Topic 6: Climate Variability and Climate Risk Management

Learning Objectives of Topic 6

After Studying this topic you should be able to:

- Understand the Australian seasonal variability in a global and regional context
- Describe the remote drivers of climate and how scientists measure the various states of El Niño Southern Oscillation and Indian Ocean Dipole
- Understand the strength of the connection between remote climate drivers and how rainfall varies depending on geographic location and time of year
- Outline the impact of the remote climate drivers on cereal and cotton production in New South Wales and Queensland
- Understand the differences between Global Combination Models (GCM) and Statistical Analysis on seasonal predictions and their limitations
- Formulate a seasonal risk assessment for a given location, based on analysis of a range of climate indices, seasonal forecasting models and Bureau of Meteorology commentary

6.1 The Australian Climate

Farming communities and business know that we have always had fluctuations from wet to dry. Dutch explorers who landed on the northern end of the west Australian coast in the seventeenth century described the terrain and usefulness of the land and climate as ‘harsh, extreme and uninhabitable’. Notes from early settlement by Europeans in the Sydney basin reveal people were forced to find new land for food production primarily due to drought and famine. In the 1820’s, settlers diaries recall a seven year period where the Nepean River in the Hawkesbury catchment stopped flowing completely. Climate variability has characterised our landscape and shaped how we manage risk in our businesses.

> We call day to day variations in our atmosphere ‘**weather**’. When we take long term averages of the weather, it becomes ‘**climate**’. **Climate** is what you expect, **weather** is what you get.
>
> Ref: Whitaker, (2010)

6.1.1 Climate Variability

To fully understand the Australian climate variability in a global context, a study by Geoff Love (2005) examines climate variability on a national and regional level across 50 year timescales. Scientists think of “climate variability**”** as the way climate fluctuates yearly above or below a long-term average value. This means that when there is a succession of extremes, or more extreme events over a period such as a season, it is possible to estimate whether these extremes are part of the normal expectation for the locality, or are so unlikely that they can only be explained in terms of some more radical shift in climate (WMO 2013).

The “co-efficient of variation” is a measure of relative dispersion and is used to compare variation in a series which differ in the magnitude of their averages (Simpson and Kafka 1977). To compare the variability of the areal average rainfall of different locations or countries, the coefficient of variation is often used. The coefficient of variation (often expressed as a percentage) is given by the standard deviation divided by the mean. In layman’s terms, the higher the co-efficient of variation the more variable the rainfall. The UK climate has a smaller co-

efficient of variation (8%) than Australia (17%), meaning that in the UK there is less variation from the annual rainfall mean during the study period.

From Figure 6.1it is evident that Australia's rainfall is highly variable relative to that of the countries that compete with us in the world's market for agricultural products (Love 2005).

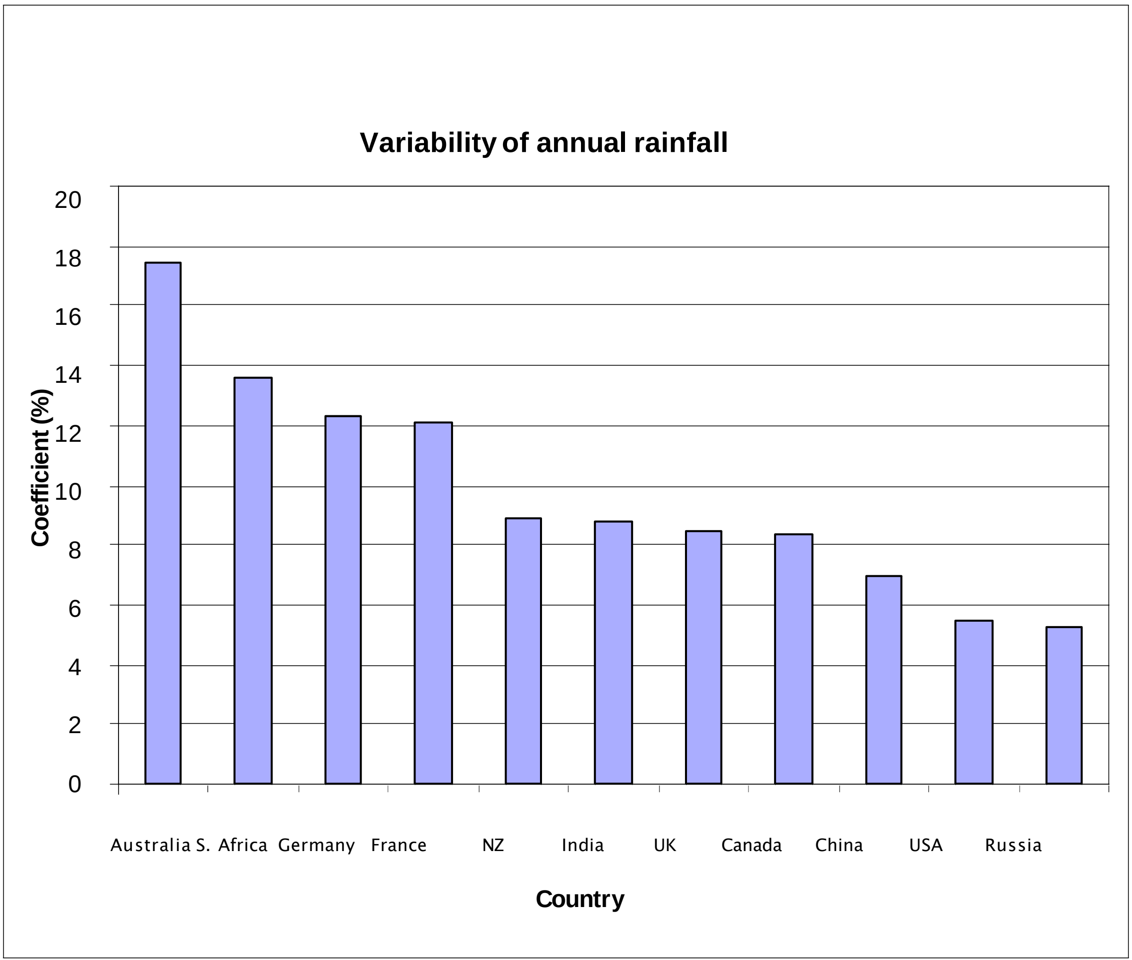

Figure 6.1 The coefficient of variation of national annual rainfall for Australia and 10 other Countries (Love 2005)

To further examine the co-efficient of variation at a regional level, the Grains Research and Development Corporation (GRDC) has defined a number of cropping regions. For the purposes of this analysis we have used rainfall data for three cropping zones (Figure 6.2):

1. **Northern cropping zone**: this zone is characterised by a tropical to sub- tropical climate with yields dependent upon the conservation of soil moisture from subtropical rainfall. There is a diverse range of cropping options, with the prospect of summer and winter crops. Cotton is mostly grown in this zone.
2. **Southern cropping zone**: this zone is characterised by a temperate climate. Cropping yields depend upon reliable spring rainfall. There is a diverse range of cropping options available although usually restricted to winter cropping unless irrigation is used.
3. **Western cropping zone**: this zone is characterised by a Mediterranean climate with cropping yields depending upon good winter rains. There is a narrow range of cropping options.

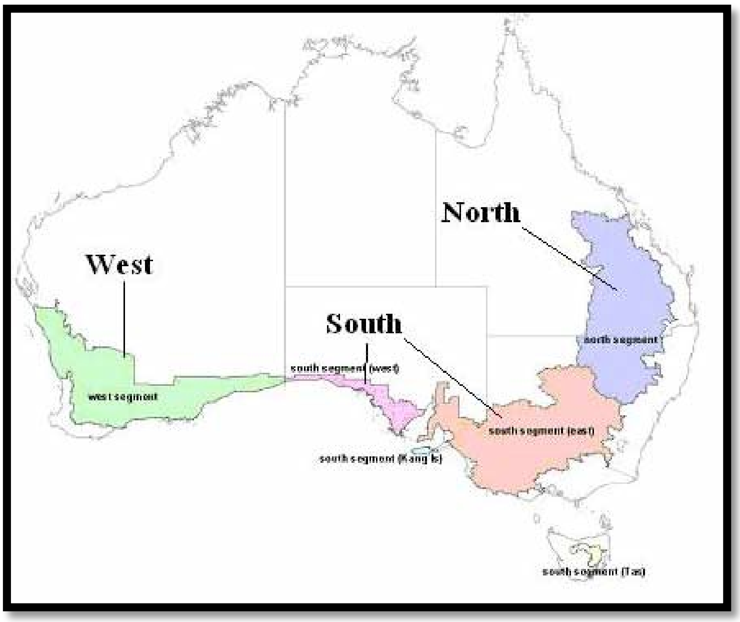

Figure 6.2. Grains Research and Development Corporation Cropping zones divided into West, South and North zones (Source: Love, 2005).

Figure 6.3 shows that the annual rainfall variability has increased in southern cropping regions over the sample period and decreased on northern cropping zones.

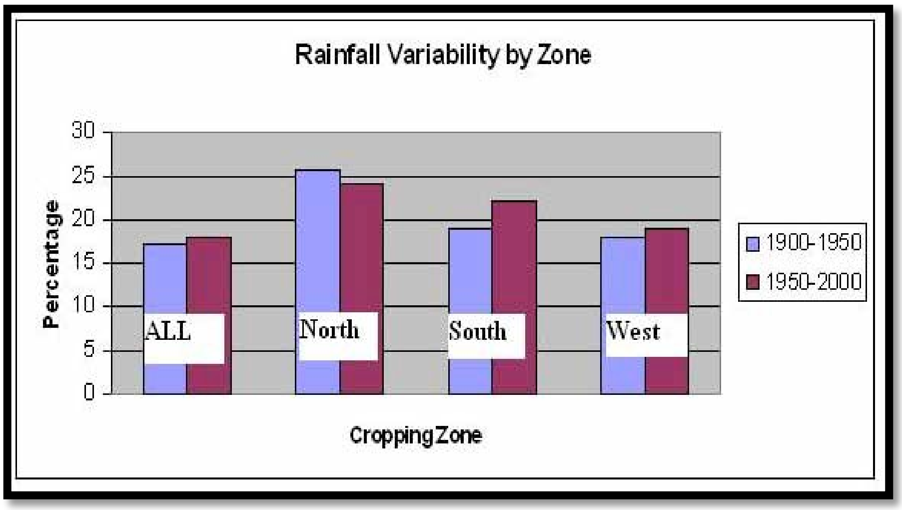

Figure 6.3: Regional rainfall variability for the three zones combined (All) and for each of the zones from figure 6.2 separately for the two periods 1900 - 1950 and 1950 – 2000 (Love 2005).

6.2 The Remote Drivers of the Eastern Australian Climate

To make it rain in eastern Australia a source of moist air is needed, which mostly comes from the north, followed by local weather conditions to promote rainfall. For example, cold fronts crossing Southern Australia often trigger rainfall when they meet warm, moist air.

This process is caused by different climate drivers that influence eastern Australia's wetter or drier years. Climate drivers vary over the months and years to influence our seasonal rainfall. For example, our driest years have been when two or more of these climate drivers have been in their 'dry phase' at the same time.

The key drivers of climate in cotton growing regions of eastern Australia include the following;

1. El Niño Southern Oscillation
   - El Niño
   - La Niña
2. Indian Ocean Dipole
   - Positive Indian Ocean Dipole
   - Negative Indian Ocean Dipole
3. Sub-Tropical Ridge
4. Southern Annular Mode
5. Madden-Julian Oscillation
6. East Coast Lows

These will now be addressed in the following sections;

6.2.1 El Niño-Southern Oscillation (ENSO)

- ENSO describes the position of warm and cool water, the strength of winds and atmospheric pressures in the Equatorial Pacific Ocean region.
- When oceans heat up, moisture evaporates into the atmosphere. Under the right conditions ENSO can deliver a lot of moisture to Australia which becomes available to fall as rain.
- ENSO is important for cotton growing regions, especially during winter and spring.
- Other weather processes, like cold fronts, help to trigger rainfall events.
- Three phases: El Niño, La Niña, and Neutral help to describe the different states of ENSO.
- Scientists monitor the ENSO phases by Sea Surface Temperature (SST) movement and changes in atmospheric pressure (Southern Oscillation Index).

6.2.1.1 El Niño

During the El Niño phase warm Pacific Ocean waters head towards South America and trade winds are weakened. This results in less atmospheric moisture available for rain in Australia. In the past, El Niño years have been correlated with an increased chance of drier winter and spring seasons.

6.2.1.2 La Niña

Historically, La Niña years deliver more moisture to Australia, because warm waters gather closer to our east coast. Combined with favourable circulation patterns this provides more moisture in the atmosphere and directs it towards eastern Australia.

In the past, La Niña years have been correlated with an increased chance of wetter springs. Figure 6.4 shows the movement in warm water in the tropical Pacific for both La Niña and El Niño conditions. The Walker Circulation directs convective moisture towards northern Australia in La Niña years and away from Australia in El Niño years.

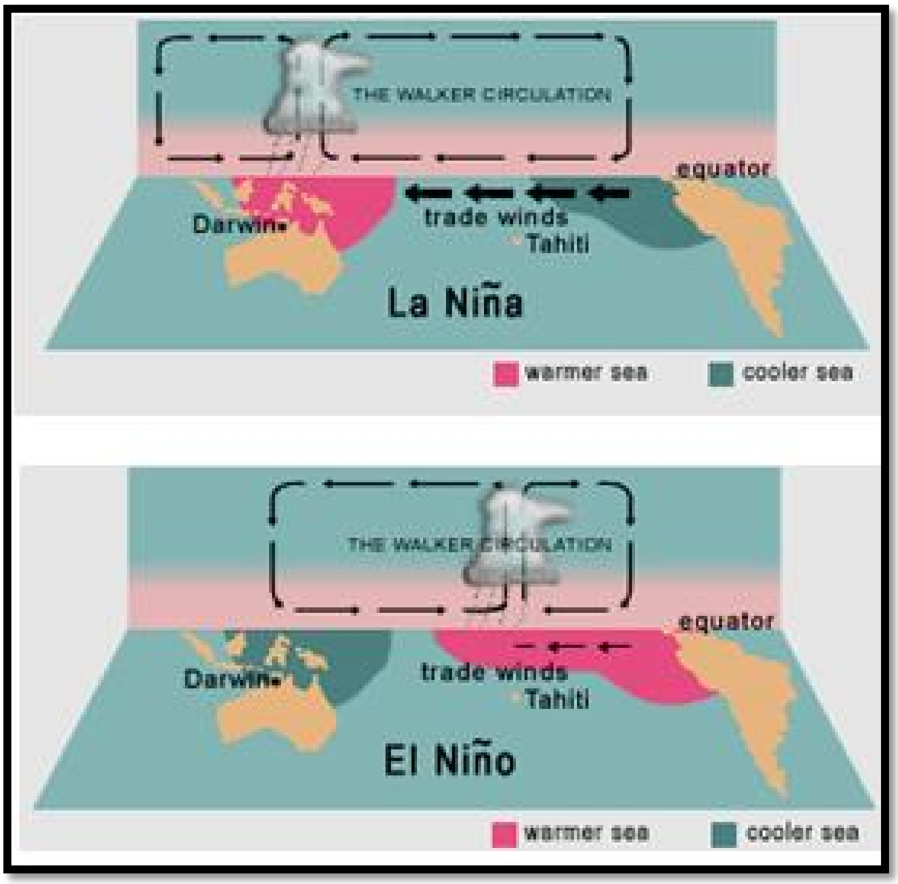

Figure 6.4 The ocean and atmospheric patterns of La Niña (top) and El Niño (bottom) (Source: BOM 2013).

The Walker Circulation:

- ***Is a major circulation cell moving air zonally between the eastern and western sides of the South Pacific Ocean***
- ***The atmospheric motion is closely related to the ocean circulation and SST's***
- ***Can deliver abundant convective moisture to Australia in the right conditions***

Source: Sturman & Tapper (2005)

6.2.1.3 El Niño-Southern Oscillation

How is ENSO measured by scientists?

