation whereas the climate file only has rainfall and maximum and minimum temperature. For APSIM (and many other climate applications), climate files are extracted from the SILO Patched Point Data set (http://www.longpaddock.qld.gov.au/silo/) and include daily temperature and rainfall (Figure 4).

year	day	radn	maxt	mint	rain	evap	vp	code
()	()	(mj/m2)	(oC)	(oC)	(mm)	(mm)	(hPa)	()
1889	1	25.0	34.0	19.5	0.0	7.6	16.0	333273
1889	2	24.0	28.5	19.5	65.0	7.8	16.0	333273
1889	3	26.0	26.5	16.5	5.6	7.8	14.0	333273
1889	4	26.0	25.0	13.5	0.2	7.8	13.0	333273
1889	5	25.0	23.0	12.0	0.3	8.0	12.0	333273
1889	6	26.0	24.5	14.5	0.0	8.0	13.0	333273
1889	7	26.0	25.5	14.5	0.0	8.0	11.0	333273
1889	8	27.0	27.5	14.5	0.0	8.0	12.0	333273
1889	9	27.0	33.0	15.5	0.0	8.2	13.0	333273
1889	10	26.0	26.0	16.5	0.0	8.2	14.0	333273

Figure 4: Example of a daily climate file used in APSIM. Data from SILO Patched Point Data set http://www.longpaddock.qld.gov.au/silo/.

Almost all applications which use daily data will require minimum and maximum temperature and rainfall. Many will also require radiation and some measure of evaporative demand. Radiation is important for photosynthesis and is one of the three key factors determining potential evaporation (along with atmospheric vapour pressure deficit and wind speed).

The data from the Goyder Institute Project includes Precipitation, Tmax, Tmin, Solar Radiation, Vapour Pressure Deficit and Potential Evapotranspiration (Figure 5). To the best of our understanding, most agro-climatic indices can be derived from this daily data set.

APSIM has the inbuilt capacity to alter the daily historical climate files in order to investigate different climate change scenarios (eg changes in temperature, rainfall and CO_2). Changes can be made for any specified time of the year, and applied on a daily basis. For example if a rainfall decline of 20% is specified between Jan 1st and Dec 31st, this will reduce the rainfall on every day of the year by 20%. Similarly, an increase in maximum temperature of 1degree from March 1st to March 31st will result in every day during March reaching 1 degree warmer than the historical record.

The Queensland Centre for Climate Change Excellence was funded by the Commonwealth Department of Agriculture to provide climate change projections with daily data in the format of the SILO file shown in Figure 4. There were different forms of downscaling used but the key difference is the number of realisations of the file.

There are challenges involved in accessing the data, processing and then storing and being able to retrieve the runs. Rearranging the climate data for 100 ensembles into an APSIM compatible format was solved by Leon Van der Linden (Task 4, SA Water) using R scripts printed in Appendix 1.

ny28.access10.his.19025.001.txt

1961	1	1	3	0.0	36.0	16.5	24.2	23.9	6.5
1961	1	2	3	0.0	29.9	15.9	29.1	15.6	7.0
1961	1	3	1	0.0	28.5	11.8	27.4	12.1	6.3
1961	1	4	3	0.0	29.6	10.6	24.8	11.5	5.9
1961	1	5	3	0.0	32.0	15.6	31.4	13.5	7.7
1961	1	6	3	0.0	35.2	15.5	28.5	17.9	7.3
1961	1	7	3	0.0	30.6	18.1	29.8	15.2	7.4
1961	1	8	3	0.0	34.1	18.8	27.4	17.2	7.2
1961	1	9	3	0.0	29.1	15.9	30.0	11.7	7.2
1961	1	10	4	0.0	34.0	15.4	26.7	18.4	6.8
1961	1	11	1	0.0	37.1	20.2	30.8	27.7	8.0
1961	1	12	1	0.0	35.9	18.5	31.1	20.3	8.0
1961	1	13	3	0.0	30.4	15.8	28.7	13.7	7.0
1961	1	14	3	0.0	31.7	12.9	24.1	15.6	6.0
1961	1	15	3	0.0	24.7	12.0	27.3	8.9	6.1
1961	1	16	3	0.0	29.0	14.0	18.3	14.2	4.9

Figure 5: Example of a daily climate file provided by the Goyder Institute Project. Columns are Year, Month, Day, Weather State, Precipitation, Tmax, Tmin, Solar Radiation, Vapour Pressure Deficit, PET(Morton's APET).

Objective 2: To conduct a preliminary investigation of the Goyder Institute Project climate files for impact of climate change on wheat cropping in Snowtown

In South Australia wheat is planted in May and harvested in November. The main driver of year to year variability is the rainfall over the growing season. A common definition of growing season rainfall (GSR) is the sum of rainfall from April to October. A first approximation of potential wheat yield is given by the equation

Wheat Yield (kg) = (GSR-110) x 20

The rate of development of wheat is largely determined by temperature. The growing season temperature (GST) is calculated by determining the mean temperature (max + min)/2 for each month and averaging the values from April to October.

The growing season rainfall and temperature provide a basis to summarise the broad changes in climate. The simulation model APSIM uses daily values and is sensitive to the timing of the rainfall and changes in temperature. Wheat yield is very sensitive to moisture stress in the period up to and immediately after flowering. Hence rainfall in early spring is much more valuable than rainfall very late in the season.

APSIM runs focussed on Snowtown in the mid North of SA (historical average GSR of 315mm). The GSR of 315 mm is about midway between the wettest edge of the grains belt at 400mm GSR and the driest edge around 210mm. Not only is Snowtown in a major grain growing region, it is a site with high quality climate records. The Goyder Institute Project data was produced for 15 different global GCMs from which we selected two as input files for APSIM: GFDL-ESM2M and ACCESS1.0. Both these GCMs overlapped between the Goyder Institute Project and the set of GCMs used in the concurrent Australian Climate Futures (ACF) project (www.australianclimatefutures.net.au) which has become the official CSIRO and Bureau of Meteorology source of information on climate change www.climatechangeinaustralia.gov.au.

The ACF project gives average "climate futures" over different regions in Australia including "Southern and SW Flatlands (East)" which includes Snowtown. GFDL-ESM2M falls into the Hotter (1.5-3.0C increase) and Much Drier (<-15% rainfall change) future for 2070 projections, whereas ACCESS1.0 is less extreme in rainfall projections, falling into the Hotter and Little Change (-5 to 5% rainfall change) future for 2070. For both GCMs we ran the Historical model data (1961-2005) and the RCP8.5 projections (2006-2100) through APSIM.

