Can ENSO combined with Low-Frequency SST signals enhance or suppress rainfall in Australian sugar growing areas?

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EXTENDED ABSTRACT

The use of three low-frequency (LF) sea surface temperature (SST) signals were combined with an El Niño/Southern Oscillation (ENSO) signal in this diagnostic study to assess if a suppression or enhancement of rainfall was observed in seven sugarcane growing regions along the east coast of Australia during the harvesting period (Jun-Nov). LF signals utilized included the Interdecadal Pacific Oscillation (IPO), Pacific Decadal Oscillation (PDO) and a decadal-frequency signal (DEC). These were stratified into cool and warm phases based on their sign (+ or –) and were combined with cool (La Niña) and warm (El Niño) ENSO phases. Box plots displaying a 95% confidence interval for the median were developed for early (Jun-Aug) and late (Sep-Nov) harvest season periods. These were used to determine if discriminatory ability among rainfall distributions is improved when combining ENSO and LF indices as apposed to using individual ENSO phases or individual LF phases only. Results displayed a strong ENSO signal across all regions for Sep-Nov, but the ENSO signal had only minor to moderate effects during Jun-Aug. All three LF indices displayed very little discriminatory ability across both harvesting periods for all sugar growing regions. When ENSO and the LF indices were combined, additional suppression or enhancement effects could not be established. Based on key results obtained in this investigation, harvesting strategies should be developed by considering the likelihood of developing ENSO conditions.

1. INTRODUCTION

In earlier times, the sugar industry has been one of Australia's leading agricultural export industries, contributing between one to two billion dollars annually to the economy. Recent years has seen a decrease in these figures however the sugar industry is still an important factor contributing to both the national and Queensland economies.

The industry's success largely depends on climate conditions at times of important events such as planting, harvesting and milling. Enhanced knowledge of climatic conditions at these times allows industry decision makers to make better judgement about when or if these activities should take place. Particularly important is prior knowledge of potential excessively wet conditions which can considerably impact on farming, harvesting and milling decision points and have devastating effects on crops, land and income levels. Excessively dry conditions are also important to consider. These conditions can effect crop size and sugar content within the cane and can impact irrigation, water allocation and dam levels.

Due to these issues, there has been emerging research over recent times about seasonal climate forecasting (SCF) applications for sugar regions along the east Australian coast (Everingham et al. 2003). Everingham et al. (2003) used the five-phase Southern Oscillation Index (SOI) system (Stone and Auliciems, 1992) to improve knowledge about the chance of rain. Current research investigating potential usefulness of decadal and interdecadal-type, low frequency (LF) signals evident in sea surface temperature (SST) data to increase decision making capability within the Australian sugar industry is limited.

This paper will investigate if enhanced knowledge about climate and thus improved decision making capability can be gained by combining LF signals with ENSO (El Niño/Southern Oscillation) signals to give an enhancement or suppression effect to rainfall distributions in sugar growing regions.

LF, decadal to interdecadal sea surface temperature (SST) signals calculated using near-global and Pacific Ocean SST have shown to modulate climatic parameters and rainfall variability in regions surrounding the Pacific Ocean, including Australia (Mantua 2002, Climate Impacts Groups (CIG), Univ. of Washington 2005, Power et al. 1999, Meinke et al. 2005, Verdon et al. 2004, Kiem et al. 2004, Abawi et al. 2005). These studies suggest that LF decadal to interdecadal SST signals can potentially enhance forecast ability of various responses (eg. rainfall, streamflow and salmon production), particularly when combined with signals relating to the El Niño/Southern Oscillation (ENSO) phenomenon.

Rainfall in Australia (Power et al. 1999, Verdon et al. 2004), New Zealand (Salinger et al. 2001) and the South Pacific (Salinger et al. 2001); streamflow in eastern Australia (Abawi et al. 2005, Verdon et al. 2004), west coast USA (Mantua et al. 1997); and even salmon production in the USA (Mantua et al. 1997) have all shown to be modulated in some form by LF SST signals. For example, LF signals are usually differentiated into cool (also called negative) or warm (also called positive) phases, with an increase (decrease) of mean rainfall often being observed during cool (warm) phases.

