AN ENSO MONITORING AND PREDICTION SYSTEM BASED ON NEW INDICES OF THE SOUTHERN OSCILLATION AND EASTERN PACIFIC SEA SURFACE TEMPERATURES

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1. INTRODUCTION

Since ENSO (El Niño-Southern Oscillation) acts like a continuum, the key to better long-lead seasonal forecasts is the track the current ENSO State and determine what ENSO transition is occurring. A review of ENSO research, reveals that initial work focused on global scale pressure changes before more recent advances were made in oceanography and the study of air-sea interactions along the equator (Allan et al., 1998). Few developments have recently occurred with the atmospheric component of ENSO and for many the Southern Oscillation is just a sea-saw in pressure between Darwin/Indonesia and the eastern equatorial Pacific.

However, recent composite mapping of ENSO events (e.g. Stephens et al. , 2007) found unique spatial and temporal patterns of pressure anomalies starting in the year before El Niño (year -1) that reversed over the following year. Inherent in this process is an eastward propagation of low pressure anomalies that bifurcates into the North and South Pacific, before becoming established across the Pacific Ocean in year (0) of a warm event. For La Niña, the reverse pattern of eastward propagating high pressure anomalies from the Australian region was found.

In this study new indices of the Southern Oscillation were derived to monitor this evolving pattern of pressure anomalies leading into and out of ENSO events. These indices were combined in a statistical analogue selection function to provide long-lead forecasts of ENSO State that begin in October (year -1).

2. NEW INDICES

To highlight the spatial and temporal components of the Southern Oscillation, the difference in pressure anomalies between La Niña and El Niño were calculated for three month intervals from May, June, July in the year before ENSO (MJJ -1), through to MJJ (+1), the year after ENSO.

In the austral winter/spring (-1) the key difference in pressure was the much lower pressure over Australia prior to El Niño. Of critical importance for predicting El Niño strength, was the finding that the magnitude of the negative pressure anomalies over southeastern Australia was related to the magnitude of warming in the Pacific a year later (Figure 1). As part of a sea-saw in pressure anomalies in the southwest Pacific (van Loon and Shea, 1985; 1987) the pressure goes from very low to very high over the 12 months leading into El Niño (Figure 1). From this result the first index that was developed was an El Niño Prediction Index (EPI). This is finalized each November and is based on the largest standardized pressure anomalies over south-eastern Australia (non- El Niño conditions), or the largest standardized sea surface temperatures in the Nino 3 region (in El Niño events). The "else if" calculation takes into account the rapid cooling that typically occurs after El Niño.

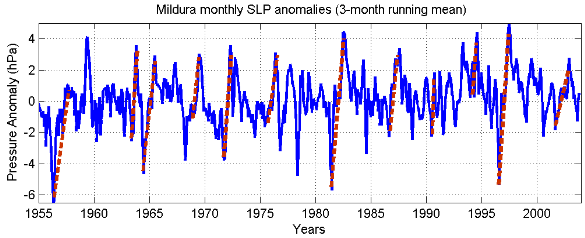

Figure 1. Monthly sea level pressure anomalies over south-eastern Australian from 1955 to 2003. Changes in pressure leading into El Niño events are highlighted with dashed red lines.

In the period November (-1) to April (0) the key regions to track are the central North Pacific and the central South Pacific east of New Zealand. Figure 2 shows that low (high) pressure anomalies spread east and bifurcate into the Pacific mid-latitudes prior to El Niño (La Niña). These changes lead those measured at Tahiti. Based on this result an ENSO Transition Index (ETI) was formed to measure the strength of the Pacific high pressure ridges. The ETI is calculated by summing the standardized pressure anomalies at Honolulu in the north, plus the average of standardized pressure anomalies at Raoul and Rapa Islands in the south.

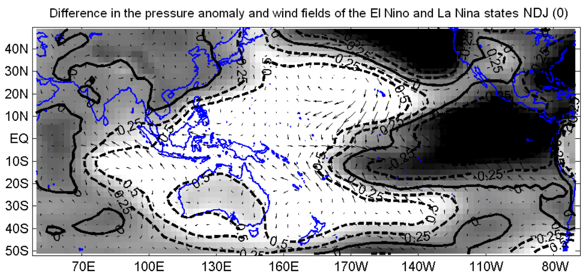

Figure 2. Difference in composite pressure anomalies between La Niña and El Niño years in November-January (0). Pressure anomalies are shown as contours with negative anomalies shown in a grey scale. Wind anomalies are shown as arrows.

