JP4.1 BRIDGING THE "MIDDLE GROUND" BETWEEN MEDIUM RANGE WEATHER FORECASTING AND CLIMATE PREDICTION: VERIFYING THE ACCURACY OF 14 DAY OUTLOOKS

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1. BACKGROUND

1.1 *Bridging the "middle ground" between medium range and climate forecasts*

THORPEX addresses the influence of sub-seasonal time-scales on high-impact forecasts out to two weeks, and thereby aspires to bridge the "middle ground" between medium range weather forecasting and climate prediction (Shapiro and Thorpe, 2004).

There are two aspects of climate prediction that are touched on in this paper, firstly, climate prediction on the monthly and seasonal scale and, secondly, climate prediction on the scale of many decades.

In Australia, the Bureau of Meteorology presently issues its Seasonal Climate Outlook (SCO) about two weeks prior to the three-month period for which the outlook is valid. The output of global climate models and statistical analyses of the influence of sea surface temperature anomalies over the Pacific and Indian Oceans on Australian seasonal climate (Appendix 1, Map A1.1, Plate A1.1, Figures A1.1a, b, c, d, e, f, g, h, I, j, k, l) are amongst the information utilised to generate the SCO, and work aimed at automatically generating worded seasonal climate outlooks (Stern, 2008a), and also worded monthly climate outlooks, is presently underway (Appendix 2, Figures A2.1 & A2.2), although the nature of the statistical relationships between predictors, such as the Southern Oscillation Index, and predictands, such as rainfall, appears to have changed with the passing of the decades (Appendix 2, Figures A2.3, A2.4 & A2.5).

It may be useful to bridge the two-week gap with a set of day-to-day forecasts out to 14 days, derived from the output of Numerical Weather Prediction (NWP) models. By way of underlining the importance of bridging this gap, the very same experimental forecasting system that automatically generates the worded seasonal climate outlooks, has been applied here to the task of generating the day-to-day forecasts out to 14 days (Figure 1).

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1.2 *The limits of "day-to-day" predictive capability*

In 1999, the present author conducted an experiment (Stern, 1999) to establish the limits of day-to-day predictive capability for the southeast Australian city of Melbourne (Aust. Meteor. Mag., 48:159-167). The results of the experiment, which involved verifying a set of quantitative forecasts for Melbourne out to 14 days, were presented. The data indicated that, even in 1999, it might have been possible to make useful statements about the expected *average* weather conditions over the 10-day period between days 5 and 14.

In a subsequent (Stern, 2005) paper (Aust. Meteor. Mag., 54:203-211), the present author presented the results of a repeat of the earlier experiment, noting that the work of Lorenz suggested that there is a 15-day limit to day-to-day predictability of the atmosphere. The 2005 paper reported that the results obtained therein suggested emerging evidence that there may now be some *day-to-day* forecast skill out to Lorenz's (1963, 1969a&b, 1993) 15-day limit, particularly for temperature.

2. INTRODUCTION

2.1 *A "real-time" trial*

A "real-time" trial (Stern, 2007) of a methodology utilised to generate Day-1 to Day-7 forecasts, by mechanically integrating (that is, combining) judgmental (human) and automated predictions, has been ongoing since 20 August 2005 (BAMS, June 2007, 88:850-851).

The methodology has been demonstrated to result in an increase in the accuracy of forecasts for a broad range of weather elements (Table 1).

2.2 *Extending forecasts out to Day-10*

In August 2006, the forecast period was extended to Day 10, by combining climatology and automated predictions. The encouraging performance of the Day-8 to Day-10 component was reported last year in a paper by the present author (Stern, 2008b) asking the question, "Does society benefit from very long range day-to-day weather forecasts?" (Symposium on Linkages among Societal Benefits, Prediction Systems and Process Studies for 1-14-day Weather Forecasts, New Orleans, Louisiana, USA, 23 Jan., 2008).

Figure 2 shows that the overall percentage variance of the observed weather explained by the forecast weather in a set of regression relationships between observed and forecast weather elements falls to about 10% by Day-8, and to about 5% by Day-10.

3. PURPOSE

3.1 *"Real-time" calculations of evapotranspiration rates*

In December 2008, a request was received to evaluate a model for "real-time" calculation of evapotaranspiration based on observed data. The subsequent investigation, "An evaluation of the South Australian evapotranspiration model using FAO-56 guidelines" by James Lannan (Internal Bureau of Meteorology Report, February 2009), found that the South Australian model had correctly followed FAO-56 guidelines in the calculation of evapotranspiration rates.

3.2 *Long-range forecasting of evapotranspiration rates*

The industry had indicated that it would not only like to be provided with calculations of observed evapotranspiration, but also with forecasts of expected evapotranspiration out to several weeks. The reason for this requirement is that it would enable planning for future water purchases.

3.3 *Motivation derives from downward trend in rainfall*

The motivation for this determination to plan derives, in part, from the observed long-term downward trend in rainfall over much of southern Australia, except during summer, which has been attributed to the strengthening and southward shift of the sub-tropical ridge (Appendix 3, Figures A3.1a, b, & c) and the corresponding retreat of the mid-latitude westerlies. This may be attributed to the Southern Annular Mode (Gillett *et al*., 2006) (Figure A3.2) undergoing a long-term transformation towards its positive phase.

3.4 *Extending forecasts out to Day-14*

Notwithstanding the encouraging performance of the Day-8 to Day-10 forecasts referred to earlier, some doubt exists about our capability at providing useful forecasts beyond Day-10. In January 2009, the system was extended so as to provide forecasts out to 14 days in order to assess that capability. The purpose of the present paper is to report on that assessment.

4. RESULTS

4.1 *Ongoing trial of the Day-1 to Day-7 forecasts*

Regarding the ongoing trial of the Day-1 to Day-7 forecasts, generated by mechanically integrating (that is, combining) judgmental (human) and automated predictions, which has been ongoing since 20 August 2005:

- The percentage increase (to 13 June 2009) in how often forecasts of whether or not there was going to be measurable precipitation at Melbourne was 6.4%, that is, mechanically integrating resulted in an enhanced performance at predicting whether or not there was going to be measurable precipitation at Melbourne; and,
- The average decrease (to 13 June 2009) in the Mean Square Error of the minimum and maximum temperature forecasts for Melbourne was 0.80ºC, that is, mechanically integrating resulted in an enhanced performance at predicting minimum and maximum temperature at Melbourne.
- The Critical Success Index for fog predictions for Melbourne (to 13 June 2009) was increased to 16.3% (from 14.3%), that is, mechanically integrating resulted in an enhanced performance at predicting fog at Melbourne.
- The Critical Success Index for thunderstorm predictions for Melbourne (to 13 June 2009) was increased to 17.2% (from 15.4%), that is, mechanically integrating resulted in an enhanced performance at predicting thunderstorms at Melbourne.

4.2 *The new trial of the Day-11 to Day-14 forecasts*

Regarding the new trial of the Day-11 to Day-14 component of the forecasts, that has been ongoing since it was first generated on 18 January 2009:

- The correlation coefficient (after 133 sets of forecasts) between the observed amounts of precipitation[1] (expressed as a departure from normal at that time of the year of the square root of the amount observed) and the corresponding Quantitative Precipitation Forecasts (QPFs)[2] (also expressed as a departure from normal at that time of the year of the square root of the amount forecast) was

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[1] The observed amount of precipitation is set equal to 0.05mm in the event of no measurable precipitation and an observation of distant precipitation, thunder, lightning, and/or funnel cloud, and to 0.1mm in the event of an observation of a trace of precipitation.

[2] The QPF is set equal to 0.05mm in the event of a forecast of no precipitation together with a forecast of "Possible Shower".

+0.144, the percentage variance of the observed amount of precipitation explained by the QPFs in a regression relationship between observed and forecast precipitation amount, being 2.06%, the "t" statistic associated with that regression relationship being +3.39, and the probability that this "t" statistic being at least +3.39 by chance being 0.09%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting precipitation amount between Day-11 and Day-14 was relatively small, as illustrated in Figure 3, that skill was not achieved through chance.

- The correlation coefficient between the observed Probabilities of Precipitation (PoPs)[3] (expressed as a departure from normal) and the corresponding forecast PoPs[4] (also expressed as a departure from normal) was +0.151, the percentage variance of the observed PoPs explained by the PoP Forecasts in a regression relationship between observed and forecast PoPs, being 2.29%, the "t" statistic associated with that regression relationship being +3.52, and the probability that this "t" statistic being at least +3.52 by chance being 0.02%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting PoP between Day-11 and Day-14 was relatively small, as illustrated in Figure 4, that skill was not achieved through chance.
- The correlation coefficient between the observed minimum temperatures (expressed as a departure from normal) and the corresponding forecast minimum temperatures (also expressed as a departure from normal) was +0.067, the percentage variance of the observed minimum temperature explained by the minimum temperature forecasts in a regression relationship between observed and forecast minimum temperature, being 0.45%, the "t" statistic associated with that regression relationship being +1.54, and the probability that the "t" statistic is of a magnitude no greater than +1.54 by chance being 6.20%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting minimum temperature between Day-11 and Day-14 was relatively small, as illustrated in Figure 5, that skill was not achieved through chance.
- The correlation coefficient between the observed maximum temperatures (expressed as a departure from normal) and the corresponding forecast maximum temperatures (also expressed as a departure from normal) was +0.141, the percentage variance of the observed maximum temperature explained by the maximum temperature forecasts in a regression relationship between observed and forecast maximum temperature, being 1.97%, the "t" statistic associated with that regression relationship being +3.27, and the probability that this "t" statistic being at least +3.27 by chance being 0.06%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting maximum temperature between Day-11 and Day-14 was relatively small, as illustrated in Figure 6, that skill was not achieved through chance.

Overall, across the four weather elements, the forecasting of which were verified, only about 2% of the observed variance was explained by the amount of precipitation, probability of precipitation, and maximum temperature forecasts, and less than 1% of the observed variance was explained by the minimum temperature forecasts. However, one may be confident that the low level of skill achieved did not arise through chance.

Furthermore, it is also useful to observe that none of the four "t" statistics associated with the elements to be predicted - precipitation amount, precipitation probability, minimum temperature, and maximum temperature - was less than +1.54. The probability of this occurring by chance is only 0.001%, suggesting that, whilst the overall level of skill that was achieved during the trial was relatively small, there is additional justification for asserting that the skill was not achieved through chance.

Now, specifically regarding the new trial of the *Day-11 component of the forecasts*, that has been ongoing since it was first generated on 18 January 2009:

- The correlation coefficient (after 133 forecasts) between the observed amounts of precipitation (expressed as a departure from normal at that time of the year of the square root of the amount observed) and the corresponding Quantitative Precipitation Forecasts (QPFs) (also expressed as a departure from normal at that time of the year of the square root of the amount forecast) was +0.204, the

[3] The observed PoP is set equal to 100% in the event of measurable precipitation, to 50% in the event of a trace of precipitation, and to 25% in the event of distant precipitation.