Two hypothetical soils representing a shallow sand and deep clay were used in APSIM simulations. The key characteristics are summarized in Table 1. The differences relate to the capacity to hold water in the root zone before drainage, and surface characteristics which influence infiltration and evaporation. Stage 1 evaporation from the soil is modelled to occur at the same rate as daily potential evaporation, and lasts until a specified amount of evaporation is reached. This is determined by the term "U" measured in mm. Stage 2 drying is at a slower rate and is determined by the term "Cona" ($mm/day^{0.5}$). The soil diffusivity constant and slope determine the movement of water in the soil

Soil	Surface % clay content	Total PAWC (mm)	Crop Lower limit at surface (mm/m)	Crop Upper limit at surface (mm/m)	U	Cona	Diffuse constant	Diffuse Slope
Shallow sand	3.75	40	67	175	4	2	250	22
Deep clay	30	120	208	377	6	4	40	16

Table 1: APSIM soil parameters for two different soils created for modeling. Soil hydraulic parameters include U and Cona (Stage 1 and 2 soil evaporation) and soil diffusivity constant and slope. The shallow sand has 3.75% clay in the surface layer and a Plant Available Water Capacity of 40mm, and the Deep clay has 30% clay in the surface layer and PAWC of 120mm.

APSIM manager files were set up to sow wheat (cultivar Mace) on May 21st each year of the simulation. Soil and surface organic matter characteristics were reset each year on Jan 1st so that there were no carry over effects from year to year. 250kg/ha of Nitrogen as urea was added at sowing each year to ensure the APSIM simulations were not nitrogen limiting. Although this rate is higher than district average, the intent was to ensure that there was no N limit. An approximation is that wheat removes 20kg of N per tonne and requires more than double this available in the soil.

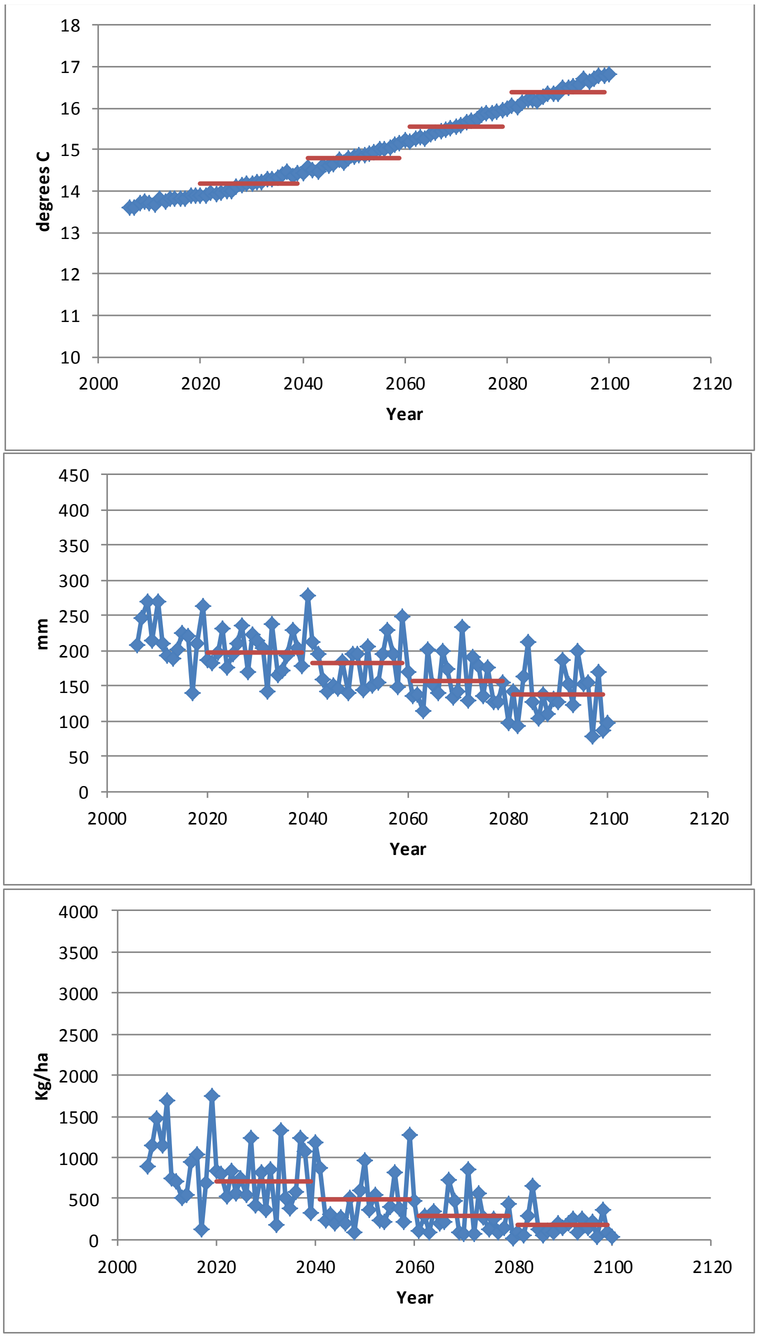


Figure 6: Time series of projected mean Growing Season Temperature from April to October (upper panel), Growing Season rainfall (mid panel) and APSIM simulated wheat yields for Snowtown using **GFDL RCP 8.5** (lower panel). Each point is the mean of 100 ensembles. The horizontal red lines show the mean for the 20 years centred on 2030, 2050, 2070 and 2090. Note the low variability in the average of all 100 ensembles for temperature and high variability in rainfall and simulated wheat yield.

