INVESTIGATING THE EFFECTS OF EL NIÑO SOUTHERN OSCILLATION ON RAINFALL ACROSS NORTHERN AUSTRALIA

FINAL YEAR PROJECT

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Letter of Transmittal

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30 October 2014

Winthrop Professor John Dell  
Dean  
Faculty of Engineering, Computing and Mathematics  
The University of Western Australia  
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Dear Professor Dell

It is with great pleasure that I submit my final year civil engineering thesis paper entitled “Investigating the effects of the El Nino southern oscillation on rainfall across northern Australia” as a partial fulfilment of the requirements for the completion of the Bachelor of Engineering (Civil).

Yours sincerely,

Sean Coffey
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Abstract

The north west of Australia is home to a significant amount of Australia’s mining and resource sector, as well as an ever-increasing tourism presence. Having an accurate climate and hydrological model of this region can allow for advantageous preparation and engineering to combat extreme rainfall and weather events. This study focuses on the region from Darwin to Exmouth, which receives most of its rainfall in the Australian monsoon season. One of the primary drivers that dictates the behaviour and magnitude of the Australian rainfall is the El Niño Southern Oscillation (ENSO).

The research in this report aims to establish where the ENSO has a significant impact on rainfall, and how much of an impact the varying ENSO strengths have. By manipulation of daily rainfall data from the Bureau of Meteorology, in conjunction with southern oscillation index values, various statistical investigations showed that Darwin had a stronger correlation with the ENSO than Karratha and Broome. Performing the Kolmogorov-Smirnov test for statistical significance showed that there were varying regions of impact along the coast, with no clear geographical pattern.

Investigation into potential links with sea surface temperatures and tropical cyclones showed a strong qualitative link between warm anomalous sea surface temperatures during ENSO events and rainfall. Similarly, there was a strong link between cyclones and coastal warmer sea surface temperatures. From this we can conclude that there appears to be a positive correlation between ENSO events (La Niña and El Niño), anomalous warming and cooling of sea surface temperatures, tropical cyclones and rainfall during the Australian monsoon season.

This study highlights the need for further quantitative and statistical research into the links between tropical cyclones, sea surface temperatures and the already analysed ENSO signal and monsoonal rainfall. A better quantitative understanding of the area will contribute towards the development of accurate climatological and hydrological models.
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Nomenclature

BOM – The Bureau of Meteorology
CSV – Comma Separated Values
DJF – December, January, February
ENSO – El Niño Southern Oscillation
IOD – Indian Ocean Dipole
KS – Kolmogorov-Smirnov
NW – North West
NWA – North Western Australia
SAM – Southern Annular Mode
SOI – Southern Oscillation Index
SST - Sea Surface Temperature
1. Introduction

1.1 Background

The north-west of Australia, while scarcely populated, is home to some of the largest mining and tourism centres in the country. For example, the iron ore industry in the Pilbara accounts for $55.8 billion alone (Pilbara Development Commission, 2013). For optimum efficiency and productivity in these, and other present sectors, it would be useful to have an accurate climate and hydrological model to mitigate the potential negative effects of extreme rainfall events. Studies by Suppiah et al. (2013) and Taschetto & England (2009) noted the lack of sites has caused under-researching of the hydrology of north-west of Australia. A major driver of rainfall in this area is the El Niño southern oscillation (BOM, n.d.).

The El Niño Southern Oscillation (ENSO) is a three-phase system, often defined using the southern oscillation index (SOI). The neutral phase of this system refers to when the warm sea in the Pacific heats the atmosphere, and if sufficiently moist, causes cloud and rain. The air then travels east before falling over the eastern-Tropical Pacific. This pattern is referred to as the Walker Circulation, and the winds that carry the clouds east to west are referred to as the trade winds (BOM, n.d.).

![Image of El Niño and La Niña events](image)

*Figure 1: Behaviour of El Niño and La Niña events, Bureau of Meteorology*

An El Niño episode occurs when the temperatures in the East Pacific become warmer than normal (when compared to the West Pacific). This causes a weakening, or sometimes reversal, of the trade winds. This leads
to increased rainfall over the Eastern Pacific, such as South America, and decreased rainfall over the West, such as Australia and Indonesia. A La Niña episode occurs when the ocean in the East becomes warmer than normal; causing a strengthening of the trade winds. This brings more rain-carrying cumulonimbus clouds over the East pacific; causing potential drought in the West Pacific.

The Bureau of Meteorology (BOM) released documentation in 2010 analysing the 12 strongest ENSO events and mapped them against rainfall percentages across the country over 3 month periods. Summer rainfall showed moderate qualitative responses in the Pilbara, Gascoyne and Kimberley regions; however the study noted the lack of data and gauging stations posed a problem. Large portions of this area showed various responses to the ENSO events; and are significant enough to suggest that the SOI needs to be accounted for in any analysis of climate variables (BOM, 2010 & Chowdhury, 2010).

1.2 Objectives

The primary objective of this study was to determine the direct relationship with the ENSO signal and rainfall over coastal Northern Australia. The focus areas are along the coast where the system will have its strongest effect, and will span from approximately Darwin to Exmouth. Statistics were used to attempt to determine where the ENSO was having a significant effect on the rainfall. Specifically, this study attempted to isolate the monsoonal rainfall signal and the lead-up (build-up) period approaching this. Determining the effect of ENSO on rainfall in the region has two primary uses:

- Knowing which geographical regions are influenced by ENSO is useful for climate modelling
- Aids in assessing the impacts of climate change

This study also aims to establish a method for accurately assessing the statistical significance the ENSO signal has on hydrological variables.
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2. Literature Review

2.1 Australian Monsoon Season

The government of Australia defines the tropical wet season, called the monsoon season, as occurring between November and March (Wells 2013). In areas moving across into WA, the annual rainfall is considered to be summer dominant (BOM, n.d.). Figure 2 shows the geographical climate zones by rainfall.

![Major seasonal rainfall zones of Australia](image)

Figure 2: Australian rainfall zones, Bureau of Meteorology

Figure 2 shows that most of the study area is a summer dominant zone, but there is a significant portion around Port Headland that is a low rainfall zone. However, further analysis of the Monsoon trough by BOM has shown that the approximate geographical position, dictated by the southern annular mode, includes our entire study area. This can be seen in figure 3 overleaf.

