

# El Niño—Southern Oscillation Impact Prediction

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## Abstract

The El Niño-Southern Oscillation (ENSO) phenomenon affects the atmosphere and ocean over much of the globe. The resultant atmospheric and oceanic anomalies can produce a variety of biological and societal impacts. Three examples of impacts that may be predictable by monitoring simple indices of ENSO are discussed. The advantages and disadvantages of such "direct" prediction of impacts are considered.

## 1. Introduction

"The Southern Oscillation (SO) is the dominant pattern of short-term climatic variation over the globe. It accounts for a greater proportion of variance of climatic and oceanic fields on time scales from a season to ten years than any other single phenomenon, excepting only the annual cycle" (Wright, 1985). The SO is related to the *El Niño*, the occasional severe warming of the equatorial eastern Pacific—the entire phenomenon is often referred to as ENSO. ENSO-related atmospheric fluctuations and oceanic fluctuations impact on the biology, economy, ecology, and agriculture of substantial areas. Glantz et al. (1987) provide a selection of case studies of ENSO impacts, some of which are severe. Russac (1986) in discussing the effects of the 1982–83 ENSO event on the northern coast of Peru, notes that, "It was a time of anguish, terror, hunger, disease and heartache." Some ENSO-related impacts may be predictable simply by monitoring indices of ENSO.

Three features of ENSO appear to provide a basis for prediction, namely its dominance of interannual atmospheric and oceanic variability, the long life cycle of ENSO fluctuations, and the way in which this life cycle is tied to the annual cycle. Rasmusson and Carpenter (1982) provide a clear description of the typical life cycle of an ENSO event<sup>1</sup> by compositing six separate events. This composite ENSO is, like most models, just a convenient artifice. In fact, each event differs, more or less, from the composite picture and has its own character and timing. Nevertheless, there is enough similarity between them to justify generalization. The composite ENSO starts early in the calendar year and lasts about 12 months.

Wright (1985) described the well-known annual cycle of persistence (the tendency for anomalies to remain of the same

sign and similar magnitude for some months) associated with the ENSO. Persistence is highest between July and February and lowest around April. The strong persistence in the second half of the calendar year has led many investigators to examine the prospects for using this persistence to predict, months ahead, ENSO-related climatic fluctuations occurring near the end of the calendar year. Walker (1910) suggested the use of Australian surface pressure to predict subsequent Australian rainfall (both rainfall and pressure in Australia are related to ENSO). Walker, with 30 years of data averaged over 12 Australian stations, found a correlation of  $-0.45$  between the October to November Darwin surface pressure and the December to April rainfall. Nicholls (1985) demonstrated that the number of tropical cyclones observed in the north Australian cyclone season (November to April) is related to ENSO and predictable by monitoring an ENSO index (Darwin pressure again) in the months preceding the cyclone season. Higher than normal Darwin pressure tends to precede inactive cyclone seasons. Many other examples of lag relations between ENSO indices and subsequent climatic fluctuations, almost all during the period of strong persistence of ENSO (July to February), have been proposed as methods for long-range weather prediction.

Once a forecast of, say seasonal tropical-cyclone incidence, has been prepared using the lag relations with ENSO, social scientists or biologists could infer the likely impacts of such climatic anomalies and recommend action to lessen the deleterious consequences or to take advantage of favorable weather. An alternative approach is to find empirical lag relations between ENSO and the biological or social impacts and to use these to forecast the impacts. Three examples of such lag relationships, all from the Australian region, are presented, as is a discussion of the advantages, disadvantages, and potential of using empirical lag relationships.

The impact-prediction methods discussed do not rely on first predicting ENSO itself. They use as predictors values of an ENSO index observed well after the usual starting time of an ENSO "event." The approach is to monitor ENSO and then predict the impact, taking advantage of the strong persistence of ENSO-related climate fluctuations during the second half of the calendar year. Darwin pressure is used here as an ENSO index<sup>2</sup>.