Strong ENSO signals which tend to have a periodicity between 2.5-8 years are evident in many sugar growing areas (Everingham et al. 2003). Rainfall amounts are likely to differ depending on which ENSO phase (El Niño or La Niña) occurs. El Niño years favour reduced rainfall amounts along the east coast of Australia. Conversely, La Niña years have a tendency to result in increased rainfall patterns. ENSO has also shown to vary on interdecadal time scales (Power et al. 1999).

When LF signals varying on decadal to interdecadal timescales are combined with ENSO signals, modulations of factors including rainfall and streamflow often become even more significant than the individual effect of either signal (Verdon et al. 2004, Abawi et al. 2005, CIG 2005). The physical processes behind LF signals have yet to be fully explained, however their existence is not denied. Many LF signals of varying frequencies ranging from interdecadal to multidecadal have been identified through sophisticated analysis methods (Mann and Park, 1999, Allan 2000). Variations of these LF signals exist, including what methods are utilized to obtain the signals (ie. which analysis, detrending and filtering methods (if any) are used) and which regions of the world's oceans are utilized to generate the LF indices (i.e. nearglobal, North, South or central Pacific or Pacific-wide).

LF SST indices include the Interdecadal Pacific Oscillation (IPO – Power et al. 1999) and the Pacific Decadal Oscillation (PDO – Mantua 2002). The PDO, coined by Mantua et al. (1997) is the leading Empirical Orthogonal Function of North Pacific Ocean SST (poleward of 20˚ N) and has a periodicity of around 20-30 years. Power et al (1999) found many LF SST signals exist, and named one of these signals (Folland et al 1998) the IPO. The signal of Folland et al. (1998) was initially calculated from an unrotated EOF analysis on low-pass filtered near-global SST data. Folland et al. (1998) discovered the 3rd EOF was similar to the PDO. Power et al. (1999) further filtered Folland et al.'s 3rd EOF by low pass filtering with a 13 yr cutoff and named this signal the IPO (Meinke et al. 2005, Verdon et al. 2004, Kiem et al. 2004, Abawi et al. 2005, Allan 2000). Meinke et al. (2005) used factor scores from time series based on EOF analysis of near global SST and MSLP data to produce ENSO, decadal, interdecadal and multidecadal signals that vary in underlying frequencies. The frequencies were identified through the spectral analysis component of the Multi-Taper Method/Singular Value Decomposition technique (MTM/SVD) (Mann and Park, 1999). Bandpass filters were used to isolate the four frequencies.

Research linking ENSO to LF signals specifically for the improvement of the Australian sugar industry is limited. This study will determine if the use of LF SST signals can further improve the capabilities of ENSO signals for the sugarcane harvesting period for a collection of sugar producing regions in Australia. This improvement will be assessed by determining if rainfall distributions are shifted giving an enhancement or suppression effect during combined ENSO and LF phases. If encouraging results are obtained, with further research many positive outcomes could result and benefit many people both directly; by having enhanced knowledge of climatic conditions at the time of important farming events thus decreasing an element of risk and indirectly; by improving the overall state of the sugar industry. However, this would be dependent on further research identifying how information in LF signals could be produced in real time.

2. DATA & METHODS

Knowledge of possible climate conditions from June to November is extremely useful for sugar industry decision makers since harvesting takes place during this time. Thus, this study considered early and late harvest rainfall periods to encompass this important time: Jun-Aug (JJA) and Sep-Nov (SON).

Seven key sugar regions along eastern coastal Queensland and Northern New South Wales were identified for this study. These regions included Cairns (CNS), Mourilyan (MLN), Lucinda (LUC), Townsville (TVL), Mackay (MCK), Bundaberg (BUN) and NE New South Wales (NSW). Collectively, these regions produce in excess of 90% of Australia's sugar. Within each region, there exists a collection of sugar mills. For each mill, patched point rainfall data (http://www.bom.gov.au/silo) from a nearby Bureau of Meteorology (BOM) station was obtained (Table 1). In some cases the same BOM station was used for different mills.

Table 1. The rainfall stations used to compute a rainfall index for each sugar producing region.