Sea surface temperature measurements in the tropical pacific can be taken at various locations; "Niño 3", "Niño 3.4", "Niño 4". Taking a measurement across two or more locations will create what scientists refer to as a Sea Surface Temperature (SST) "Gradient". Once established, results of the SST gradient can provide details of general shifts in the movement of warm waters and areas of convective activity, or alternatively cool water and more stable air masses.

Figure 6.6 shows the various "Niño" regions of the tropical Pacific. A combined indice of Niño 3 and Niño 4 is known as "Niño3.4" which is often used by scientists monitoring the Australian region.

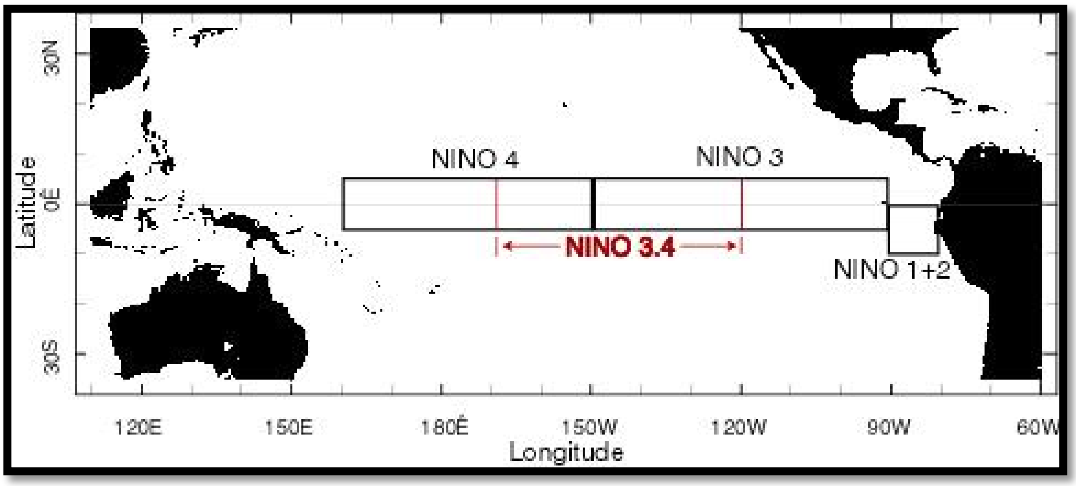

Figure 6.6 Regions of the Pacific Ocean where Sea Surface Temperature anomalies are measured; Niño 1,2,3,4. The most commonly reported indice in the Australian Climate is a combined indice known as Nino 3.4 (Source BOM, 2013)

What are ENSO threshold values?

There are normally 3 categories when the climate scientists report on the state of the tropical Pacific;

1. "Neutral" range; Warm Sea surface temperatures not favouring East or West Pacific region and remain within a threshold range of -0.5ºC and +0.5ºC.
2. "El Niño" range; Sea surface Temperatures in the central Pacific Ocean exceed levels above +0.5ºC.
3. "La Niña" range; Sea Surface Temperatures in the central Pacific Ocean exceed levels below -0.5ºC anomaly.

El Niño or La Niña conditions occur when the monthly Niño 3.4 SST departures meet or exceed +/-0.5ºC along with consistent atmospheric features for a period of 3 consecutive months (US Climate Prediction Centre, National Oceanic and Atmospheric Administration, 2013).

Figure 6.7 illustrates the variation in observed values of the Niño 3.4 SST anomaly from 1965 through to 2005. Areas marked in blue exceed La Niña SST thresholds and areas shaded red exceeds El Niño SST thresholds. This key ocean indice is reported on a regular basis by most international climate agencies. Updated values can be obtained on the Australian Bureau of Meteorology website: www.bom.gov.au

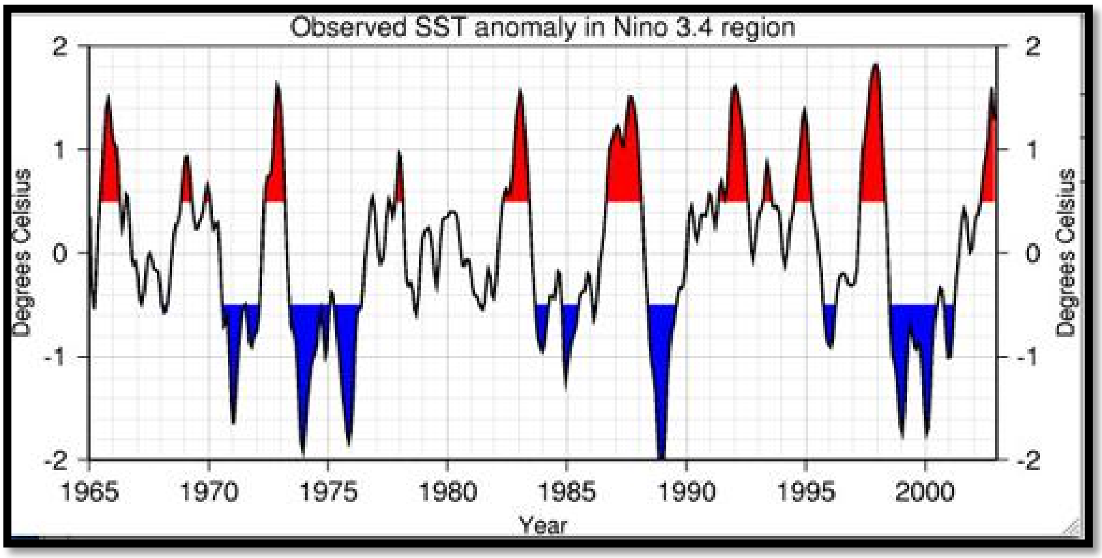

Figure 6.7 A time series analysis of observed SST anomalies of Niño 3.4 illustrating SST threshold values of La Niña (blue) and El Niño (red) (Source: Earth Systems, 2013)

6.2.1 Indian Ocean Dipole (IOD)

As with ENSO phenomena, the currents in the Indian Ocean also oscillate between warm waters in the west in some years, to neutral and warmer waters in the east in others. IOD changes between positive, neutral and negative phases.

- When warmer surface waters are closer to Australia (IOD negative), more moisture becomes available for rainfall.
- This phenomena occurs from May to November each year.
- This moisture can travel towards eastern Australia through stronger winds and large north-west cloud bands.
- When moisture arrives in eastern Australia, and connects with cold fronts, higher rainfall can occur.
- Positive and neutral IOD events have been linked with drought in Australia.

(Source: BOM, 2013).

6.2.1.2 Positive Indian Ocean Dipole (IOD+)

This occurs when the Indian Ocean is warmer in the west (near the coast of Kenya) than it is in the east (near Sumatra). This reduces tropical moisture availability for eastern Australia, and can make for a drier winter and spring season (BOM, 2013).

6.2.1.3 Negative Indian Ocean Dipole (IOD-)

When the Indian Ocean is warmer in the east than it is in the west we have an IOD negative event. This means that more moisture is available closer to Australia, and can be delivered to Eastern Australia through northwest cloud bands. Typically *IOD negative* events have been associated with wetter seasons in Southern Queensland and New South Wales (BOM, 2013).

Figure 6.8 shows the various modes of the Indian Ocean Dipole with a positive mode (left) and a negative mode (right). The red colouring represents a warmer sea surface temperatures, a blue represents cooler sea surface temperatures.

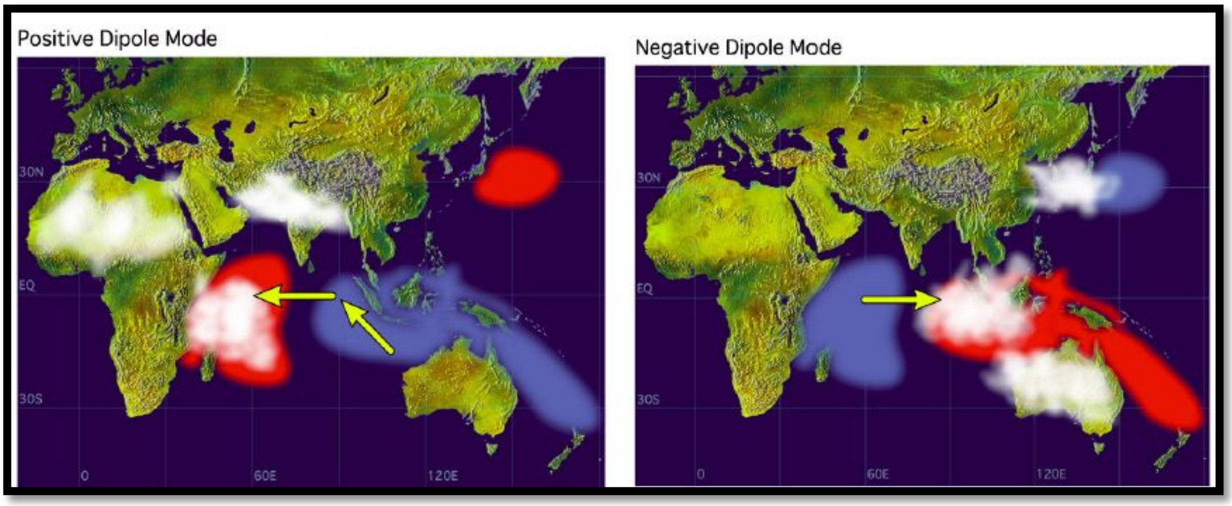

Figure 6.8 Various modes of the Indian Ocean Dipole; Left, a positive IOD and right, a negative IOD. (Source: Jamstec, 2013)

How is the Indian Ocean Dipole measured by scientists?

The IOD is commonly measured by an index that is the difference between SST anomalies in the western (50°E to 70°E and 10°S to 10°N) and eastern (90°E to 110°E and 10°S to 0°S) equatorial Indian Ocean. The index is called the Dipole Mode Index (DMI).

Figure 6.9 shows the east and west poles of the IOD for November 1997; a positive IOD year where moisture availability was reduced for both the winter and spring seasons (Source: BOM, 2013).

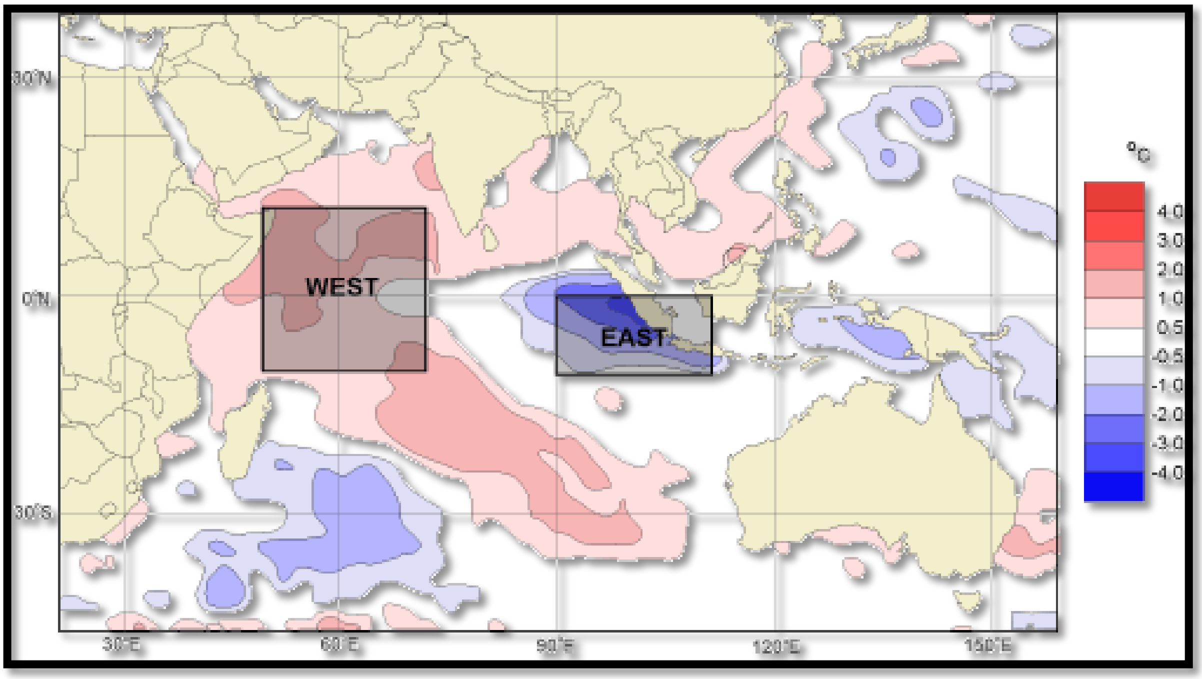

Figure 6.9 Locations in the eastern and western Indian Ocean used to measure the Dipole Mode Index (DMI). Shaded areas display the Indian Ocean Sea Surface Temperature anomaly (Source: BOM, 2013)

When observations exceed +/- 0.4ºC, scientists will define the mode as positive IOD or negative IOD respectively. Values inside these anomalies are considered to be within the neutral range of the Indian Ocean Dipole. Figure 6.10 shows observed values of the Dipole Mode Index for years 2010 and 2011. Cotton growing regions in Eastern Australia experienced more moisture in the IOD negative event in 2010 spring than the IOD positive event in spring of 2011.

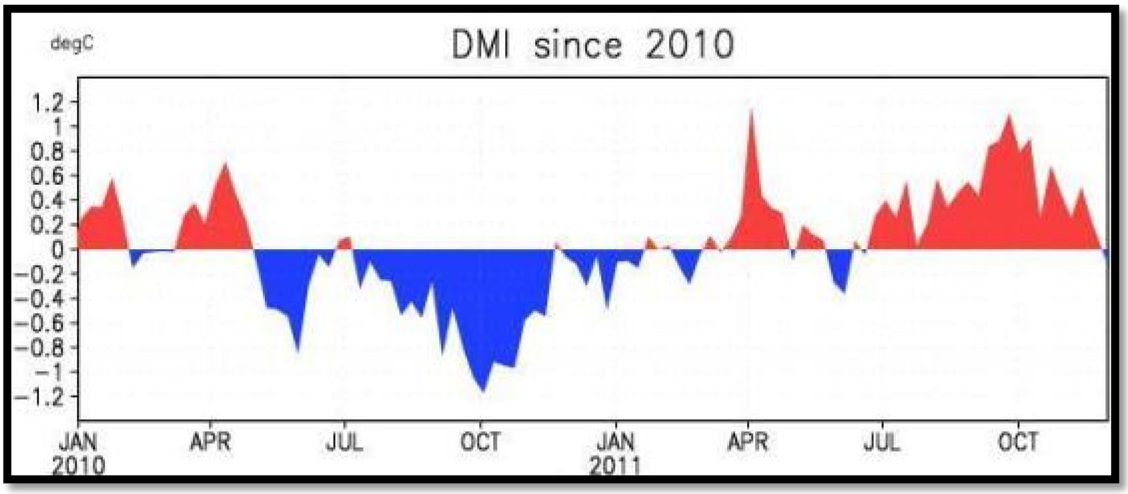

Figure 6.10 Observations of the Dipole Mode Index illustrates the negative IOD for the year 2010 when Eastern Australia received widespread spring rainfall. (Source: NEA, 2013))

6.2.2 Sub Tropical Ridge (STR)

The sub-tropical ridge moves north and south seasonally over Australia. This can affect the passage of cold fronts across southern Australia. Fronts are a good source of moisture and potential rainfall. Typically in winter the STR moves north, allowing fronts to pass over southern Australia. In summer, the STR typically moves south, blocking the passage of fronts. This is part of the reason why Southern/Central NSW experiences rain bearing cold fronts during winter.