## 2. ENSO impacts—three examples

### a. *Sorghum* yield

Sorghum is an important, rainfall fed and limited, Australian summer crop. Rainfall in the sorghum-growing region, before

<sup>1</sup> The concept of an ENSO "event" itself is an artifice, albeit a useful one. Examination of time series of ENSO indices (e.g. Figure 1 in Wright, 1985) indicates that the phenomenon is in fact a continuum with negative and positive values of all magnitudes. There is some evidence of bimodality (e.g. Nicholls, 1979; Meyers, 1982) and this may justify use of the idea of "ENSO events" and "anti-ENSO events", at least for illustrative and instructive purposes. Throughout the remainder of this paper, however, the impacts of ENSO fluctuations of all magnitudes and both positive and negative values of SO indices will be considered. Indeed, some of the impacts discussed below occur during "anti-ENSO" episodes.

<sup>2</sup> This is just one of several indices routinely used in ENSO monitoring, all closely related to each other. Chen (1982) examines the relationships between various ENSO indices.

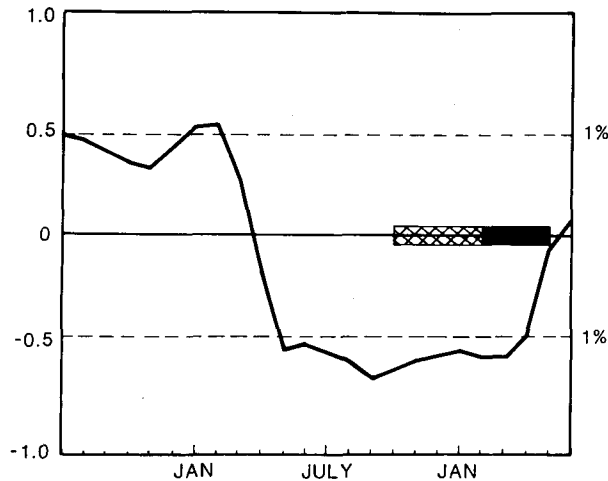


FIG. 1. Correlations of Australian sorghum yield (tonnes per hectare) with monthly means of Darwin station-level atmospheric pressure during and before the sorghum growing season. Data from 1954–1983. The planting period is shown as a hatched box and the harvest period as a black box. The one-percent significance levels for the correlation coefficients are shown as thin dashed lines. The Januaries before and during the planting season are indicated by “J” on the abscissa.

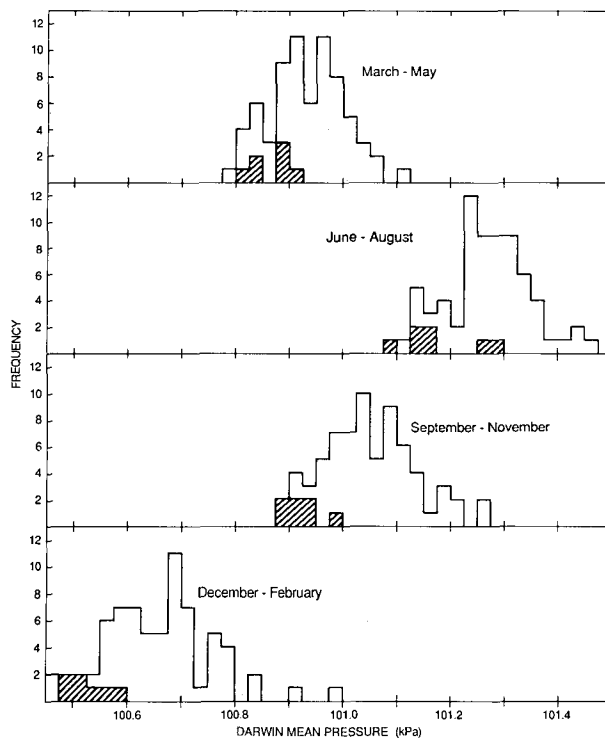


FIG. 2. Frequency distributions of Darwin mean sea-level pressure (in 0.025 kPa classes) for four three-month seasons leading up to the time when Murray Valley Encephalitis may occur in southeast Australia (January to April). Seventy years of data, 1915–16 to 1984–85, were used. The seven years in which clinical cases of MVE were recorded in southeast Australia are shown by the shading; the 63 years with no MVE occupy the unshaded areas.