A study by Kirono et al. (2010) established that there was a lag of up to 9 months for ENSO effects in Australia, though some Australian locations showed only a 1-3 month lag. The study used rainfall and runoff as the primary indicator for ENSO effects, in particular the 3 month period from December to February was analysed and the lead-up behaviour of ENSO and monsoon in Australia was demonstrated. It has also been shown that Darwin is heavily monsoon active, and undergoes a strong build-up / monsoon cycle (May et al. 2012).
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Research by Smith et al. (2013) showed mainland rainfall in Papua New Guinea had a strong ENSO correlation from January to March. This study attempted to establish geographical regions and boundaries where the ENSO had different effects, and was able to do so for most analysed areas.

Figure 3: Synoptic patterns associated with the active Australian monsoon trough (Bureau of Meteorology, 2008)

An El Niño Modoki event occurs when the temperature anomaly occurs not between the east and west Pacific, but between the central Pacific and the surrounding region. A study by Taschetto et al. (2009) shows that during an El Nino Modoki event, the Australian monsoon season becomes shorter and more intense; primarily acting between January and February. It was found that the Modoki event leads to an overall decrease in rainfall over the event, and a late onset in December and sharp decline for rainfall in March. The study concludes that the Australian monsoon season is sensitive to the position and magnitude of sea surface temperatures in the Pacific.

Colman et al. (2011) modelled the Australian monsoon using 23 different simulated models, and assessed their accuracy. The models were adequate for low resolutions in terms of both time-scale and space-scale predictions, but noted the need for analysis and testing of the physical processes that are important to precipitation. It was also noted that most of the models overestimated the correlation between the ENSO signal and precipitation.
2.2 Other Rainfall Drivers

A study published in the Journal of Climate looked at the increase in rainfall in North Western Australia (NWA), despite the decrease in Eastern Australia; in particular looking at the links between an increase in Northern hemisphere aerosols (Shi et al. 2008). The same study analysed the drivers of the high variability of rainfall in NWA and found that year-round there is a weak correlation with ENSO, and from July to November there is a statistically significant Indian Ocean Dipole (IOD) influence. Similarly, higher levels of rainfall have been linked to an increase in Indian Ocean sea surface temperature (Shi et al. 2008). This study can be used to verify trends of increasing weather events in the Northern and Coastal parts of the region; however the study lacks the in-region analysis required for this project, so it can only be used as an overall regional comparison. Similar to previously referenced articles, this study also concluded that further analysis on NWA climate data needed to be completed in conjunction with ENSO and IOD data.

A 2009 study suggested that the positive trend in NWA annual and summer rainfall could be linked to an increase in intensity of deep convection; caused by changes in the monsoon trough. It is also predicted that an earlier northward shift of the monsoon trough is causing the negative rainfall trend in NW Australia during autumn (Taschetto & England, 2009).

The variability of the southern annular mode (SAM) has been linked to intra-seasonal rainfall patterns; for example the study found that different SAM phases had correlations with rainfall in the southern parts of Australia (Frederiksen et al. 2013). However, the same study also finds that the correlation is rarely present for the more northern regions of Australia. This region is, however, strongly influenced by the sub-tropical ridge (BOM 2008). The southward movement of the high pressure system during the summer months leads to the monsoonal trough that allows the movement of heavy rain and cloud over northern Australia (BOM, 2008).

2.3 Sea Surface Temperatures & Tropical Cyclones

The behaviour of the oceanic currents off the west coast of Australia is dominated by the Leeuwin current; which transports warm pacific waters south down the coast of Australia (Feng et al. 2013). The northern part of Australia is also subject to tropical cyclones that form only when the sea surface temperature of the ocean is at least 26.5 degrees Celsius (BOM, 2014). The strength of the easterly Pacific winds have been shown to have an effect on the strength of the Leeuwin current, where these Pacific winds are directly in correlation with the strength of El Niño and La Niña events (Feng et al. 2013). Extensive studies have been undertaken on the intense 2010-2011 La Niña event; in particular the effect it had on the SST on the north of Western Australia where peak SST during a 2-week period were 5 degrees warmer than normal (Feng et.al 2013).

It has been predicted that, in general, a warmer atmosphere will cause more precipitation and hold more moisture (Gordon et al. 1992). Simulations of the greenhouse effect have predicted increased rainfall intensity;
this implies that if a trend in ambient and sea-surface temperatures can be found, there could potentially be a statistical link to an increase in extreme rainfall events in the regions. The study by Gordon et al. (1992), however, cannot aid combining the impacts of the greenhouse effect with analysis of regional driving factors (ENSO, IOD etc.).

### 2.4 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov (KS) test has been commonly used to compare hydrological data to determine how it is distributed (Lin & Wu, 2010). Research by Ren & Kingsford (2014) used the two-sample KS-Test to compare low and high regulated flood flows in Australia. Specifically, the test was used to confirm that there was a statistically significant difference between litres of flow for low and high regulated flows. The KS test has also been used to compare daily rainfall values to analyse ENSO forced precipitation in the Gulf of Mexico (Munroe et al. 2013). The study compared daily rainfall for La Niña and El Niño years at a nominated significance level in 1x1 degree regions. From this it was concluded that the method was able to determine statistical significance of the rainfall between ENSO episodes from August to December.
3. Methodology

3.1 Data Acquisition

The primary data used in the analysis was daily rainfall. BOM provides a graphical ‘Environmental Information Explorer’, where sites can be selected based on geographical location. Graphical searches were further filtered to only display meteorological (atmosphere) data and selecting daily reporting frequency. The site ID was acquired from this explorer and taken to BOM’s Climate Data Online page, where the station number was entered and the data can be downloaded in CSV form.