The strength (or intensity) of the high pressure systems also affect rainfall. Higher pressure means less rainfall. Farmers know that the seasons with stronger or more frequent blocking high pressure systems over southeast Australia don't tend to produce the regular rainfall we would like.

Figure 6.11 shows the typical winter and summer positions of the Sub-tropical ridge.

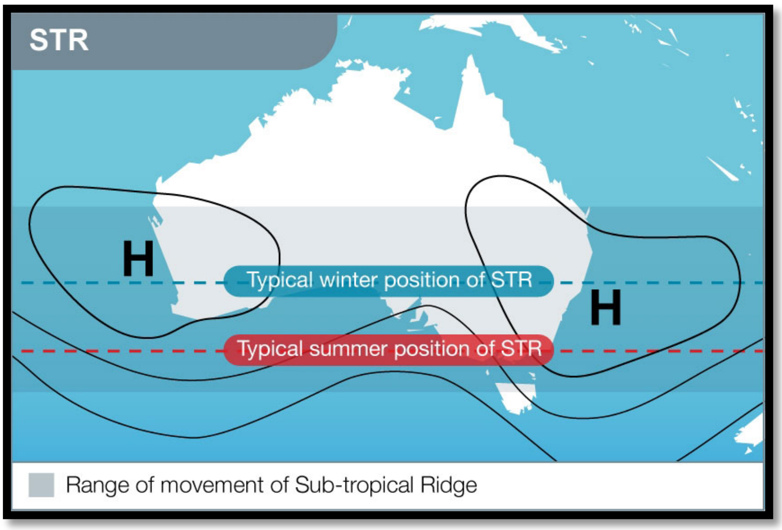

Figure 6.11 Illustrates the position of the sub tropical ridge in winter and summer seasons (Source: BOM 2013)**.**

6.2.3 Southern Annular Mode (SAM)

The changing position of the SAM influences the strength and position of frontal activity. Frontal activity is important for bringing moisture from the Southern Ocean for rainfall. Fronts also trigger rainfall events when combined with other climate processes (ENSO & IOD). New South Wales farmers know that seasons with regular or stronger frontal activity tend to provide more rainfall. Remarkably, the SAM has influence across both northern and southern cotton growing regions particularly in our spring season. It has two phases which can vary fortnightly. The phases describe the northward and southward position of the low air pressure belt.

6.2.3.1 Positive SAM

When the belt of westerly winds contracts around Antarctica less (or weaker) rain producing fronts move across southern Australia. This is called the positive SAM phase and decreases the chance of rainfall (from fronts) during winter for southern Australia. However, studies by Marshall *Et.al*, (2010) have shown a positive SAM increases moist, easterly airflow through northern NSW and Southern Queensland during the spring season and increases the chance of rainfall.

Figure 6.12 shows the frontal systems well below the Australian continent during the positive phase of the SAM.

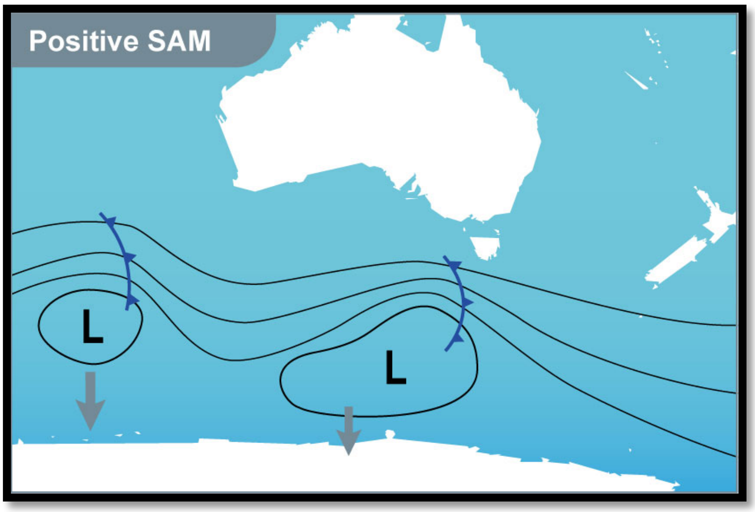

Figure 6.12 The frontal passage of low pressure systems under a positive SAM (Source: BOM, 2013).

6.2.3.2 Negative SAM

Figure 6.13 illustrates when the westerly wind belt expands, more (or stronger) fronts can come closer to southern Australia. Negative SAM increases the likelihood of above average winter and spring rainfall in Southern Australia.

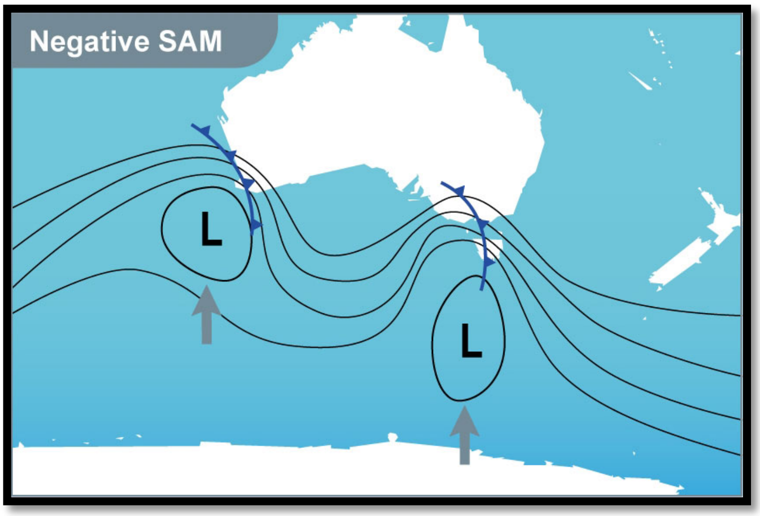

Figure 6.13 The frontal passage of low pressure systems under a negative SAM (Source: BOM, 2013).

6.2.4 Madden Julian Oscillation

Madden-Julian Oscillation (MJO) is a tropical disturbance that propagates eastward around the global tropics with a cycle in the order of 30-60 days. The MJO has wide ranging impacts on the patterns of tropical and extra tropical precipitation, atmospheric circulation, and surface temperature around the global tropics and subtropics. There is evidence that the MJO influences the ENSO cycle. It does not cause El Niño or La Niña, but can contribute to the speed of development and intensity of El Niño and La Niña episodes. MJO is one of the key transport mechanisms for moisture during the summer months in Queensland and to a lesser extent, New South Wales.

How does MJO activity vary over the course of the year?

The MJO is often quite variable, with periods of moderate-to-strong activity followed by periods of little or no activity. Because MJO impacts are well known, especially in the global tropics, periods when the MJO is active offer opportunities for enhancing climate prediction and decision assistance. Typically, the onset of the monsoon season in northern Australia (December – March).

How does the MJO change during the ENSO cycle?

Overall, the MJO tends to be most active during ENSO neutral years, and is often absent during moderate-to-strong El Niño and La Niña events. The extensive MJO activity during late 2007 and early 2008, which occurred during La Niña conditions, is unusual but not unprecedented.

Predictability of MJO

A tracking model has been designed by researchers to monitor the MJO through various phases along the tropics. For shorter lead times (1-3 weeks), the MJO indices displayed skill equal to or greater than the inter-annual Sea Surface Temperature variability (i.e. ENSO or the IOD). The value of the MJO as a predictor declined after three weeks. Hindcasts with the statistical model were most accurate when the MJO strength was large, suggesting that the influence of the MJO on predictability scaled with the strength of the MJO itself.

Source: MJO information provided by the Climate Prediction Centre, USA (2013).

6.2.5 East Coast Lows

East Coast Lows (ECL) are intense low-pressure systems which occur on average several times each year off the eastern coast of Australia, in particular southern Queensland, and eastern NSW. Although they can occur at any time of the year, they are more common during Autumn and Winter with a maximum frequency in June. Scientists are currently studying the formation of ECL's to improve predictability of these events.

ECLs can generate one or more of:

- Gale or storm force winds along the coast and adjacent waters
- Heavy widespread rainfall leading to flash and/or major river flooding

East Coast Lows generally have much shorter lifetimes than Tropical Cyclones and last only a few days. They develop over the Tasman Sea and close to the NSW and Q'ld coast and can intensify rapidly in the overnight period.

Unlike Tropical Cyclones, where the warm seas provide the energy source, East Coast Lows are driven by the temperature gradient between the Tasman Sea air and cold air in the high levels of the atmosphere over the continent (Whitaker, 2010).

Farmers in eastern cotton growing areas of the Murray Darling Basin will often benefit from these events through increased inflows into storages and/or experience above average monthly precipitation.

Figure 6.14 shows the synoptic chart and the intense low pressure cell off the east coast which can produce gale to storm-force winds, cold temperatures and very heavy rainfall over cotton catchments.

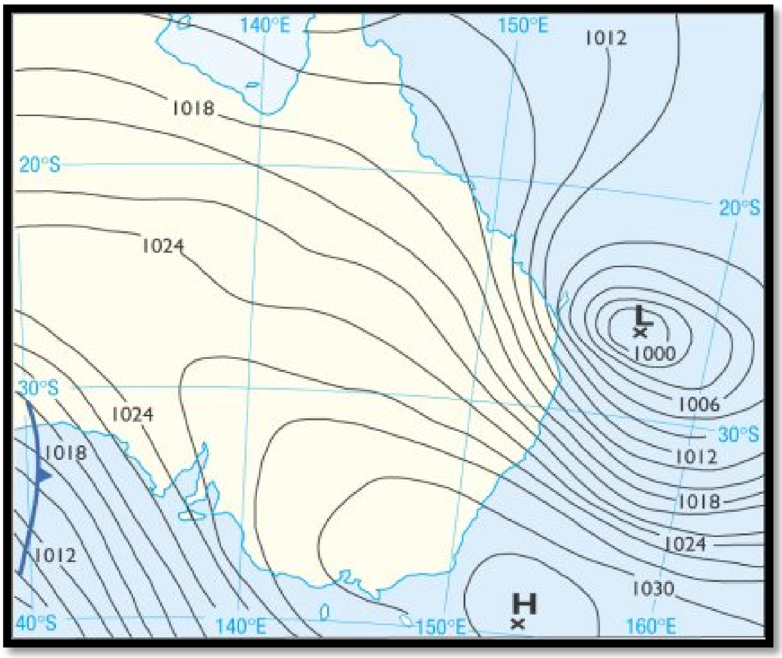

Figure 6.14 The synoptic chart illustrating the intensity of an 'East Coast Low' of the Eastern Coast of Australia (Source: BOM, 2013).

6.3 The Australian Climate

Droughts: Not a matter of "if" but "when".

A look at key climate drivers and the variability on Australian rainfall:

Put simply, a drought occurs when there is an extended period of well-below average rainfall across a particular area. If this persists over a protracted period, the consequences can be severe.

Like other mid-latitude areas around the world where belts of high pressure tend to dominate, Australia is particularly drought prone and even coastal areas that normally receive bountiful and reliable rainfall are occasionally subject to the ravages of drought.

During the 20th Century alone, there were at least six major droughts affecting different parts of Australia, several of which were truly catastrophic. The ramifications for affected regions

are dire, with acute water shortages for rural and metropolitan areas, record agricultural losses, the drying out of the Murray/Darling Basin and far reaching ecosystem damage (Whitaker, 2010).

Even today, despite numerous attempts to 'drought proof' rural economies through irrigation, drought remains the greatest threat to rural Australia. Evidence is emerging that while droughts may not be more frequent today, their severity is possibly being exacerbated by global warming. This is resulting in higher impact dry spells with an increased frequency of extreme temperatures and higher rates of evaporation.

In 2009, a number of Australian Research Institutions collaborated to investigate the key climatic influences on rainfall and temperature variability in South-eastern Australia between 1889 and 2006 (Ummenhofer *et al*, 2009).

This study (as summarised in Figure 6.15) looks at the two key drivers of climate; ENSO (La Niña/El Niño) and Indian Ocean Dipole (IOD-/IOD+) coupled with Rainfall and temperature observations across a geographical area of South Eastern Australia. The June to October season is assessed, when the majority of the annual precipitation falls in this area.

Rainfall and temperature records reveal regular drought cycles interspersed with years of above average rain through this 120 year timescale. To add to the analysis, an index showing the severity of climatic conditions has been included. The Palmer Drought Severity Index (PDSI) was developed by Wayne Palmer in the 1960s and uses temperature and rainfall information in a formula to determine dryness. The PDSI is most effective in quantifying the severity of long term drought over a matter of several months or more.

In the analysis provided in Figure 6.15, all years for the period are classified as El Niño, La Niña or neutral, similarly with Indian Ocean measurements; IOD positive, IOD negative and IOD neutral.

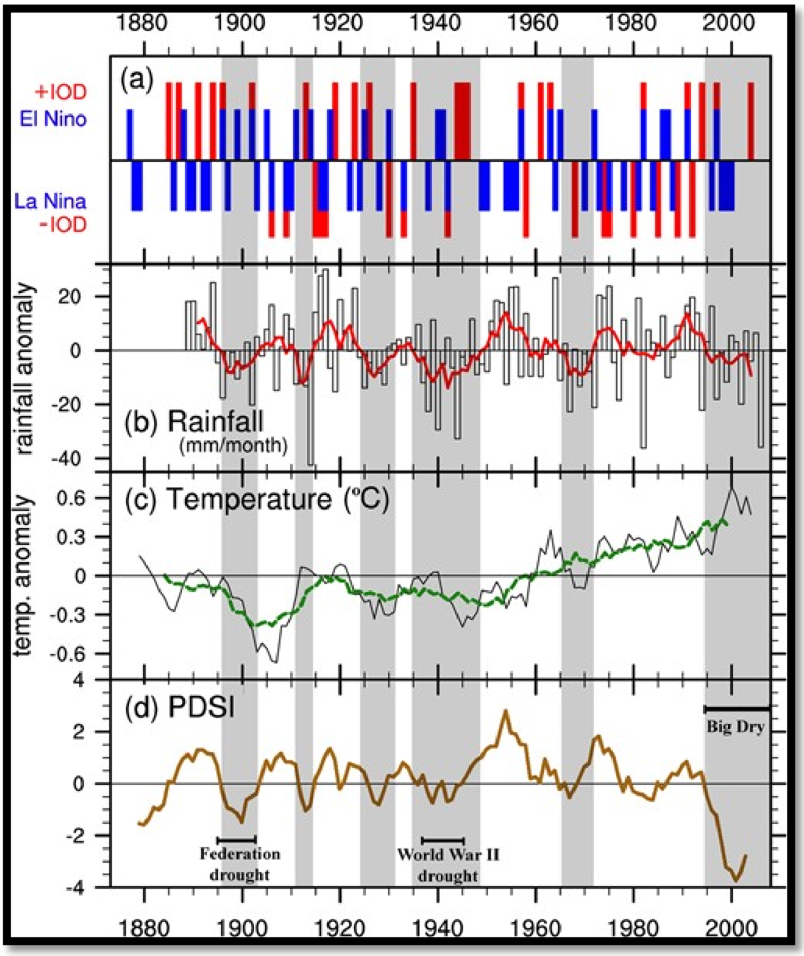

Figure 6.15 historical records of IOD and ENSO years and mean climatic conditions over Southeast Australia. (a) Years of positive/negative IOD (red) and El Niño/La Niña (blue) years. (b) Time series of anomalous precipitation (mm month1), with 5-year running mean superimposed in red,(c) 5-yr running mean of temperature (C), with a 15-year running mean superimposed in green, and (d) 5-yr running mean of Palmer Drought Severity Index (PDSI) over South-eastern Australia during June –October. The grey shaded bars highlight periods of below average precipitation when the 5-year running mean falls below one standard deviation. (d) The duration of three major droughts indicated with horizontal black bars (Source: Ummenhofer, et al 2009).

To better understand the impact of key drivers of growing season (May-November) rainfall, a summary of the five major droughts is provided in Table 6.1. Here we identify the modes of ENSO and IOD during these extended periods of extremely dry conditions in the study period 1889-2006.