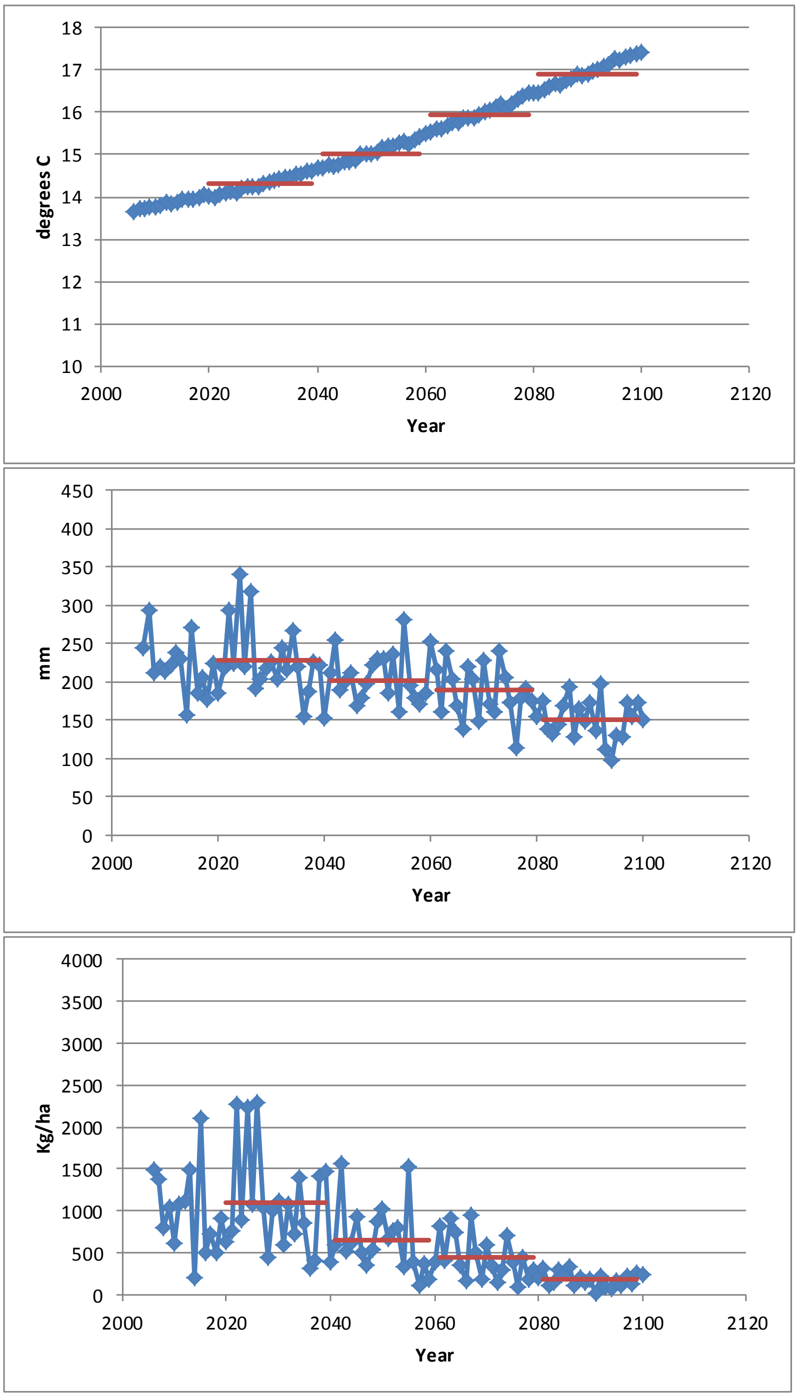


Figure 7: Time series of projected mean Growing Season Temperature April to October (upper panel), Growing Season rainfall (mid panel) and APSIM simulated wheat yields for Snowtown **ACCESS RCP 8.5**. (lower panel). Each point is the mean of 100 ensembles. The horizontal red lines show the mean for the 20 years centred on 2030, 2050, 2070 and 2090. Note the slightly increased level of warming and decreased level of drying compared to the GFDL model in Figure 6.