[4] The observed PoP is set equal to 100% in the event of measurable precipitation, to 50% in the event of a trace of precipitation, and to 25% in the event of distant precipitation.

percentage variance of the observed amount of precipitation explained by the QPFs in a regression relationship between observed and forecast precipitation amount, being 4.17%, the “t” statistic associated with that regression relationship being +2.39, and the probability that this “t” statistic being at least +2.39 by chance being 0.92%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting precipitation amount for Day-11 was relatively small, that skill was not achieved through chance.

- The correlation coefficient between the observed Probabilities of Precipitation (PoPs) (expressed as a departure from normal) and the corresponding forecast PoPs (also expressed as a departure from normal) was +0.248, the percentage variance of the observed PoPs explained by the PoP Forecasts in a regression relationship between observed and forecast PoPs, being 6.17%, the “t” statistic associated with that regression relationship being +2.94, and the probability that this “t” statistic being at least +2.94 by chance being 0.20%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting PoP for Day-11 was relatively small, that skill was not achieved through chance.
- The correlation coefficient between the observed minimum temperatures (expressed as a departure from normal) and the corresponding forecast minimum temperatures (also expressed as a departure from normal) was +0.134, the percentage variance of the observed minimum temperature explained by the minimum temperature forecasts in a regression relationship between observed and forecast minimum temperature, being 1.79%, the “t” statistic associated with that regression relationship being +1.54, and the probability that the “t” statistic is of a magnitude no greater than +1.54 by chance being 6.25%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting minimum temperature for Day-11 was relatively small, that skill was not achieved through chance.
- The correlation coefficient between the observed maximum temperatures (expressed as a departure from normal) and the corresponding forecast maximum temperatures (also expressed as a departure from normal) was +0.256, the percentage variance of the observed maximum temperature explained by the maximum temperature forecasts in a regression relationship between observed and forecast maximum temperature, being 6.54%, the “t” statistic associated with that regression relationship being +2.98, and the probability that this “t” statistic being at least +2.98 by chance being 0.15%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting maximum temperature for Day-11 was relatively small, that skill was not achieved through chance.

Now, specifically regarding the new trial of the *Day-12 component of the forecasts*, that has been ongoing since it was first generated on 18 January 2009:

- The correlation coefficient (after 133 forecasts) between the observed amounts of precipitation (expressed as a departure from normal at that time of the year of the square root of the amount observed) and the corresponding Quantitative Precipitation Forecasts (QPFs) (also expressed as a departure from normal at that time of the year of the square root of the amount forecast) was +0.217, the percentage variance of the observed amount of precipitation explained by the QPFs in a regression relationship between observed and forecast precipitation amount, being 4.71%, the “t” statistic associated with that regression relationship being +2.55, and the probability that this “t” statistic being at least +2.55 by chance being 0.60%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting precipitation amount for Day-12 was relatively small, that skill was not achieved through chance.
- The correlation coefficient between the observed Probabilities of Precipitation (PoPs) (expressed as a departure from normal) and the corresponding forecast PoPs (also expressed as a departure from normal) was +0.236, the percentage variance of the observed PoPs explained by the PoP Forecasts in a regression relationship between observed and forecast PoPs, being 5.57%, the “t” statistic associated with that regression relationship being +2.78, and the probability that this “t” statistic being at least +2.78 by chance being 0.31%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting PoP for Day-12 was relatively small, that skill was not achieved through chance.

- The correlation coefficient between the observed minimum temperatures (expressed as a departure from normal) and the corresponding forecast minimum temperatures (also expressed as a departure from normal) was +0.159, the percentage variance of the observed minimum temperature explained by the minimum temperature forecasts in a regression relationship between observed and forecast minimum temperature, being 2.51%, the “t” statistic associated with that regression relationship being +1.84, and the probability that the “t” statistic is of a magnitude no greater than +1.84 by chance being 3.42%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting minimum temperature for Day-12 was relatively small, that skill was not achieved through chance.
- The correlation coefficient between the observed maximum temperatures (expressed as a departure from normal) and the corresponding forecast maximum temperatures (also expressed as a departure from normal) was +0.198, the percentage variance of the observed maximum temperature explained by the maximum temperature forecasts in a regression relationship between observed and forecast maximum temperature, being 3.90%, the “t” statistic associated with that regression relationship being +2.31, and the probability that this “t” statistic being at least +2.31 by chance being 1.13%. One may therefore be confident that, whilst the level of skill that was achieved during the trial at forecasting maximum temperature for Day-12 was relatively small, that skill was not achieved through chance.

Now, specifically regarding the new trial of the *__Day-13 component of the forecasts__*, that has been ongoing since it was first generated on 18 January 2009:

- The correlation coefficient (after 133 forecasts) between the observed amounts of precipitation (expressed as a departure from normal at that time of the year of the square root of the amount observed) and the corresponding Quantitative Precipitation Forecasts (QPFs) (also expressed as a departure from normal at that time of the year of the square root of the amount forecast) was +0.090, the percentage variance of the observed amount of precipitation explained by the QPFs in a regression relationship between observed and forecast precipitation amount, being 0.81%, the “t” statistic associated with that regression relationship being +1.03, and the probability that this “t” statistic being at least +1.03 by chance being 15.14%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting precipitation amount for Day-13 relatively small, that skill could very well have been achieved through chance.
- The correlation coefficient between the observed Probabilities of Precipitation (PoPs) (expressed as a departure from normal) and the corresponding forecast PoPs (also expressed as a departure from normal) was +0.072, the percentage variance of the observed PoPs explained by the PoP Forecasts in a regression relationship between observed and forecast PoPs, being 0.52%, the “t” statistic associated with that regression relationship being +0.41, and the probability that this “t” statistic being at least +0.41 by chance being 20.50%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting PoP for Day-13 relatively small, that skill could very well have been achieved through chance.
- The correlation coefficient between the observed minimum temperatures (expressed as a departure from normal) and the corresponding forecast minimum temperatures (also expressed as a departure from normal) was -0.021, the negative value suggesting that the Day-13 minimum temperature forecasts possess no useful predictive skill.
- The correlation coefficient between the observed maximum temperatures (expressed as a departure from normal) and the corresponding forecast maximum temperatures (also expressed as a departure from normal) was +0.022, the percentage variance of the observed maximum temperature explained by the maximum temperature forecasts in a regression relationship between observed and forecast maximum temperature, being 0.04%, the “t” statistic associated with that regression relationship being +0.26, and the probability that this “t” statistic being at least +0.26 by chance being 39.92%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting maximum temperature for Day-13 relatively small, that skill could very well have been achieved through chance.

Now, specifically regarding the new trial of the *Day-14 component of the forecasts*, that has been ongoing since it was first generated on 18 January 2009:

- The correlation coefficient (after 133 forecasts) between the observed amounts of precipitation (expressed as a departure from normal at that time of the year of the square root of the amount observed) and the corresponding Quantitative Precipitation Forecasts (QPFs) (also expressed as a departure from normal at that time of the year of the square root of the amount forecast) was +0.068, the percentage variance of the observed amount of precipitation explained by the QPFs in a regression relationship between observed and forecast precipitation amount, being 0.46%, the "t" statistic associated with that regression relationship being +0.78, and the probability that this "t" statistic being at least +0.78 by chance being 21.88%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting precipitation amount for Day-14 relatively small, that skill could very well have been achieved through chance.
- The correlation coefficient between the observed Probabilities of Precipitation (PoPs) (expressed as a departure from normal) and the corresponding forecast PoPs (also expressed as a departure from normal) was +0.073, the percentage variance of the observed PoPs explained by the PoP Forecasts in a regression relationship between observed and forecast PoPs, being 0.53%, the "t" statistic associated with that regression relationship being +0.40, and the probability that this "t" statistic being at least +0.40 by chance being 20.19%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting PoP for Day-14 relatively small, that skill could very well have been achieved through chance.
- The correlation coefficient between the observed minimum temperatures (expressed as a departure from normal) and the corresponding forecast minimum temperatures (also expressed as a departure from normal) was -0.031, the negative value suggesting that the Day-14 minimum temperature forecasts possess no useful predictive skill.
- The correlation coefficient between the observed maximum temperatures (expressed as a departure from normal) and the corresponding forecast maximum temperatures (also expressed as a departure from normal) was +0.088, the percentage variance of the observed maximum temperature explained by the maximum temperature forecasts in a regression relationship between observed and forecast maximum temperature, being 0.77%, the "t" statistic associated with that regression relationship being +1.01, and the probability that this "t" statistic being at least +1.01 by chance being 15.69%. One may therefore be justified in asserting that, not only was the level of skill that was achieved during the trial at forecasting maximum temperature for Day-14 relatively small, that skill could very well have been achieved through chance.

4.3 *Forecasting extreme events*

During the period of the trial, Melbourne registered its all-time record maximum temperature of 46.4ºC on 7 February. The long-term average maximum temperature for the first 10 days of February is 26.7ºC, but the predictions 14 and 13 days in advance were for below normal maximum temperatures of 25ºC and 26ºC, respectively. However, the predictions 12 and 11 days in advance were better, being for above normal maximum temperatures of 27ºC and 28ºC, respectively.

The coldest night during the trial period was 29/30 April, when 2.9ºC was recorded. This was Melbourne's coldest April night since 1957. The long-term average minimum temperature for the last 10 nights of April is 11.3ºC, but the predictions 14, 13, 12, and 11 days in advance, being 11ºC, 11ºC, 11ºC, and 10ºC, respectively, all suggested that the overnight minima would only be very slightly below normal.

The wettest day during the trial period was 14 March, when 20.4mm was recorded. Predictions 14, 13, 12, and 11 days in advance all failed to indicate the possibility of such a heavy fall of rain occurring, being *Nil*, *0.05mm ("Possible Shower")*, *Nil*, and *Nil*, respectively.

5. CONCLUDING REMARKS

This paper has explored whether or not it is now time to bridge the two-week gap between medium range weather forecasting and climate prediction with a set of day-to-day forecasts out to 14 days, derived from an interpretation of the output of Numerical Weather Prediction (NWP) models.

With this in mind, the performance of a system, at predicting Day-11 to Day-14 amount and probability of precipitation, and at predicting Day 11 to Day-14 minimum and maximum temperature, has been reported upon. It was found that although the overall skill displayed by the forecasts was small, that skill was not achieved by chance. However, there was little indication that extreme events could be forecast 11 to 14 days in advance.

Analysis of the performance on a day-to-day basis indicates that the overall skill achieved derives largely from the performance of the Day-11 and Day-12 predictions, and that there is little evidence of any skill being displayed by the Day-13 and Day-14 predictions.

