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Trends in sea surface temperature off the coast of Ecuador and the major processes that contribute to them

Laurence C. Breaker [a,b,*], Hans R. Loor [c], Dustin Carroll [d]

[a] *Moss Landing Marine Laboratories, United States*
[b] *University of Delaware, United States*
[c] *University of Manta, Ecuador*
[d] *University of Oregon, United States*

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ABSTRACT

Monthly-averaged sea surface temperatures (SSTs) from seven adjoining sub-regions spanning the coast of Ecuador have been examined for long-term trends and the major processes that contribute to them. The study area extends from the coast out to 84°W longitude, and from 4°S to 2°N latitude. The period of observation extends from 1900 through 2014, a period of 115 years.

Linear trend analysis shows that the slopes are positive in all sub-regions and statistically significant in 5 out of 7 of them. Based on the trends SSTs increased from +0.10 °C to +1.42 °C over the entire period with the greatest increases occurring in the sub-regions next to the coast and to a lesser extent in the northern and southern sub-regions.

A second non-linear trend analysis was conducted using Ensemble Empirical Mode Decomposition (EEMD). The results from EEMD for the various sub-regions indicate that SSTs increased significantly from 1900 to at least 1940 in the majority of cases. After 1950, SSTs tended to fluctuate with a minimum that often occurred during the 1960s or 1970s. Since circa 1990, SSTs have experienced little change. Because the data tended to be spatially homogeneous, with two sub-regions being possible exceptions, a mean data set was calculated and likewise subjected to EEMD. The results show that SSTs have increased by approximately 1 °C since 1900 but the process has not been uniform. The increase in temperature between 1900 and at least 1940 approaches 1 °C, similar to the trends found in the majority of sub-regions. Between ~1950 and 1990, temperatures decreased slightly until the mid-1960s and then gradually increased until about 1990. Since ~1990 there has been no significant change in SST. Overall, the results of the global mean analysis are generally consistent with the sub-regional results.

Several sources of variability have been tentatively identified that may contribute to the long-term changes in temperature that we have observed. Both spectral analysis and EEMD suggest the importance of the Pacific Decadal Oscillation as possibly the greatest contributor. The two major maxima in the PDO index that occurred during the past century (~1940 and ~1990) are generally consistent with maxima and/or inflection points that occur both in the sub-regional and regional long-term trends. It has been difficult to associate specific ENSO episodes with the long-term trends. However, ENSO and the PDO are closely related. Recent modeling studies have shown that the PDO essentially owes its existence to ENSO. Thus, ENSO appears to be a major contributor to the long-term trends through its primary contribution to the PDO. Finally, spectral analysis also revealed the existence of an oscillation whose period is ~73 years, easily of sufficient length to influence the long-term trends. Climate-related oscillations in the range of 70–100 years are often associated with the Gleissberg sunspot cycle and this could be a contributing factor.

The long-term trends are not necessarily a dominant feature in our data. However, had the observations been limited to the period from 1900 to ~1940, the trends would have been, without a doubt, dominant. Overall, the likely influence of the PDO on the observed long-term trends in SST must be emphasized. Finally, over the past 25 years there has been no significant change in surface temperature over the study area and this may be due in part to the cooling influence of the PDO since ~1990.

1. Introduction

In this study we examine long-term trends in Sea Surface Temperature (SST) off the coast of Ecuador and the major processes that

* Corresponding author.
E-mail address: lbreaker@mlml.calstate.edu (L.C. Breaker).

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contribute to them. The region of interest extends from the coast of Ecuador out to 84°W, and from 4°S, to 2°N. The study area is divided into seven sub-regions. Each sub-region is 2° of latitude by 2° of longitude. Fig. 1 shows a map of the study area and its sub-regions or boxes. Within each box we have acquired monthly-averaged SSTs from 1900 through 2014. This is an unusually long record and may be the longest record of sea surface temperature to be examined off the coast of Ecuador. We note that although there has been extensive oceanographic data acquired and research conducted in the Equatorial Pacific between the western Pacific (at least as far west as 130E), and the Galapagos Islands since the 1970s, less interest has been shown in the region that lies between the Galapagos Islands and the coast of Ecuador. This observation is consistent with an internet search for oceanographic analyses specifically addressing the region east of the Galapagos where a dearth of relevant information was found. We were motivated, in part, to conduct this study to see if obvious or even not so obvious indications of recent global warming could be found in these data that might give support to other studies of a similar nature that have been conducted in the eastern tropical Pacific. Finally, the study area encompasses one of the most dynamic and productive marine ecosystems in the world (Martinez-Ortiz et al., 2015) where SST is expected to serve as a key indicator of fish behavior.

The study area comprises an oceanic region influenced by the Peru or Humboldt Current which transports cool waters across the southwest corner of the study area as it travels from the coast of Peru to the Galapagos Islands. Flow near the coast of Ecuador and south of the Gulf of Guayaquil is weak (< ~10 cm/s) and generally to the northwest, more-or-less paralleling the coast (Wyrtki, 1965). Further offshore the flow intensifies and becomes more westerly as the influence of the Peru Current starts to reveal itself. Off the coast of northern Ecuador, the relatively warm Panama Current flows in a southwesterly direction as it approaches the Equator before turning westward toward the Galapagos. This current enters the study area across its north face. Overall, the mean annual circulation is generally weak but increases near the western boundary of the study area where it becomes westerly at speeds of 5–10 cm/s (Kessler, 2006).