Region	Mill Name	BOM Station Number
Cairns (CNS)	Mossman	31055
	Mulgrave	31089
Mourilyan (MLN)	Babinda	31004
	South Johnstone	32037
	Mourilyan	32037
	Tully	32042
Lucinda (LUC)	Macknade	32032
	Victoria	32078
Townsville (TVL)	Kalamia	33035
	Invicta	33069
	Pioneer	33035
	Inkerman	33033
Mackay (MCK)	Proserpine	33041
	Farleigh	33023
	Marian	33152
	Pleystowe	33072/ 33060
	Racecourse	33047
	Plane Creek	33067
Bundaberg (BUN)	Fairymead	39037
	Bingera	39009
	Millaquin	39174
	Isis	39168
	Maryborough	40126
NE New South Wales (NSW)	Harwood	58027
	Ballina	58001
	Condong	58013

JJA and SON three-monthly total rainfall data from BOM stations within each region were used to produce 14 rainfall indices for each of the seven locations and two rainfall periods. The rainfall indices were obtained through the use of Principal Component Analysis (PCA) (Johnson & Wichern 2002). The rainfall index was defined as the first principal component (PC) of rainfall data for each region, for each rainfall period. PCA was the chosen technique, since the leading PC combines the individual rainfall station data within a region in such a way that the new index maximizes the variance explained. This avoids doing multiple tests for nearby rainfall stations where spatial correlations are likely to exist. The BOM utilizes a similar PCA methodology by calculating nine rotated rainfall principal components for producing three-monthly rainfall forecasts (Drosdowsky & Chambers 1998).

Whilst many ENSO classifications exist, we chose the ENSO index based on the poster titled "Australia's Variable Rainfall 1890-2004" (http://www.longpaddock.qld.gov.au/Products/AustraliasVariableClimate/index.html) which differentiates El Niño and La Niña years based on average June to November Southern Oscillation Index (SOI) values.

The LF indices utilized in the study include the IPO (Power et al. 1999, Meinke et al. 2005), PDO (Mantua et al. 2002, http://jisao.washington.edu/pdo/PDO.latest), and the decadal signal (DEC) utilized by Meinke et al. (2005). Regimes used by Mantua et al. (2002) were used to define PDO phases. These include cool phases from 1890-1924 and 1947-1976 and warm phases from 1925-1946 and 1977 to approximately the mid 1990s.

Each monthly IPO value was assigned cool or warm. Similarly to the study by Meinke et al. (2005), this assignment was based on the sign (+ or -) of the IPO value for that month. Positive (negative) values indicate a warm (cool) phase. A warm (cool) IPO *year* was defined if six or more months (Jan-Dec) were positive (negative). The DEC signal was stratified into cool and warm phases in the same manner as the IPO.

The suppression and/or enhancement of rainfall distributions was investigated through ENSO phases, LF phases and their combination. El Niño phases were combined with a) warm IPO b) warm PDO and c) warm DEC. Similarly, La Niña phases were combined with a) cool IPO b) cool PDO and c) cool DEC. Box plots were developed for each of the seven regions for early (JJA) and late (SON) harvest rainfall to investigate suppression and/or enhancement effects. Box plots were used as a convenient way to display shifts between rainfall distributions and differences in variability. An enhancement effect of rainfall was assessed by comparing, for example, La Niña, cool IPO and La Niña/cool IPO combined in each set of box plots. Similarly, suppression of rainfall was determined by comparing, for example, El Niño, warm IPO and El Niño/warm IPO combined. A 95% confidence interval for the median (S-PLUS v6.1) was superimposed onto each of the box plots to indicate a range of values that the population median is likely to encompass under repeated random sampling.

It is important to note that this study applied ENSO and LF indices in a diagnostic (non-forecast) mode for preliminary exploratory purposes only. This is because the LF signals are a) highly filtered and b) their underpinning physical processes are still unknown and the ENSO phase was not defined until the end of November.

3. RESULTS/DISCUSSION

The three LF signals (IPO, PDO and DEC) and their positive/warm and negative/cool periods are shown in Figure 1. The PDO (blue line) and IPO regimes (black line) are shown to have similar phasing from around early 1920s until the mid 1990s, with the DEC signal having a different, higher frequency oscillation.

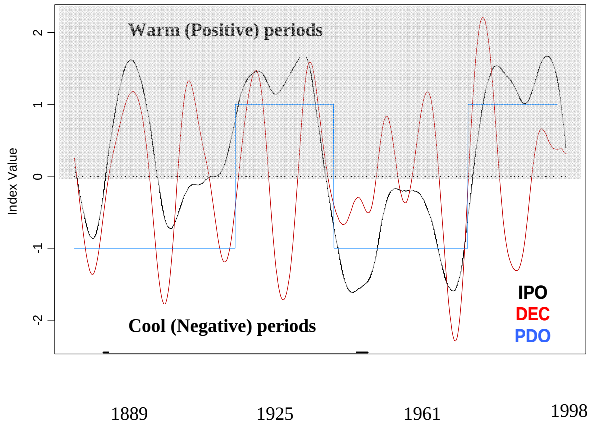

Figure 1. The LF signals: IPO (black line), DEC (red line) and PDO (blue line) regimes and their warm and cool periods from 1889 to 1998.