and during the growing season (October to April), is related to ENSO. Thirty years of average Australian sorghum yields per unit area have been correlated with Darwin pressure during and before the growing season (Nicholls, 1986a). Long-term trends,

presumed due to changing cultivars or management practices, were removed from the yield time series prior to calculating the correlations with pressure<sup>3</sup>. Figure 1 shows the correlations, along with the seasons of planting and harvesting. Statistically significant correlations exist, even with pressures from several months before the time of planting. Thus the interannual fluctuations of sorghum yield appear to be related to ENSO and may be predictable, well before planting, simply by monitoring ENSO<sup>4</sup>.

#### b. Murray Valley Encephalitis (MVE)

MVE is a severe, often fatal, viral illness transmitted to humans by mosquitoes. Since 1917 when the clinical symptoms of the illness were first diagnosed, there have been seven years when cases were observed in southeastern Australia. Cases occur between January and April and follow widespread flooding over several seasons (Forbes, 1978). Flooding leads to increased mosquito numbers by increasing the numbers of breeding sites and host populations (birds, marsupials). Rainfall over eastern Australia is related to ENSO, and ENSO-indices can be used to both monitor and predict rainfall during the winter, spring and early summer (Walker, 1910; Nicholls and Woodcock, 1981; McBride and Nicholls, 1983). It is not surprising, therefore, that Darwin pressure during the southern winter (June to August) and spring (September to November) is related to MVE outbreaks in the following January to April (Nicholls, 1986b).

Figure 2 shows frequency distributions of Darwin mean sea-level pressure averaged over the three-month seasons leading up to the period when MVE may occur in south-eastern Australia (January to April). Seventy years of data (1916–1985) were used in preparing the frequency diagram. The seven years when MVE was observed in south-eastern Australia are shown by the shaded boxes. All MVE years were preceded by low Darwin pressures (“anti-ENSO”). Since 1916 there have been nine years when Darwin mean September to November pressure was below 100.95 kPa (Figure 2). In six of these years MVE was observed in the subsequent January to April. In only one of the other 61 cases, with Darwin pressure above 100.95 kPa, was MVE subsequently observed. No cases have been observed subsequent to the 49 occasions when September to November pressure was above 101.0 kPa. Thus ENSO appears to provide a simple, objective early warning of the likelihood of MVE in south-eastern Australia. Such an early warning although far from perfect, may be useful to public-health authorities—for instance, to increase insecticide use and other prophylactic measures in years when Darwin pressures are low (i.e. indicating a higher than normal likelihood of MVE incidence).

#### c. Green turtles

The number of green turtles (*Chelonia mydas*) observed nesting around northern Australia and Indonesia varies substantially

<sup>3</sup> Both the residual yield and the pressure are normally distributed.

<sup>4</sup> The relationship in Figure 1 is with yield averaged over a large area. Weaker relationships could be expected with yield at, say, farm level. So the relationship may not be much use for any individual farmer but it could be useful for sorghum-marketing authorities to estimate, months in advance, the size of the total crop, if the relationship is confirmed on independent data.

from year to year. Interannual fluctuations in the numbers of breeding turtles are in phase at widely separated rookeries and large numbers of turtles breed two years after ENSO events (Limpus and Nicholls, 1988). Figure 3 is a scatter diagram of the numbers of turtles breeding at two rookeries (Heron Island and Raine Island) situated at opposite ends of the Great Barrier Reef. The natural logarithm of the numbers of turtles breeding is plotted against the Darwin pressure for the period November to January two years earlier. Turtle numbers from 1974–75 to 1985–86 were used. Although the samples were very small significant correlations were found between the turtle numbers at both islands and Darwin pressure twenty to thirty months earlier. For Heron Island the correlation was strongest (0.78) when the Darwin pressure led by two years.

