Characteristics of Sea Surface Temperatures (SSTs) between 23°C and 24°C West of the Galápagos Islands

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ABSTRACT
Previous research showed that low-level flow over the Galápagos Islands was decoupled from that above during some time periods studied. When decoupling occurred, sea surface temperatures (SSTs) were cooler than 23°C; during the coupled cases, SSTs were warmer than 24°C. Here six TAO buoys provided SSTs collected from 1994 to 2003 were used to look at characteristics of SSTs west of the Galápagos in the range of 23°C to 24°C. The occurrence of SSTs in this range depended on cold and warm seasons; whether it was during El Niño, La Niña, or normal periods; and on the locations of the TAO buoys. SSTs between 23°C and 24°C were less frequent at the 2°N buoys, during strong El Niño periods, and in the middle of cold and warm seasons.
1. Introduction

During relatively cool sea surface temperatures (SSTs), winds on the Galápagos that are below 500m are decoupled from winds that are just above them (Harten and Datulayta 2004, hereafter H&D). During slightly warmer SSTs, the winds are usually completely coupled with one another. If the flow is coupled/decoupled, it means that physical properties of the atmosphere and ocean are shared differently. Studying the winds above the surface may better our knowledge of local and distant atmospheric and oceanic processes. This phenomenon may be the reason for vertical mixing of momentum or vertical increase of tidal or wave signatures over the region (H&D). If we help confirm what was previously stated, it may help us to better predict this phenomenon over a larger area. This is important, because decoupled winds can limit vertical mixing of momentum, moisture, and temperature and this research can also give a deeper understanding why winds become decoupled with height.

The main instrument H&D used for obtaining information and locating these cases of decoupled and coupled winds is the wind profiler. A wind profiler is a Radio Detection and Ranging (radar) device that is used to measure wind speed and direction at several heights in the atmosphere. Through the use of profiler winds, H&D were able to find that during El Niño/warm events, warm seasons, and the 1997 cold season conditions, the daily cycle involved mainly meridional anomalies at all heights, southerly during the middle of the day and north northwesterly during the middle of the night. During La Niña/cold events and cold seasons, anomalies showed a remarkable decoupling from the flow aloft. Since the vertical decoupling of the diurnal cycle of winds appeared to occur during cold periods but not during warmer periods, it suggests that the effects of the near-surface stability extend well above the surface (H&D 2004).
Figure 1 shows where the Galápagos Islands are located in the Pacific Ocean. There are approximately 70 TAO buoys in the Tropical Pacific Ocean (McPhaden 1995). TAO arrays measure oceanographic and surface meteorological variables, which are important for improved detection, understanding, and prediction of seasonal to semiannual climate changes originating in the tropics, most especially those related to the El Niño/Southern Oscillation (ENSO). The array spans one-third the circumference of the globe, from 95°W near the Galápagos Islands to 137°E off the coast of New Guinea (McPhaden 1995).

During El Niño/warm events, warm seasons, and the 1997 cold season, the daily cycle projects predominantly onto meridional anomalies and is fairly consistent with height. During La Niña/cold events and the 1998 and 1999 cold seasons, it projects onto zonal anomalies above 500m and meridional anomalies below that height. The decoupling of the low-level flow during these periods is presumably caused by the enhanced stability of the lowest levels of the atmosphere caused by the very cold SSTs. During periods with coupled flow, SSTs recorded by the TAO buoys at 0°, 95°W and 2°S, 95°W were greater than 24°C, while during periods with decoupled flow SSTs were less than 23°C (H&D). Since the H&D project was conducted over cold/warm seasons and El Niño/La Niña events, there is a small area of SSTs that are not accounted for. The goal of my research is to examine characteristics that are related to the SSTs between 23°C and 24°C. By focusing on this minute range of SSTs, the importance of this “unknown zone” will be addressed. The goal of this study is to determine when, where, and how often SSTs fall between those temperatures.
2. Data

The TAO buoys used were stationed at: 2ºN, 95ºW; 0ºN, 95ºW; 2ºS, 95ºW; 2ºN, 110ºW; 0ºN, 110ºW; 2ºS, 110ºW.