All rainfall indices (first PC) across all regions for JJA and SON explained at least 60% of the variance, with an average of 86.5%, thus demonstrating that the majority of variability in rainfall was captured by the leading PC.

The box plots for the ENSO index, LF indices and combined ENSO and LF indices across JJA (top row) and SON (bottom row) for two of the seven locations are displayed in Figure 2 (CNS) and Figure 3 (BUN). Owing to space limitations, box plots for the remaining regions are not presented although these results do form part of the following discussion. The ordering of the six distributions in each set of box plots is in Table 2.

Table 2. The ordering of the six box plots in Figures 2 and 3, and their description.

Box plot Order	Box plot Name	Box plot Description
1	**LN**	La Niña
2	**EN**	El Niño
3	**CI**	Cool IPO
	CP	Cool PDO
	CD	Cool DEC
4	**WI**	Warm IPO
	WP	Warm PDO
	WD	Warm DEC
5	**LN-CI**	La Niña/Cool IPO
	LN-CP	La Niña/Cool PDO
	LN-CD	La Niña/Cool DEC
6	**EN-WI**	El Niño/Warm IPO
	EN-WP	El Niño/Warm PDO
	EN-WD	El Niño/Warm DEC

Compared to JJA which shows no strong ENSO displacement for the remaining regions and only moderate ENSO displacement for CNS (Figure 2), LUC (figure not shown) and BUN (Figure 3), the ENSO signal shows much greater discriminatory ability during SON. All seven locations display a strong difference between El Niño and La Niña distributions in SON (with La Niña phases showing higher rainfall than El Niño phases). There is minimal observable difference between warm and cool LF indices for each location across JJA and SON. In CNS (Figure 2), MLN, LUC and TVL in particular, SON La Niña phases are more variable than the corresponding SON El Niño phases. In comparison, the LF indices show little variation between the two phase distributions for both JJA and SON.

Although Meinke et al. (2005) used more formal statistical tests, and different rainfall indices and periods, our key findings align with Meinke et al. (2005) particularly for the IPO. Using normalized annual rainfall on a global scale, Meinke et al. (2005) found that the IPO signal had little effect on NE Australian rainfall, with rainfall areas in SE Australia showing a stronger relationship to the IPO. Meinke et al. (2005) also found a strong decadal (DEC) signal exists for most of eastern Australian rainfall except for a small band in North QLD. This band appears to be where a lot of the regions in our study are located (CNS, MLN, LUC, TVL and MCK), although exact locations are difficult to determine. However, based on findings by Meinke et al. (2005), southern regions BUN (Figure 6) and NSW (Figure not shown) might have been expected to show some differentiation.

Unlike Verdon et al. (2004), Abawi et al. (2005), and CIG (2005), the suppression/enhancement effect from combining LF signals with ENSO could not be extended to rainfall indices and periods used in this study. The distributions of combined ENSO and LF indices display minor discriminatory ability, however observed differences between these La Niña/cool LF and El Niño/warm LF events is dominated by the ENSO effect. This is most evident for SON where the difference observed between ENSO phases is very similar to the differences observed during the combined ENSO and LF index phases (e.g. Figure 3, Bundaberg SON). Thus, it was discovered that whilst knowledge of ENSO conditions can help with planning the harvest season, we were unable to assess if conditions during El Niño/La Niña events are likely to be even drier/wetter if in phase with a LF signal.

4. CONCLUSION

This diagnostic investigation assessed whether the use of LF indices combined with in-phase ENSO patterns can enhance or suppress rainfall in sugar growing regions along Australia's east coast for early and late season harvesting periods. Extra suppression or enhancement effects could not be established in JJA or SON by combining cool and warm phase LF signals: IPO, PDO and DEC with La Niña and El Niño ENSO phases. Note than an enhancement/suppression may have been observed if different time periods were utilized (e.g. Dec-Feb) instead of the cane harvesting period. Future work could involve assessing shifts in probabilities and rainfall distributions for alternative rainfall periods that impact on different decision points for the Australian sugar industry.