The Equatorial Undercurrent (EUC) shoals in the eastern tropical Pacific and as a result contributes cooler waters to the surface layer as it passes through the Galapagos Islands on its path eastward. According to Lukas (1986), the influence of the EUC extends to the coast of Ecuador. These waters provide a cooling influence on SSTs in the study area near the Equator. During ENSO episodes, however, the EUC is driven downward by warmer waters from the western Pacific and its influence at or near the surface is greatly reduced.

The processes that affect SST and their interaction in the tropics form a complicated picture. According to Sarachik (1978), equilibrium surface temperatures near the Equator are determined by the interaction between short-wave solar radiation, infrared radiation, and evaporation, and so are strongly influenced by atmospheric processes. More specifically, with regard to the eastern tropical Pacific, SST tends to be a balance between four processes (Behringer et al., 1998). First, is the strength of upwelling along the Equator which is determined by the westerly component of the wind. Stronger winds to the west produce greater Ekman transport away from the Equator leading to increased upwelling. Second, is the northwesterly transport of colder waters from the coasts of Peru and Ecuador toward the Galapagos. Third, is the mixing of cooler Equatorial waters with warmer waters to the North and South of the Equator. Finally, the fourth process is heat exchange between the ocean and the atmosphere along the Equator. When changes from non-El Niño to El Niño conditions occur each of these processes is strongly affected.

The study area has two rather distinct oceanic seasons: summer, which occurs between January and April, and winter, which occurs between July and October. Other times of the year are considered to be transition periods between summer and winter (Cucalon, 1989). The study area is also a transition zone that separates two water masses, Tropical Surface Water to the north, and Subtropical Surface Water to the south. Between these water masses lies a major oceanic boundary called the Equatorial Pacific Front (Laevastu and LaFond, 1970). This frontal region is characterized by strong property gradients including SST. According to Cucalon (1989) this front is unpredictable during the summer regarding both its location and strength. During the winter

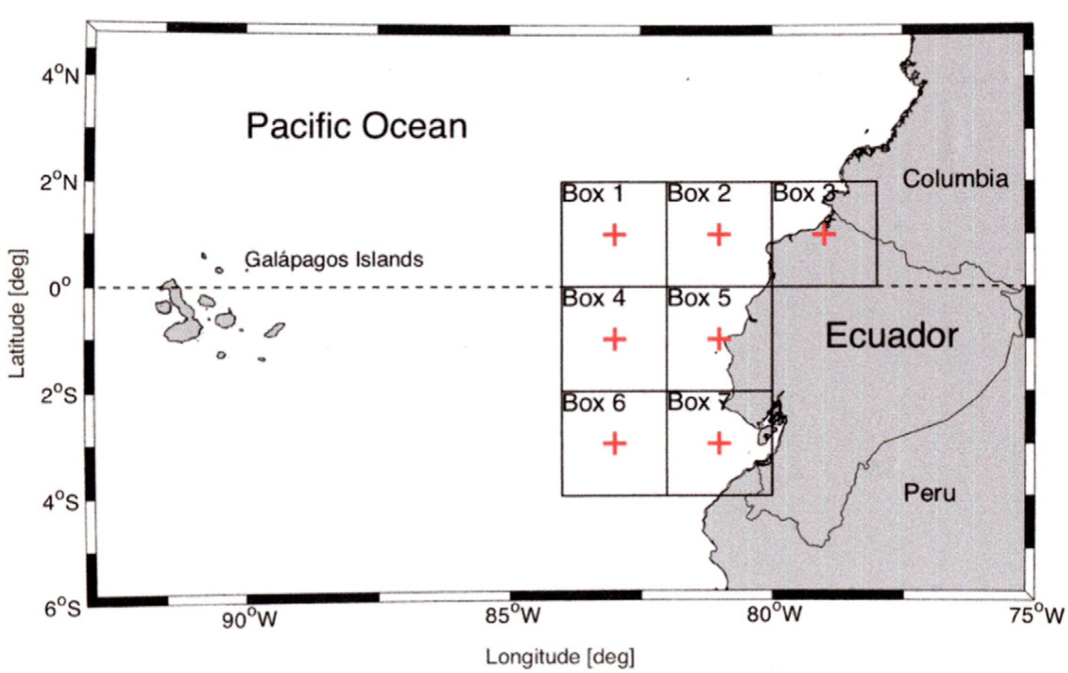

Fig. 1. This figure shows the oceanic region employed in this study. Monthly-averaged Sea Surface Temperatures (SSTs) from 1900 through 2014 provide the basis for this study. The region is subdivided into seven sub-regions or boxes and are numbered accordingly. Each box covers an area that is 2° of latitude by 2° of longitude (2° × 2°). Boxes closest to the coast (3, 5, and 7) are partially covered by land. The center locations for each box are as follows: Box 1: 1°N, 83°W; Box 2: 1°N, 81°W; Box 3: 1°N, 79°W; Box 4: 1°S, 83°W; Box 5: 1°S, 81°W; Box 6: 3°S, 83°W; Box 7: 3°S, 81°W.