A biological cause for the apparent relationship in Figure 3 is unknown, although a lag of more than a year is not surprising. Only a portion of the mature female green turtles breed in any one season, each female breeds on average only once every five years, and preparation for breeding commences well over a year before oviposition (Limpus and Reed, 1985). Some atmospheric or oceanic anomaly associated with ENSO may “trigger” the turtles to commence preparation for breeding. The oviposition triggered by ENSO takes place more than a year later. Further work will be needed to confirm the apparent relationship in Figure 3 and to verify a proximate environmental “trigger”. The relationship, if confirmed, may allow prediction, two years in advance, of the approximate numbers of turtles breeding. Such a prediction is potentially useful in sea-turtle management in areas where eggs, courting turtles, or nesting females are harvested.

### 3. Impact prediction: advantages, problems, and potential

#### a. Advantages

The examples of the previous section suggest that a wide variety of biological impacts may be predictable by monitoring simple indices, at least in areas where ENSO strongly modulates the atmosphere or ocean. But why directly forecast impacts, rather than using the conventional approach of forecasting atmospheric and oceanic anomalies first and then interpreting the impacts of these anomalies? Four potential advantages suggest themselves.

First, many of these impacts aggregate climate anomalies over a large area, and sometimes over a long period. Thus MVE only appears to occur if rainfall is very heavy over a large area, and for several seasons. Rainfall could be aggregated and used as a predictor but it is simpler to monitor pressures at just a single station (Darwin). Predictions from aggregated rainfall also may have a reduced lead time relative to that possible through monitoring an ENSO index.

Second, an impact prediction is more-readily understood and acted upon by a potential user, without the further interpretative step which would be required if climate anomalies are predicted first. Also, it may be easier to quantify the uncertainty in the impact prediction using the single step approach. In the conventional approach of first forecasting climatic anomalies and then forecasting impacts expected from these anomalies, the uncertainty in the climatic forecast must be explicitly factored

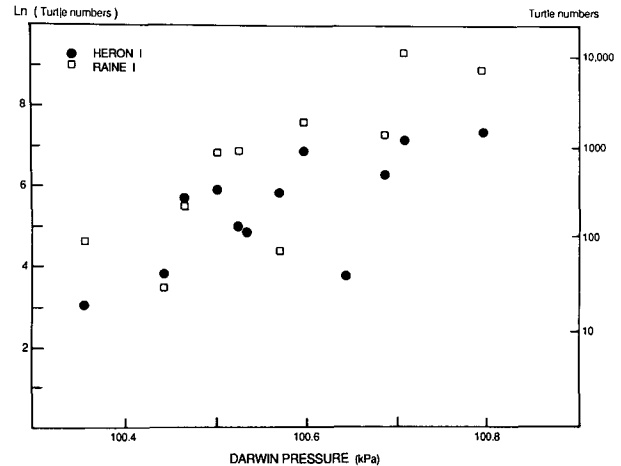


FIG. 3. Scatter diagrams of natural logarithms of numbers of green turtles breeding at Raine Island and Heron Island versus Darwin atmospheric pressure for the November to January period two years earlier. Data from 1974–75 to 1985–86, Raine Island data for 1983–84 and 1985–86 unavailable.

into the impact-prediction model. In the “direct” approach such uncertainty is included “automatically.” On the other hand, users may be less inclined to accept a prediction based on an ENSO index compared to one based on other climate variables, such as rainfall, with biological effects that are clearer.

