Monitoring and Predicting El Niño Invasions

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ABSTRACT

Southern Oscillation indices (differences in sea level atmospheric pressure between Easter Island and Darwin, Australia, and between Juan Fernandez Island and Darwin) were treated so as to emphasize interannual changes and considered for monitoring unusual equatorial Pacific ocean-atmosphere developments and certain of their consequences (e.g., El Niño invasions). It now appears that their trends can be used to predict activity of El Niño intensity several months in advance.

1. Introduction

Earlier work indicated that there was a close relationship between the Southern Oscillation and abnormally heavy rainfall developments over the central and western equatorial Pacific (Quinn and Burt, 1970, 1972). These developments (a greatly weakened southeast trade system with a related slackening in upwelling of cooler waters to the equatorial surface, resulting in

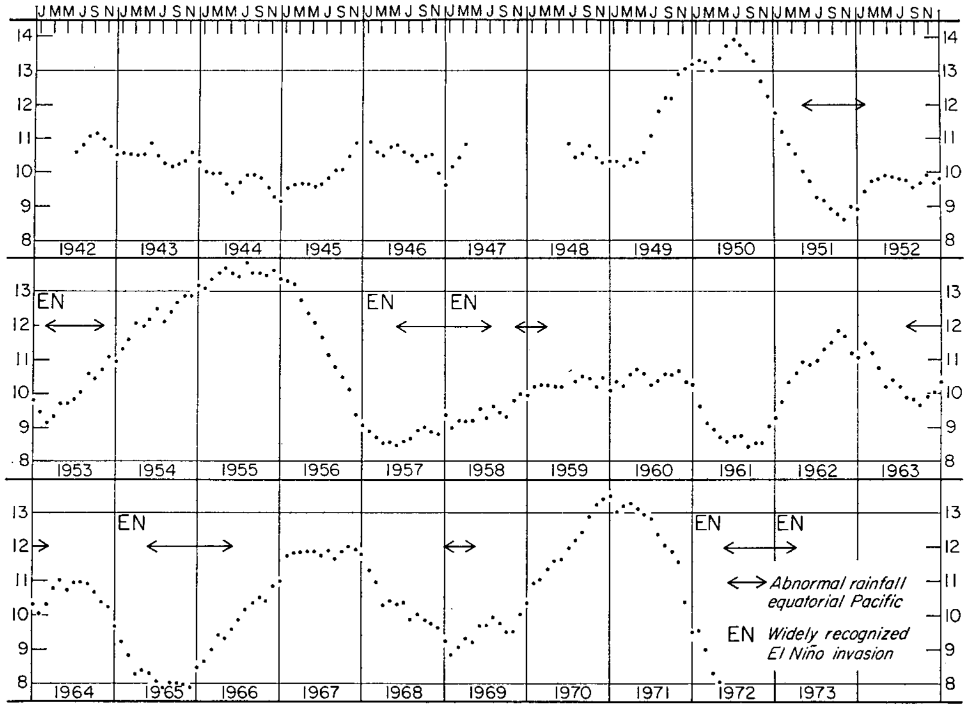

FIG. 1. The 12-month running means (points plotted at middle of the 12 months) of the difference in sea level atmospheric pressure (mb) between Easter Island and Darwin, Australia, for 1942–72. Periods of El Niño and abnormally heavy central and western equatorial Pacific rainfall are indicated.

unusually high equatorial sea surface temperatures and abnormally heavy rainfall) were sometimes associated with an El Niño invasion and sometimes not. Although methods for predicting the abnormally heavy equatorial rainfall through the use of a Southern Oscillation index (the monthly mean sea level atmospheric pressure difference between Easter Island and Darwin, Australia) trend were discussed, no attempt was made to predict El Niño which often sets in several months prior to the anomalous equatorial rainfall. (El Niño refers to the anomalously warm surface water invasion along the southern Ecuadorian and Peruvian coastal regions which are usually under the influence of cooler waters from coastal upwelling and the northward flowing Peru Current. These infrequent invasions set in between January and March, the Southern Hemisphere summer, when sea temperatures are at a seasonal high, but they may persist well into the Southern Hemisphere fall. They are at times accompanied by abnormally heavy rainfall over this ordinarily arid coastal region and may also cause mass mortality of indigenous marine life. They usually have a disastrous effect on Peruvian Anchoveta fisheries, and as a result can seriously reduce world fishmeal supplies for two, three or more years.)