Similarly, BOM provides monthly SOI values in CSV form. The SOI value is determined by comparing the mean sea level pressure between Tahiti and Darwin, and is calculated using the following:

\[
SOI = 10 \frac{P_{\text{diff}} - P_{\text{diff, av}}}{SD(P_{\text{diff}})}
\]  

\[P_{\text{diff}} = \text{Tahiti} - \text{Darwin average pressure for month}\]  

\[P_{\text{diff, av}} = \text{long term average of } P_{\text{diff}} \text{ for month of interest}\]  

\[SD(P_{\text{diff}}) = \text{long term standard deviation } P_{\text{diff}} \text{ for month of interest}\]

3.2 Data Manipulation and Preparation

The data was provided in columns with headings: “Product Code”, “Bureau of Meteorology station number”, “Year”, “Month”, “Day”, “Rainfall amount (millimetres)”, “Period over which rainfall was measured (days)”, and “Quality”. Given the data is provided in daily sets, but is not always required like this; various methods were employed to filter and convert the data into desirable forms. This was completed primarily through the use of MATLAB, where various “for”, “while” and “if” loops were employed to count and measure different variables, as well as to confirm data quality. Before being run through the MATLAB codes, the CSV sheet was prepared by deleting the text field headings, and leaving only the year, month, day rainfall and quality columns. BOM records the quality of their data by recording a value if the collection site is functioning correctly, i.e. “0” if no rainfall. If this data is of known to be of good quality the quality field is also filled with a “Y”. Using an Excel formula, a new column was created to check that the rainfall field contained a value and the quality was good; this field was filled with either a 1 or 0 corresponding to the checks. This was important as anecdotal evidence suggested that often there may have been a positive quality entry but no data entered into the rainfall amount column. The MATLAB codes used are provided in Appendix 2.

The primary output used was a comparison of monsoonal season (November – February) rainfall to the average SOI lead-up (May – October) value, taking into account the number of quality days of data. The 4 month monsoon period has 121 days (or 122 days in a leap year), and subsequently for adequate statistical analysis a
cut-off of 95% data was implemented. That is, a monsoon season had to have had 115 days of quality data to be included in analysis. Data obtained for the number of rainy days for various rain thresholds was also analysed. The thresholds used were 1mm, 10mm and 25mm to represent different rainfall depths.

The SOI lead-up values were prepared by averaging the lead-up values from the earliest available data to 2013 in two different sets. Years with SOI values between -5 and +5 were ignored; this represented ENSO events of at least mild magnitude. A second set of data was produced where SOI values between -10 and +10 were ignored; this was to represent ENSO events of extreme magnitude. Ideally, only the extreme events would be analysed but because of the poor rainfall data availability in northern Australia it was required to use the mild cases to have sufficiently long data sets.

### 3.3 Preliminary and Investigative Analysis

The initial analysis primarily involved qualitatively verifying that the data acquisition, preparation and manipulation would yield results that were in line with previous studies. This involved searching for the ENSO relationship at Darwin, and then extending that analysis to Broome and Karratha. The most common was comparing the box and whisker plots for La Niña and El Niño years for both mild and extreme cases.

To address the presence of short data set lengths for initial analysis at regional centres in Darwin, Karratha and Broome, a method was employed to extend the length of the data sets. Four sites within the geographical region for each town were taken and analysed separately. Next, the sets of monsoonal rainfall for common years were completed using a standard correlation coefficient check in Excel. For this a cut-off value of \( r = 0.9 \) was employed. This resulted in being able to average and data fill to create longer, more reliable datasets when analysing these three regions.

### 3.4 Kolmogorov-Smirnov Test for Statistical Significance

After qualitative analysis or semi-quantitative analyses are performed, the statistical significance of these results must be confirmed. For this study, the Kolmogorov-Smirnov test was employed.

The KS test (in particular the two-sample test employed for this study) is a ‘goodness of fit test’, that compares the agreement between the distribution of two sets of single variable data. The test sets a null and alternative hypothesis comparing the cumulative distributions of the sets. The interpretation of this is that the null hypothesis \( (H_0) \) says that the two sets are from the same distribution, while the alternative hypothesis \( (H_1) \) says that they are from different distributions. Considering \( x \) to be the variable of interest;

\[
H_0: F(x) = G(x), \text{for all } x \tag{2a}
\]

\[
H_1: F(x) \neq G(x), \text{for some } x \tag{2b}
\]
Thus, once a level of significance is set, we reject the null hypothesis when P-value is less than $\alpha$.

The test functions by determining the maximum distance ($D_{KS}$) between the CDFs at any point.

$$D_{KS} = \max | F(x) - G(x) | \quad (3)$$

The critical $P$-value is calculated from

$$D_{KS} = c(P) \sqrt{\frac{n_1 + n_2}{n_1 \times n_2}} \quad (4)$$

Where $n_1, n_2$ are the number of points in each set, the coefficient $c(P)$ can be determined manually from the below table values, however the built-in calculator handles the accurate interpolation.

<table>
<thead>
<tr>
<th>$P$</th>
<th>0.1</th>
<th>0.05</th>
<th>0.025</th>
<th>0.01</th>
<th>0.005</th>
<th>0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c(P)$</td>
<td>1.22</td>
<td>1.36</td>
<td>1.48</td>
<td>1.63</td>
<td>1.73</td>
<td>1.95</td>
</tr>
</tbody>
</table>

Table 1: $c(P)$ coefficient values for different $p$-values

For this study, the value $\alpha = 0.05$ (95% confidence) was set.

The KS test was used to compare monsoonal rainfall for mild La Niña to El Niño years (SOI greater or less than $\pm 5$). If the resulting P-values for the test were less than or equal to alpha, the distribution of the monsoonal rainfall for La Niña years is statistically different from El Niño years; that is, the ENSO signal is statistically significant.

This test was performed using an online tool written by T. Kirkman for The College of Saint Benedict & Saint John’s University physics faculty. The tool takes the two sets of data as an input, and performs the KS test, outputting the $D_{KS}$ and P-values. In conjunction with this, the online tool performs distribution analysis on the two sets of data and the parameters describing their distribution. The latter was useful for determining whether data was appropriate to analyse; only data sets that were normally or log-normally distributed were included in the final analysis, as this suggests the method of analysis used is appropriate.

To visualise the results of the many sites analysed using the KS test, the results were plotted geographically on a map. This was done using Google maps engine and using simple colour codes to differentiate between sites where the ENSO was and was not statistically significant.