6. REFERENCES

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Enhanced forecast accuracy for various weather elements.

Element	Verification parameter	Human (official)	Combined
All elements	% variance explained	33.40	41.30
Rain or no rain	% correct	70.10	76.80
Rain amount	RMS error ($mm^{0.5}$)	1.05	0.97
Min temp	RMS error (°C)	2.39	2.27
Max temp	RMS error (°C)	2.82	2.49
Thunder	Critical Success Index (%)	17.90	21.60
Fog	Critical Success Index (%)	15.50	17.80

Table 1 The application of a methodology, that generates forecasts by mechanically integrating (that is, combining) judgmental (human) and automated predictions, has been has been demonstrated to result in an increase in the accuracy of forecasts for a broad range of weather elements (from Stern, 2007).

Day & Date	Morning	Afternoon	Min Temp (deg C)	Max Temp (deg C)	Precip Amount (mm)	Precip Prob (%)	9am Wind/ 3pm Wind Melb Apt (km/hr)
Sat-21-3-2009	Sunny.	Partly Cloudy.	17	33	0	9	N 25 N 25
Sun-22-3-2009	Shower.	Shower.	19	24	1.1	57	WSW 8 S 15
Mon-23-3-2009	Cloudy.	Sunny.	13	21	0	27	SW 15 S 15
Tue-24-3-2009	Fog.	Sunny.	12	23	0	15	VRB 3 S 15
Wed-25-3-2009	Partly Cloudy.	Cloudy.	14	25	0	34	N 25 N 25
Thu-26-3-2009	Partly Cloudy.	Cloudy.	14	26	0	33	N 8 S 15
Fri-27-3-2009	Cloudy.	Sunny.	14	23	0	27	W 8 S 15
Sat-28-3-2009	Cloudy.	Sunny.	14	24	0	22	N 15 WSW 15
Sun-29-3-2009	Fog.	Partly Cloudy.	14	24	0	21	N 8 S 15
Mon-30-3-2009	Partly Cloudy.	Partly Cloudy.	14	25	0	25	N 8 N 15
Tue-31-3-2009	Cloudy.	Sunny.	15	24	0	28	SSE 8 S 15
Wed-1-4-2009	Mist.	Partly Cloudy.	13	21	0	39	SW 15 S 25
Thu-2-4-2009	Possible Shower.	Possible Shower.	12	21	0	45	WSW 8 S 15
Fri-3-4-2009	Possible Shower.	Possible Shower.	13	21	0	42	SW 15 S 25

Figure 1 The 14-Day forecast for Melbourne valid from Sat 21-3-2009 to Fri 3-4-2009.

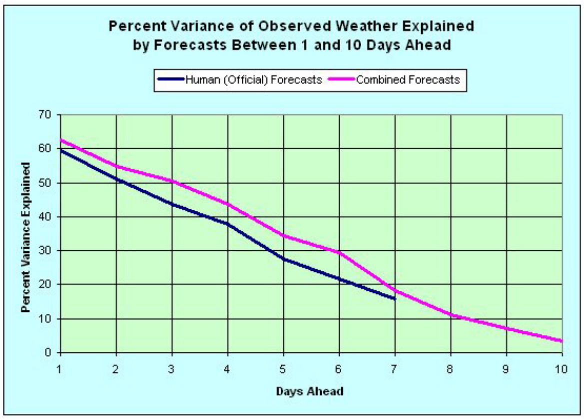


Figure 2 The overall performance of Day-1 to Day-7 forecasts generated by combining automated predictions with human predictions (20 August 2005 to 19 August 2007), and Day-8 to Day-10 forecasts generated by combining automated predictions with climate normals (20 August 2006 to 19 August 2007) as measured by the overall percentage variance of the observed weather elements explained by the forecast weather elements in a set of regression relationships between observed and forecast weather elements (from Stern, 2008).

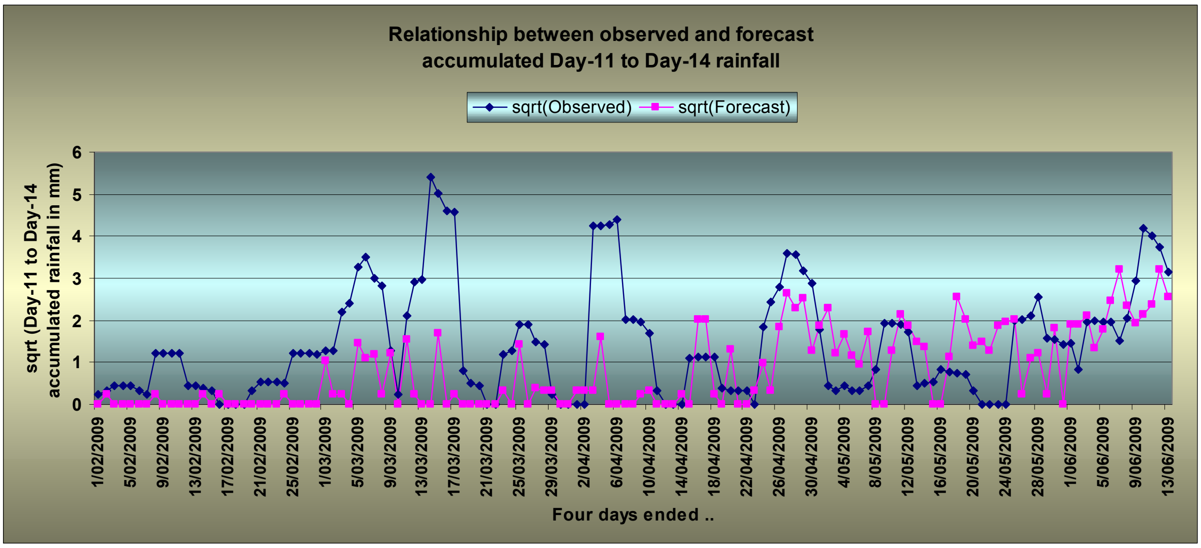


Figure 3 The relationship between observed and forecast accumulated Day-11 to Day-14 rainfall. Although the relatively dry period during February was well forecast, as well as the wet periods during March, April, and early June, a substantial bias towards under-forecasting rainfall amount is also evident.

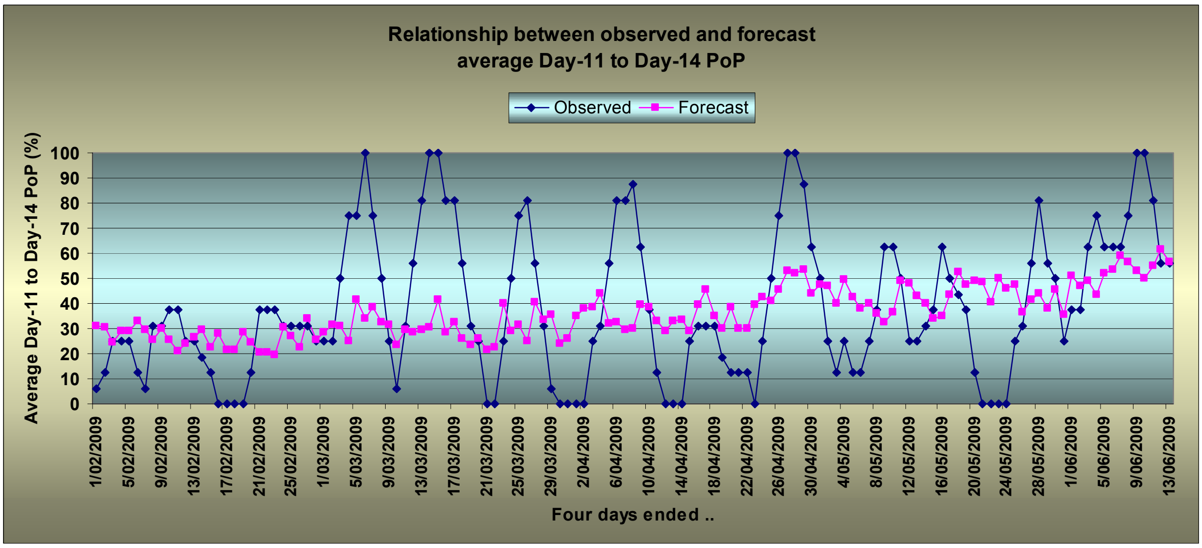


Figure 4 The relationship between observed and forecast average Day-11 to Day-14 PoP. The relationship is clearly quite weak, although there was some indication of the wet periods in March, April, and early June.

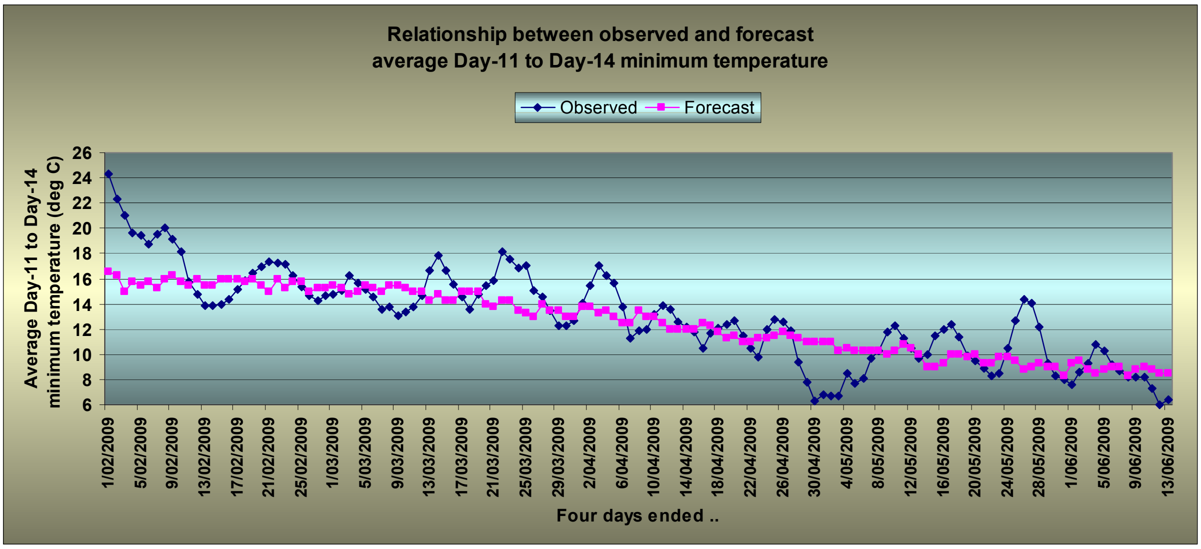


Figure 5 The relationship between observed and forecast average Day-11 to Day-14 minimum temperature. The relationship is clearly quite weak, although there is some suggestion of the relatively warm period leading up to 1-Feb and also the cool period leading up to 30-Mar.