Table 6.1 Summary of modes of variability of the remote climate drivers of Australian Rainfall (Ummenhofer, *et al* 2009)

	Years	Indian Ocean	ENSO	PDSI low level
Federation Drought	1895 – 1903	No IOD- events, 2 IOD+ events	3 El Niño events La Niña at the start and finish	Minus 2
1913 drought	1911 - 1913	No IOD– events 1 IOD+ event	2 El Niño events No La Niña events	Minus 1
World War 2 Drought	1937 - 1945	1 IOD - event 4 IOD + events	2 El Niño events 2 La Niña events	Minus 1
1960's drought	1965 - 1972	1 IOD- event 0 IOD+ event	2 El Niño events 1 La Niña event	Minus 0.5
The 'Big Dry'	1994 – 2006	No IOD- events 3 IOD+ events	1 El Niño event 4 La Niña events	Minus 4

- The study also shows the Indian Ocean Dipole can occur independently of ENSO events (La Niña and El Niño)
- A positive Indian Ocean Dipole occurred 20 times compared to 15 negative Indian Ocean Dipoles over the assessment period
- A La Niña condition occurred 37 times through the observation period compared with 22 El Niño events
- Higher temperatures in the 'Big Dry' exacerbate drought conditions as measured by the Palmer Drought Severity Index

6.3.2 A seasonal analysis of the remote drivers of Australian rainfall

Intraseasonal and interannual Australian rainfall variability has been linked to a variety of processes, mostly tropical in origin. In order to complete an appraisal of the key climate drivers affecting Eastern Australia, we now have a closer look an when and where they occur. From a user's perspective, it may be helpful to know which processes are most relevant.

Please note that the drivers of rainfall considered here are largely remote from the Australian continent, pertaining to large scale processes in the oceans and atmosphere.

Variability in rainfall and temperatures in Australia is also driven by local processes such as land-ocean temperature gradients and convection and may also be related to vegetation characteristics and soil moisture.

The set of climate drivers listed here are not entirely independent. In particular, El Niño Southern Oscillation (ENSO) appears to exert influence on, or mutually interact with, some of the other drivers. ENSO is more correlated with Indian Ocean Dipole, Southern Annular Mode or the Sub Tropical Ridge than any of the other drivers are with one another.

6.3.2.1 Seasonal impact of ENSO on Precipitation

ENSO is the most well established driver of Australian rainfall. There are a number of useful indices used to measure the affects of ENSO on our climate. There are location specific Pacific Ocean Sea Surface Temperature measurements (Niño 1,2,3, Nino 3.4, Nino 4) and there is a more commonly used atmospheric signature, the Southern Oscillation Index (SOI).

Initially, for the purposes of simplicity we will examine the effects of the SOI which is a measure of the anomalous pressure difference between Tahiti and Darwin and seasonal precipitation. It can be argued that this index is more closely related to the rainfall process through its relation to large scale surface pressure and by the longer records available to study its influence. A positive correlation is shown in the Figure 6.16 I.e. a positive SOI has a positive effect on rainfall anomalies.

Results also show a weak correlation with cotton growing regions of eastern Australia for the summer and autumn periods. The SOI has shown to be reasonably well correlated with growing areas in winter and spring, except for eastern areas of the Darling Downs. Inland regions of the Murray/Darling Basin of New South Wales show quite a strong correlation with the SOI during the winter and spring season.

Diagrams (a) and (b) in the summer and autumn season show little or no correlation with precipitation. When monitoring seasonal conditions, using the SOI values as a decision tool

will have little value in formulating a risk assessment for agricultural businesses during these seasons.

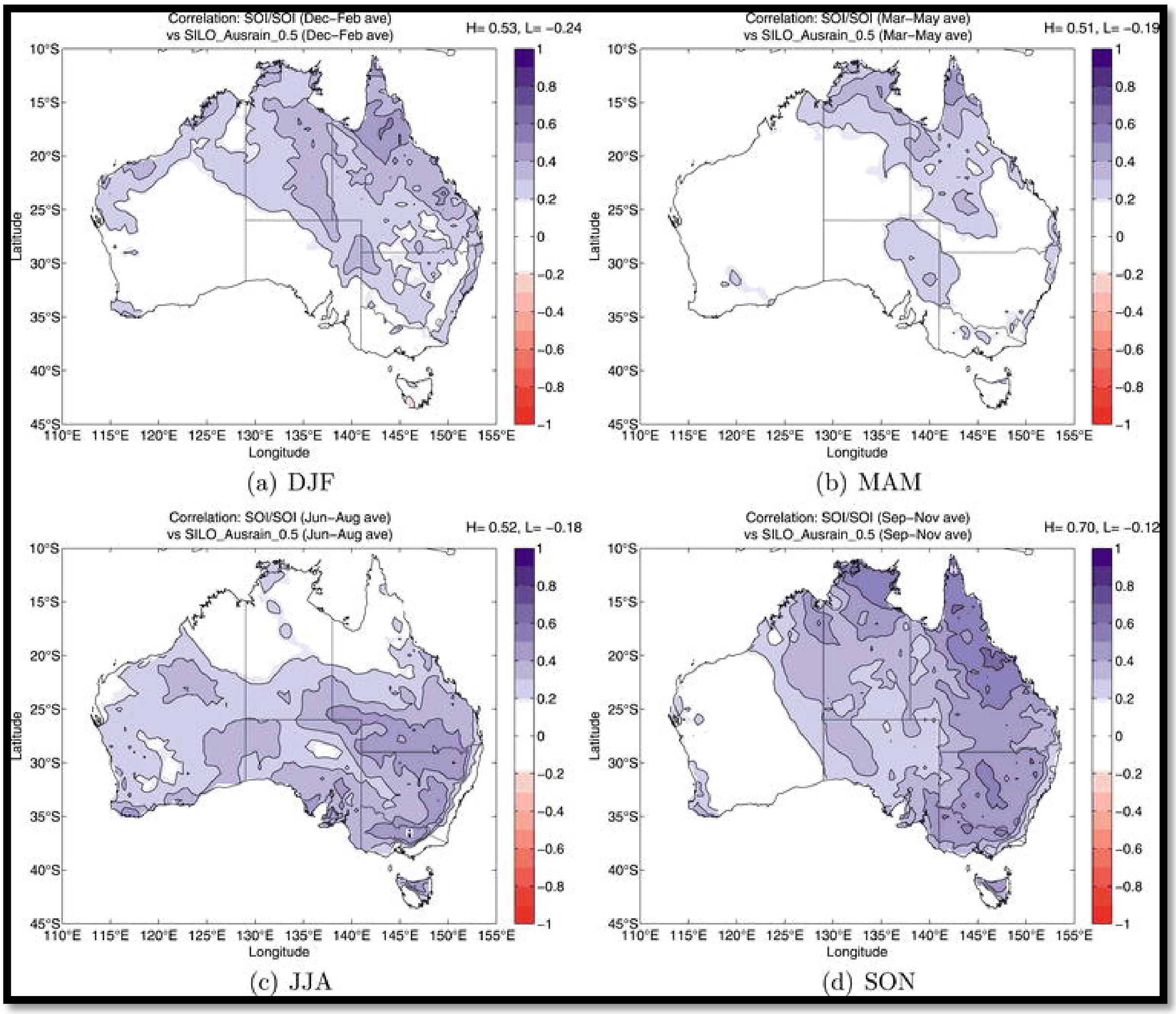

Figure 6.16 Seasonal influence of ENSO using SOI values on precipitation for summer (a), autumn (b) (Source: Risbey *et al*, 2009)

The Niño 3 indices (SST measurement at 5ºS-5ºN) also shows an interesting correlation with rainfall (illustrated by Figure 6.17) for the cotton growing regions and small areas of northern NSW through the June to October Period. I.e. A positive value of Niño 3 anomaly shows a negative impact on rainfall anomalies for the given period. Niño 3 or 3.4 indices are often reported on popular weather forecasting websites. Depending on your geographic location, Niño 3 may serve as a useful predictor when formulating seasonal risk assessment in the June-October period.

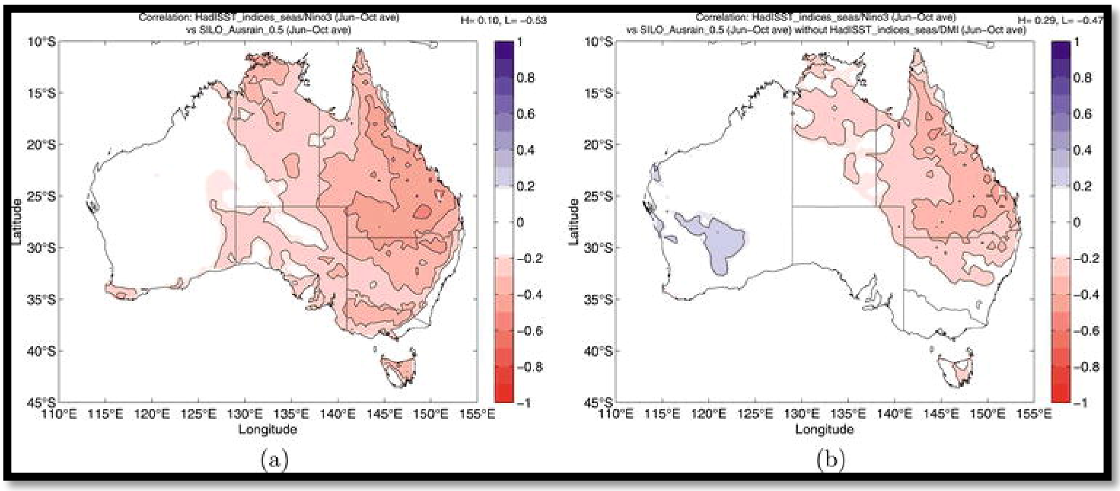

Figure 6.17 The relationship between the Nino 3 Sea Surface Temperature (a) June-October and (b) without Indian Ocean influence for the same period (Source: Risbey *et al*, 2009).

6.3.2.2 The Indian Ocean Dipole

The IOD is an irregular oscillation of sea-surface temperatures in which the western Indian Ocean becomes alternately warmer and then colder than the eastern part of the ocean.

The IOD and ENSO can occur together in such a way to reinforce each other but can also act independently. There is some debate in the research community as the extent of the teleconnection between IOD and ENSO. Figure 6.18 illustrates the correlation of the Dipole Mode Indices (DMI) and rainfall for peak IOD period of June to October. A red shaded area illustrates a negative correlation. I.e. A positive IOD results in negative precipitation anomalies.

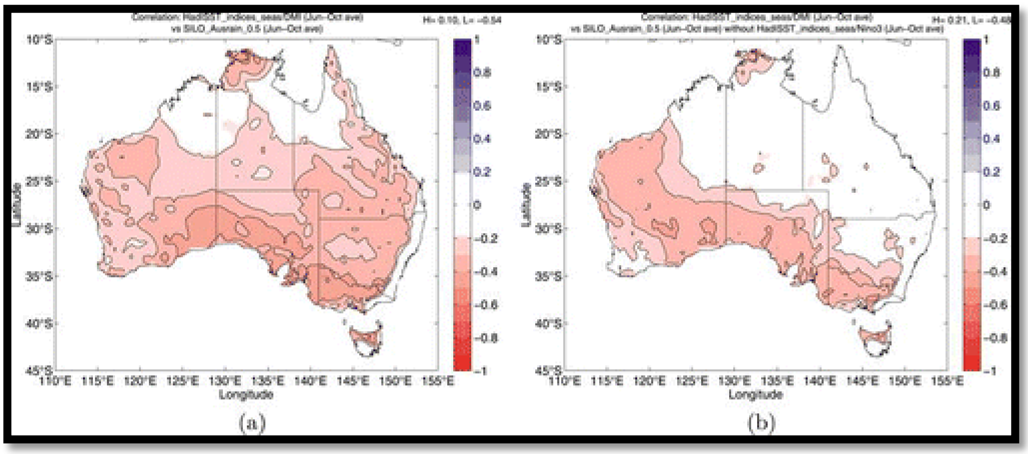

Figure 6.18 The correlation between the Indian Ocean Dipole (IOD) and precipitation with ENSO combined (a) and without ENSO influence (b) (Source: Risbey *et al*, 2009).

6.3.2.3 The Southern Annular Mode

The behaviour of the SAM under a changing climate is the subject of much discussion in the scientific community, particularly in regard to its connection with ENSO. Many attributes of the SAM are not well understood by scientists. The predictive skill of the SAM index is weak on lead times greater than 7-10 days (Marshall *et al*, 2010).

A positive SAM phase is defined when pressures are lower than normal in the polar region with enhanced westerly winds along a given latitude. The relationship between the positive mode of the SAM and spring rainfall as demonstrated in Figure 6.19, through broad areas of New South Wales and eastern areas of Queensland. The positive phase of the SAM is associated with an onshore circulation in this region and period which enhances rainfall (Marshall *et al*, 2010).

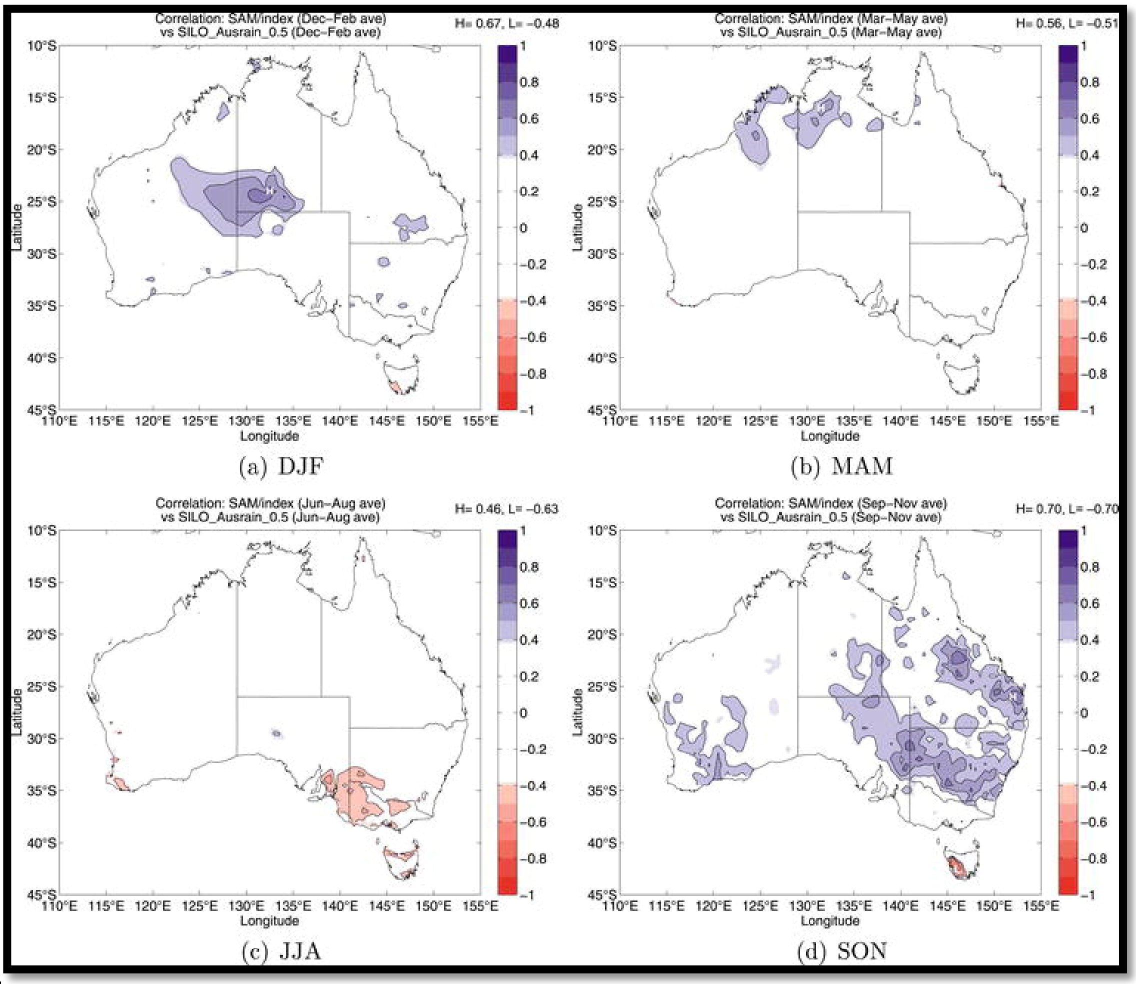

Figure 6.19 The correlation of the Southern Annular Mode with precipitation for (a) summer, (b) autumn, (c) Winter and (d) Spring (Source: Risbey *et al*, 2009).