### 3.5 Sea Surface Temperatures and Tropical Cyclones

To try and determine why the ENSO behaved the way it did, a preliminary investigation into sea surface temperatures and cyclones was performed. From the understanding of the ENSO, it would make sense that there is a strong correlation with SSTs and tropical cyclones during El Niño/La Niña episodes.
BOM provides detailed analyses of all tropical cyclones, as well as the areas which are at cyclone risk. This includes the path, speed and rainfall amount each cyclone will bring. Because of the time constraints of this study, the cyclone analysis conducted was notably preliminary and qualitative. All plots and results analysed are from research conducted and presented by BOM on their website. Analysis for WA consisted of the following relevant regions:

- Broome
- Carnarvon
- Dampier/Karratha
- Derby
- Exmouth
- Port Headland
- Wyndham

Sea surface temperature analysis is provided in a similar way, where BOM published an analysis of the 2010-2011 La Niña, looking at the anomalous SSTs. There are also historical anomalous sea surface temperatures averaged for the NW region which can be obtained from an interactive plotter. As well as geographical contour plots of SST trend data.
4. Results

4.1 Preliminary Results

Given that a strong link between the lead-up SOI and rainfall has previously been established in Darwin; preliminary analysis was performed on this location to verify that the methods obtained similar results. Initially, many variables, including total monsoonal rainfall, number of rainy days, annual rainfall distribution, rainfall depth and total annual rain, among others, were investigated to try and develop an understanding of the rainfall behaviour. The data presented is most significant to this study.

![Figure 4: Darwin Box and whisker plot for monsoon rainfall during mild events](image1)

![Figure 5: Darwin box and whisker plot for monsoon rainfall during extreme events](image2)

As can be seen in figures 4 and 5, these methods verified that Darwin was observing statistically more rain in La Niña years than El Niño years, as expected according to previous studies.
4.2 Extended Analysis

The extension of statistical analysis of rainfall data to Broome and Karratha;

Statistical Difference Between La Niña and El Niño Years

±5 SOI

Figure 6: Statistical differences between mild El Niño and La Niña years in Darwin, Broome and Karratha

Statistical Difference Between La Niña and El Niño Years

±10 SOI

Figure 7: Statistical Differences between extreme El Niño and La Niña years in Darwin, Broome and Karratha

These results similarly showed that, in general, statistically more rain fell in La Niña than El Niño years. To check the statistical significance of these results, a KS test was performed on the data sets.
4.3  Kolmogorov-Smirnov Test Results

<table>
<thead>
<tr>
<th>SOI</th>
<th>Darwin</th>
<th>Broome</th>
<th>Karratha</th>
</tr>
</thead>
<tbody>
<tr>
<td>±5</td>
<td>0.014</td>
<td>0.191</td>
<td>0.004</td>
</tr>
<tr>
<td>±10</td>
<td>0.025</td>
<td>0.746</td>
<td>0.169</td>
</tr>
</tbody>
</table>

Table 2: P-values for KS-test performed on monsoonal rainfall for Darwin, Broome and Karratha

These results were not in line with the initial expectation, given that Karratha was statistically significant, however Broome, located between Karratha and Darwin was not statistically significant. Geographically this appears illogical. For this reason, the results were extended to include many other rainfall stations across northern Australia, to observe how the sites were geographically distributed. Appendix 1 shows the resulting P-values from the KS-tests performed on all these extra sites. Due to data restrictions mentioned earlier, the analysis from here on was restricted to mild (±5) episodes. To aid in the visualisation of this, figure 8 overleaf contains a map of the analysed rainfall sites. Green markers indicate a P-value less than 0.05 (ENSO is significant), and red indicates a P-value greater than 0.05 (Insignificant).

There appeared to be no clear linear pattern as to which sites are affected and those which are not. The Jakarta data was approximated from a plot provided by Keith Smettem from an earlier study and the numerical interpretation of this is provided in Appendix 3. Unfortunately due to data restrictions, there are significant geographical regions where no useful data sites were available for analysis.
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Figure 8: KS-test results plotted on map (Green - ENSO is statistically significant, Red – Insignificant)
4.4 Sea Surface Temperatures

From the BOM study into the 2010-2011 La Niña;

Figure 9: Sea Surface Temperature Anomaly plot for Australia from the May 2010 to April 2011 La Niña, Bureau of Meteorology

The figure shows that the northern region of Australia can be subject to high SST variability during strong ENSO episodes. While the 2010-2011 episode had a very strong impact on the SSTs, this did not correlate with a significant increase in rainfall because of a strong positive SAM event (BOM, n.d.).

If we compare the NW region of Australia in this figure to the KS-test results in figure 8, there appears to be some correlation between the location of the warmer regions and the areas of rainfall.

The Bureau of Meteorology also provides a tool to look at trend maps. This allows for variables and regions to be selected and plotted. Figure 10 shows one such trend map of the SST trend from 1970-present for the summer months (DJF)
Interpretation of Figure 10 shows that the regions that appear to be warming over NW Australia are loosely similar to those in Figure 8 which are showing that the ENSO is statistically significant. Next, the long term sea surface temperature was investigated to determine whether this had any obvious correlations to the ENSO signal. An anomaly plot for summer rainfall (DJF) for the NW region using data for 1900-2013 is shown in Figure 11.
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Figure 11: Summer sea surface temperature anomaly - NW Australia (1910-2013), Bureau of Meteorology

Figure 12: Cumulative SOI (Yearly calculation) from 1876
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Figure 12 is included for comparison to Figure 11, and to determine whether any trends can be ascertained. From this data alone, it is unlikely there is a direct link between the long-term trends of ENSO and SSTs. It is much more likely, as in Figure 9, that significant ENSO episodes can affect the SST in a way that produces short term effects that aren’t statistically significant in long-term analysis.
4.5 Tropical Cyclone Activity

Figure 13: Average annual number of tropical cyclones - La Niña years, Bureau of Meteorology

Figure 14: Average annual number of tropical cyclones - El Niño years, Bureau of Meteorology
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Figures 13 and 14 show the average number of tropical cyclones for La Niña and El Niño years respectively. As would be expected, the total number of cyclones is on average lower for El Niño than La Niña years. In La Niña years, it also appears that the cyclones closest to the NW Australian coast are at the same region that was statistically significant in Figure 6. Specifically, this appears to occur along the coast running between Karratha/Dampier to Port and South Headland. The significant concentration of cyclones appear to occur more north during El Niño years, closer to Broome. They also appear to be further off the coast than in La Niña years.