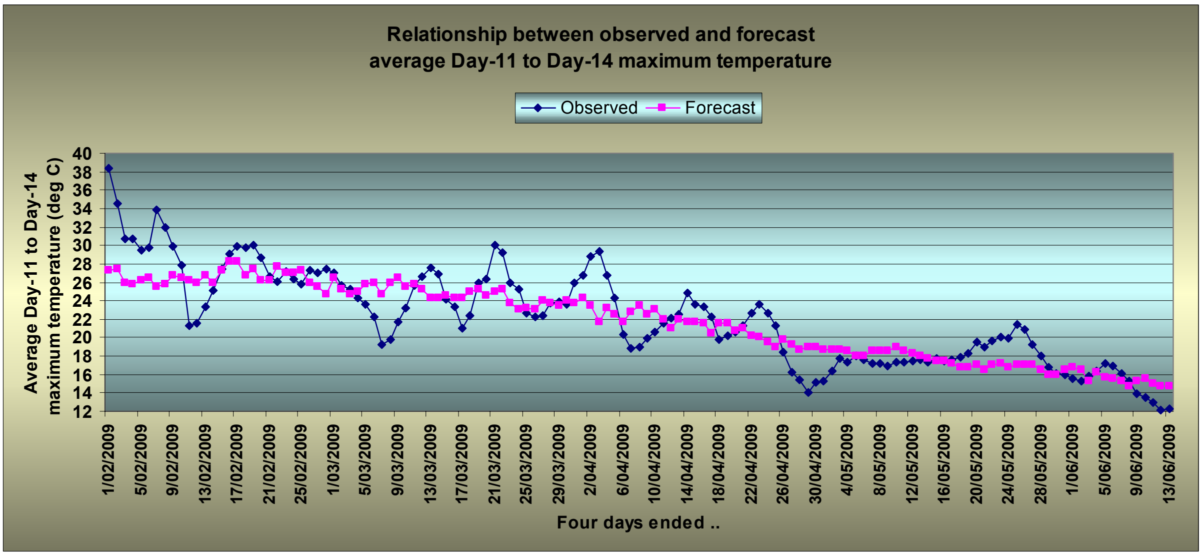
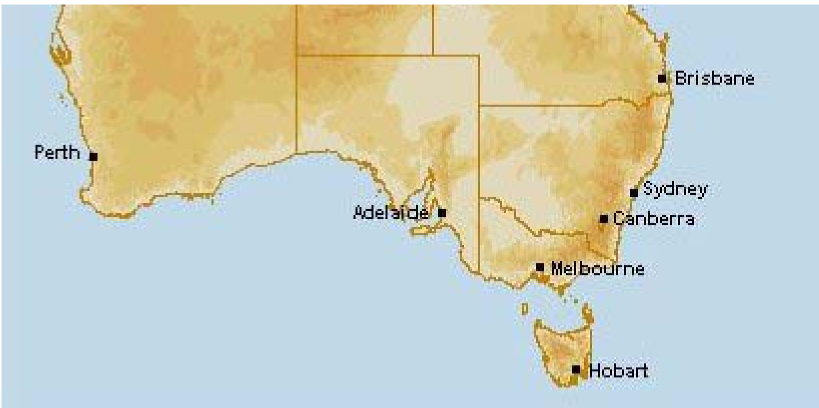


Figure 6 The relationship between observed and forecast average Day-11 to Day-14 maximum temperature. The relationship is clearly quite weak, although there is some suggestion of the relatively warm period leading up to 18-Feb and also the cool period leading up to 7-Mar.

APPENDIX 1. THE INFLUENCE OF SEA SURFACE TEMPERATURE ANOMALIES OVER THE PACIFIC AN INDIAN OCEANS: A FOCUS UPON IMPACTS ON RAINFALL AT MELBOURNE AND BRISBANE.



Map A1.1 Location map.

Probability of a dry season at Melbourne =

$$\exp(-0.603+0.250*DMI+0.084*MEI -0.241*DMI*\sin D-0.088*DMI*\cos D-0.064*DMI*\sin 2D-0.042*DMI*\cos 2D -0.162*MEI*\sin D-0.113*MEI*\cos D-0.034*MEI*\sin 2D-0.052*MEI*\cos 2D)/$$

$$(1+\exp(-0.603+0.250*DMI+0.084*MEI -0.241*DMI*\sin D-0.088*DMI*\cos D-0.064*DMI*\sin 2D-0.042*DMI*\cos 2D -0.162*MEI*\sin D-0.113*MEI*\cos D-0.034*MEI*\sin 2D-0.052*MEI*\cos 2D))$$

Probability of a dry season at Brisbane =

$$\exp(-0.605+0.065*DMI+0.337*MEI -0.008*DMI*\sin D+0.020*DMI*\cos D+0.025*DMI*\sin 2D+0.051*DMI*\cos 2D -0.163*MEI*\sin D+0.092*MEI*\cos D+0.117*MEI*\sin 2D+0.135*MEI*\cos 2D)/$$

$$(1+\exp(-0.605+0.065*DMI+0.337*MEI -0.008*DMI*\sin D+0.020*DMI*\cos D+0.025*DMI*\sin 2D+0.051*DMI*\cos 2D -0.163*MEI*\sin D+0.092*MEI*\cos D+0.117*MEI*\sin 2D+0.135*MEI*\cos 2D))$$

Terms significant at the 5% level are highlighted in yellow, whilst terms significant at the 20% level are highlighted in green.

Plate A1.1 The probability of dry seasons at Melbourne and Brisbane, where the Multivariate ENSO Index (MEI) and the Dipole Mode Index (DMI) are both expressed in terms of number of standard deviations' departure from the norm, and sinD and cosD represent sin and cos of the day of the year of the mid-point of the season's first month.

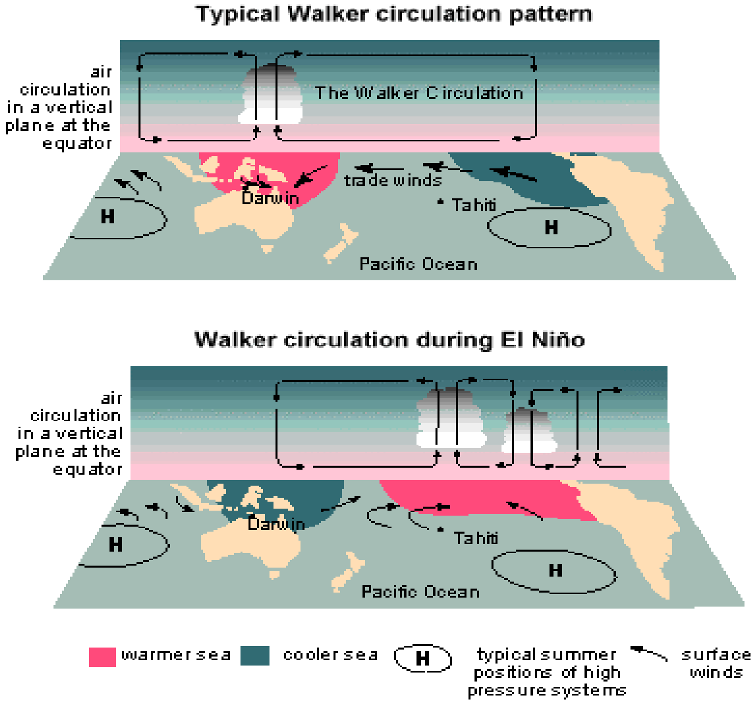


Figure A1.1a During El Niño's, sinking and drying of the air over northern Australia often leads to drought over eastern Australia (Source: http://www.bom.gov.au/lam/climate/levelthree/analclim/elnino.htm#four).

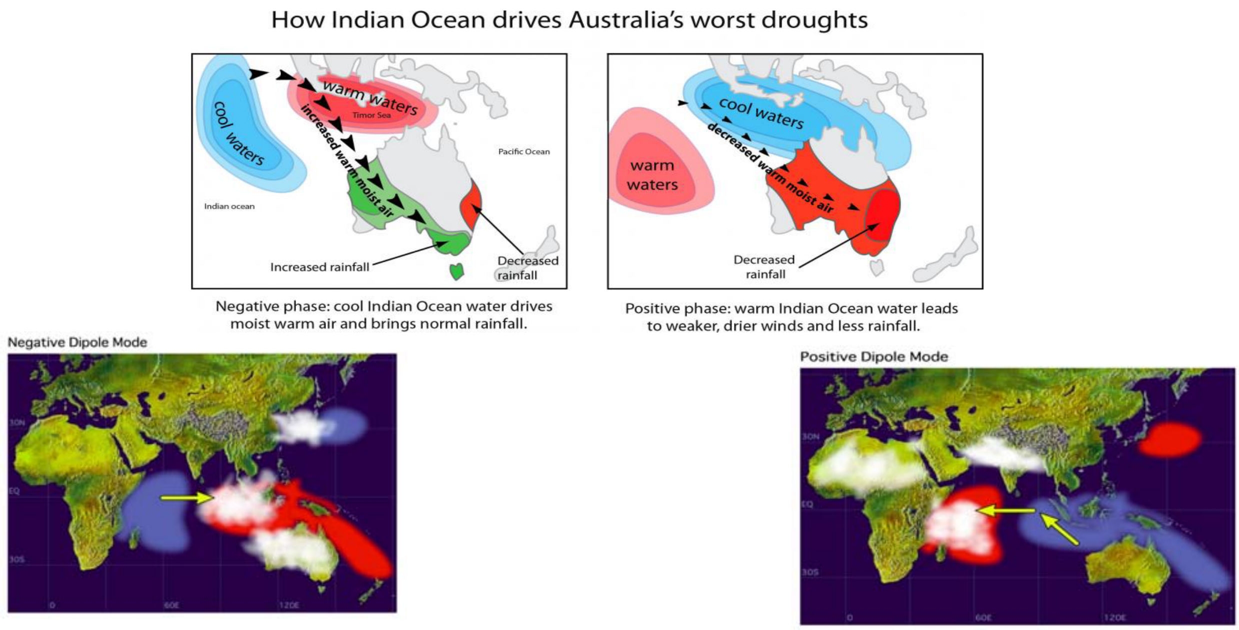


Figure A1.1b During the Indian Ocean Dipole's positive mode, the formation of rain-bearing northwest cloud bands is often discouraged (Ummenhofer *et al.*, 2009), leading to dry conditions, especially over southeastern Australia (Sources:
http://www.science.unsw.edu.au/news/indian-ocean-drought/ & http://www.jamstec.go.jp/frsgc/research/d1/iod/).

