A Changing Climate - South Coast Region of Western Australia

A background paper for the Climate Adaptation Addendum to *Southern Prospects 2011 - 2016.*
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Abbreviations used in this report.

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
APSIM	Agricultural Production Systems sIMulator
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CRC	Cooperative Research Centre
DAFF	Department of Agriculture, Forestry and Fisheries
DAFWA	Department of Agriculture and Food, Western Australia
NRM	Natural Resource Management

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Contents

1 - Forward

The background papers to the *Climate Adaptation Addendum of Southern Prospects 2011-16* are a series of detailed technical documents on the potential impacts of the South Coast region's changing climate and how people are adapting to it.

The papers were commissioned by South Coast NRM in 2014 and were part of the Regional Natural Resource Management Planning for Climate Change - Stream 1 project of the Australian Government.

The background papers synthesise the current information on the effect of climate change on each natural resource theme, community capacity to adapt and how people are already adapting. They also document some of the gaps. The papers provide useful background for community consultation through South Coast NRM reference groups. The reference groups have used the papers to develop climate adaptation goals and outcomes for *Southern Prospects 2011-2016*.

South Coast NRM recommends the papers are best read in conjunction with *Fry (2015) A Changing Climate- South Coast of Western Australia* and information on the CSIRO and Bureau of Meteorology Climate Change in Australia website *www.climatechangeinaustralia.gov.au/en/*.

Climate change planning at South Coast NRM will be flexible and adaptive and so information on climate and its impacts will be continually reviewed.

- Kaylene Parker, Climate Change Project Leader, 2015

"...decisions will need to be made before we have absolute certainty about the future. The role of climate science is to inform these decisions by providing the best possible knowledge of climate outcomes and the consequences of alternative courses of action," (Australian Academy of Science 2010, p16).

2 - Introduction

The topics of global warming and climate change are often controversial, polarising and highly politicised. There are very different views in any regional community on the need for action.

It is difficult to convey the complexities of climate change science and the public finds it hard to accept the scientific uncertainty associated with climate projections. In many cases people also find the projections do not relate to their personal experience of their local climate and *"this lack of understanding can result in disengagement or active disagreement," (Buys et al. 2012, p237).*

It is important to convey that climate projections are not forecasts, but *"projections of plausible future climate scenarios," (IPCC, 2007; IOCI 2012).* The projections are based on models using the best available scientific information at any given time and are given as a range. The climate scientists make the uncertainties in the modelling and projections very clear.

Even though there is uncertainty, climate change and increased climate variability are very real NRM risks for the South Coast region and have to be managed in an integrated way with other NRM risks.

Uncertainty is not a reason to do nothing. There are also linkages, complex relationships and non-linear feedbacks between socio-economic, ecological and climatic systems *(Alexandra 2012).* These interactions need to be considered at landscape level and it will important for South Coast NRM to determine where in the landscape there are particular vulnerabilities as a result of climate change.

The problem is, that with increasing variability in climate and the likelihood of major long-term changes, past climate is much less likely to be a reliable indicator of future climate *(Loch et al., 2012).* Sudden, stepped changes in rainfall have already occurred in the south-west corner of WA (*IOCI 2012).* These rainfall declines are mainly due to large-scale changes in the atmospheric circulation and are thought be from both natural variability and global warming *(IOIC 2012).* Land use change may also have contributed (*Pitman, 2004).* Increases in temperature, which are considered highly likely *(IOCI 2012; CSIRO, BoM, 2014a,b),* will also increase evaporation.

The combination of more dry seasons, higher temperatures and increased evaporation will have impacts on biodiversity, agriculture and hydrological systems such as wetlands, waterways and groundwater. Many of the ecological systems on the South Coast are already under stress, and there is a risk that climate change may push them beyond their capacity to adapt.

Climate change is also impacting on Indigenous cultural links with the landscape. Aboriginal people on the South Coast developed natural seasonal calendars based around their interaction with ecological cycles. Climate change is changing the characteristics of those calendars.

For example the Noongar seasons: *Birak, Bunuru, Djeran, Makuru, Djilba and Kambarang*, have been a guide to Aboriginal people as to what is happening at different times of the year. In the report of the *Indigenous Peoples' Global Summit on Climate Change* held in 2009 Indigenous participants called for immediate action on climate change including:

"We call upon the parties to the UNFCCC [United Nations Framework Convention on Climate Change] to recognise the importance of our Traditional Knowledge and practices shared by Indigenous Peoples in developing strategies to address climate change," (Galloway et al. 2009 p6).

Greenhouse gases and global warming are impacting on oceans off the South Coast. At present the oceans absorb approximately one-third of the total amount of greenhouse gases emitted to the atmosphere. The absorption of carbon leads to acidification of the oceans *(Hobday and Lough 2011)* with the Southern Ocean predicted to reach a tipping point at 450ppm carbon dioxide *(McNeil and Matear, 2008).* Global warming is increasing sea-levels as oceans warm and expand.

The Intergovernmental Panel on Climate Change (2014) found that as a result of the capacity of the water to absorb heat and the huge mass of the ocean, oceans have accumulated more than 90 per cent of the surplus heat associated with increasing greenhouses gas concentrations since the 1950s. Melting ice also contributes to rising sea levels. The interaction between ocean temperatures and atmospheric circulation is one of the factors driving climate variability in an extremely complex system.

3 - The Changes in South Coast Climate

Climate refers to *"the atmospheric conditions for a long period of time and generally refers to the normal or mean course of the weather,"* (BoM 2015). Most regions in Australia have a high degree of year-to-year variation in rainfall. This makes it difficult to assess underlying long-term climate changes and to distinguish natural variation from the impacts of global warming.

Large-scale circulation changes have already been observed in the south-west of WA. Although it has the same large-scale climate influences as the west coast, the South Coast region often responds slightly differently with considerable variation from western parts of the region to central and eastern parts. The summary climate projections from CSIRO and BoM therefore need to be viewed in that context. Confidence in climate model projections decreases at finer scales. This is because at finer spatial scales the magnitude of natural variability in climate increases and local influences on climate become more significant *(CSIRO 2007, p41; CSIRO, BoM 2015).*

3.1 - Projections for the South Western WA NRM Regions

The Australian Government established the *Regional Natural Resource Management Planning for Climate Change Fund* to provide up-to-date science to support NRM regions planning for adaptation to climate change. The regions have been grouped into *clusters* based on broad-scale climatic and biophysical features. The South Coast region is included in the *Southern and South-Western Flatlands* cluster and more specifically in the *South-West of WA sub-cluster (Figure 1).*

The subsequent report *(Figure 2)* provides climate projections based on the best available climate science in 2014 - 2015 at three scales of reporting: *Southern Australia, the Southern and South-Western Flatlands and the South West of WA.* The report contains technical information explaining how global climate models have been used to develop the projections and their limitations.

The *Climate Addendum to Southern Prospects 2011-2016* summarises the main points relevant to the South Coast region. In addition, South Coast NRM can access the latest projection data from CSIRO and BoM to assist in planning for climate change.