<u>Supplementary Material for Climate Drivers:</u>

If you would like some more information on these key climate drivers here are some useful webinars and animations:

1. QDPI ENSO Webinar QDPI_webinar.htm
2. Climate "Dogs"; Short animations of key climate drivers

   - El-Niño Southern Oscillation
   - Indian Ocean Dipole
   - Sub-Tropical Ridge
   - Southern Annular Mode
   - East Coast Low
   - Madden Julian Oscillation (under construction)

   http://www.dpi.nsw.gov.au/agriculture/resources/climate-and-weather/variability/climatedogs

6.4 Remote Drivers of Climate: Impact on Cotton and Grains

Knowing the key drivers of our climate in Eastern Australia is an important first step in understanding the usefulness of forecasts during certain seasons in a given year. Monitoring the state of these indicators can serve as useful tools when forming climate and price risk assessments for farming businesses. In this section we examine the effects of remote drivers of our climate on various measurements of farm production and price in both New South Wales and Queensland. The analysis will separate the two states given the Indian Ocean Dipole has limited impact on more northern regions of eastern Australia.

6.4.1 NSW summer crop plantings and El Niño –Southern Oscillation and Indian Ocean Dipole

Figure 6.20 illustrates the trend for NSW combined Sorghum/Cotton summer crop plantings and average winter/spring values of the Southern Oscillation Index (SOI).

The analysis shows the planted area has a direct relationship with SOI values, i.e. a positive SOI leads to more suitable planting conditions due to greater moisture availability. Extreme values of the Indian Ocean Diploe Mode Index (DMI) do also interact with ENSO and SOI measurements. Strongly negative DMI values contribute to an increase of the planted area and a positive (unfavourable) DMI serves as a

counterbalance to a positive SOI. Similarly, strongly positive Indian Ocean Dipole reduces the effects of a positive SOI.

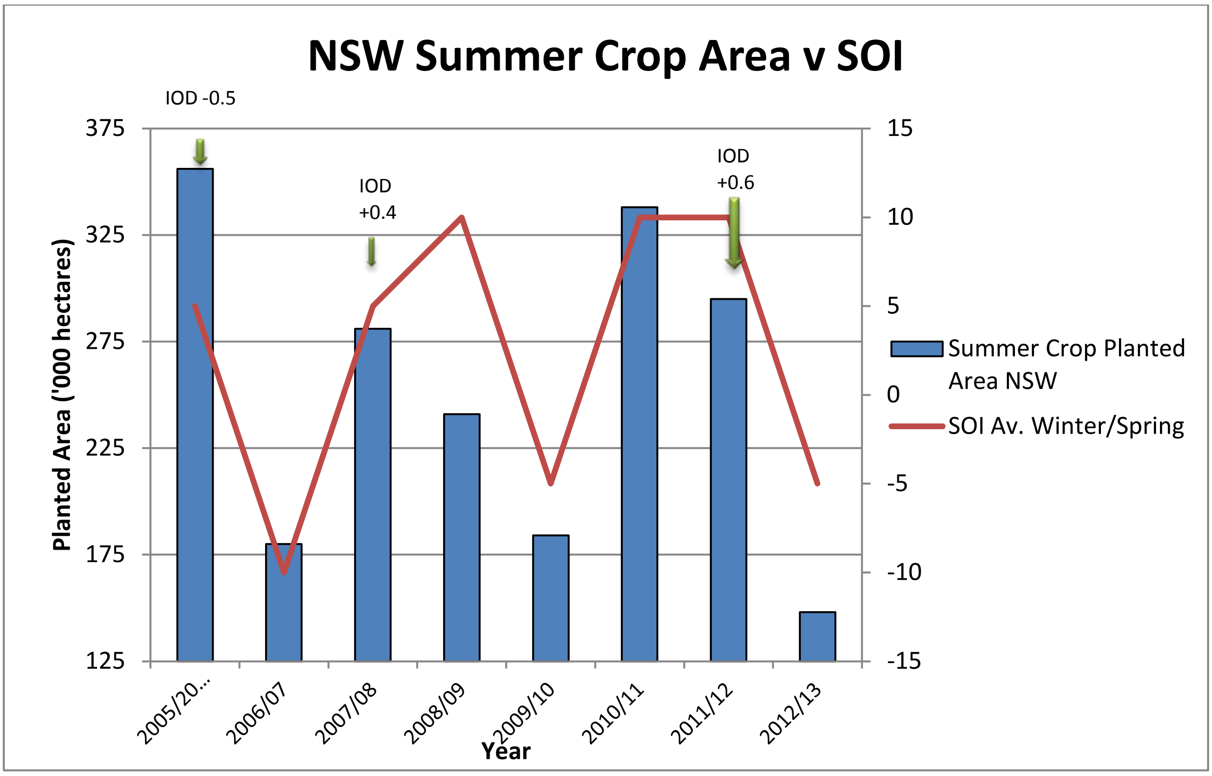

Figure 6.20 NSW Cotton/Sorghum planted area ('000 hectares source: ABARE 2013) vs Average Value Southern Oscillation Index (June – November Source: The Long Paddock 2013).

6.4.2 Queensland Summer Crop Plantings and ENSO

Figure 6.21 shows the relationship between ENSO as measured by the SOI and the planted area of 2 combined summer crops, Cotton and Sorghum. This illustrates a trend towards smaller areas of Cotton/Sorghum planted during years of below zero values of SOI. That is, when the average spring values of SOI are positive, planting conditions become more favourable for summer crop plantings. When the SOI is above zero, areas planted can often increase by 100-200% from those years when the SOI is strongly negative. It should be noted that correlations of both ENSO and IOD and precipitation are relatively weak for highly productive farming land on the eastern Darling Downs.

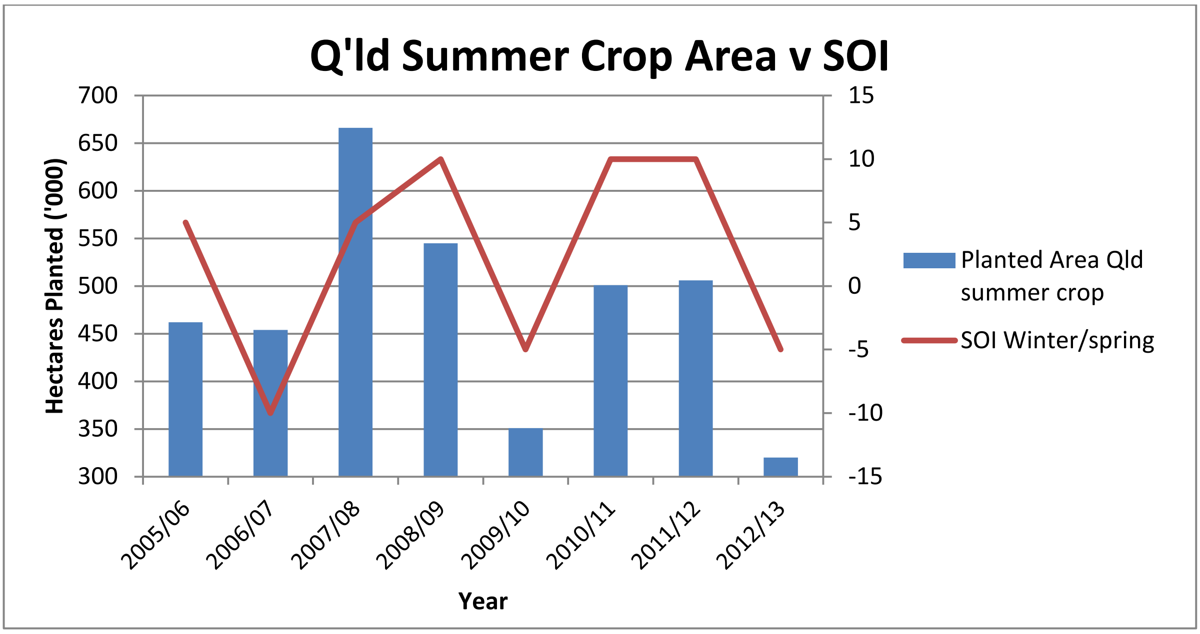

Figure 6.21 Queensland Summer Crop plantings ('000 ha Cotton/Sorghum: ABARE 2013) vs Average SOI June – November (Source: The Long Paddock 2013)

6.4.3 NSW Wheat Production and Indian Ocean Dipole

Figure 6.22 illustrates the relationship between New South Wales wheat production and the average winter/spring value of the Indian Ocean Dipole Indices. An inverse relationship exists where a negative IOD in the growing season increases wheat production in NSW.

Where IOD values are in the neutral range, the ENSO state has a large bearing on wheat yields in NSW indicated by average SOI values for winter and spring. However, whilst the IOD mode reflects the winter/spring growing conditions, the analysis does not reflect the amounts of soil moisture stored during fallow period under no tillage practices.

Importantly, the analysis shows an extremely positive or negative IOD value has a significant bearing on the quantity of the NSW wheat crop. Similarly with other analyses undertaken, the state of ENSO can act as a counterbalance in a positive or negative way with precipitation and various modes of the IOD.

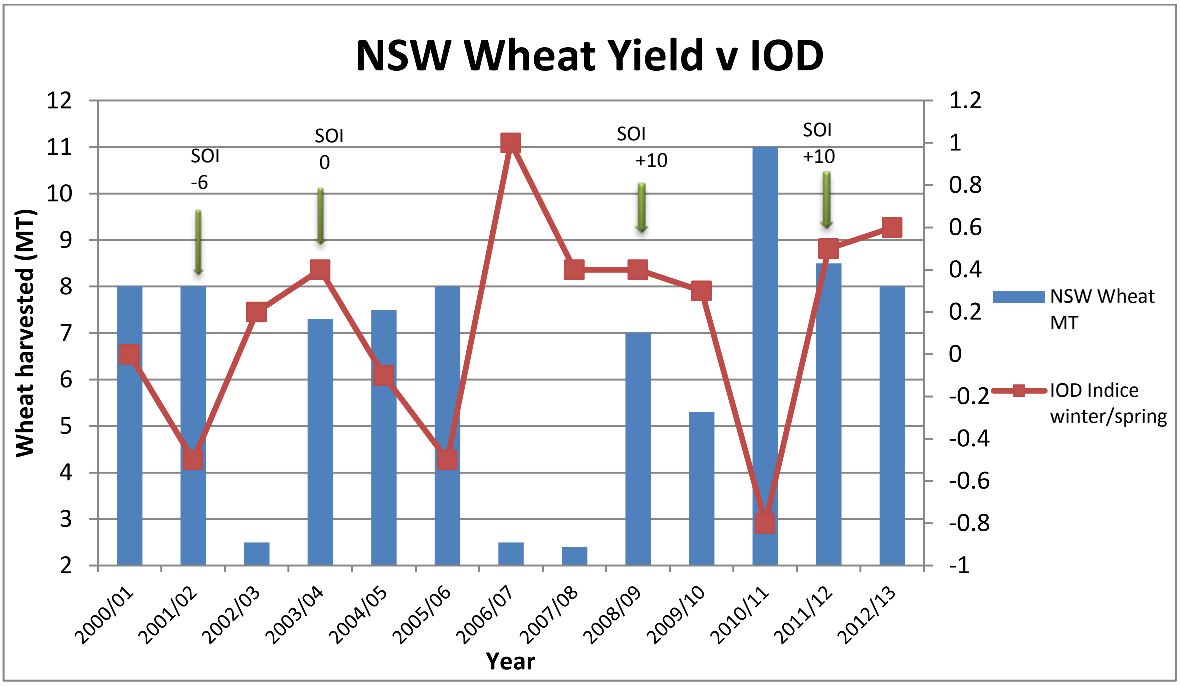

Figure 6.22 NSW Wheat Production (Million Tonnes: ABARE 2013) vs Indian Ocean Dipole Indice av. Winter/Spring (Source: BOM 2013).

6.4.4 ENSO and Cotton Seed Price

The relationship between our spring growing conditions and ENSO state can be further examined by investigating the price change of White Cotton Seed (ex gin Moree) between April ginning period spot price and December spot price.

When winter and spring conditions are unfavourable for pasture growth (negative average SOI), demand for fodder and feed grains puts upward pressure on WCS price. Conversely, when winter and spring growing conditions are more favourable (positive SOI) the demand for WCS reflects the minimal price movement across the sample period.

Figure 6.23 shows the relationship between the SOI and the change in White Cotton Seed price for the April – November period between 2006 and 2012. This study period was characterised by extremely dry conditions in 2006, 2009 and 2012 interspersed with very favourable winter spring conditions in 2007, 2010 and 2011.

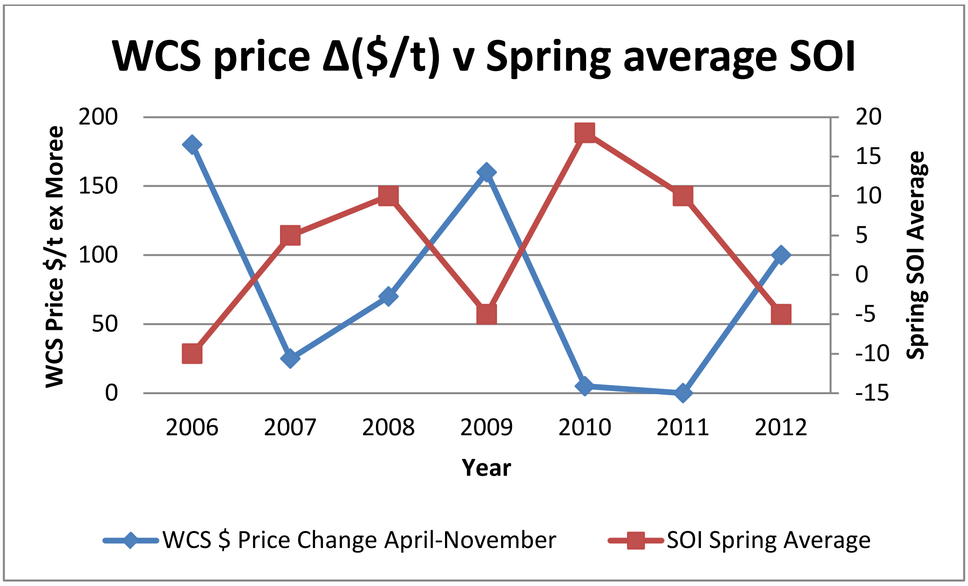

Figure 6.23 Cotton Seed Price changes April – November $/t ex. Gin Moree (Source: Woodside Commodities 2013) vs Southern Oscillation Index (average value Winter/Spring: Long Paddock 2013)

6.3 A guide to climate risk management

This section takes a look at the scientific information available for climate risk management strategies for agricultural production. Smaller shifts in shorter term "weather" observations are not the focus of climate risk management. Monitoring "climate" on longer lead times allows agricultural producers/advisors time to assess likely scenarios for rainfall and precipitation, with the view to planning and preparing resource allocation for extreme events in line with climatic conditions.