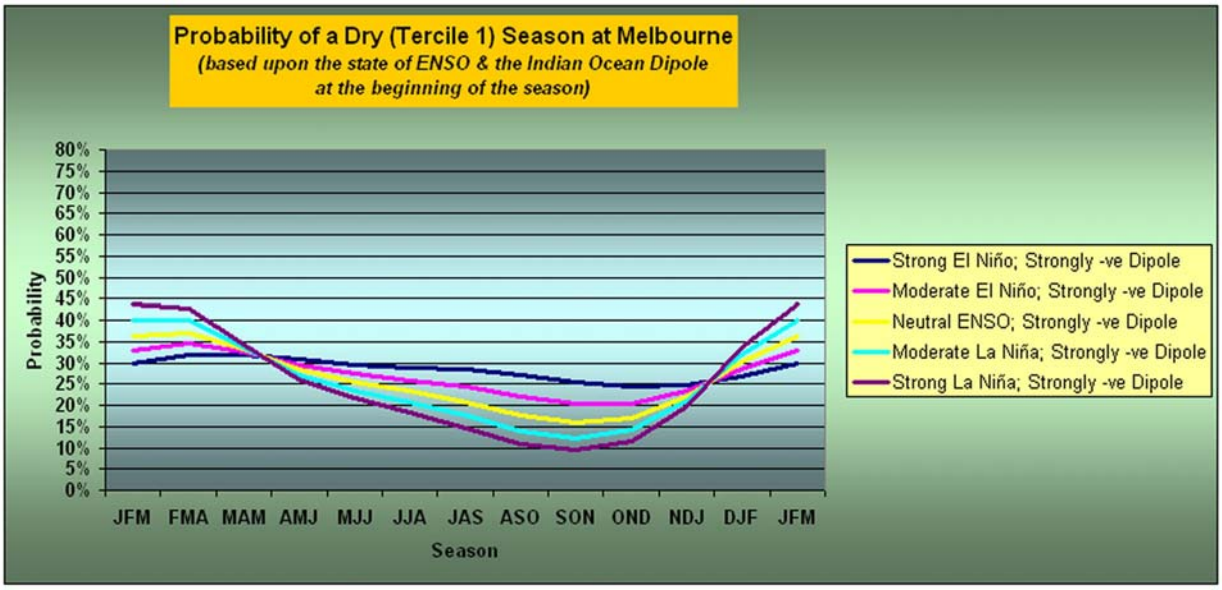


Figure A1.1c The influence of ENSO upon the likelihood of a dry season at Melbourne during a strongly negative Indian Ocean Dipole event.

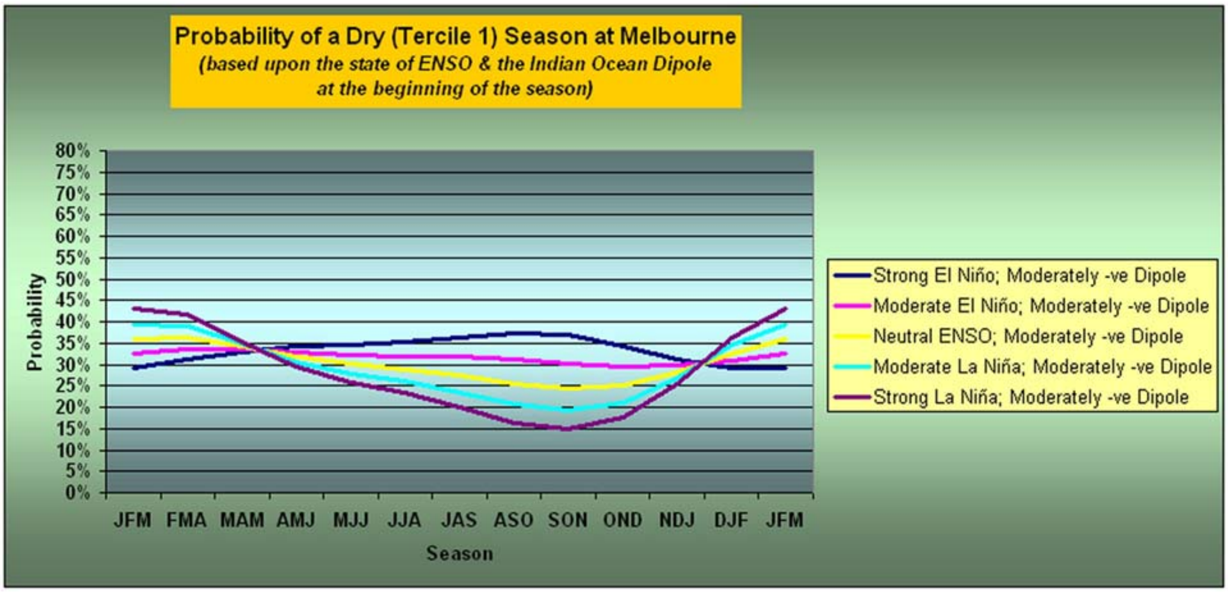


Figure A1.1d The influence of ENSO upon the likelihood of a dry season at Melbourne during a moderately negative Indian Ocean Dipole event.

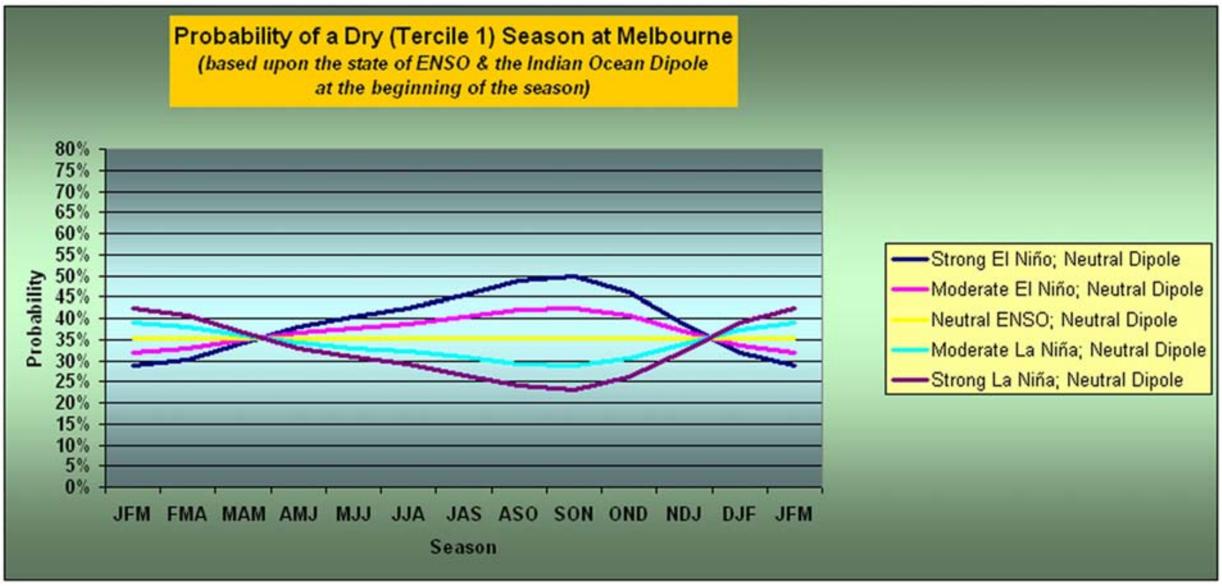


Figure A1.1e The influence of ENSO upon the likelihood of a dry season at Melbourne during a neutral Indian Ocean Dipole event.

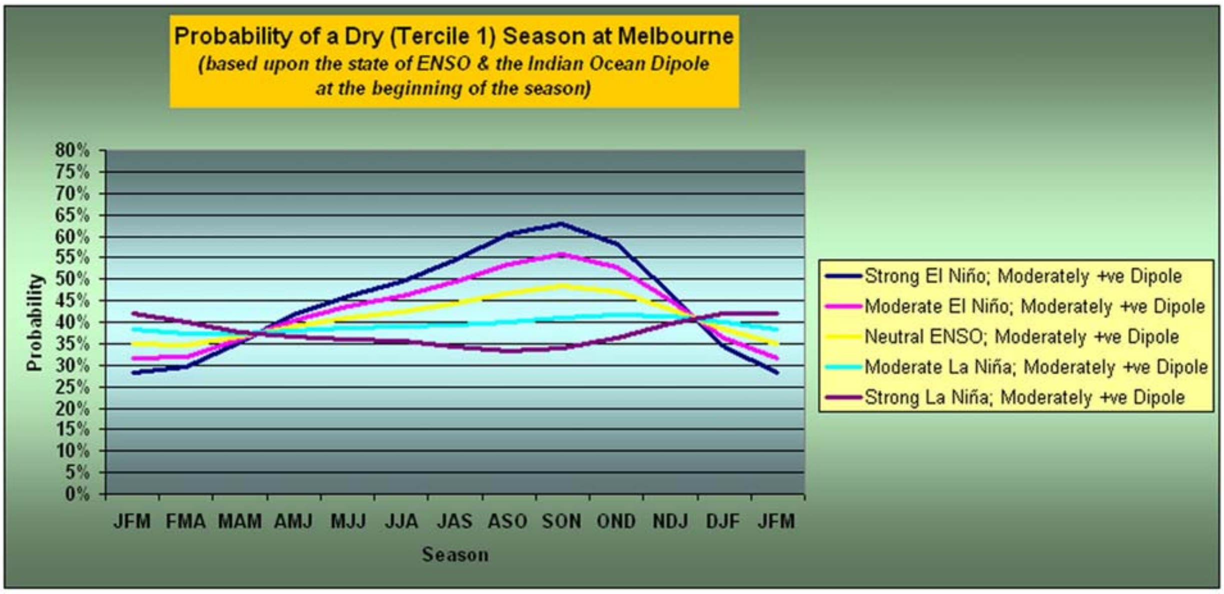


Figure A1.1f The influence of ENSO upon the likelihood of a dry season at Melbourne during a moderately positive Indian Ocean Dipole event.