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In the critical months of May(0) - October(0) the key signature of the Southern Oscillation are the two broad regions of oppositely varying pressure (Figure 3) A two station index such as the SOI struggles to measure this pattern and can be strongly influenced by local weather at one of the stations, e.g. tropical cyclones. Therefore, a MeanSOI was derived which is calculated by averaging real-time weather stations at: 1) the existing SOI at approximately 15°S (Darwin, Tahiti), 2) the Equatorial SOI (EQSOI) along the equator (EPAC – 5°S-5°N; 80-130°W; INDO – 5°S-5°N; 90-140°E), 3) a Mid-latitude SOI (MLSOI) close to 30°S (Alice Springs and Mildura in the west; Rapa Island in the east) and 4) Hawaii pressure (Honolulu, 21°N,158°W).

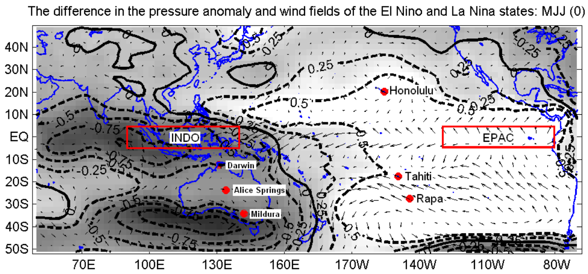

Figure 3. Difference in composite pressure anomalies between La Niña and El Niño years in May-July (0). Pressure anomalies are shown as contours with negative anomalies shown in a grey scale. Wind anomalies are shown as arrows.

The MeanSOI is more stable than the SOI, tends to indicate ENSO state changes earlier, and has a reduced risk of falsely indicating ENSO events. Further, the largest trend in the MeanSOI over the previous six months also has a threshold decline needed for an El Niño to develop. This result was utilized in early June 2002 to predict an El Niño when there was much uncertainty in the forecasts from other models.

As the ENSO signal starts to appear, the critical thing to monitor is the degree of coupling between the ocean and atmosphere at the global scale. Gergis and Fowler (2005) defined a Coupled ENSO Index (CEI) by calculating the difference between the SOI and Nino 3.4. We developed an equivalent CEI* based on the MeanSOI and Nino 3 SST. This index is useful on its own in differentiating ENSO transition changes, especially when comparing transitions from El Niño to La Niña, compared to El Niño to neutral.

3. MODEL- ENSO SEQUENCE SYSTEM (ESS)

So as to predict ENSO State with lead time an ENSO Sequence System (ESS) was developed to select years in the past that are most similar (analogous) in the global scale ocean and atmosphere. Five variables were selected in the model to account for the key features of the changing Southern Oscillation pattern through the year.

The first variable was the 9-month sequence of the CEI* which is used to measure which ENSO transition is taking place, i.e. from what ENSO state we are coming out of. The choice of nine months was motivated by Drosdowsky (1994) who found that nine months in an analogue forecasting system gave the best long lead predictions of the SOI. The second variable was the last monthly value of the CEI* (present ENSO State), the third, the El Niño Prediction Index (EPI), the fourth, the last 4-month mean of the ENSO Transition Index (ETI), and the fifth, the largest 6-month trend in the MeanSOI.

The ESS selection of analogue years in any given month is done by a weighted sum of deviances, with half the weight given to the average absolute difference of the latest nine monthly values of the CEI. This was done to ensure analogue years were selected that closely resembled the recent history of the current situation. The monthly weights for the last four variables were determined using a 'weighted space search' (after Mullen and Thompson, 2006) with the model calibrated to predict the mean CEI* in the following September-December. All five variable rankings are combined, with their monthly weights, to give an overall rank and similarity score. The similarity score uses a "closeness of fit" technique and measures how closely the five variables compare to the present pattern through a weighted sum of standard differences. This measure ranges from -2 (no similarity) to +2 (highly similar sequences) and acts like a standardised Z score

Prediction skill is defined as the mean absolute error (MAE) between predicted and observed average CEI* for the following September to December (as a proxy for ENSO state). The number of analogues selected was varied from one to ten, with the optimal number being five, i.e. had the highest skill at predicting ENSO State. Figure 4 shows the cross-validated prediction skill for five analogues, and as expected, the skill increases as we get closer to the ENSO event being predicted. Confidence in the analogue years is steady from September (-1) through to February, but then increases in April as the skill improves