Figure 2. This graph shows the TAO/TRITON arrays in the Pacific Ocean. The buoys highlighted in red are the six buoy stations used in this research. The capitalized G east of the highlighted red buoys indicates where the Galápagos Islands are located. NOAA/PMEL/TAO Project Office

Figure 2 shows a chart of all the buoys in the Pacific, with the six buoys used for this research highlighted in red. The TAO buoy data was gathered from the PMEL website. The data covered a time range from 1994 to 2003, since ultra high frequency (UHF) wind profiler observations of lower tropospheric winds at Isla San Cristábal in Ecuador’s Galápagos Islands commenced in October 1994. To update the H&D choice of cold and warm seasons between the years of 1994 to 2001, this research will cover a larger time range. TAO buoys cover one third the circumference of the globe, from 95ºW near the Galápagos Islands to 137ºE off the coast of New Guinea (McPhaden 1995). The measuring instrument located on the TAO arrays used was the SST sensor. The SST sensor, which is located 1 meter below the surface, measures the sea surface temperature.
3. RESULTS

a. Complete range of SSTs west of the Galápagos Islands

Figure 3. These graphs show data from six sites of TAO buoys, just west of the Galápagos Islands. The variable of this graph is the SSTs and the green line is the daily count of SSTs between the years of 1994-2003.

The opening step of this research was graphing the data from the TAO buoy sites that were chosen. These graphs consisted of the years of 1994 to 2003 as well as the SSTs of those years. Due to computer trouble at NOAA the data did not continue into December of 2003. The values go from January 1, 1994, to mid September of 2003. Figure 3 shows time series of SSTs at the six TAO Buoys. Since H&D research found SSTs higher than 24ºC seemed to have coupled wind aloft, it was decided to outline 24ºC and above in red. H&D research also found that SSTs lower than 23ºC seemed to show decoupled winds aloft, so 23ºC and below was highlighted in blue. Between 23ºC and 24ºC, there is an area highlighted yellow, which...
could be called the unknown zone considering it was not reviewed in H&D’s research. These line graphs showed the importance of the yellow zone and how large it was.

This graph was plotted in order to show how the SSTs around the Galápagos acted over a period of approximately 10 years. All of the graphs clearly show a seasonal up and down pattern, and demonstrate when the warm season and cold seasons are taking place. The cold season is during the months of July to October, and the warm season is during the months of February to May (Wallace 1989). Figure 3 shows that there is an increase in SSTs between the years of 1997-1998. During these years the SSTs hardly ever fall into the yellow band, which is a range between 23°C and 24°C.

The two graphs stationed at 2ºN both seem to be in the higher temperature range than the other 4 sites stationed at 0ºN and 2ºS. They also hardly ever enter into the yellow band. The graph at 2ºN, 95ºW not only hits the yellow band less frequently but it hardly goes below 23°C at all. Though both SSTs at these buoys are reasonably warmer than the SSTs south of them, the SSTs at 2ºN continue to show an up and down seasonal pattern.

b. SSTs between 23°C and 24°C

Figure 4. These graphs show TAO buoy data west of the Galápagos Islands. These plots show the daily count of SSTs between 23°C and 24°C by every pseudo month (366/12 day- long periods) in the years of 1994-2003. N represents the numerical amount of occurrences of SSTs between 23°C and 24°C.
Figure 4 shows a bar graph of the exact amount of days per pseudo month that the temperature fell between 23°C and 24°C. Pseudo months were calculated by dividing 366 days by twelve, which gave 12 approximately monthly periods. This research chose to put the data in pseudo months, so it would be possible to classify the data in seasons, to stay in consistency with H&D’s study.

The lowest count of days between 23°C and 24°C was always during the warm or cold season. The higher count of SSTs between 23°C and 24°C usually took place during the switch of seasons. In Figure 3, the SSTs go from the red zone to the blue zone and passes through the yellow band in just about every year. The only locations that did not only have the highest number of SSTs between 23°C and 24°C during the switch of seasons were at 2°N, 110°W and 0°N, 110°W, yet they both had a high count during the beginning of the cold season. Therefore, areas at 2°N, 110°W and 0°N, 110°W were close to the switch from warm season to cold season.

Once again the sites that show the lowest count of SSTs between 23°C and 24°C are stationed at 2°N. Also at 2°S you see some of the highest recorded counts of SSTs between 23°C and 24°C. In both of the 2°S sites you see that the counts range over 340 times, which is difference between the highest counts in 2°N, which doesn’t even quite make it to 200. The data shows going from north to the south the high counts of SSTs between 23°C and 24°C go from higher to lower. Also if the 110°W graph is compared with the 95°W graph at the same latitude it is a higher count of SSTs between 23°C and 24°C at the 110°W graphs.