<table>
<thead>
<tr>
<th>REGION</th>
<th>NUMBER OF CYCLONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broome</td>
<td>26</td>
</tr>
<tr>
<td>Carnarvon</td>
<td>24</td>
</tr>
<tr>
<td>Derby</td>
<td>13</td>
</tr>
<tr>
<td>Exmouth</td>
<td>45</td>
</tr>
<tr>
<td>Karratha/Dampier</td>
<td>54</td>
</tr>
<tr>
<td>Port Headland</td>
<td>49</td>
</tr>
<tr>
<td>Wyndham</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3: Number of cyclones of at least category 1 passing through regions since 1910

Using the same method described in section 3.4, Google maps engine was used to generate a geographical map (Figure 15) of the data in Table 3. Figure 16 shows the landfall of various category cyclones, provided by the Bureau of Meteorology, for comparison.
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Figure 15: Map of data from table 4 - Number of tropical cyclones affecting different WA locations

Figure 16: Map of Australian tropical cyclone landfall locations 1970-2002, red dot = greater than category 3, black = less than or equal to category 3, Bureau of Meteorology
5. Discussion

5.1 Preliminary, Extended and KS Test Results

The preliminary analysis acted as a data and methodology verification, where Figures 4 and 5 show that the monsoonal rainfall in Darwin is different in an El Niño and La Niña year. Similar qualitative analysis of each of the sites analysed showed similar results. The result is that, in general, we can expect a greater volume of monsoonal rainfall in northern Australia during a La Niña event in comparison to neutral or El Niño events. However, as stated, each site had to be analysed for statistical significance.

From the extended analysis in Section 4.2, in particular Figures 6 and 7, we can see that the ENSO seems to have a much more significant effect on Darwin in comparison to Broome or Karratha. This was the case for both mild and extreme ENSO events, where a La Niña episode triggers an average of 150mm more rain than an El Niño episode. From these figures it would have appeared safe to assume that there was still a strong effect in Broome and Karratha; with both statistical parameters being similarly affected by the ENSO signal. The set sizes for the ±10 SOI events for both Broome and Karratha were barely over the minimum size (10); this is most likely the reason for the anomalies in the Broome El Niño/La Niña analysis. Furthermore, it is most likely the reason for the discrepancy between the P-values for Karratha in mild and extreme years in Table 2. This highlights the need for lengthy data sets to obtain accurate values.

It became evident from performing the KS-test on many rainfall sites that the ENSO signal is not simple nor geographically linear in behaviour. However, it is important to note that not all the data is ideal. In some areas, there were no coastal rainfall stations suitable for this statistical analysis; this included much of the area between Darwin and Broome. As such, some sites further inland were used, or that part of the coast could not be included in the analysis.

5.2 SST Results

When the full map of KS-test results shown in Figure 8 were compared to the SST plots in Figures 9 and 10 there are a series of things to note:

- Both SST graphs show increased temperature around the coast from Carnarvon, around the North West Cape and around to approximately Karratha.
- This appears to correlate well with the region of ENSO significance around Karratha and Dampier
- Similarly there appears to be a correlation between the heating of the SST around Dampier peninsula

Observing the long term SST anomaly (figure 11) for the NW region during summer and comparing to the long term cumulative SOI (figure 12), some inferences can be made:
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- The increasing anomaly temperatures since 1980 seems to line up with the overall SOI decline since 1976
- Outside of this, however, the long term trends do not appear to have a significant correlation, as mentioned in Section 4.4
- Possible reasons for this could be that the ENSO exhibits longer term cyclic behaviour than can be seen in the available data (135 years)
- It is also more likely that the SST increase is related to climate change or other human behaviour

5.3 Tropical Cyclone Results

By an observation of the cyclone data in Figures 13 and 14:

- The concentration of cyclones during La Niña years near the coast of NW Australia appears to be in the same location as the warm ocean anomalies for the 2010-2011 La Niña years
- The cyclone concentration for both La Niña and El Niño years are within the regions that have been warming most since 1970
- More cyclones pass through Dampier and Port Headland than anywhere else in Western Australia, this is also the region where high category cyclones pass
5.4 Potential Errors

There are portions of the analysed regions that aren’t as monsoonal in behaviour as the others; this can be seen in the figure below,

![Australian Rainfall Analysis (mm)
January 2006
Product of the National Climate Centre

Figure 17: Australian rainfall map for January 2006, Bureau of Meteorology

This figure was produced from an analysis of the 2006 monsoon season, which was considered to be very active. Following on from the results obtained earlier, this shows an increase in rainfall specifically around Karratha/Dampier when compared to surrounding regions. However, the figure shows that parts of the NW coast receive variable amounts of effects from a typical monsoon season; as much as 500mm difference in rainfall for one month between Port Headland and the Prince Regent Nature reserve. The January rainfall of 100-200mm rain along the majority of Eighty Mile Beach, compared to the 200-400mm amounts of rain would seem to verify the region of statistical insignificance that this region was found to have in this study (Figure 8). To independently investigate how the sites used in this analysis have their rainfall distributed, a small analysis was performed to identify when rain fell. This is shown below;
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The figure highlights how the rainfall distribution profiles vary geographically. This presents a potential error, given all sites were analysed identically. Initially, November – February was selected as the monsoonal rainfall as a method to attempt to isolate only the monsoonal impact of ENSO, as this was where the majority of the effects were expected to present themselves. However, moving west, it is evident that certain locations are affected by the monsoon in different months. Notably, Broome and Darwin appear to receive much more of their rainfall in January when compared to the other locations which generally receive a significant amount more in February in comparison to January.

Similarly to Figure 17, Figure 18 also notes the potential error caused by not including March. In Balmoral and Dampier, March is observed to be the second wettest month of the year, and a (relatively) drier December. It could have been useful to factor in the geographical phase lags when calculating the monsoon rainfall by assessing the actual monsoon season for each region in either an average or per year basis (as monsoon season will actually be different year to year).