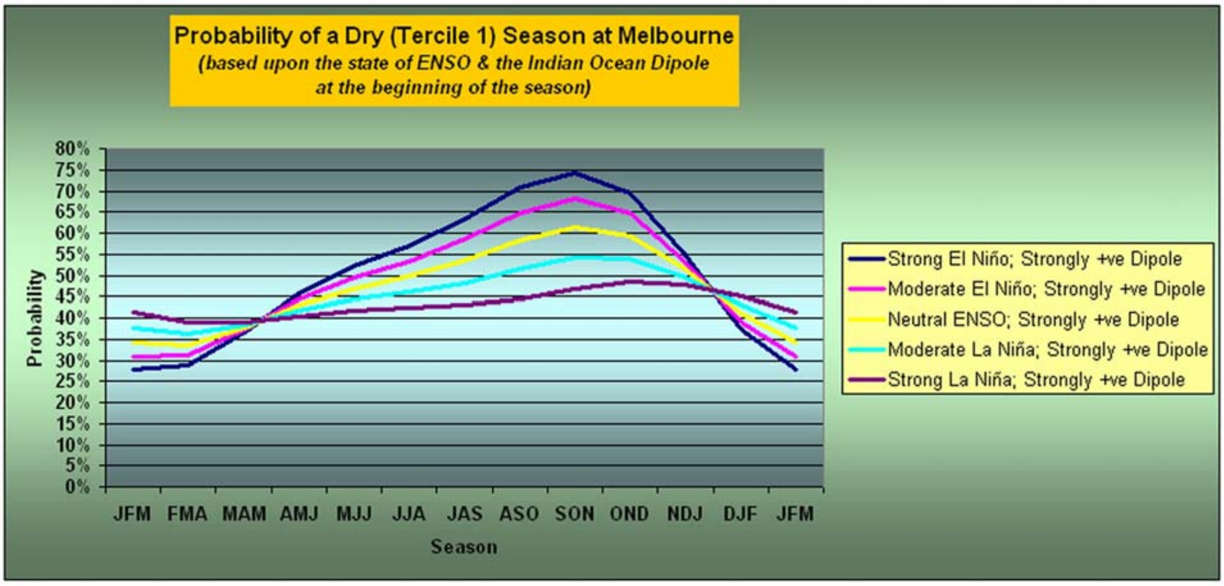


Figure A1.1g The influence of ENSO upon the likelihood of a dry season at Melbourne during a strongly positive Indian Ocean Dipole event.

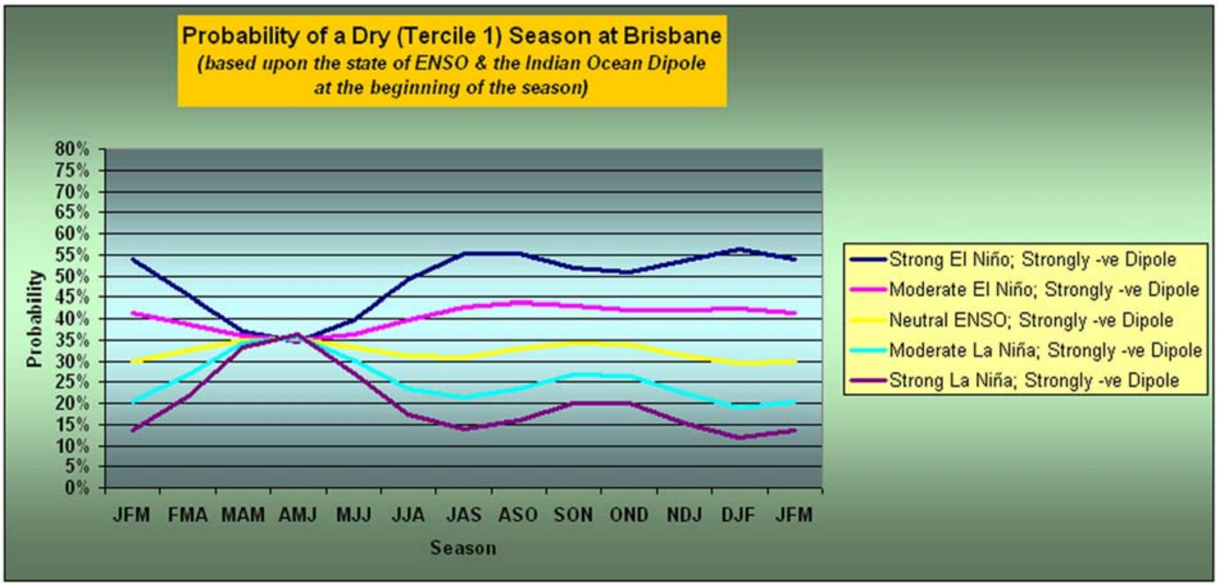


Figure A1.1h The influence of ENSO upon the likelihood of a dry season at Brisbane during a strongly negative Indian Ocean Dipole event.

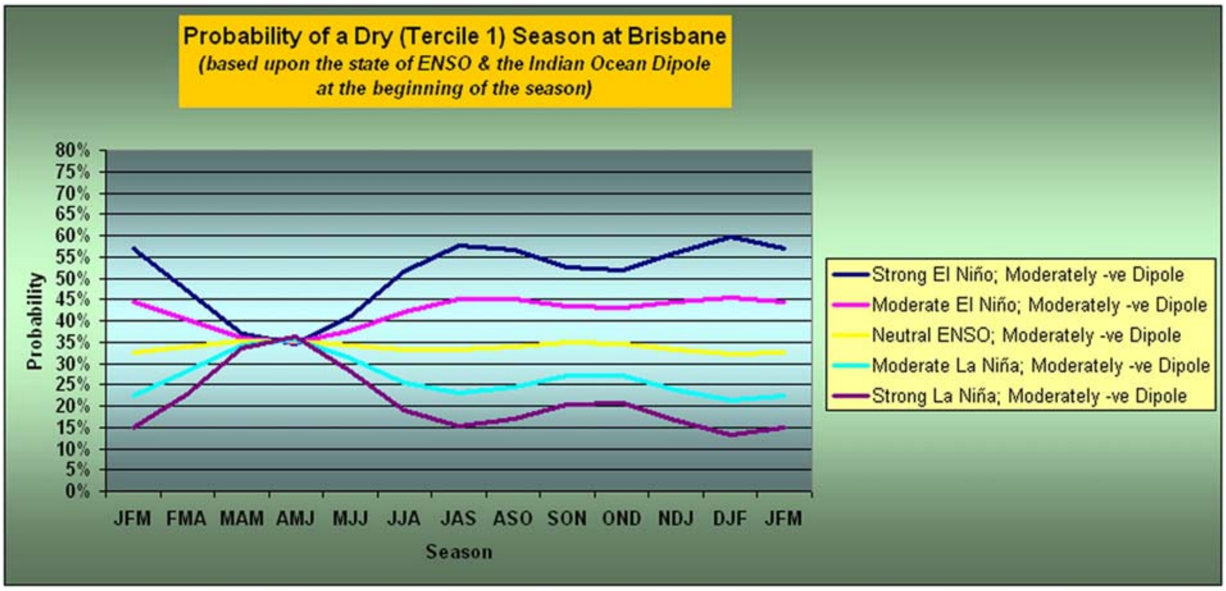


Figure A1.1i The influence of ENSO upon the likelihood of a dry season at Brisbane during a moderately negative Indian Ocean Dipole event.

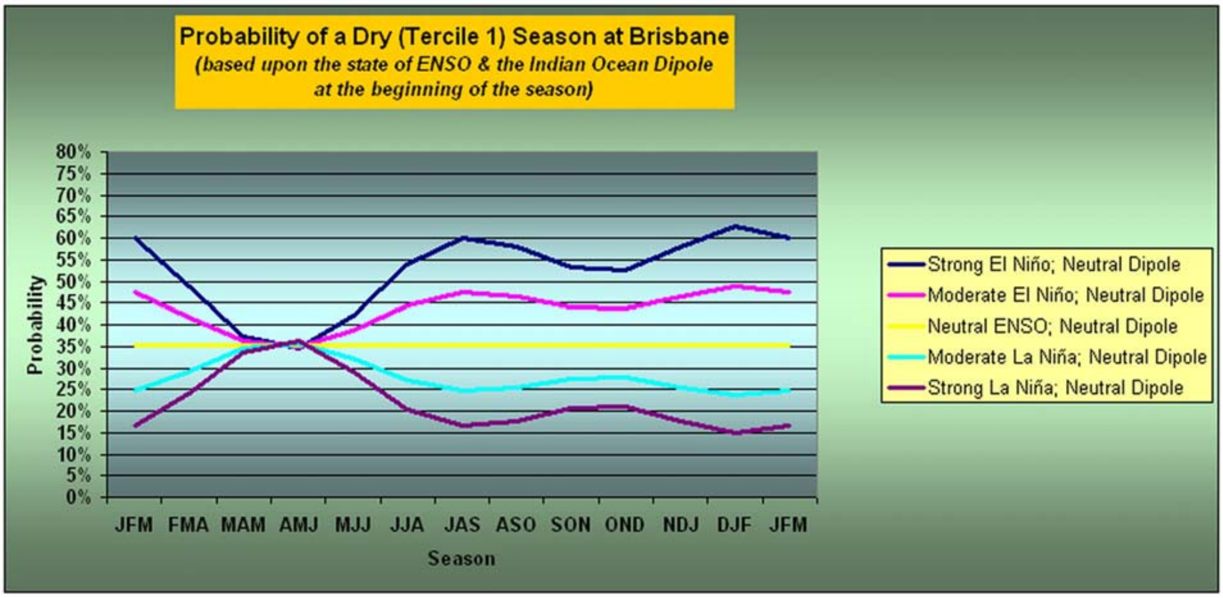


Figure A.1.1j The influence of ENSO upon the likelihood of a dry season at Brisbane during a neutral Indian Ocean Dipole event.

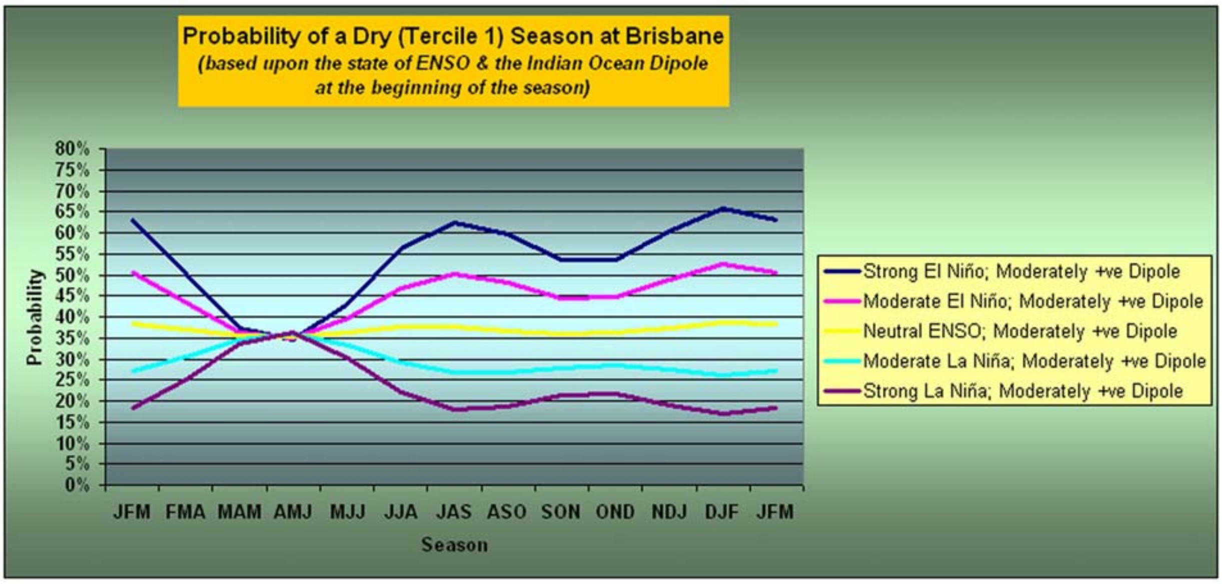


Figure A.1.1k The influence of ENSO upon the likelihood of a dry season at Brisbane during a moderately positive Indian Ocean Dipole event.