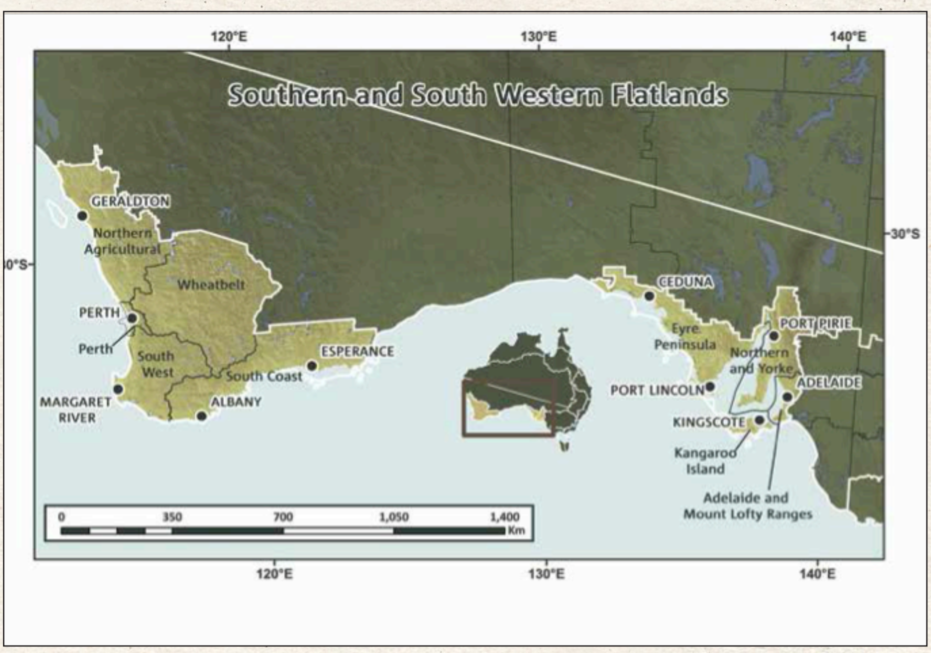


Figure 1 (left): Australian Government Regional Natural Resource Management Planning for Climate Change Fund -Southern and South Western Flatlands Cluster. **Figure 2:** Climate Change in Australia. Projections for Australia's NRM Regions, *Hope et al. (2015) CSIRO, BoM Canberra.*

These projections support impact assessment and adaptation planning for NRM groups, but it is important the projections are used in conjunction with the guidance material accompanying the *Climate Change in Australia Projections for NRM Regions (Hope et al. 2015)*. These are all available at: *www.climatechangeinaustralia.gov.au.*

The 2015 climate projections in the report are based on the latest global climate model archive, the *Coupled Inter-comparison Project Phase 5 (CMIP5)*. The projections are based on historical and future climate simulations submitted by 20 modelling groups (*Hope et al. 2015*). CSIRO and BoM have also produced a climate futures tool to support regional NRM groups in assessing the impact of climate change. Projections are summarised in *Table 1* and based on a range of emissions scenarios from low to high, known as *Representative Concentration Pathways (RCPs)*, as used by the IPCC in its fifth report. Up until 2030 the projections for each emissions scenario are fairly similar and climate responses are often masked by natural variation, but after 2030 they diverge quite radically depending on emission scenarios.

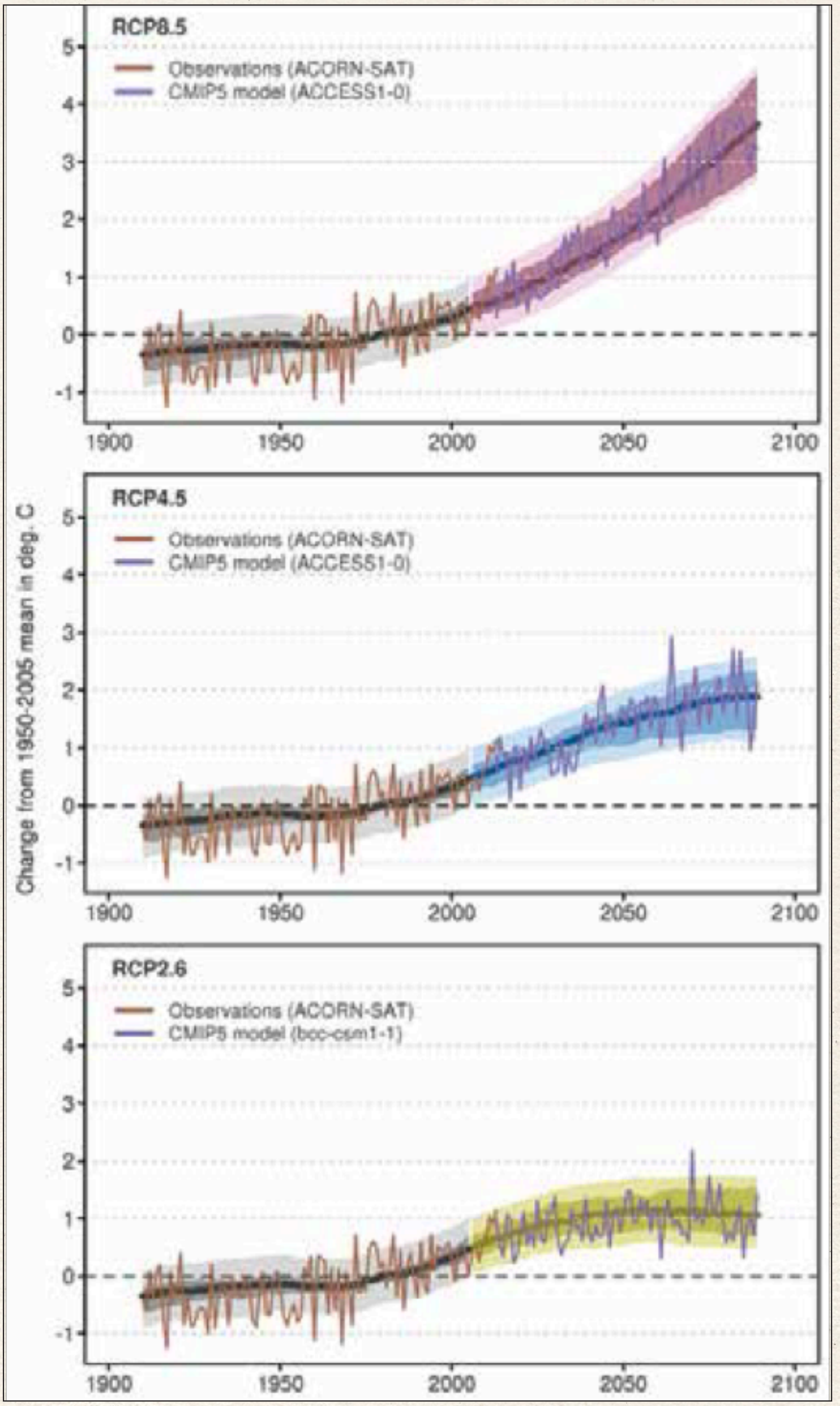


Figure 3: Time series for annual average surface air temperature (0C) for 1910 - 2090 as simulated in CMIP5 relative to the 1950 - 2005 mean SW of WA.

The central line is the median value and the shading historical simulation.

There are three future scenarios for low, medium and high emissions. (RCP 2.6, 4.5 and 8.5).

Acorn-Sats observations and projected values from a typical model are shown, from *Hope et al. (2015, p19).*