Different regions also have different cyclone behaviours, for example Figure 19 shows the cyclone frequency at Dampier and Karratha per month from 1910 -2006. It highlights the substantial number of cyclones that occur in March in the region; more than any other month. This study was restricted to November – February, and as a result, this study would miss the rainfall derived from the March cyclones.
Throughout this study it has been shown that the area around Karratha and Dampier is subject to a significant amount of monsoonal rainfall, cyclones and off-coast anomalous warm sea surface temperatures. This location is susceptible to storm-surge flooding, but not major flooding, given it is not on a major river.

Incomplete data sets may have given incorrect KS test results. After analysing over 40 different rainfall sites, the amount of missing years of data in the middle of the operation time was quite significant. Under certain circumstances, there could have been large numbers of monsoon seasons missing when there were significant El Niño or La Niña events. However, given the time constraints, it was unreasonable to spend time assessing each set for suitability against individual events such as this. This also raises the issue of data set length requirements. For the KS tests, a minimum of 10 La Niña and 10 El Niño years was required, however it is unclear whether this is actually sufficient to make statistical conclusions. Similarly, errors could present themselves in the discontinuity of the data sets; for example, an El Niño set for one site could include monsoonal rainfalls many years apart.
6. Conclusion and Recommendations

From this study it appears that the El Niño southern oscillation, monsoonal rainfall, sea surface temperature anomalies and tropical cyclones are all closely connected. This is seemingly more significant for La Niña events. A likely system behaviour would be that a strong La Niña year causes stronger trade winds and higher western pacific SSTs. This system brings with it the expected increase in rainfall from cloud; while the winds also cause a stronger Leeuwin current down the west coast. The increased ocean temperatures around the lower NW coast, as well as stronger winds, cause tropical cyclone conditions. These tropical cyclones often carry a large amount of rainfall that they drop over regional centres. Regions like Dampier and Karratha with large amounts of anomalous SST heating in a La Niña event are subject to far more cyclones than those around them. The overall effect is that during a La Niña event more monsoonal rainfall occurs in clusters where we do not expect to see an ENSO effect.

From these results, it would seem that using the Kolmogorov-Smirnov test to check the significance of the effect the ENSO signal is having on rainfall is a useful method. It would however be useful to obtain rainfall data that has been filled to enable better analysis. CSIRO has indicated that there are hydrological data sets available for purchase that have been filled to allow for more accurate research. Further to this, comparison of the KS-test results to other data has shown that given the complex behaviour of the systems involved, more variables must be taken into account to yield a more accurate statistical understanding of the system. From current understanding and qualitative assessment of the data available, it would seem there is a significant amount of research left to be completed involving sea surface temperatures and the correlation this has with both the ENSO and tropical cyclones.

Further work should focus on understanding what magnitude SOI values will allow for attributing extreme behaviour of the SSTs and Leeuwin current to the ENSO signal. Following on from this, stronger analysis of rainfall carrying cyclones during El Niño and La Niña events need to be investigated to determine how much rain they bring in and how accurately SOI and SST data can be used to predict this.

Cyclone events should be investigated in conjunction with ENSO data by the following approach:

- The set of initial conditions for specific tropical cyclones should be established (Lead-up SOI, anomalous SST and location of formation, IOD value, SAM and sub-tropical ridge events)
- The path the cyclones took in relation to these initial conditions
- The effect of changing conditions on cyclone path and the strength category of the cyclone.
- The landfall location given the initial and changing conditions
- The amount of rainfall carried over land compared to the variables
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Work completed by Gregory Frampton in partnership with this study has researched some of the effects that cyclones have on rainfall in the Pilbara and Gascoyne regions. The preliminary study sets a basis for further analysis of tropical cyclones and illustrates how cyclones can be compared to different initial meteorological conditions. This study also showed that there appears to be a link between large outliers in rainfall and the outliers for the number of tropical cyclones. If the sea surface temperatures, SOI and IOD could be used to accurately predict the number of tropical cyclones and how they would behave, it would seem that anomalous large scale rainfall could be predicted in conjunction with long-term trends (climate change, decadal variations).

BOM (n.d.) already provides a fairly comprehensive tropical cyclone outlook, however they state that Tropical cyclones have historically had a reputation for being unpredictable and although the skill in track forecast has improved greatly, there has been much slower progress in intensity forecasting. This further highlights the need to see if the category and rainfall can be predicted from the initial and changing conditions.

The more work that can be done to quantify additional aspects of this study, the field moves closer to developing a complete understanding of how the climate and hydrology of Western Australia behaves. This can be used to create a safer, more productive environment for all sectors, and assist in future engineering design. As part of the wider scheme of hydrology and climatology, the more that can be understood and modelled, the closer the ability to prevent damage to the environment and civilisation by extreme events and climate change becomes.
7. References


8. Appendices
8.1 KS Test P-Values

<table>
<thead>
<tr>
<th>SITE NAME</th>
<th>BOM SITE ID</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>KS TEST P-VALUE (+5 SOI)</th>
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</table>
8.2 Matlab Codes

exec_rainfall.m

This function runs all the other codes included in the appendices as a function of just the file that needs to be operated on.

```matlab
function ans = exec_rainfall(file)
%exec_rainfall outputs a series of CSV files filtering & analysing data

% SOI_rainydays_monsoonseason_SITENAME.csv is in the form: (Year, days>1mm, days>10mm, days>25mm, SOI_index) where rainy days are for the 4 month monsoon period (nov-feb) and the SOI_index is for the 6 month runup to monsoon (may-october)

% monsoon_ave_2_SITENAME.csv is in the form (Year, average rain on raining day, SOI_index), rain is averaged over monsoon, SOI_index averaged over runup period

% n_rainy_days_(1,10,25)_SITENAME.csv is in the form (year, monthly rainy days greater than (1, 10, 25)mm of rain; binned per month)

% n_yearly_ave_rain_1_SITENAME.csv is in the form (year, rain averaged over raining day; binned monthly)

% n_yearly_total_rain_SITENAME.csv is in the form (year, total rain per month; binned monthly)

%NOTE: for some analysis, when first opening exported csv files, replace all NaN with blank cells.

for thresh=[1 10 25]
    n_rainydays(thresh,file);
end
n_yearlyrain(1,file);
n_yearlytotalrain(0,file);
monsoon_ave2(1,file);
rainydaysSOI(file);
monsoon_total(file);
monsoon_total_10(file);
monsoon_total_line(file);
end
```
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n_rainydays.m

function ans = n_rainydays(threshold,file)

