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ENSO and Seasonal Rainfall Variability over the Hawaiian and US-affiliated Pacific Islands

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The tropical Pacific region is one of the world's most vulnerable areas with respect to weather-related natural disasters and extreme hydro-meteorological events. Short-term climate fluctuations, such as the El Niño-Southern Oscillation (ENSO) phenomenon and its recurring warm and cold episodes, are found to play an important role in the climate variability over the Hawaiian and tropical Pacific region.

The influence of ENSO episodes on Pacific Basin precipitation is described in greater detail using composite analysis, in which responses to warm ENSO episodes are considered separately from responses to cold episodes. The degree of realism of the assumption of linearity in the ENSO-rainfall relationship, which is needed in the overall interpretation of the correlations, is evaluated in composite analysis. If rainfall anomaly composites are fairly equal-but-opposite for warm versus cold ENSO conditions, approximate linearity is confirmed. While the resulting set of winters is in general agreement with the sets as defined earlier by Loon and Madden (1981), Rasmusson and Carpenter (1983) and Ropelewski and Jones (1987), a few differences exist.

As an example, Fig. 1 shows ENSO composite rainfall results for Kahului, Hawaii. The differences between the composited rainfall totals for the samples representing the warm or cold phases of ENSO versus the totals of the remaining years (neutral-plus-oppositely phased years) were statistically tested with the Student's t-test. It should be noted that the statistical assumptions underlying the t-test (*e.g.* Gaussian distributions) may not be sufficiently satisfied. Nonetheless, we use it as a rough guide for indicating significant mean differences in rainfalls as a function of ENSO category. Near the time of the mature episode boreal winter at Kahului, warm episodes are associated with deficient precipitation with 0.05 or stronger statistical significance in Dec-Jan-Feb, Jan-Feb-Mar, Feb-Mar-Apr. Cold episodes associate with slightly enhanced rainfall but not at the 0.05 significance level. More detailed information (*e.g.*, the seasonal variation of the tropical rainfall with ENSO) can be found in the He *et al.* 1998. Recent study (O'Connor *et al.* 2015) shows a drying trend in Hawaii rainfall

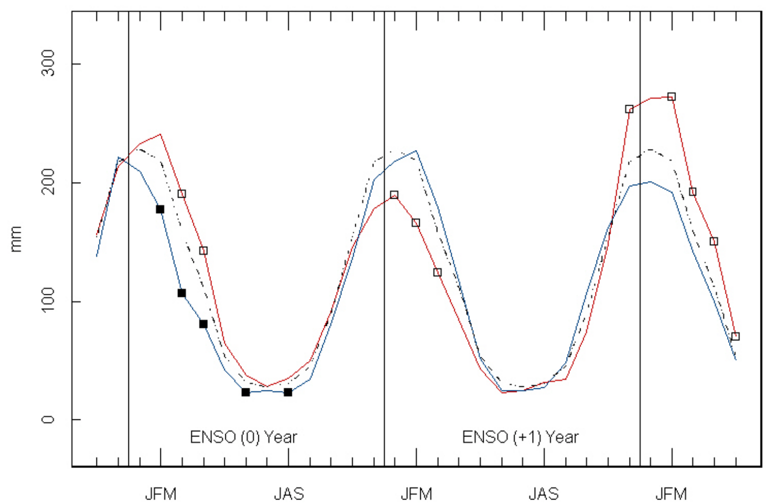

Fig. 1 Composite rainfall amounts for Kahului, Hawaii, by ENSO status. The dashed line denotes the climatological mean rainfall for all years, the red line the mean for the composited warm ENSO episode years, and the blue line the mean for the cold episode years. Differences between the composited rainfalls for the samples representing the warm phases of ENSO versus that of the remaining (neutral plus cold phase) years passing a 2-tailed significance test at the 0.05 level are indicated with a hollow square along the red line. Significant differences at the 0.05 level with respect to the cold phase composite rainfalls versus remaining (neutral plus warm phase) years are indicated with a solid square along the blue line.

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during La Niña years. A change-point analysis determined that the shift occurs in 1983.

In looking at the time of mature episode boreal winter over 66 tropical Pacific stations (not shown), the general relationship between ENSO and rainfall described in Ropelewski and Halpert (1987) is found: At the off-equator stations (such as many of the U.S.-affiliated stations) warm ENSO is associated with suppressed rainfall, while at the near-equatorial stations from the date line eastward to the South American coast, where the SST anomaly is positive, rainfall is enhanced. Enhanced rainfall with El Niño is particularly dramatic at Kiribati stations (Banaba, Butaritari, Tarawa, Beru, Arorae, Fanning and Christmas), at Nauru, and at two of four Tuvalu stations (Nui and Atafu). All of these effects tend to occur in reverse for cold ENSO episodes. Because equatorial Christmas Island (Fig. 2) is surrounded by a somewhat cool ocean most of the year, it receives fairly light climatological rainfall, but with very large positive deviations occurring during El Niño episodes. Many of the more off-equator locations, especially west of 170°W, experience drought with El Niño.