Recent work with 12-month running mean plots of Southern Oscillation indices indicates that they cannot only represent the variable amplitude and period of the Oscillation, but can also reflect the stage and intensity of related equatorial developments and their consequences (e.g., El Niño invasions). Also, it appears that by being aware of the related developmental sequence, once one determines an existing developmental stage and intensity he can anticipate conditions that will prevail in a later stage. This study has now progressed to a point where it seems appropriate to put out a short note on a prediction concept that may have considerable merit. The note will pertain primarily to prediction of the stronger equatorial developments that relate to El Niño invasions.

2. The indices and their components

Since El Niño invasions are associated with periods of unusually weak southeast trades, the strength of the trades varies with development of the South Pacific subtropical high, and the eastern core of the Southern Oscillation is considered to be in the vicinity of this high (Berlage, 1966), it appeared that indices which represent the Southern Oscillation might also be quite effective for monitoring the low-latitude Pacific developments that lead up to El Niño. Two indices were originally considered for this purpose: 1) the monthly mean sea level atmospheric pressure difference between Easter Island (27°10′S, 109°26′W) and Darwin, Australia (E-D index), which was used earlier (Quinn and Burt, 1972); and 2) the monthly mean sea level atmospheric pressure difference between Juan Fernandez Island (33°37′S, 78°52′W) and Darwin (JF-D index). Darwin pressure values reflect changes taking place in the Indonesia equatorial low. Easter and Juan Fernandez pressures reflect changes associated with the southeast Pacific subtropical high. It was assumed the site generally closer to the high pressure center would provide the most effective input to a Southern Oscillation index. Individual monthly mean pressure values and/or monthly mean pressure analyses (Deutscher Wetterdienst, Seewetteramt, 1956–72) were used to consider the relative proximity of the pressure center to the two sites. Over the past 30 years there was only one extended period, April 1961–January 1963, during which the southeast Pacific subtropical high center remained closer to Juan Fernandez; generally it was closer to Easter. Berlage's (1957, 1966) analyses also indicate Easter's pressures would be preferable for representing changes in the eastern core of the Oscillation.

Due to the nature of El Niño and the anomalous equatorial Pacific developments, it appeared most suitable to consider plots of the 12-month running mean values of the indices in order to emphasize the interannual changes associated with these phenomena. Fig. 1 shows the 12-month running mean values of the E-D index (plotted at the middle of the 12 months); the approximate 30-year record is limited by the availability of Easter Island data (Quinn and Burt, 1972). Periods of abnormal equatorial rainfall and reported El Niños are included in Fig. 1. Fig. 2 shows the 12-month running mean values for the separate Easter and Darwin atmospheric pressure components (plotted at the middle of the 12 months). In the latter case, the Darwin component was extended back through 1938 to show how this component looked during the years associated with the unusual 1939–41 anomalous equatorial and recurrent El Niño conditions. Fig. 3 shows similar plots for the JF-D index and its components for the time leading up to, during, and following the unusual April 1961–January 1963 period discussed earlier.

3. Anomalous developments

Over the period during which the E-D index was available, El Niños were reported for the following years: 1953, 1957, 1958, 1965, 1972 and 1973. [There is some controversy with regard to the status of the 1965 El