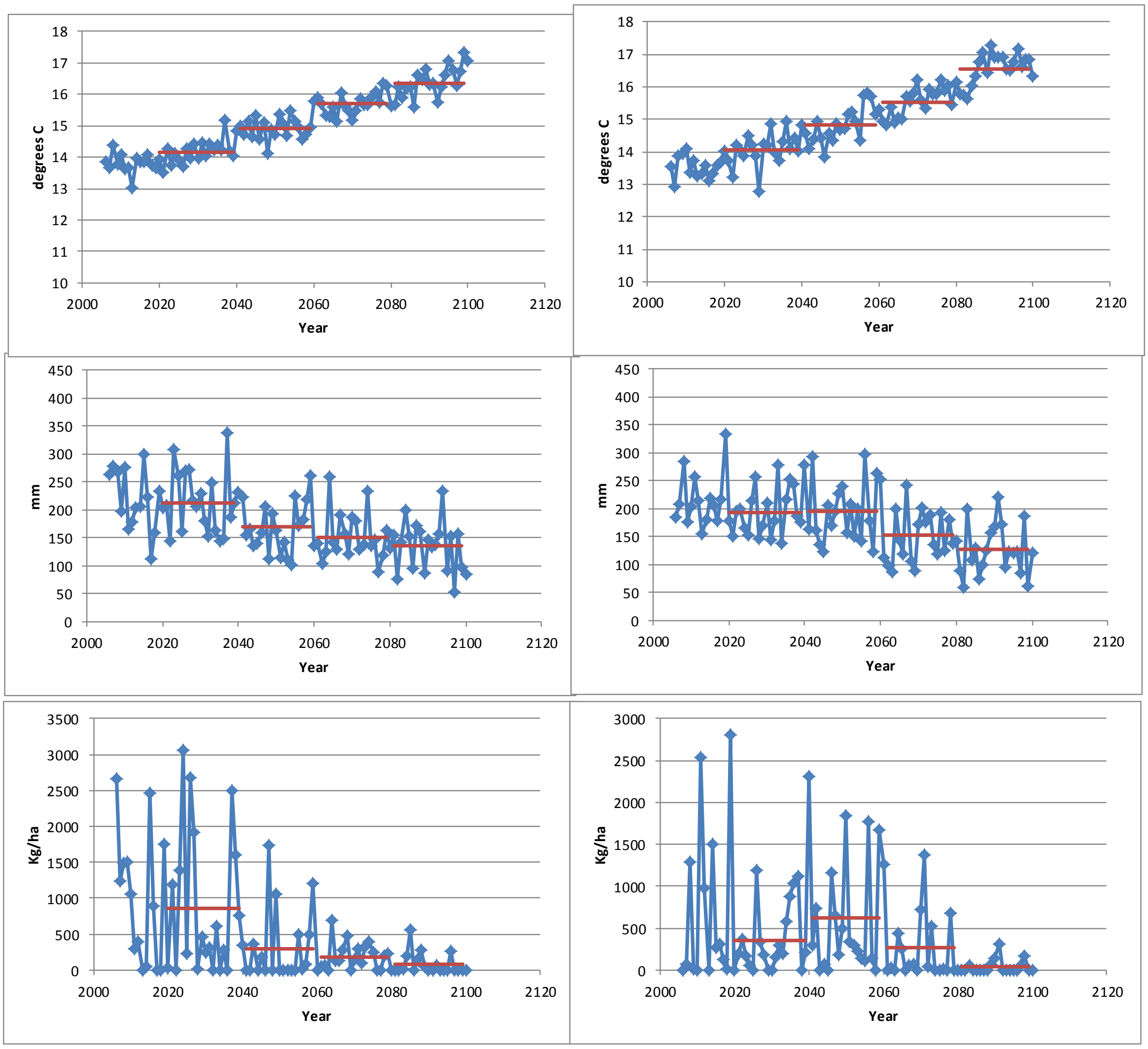


Figure 8: Two randomly selected ensembles showing mean Growing Season Temperature (April to October), Growing Season rainfall and APSIM simulated wheat yields for Snowtown for **GFDL RCP8.5.** These ensembles are 2 of the 100 ensembles that are averaged in Figure 6. The horizontal red lines show the mean for the 20 years centred on 2030, 2050, 2070 and 2090. Note the wider range of year to year variability compared to Figure 6 and in the lower right panel a situation where the 20 year mean crop yield for the 20 year mean centred on 2050 is higher than the 20 year mean centred on 2030.

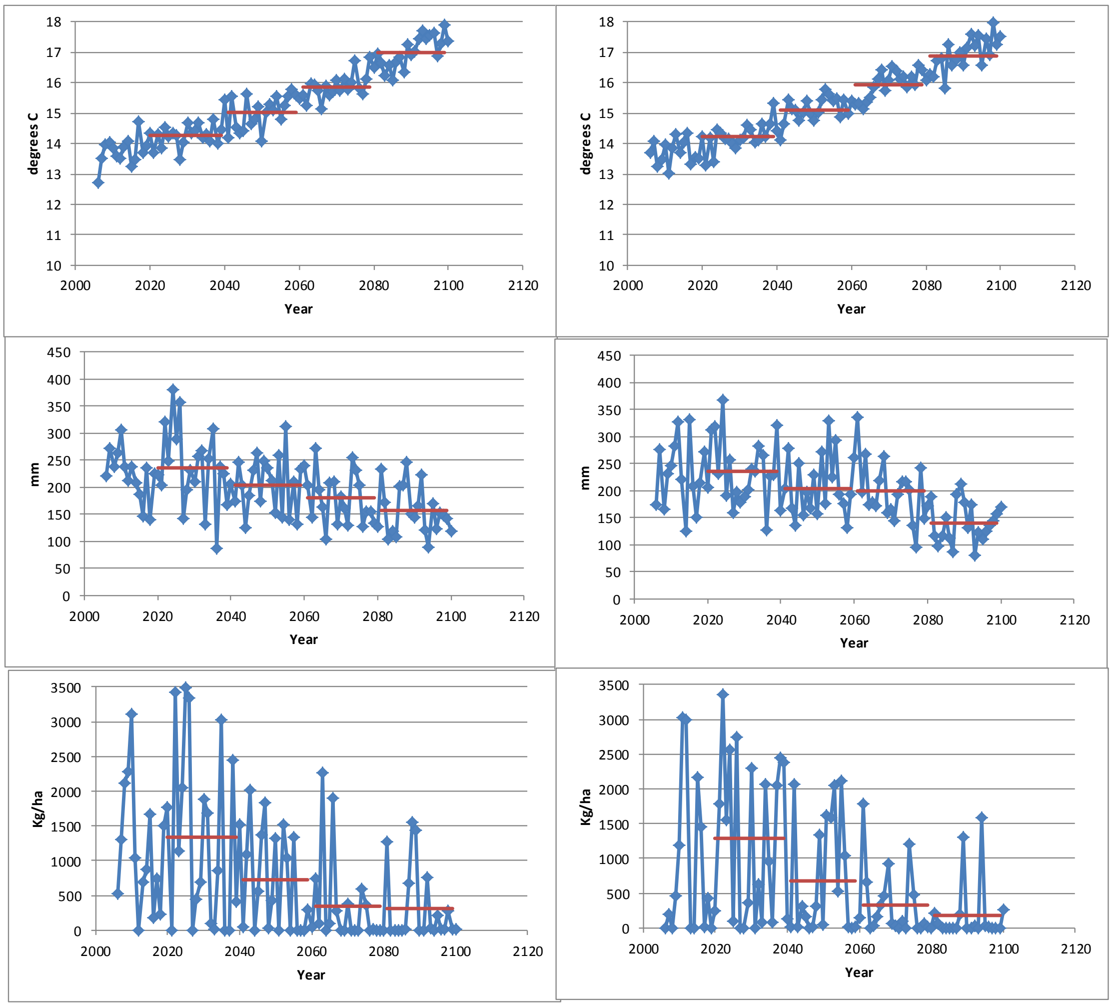


Figure 9: Two ensembles showing mean Growing Season Temperature (April to October), Growing Season rainfall and APSIM simulated wheat yields for Snowtown for **ACCESS.** These ensembles are 2 of the 100 ensembles that are averaged in Figure 7. The horizontal red lines show the mean for the 20 years centred on 2030, 2050, 2070 and 2090. Note the wider range of year to year variability compared to Figure 7.

Key messages from Figures 6 to 9

As expected, the year to year variability in GST, GSR and simulated yield is much higher in the individual ensemble runs than the average of 100 ensembles. The two ensembles show different patterns of warming, drying and yield decline as shown by the 20 year means. This is particularly pronounced for simulated crop yield.