Climate Response	Confidence in Projection	Reason for Confidence
Higher temperatures	Very high	Knowledge of physical processes and strong agreement in models and downscaling
Hotter, more frequent hot days	Very high confidence	Knowledge of physical processes and strong agreement in models
Less frost	High confidence	Strong model agreement
Less rainfall in winter and spring	High confidence	Strong model and downscaling agreement, good understanding of shift of winter storm systems and greater prevalence of high pressure systems
Rainfall in other seasons unclear	Low confidence in any projections, unable to project summer rain due to uncertainty of tropical rainfall	GSMs unclear, downscaling shows different results for autumn. GCMs show both wetter and drier for summer.
Increased intensity of rainfall events	Medium confidence but low confidence in magnitude of change	Southward shift of rain bearing systems may reduce extreme events
Increase in drought duration	High confidence	High confidence in projected decline in rainfall
Decrease in winter mean wind speed	High confidence for 2030 and 2090	Related to decrease in winter storms
Increase in summer wind speed SW of WA	Low confidence	Models agree but poorly understood
Little change in solar radiation to 2030	High confidence	Models simulate little change
Increased solar radiation 2090	High confidence for medium and high emissions for winter, medium confidence for spring, little change in summer and autumn	Due to decrease in cloudiness and rainfall. High model agreement, and models may underestimate magnitude
Increased evaporation rates	High confidence but medium confidence in magnitude.	Shortcomings in simulations in relation to magnitude
Decrease in relative humidity, in winter and spring, away from coasts after 2030	High confidence	Increased moisture holding capacity of warming atmosphere and greater warming of land compared to ocean
Reduced soil moisture and run-off by 2090	High confidence, but not in the magnitude,	Related to decrease in rainfall enhanced by increase in evapotranspiration
Harsher fire weather climate, increased days of severe fire danger rating	High confidence but low confidence in magnitude of change	Increased temperatures, lower rainfall, magnitude will relate to rainfall changes
Higher sea levels and more frequent sea level extremes	Very high confidence, projections beyond 2030 depend on emissions scenarios	Due to thermal expansion and melting of sea ice and glaciers, collapse of Antarctic sea ice would increase projected magnitude
Warmer and more acidic oceans	Very high confidence, By 2090 1.5-3.9°C for highest emission scenario	Highly dependent on emissions scenario; rate of acidification proportional to carbon dioxide emissions.

Table 1: Summary of climate response, confidence in projection and reason for the South-West of WA sub-cluster (which includes the South Coast Region), *information from Hope et al. 2015.*

It should be noted these are projections only, not predictions. High confidence in projections should not be translated directly into high probability.

The confidence level is based on the ability of the models to represent important features of current and past climate and knowledge of physical systems *(CSIRO, BoM 2015)*. Models can never be totally realistic and climate models have many uncertainties. Uncertainty does not preclude the need for adaptation planning. It just means planning needs to consider the most likely climate futures eg. hotter, drier, more or less autumn rainfall and then also plan for uncertainties. Uncertainty increases at longer timescales.

"Planners need to have options that will help achieve good outcome across this range of futures. At shorter timescales, this uncertainty is reduced, so decisions with a shorter lifetime can be made with more confidence," (Rissik et al. 2014, p4).

3.2 - Downscaling from Global Climate Models

Downscaling from global climate models enabled the CSIRO and BoM climate scientists to input more detailed climate information. They used two different downscaling methods. For statistical downscaling they used 22 global climate models and for dynamical downscaling six models.

Downscaling from a global climate model produces more detail and more plausibility in projecting climate changes for southern Australia, particularly areas with complex topography (such as Tasmania), *(Hope et al. 2015)*. Nevertheless there should not be too much emphasis put on downscaling from CMIP5 for the South Coast region. Downscaling should only be used as a complementary source of information where it adds value *(CSIRO, BoM 2015)*. Downscaling used for the South Coast showed little difference in the climate responses from the global climate models, except for summer and autumn rainfall. Different downscaling methods have different strengths and weaknesses and can show different results.

For example, one of the downscaling methods showed decreased and another increased autumn rainfall. A downscaling projection showing a wetter autumn or summer is another plausible projection but not necessarily a more plausible projection than that generated from the courser scale global climate model *(CSIRO, BoM 2015)*. In other words, finer scale does not directly translate into more accurate projections.

"While downscaling can provide added value on finer scale processes, it increases the uncertainty in the projections," (Hope et al. 2015, p14).

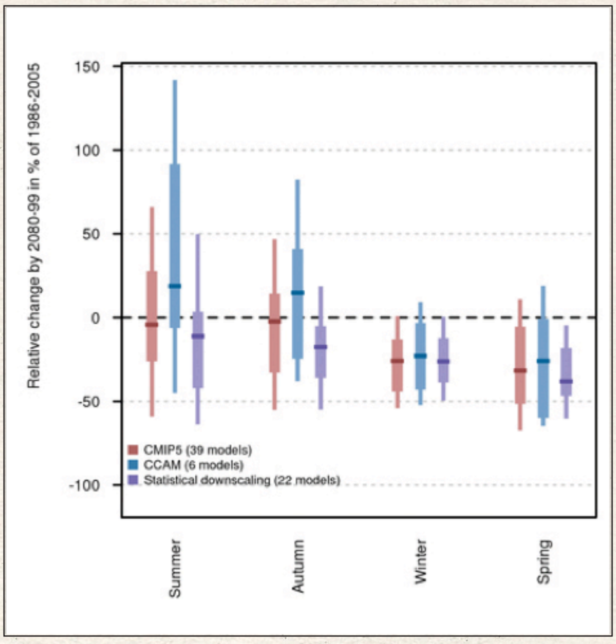


Figure 4: Projected change in seasonal rainfall for 2090 for the Southern and SW Flatlands and two different downscaling methods with a high emissions scenario, *Hope et al. 2015, p27.*

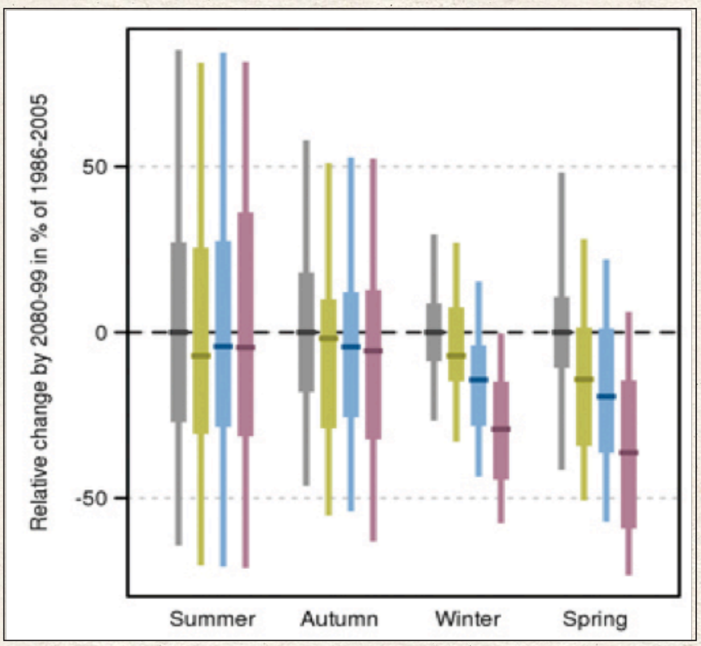


Figure 5: Projected seasonal rainfall changes for SW of WA for 2090. Natural variation is in grey, and the three emissions scenarios are low RCP (2.6), medium RCP (4.5) and high (8.5) RCP, *Hope et al. 2015, p27.*

3.3 - Impacts of Changes in Climate in the South Coast Region

The projections indicate with very high confidence, that increases in temperature are one of the responses to increasing emissions. There is also high confidence in reductions in winter and spring rainfall.

The combination of more dry seasons, more heat waves, higher temperatures and more evaporation will have impacts on biodiversity, agriculture and forestry and hydrological systems such as wetlands, waterways and groundwater.

Many of the ecological systems on the South Coast are already under stress and there is a risk climate change will push them beyond their capacity to adapt. There will be changes in sea-level due to expansion of the oceans and melting of ice. The absorption of CO_2 by oceans is causing acidification. Climate change will also affect the region's cultural heritage and Aboriginal links with landscape.

The *Climate Addendum to Southern Prospects 2011 - 2016* reviews the potential impacts of climate change on each of the South Coast NRM themes including adaptive capacity. In addition, it gives an overview of climate science, the complexity of climate, the influences on the South Coast climate and how it might be changing, due to natural variation and changes as a result of greenhouse gas emissions, the limitations of climate science and models and the uncertainties.

There is more detailed information in the background papers to the Addendum and in the technical report *Climate Change in Australia CSIRO, BoM (2015).*

4 - The Complexity of Climate and Climate Science

The global climate system involves interactions of a whole range of factors such as position of land masses, solar radiation, sea surface temperatures, ocean currents, ice sheets, atmospheric temperature and other factors, such as volcanic activity. One of the problems with complex systems like the global climate system is there are non-linear effects.