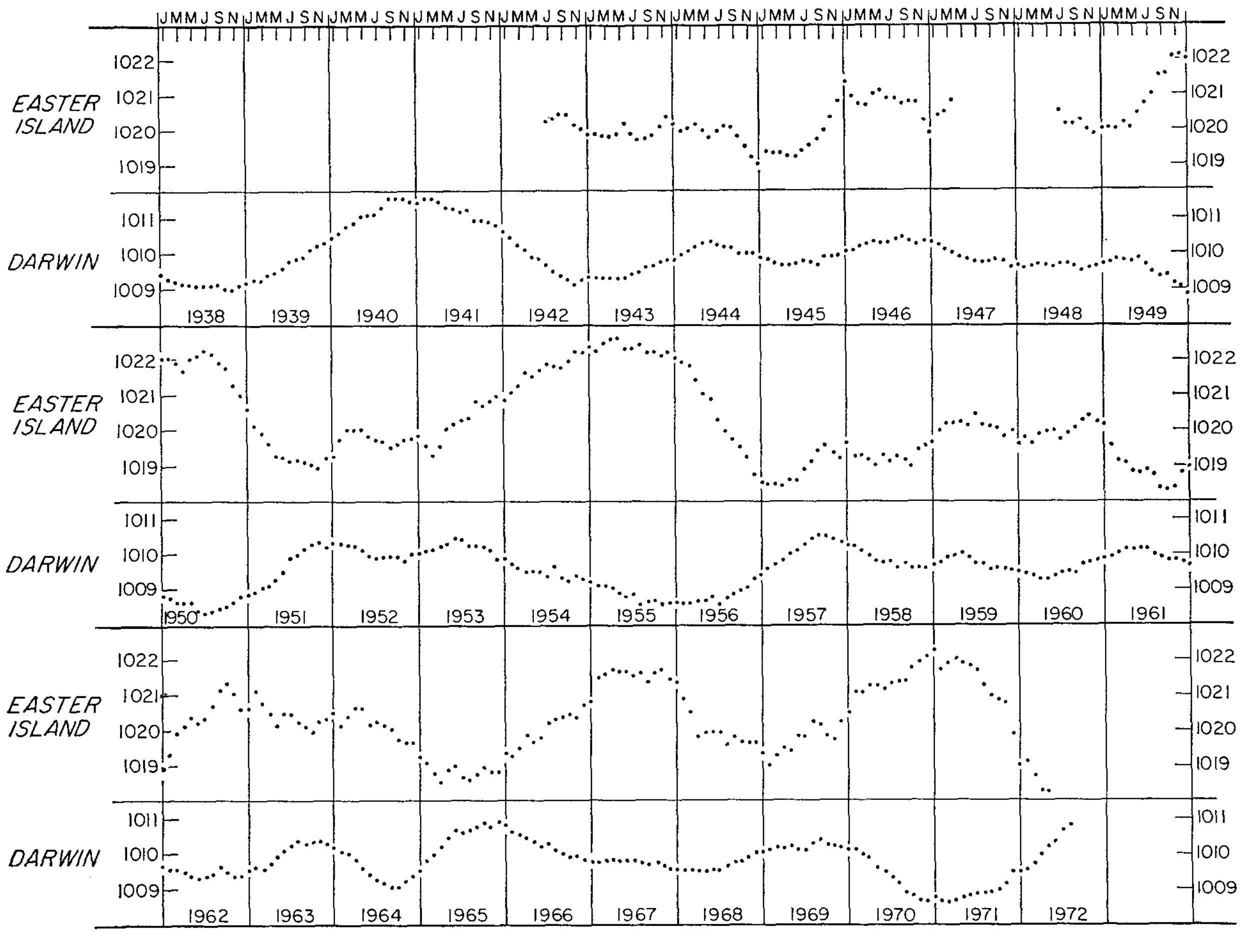

Fig. 2. The 12-month running means (points plotted at middle of the 12 months) of sea level atmospheric pressure (mb) for Easter Island (1942–72) and Darwin, Australia (1938–72).