% n_rainydays takes input as CSV file. Text headers removed, 5 columns. %
% top level function iterates year. Returns number of rainy days per month per %
% year for a given rainfall depth

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
st=num2str(threshold);
while year<2014
    x = betterallmonth2(threshold,year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['n_rainy_days_ ' st '_ ' file],out1);

function ans2 = betterallmonth2(threshold,year)
% betterallmonth2 counts number rainy days for all months
jj = 1;
out2=[];
for month = 1:12
    ndays = rainydays2(threshold,year,month);
    out2(jj,1)=year;
    out2(jj,month+1)=ndays;
end
ans2=out2;
end

function ans3 = rainydays2(threshold,year,month)
% rainydays2 checks that the data matches the current year & month,
% is over the threshold and is quality data.
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,4)>threshold && fullCSV(jj,2)==month
        ndays=ndays + 1;
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
ans3 = ndays;
end
n_yearlyrain.m

function ans = n_yearlyrain(threshold,file)

%average rainfall for each month of each year

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
st=num2str(threshold);
while year<2014
    x = monthlyrain(threshold,year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(["n_yearly_ave_rain_" st '_'] file,out1);

function ans2 = monthlyrain(threshold,year)

%jj = 1;
out2=[];
for month = 1:12
    ndays = rainfall(threshold,year,month);
    out2(jj,1)=year;
    out2(jj,month+1)=ndays;
end
ans2=out2;
end

function ans3 = rainfall(threshold,year,month)

%total=0;
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5) == 1 && fullCSV(jj,1) == year && 
    fullCSV(jj,4)>threshold && fullCSV(jj,2)==month
        ndays=ndays + 1;
        total=total + fullCSV(jj,4);
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
ans3 = total/ndays;
end
n_yearlytotalrain.m

function ans = n_yearlytotalrain(threshold,file)

%n_yearlytotalrain converts the daily row orientated file into a table of %year x month. Months running horizontally. The values are total monthly %rainfall. Threshold gives the value above which to count towards total %rain.

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
st=num2str(threshold);
while year<2014
    x = monthlyrain(threshold,year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['n_yearly_total_rain_' st '_' file'],out1);

function ans2 = monthlyrain(threshold,year)

%jj = 1;
out2=[];
for month = 1:12
    total = rainfall(threshold,year,month);
    out2(jj,1)=year;
    out2(jj,month+1)=total;
end
ans2=out2;
end

function ans3 = rainfall(threshold,year,month)

%total=0;
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,4)>threshold && fullCSV(jj,2)==month
        total=total + fullCSV(jj,4);
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
ans3 = total;
end
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monsoon_ave2.m

function ans = monsoon_ave2(threshold,file)

%monsoon_ave2 looks at the monsoon season from November-February and produces a table with the columns: Year, Average Rainfall, SOI. The SOI is called from a separate data sheet and is just the extreme values (5,-5,0). The average rainfall is calculated by counting the total amount of rain over the period and the number of days where rain exceeded the threshold. The SOI data is for the leadup period May-Oct.

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
st=num2str(threshold);
while year<2014
    x = monthlyrain(threshold,year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['monsoon_ave_' st '_'] file, out1);

function ans2 = monthlyrain(threshold,year)

%soi_data = csvread('soi_6month.csv');
jj = 1;ll=1;
out2=[];soi_index=0;
while ll<size(soi_data,1)
    if soi_data(ll,1)==year
        soi_index=soi_data(ll,3);
        ll=ll+1;
    else
        ll=ll+1;
    end
end

for month = 11
    [total1,ndays1] = rainfall(threshold,year,month);
end
for month = 12
    [total2,ndays2] = rainfall(threshold,year,month);
end
for month = 1
    [total3,ndays3] = rainfall(threshold,year+1,month);
end
for month = 2
    [total4,ndays4] = rainfall(threshold,year+1,month);
end
out2(jj,1)=year;
out2(jj,2)=(total1 + total2 + total3 + total4)/(ndays1+ndays2+ndays3+ndays4);
out2(jj,3)=soi_index;
ans2 = out2;
end

function [total, ndays] = rainfall(threshold,year,month)
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey

```matlab
total=0;
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,4)>threshold && fullCSV(jj,2)==month
        ndays=ndays + 1;
        total=total + fullCSV(jj,4);
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
```
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia  

Sean Coffey

rainydaysSOI.m

function ans = rainydaysSOI(file)

%rainydaysSOI produces a table with rows in years, and the columns: number %days exceeding 1mm rain, Days exceeding 10mm, days exceeding 25mm rain, %SOI (absolute +5, -5, 0).
%The data is only for the monsoon season running Nov-Feb. The SOI data is %for the monsoon lead-up period May-Oct

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
while year<2014
    x = monthlyrain(year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['SOI_rainydays_monsoonseason_' file],out1);

function ans2 = monthlyrain(year)