There can be critical thresholds and interactions, which result in rapid shifts and surprises, with sudden and potentially disastrous consequences. The changes in the climate system, induced by greenhouse gas emissions, also interact with unknown natural climate variations, or climate changes due to land use change, and this leads to even more uncertainty about future climate.

A number of major climate drivers influence regional scale climate in the South Coast region but local climate is also influenced by changes in the shape of the coastline, ocean currents, topography, vegetation cover and other factors, which can influence climate at a local scale. There are also seasonal variations with increasing and decreasing periods of rainfall due to natural climate variation.

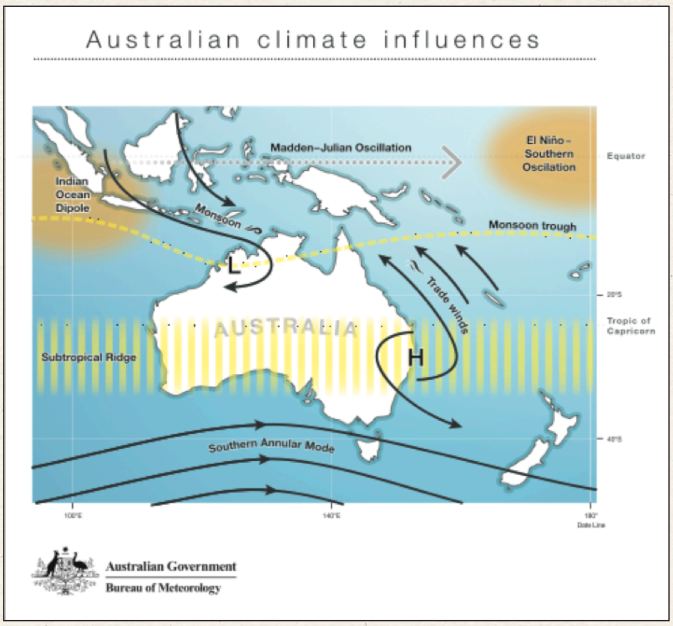
The region's climate is highly variable from season to season and this natural variability is governed by some major climate influences, some of which have only recently been described. Winter rainfall in the south-west of WA is influenced by the upper level jet stream and the fronts, lows and high-pressure systems. Summer rainfall is sporadic and can be associated, particularly in the east of the region, with the end of tropical cyclones *(IOCI 2012).*

5 - Major Factors Influencing Climate Variability in the South Coast Region

The climate influences in WA have been better understood since the advent of the Indian Ocean Climate Initiative (IOCI). This research initiative was set up in 1998 as a partnership between CSIRO, BoM and the Government of WA.

The results are summarised in *Bates et al. (2008)* and in a report by the IOCI in 2012: *Western Australia's Weather and Climate. A Synthesis of Indian Ocean Climate Initiative Stage 3 Research.* The IOCI (2012) report gives a technical overview of current knowledge about the state's climate and the main causes of climate change in the south-west of WA. The main influence on climate in the south-west in recent years has been changes in the upper-level jetstream *(Fredericksen and Fredericksen 2007).* These changes appear to have decreased the number of storms coming to the south-west.

The El Niño Southern Oscillation, which when it seesaws, changes conditions between wet and dry in the eastern states, has less effect on WA climate. Scientists believe the main see-saw influences on the climate of the south-west is the Southern Annular Mode (SAM) and the Indian Ocean Dipole (IOD). Just to make it confusing, SAM and the IOD, when labelled 'negative' mode tend to have a positive effect on rainfall on much of the south-west and South Coast.



Pic: Australian Bureau of Meterology.

5.1 - Southern Annular Mode

The Southern Annular Mode (SAM), also known as the Antarctic Oscillation, is a westerly wind belt that circles Antarctica *(IOCI 2012).*

It is labelled negative when it moves north away from Antarctica and positive (or in high mode) when it moves towards higher latitudes and Antarctica.

In a positive SAM, the westerly wind belt moves south and this results in weaker westerlies and more high-pressure systems over the south-west and South Coast and restricts the penetration of cold fronts.

This results in low rainfall in autumn and winter. Although a positive SAM results in drier conditions on most of the South Coast it correlates with more rainfall in spring in the eastern part of the region. In a negative SAM the wind belt moves north, causing more low-pressure systems over the south-west and South Coast and more winter storms.

There is an increasing trend in SAM towards a positive phase; eg. with westerly winds moving further towards Antarctica in summer and autumn months (IOCI 2012).

The westerly winds and associated low-pressure systems end up bringing their rain to the Southern Ocean rather than the South Coast. The climate models show that as greenhouse gases rise, there is a trend for SAM to move towards Antarctica (*Hope 2006; Hendon et al. 2007; IOCI 2012).*

5.2 - Indian Ocean Dipole

Changes in sea surface temperatures in the tropical parts of the Indian Ocean influence rainfall in central and southern Australia. The Indian Ocean Dipole (IOD) is generally measured as an index based on sea surface temperatures in the western, compared to the eastern, tropical Indian Ocean.

In a positive IOD, the sea surface temperatures off the Sumatra-Java coast to the north-west of WA tend to be cooler than normal and water in the tropical western Indian Ocean is warmer than normal. These changes in sea surface temperature cause a decrease in rainfall over parts of central and southern Australia.

When the relative sea temperatures reverse, a negative IOD causes an increase in rainfall *(BoM, nd, IOCI 2012). Weller and Cai (2013)* have found positive IOD modes have a bigger effect than negative modes, so the influence of a positive IOD on rainfall decline is greater. When the IOD is in a positive phase at the same time as an El Niño phase, the drying effect is more extreme in Australia *(BoM nd).* There is still scientific uncertainty about the IOD and its impact and relationship with El Niño phases *(Meyers et al. 2007).*

5.3 - El-Nino Southern Oscillation

The El Niño Southern Oscillation (ENSO) is the oscillation between El Niño (drier) and La Niña (wetter) conditions in Australia. The oscillation is caused by changes in the strengths of the trade winds and hence temperatures in the western, versus the eastern and central Pacific Ocean.

The change in the warming pattern causes rain and cloud to move from one side of the Pacific to the other. In the La Niña phase the western Pacific is warmer, bringing the clouds and rainfall to eastern Australia. In El Niño the rain and cloud move away from Australia *(BoM 2008; Holper 2013b).* ENSO is measured as the pressure difference between Tahiti and Darwin. Negative values over a period (below -8) often indicate an oscillation to El Niño *(BoM nd).*

BoM has compared rainfall across Australia for La Niña and El Niño oscillations to get a better understanding of how these episodes impact on rainfall anomalies. From this data it appears some areas of the South Coast region have a decline in winter-spring rainfall during El Niño events, while some patchy eastern areas of the South Coast appear to receive a little more summer rainfall.

The interpretation may be complicated by interrelationships between ENSO and the IOD *(Meyers et al. 2007)*. A central Pacific sea surface temperature pattern (El Niño-Modoki) that appears to influence winter rainfall in Australia was described in 2007 *(Ashok et al. 2007)*.

5.4 - Sub-tropical Ridge

The sub-tropical ridge runs across a belt of high-pressure systems. It moves south in summer and is associated with dry and stable conditions because of the descending air. In autumn the sub-tropical ridge moves northwards *(BoM, nd)*.

5.5 - South West Australian Circulation

In addition to the large-scale atmospheric circulations there appears to be an independent regional atmospheric circulation over the south-west. Feng et al. (2010) found evidence the Southwest Australian Circulation (SWAC) becomes stronger or weaker just as the monsoon does and this appears to govern winter rainfall in the south-west. The SWAC has become weaker in recent years and may explain the early winter drying trend but the reason is unclear *(IOCI 2012, p56)*.