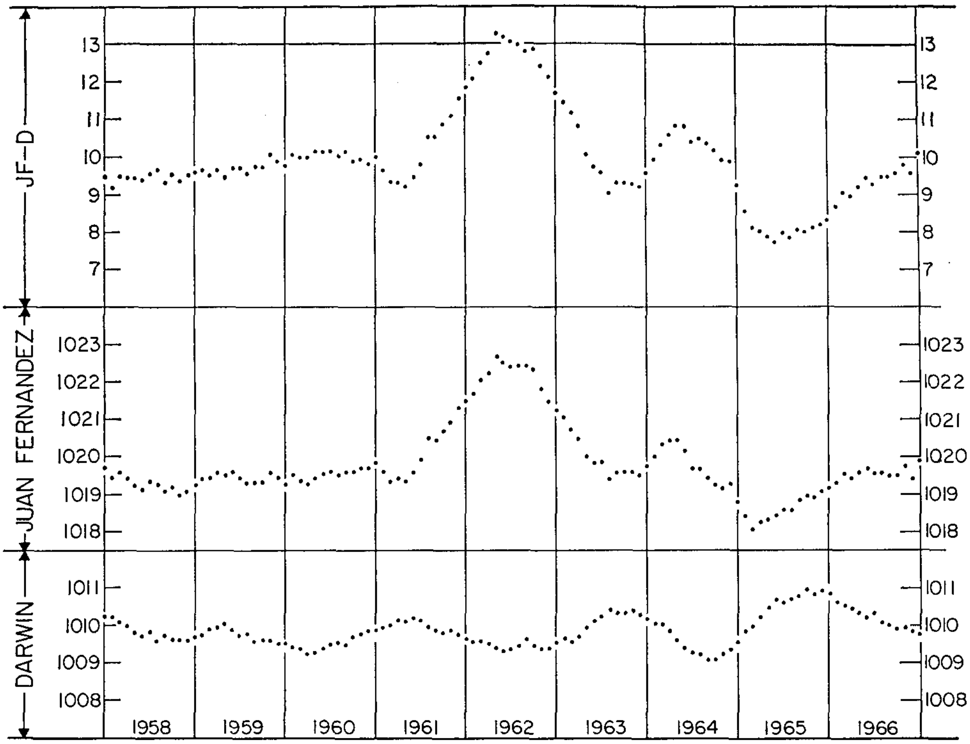

FIG. 3. The 12-month running means (points plotted at middle of the 12 months) of the difference in sea level atmospheric pressure (mb) between Juan Fernandez Island and Darwin, Australia (JF-D), for 1958–66, and the 12-month running means of sea level atmospheric pressure for Juan Fernandez and Darwin for 1958–66.

Niño; Stevenson *et al.* (1970) did not recognize it, whereas several other authors did. Here it will be considered a relatively weak El Niño.] Considering this information in relation to Fig. 1 (for 1942–60 and 1966–72) and Fig. 3 (for 1961–65), it was noted that each of the exceptionally high index peaks (>13 mb), i.e., June–July 1950, May–November 1955, May 1962 and January 1971, was followed by a large fall in index (~4½–6 mb), then an El Niño invasion and/or abnormally heavy equatorial Pacific rainfall. It took about 14–30 months to build up to the unusual running mean peaks, 12–15 months to subsequently relax to the 9-mb level, and 14–16 months to reach trough values. It appears that relaxation to the 9-mb level by the early part (January–March) of a subsequent year was essential, if the first sign of unusual activity was to be an El Niño invasion; otherwise, the first sign of such activity would be anomalous equatorial Pacific rainfall. In the case of the 1950 peak, relaxation started too late in 1950 to cause a 1951 El Niño. The necessary fall was realized later in 1951 and abnormally high sea surface temperatures were experienced along the Peru coast in the Southern Hemisphere winter (Schweigger, 1961; Bjerknes, 1966); hence, the first sign of unusual activity was the abnormally heavy rainfall over the central and western equatorial Pacific from mid 1951 to early 1952 (Fig. 1). El Niño appeared as a seasonal recurrence of activity in early 1953 and anomalously heavy rainfall was again noted in the central and western equatorial Pacific in 1953 (Fig. 1). In the case of the 1955 peak, relaxation began at the end of 1955, and the index fall was sufficient by early 1957 to have an El Niño invasion. Heavy equatorial Pacific rainfall occurred from mid 1957 through mid 1958, a seasonal recurrence of El Niño in early 1958, and anomalous equatorial rainfall from late 1958 through early 1959 (Fig. 1). The situation following the 1962 peak (Fig. 3) was similar to that following the 1950 peak, in that relaxation set in too late in 1962 to cause an early 1963 El Niño; therefore, the first sign of activity was the anomalous rainfall over the central and western equatorial Pacific from mid 1963 through early 1964 (Fig. 1). El Niño appeared in a seasonal recurrence of activity in early 1965, and anomalous equatorial rainfall from mid 1965 through early 1966 (Fig. 1). Considering the January 1971 peak, relaxation set in early in 1971, and the index fall was sufficient by early 1972 for an El Niño invasion. There was abnormally heavy rainfall over the central and western equatorial Pacific from mid 1972 through early 1973, and a seasonal recurrence of El Niño conditions in early 1973 (Fig. 1). As further evidence of this typical pattern of activity, it was noted through an earlier study, when using just the less-desirable JF-D index, that the anomalous 1939–41 activity also occurred during a period of low running mean values following a high running mean peak. Activity consisted of El Niños in early 1939 and early 1941 and anomalously heavy rainfall over the central and western equatorial Pacific from late 1939 through 1941. A moderate index peak of 12 mb developed in 1967 (Fig. 1), relaxation occurred during 1968, and heavy central and western equatorial Pacific rainfall in early 1969. This latter case following a peak of lower amplitude resulted in equatorial activity of a less extensive nature and no El Niño invasion.