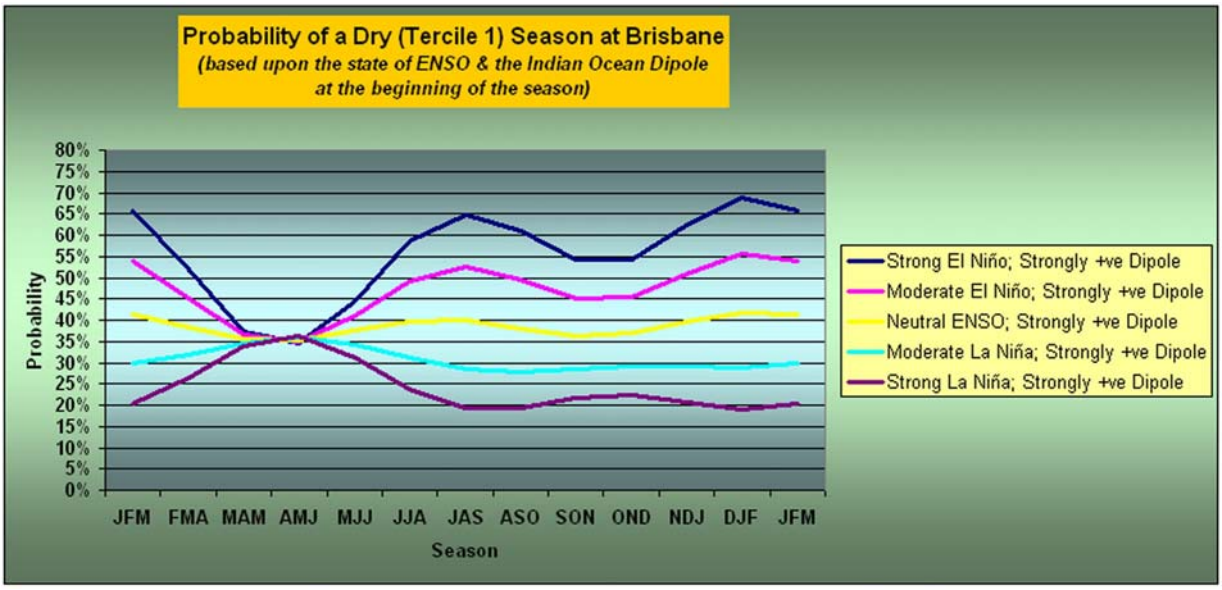


Figure A.1.1l The influence of ENSO upon the likelihood of a dry season at Brisbane during a strongly positive Indian Ocean Dipole event.

APPENDIX 2. EXAMPLES OF AUTOMATICALLY GENERATED WORDED SEASONAL AND MONTHLY OUTLOOKS.

The average Indian Ocean Dipole Mode Index for the past week is 0.11, the average Southern Oscillation Index (SOI) for the past 90 days is 6.55, the average SOI for the past 30 days is 1.96, the latest recorded bimonthly Multivariate ENSO Index (MEI) is -0.737, and the expected MEI, adjusted by the Indian Ocean Dipole Mode Index, for MAR/APR is -0.19. Such a value of MEI indicates a sea surface temperature distribution that corresponds to a very weak La Niña. This suggests:

RAINFALL: There is little indication as to whether total MAY/JUN/JUL rainfall will be below, near or above normal in Victorian Districts.

OVERNIGHT TEMPERATURES: There is a very slightly enhanced chance that average MAY/JUN/JUL overnight temperatures will be below normal in the CENTRAL and WIMMERA Districts, but there is little indication as to whether overnight temperatures will be below, near or above normal in other Victorian Districts.

DAYTIME TEMPERATURES: There is a very slightly enhanced chance that average MAY/JUN/JUL daytime temperatures will be above normal in the WESTERN District, there is a very slightly enhanced chance that average MAY/JUN/JUL daytime temperatures will be below normal in the MALLEE, NORTHERN COUNTRY, EAST GIPPSLAND and CENTRAL Districts, but there is little indication as to whether daytime temperatures will be below, near or above normal in other Victorian Districts.

Intra-Seasonal (Madden-Julian) Oscillation (MJO)

The Intra-Seasonal (Madden-Julian) Oscillation (MJO) is presently operating in Phase 2. This is reflected in the near-equatorial enhanced convection being found over the over the western Indian Ocean. In Victoria, during autumn, Phase 2 of the MJO is not usually characterised by surface flow being significantly different from normal, but associated rainfall is usually significantly below normal in the west of the State. Following Phase 2, the region of enhanced convection often moves from the western Indian Ocean to the eastern Indian Ocean.

Risk Management

Specifically for Melbourne, the fair value price of a contract to protect a business against an unusually dry season, whereby you are paid $10000 if the rainfall in the forthcoming MAY/JUN/JUL season is in **Tercile One (less than 145.8 mm)**, is $3203

Figure A2.1 An automatically generated worded seasonal climate outlook.

30 DAY OUTLOOK FOR MELBOURNE:

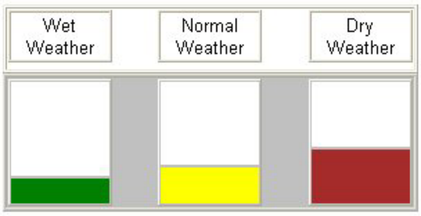
Today's scientists talk in terms of the continent's large climate variability from season to season, and from year to year. What causes these fluctuations? They are, in part, connected with the climate phenomenon called the Southern Oscillation, a major air pressure shift between the Asian and east Pacific regions whose best-known extremes are El Niño events and La Niña events. The Pacific Ocean is a huge mass of water which controls many climate features in its region. Its equatorial expanse, far larger than the Indian or Atlantic Oceans, is critical to the development of the Southern Oscillation and the El Niño and the La Niña. The Multivariate ENSO (El Niño Southern Oscillation) Index, which combines the Sea Surface Temperature (SST) distribution across the Pacific with various features of the atmospheric circulation, is used to monitor the evolution of the El Niño and Southern Oscillation phenomena. **The current Multivariate ENSO Index (MEI) is 0.41 standard deviations.** This reflects a mild El Niño event.

Another region of Sea Surface Temperature variability that impacts on Australian climate is that of the Indian Ocean. One mode of variability that appears to affect Australian rainfall, particularly the south east of the country, is the Indian Ocean Dipole (IOD). The IOD referred to here is defined by an index that is the difference between SST in the western (50°-70°E, 0°S-10°N) and eastern (90°-110°E, 10°-0°S) tropical Indian Oceans. A positive Indian Ocean Dipole Mode Index (DMI) occurs when the western basin is warmer than average and the eastern basin is cool and hence the DMI is positive. These regions were proposed in a paper by Saji et al. (1999) on the Indian Ocean Dipole that showed a modulation in Australian seasonal rainfall with DMI positive and negative years. **The current Indian Ocean Dipole Mode Index (DMI) is 0.69 standard deviations.** This reflects a mildly positive Indian Ocean Dipole.

Also impacting upon Australian climate variability is a phenomenon known as the Intra Seasonal Oscillation (ISO) (also known as the Madden-Julian Oscillation (MJO), after Madden and Julian, who first identified it in the early 1970s). They discovered that, at many locations in the tropics, surface pressure and upper atmospheric winds tend to go through a coherent cycle over periods of about 40 to 50 days. It has been found that a broad area of active cloud and rainfall propagates eastwards around the equator at intervals of between about 40 and 50 days. These are not strict time limits - research over the years has pushed the limits of the oscillation's period to between about 30 and 60 days. **The Madden-Julian Oscillation (MJO) is presently operating in Phase 8.** This is reflected in the near-equatorial enhanced convection being found over the over the Western Hemisphere (South America). Following Phase 8, the region of enhanced convection over South America often moves to Africa.

In Melbourne, at this time of the year, a combination of the MEI, the DMI, and the MJO Phase, such as what we have operating now, suggests, over the following 30 days:

RAINFALL: There is a 22.6% chance of it being wet, a 31.7% chance of normal rainfall, and a 45.7% chance of it being dry.



OVERNIGHT TEMPERATURES: There is a 23.6% chance of warm nights, a 31.9% chance of normal overnight temperatures, and a 44.5% chance of cool nights.

DAYTIME TEMPERATURES: There is a 40.6% chance of warm days, a 32.7% chance of normal daytime temperatures, and a 26.7% chance of cool days.

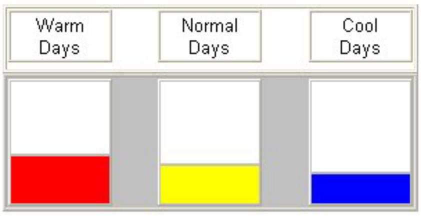


Figure A2.2 An automatically generated worded monthly climate outlook.

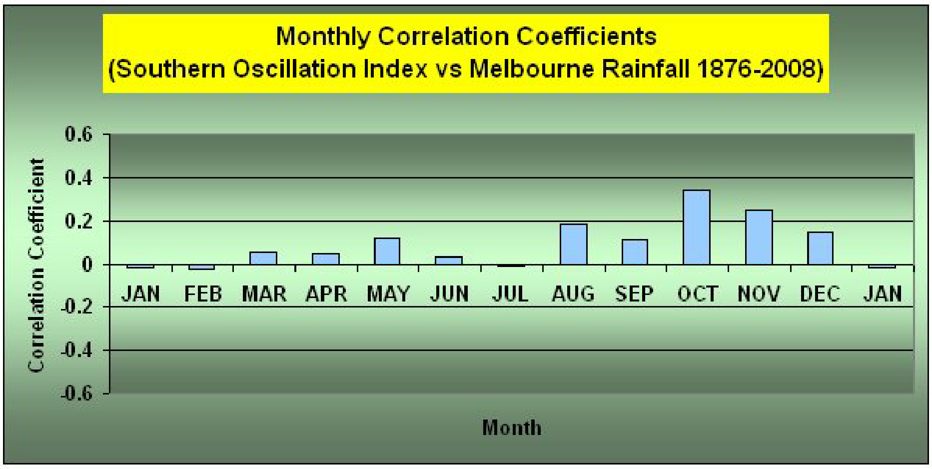


Figure A2.3 Monthly Correlation Coefficients (*Southern Oscillation Index* vs *Melbourne Rainfall* over all years of record 1876-2008) showing spring as the time of the year with the most positive correlation coefficients.

Figure A2.4 Trend in the October Correlation Coefficient (*Southern Oscillation Index* vs *Melbourne Rainfall*), October being the month with the highest Correlation Coefficient over all years of record, showing a sharp decline over recent years.