A risk management plan for your business essentially acts as an "Early Warning System" for extremes in seasonal variability associated with climate. The following subsections identify key content to be familiar with when formulating a seasonal risk management plan:

6.3.1 Subscribing to, and interpreting BOM updates and Climate Notes

By submitting contact details on the Bureau of Meteorology email register, producers and advisors can obtain fortnightly ENSO updates and weekly climate notes as they come to hand. These updates provide commentary on key indicators; movement is Sea Surface Temperatures, air pressure, trade winds, cloudiness and other atmospheric based conditions. An extract of a BOM climate note from the 27th of August, 2013 together with an interpretation in the footnote is provided in figure 6.24 below;

ENSO remains neutral as negative IOD weakens

Issued on Tuesday 27 August 2013 | Product Code IDCKGEWWOO

The El Niño-Southern Oscillation (ENSO) has remained neutral[1] since mid-2012. While most indicators have clearly remained neutral over recent months, the Southern Oscillation Index (SOI) has at times approached La Niña levels. It has now returned to neutral values[2].

Climate models surveyed by the Bureau of Meteorology suggest the tropical Pacific will remain ENSO-neutral for the rest of the year. Only one of the seven models[3] surveyed suggests a brief period of La Niña-like cooling of the tropical Pacific.

The negative Indian Ocean Dipole (IOD) has weakened[4] over recent weeks, with latest values of the index in the neutral range. If neutral IOD values persist to mid-September, the 2013 negative IOD event will be considered to have ended. Climate models are mixed, with some suggesting neutral IOD values for the months ahead, and some indicating negative IOD values may persist until at least mid-spring[5].

Negative IOD events during winter–spring are associated with above-average rainfall over southern Australia and increased humidity over parts of northern Australia. A negative IOD can also contribute to below-average mean sea level pressure (MSLP) over Darwin, which may in turn raise the value of the SOI.

Next update expected on 10 September 2013 |

Source: BOM, 2013

Figure 6.24 An extract of a BOM climate note with interpretation provided in the footnotes

[1] Referring to Sea Surface Temperature indices and SOI not within El Niño or La Niña thresholds
[2] SOI has been in a strongly positive phase to a now 'neutral' phase. Downward movement equates to higher barometric pressure over Australia. Not a positive sign for precipitation
[3] International climate SST forecasting model survey. Majority consensus of La Niña/El Niño can provide some direction for the coming season
[4] Dipole Mode Index has fallen towards a more neutral range where spring rains will be less pronounced
[5] Climate models are split on a 'neutral' or 'negative' IOD for the coming months showing no tendency towards 'wet' or 'dry' conditions for eastern Australia

6.3.2 Do-It-Yourself Seasonal Forecasting Checklist

Although a large suite of Global Combination Models, Statistical Models and Consulting services are available to decision makers at any given moment, there are a range of useful assessments that can be performed in a seasonal risk analysis. At critical decision making periods in a calendar year, conducting a review of Seasonal Indicators can be simplified into 2 categories; Remote Climate Drivers and Local Climate Drivers. The seasonal influence of indicators will also vary depending on geographic location as discussed in section 6.3.2.1. A series of basic steps can help identify trends for wet and dry periods;

- Survey climatic indicators
- Research the 'Analogue Year' as a predictive tool
- Survey seasonal Global Combination Models on temperature and rainfall

6.3.2.1 Survey Climatic Indicators:

A summary of the remote climate drivers can be accounted for in table 6.1 below, where numerical values or modes of each driver can be found on the Bureau of Meteorology website www.bom.gov.au An assessment of the current mode for preferred status as compared to current status these 3 remote drivers provides an indication of the potential moisture available for rainfall events to occur.

Table 6.1 Checklist of Remote Climate Drivers on Australian Rainfall

Climate Indicator	Measure	Preferred Status for rain	Seasonal Influence	Current Status
Pacific Ocean Indicators	Sea Surface Temperatures	✓La Niña-negative Niño 3.4	Location Specific	
Indian Ocean Indicators	Sea surface temperatures	✓ IOD negative DMI	May-November	
Southern Annular Mode	Alters circulation to push moisture east into NSW and Q'ld	✓ positive SAM Index for Cotton regions	Spring	

A checklist of more local indicators is provided below. As with the remote drivers of climate, it is important to identify the connection with each driver in establishing a seasonal forecasting risk assessment. As with table 6.1, here we identify what the indicator is measuring, its preferred status, seasonal influence and a column to enter the current status of the indicator. This allows us to benchmark the current status of the indicator against the preferred status for precipitation.

Table 6.2 Checklist of Local Climate Drivers on the Australian Climate

Climate Indicator	Measure	Preferred Status for rain	Seasonal Influence	Current Status
Southern Oscillation Index	Air Pressure Gradient	✓ Above +5 and stable/rising	Location Specific	
Madden Julian Oscillation	Long Wave Trough of low air pressure	✓ MJO Phase 5/6	Wet season Nov-April	
Blocking Activity	High/low air pressure in the Tasman Tea	✓ favourable	Year round	

6.5 Seasonal Forecasting: Using Analogue Years

What is an analogue year? A team of climate researchers at the Department of Agriculture and Food Western Australian (DAFWA) are using an experimental system to offer an alternative to Global Combination Models and add a new perspective to seasonal forecasting. This involves comparing indices of global atmospheric pressure and sea surface temperatures in the eastern Pacific to select the most similar “analogue years”.

To do this, it picks years from all available historical data with the most similar sequences in these indices, compared to the present year; a method known as the ENSO Sequence System (ESS).

The ESS is a form of statistical modelling. Ie. the statistical model compares past sea surface temperatures in the Pacific Ocean to corresponding Australian rainfall and temperatures, and then uses these historical relationships and current observations to make a three-month rainfall or temperature

outlook. In other words, the statistical model assumes that the past represents the future (BOM, 2013) http://www.bom.gov.au/climate/ahead/outlooks/model-differences-faq.html).

The benefits of using this methodology in decision making is that the precipitation from the nominated analogue year can be easily accessed using on-farm rainfall records or found by accessing data from the nearest registered Bureau of Meteorology weather station.

Caution must be taken with the ESS-Analogue year approach. Given the analysis is conducted on ENSO characteristics, usefulness will vary depending on the strength of the seasonal and geographic connections of this important climate driver. As with most ENSO related seasonal studies, significance will vary depending on geographic location and season of interest for application in Eastern Australia.

6.6 Dynamic Seasonal Forecasting Models

6.6.4 An Introduction to Dynamic Seasonal Forecasting Models

A Dynamic Seasonal Forecasting Model or General Circulation Model (GCM) is a mathematical model of the general circulation of a planetary atmosphere or ocean and based on complex mathematical equations.

High capacity hardware is required for complex computer programs commonly used for simulating the atmosphere or ocean of the Earth.

Progress has been made in incorporating more realistic chemistry and physics in the models, but significant uncertainties and unknowns remain, especially regarding the future course of human population, industry, and technology. Most Dynamic Global Circulation Models will have predictions of Ocean Indices out to a 9 months lead time. GCM's can be a useful tool to evaluate trends in temperature and rainfall on 1-3 month lead times.

6.6.5 Applications of Seasonal Forecasting Models to Agriculture

All leading International Climate Agencies conduct weekly or monthly seasonal forecasts for all countries. In conducting a risk assessment for a farming business, seasonal forecasting models can often validate movement in critical ocean and atmospheric indicators from our observational summary in section 6..5.5.1. Taking a survey of at least 4 Climate Models at key decision making times of year will help visualise likely scenarios of temperature and rainfall for a (3 month) season and aid in the confidence of resource allocation in your business.

A list of useful seasonal forecasting models;

- IRI – Columbia University (USA): www.iri.columbia.edu
- BOM – Seasonal outlook (AUS): www.bom.gov.au/climate/
- UK Met. Office (UK): www.metoffice.gov.uk/
- European centre for medium range forecasting (UK): www.ecmwf.int/products/forecasts/
- JAMSTEC forecasts (JP): www.jamstec.go.jp/
- WA Dept. Agriculture & Food (AUS): www.agric.wa.gov.au/

APPENDIX 1

Climate Risk Management Workshop

1. Survey of remote climate drivers

Research the following climatic indicators from the Bureau of Meteorology website to complete the table:

Climate Indicator	Measure	Preferred Status for rain	Seasonal Influence	Current Status
Pacific Ocean Indicators	Niño 3.4 Index	✓La Niña-negative Niño 3.4	Location specific	
Indian Ocean Indicators	Dipole Mode Indice (DMI)	✓ IOD negative DMI	May-November	
Southern Annular Mode	Alters circulation to push moisture east into NSW and Q'ld	✓ positive SAM Index for Cotton regions	Spring	

2. Survey of local climate drivers

Research the following local climate drivers and document their current status in the table below:

Climate Indicator	Measure	Preferred Status for rain	Seasonal Influence	Current Status
Southern Oscillation Index	Air Pressure Gradient	✓ Above +5 and stable/rising	Location Specific	
Madden Julian Oscillation	Long Wave Trough of low air pressure	✓ MJO Phase 5/6	Wet season Nov-April	
Blocking Activity	High/low air pressure in the Tasman Tea	✓ favourable	Year round	

3. DAFWA ENSO Technical Summary – Analogue Year

Research the latest DAFWA ENSO Technical summary from the DAFWA Website.

- Identify the 'Analogue Year' in the DAFWA ENSO-Technical summary
- Using the historical observational data from the Bureau of Meteorology website, identify the precipitation in the analogue year for the next 3 month period in the following locations to fill out the table:

Location	Monthly Rainfall		
	Eg. June (mm)	July (mm)	August (mm)
Dalby, Q'ld			
Narrabri, NSW			
Hay, NSW			

4. Seasonal Global Combination Model Forecasts

Identify the following international seasonal forecasting models (weblinks provided in section 6.6.5) to complete the following table:

Table 6.3 A sample summary of Seasonal forecasting GCM's where each model result is tabled with the aim of identifying trends towards wet/dry and cold/warm temperatures

		Model Results	
Climate Model	**Summary Period**	**Temperature Outlook**	**Precipitation Outlook**
Bureau of Meteorology (BOM) Australia	3 month average Updated monthly		
International Research Institute (IRI) USA	3 Month average Updated Monthly		
United Kingdom Met. Office (UKMET) UK	3 month average Updated monthly		
European Centre for Medium Range Forecasting (UK)	3 month average Updates monthly		
Japan Agency for Marine Earth Science & Tech. (JAMSTEC) Japan	3 Monthly – separated into monthly intervals Updated monthly		

5. Climate risk assessment of local historical data

Historical observational data can be a useful tool in determining the climatic characteristics of a given location. Predictive tools such as Rainman Streamflow (V4) are often used to determine probabilities of rainfall and also determine likely probabilities of seasonal outcomes based on ENSO and historical data.

Farmers are required to be more aware of there own climate in managing climatic variability. Commercial lending institutions are placing more emphasis on climatic risk management in the agriculture sector, often used in part, to determine their own risk margins. The next generation of farmers will be well positioned with lending institutions if they are able to demonstrate an awareness of climatic risk factors in business plans and loan applications.

Given the wide geographical spread of cotton growing areas in eastern Australia, a statistical analysis has been performed on 3 different locations in Appendix 2 examining a number of key variables affecting cotton production;

- Statistical analysis on the remote climate drivers and annual average precipitation
- Co-efficient of Variation test (reliability test)
- Long term min/max temperature trends
- Statistical relationship between ENSO years and annual average precipitation

Use the analysis provided in Appendix 2 to fill out the table below;

Location	What are the key remote drivers of rainfall in the spring period (planting)	Trend in min/max Temps	The most reliable rainfall month	The least reliable rainfall month	Relationship with ENSO on annual rainfall
Dalby, Q'ld					
Narrabri, NSW					
Hay, NSW					

6. Interpret the following Bureau of Meteorology ENSO Update:

(Use an extract from the latest BOM ENSO update and climate note)

- What is the current ENSO phase (La Niña/Neutral/El Niño)?
- What are the implications for a dry land farmer in Hay, NSW?

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Appendix 2

Case Studies of Cotton Growing Regions

Source: Cotton Australia, 2013.

1. Dalby, Q'ld (27.18ºS, 151.27ºC)

1.1 Remote Drivers of Rainfall

The Statistical Correlation with Seasonal Rainfall 1957 – 2013 (source: Silo: BOM, 2013)

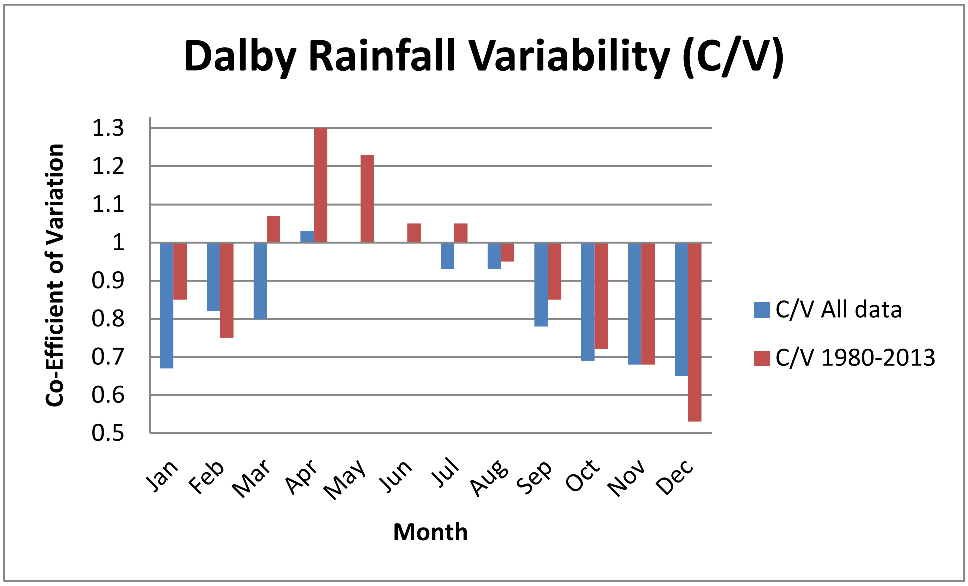
A ✓ represents a statistical correlation above the 95% level.

A X represents no statistical correlation.

Season	ENSO (SOI)	Indian Ocean (DMI)	Southern Annular Mode (SAM)
Summer	✓	X	X
Autumn	✓✓✓	X	X
Winter	X	✓	X
Spring	X	X	✓✓✓

Statistical Analysis provided by the CSIRO Marine and Atmospheric Research, 2013.