These climate influences on the south-west and their interactions with one another are not completely understood and there is need for more research. Nevertheless, it is clear the main climate influences are driving a trend to drying and warming. Climate projections based on scenarios of increased greenhouse gas emissions indicate that this trend is likely to continue.

6 - Enhanced Greenhouse Effect, Emission Scenarios & Global Climate Models

The greenhouse effect describes the process by which certain gases trap the heat in the earth's atmosphere. This natural process enables the earth to be warm enough for us to live on it.

Physical principles make it clear that increasing greenhouse gases will increase the temperature of the planet *(Australian Academy of Science, 2010)*. The enhanced greenhouse effect is the effect of adding extra greenhouse gases from human activities such as burning of forests, fossil fuel combustion (coal, oil and natural gas) land clearing and agriculture.

Greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide, ozone and chemicals such as chlorofluorocarbons (CFCs). Global atmospheric concentrations of major greenhouse gases have increased as a result of human activities since industrialization began in 1750 and the rate of increase is speeding up *(CSIRO, BoM 2007; CSIRO, BoM 2014a; IPCC 2014)*.

Human activity is rapidly changing the earth's carbon cycle. Between 1990 and 2010, fossil fuel carbon dioxide emissions increased by 49 per cent, even with a 1.3 per cent decline in 2009, due to the global financial crisis *(Peters et al. 2012; Holper 2013a)*.

Rapid warming of the planet is causing major changes in the dynamics of the earth's climate system. Solar radiation and volcanic activity are the two main natural causes of climate forcing *(IPCC, 2014)* but the evidence is extremely strong that the current rate of global warming is not related to either of those causes. Most climate scientists accept the current rapid global warming is due to greenhouse gas emissions *(Australian Academy of Science, 2010)*.

Evidence for global warming comes from data on increased air and sea temperatures, melting of snow and ice and rises in sea level *(CSIRO, BoM 2007; IPCC 2014)*.

Even if greenhouse gases were stabilised at some time in the future, climate change would continue for a long time and the climate may not return to its original conditions *(Australian Academy of Science 2010)*.

Australian scientists have been measuring greenhouse gases at Cape Grim in Tasmania for 50 years - Cape Grim is considered to have the cleanest air in the world. The level of CO_2 has increased linearly from 328 to nearly 400 ppm *(CSIRO, 2014)*. Scientists also have measurements of ancient air locked in ice from Antarctica. This shows the air and oceans contain more CO_2 that at any time in the past 800,000 years *(CSIRO, BoM, 2014a, p14)*.

Warming of the atmosphere and oceans caused complex reactions within the global climate system and this is why there is some level of uncertainty and the possibility of sudden climate shocks. Scientists use all the information they have on the factors influencing global climate to try and determine the likely effects of increased greenhouse gases on these factors.

"Evidence that the Earth's climate continues to warm is unequivocal. Multiple lines of evidence indicate that it is extremely likely that the dominant cause of recent warming is human- induced greenhouse gas emissions and not natural climate variability," (CSIRO, BoM 2014a, p10).

For example if the oceans warm, it will impact on ocean currents and atmospheric circulations and change the position of some of the main climate drivers for the South Coast.

Although there are still many gaps in knowledge about what influences climate in WA, BoM and CSIRO can put their current knowledge into their models and evaluate them against past climate to increase confidence in the modelling.

6.1 - Global Climate Models (General Circulation Models)

"Essentially, all models are wrong, but some are useful," is a very famous quote from statistician G.E.P Box in his 1987 book with Norman Draper, *Empirical Model-Building and Response Surfaces.* It means that mathematical models cannot perfectly represent reality but they can provide information that helps reduce some of the uncertainty.

Climate models are mathematical representations of global climate systems based on the laws of physics *(CSIRO 2007).* Climate model projections are tools aimed at reducing the uncertainty as to how the climate will respond to increased atmospheric greenhouse gas concentrations (CSIRO 2007).

The term "GCM" is used by climate scientists to refer to General Circulation Models but it also increasingly being used interchangeably with Global Climate Models.

General Circulation Models represent physical processes in the atmosphere, ocean, cryosphere and land surface *(IPCC 2014).* Data entered into the models are large-scale distributions of atmospheric temperature, precipitation, radiation, wind, sea temperatures, ocean currents and sea ice cover (IPCC 2014). The models are becoming increasingly complex but also beginning to show more consistent projections.

With increasing computing power there is increasing confidence in the models but it should be remembered that the models will only simulate the interactions in the climate systems well, if there is a good understanding of the processes that govern the climate system *(CSIRO, BoM, 2007, p39).* Models are evaluated by comparing their predictions to current and past climate and these evaluations are providing increasing agreement and confidence. Projections on temperature are less uncertain than those of rainfall *(CSIRO, BoM 2014).*

Confidence in projections is higher for some models than others *(CSIRO, BoM 2014).* Some of the global climate models do show the changes that have occurred in the broader region of the south-west of WA, in terms of atmospheric instability, storm track modes and rainfall.

So, although the projections are uncertain, the models simulate the patterns of high and low pressure systems in the westerly wind belts quite well.

Therefore there is less uncertainty about the projections of a drying climate in the SW of WA (*IOCI 2012, p31)* than other climate projections and 90 per cent of the global models in CMIP3 agreed the south-west of WA will become dryer *(IOCI 2012).*

Nevertheless, projections from global climate models need to be regarded with caution, particularly when dealing with climate at the sub-regional scale. It is very important to recognise their limitations.

Confidence in climate model projections decreases at finer scales. This is because at finer spatial scales the magnitude of natural variability in climate increases and local influences on climate become more significant *(CSIRO 2007 p41).*

Although the models are not currently specific to particular parts of the South Coast, the evidence from the SW projections is quite strong in showing that much of the South Coast region needs to adapt to a warmer and dryer climate, or at least to more frequent hot dry seasons. The CSIRO and BoM are producing more fine-scaled projections.

Some of the terms CSIRO and BoM scientists use in the projection information they provide to NRM groups are outlined in the next section.

6.2 - Representative Concentration Pathways

Climate projections have to use an estimate of greenhouse gases in the atmosphere at a given time to determine the impact on future climate. The projections depend on the amount of greenhouse gas emissions and therefore on human activities in the future *(Australian Government Department of Environment nd).*

This is very hard to calculate and climate modellers need to have a consistent set of scenarios. In the third and fourth IPCC reports, they used Special Report on Emissions Scenarios (SRES) which were four narrative storylines labelled A1, A2, B1 and B2.

Each storyline represented different demographic, social, economic, technological, and environmental developments. To ensure consistency for modelling and projections, in its fifth report, the IPCC decided to use four representative scenarios.These scenarios give an estimate of the extra heat energy (radiactive forcing) from emission of greenhouse gases to 2100.

They include a pathway of greenhouse gas concentrations, over time to 2100 *(Australian Government, Department of Environment, nd; Jubb et al. 2013).*

Models of the carbon cycle are used to convert emissions into atmospheric concentrations of CO2 in parts per million *(CSIRO 2007, p37).* The Representative Concentration Pathways (RCPs) are therefore representative of possible future emissions and concentrations of CO2. They are based on scenarios published in the literature *(van Vuuren et al. 2011).*

They include one early mitigation scenario leading to a very low forcing level with a peak and decline (RCP2.6), a stabilisation before 2100 (RCP4.5) and stabilisation after 2100 (RCP6) and one very high emission scenario where there is little action to reduce greenhouse gas pollution and emissions are still rising (RCP8.5) *(Table 1).* The advantage of using RCPs is that they allow consistency in climate modelling *(Jubb et al. 2013).*

Scenario	RCP	CO2 in ppm
Early Mitigation, with peak and decline before 2100	2.6	490
Stabilisation before 2100	4.5	650
Stabilisation after 2100	6	850
Emissions still rising after 2100	8.5	>1370

Table 2: Representative concentration pathways with different scenarios.