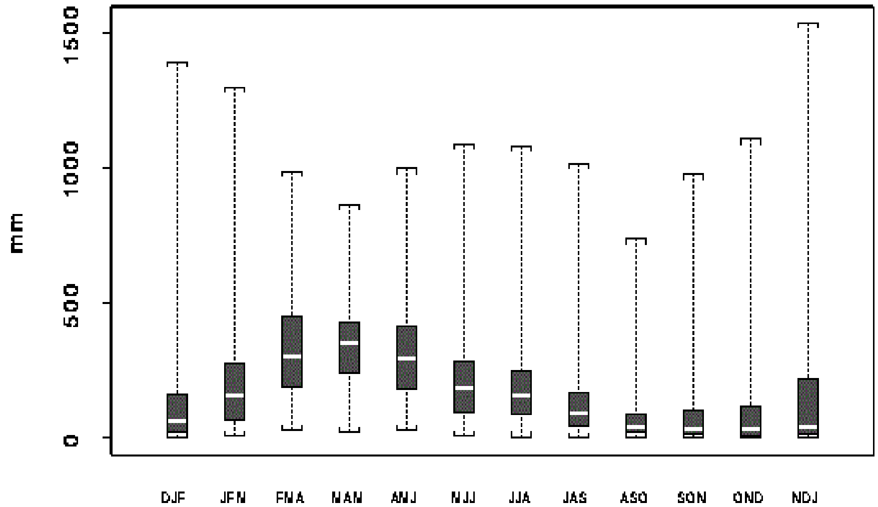

Fig. 2 Annual cycle of climatological running total 3-month precipitation for Christmas Island. The median (50 percentile) amount is indicated by the white horizontal strip inside the dark box, whose upper and lower limits show the 75 percentile and 25 percentile amounts, respectively. The extreme or record amounts are indicated by the horizontal bracket symbols at the top and bottom ends of the vertical dotted lines.

ENSO-rainfall correlations can be examined both contemporaneously and at lag (in which the ENSO index occurs before the rainfall, and is thus viewed as a predictor). Fig. 3 shows the spatial distribution of correlation between a standardized Southern Oscillation Index (SOI) and rainfall, where SOI leads rainfall by 6 months. To simplify interpretation, the sign of the SOI is reversed so that positive SOI is associated with El Nino. The maps show that the SOI offers some meaningful hints about rainfall anomalies to occur 6 months later, especially for northern winter rainfall. The Hawaiian result at 2 season lag was also obtained by Chu and He (1994), and implies that useful precipitation forecasts can be made for Jan-Feb-Mar as early as early autumn, providing several months for impact mitigation efforts by water managers in affected regions. Significant relationships at 6 months lead also exist in parts of Fiji and southern Tonga, and form a familiar horseshoe-shaped pattern of off-equator El Niño-related dryness surrounding the equatorial wet zone, with northern and southern dry regions nearly meeting in the western equatorial Pacific. Moderately strong correlations for Jan-Feb-Mar at 6 months lag appear close to the equator both east and slightly west of the date line, at most of the Kiribati stations. The general geographical extent of the predictive potential shown here is qualitatively similar to that described by Ropelewski and Halpert (1987, 1996), the canonical correlation analysis (CCA) studies of Barnston and He (1996) for Hawaii, and He and Barnston (1996) for the tropical Pacific islands in general. When an ENSO phase has developed by boreal mid-summer, that phase tends to persist through the remainder of the calendar year (Barnston and Ropelewski 1992). This causes the lagged correlation relationships with Jan-Feb-Mar rainfall to be somewhat more similar to the Jan-Feb-Mar simultaneous relationships than is the case for other target seasons. By contrast, the "spring barrier" in the continuity of the ENSO state causes the ENSO-rainfall relationships to weaken more quickly for boreal summer and fall target periods when lag time is introduced (not shown). Some ENSO phase-specific rainfall impacts are distinguishable in Fig. 1 that are not visible in the overall correlation results of Fig. 3.