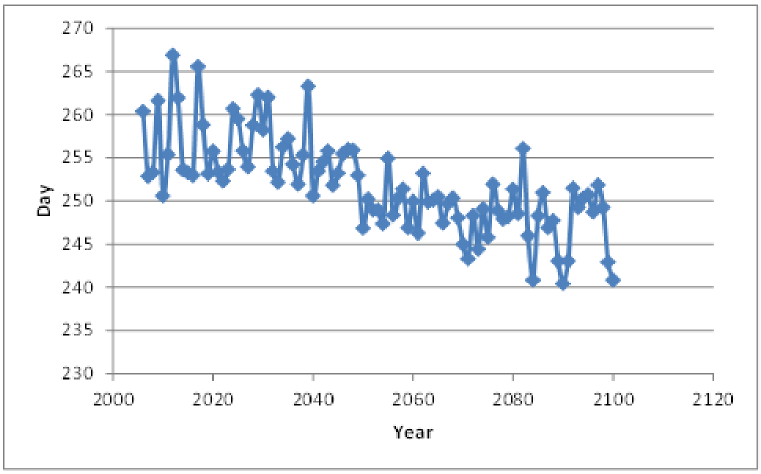


Figure 10: Simulated flowering date. Each point is the average of simulations using daily data from each of the 100 ensembles for that year. The global climate model was from GDFL and emission pathway was RCP 8.5. On the Y axis day 270 corresponds to the end of September and day 240 the beginning of September.

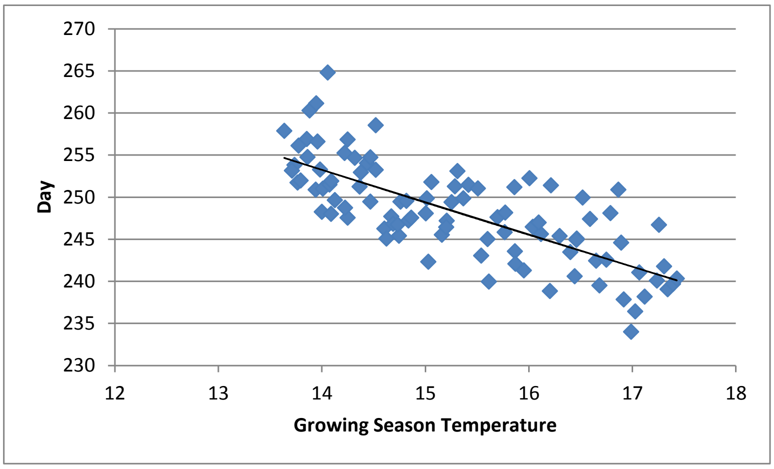


Figure 11: The relationship between growing season temperature and flowering date. Each point is the average of 100 ensembles. The global climate model was from GDFL and emission pathway was RCP 8.5. On the Y axis day 270 corresponds to the end of September and day 240 the beginning of September.

Key messages from Figures 10 and 11

The simulated warming shown in Figure 6 is expected to hasten crop development and result in earlier flowering. The relationship between GST and flowering date is significant (r=0.74) but there is a wide range of flowering dates for a given GST. The most likely cause of the variation is that flowering is determined by a subset of growing season temperature (June, July August). The change in GST from less than 14 to over 17 is substantial. Emerald in Queensland is the most northern fringe of the Australian cropping belt with a GST of 18. The change in phenology will have implications for frost risk and heat events. With the increase in mean temperature there will be more spring heat events and most likely a reduction in frost events.

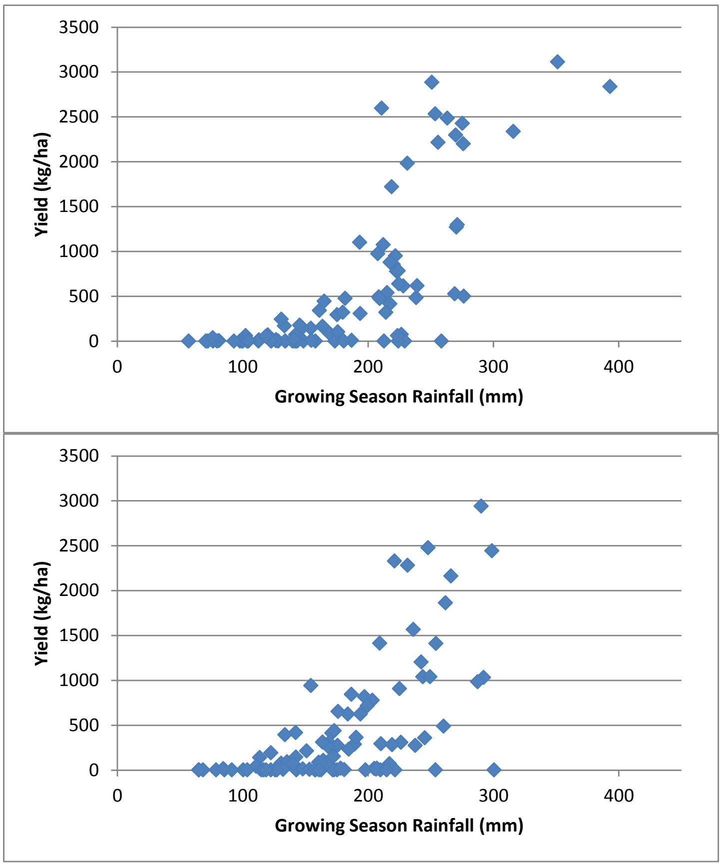


Figure 12: APSIM simulated wheat yield plotted against growing season rainfall (April to Oct) from 2 ensembles (GFDL RCP 8.5).

Key messages from Figure 12: The overall pattern of the relationship between GSR and simulated yield is what would be expected in a water limited environment. However the relationship between GSR and yield is not simple. Using the example of 200mm GSR, there is a wide range from very low yields to over 3t/ha. Major sources of the variation are likely to be 1) the timing of rainfall, 2) a failure of the simulated crop to establish due to a dry period after sowing and 3) the shifts in phenology shown in Figure 11.

Objective 3: To report on the challenges and opportunities for the use of Goyder Institute Project data in agricultural applications in SA

As outlined in the introduction, one of the purposes of SARDI Climate Applications being involved in the applications test bed was to observe and reflect on the challenges and opportunities of using the Goyder Institute Project data in agricultural applications.

The reporting under objective 1 highlighted the IT challenges and objective 2 showed the results from APSIM modelling. There are two broad approaches to using the Goyder Institute Project data in an application:

1. Run the 100 ensembles through the application model and then summarise the data for presentation. For example present the 10th, 50th and 90th percentile of wheat yield or growing season rainfall in 2050.
2. Select ensemble runs that represent the 10th, 50th and 90th percentile and run these three ensembles through the application model and report the simulated wheat yields.