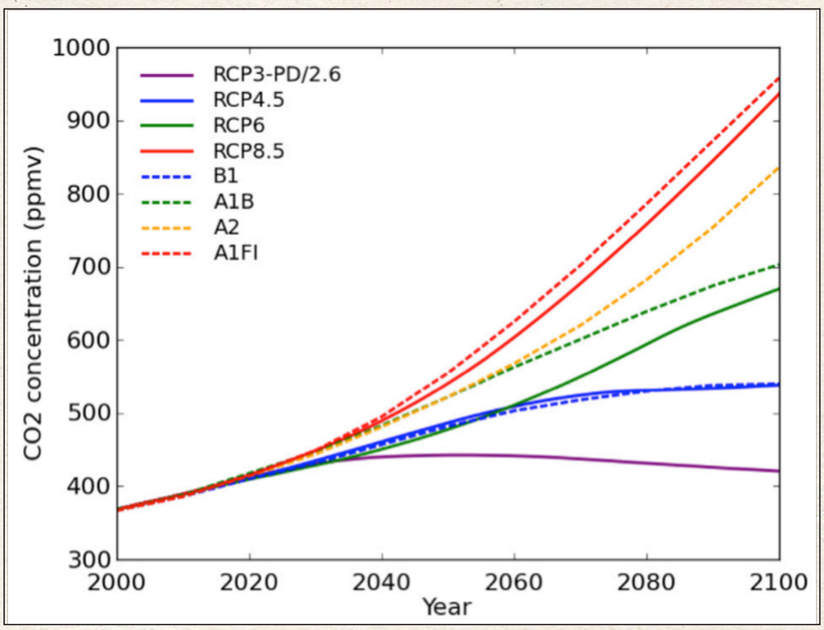


Figure 1: Comparison of carbon dioxide concentrations for the 21st century from the RCPs and SRES scenarios.

RCP8.5 is closest to A1FI, RCP6 is closest to A1B, RCP4.5 is similar to B1 and RCP2.6 is lower than any of the standard SRES scenarios.

The SRES scenarios were used in the third IPCC report. **Source:** *Jubb et al. 2013 (data from Meinshausen et al 2011 and IPCC TAR WG1 Appendix 2).*

Each RCP is a measure of approximate extra radiactive forcing in 2100 compared to 1750. Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere. For an RCP of 8.5, the radiactive forcing in 2100 would be 8.5 Watts/m2.

That represents the extra warming from greenhouse gas pollution if emissions were still rising at the end of the century. The amount of warming can not be predicted precisely because other factors could influence the climate systems, but it gives some indication of the consequences of continuing CO_2 emissions versus mitigation.

Although the different RCPs don't show large differences up to 2030 they diverge dramatically after 2100 *(IOCI 2012)*. In other words, even though the climate this century may not be very different under different levels of mitigation, the implications for climate change in the next century are much larger.

Climate modelling and particularly climate projections are coordinated through a series of major projects called Coupled Intercomparison Projects. 'Coupled' refers to the coupling of Ocean General Circulation Models and Atmosphere General Circulation Models. It is now in phase 5 to correspond with the fifth IPCC report.

6.3 - Coupled Intercomparison Project Phase 5 (CMIP5)

The Coupled Intercomparison Project (CMIP) is a project involving coordination of a range of climate model experiments and projections *(PCMDI nd; WRCP nd)*.

The objective of the CMIP is to better understand past, present and future climate changes arising from either natural climate variability, or in response to changes as a result of human activities causing increased greenhouse gas emissions. It collects the output from the global coupled atmosphere General Circulation Models (coupled GCMs) (PCMDI nd).

Amongst other objectives, CMIP5 provides climate projections out to 2035 and 2100 and beyond. CMIP5 projections include factors not included in CMIP3 but which may be important for South Coast climate. For example, CMIP 5 includes ozone hole recovery, which is likely to have an impact on the South Coast climate *(Eyring et al. 2013)*.

CSIRO and BoM are providing the projections from CMIP 5 to regional NRM groups as a tool to assist them in planning for climate change.

6.4 - Statistical Downscaling & Regional Climate Models

Regional NRM planning requires information at finer spatial scales than provided by the coarse resolution of global climate models. Statistical downscaling is the process used to transform climate information at large scale to higher resolution *(IOCI 2012, p 23)*.

Regional climate models are nested in the global climate model to increase the resolution. Outputs from the global climate model are used as inputs for the regional climate model which contain finer scale information such as landuse and topography *(IPCC 2014)*.

Downscaling does not reduce the uncertainty in the models, but can help to see how well the models are behaving in relation to actual temperature and rainfall in a given location, such as a water catchment. The projections from downscaling must be used with caution *(IOCI, 2012)*.

There has been some limited statistical downscaling for small-scale areas of the region in the past. For example, *Smith et al (2009)* used statistical downscaling of the CSIRO Global Climate Model for the Denmark catchment. They found the rainfall distribution in Denmark was different from the actual distribution with the model showing lower rainfall in autumn, winter and spring and higher rainfall in summer than the measured rainfall.

The time period used can also influence the modeling, because there appears to have been a change in climate drivers from 2000 on the South Coast *(Smith et al. 2009)*. Another problem is that different downscaling methods can produce different results *(IOCI 2012)*.

It is becoming apparent, however, that downscaling also has serious practical limitations, especially where the meteorological data needed for model calibration may be of dubious quality or patchy, the links between regional and local climate are poorly understood or resolved, and where technical capacity is not in place. Another concern is that high-resolution downscaling can be misconstrued as accurate downscaling, *(Wilby and Dessai 2010, p180)*.

7 - Observed Changes in Climate in the South Coast Region

The extent of climate change in the last decade has been variable across the South Coast region and the South Coast climate did not show the early drying trend of the west coast.

The west coast appeared to show an earlier and greater rainfall decline than the global climate models suggested, and this is probably partly because of natural variation with a wet period from 1961-1990 *(Timbal et al. 2010; IOCI 2012)*. It is difficult to separate natural variation from the impact of human activities on climate but models are helping to differentiate these effects *(IOCI 2012)*.

The South Coast region has a range of climates, varying from higher rainfall areas in the south-west of the region, to lower rainfall areas in the north-east of the region. These areas have shown different degrees of climate change in the past 40 years.

The baseline for comparison is important because there appear to be two different climate change points, from 1975 for the reduction in low-pressure systems, affecting western areas and from 2000, for the increase in high-pressure systems affecting the wider area of the South Coast *(Hope et al. 2006; Hope and Ganter 2010)*.

There is not yet enough data to determine whether the trend from 2000 is a long term one, because natural variability can mask any trends in short term data. *Table 2* shows some comparisons between Kojonup, Ravensthorpe and Salmon Gums for the period to 2000.

Rainfall	Kojonup Changes 1975-2000 v 1939-1974	Ravensthorpe Changes 1975-2000** v 1939-1974	Salmon Gums Changes 1975-2000 v 1939-1974
Mean Growing Season Rainfall (April-Oct*)	10 per cent decline	0.17 per cent decrease	2 per cent decline
Rainfall Distribution	Decrease in June rainfall	Increase in May, decrease in June, small decrease in November, increase in December.	Decrease in June rainfall, increase in November rainfall.

Table 3: Rainfall change in the past 40 years for Kojonup *(Farre et al. 2011 a)*, Salmon Gums *(Farre et al. 2011b)* and Ravensthorpe.

* April to October was used as growing season rainfall in the *Farre et al. (2011 a and b)* data for Kojonup and Salmon Gums. If May to October is used growing season rainfall increased slightly in Ravensthorpe.

** Comparison of Ravensthorpe to Kojonup and Salmon Gums to 2010 could not be made because of data missing from BoM monthly rainfall statistics for Ravensthorpe for 2003 and 2008.