1.2 Precipitation Co-Efficient of Variation

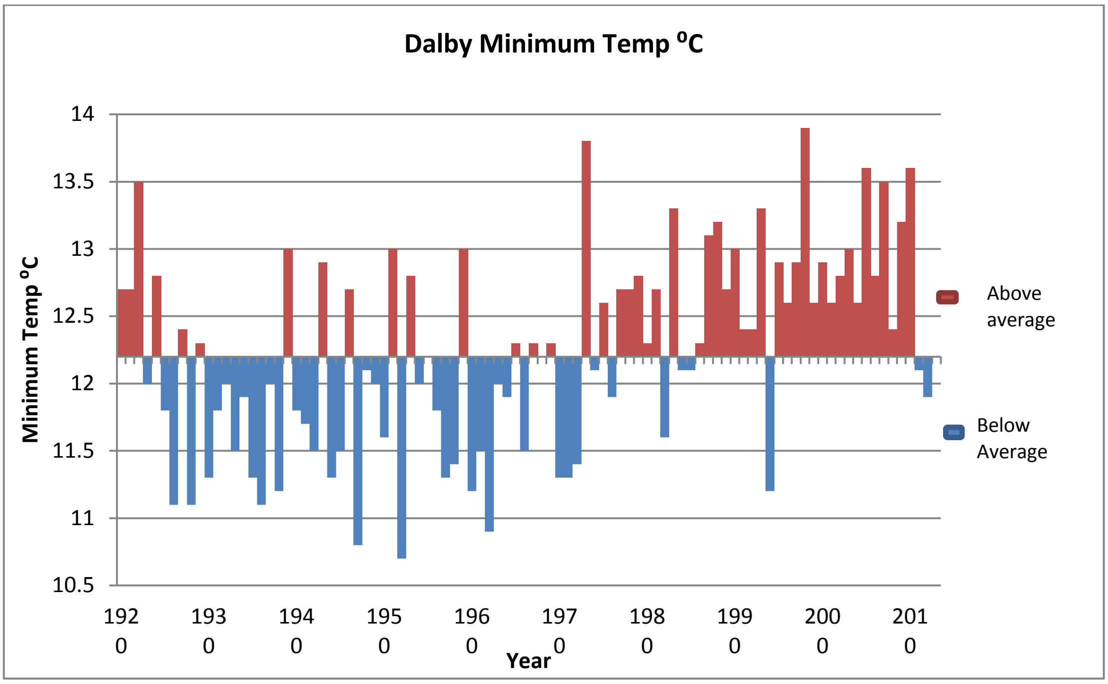


- The co-efficient of variation is defined as the Standard Deviation divided by the Mean
- The smaller the C/V, the more reliable the rainfall. Conversely, the larger the C/V the less reliable the rainfall.
- The blue bar represents all available precipitation data (1880-2012)
- The red bar indicates the co-efficient of variation from 1980-2012

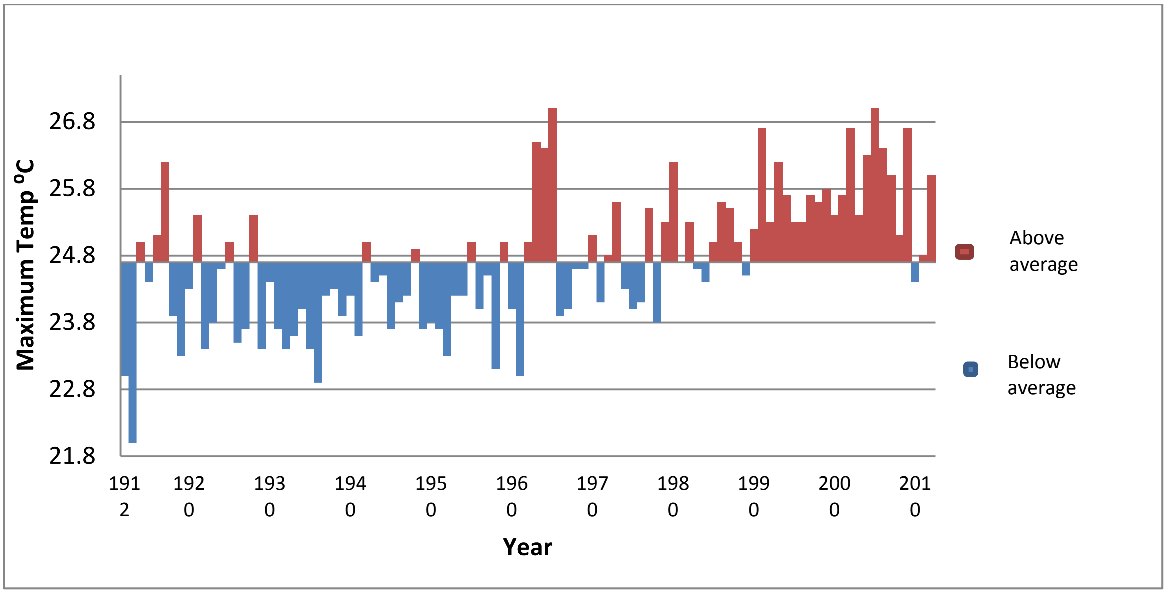
1.3 Dalby Minimum Temperatures

The chart below illustrates the changes in average annual minimum temperatures from 1912-2012.

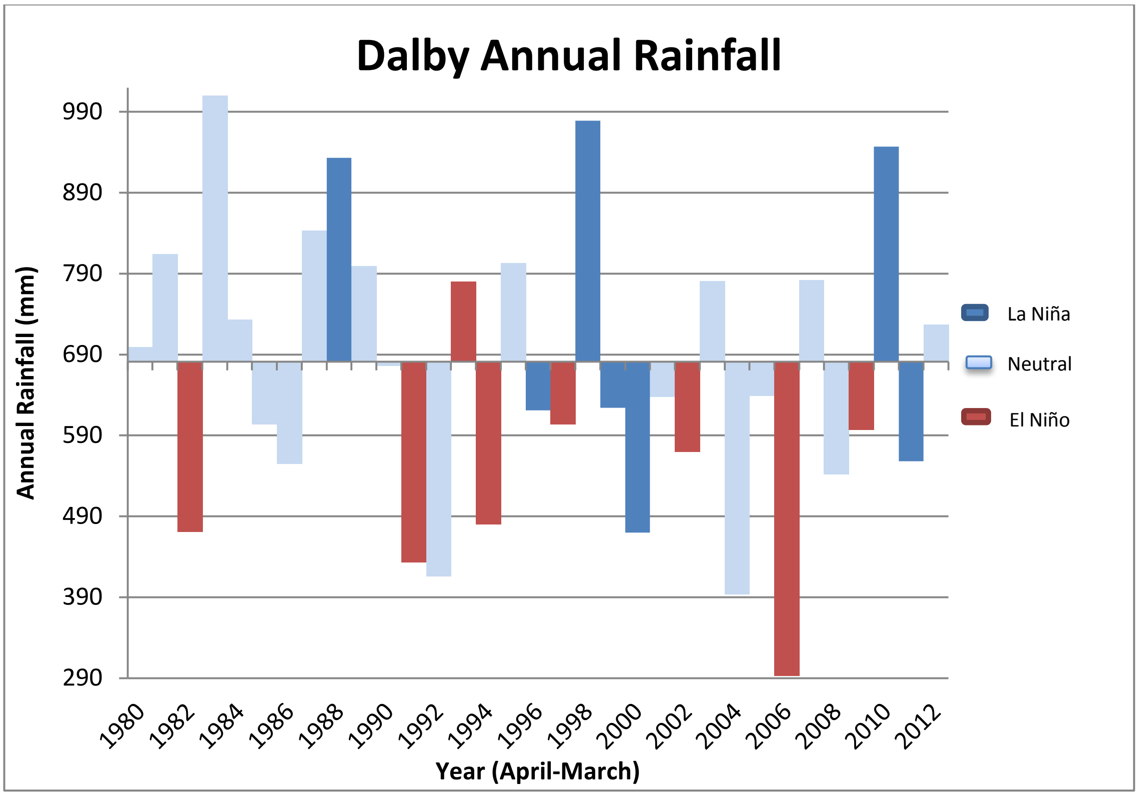
Source (BOM, 2013)



1.4 Dalby Annual Average Maximum Temperatures



1.5 Dalby Annual Rainfall (1980-2012) and Relationship with ENSO



2. Narrabri, NSW (30.33ºS, 149.77ºE)

2.1 Remote Drivers of Rainfall

The Statistical Correlation with Seasonal Rainfall 1957 – 2013 (source: Silo: BOM, 2013)

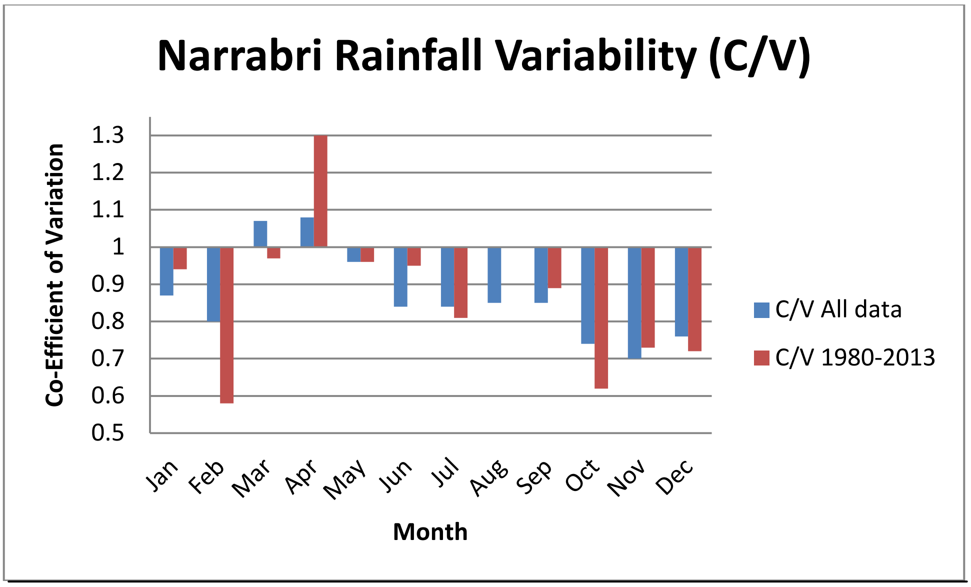
A ✓ represents a statistical correlation above the 95% level.

A X represents no statistical correlation.

Season	ENSO (SOI)	Indian Ocean (DMI)	Southern Annular Mode (SAM)
Summer	X	X	X
Autumn	X	X	X
Winter	✓✓	X	X
Spring	✓✓✓	X	✓✓✓

Statistical Analysis provided by the CSIRO Marine and Atmospheric Research, 2013.

2.2 Precipitation Co-Efficient of Variation

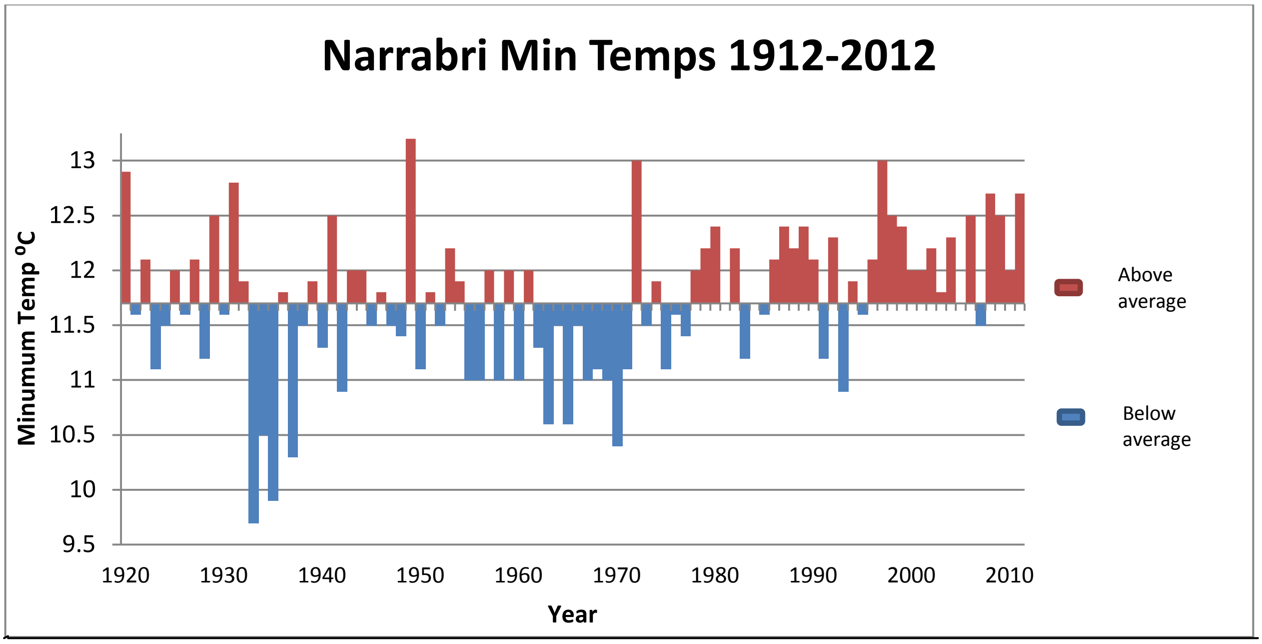


- The co-efficient of variation is defined as the Standard Deviation divided by the Mean
- The smaller the C/V, the more reliable the rainfall. Conversely, the larger the C/V the less reliable the rainfall.
- The blue bar represents all available precipitation data (1880-2012)
- The red bar indicates the co-efficient of variation from 1980-2012

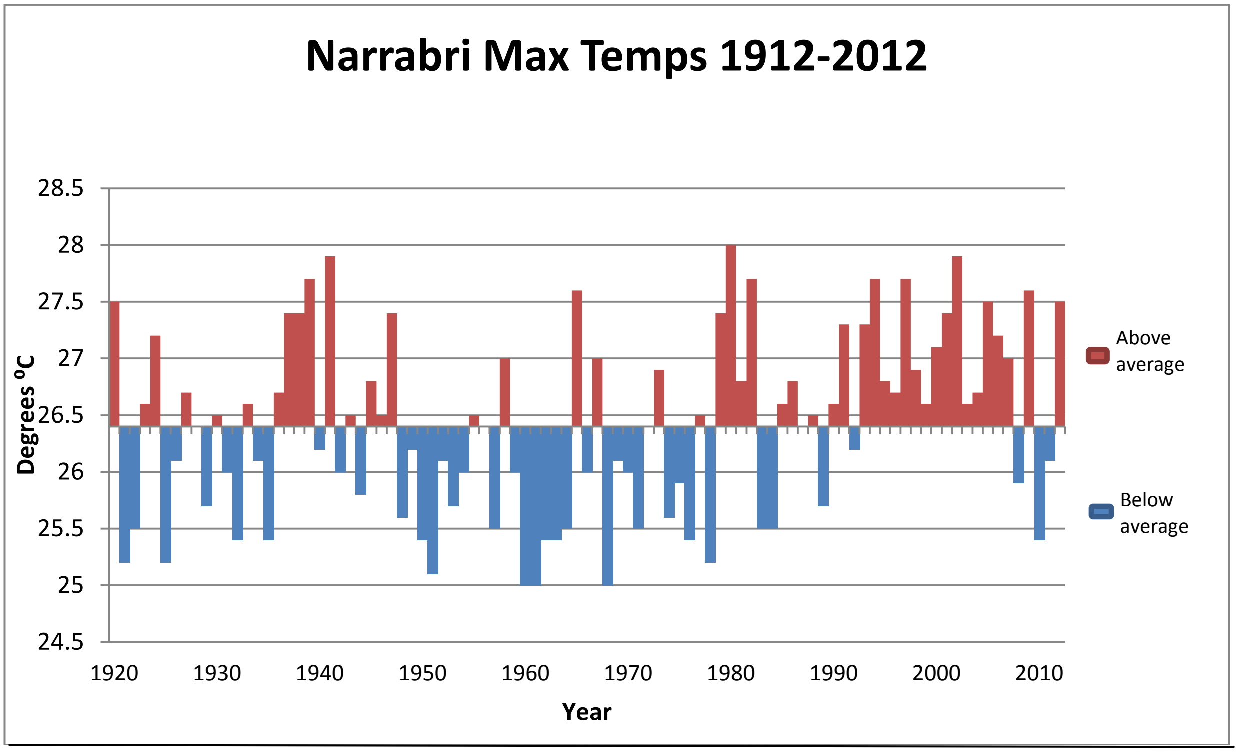
2.3 Narrabri Annual Minimum Temperatures

The chart below illustrates the changes in average annual minimum temperatures from 1912-2012.