Based on the foregoing evidence, the following appeared to hold:

1) The longer periods of unusual equatorial Pacific activity (i.e., 1951–53, 1957–59, 1963–66 and 1972–73), with which El Niños occurred, followed relaxation from unusually high running mean peaks (>13 mb).

2) The time of the year that relaxation from these peaks began, determined whether the first appearance of unusual activity was an El Niño invasion during the early part of the year or anomalous central and western equatorial Pacific precipitation during the latter half of the year.

3) The occurrence or recurrence of a later El Niño during the post-relaxation period depends on running means of the index remaining low or returning to a low value after a short excursion upward (e.g., 1952, 1964) and regional seasonal meteorological and oceanographic factors remaining favorable to invasion.

4) Peaks ⩽12 mb do not have sufficient relaxation potential to bring about extensive equatorial activity or an El Niño invasion.

4. General discussion

Since the southeast trades are ordinarily effective up to somewhere between 3° and 10° north of the equator over the eastern tropical Pacific, they should have considerable influence over the equatorial oceanic circulation in the eastern Pacific. Relaxation following large running mean peaks is associated with a general decrease in strength of the southeast trade system; therefore, on relaxation from peak values, equatorial countercurrent flow should increase and reach a maximum during minimum index values. (Likewise, equatorial countercurrent flow should decrease as the running mean values increase and reach a minimum during peak values.) Large increases in countercurrent flow should transport large amounts of warm water into the eastern tropical Pacific and thereby set the stage for El Niño invasions. Therefore, the greater the relaxation (from unusually high 12-month running mean peaks), the larger the expected accumulation of warm water in the eastern tropical Pacific and the greater the El Niño threat. El Niño then sets in during the Southern Hemisphere summer while running mean values are low, the weakened southeast trades reach their further seasonal minimum over the eastern tropical Pacific, and surface water temperatures are at a maximum. These large accumulations of warm water in the eastern tropical Pacific may result in a recurrence of El Niño in subsequent summer seasons for one or two more years providing indices remain low and local seasonal factors favor it. Relaxation from smaller peaks may also bring increased amounts of warm water into the eastern tropical Pacific, but the intensity of such developments is lower and resulting equatorial activity correspondingly weaker. This concept agrees with findings of Wyrtki (1973) with regard to relationships between north equatorial countercurrent flow and formation of large positive thermal anomalies in the eastern tropical Pacific. It is also in agreement with Bjerknes (1961) on the relationship between accumulations of large quantities of warm water in the eastern tropical Pacific and El Niño invasions. Schweigger (1961) suggests El Niño invasions may also be the result of a south equatorial countercurrent causing transgressions from the west (rather than just from the north through a southward diversion of north equatorial countercurrent water); this would agree with certain findings of Wooster (1960). In such cases, plots of the 12-month running means of the indices would be similarly effective for following and anticipating developments, since again the strength of the southeast trade system would be a critical aspect.