The first approach of running 100 simulations is common practice in hydrology due to the highly non-linear nature of the system and the interest in extreme events such as flooding. As we have shown in objective 2, running 100 simulations of 94 years of a daily time step wheat model is possible, and takes about 2.5hrs to run on a personal computer. However, the current emphasis in climate change adaptation is to focus on management of future risks rather than repeating impact studies (beyond the damage report). Although there are hardware solutions such as networked PCs, for whatever level of resources available for a study, the time running the many simulations will detract from simulations of management options in future climates. Figure 10 shows a shift in phenology and ideally we would have compared a long season, mid- season and short season variety for each simulation. This increases the number of yearly simulation runs from 9,400 to 28,200. If different fertiliser rates or sowing rules are incorporated the simulation experiment grows exponentially. The number of simulation runs rapidly grows as soon as more GCMs and Representative Concentration Pathways are included.

The ensembles are best treated as 100 random samples of future climates from the host GCM. Subsampling ensembles enables us to reduce the number of simulation runs. It is problematic to use the mean of the 100 ensembles (Figure 6 for GFDL and Figure 7 for ACCESS) as this process eliminates the year to year and decade to decade variability that is shown in individual ensembles (Figure 8 for GFDL and Figure 9 for ACCESS).

Rather than showing the mean GSR or the full 100 ensembles another approach is to use a threshold of what farmers might now consider a critically low rainfall. An example using 150 mm GSR is presented in Figure 13. This highlights the large increase in risk of a low rainfall year in a drying trend and illustrates one way of summarising the output. A limit to this approach is that choosing thresholds can be somewhat arbitrary. Furthermore it is under-utilising the projection information as a farmer is interested in the range of both good and bad years rather than just the droughts.

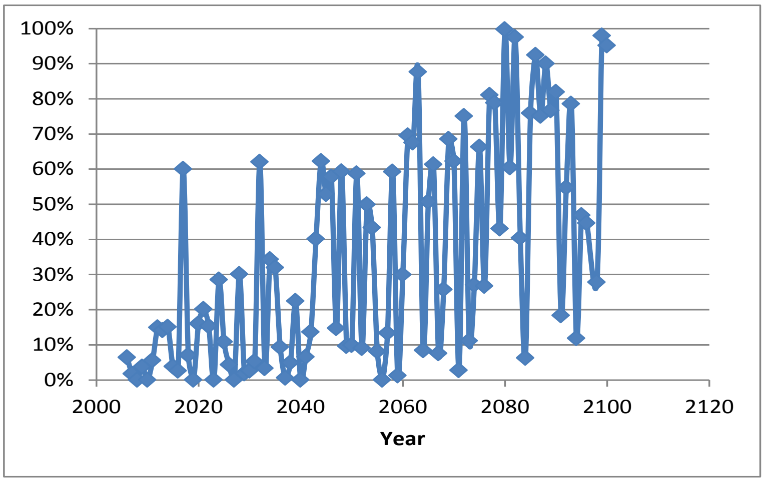


Figure 13: The chance of ensembles of growing season rainfall being less than 150mm, from APSIM simulations using GFDL RPC 8.5.

A common way to summarise projections is to present a severe, average and mild level of drying (90th, 50th and 10th) percentile. The applications community is familiar with this information from the Climate Change in Australia report in 2007 prepared by the Bureau of Meteorology and CSIRO.

Figures 8 and 9 presented the time series of individual projections and, as outlined earlier, the trajectory of drying from individual projections presents a different picture than the mean of the 100 ensembles. As each ensemble is unique, the ensemble that is driest at 2100 (lowest GSR) will not necessarily be the driest at 2030 and 2050. Figure 14 shows that there is almost no relationship between the ranking of ensembles on GSR at 2100 and the 20 year mean centred on 2030, 2050 or 2070.

Figure 14: April to October GSR rank in 2100 compared to the rank of the 20 year mean at 2030, 2050 and 2070. GFDL RCP 8.5.

An alternative approach to selecting the 10th, 50th and 90th percentile is to select a year (eg. 2070) or group of years in the future and compare the result of the 100 ensembles for that year. An attraction of this approach is that there will be an average level of warming and drying for 2030 and the ensembles will provide a guide to the variability around this average and a range of patterns of seasonal and daily rainfall.

Figures 15 and 16 show a matrix of growing season rainfall with the 94 years from 2006 to 2100 as rows and the 100 ensembles as columns. Conditional colouring of cells from EXCEL is used to show the pattern of drying using GFDL in Figure 15 and ACCESS in Figure 16.

Figure 15: Growing season rainfall GFDL RCP 8.5. Matrix with years as rows and ensembles as columns. Green is wetter and red drier.

Figure 16: Growing season rainfall ACCESS RCP 8.5. Matrix with years as rows and ensembles as columns. Green is wetter and red drier.

Figures 15 and 16 present a quick overview of the pattern of drying that demonstrates the drying over the time period and the variability scanning across (variability in ensembles) and scanning down (variability year to year). An interesting feature is the horizontal striping which indicates many ensembles showing a drying for a single year. This is because, even though the 100 ensembles differ from each other, they are all produced using the same climate model. For example, where heavy red horizontal striping occurs the climate model is predicting a drier year which is manifested in the majority of ensemble runs for that year. In contrast to the horizontal striping, there are no vertical stripes. The lack of vertical stripes is consistent with the difficulty in selecting a median, 10th and 90th percentile ensemble.

To further explore the horizontal stripes in the matrix of the ensemble vs time we detrended the data by finding the slope of the linear regression for each ensemble where time is the independent variable and yield is the dependent variable. We subtracted the linear trend with time for each year so that the linear slope of each detrended ensemble was zero. We then compared each year for each ensemble with the mean of all years and all ensembles.