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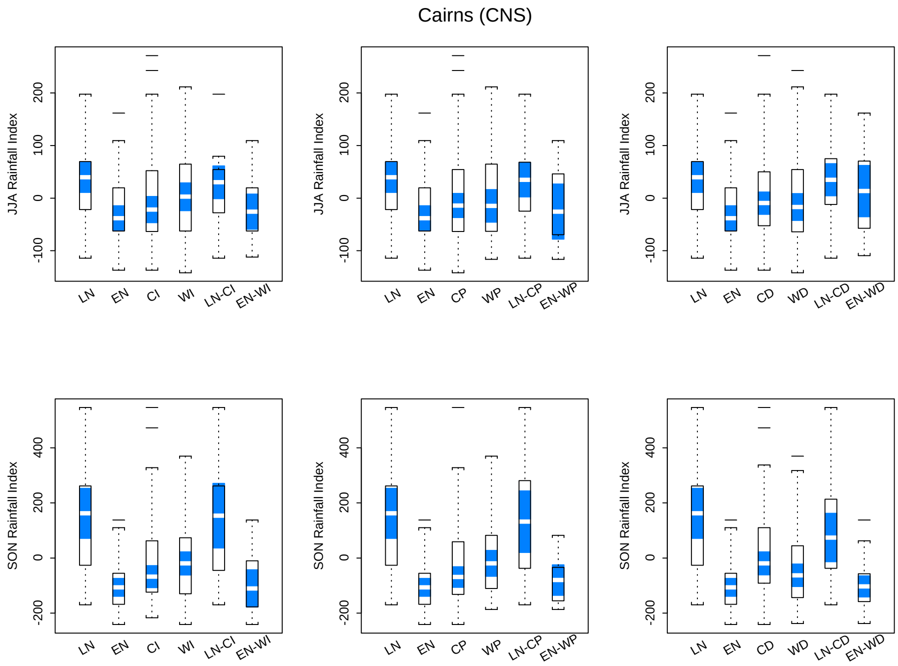

Figure 2. Cairns (CNS) rainfall distributions for individual 1) La Niña and 2) El Niño ENSO phases, 3) individual cool and 4) individual warm LF phases (IPO, PDO and DEC), and 5) combined ENSO-LF cool and 6) combined ENSO-LF warm phases.

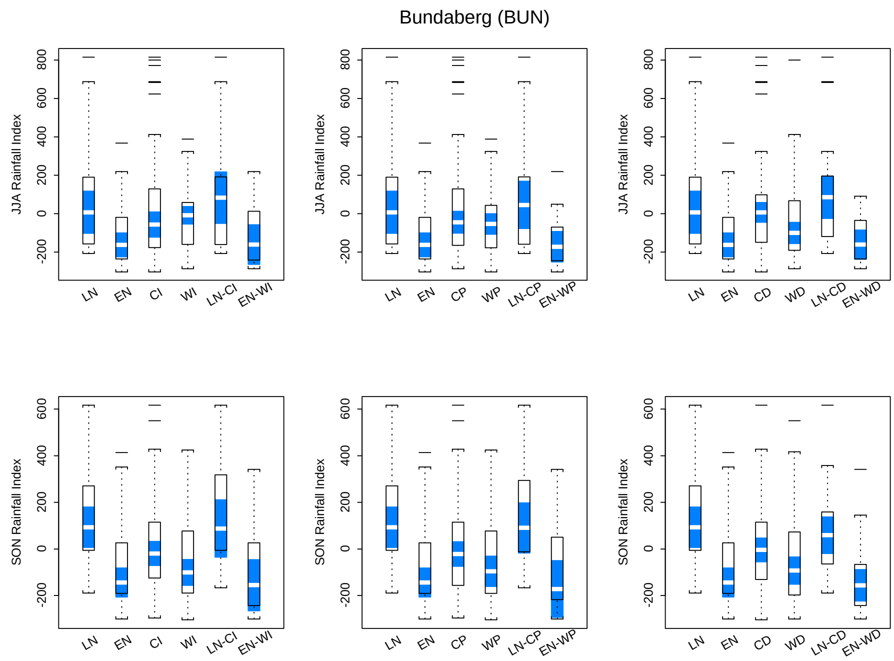

Figure 3. Bundaberg (BUN) rainfall distributions (as in Figure 2)