Figure 5. These graphs show TAO buoy data west of the Galápagos Islands. These plots show the daily count of SSTs between 23°C and 24°C for every year from 1994-2003.

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Figure 6. This graph shows the 5 month running mean anomalies of the Southern Oscillation Index (SOI). Shaded values show that the white area in between El Niño and La Niña represents periods of normal conditions. NOAA CPC provided the SOI anomalies.

Figure 5 shows a bar graph of the total count of days per year in which the temperature fell between 23°C and 24°C. By looking at Figure 6 one can see during what years we have El Niño and La Niña periods. All of the lower occurrences of SSTs between 23°C and 24°C are during a strong El Niño period. This incidence also supports the observation of Figure 3, since a very strong El Niño period happened during 1997-1998. Most of the high occurrences of SSTs between 23°C and 24°C were during an El Niño year. The only exception to the highest occurrences not being during an El Niño year is at 2°N, 110°W. Also if one were to look at the sites at 2°N there again is a lower count of SSTs between 23°C and 24°C, so at 2°N the SSTs do not occur in the temperature range of 23°C and 24°C as much as the other sites. Figure 7 gives a total count of SSTs between 23°C and 24°C between the years of 1994 and 2003. It proves that there is a more frequent count of SSTs between 23°C and 24°C south of the equator than north of the equator.
Figure 7. The distribution charts show how often between the years of 1994 and 2003 the sea surface temperatures were between 23°C and 24°C compared to other SSTs at each different site. The area between 23°C and 24°C is highlighted in yellow.
4. Discussion

Figure 8 A comparison of SSTs over the Pacific Ocean during normal conditions (top) and El Nino conditions (bottom). The color scale for SSTs (°C) is on the right. Maps provided by the NOAA/PMEL/TAO Project Office.

As seen in most of the charts during the strong El Niño period of 1997-1998, the SSTs hardly ever enter the range of 23°C to 24°C. Therefore, what El Niño effects on SSTs across the Pacific must be addressed. El Niño is an extensive ocean warming that begins along the coast of Peru and Ecuador (Ahrens 2003). Figure 8 shows an example of how SSTs over the Pacific Ocean warm during El Niño conditions compared to normal conditions. One can clearly see this warming of SSTs, especially in the east Pacific cold tongue. This extensive warming of the ocean causes SSTs to get well above 24°C even during cold seasons.

The observations of Figure 4 showed that during El Niño periods there usually was a rise in the amount of times the SSTs fell between 23°C and 24°C.
Figure 9 Map was adapted from the NOAA/PMEL/TAO Project Office. The map shows the average SSTs on the Pacific Ocean during normal conditions.

Figure 9 shows normal conditions for SSTs in the east Pacific cold tongue, which is where the Galapagos Islands are located. From the graph one can see that the further north of the equator, the warmer the SSTs. The SSTs at 2°N appear to be above 24°C, so that may be the reason why the SSTs are hardly ever found to be between 23°C and 24°C at that site. However, SSTs on or south of the equator are naturally cooler or near the range of 23°C and 24°C. The reason that the 0°N and 2°S sites tend to have a higher rate of SSTs between 23°C and 24°C during El Niño periods is because El Niño warms the ocean up to the range of 23°C and 24°C. One can also use Figure 9 to notice that at about 100°W to 120°W the SSTs are naturally in the range of 23°C and 24°C and that may be the reason there are higher counts at 110°W than 95°W on Figures 4 and 5.

5. Conclusions

When observing the SSTs west of the Galápagos Islands, it would be good to take in consideration when and where the observations on the Pacific Ocean take place. If one were to look at SSTs in the eastern Pacific cold tongue there are three conditions to consider. One is the awareness of what condition the Pacific Ocean is under, such as El Niño, La Niña and regular conditions. These conditions will greatly affect how often SSTs reach or get into a certain range. Secondly, one should consider whether the Pacific is experiencing a warm season or cold season as well as the transition between a cold or warm season. Lastly, one should take into account where in longitude the SST data are being observed in the east Pacific cold tongue, considering that with longitudinal height the SSTs warm.
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