%soi_data=csvread('soi_6month.csv');
jj = 1;ll=1;
out2=[];soi_index=0;
while ll<size(soi_data,1)
    if soi_data(ll,1)==year
        soi_index=soi_data(ll,3);
    end
    ll=ll+1;
end
for month = 11
    ndays11 = rainfall(1,year,month);
    ndays110 = rainfall(10,year,month);
    ndays125 = rainfall(25,year,month);
end
for month = 12
    ndays21 = rainfall(1,year,month);
    ndays210 = rainfall(10,year,month);
    ndays225 = rainfall(25,year,month);
end
for month = 1
    ndays31 = rainfall(1,year+1,month);
    ndays310 = rainfall(10,year+1,month);
    ndays325 = rainfall(25,year+1,month);
end
for month = 2
    ndays41 = rainfall(1,year+1,month);
    ndays410 = rainfall(10,year+1,month);
    ndays425 = rainfall(25,year+1,month);
end
out2(jj,1)=year;
out2(jj,2)=(ndays11+ndays21+ndays31+ndays41);
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey

out2(jj, 3) = (ndays110 + ndays210 + ndays310 + ndays410);
out2(jj, 4) = (ndays125 + ndays225 + ndays325 + ndays425);
out2(jj, 5) = soi_index;
ans2 = out2;
end

function ndays = rainfall(threshold, year, month)
% ndays = 0; jj = 1;
while jj < size(fullCSV, 1)
    if fullCSV(jj, 5) == 1 && fullCSV(jj, 1) == year &&
        fullCSV(jj, 4) > threshold && fullCSV(jj, 2) == month
        ndays = ndays + 1;
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
end
function ans = monsoon_total(file)
%monsoon_total operates almost exactly the same way rainydaysSOI operates, %but the cells are populated with the total rain over the monsoon period.
fullCSV = csvread(file);
year = fullCSV(:,1);
out1=[];
ii=1;
while year<2014
    x = monthlyrain(year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['monsoon_total_ ' file],out1);

function ans2 = monthlyrain(year)
%soi_data=csvread('soi_6month.csv');
jj = 1;ll=1;
out2=[];soi_index=0;
while ll<size(soi_data,1)
    if soi_data(ll,1)==year
        soi_index=soi_data(ll,3);
        ll=ll+1;
    else
        ll=ll+1;
    end
end
for month = 11
    [total1,ndays1] = rainfall(year,month);
end
for month = 12
    [total2,ndays2] = rainfall(year,month);
end
for month = 1
    [total3,ndays3] = rainfall(year+1,month);
end
for month = 2
    [total4,ndays4] = rainfall(year+1,month);
end
out2(jj,1)=year;
out2(jj,2)=(total1 + total2 + total3 + total4); 
out2(jj,3)=soi_index;
ans2 = out2;
end
function [total, ndays] = rainfall(year,month)
%total=0;
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,2)==month
        ndays=ndays + 1;
        total=total + fullCSV(jj,4);
        jj = jj + 1;
    else
        jj = jj + 1;
    end

end
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Sean Coffey
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey

monsoon_total_10.m

function ans = monsoon_total_10(file)

fullCSV = csvread(file);
year = fullCSV(1,1);
out1=[];
ii=1;
while year<2014
    x = monthlyrain(year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans = out1;
csvwrite(['monsoon_total_10_' file], out1);

function ans2 = monthlyrain(year)
    soi_data = csvread('soi_6month.csv');
    jj = 1; ll=1;
    out2=[]; soi_index=0;
    while ll<size(soi_data,1)
        if soi_data(ll,1)==year
            soi_index = soi_data(ll,4);
            ll = ll+1;
        else
            ll = ll+1;
        end
    end
    for month = 11
        [total1,ndays1] = rainfall(year,month);
    end
    for month = 12
        [total2,ndays2] = rainfall(year,month);
    end
    for month = 1
        [total3,ndays3] = rainfall(year+1,month);
    end
    for month = 2
        [total4,ndays4] = rainfall(year+1,month);
    end
    out2(jj,1)=year;
    out2(jj,2)=(total1 + total2 + total3 + total4);
    out2(jj,3)=soi_index;
    ans2 = out2;
end

function [total, ndays] = rainfall(year,month)
    total=0;
    ndays=0; jj=1;
    while jj<size(fullCSV,1)
        if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,2)==month
            ndays=ndays + 1;
            total=total + fullCSV(jj,4);
            jj = jj + 1;
        else
            jj = jj + 1;
        end
    end
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey

```matlab
function ans = monsoon_total_line(file)
fullCSV = csvread(file);
year = fullCSV(1,:);
out1=[];
ii=1;
while year<2014
    x = monthlyrain(year);
    out1(ii,:) = x;
    year = year + 1;
    ii = ii + 1;
end
ans=out1;
csvwrite(['monsoon_total_line' file],out1);

function ans2 = monthlyrain(year)
% soi_data=csvread('soi_6month.csv');
jj = 1;ll=1;
out2=[];soi_index=0;
while ll<size(soi_data,1)
    if soi_data(ll,1)==year
        soi_index=soi_data(ll,3);
        ll=ll+1;
    else
        ll=ll+1;
    end
end
for month = 11
    [total1,ndays1] = rainfall(year,month);
end
for month = 12
    [total2,ndays2] = rainfall(year,month);
end
for month = 1
    [total3,ndays3] = rainfall(year+1,month);
end
for month = 2
    [total4,ndays4] = rainfall(year+1,month);
end
out2(jj,1)=year;
out2(jj,2)=(total1 + total2 + total3 + total4);
out2(jj,3)=(ndays1 + ndays2 + ndays3 + ndays4);
out2(jj,4)=soi_index;
ans2 = out2;
end
function [total, ndays] = rainfall(year,month)
% total=0;
ndays=0; jj=1;
while jj<size(fullCSV,1)
    if fullCSV(jj,5)==1 && fullCSV(jj,1)==year && fullCSV(jj,2)==month
        ndays=ndays + 1;
        total=total + fullCSV(jj,4);
        jj = jj + 1;
    else
        jj = jj + 1;
    end
end
```
Investigating the effects of the El Niño southern oscillation on rainfall across northern Australia

Sean Coffey
8.3 Jakarta Data
Data was approximated from graph provided from study conducted by Keith Smettem.

<table>
<thead>
<tr>
<th>SOI</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-26</td>
<td>130</td>
</tr>
<tr>
<td>-24</td>
<td>130</td>
</tr>
<tr>
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<tr>
<td>-17</td>
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<tr>
<td>-17</td>
<td>180</td>
</tr>
<tr>
<td>-14</td>
<td>210</td>
</tr>
<tr>
<td>-10</td>
<td>230</td>
</tr>
<tr>
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</tr>
<tr>
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<td>310</td>
</tr>
<tr>
<td>-13</td>
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<tr>
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<tr>
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</tr>
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<tr>
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<tr>
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<td>840</td>
</tr>
</tbody>
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