In Kojonup total annual rainfall from 1975 - 2010 compared to 1939 - 1974, decreased by 8 per cent while in Salmon Gums it increased by 5 per cent. The Salmon Gums increase was due to increases in rainfall outside of the growing season. Between 2000 and 2010 there was a further decline in growing season rainfall in Kojonup of 7 per cent and in Salmon Gums of 2 per cent *(Farre et al. 2011a and b)*.

In Ravensthorpe, mean annual rainfall declined by 0.9 per cent from 1975 - 2000 compared to 1939 - 1974 and growing season rainfall by 0.17 per cent. Changes in rainfall for Ravensthorpe can be regarded as insignificant.

There is no doubt there has been major climate change in the south-west of WA and this includes much of the western part of the South Coast region. Weather patterns bringing wet conditions have declined and those bringing dry conditions have increased. There has been a decline in the frequency and intensity of high rainfall events and a reduction in the sub-tropical jetstream, a strong belt of upper level westerly winds.

This has led to a reduced likelihood of storms developing. There has been a weakening of low-pressure systems (from approximately the mid-1970s) and also a southward deflection of winter storms, *(Frederiksen and Federiksen, 2007)*.

More recently (from the mid-1990s) there has been less of a decrease in the low-pressure systems but an increase in the persistence of high-pressure systems *(Hope et al. 2006; Hope and Ganter, 2010)*. The increase in high-pressure systems has exerted its influence over a wider geographic area than the decrease in low-pressure systems *(IOCI, 2012)*, which is why the western part of the South Coast region started drying from 2000, while the west coast climate changed much earlier.

Warming in the south has also reduced the temperature gradient between the equator and the pole, which in turn, lessens storm development in WA and increases storms further south in the Southern Ocean at latitudes around 60°S *(IOCI, 2012, p27)*.

Several factors, such as natural variation, vegetation cover change *(Pitman, 2004)* and greenhouse gases could have contributed to this climate change *(IOCI,2012)*. In addition, north-west cloud bands from the Indian Ocean have increased in the past 50 years. In the past they were generally too far east to bring significant rainfall to the region, but if they move south with global warming *(IOCI 2012 p 35)* they could increase rain to the central and eastern South Coast in the future.

It is difficult to ascertain the proportion of the drying climate due to greenhouse gas emissions (greenhouse gas forcing), but modelling suggests that increasing concentrations of greenhouse gases have caused half of the winter rainfall reduction *(Cai and Cowan, 2006)*. Therefore the drying climate in the south-west of WA is likely to be the result of several factors all driving the climate in one direction. The projected increase in SAM (eg. moving further southwards) in the future, suggests a continuation of the drying trend and more frequent dry seasons in the south-west of WA *(Cai et al. 2011)*.

The models show the higher the greenhouse gas emissions, the more the high pressure systems will dominate and low pressure systems will move closer to Antarctica. Consequently westerly winds will be much weaker over the SW. This will increase the drying trend in the SW of WA.

Although the ozone hole is projected to close in the next 50 years and may have some cooling effect on the south-west, the greenhouse gas concentration is expected to override the effect *(Arblaster et al. 2011; CSIRO 2007; Arblaster et al. 2011; Eyring et al. 2013)*.

It is still possible ozone recovery may lead to some cooling in the short-term on the South Coast *(Hope pers.com.)*, but it will depend on how rapidly emissions rise. The broad trend maps for WA from the IOCI and BoM do not completely reflect the changes on the South Coast including the increases in annual rainfall (mainly summer rainfall) in the central and eastern parts of the South Coast. DAFWA maps (below) of the Southern Agricultural Region reveal a clearer picture of the changes.

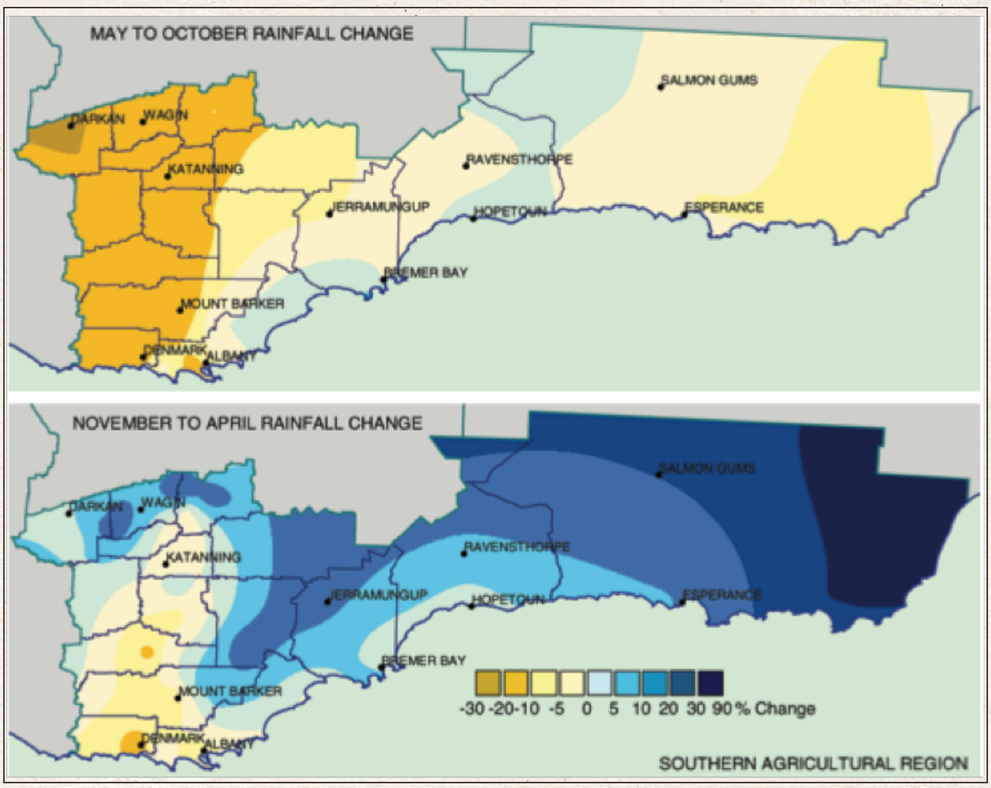


Figure 2: Changes in rainfall in the Southern Agricultural Region, Department of Agriculture and Food 1910 - 1975 versus 1976 - 2008. ***Source:*** *Carmody et al. 2010.*

8 - Climate Projections from CMIP 5

A climate futures software tool will be available by June 2014. This will provide tools and guidance on the likelihood of the different projections *(CSIRO, BoM 2014b).*

The interim climate projections for the Southern and South-Western Flatlands cluster (a broad area that includes the whole of the south-west of WA and parts of South Australia) *(BoM and CSIRO 2014b) are:*

- Temperature to increase in all seasons.
- More hot days and fewer cold days.
- Decline in winter rainfall.
- Uncertain summer rainfall.
- Extreme rainfall intensity will increase.
- Natural rainfall variability will continue and may mask any trend in average rainfall for some decades particularly in summer.

8.1 - Uncertainties in Climate Projections

Uncertainty in climate projections is a challenge for NRM planning for adaptation to changes in climate. There are a number of levels of uncertainties associated with climate projections. These include:

- Emissions scenarios and uncertainties in relation to human activities.
- Climate models eg. scientific uncertainties associated with how climate systems behave.
- Local climate, uncertainties in relation to microclimatic effects.
- Natural climate variability.
- Behaviour of complex climate systems interacting with other systems (*Pittock, 2003; CSIRO, BoM, 2007).*

The problem is that the uncertainties multiply *(Pittock 2003).* There is a cascade of uncertainty from emissions pathways, concentration of greenhouse gases, climate changes in global models, statistical downscaling to regional models, local climate effects and adaptation responses *(Wilby and Dessai 2010).* The uncertainties vary with time *(Hawkins 2014).*

For example, the uncertainty in RCPs become much more important after 2030. Uncertainties increase even further when modelling for other factors, such as distribution of particular species, pests and diseases or agricultural impacts, uses global climate models or often just a selection of global climate models.