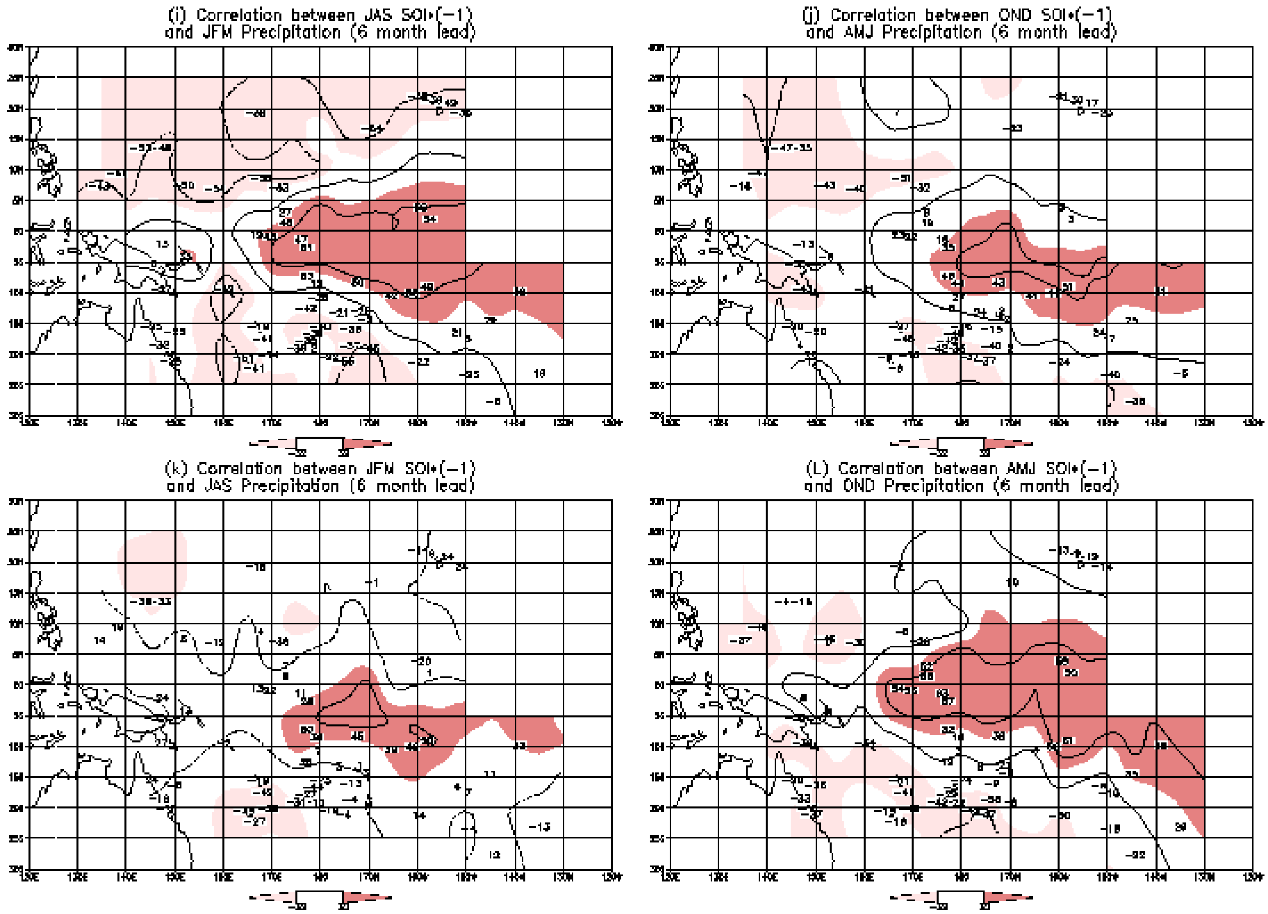

Fig.3. Spatial distribution of correlation between SOI (where SOI is multiplied by –1 so that it is positive correlated with the ENSO-related east-central tropical pacific SST anomaly) and rainfall for Jan-Feb-Mar (top left), Apr-May-Jun (top right), Jul-Aug-Sep (bottom left) and Oct-Nov-Dec (bottom right). Panels show results where the ENSO index is centered 6-months earlier than the target period. Light shading denotes statistically significant negative correlations at the 0.05 significance level, and dark shading shows significant positive correlations.

In general, ENSO effects during periods other than the boreal late summer through fall, winter and spring of the mature phase, are not very noteworthy. However, in some cases an apparent ENSO effect can be noted in the boreal winters a year before or a year after the mature episode boreal winter. At Kahului, for example, there is a significant tendency toward a wet winter the year following the mature warm episode, which itself tends to be dry. Adjacent winter responses may be associated with the episode that peaks a year beforehand or a year afterward (*e.g.* positive temperature anomalies in Hawaii are seen to occur the boreal winter one year after a mature El Nino as much as during the El Nino boreal winter itself; Barnston and He 1996). However, they may also be explained in part by adjacent year mature episodes in their own right.

The potential utility of seasonal precipitation prediction and climate information on many of the populated tropical Pacific islands that is clear, given their agricultural and otherwise water-dependent economies. The strong ENSO (*i.e.* 97-98) events also give us a unique chance to study the oceanic and atmospheric anomalies. Predictability is related mainly to the phenomenon known to dominate the region's climate (*i.e.* ENSO), but also to a lesser extent to phenomena of which our knowledge is only now emerging (*e.g.* interdecadal variability). It is also a challenge for our long-lead climate forecast for the Hawaiian and tropical Pacific region due to the interannual variability compounded by decadal variability in rainfall (*i.e.* predicting La Niña rainfall be conditioned on short-time scale phenomenon such as ENSO).

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