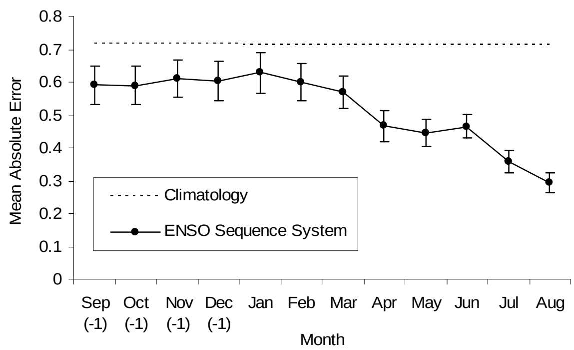

Figure 4. Prediction skill of the ESS, compared to climatology (dashed line). Vertical bars show plus and minus one standard error of the mean absolute error.

An example of a real-time forecast of ENSO State using the ESS is illustrated in Figure 5. Whereas most ENSO models were predicting El Niño conditions to persist into autumn 2007, the ESS analogues were suggesting a rapid cooling into La Niña or neutral conditions. The verification line shows that Nino 3 SST anomalies closely followed the mean of the five analogue years for the first eight months. By choosing a number of analogues a range in expectation is able to be shown. The confidence that can be placed in predictions is proportional to the spread in analogue projections.

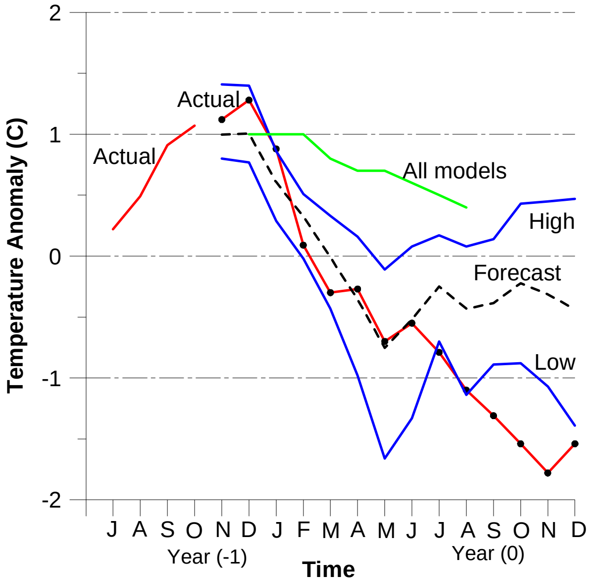

Figure 5. Predictions of Nino 3 SST anomalies based on analogues selected on the 7th November 2006, along with verification values after that time (red line). 'All models' represents the average of all operational ENSO models summarised in the IRI ENSO Prediction Plume, 15 November 2006. However, a direct comparison with 'All models' is difficult as the seasonal mean for the Nino 3.4 region is plotted (compared to monthly values of Nino 3 from ESS.

The ESS analogue years were used to predict Australian rainfall by taking the median rainfall ranking of the five analogues at each rainfall station across Australia. Skillful May to October growing season rainfall forecasts were found for much of northeastern and southwestern Australia as far back as early February (using analogue years selected with January data). As expected, the skill was generally highest for regions that are most consistently impacted by ENSO events, though the skill for southwestern Australia was better than expected. Such skilful forecasts with lead-time suggest that this model has potential to assist farmers in decision making early in the year, especially in relation to the size of crop to be planted and the amount of inputs to be applied.

Each month an ENSO technical summary is produced which summarizes the new Southern Oscillation Indices and lists the five analogue years from the ESS. A growing season outlook is also produced for all of Australia. These products are placed on the DAFWA website: www.agric.wa.gov.au/climate

The model was also tested to include sub-surface heat in the Pacific Ocean. However, the short period of heat data since 1980 meant that there were few analogous situations to calibrate the model on and the skill of the model was reduced.

4. Conclusions

The Southern Oscillation has unique spatial and temporal patterns that must be monitored through the year in conjunction with oceanic changes. By deriving new indices that track the ENSO cycle through the year, better predictions of ENSO transitions can be made. When these indices are combined in an analogue selection function (ESS) skillful forecasts of ENSO State can be made from late in the previous year. The ESS can also be used to predict Australian rainfall with up to three months lead-time. This suggests that the model could be used for seasonal forecasting in other regions of the world affected by the ENSO phenomenon.

5. References

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