Thus, biological-weather interactions may result in longer lags between ENSO “events” and their biological impact, relative to the lags between ENSO and climatic anomalies. This likely occurs in the case of the green turtles and results in a longer forecast lead time than is feasible for prediction of atmospheric or oceanic anomalies.

Finally, the interdisciplinary research necessary for the development of “direct” impact-prediction methods focuses the work on predictands important to the final user, rather than just the conventional predictands (monthly or seasonal anomalies of rainfall, temperature) that have been the traditional focus in climatic prediction. Such traditional climatic predictands may not be the most important in terms of an impact prediction. A related outcome from the interdisciplinary research is that it may generate interesting research questions for both biological and physical scientists (e.g. Is there a proximate ENSO-related environmental cause of the fluctuations in turtle breeding?).

#### b. Problems

Not all studies of the feasibility of direct prediction of impacts by monitoring SO indices are likely to be successful, for several reasons. First, the approach is limited to areas where ENSO strongly modulates the atmosphere or ocean.

Second, many biological impacts will arise from more-complicated climatic anomalies than those described here. In such cases the relationship with ENSO might also be more complicated and this might remove the possibility of simple, direct prediction. Better predictions in such cases might be achieved using primary climatic variables (rainfall, temperature).

Third, data collection in some biological sciences can be more difficult than in meteorology and oceanography. Yet impact data over many years are required if we are to relate them

to the ENSO. The examples in the previous section all use relatively small samples, because of the difficulties of collecting biological data. The small data samples available make it difficult to test relationships on independent data.

Finally, other factors influence biological responses to climatic anomalies. For example, insect pests affect crop yields. Some other factors may confound any potential relationship with ENSO.

Even where lag relationships between ENSO and its impacts are found, the predictions from these relationships will be far from perfect. A forecast of MVE, if made when Darwin September to November pressures were below 100.95 kPa would have given three false alarms out of nine forecasts of MVE. One outbreak of MVE would not have been predicted at all.

### c. Potential

Despite the possible problems, the potential for developing methods for directly predicting impacts appears to be high, as does the potential value of such methods. ENSO does affect the atmosphere and ocean over much of the globe and many of these areas also face problems arising from environmentally related disease or fluctuations in crop yields. It appears to be an opportune time, as meteorologists and oceanographers increase their knowledge and understanding of ENSO, and the field of climatic-impact studies matures (Kates et al., 1985), for increased multidisciplinary work to determine which impacts of ENSO may be predicted, and how accurately.

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## announcements (continued from page 172)

### First Interdisciplinary Conference on Urban Air Quality, 15–18 November 1988, Boulder, Colorado

The conference titled "Out of the Cloud: Toward Land Use, Science, and Policy Solutions" is jointly sponsored by the National Air Quality Center, the Air Pollution Control Association, and the American Meteorological Society. This conference shall bring scientists together with policy makers, planners, and engineers to address problems and stimulate dialogue toward interdisciplinary solutions to urban air pollution. The conference will consist of invited papers, oral presentations, and poster sessions covering scientific, policy, and land use; transportation and fuels; and health issues.

Papers are solicited on the following topics: urban microclimates, complex terrain influences on air quality, synoptic and mesoscale controls on urban air quality, physical and

chemical characteristics of pollutants, and source apportionment.

Following the oral presentations, a panel discussion will focus on conclusions and define new directions for application of meteorology to urban air quality problems. A synopsis of the panel discussion will be included in a volume of abstracts to be distributed to conference registrants.

Titles and reviewer's abstracts (300–400 words) should be submitted in triplicate by 15 June 1988 to: National Air Quality Center, PO Box 791, Boulder, Colorado 80306. Be sure to include the complete mailing address of the senior author. Authors should state preference for oral or poster presentations. Time will be set aside at the conference for 1–2 minute oral summaries of the posters.

For further information, contact W. Gale Biggs (telephone: 303-494-4288) or Dennis M. Rodgers (telephone: 303-497-6933).

## announcements (continued on page 207)