Considering 12-month running mean plots of the E-D index components (Fig. 2), it can readily be seen that the abnormally large buildups in the 12-month running mean values of the index are caused by the rough coincidence of the large interannual deepening of the Indonesia equatorial low, as reflected by low Darwin values, and large interannual strengthening of the southeast Pacific subtropical high, as reflected by high Easter Island values. El Niños occur after relaxation from this situation to a contrasting state where abnormally great filling of the equatorial low, as shown by high Darwin values, roughly coincides with the abnormal weakening of the subtropical high, as indicated by low values at Easter Island. These developments are shown by the convergence and divergence in graphic trends of Fig. 2. The rough coincidence of the unusually large interannual peak and trough developments in these plots, which cause the extremes in index values, illustrate the complementary nature of processes taking place in the core areas that result in the large atmospheric fluctuations. These data also indicate that the abnormal maxima in Easter Island data may in some cases be reached several months prior to the trough minima in Darwin data. In these developments the departure from the mean is almost twice as large at Easter as it is at Darwin. Fig. 3 shows similar plots for the Juan Fernandez and Darwin components for the period leading up to and following the 1962 JF-D running mean peak. (This latter case requires further study.)

5. Findings and their use

The key to strong equatorial developments is apparently the $4\frac{1}{2}$–6 mb relaxation from high running mean peaks (>13 mb), which is required to induce events of this magnitude. Using historical guidance concerning behavior of the Southern Oscillation, quantitative limits suggested by the 12-month running means of the indices and the time required for certain changes to take place, it appears that one could anticipate El Niño-type developments if he knows the existing phase, amplitude and trend of the graphic plots. When the 12-month running mean value of an index reaches 13 mb or higher, one could speculate with a reasonable degree of assurance that an unusual equatorial development was imminent, that it was likely to set in within the next couple of years, and that an El Niño invasion could occur during the early part of one or more of the involved anomalous years.

Once the index peak (⩾13 mb) is reached and a downward trend sets in, one could expect an El Niño invasion about 9–13 months later, with January to March of the following year as the inception time. (This assumes the downward trend sets in early enough in the prior year to avoid abortive situations such as occurred in 1951 and 1963.) Considering the necessary 6-month lead time required for a 12-month running mean data point, the outlook could be given 3 months or more in advance of the El Niño invasion. If relaxation sets in later in the prior year, the anomalous precipitation over the central and western equatorial Pacific would appear first and would set in during the mid-part of the following year; this outlook could also be given 3 months or more in advance. Outlooks may be further refined by considering monthly mean index values over the most recent 6-month period, individual component indications, and the gradually changing sea surface temperature distribution over the tropical Pacific as developments take place.

A convincing piece of evidence favoring the use of these tools is the fact that at no time during periods when index data were available have either anomalous equatorial Pacific rainfall developments or El Niño invasions occurred during a 12-month running mean peak. It appears that in many cases this approach could also be used to signal the onset and intensity of the Pacific basin-wide and near-global ocean-atmosphere changes that set the stage for, accompany or follow El Niño developments.

A study of the 12-month running mean values of index components, including a 92-yr record of Darwin data, indicates the maximum 12-month running mean value of the E-D index is likely to be about 15 mb and the maximum relaxation potential about 8 mb. It is expected that an 8-mb relaxation would lead to extreme equatorial sea temperature and rainfall anomalies, and a highly disastrous El Niño invasion.

6. Conclusion

In conclusion, it appears that plots of the 12-month running mean values of the E-D and JF-D indices, used in conjunction with monthly mean pressure analyses, are very useful tools for monitoring large interannual fluctuations in circulation over the equatorial Pacific and for evaluating their intensities. They also show promise for use as predictors of the more unusual equatorial Pacific activity and El Niño invasions many months in advance of their occurrence. The Southern Oscillation indices not only reflect changes in lower latitude atmospheric circulation and resulting wind stress effects on the lower latitude Pacific Ocean surface but also east–west variations in hydrostatic pressure (also caused by deepening and filling in the low and high pressure regions). Of course, when one considers developments involving time and space scales of the magnitude discussed here, he must also consider other sources of variable input, for instance Northern Hemisphere contributions as discussed by Namias (1973), and in the specific case of El Niño, existing local regional meteorological and oceanographic peculiarities, for further refinements to specific predictions.

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