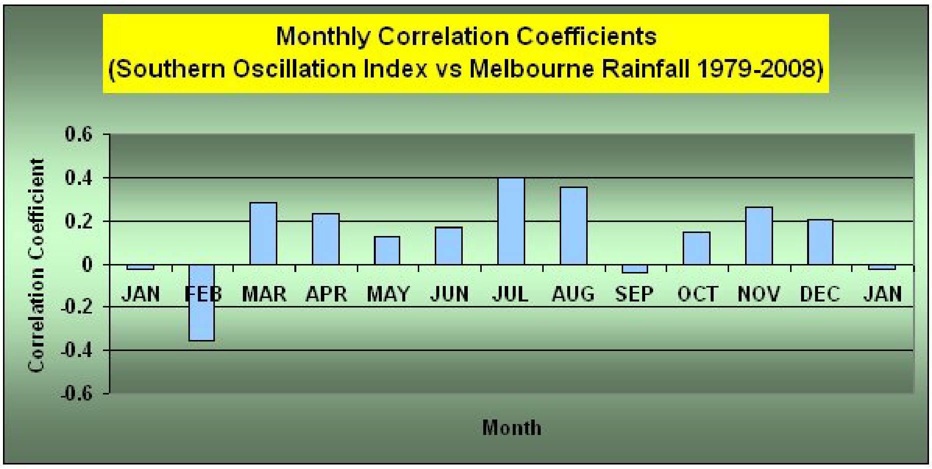


Figure A2.5 Monthly Correlation Coefficients (*Southern Oscillation Index* vs *Melbourne Rainfall*) over recent years 1979-2008, illustrating that the time of the year with the most positive correlation coefficients has shifted to the autumn-winter.

APPENDIX 3 EXPLAINING THE OBSERVED DOWNWARD TREND IN SOUTHERN AUSTRALIAN RAINFALL

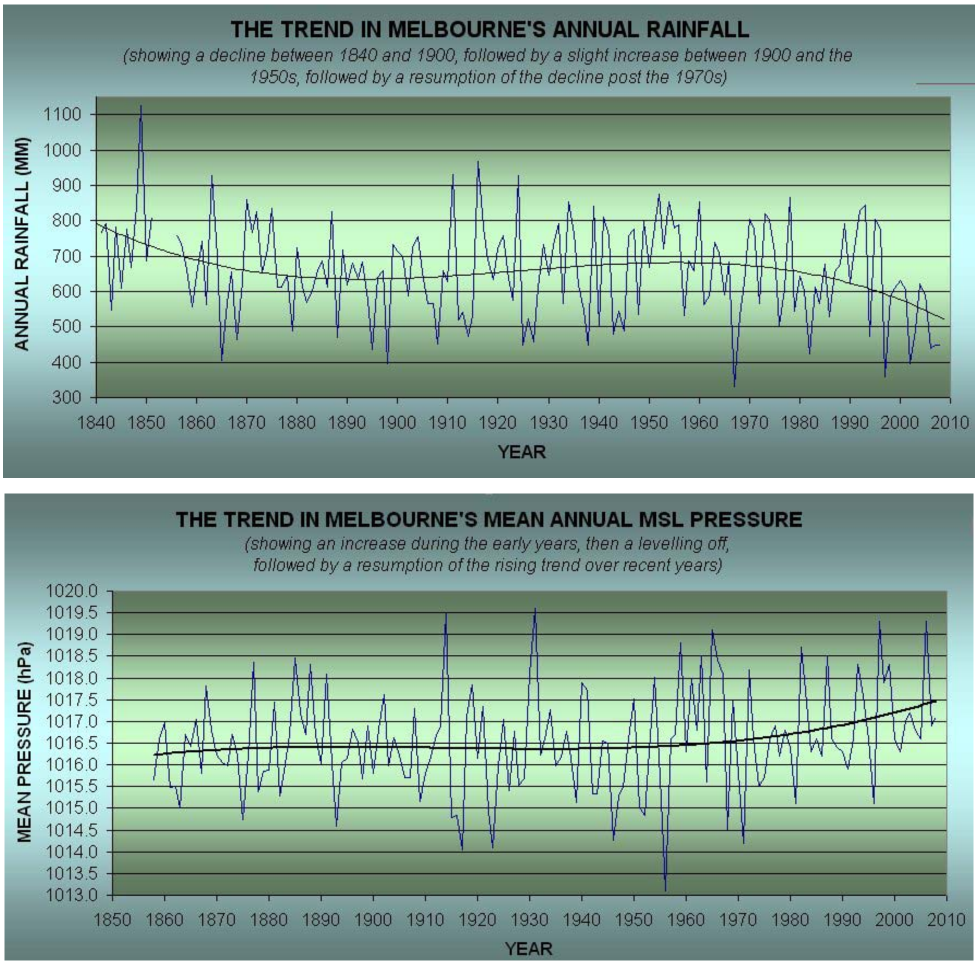


Figure A3.1a The trend in Melbourne's annual rainfall and mean annual MSL pressure.

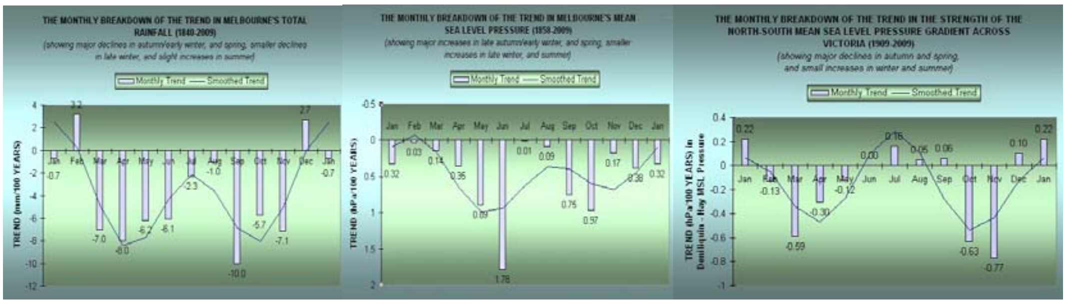


Figure A3.1b The monthly break down of the trend in Melbourne's annual rainfall, the trend in MSL pressure, and the trend in the strength of the north-south MSL pressure gradient across Victoria. The percentage variance of the observed monthly rainfall trend explained by the pressure and pressure gradients in a regression relationship between the monthly rainfall trend and the corresponding trends in Melbourne MSL pressure and the north-south MSL pressure gradient is 38.6%. The "t" statistic associated with the Melbourne Mean Sea Level Pressure trend partial regression coefficient is –1.62 (the probability that this "t" statistic being as low as, or lower than, -1.62 by chance is 7.0%). The "t" statistic associated with the north-south MSL pressure gradient is +1.80 (the probability that this "t" statistic being as high as, or higher than, +1.80 by chance is 5.2%).

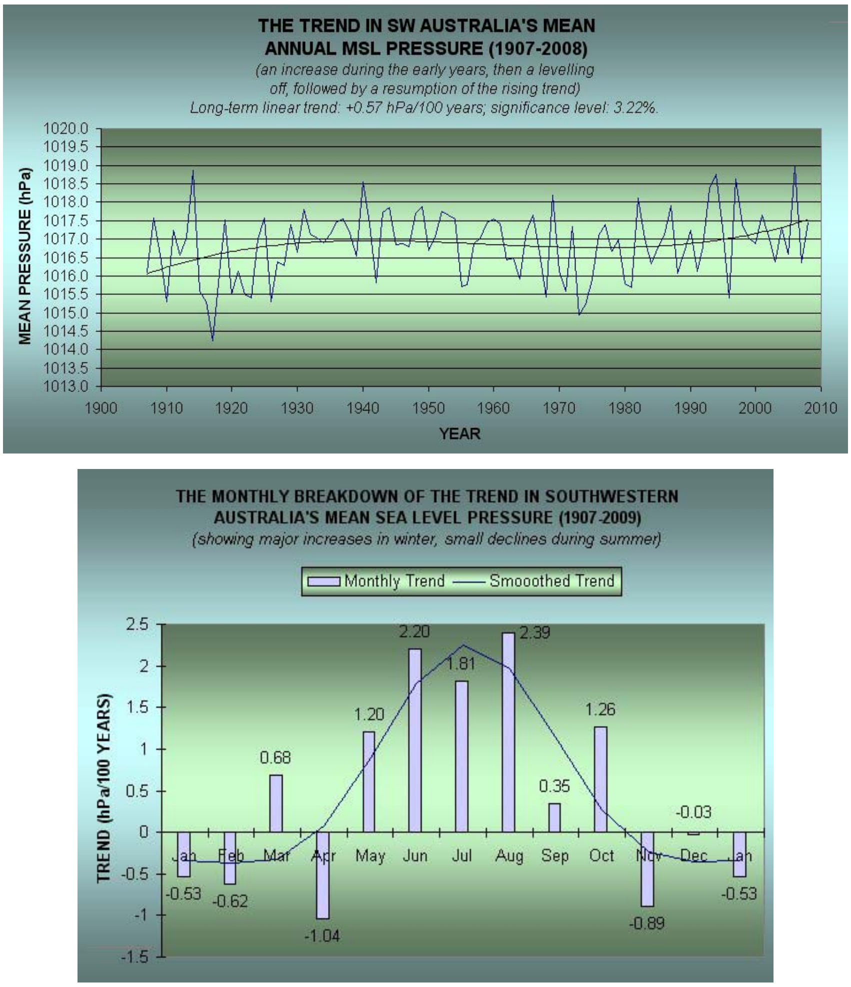


Figure A3.1c The trend in the Mean Sea Level pressure over southwest Australia and its monthly break down.

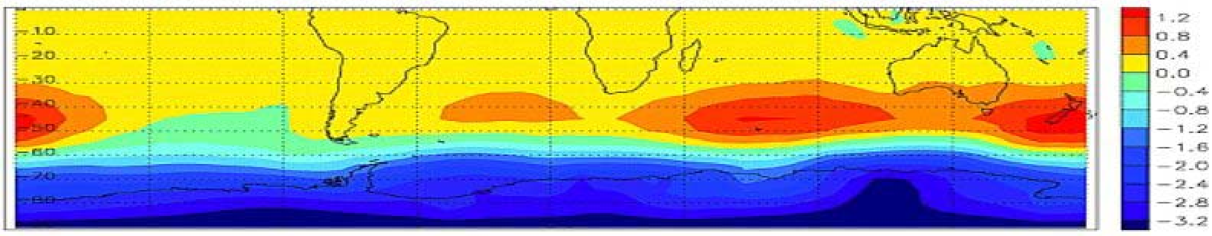


Figure A3.2 The MSL pressure distribution anomaly associated with the Southern Annular Mode during its positive phase (from Gillett *et al*., 2006).