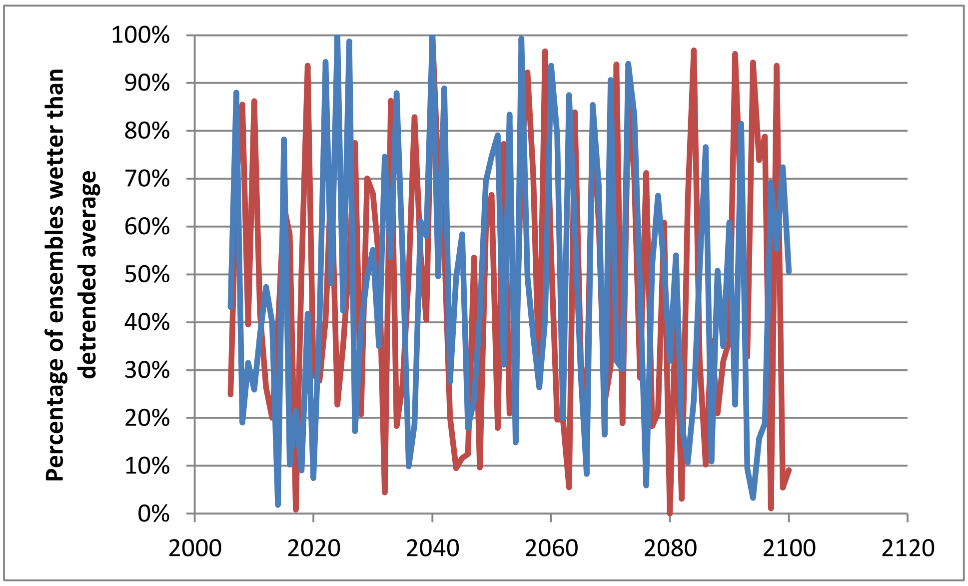
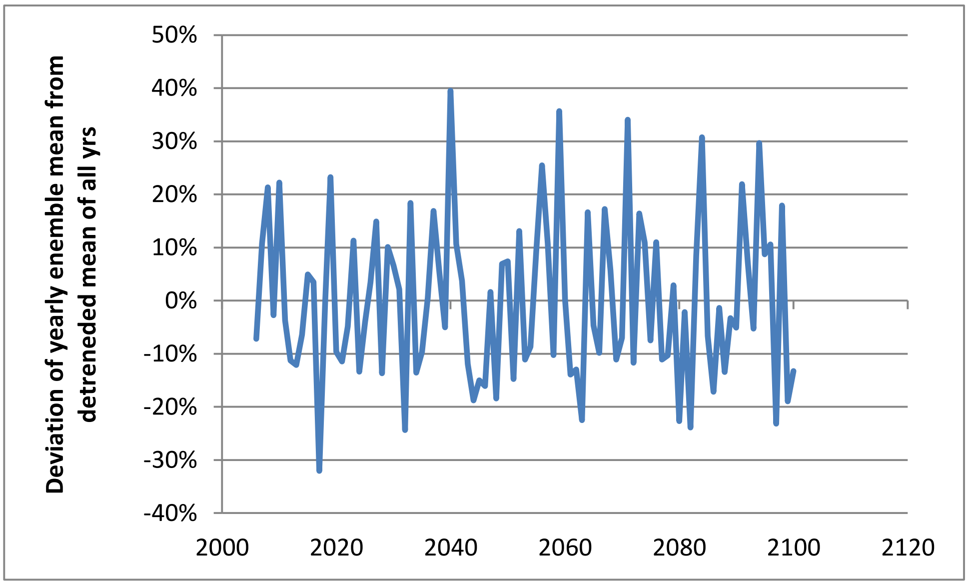


Figure 17: The percentage of de-trended ensembles wetter than the average of all years and all ensembles. GFDL shown in blue and ACCESS shown in red.

The data in Figure 17 is another way to show the horizontal striping. Figure 17 indicates that in some years the number of ensembles showing wetting or drying can be close to 100%. As expected, there is no consistency between years in GFDL and ACCESS.

A question that follows from Figure 17 is the amount of deviation from the mean of all ensembles and all years. It is possible to have 95% of ensembles wetter than the long term median, but this may only be by a few mm. Figure 18 shows that the deviation is substantial, and this is consistent with considerable year to year variability in the base GCM before the 100 ensembles have been generated.



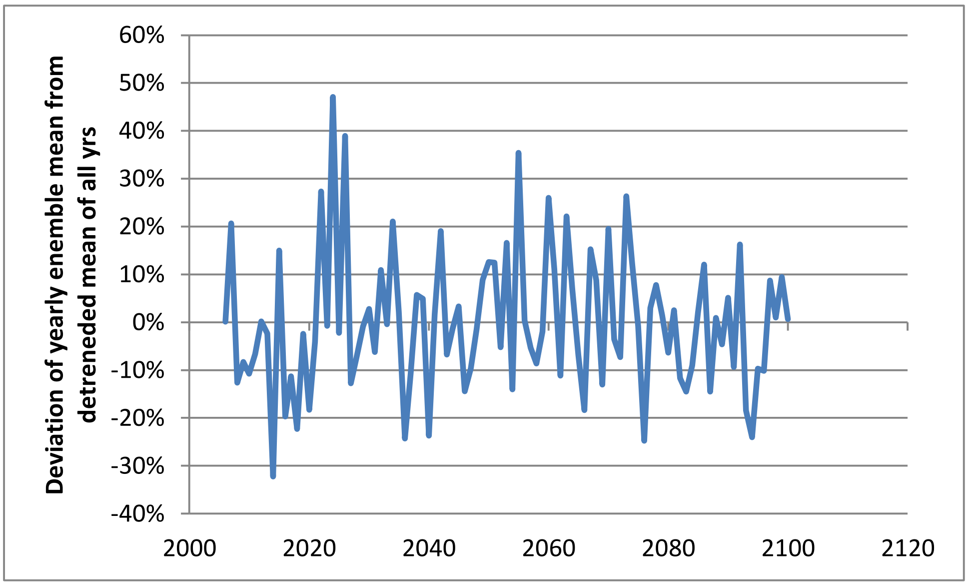


Figure 18: The deviation from the average of all years and all ensembles. All ensembles are de-trended. GFDL in upper panel and ACCESS in lower panel.

Key message from Figures 15 to 18

The approach of taking a single year in the future and using the 100 ensembles is problematic as it will give an unrepresentative consistency on the extent of drying. Any attempt to compare GCMs in say 2050 by using the 100 ensembles for 2050 would be misleading.

Concluding remarks

This project set out to run the simulation model APSIM with climate change projections generated by other sections of the Goyder Institute Project “An agreed set of climate change projections for South Australia”. We were able to successfully run APSIM with the revised climate files and showed that a warming and drying trend will result in a substantial reduction in simulated crop yield.