Pittock argues this is why it is important to integrate climate change with other NRM activities to make systems as resilient as possible so NRM takes into account the combined stresses on natural systems.

Planning has to be for climate uncertainty and interactions of changes in climate with other NRM problems.

9 - Planning for Climate Uncertainty

There are challenges in planning for adaptation to climate change. *The National NRM Impact and Adaptation Project (2013)* listed the main challenges as:

- Making decisions for multiple possible futures.
- Employing flexible and adaptive planning processes.
- Explicitly identifying and preparing for likely future decisions.
- Strengthening the adaptive capacity of people and organisations.

Because of the uncertainty about future climate, the Commonwealth Government *(Australian Greenhouse Office, 2006)* advocated using risk management and adaptive management approaches as a way to deal with the uncertainty. CSIRO and BoM stress care must be taken in using the climate projections in the risk assessment. It is particularly important to determine the spatial resolution, and to consider the uncertainty.

"Risk management is defined as *a five-step process that identifies, analyses and evaluates a risk, and plans and implements a strategy to reduce the chances of the undesirable event occurring or reduce the scale of damage caused by the event," (Standards Australia & Standards New Zealand, 2009).*

The initial stage is in a workshop format. The Australian Government recommends the framework for risk management is the Australian and New Zealand Standard AS/NZS 4360 Risk Management.

Climate scientists from CSIRO and BoM stress the importance of making sure the scenarios used in risk assessment are internally consistent and under a consistent set of assumptions including choice of global climate models, time period and RCP. They stress the importance of not mixing and matching of projections *(CSIRO, 2007; CSIRO, BoM, 2014).*

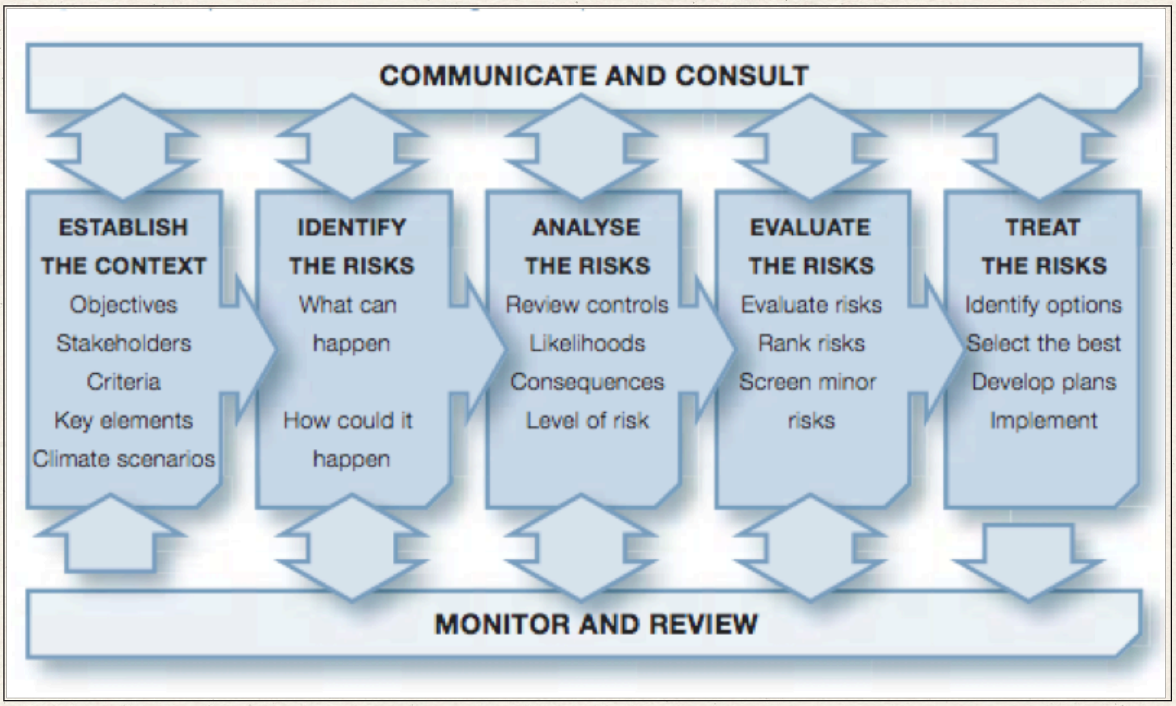


Figure 3: Steps in Risk Management. **Source:** *Climate Change Impacts & Risk Management, A Guide for Business and Government Australian Greenhouse Office 2006.*

Bardsley and Sweeney (2008) outline the approach to planning for climate change developed between the Adelaide and Mt Lofty Ranges Natural Resources Management (AMLR NRM) Board and the Government of South Australia.

Their report (p2) recommends some steps in planning for climate change:

- Awareness raising and ownership of climate change.
- Vulnerability analyses.
- Development of adaptation responses.
- Appropriate integration of adaptation responses into management and planning activities across different timeframes.
- Incorporation of climate change into risk management approaches in the short-term.
- Application of adaptive management techniques which can be adjusted over time.
- Application of decisions based on the precautionary principle that allow for increased long-term risk.
- Ongoing revision, reassessment and alteration of the approaches above.

10 - Summary

Climate change is a controversial topic and there are many different viewpoints in the South Coast region.

There are consequently different attitudes to the risk and the need for action.

Most Australian climate scientists believe the evidence for global warming is unequivocal and there will be major impacts on climate. Research through the IOCI has increased the body of knowledge about the main influences on climate in the south-west of WA.

Nevertheless, the global climate system is very complex and there is a lot of uncertainty about rainfall projections for the South Coast region.

Risk management is the best approach to use in an environment of uncertainty and planning for climate change risk should be integrated with other NRM risks at landscape scale.

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12 - Glossary

Adaptation. This is defined by the United Nations Framework Convention on Climate Change as an *"adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"*. In simpler terms, adaptation refers to any activity that reduces the negative impacts of climate change and/or enables us to take advantage of any opportunities that climate change may present *(IOCI, 2012).*

Climate. In its narrowest meaning is usually defined as the *"average weather"* over a long period of time but it has a broader meaning about variability and likelihood of events *(BoM 2008).*

Enhanced greenhouse effect. Additional warming due to the increase in greenhouse gases from human activities (BoM 2008).

Greenhouse effect. The greenhouse effect is a natural process that warms the Earth's surface. Greenhouse gases absorb heat and prevent it being radiated into space. They include water vapour, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs). The absorbed energy warms the atmosphere and the surface of the Earth. This process maintains the Earth's temperature at around 33 degrees Celsius warmer than it would otherwise be, allowing life on Earth to exist (Australian Government Department of Environment, www.climatechange.gov.au/greenhouse-effect).

Jetstream. A flat tubular current of air located in the tropopause the area in the earth's atmosphere between the troposphere and the stratosphere. These powerful winds are generated by strong pressure gradients which reflect the great temperature differences at high altitudes. *(BoM nd).*

Projection. A set of future conditions or consequences, derived on the basis of explicit assumptions. A projection may have a probability or likelihood associated with it *(Pittock, 2003; CSIRO, BOM, 2007).*

Radiative forcing. This is a measure of the energy absorbed and retained in the lower atmosphere. It is also used to describe an externally imposed change in the radiation balance *(CSIRO 2007,p 38).* Forcing agents include: greenhouse gases, aerosols, changes in solar radiation, volcanic activity, changes in albedo (reflectivity of the terrain) and changes due to land use.

water

land

coastal and marine

cultural heritage

biodiversity

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