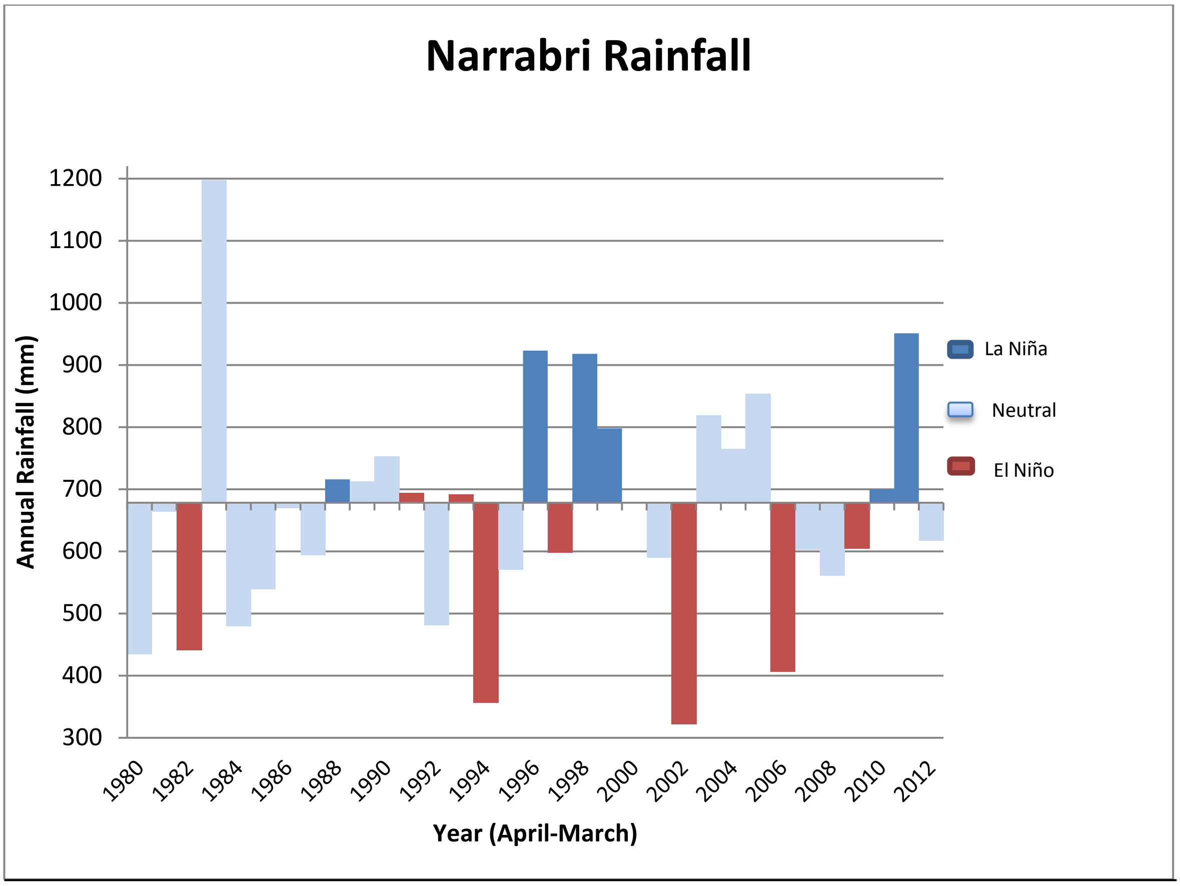
Source (BOM, 2013)



2.4 Narrabri Annual Average Maximum Temperatures



2.5 Narrabri Average Precipitation (1980-2012) and relationship with ENSO



3. Hay, NSW (34.50ºS, 144.83ºE)

3.1 Remote Drivers of Rainfall

The Statistical Correlation with Seasonal Rainfall 1957 – 2013 (source: Silo: BOM, 2013)

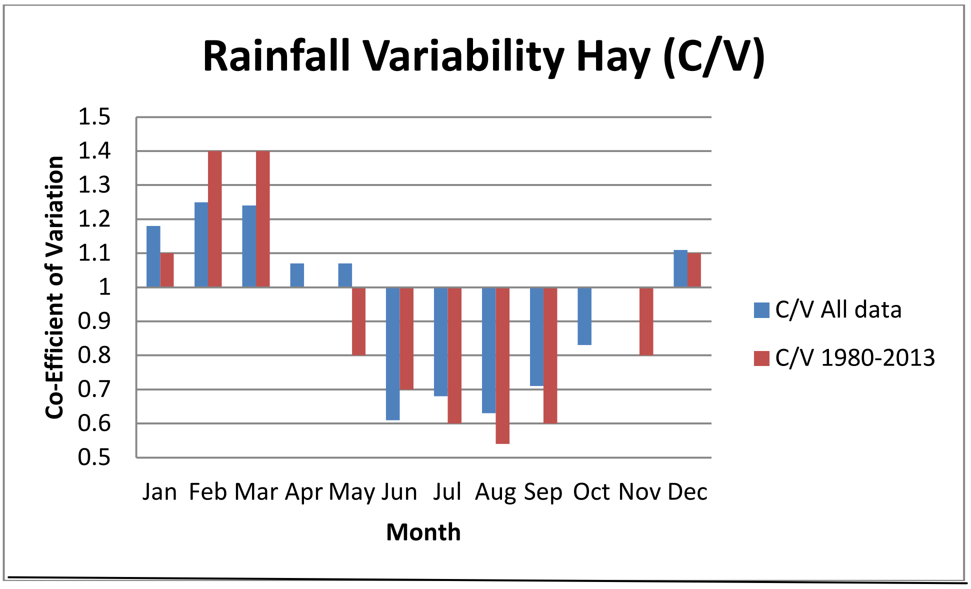
A ✓ a statistical correlation above the 95% level.

A X represents no statistical correlation.

Season	ENSO (SOI)	Indian Ocean (DMI)	Southern Annular Mode (SAM)
Summer	✓✓	X	✓
Autumn	✓✓	X	X
Winter	✓	X	X
Spring	✓✓✓	✓✓	✓✓✓✓

Statistical Analysis provided by the CSIRO Marine and Atmospheric Research, 2013.

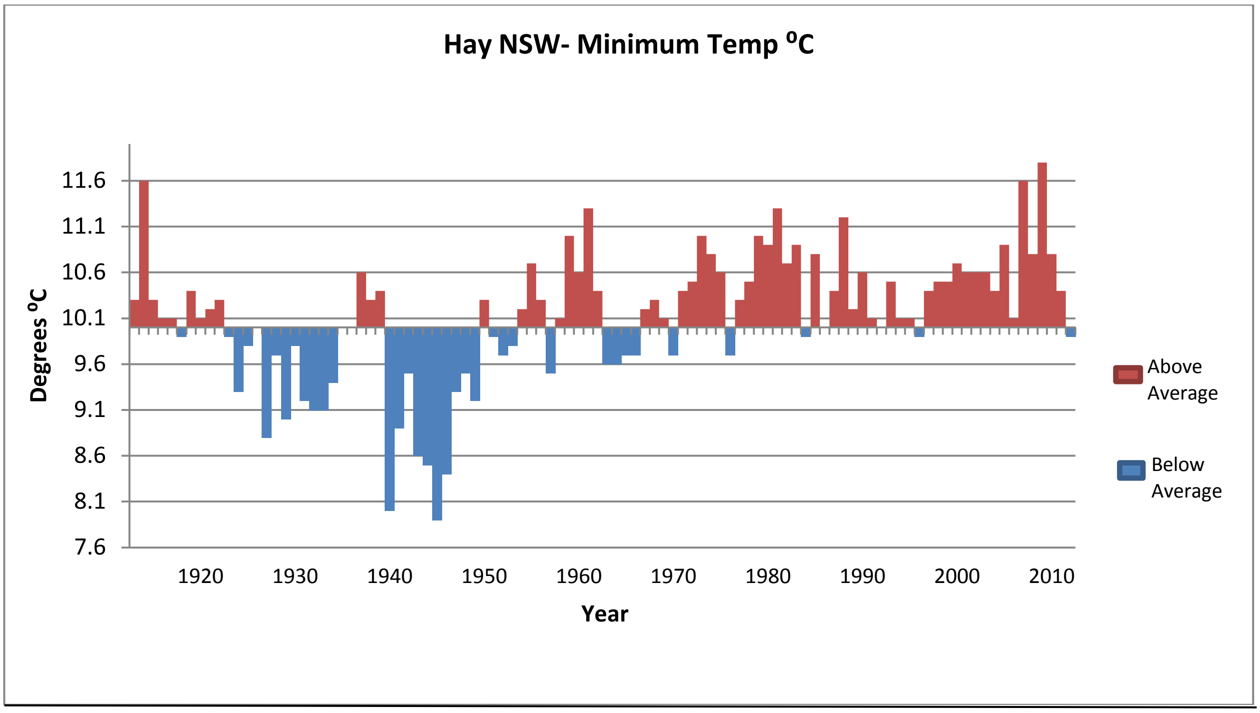
3.2 Precipitation Co-Efficient of Variation



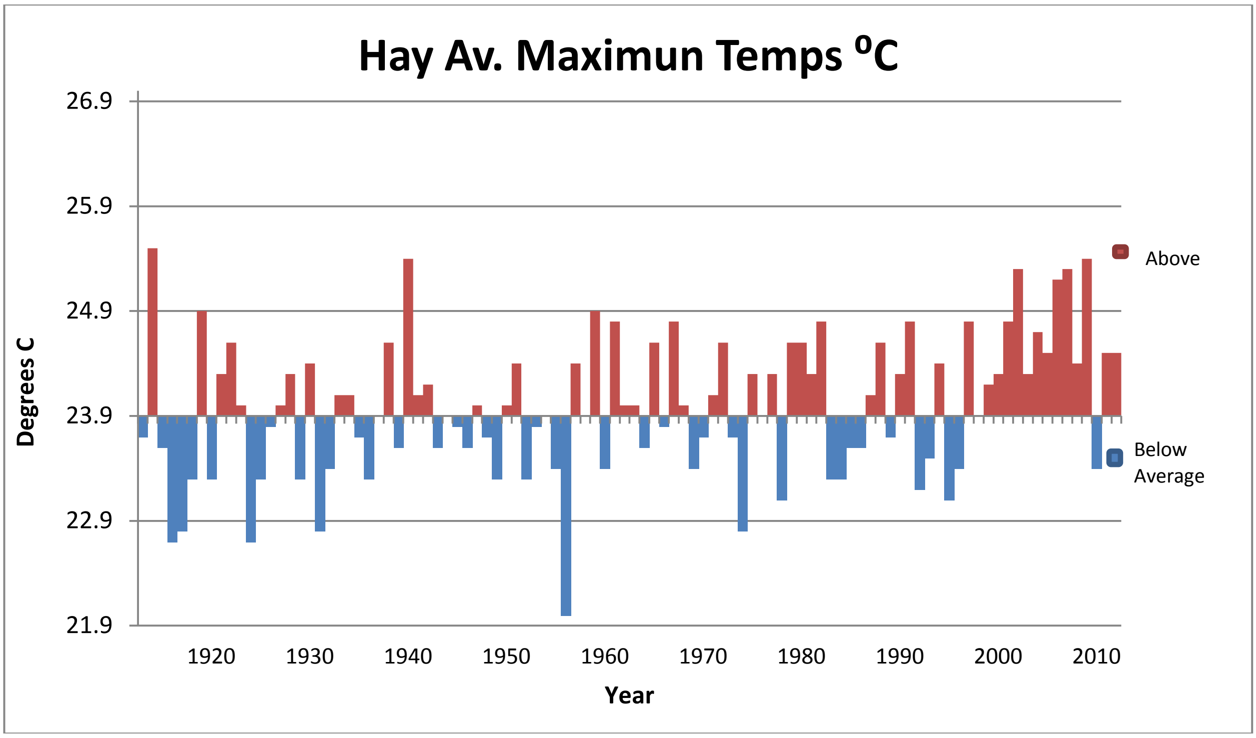
- The co-efficient of variation is defined as the Standard Deviation divided by the Mean
- The smaller the C/V, the more reliable the rainfall. Conversely, the larger the C/V the less reliable the rainfall.
- The blue bar represents all available precipitation data (1880-2012)
- The red bar indicates the co-efficient of variation from 1980-2012

CottonInfo
Australian Government
une University of New England

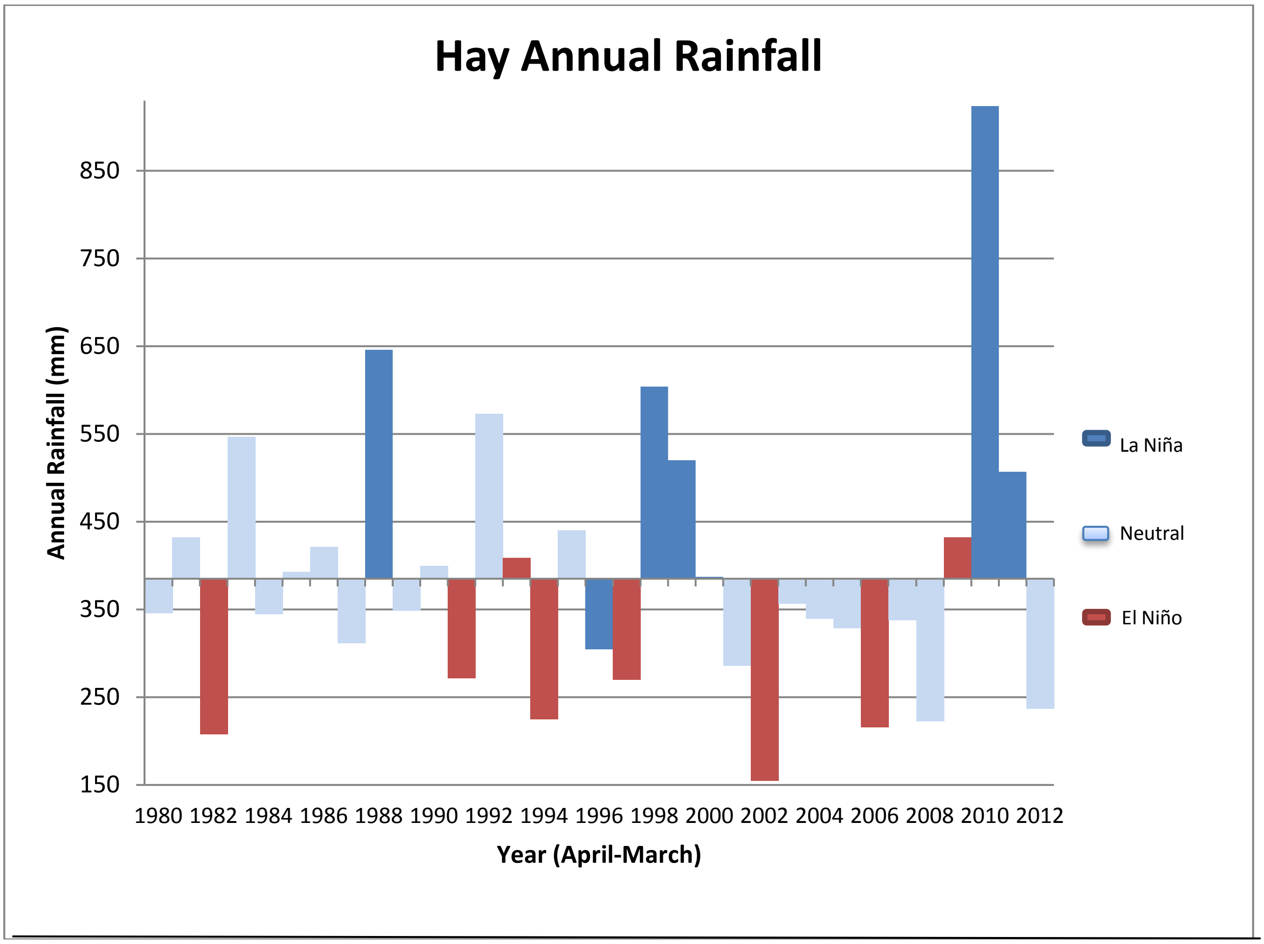
3.3 Hay Annual Minimum Temperatures



3.4 Hay Annual Maximum Temperatures



3.5 Hay Annual Precipitation and relationship with ENSO



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