Using 100 ensembles of the 94 year period generated from a GCM is problematic for daily time step crop models like APSIM run on a PC. There is a good case for 100 ensembles being required for a hydrologist interested in changes to the 1 in 100 year flood events. The case is less clear for crop modelling. This is partly due to the processing time required for 9400 yearly simulations for each climate model and projection pathway. One approach is to find hardware and programming solutions to run numerous iterations of simulation models like APSIM. CSIRO colleagues in Canberra and Toowoomba have developed this capacity. Even with increased computing capacity, the main interest in adaptation research is management options such as fertiliser rates, or choice of crop and variety. It is likely that end users in the applications community will be interested in subsampling the 9400 years of simulations. In this project we have raised some of the issues but not resolved the best way forward. Key questions are how many subsamples are required for a given application and whether a variable like seasonal rainfall can be used in the process of subsampling.

In this project the applications projects were run in parallel rather than in series with the main project of developing projections. Although there are challenges with this approach, there are substantial advantages both in feedback to the developers of the projections and in learning with other application groups.

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Appendix 1: R scripts to change data from the Goyder Institute Project "An agreed set of climate projections for South Australia" into APSIM format. Scripts developed by Leon Van de Linden, SA Water.

Convert C11T3 downscaling to APSIM input

```
# Script to convert Goyder Climate Change project C.1.1 Task 3 NHMM downscaling to APSIM
#format.

source('formatting functions.R')

require(chron)

con <- file('Maitland_22008.sim')

template.header <- readLines(con, n = 24)

template.header <- template.header[c(1,4:7,23:24)]

close(con)

template.header[6] <- "year  day radn  maxt   mint  rain  vp"

template.header[7] <- " ()   () (MJ/m^2) (oC)  (oC)  (mm) (hPa)"

stations <- read.csv("NorthernYorke.28stations.csv", header = T)

data.dirs <- list.files()[grep(".",list.files(), fixed = T, invert = T)]

for(dd in data.dirs){ # dd <- data.dirs[2]

 dest.dir <- paste(getwd(),'apsim.conv',dd, sep = '/')

 if(!file.exists(dest.dir)){

  dir.create(path = dest.dir, recursive = T)

 }

 # subset of station numbers; start with Woodside only (23829)

 # eventually for loop of desired stations

  for(st.number in stations$Number){#    st.number <- 23829

 #for(st.number in 22008){#    st.number <- 23829

  details <- stations[grep(st.number,stations$Number),]

  data.files <- list.files(dd, pattern = as.character(st.number))
```

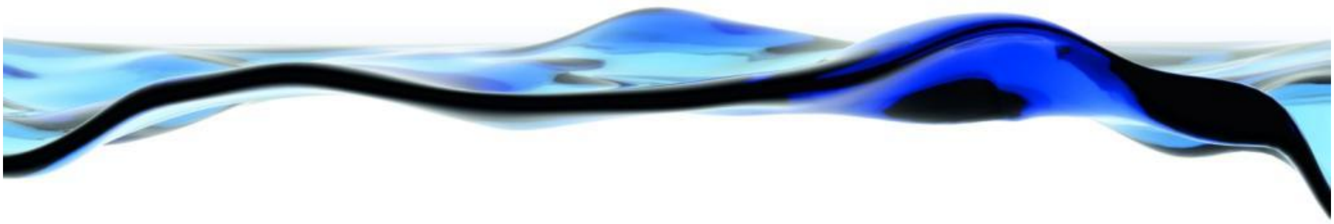
```
  header <- template.header
  header[2] <- paste('latitude = ',details[1,3],' (DECIMAL DEGREES)')
  header[3] <- paste('longitude = ',details[1,4],' (DECIMAL DEGREES)')
  for(ff in data.files){ # ff <- data.files[1]
    dat <- read.table(paste(getwd(),dd,ff, sep = '/'))
    # calculate Tav and Amp values and insert into header
    dailyTav <- (dat[,6]+dat[,7])/2
    Tav <- mean(dailyTav)
    monthTav <- aggregate(x = dailyTav, by = list(month = dat[,2]), FUN = mean)
    Amp <- monthTav$x[which.max(monthTav$x)]-monthTav$x[which.min(monthTav$x)]
    header[4] <- paste('tav = ', format(Tav, digits = 4),' (oC) ! Annual average ambient temperature',
sep = '')
    header[5] <- paste('amp = ',format(Amp, digits = 4),' (oC) ! Annual amplitude in mean monthly
temperature', sep = '')
    # convert data table
    dat.apsim <- scToApsim(sc = dat)
    # format comments
    comment <- paste('! Source file: ', dd, ff, sep = '/')
    comment[2] <- paste('! Station: ', details[1,1], details[1,2], sep = ' ')
    fc <- paste(dest.dir,sub(pattern = 'txt', replacement = 'sim', x = ff), sep = '/')
    file.create(fc)
    con <- file(fc)
    writeLines(c(header[1],comment,header[2:length(header)]), con = con)
    close(con)
    write.table(dat.apsim, file = fc, append = T, sep = ' ',
          col.names = F, row.names = F)
  }
 }
```

```
}
```

formatting functions.R

```
scToApsim <- function(sc){
 # sc is in the format provide from Steve Charles' (CSIRO) NHMM downscaling
 # columns correspond to:
 # c('Year','Month','Day','WeatherState','P','Tmax','Tmin','Radn','VPD','PET')
 # output is to apsim data table thus:
 # "year  day radn  maxt   mint  rain  vp"
 # " ()   () (MJ/m^2) (oC)  (oC)  (mm) (hPa)"
 # with leap year days added as repeat of last day of year as suggested by Bronya Alexander (PIRSA)
 #as the wheat in the crop model is harvested by this time.
 out <- matrix(ncol = 7)
 require(chron)
 for(yy in unique(sc[,1])){ # yy <- 1961
  if(leap.year(yy)){
   ndays <- 366
  }else{
   ndays <- 365
  }
  tmp <- matrix(ncol = 7, nrow = ndays)
  tmp[,1] <- rep(yy,ndays)
  tmp[,2] <- 1:ndays
  tmp[1:ndays,3] <- sc[sc[,1]==yy,8]
  tmp[1:ndays,4] <- sc[sc[,1]==yy,6]
  tmp[1:ndays,5] <- sc[sc[,1]==yy,7]
  tmp[1:ndays,6] <- sc[sc[,1]==yy,5]
  tmp[1:ndays,7] <- sc[sc[,1]==yy,9]
```

```
    #if(leap.year(yy)){
    #  tmp[366,3:7] <- tmp[365,3:7]
    #}
    out <- rbind(out,tmp)
  }
  out <- out[-1,]
  return(out)
}
```



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.