

Interpretation of a temperature and salinity section at 180 degrees longitude in relation to the  
ENSO cycle in the equatorial Pacific for March 2023

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## **Abstract**

El Niño-Southern Oscillation (ENSO), which is the cycle consisting of El Niño and La Niña has major global impacts on climate. El Niño and La Niña are characterized by large changes in temperature in the equatorial Pacific, and understanding these changes is vital for a broader understanding of global climate. The goal of this study is to place data collected on a cruise conducted in early March 2023 in a broader context, comparing features such as 20°C isotherm depth, surface temperature, and barrier layers. Data used for this paper was collected from March 3<sup>rd</sup> to March 7<sup>th</sup> of 2023, along the International Date Line from 5°N to 5°S. Cruise data was more similar to La Niña conditions than El Niño conditions, but still had significant differences when compared to La Niña data collected from a Tropical Atmosphere Ocean (TAO) array. Thermoclines were deeper in El Niño conditions when compared to La Niña conditions, but the cruise data had thermoclines significantly deeper than La Niña data in the TAO. A barrier layer was found at 5-4°N, and a salinity maximum was found near 1-5°S, which matched observations reported in a previous study.

## **Plain Language Summary**

Large changes in mean sea surface temperature characterize the cycle known as El Niño-Southern Oscillation (ENSO). Cooling is referred to as La Nina, while warming is referred to as El Nino. For this study, data collected on a cruise in early March 2023 along the International Date Line near the equator is being compared to data from an array of moored buoys known as a Tropical Atmosphere Ocean (TAO) array. The depth at which water changes temperature rapidly, also known as the thermocline in the cruise data was more similar to the La Nina than El Nino periods in the TAO array, but still had significant differences at most latitudes. Much higher salinities were found at latitudes south of the equator, which agreed with another study done in a

similar area. The cruise data is mostly within expected values, but the thermocline depth could signify changes in the ENSO cycle.

## **Introduction**

The ENSO cycle can have a range of effects on physics, chemistry, and biology in the equatorial Pacific, as well as having global impacts on these factors. At the equator, phases of El Niño are characterized by warmer sea surface temperatures than normal, while phases of La Niña are characterized by lower sea surface temperatures than normal. El Niño leads to a cycle of weakening trade winds and weaker upwelling, while La Niña leads to intensified trade winds and greater upwelling. El Niño heats up the temperature of the atmosphere, and changes to the temperature of the atmosphere also change sea surface temperature (SST) (Philander 1985). As a result of the changes in temperature from El Niño in 1997-1998 there was a decrease in the amount of upwelling, which caused the equatorial Pacific to retain an anomalously large amount of carbon. This led to large decreases in primary production and chlorophyll concentrations (Chavez et al. 1999). In 2011, a transition into La Niña caused a global sea level drop of 5 mm due to a change in precipitation patterns (Boening et al., 2012). Because El Niño and La Niña can have large effects on the surrounding ocean, understanding more about the variations in these processes can help with predictions of ENSO events that occur in the future and their potential impact on the environment.

One of the key factors in understanding the ENSO cycle is barrier layers. Barrier layers are layers which separate the surface layer and thermocline. Generally, barrier layers form due to large infusions of fresh water, moving over subducted salty water (Misra 2020). A salinity distribution with low salinity at the surface and a sudden increase in salinity before going back to standard values is a good indication of a barrier layer. Barrier layers are necessary for El Niño

development, due to their ability to maintain the heat buildup necessary to create El Niño conditions (Maes et al. 2005). One study done by Maes et al. (2005) used a model in order to remove the barrier layer, and they found that changing the barrier layer caused changes in SST which resulted in various responses, including a failure in the development of El Niño. In a study based upon the TAO mooring data in the western Pacific, Sprintall and McPhaden (1994) reported that the barrier layer prevented entrainment of underlying denser, cooler waters into the mixed layer. As a result, they concluded that a majority of the surface temperature changes were caused by local heat flux.

Numerous studies (e.g. Kessler et al. 1996, Enfield 1989, Richards and Pollard 1991) report on the variability of the equatorial Pacific. In one study, Tropical Atmosphere Ocean (TAO) arrays were used, estimating the time and space scales of the variance. These TAO arrays included measurements along the water column. Using high temporal resolution data collected via the TAO array, Kessler et al. (1996) reports larger low-frequency signals in the east, leading to a larger signal to noise ratio with more variability. Enfield (1989) found significant sea surface temperature anomalies, related to El Niño. Large spatial and temporal variations were also found in another study, which graphed out sections of temperature and salinity 14 days apart (Figure 1). Surface layers had low salinity, with higher salinity surface

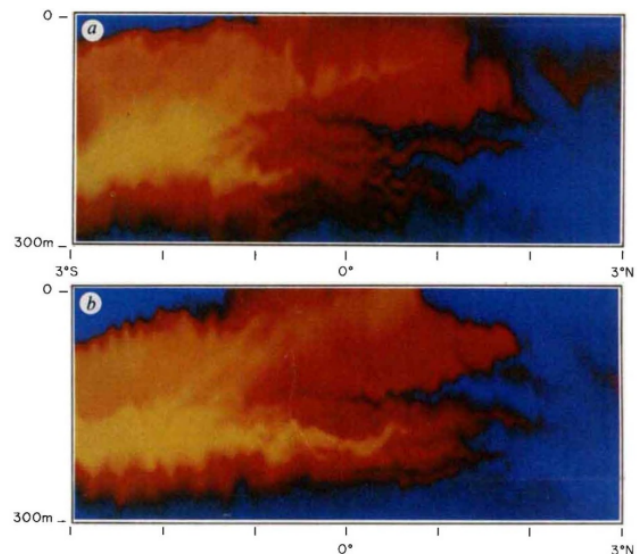


Figure 1: North-south sections of salinity, with blue being low and yellow being high. The maximum salinity in a was 35.8 with a minimum of 34.5, while the maximum salinity in b was 35.9 with a minimum of 33.8. Section a and section b were taken 14 days apart at 165°E (Richards and Pollard 1991)

waters near the Equator matching the upwelling (Richards and Pollard 1991). Johnson et al. (2002) detailed the variability in temperature, salinity, and velocities in the equatorial Pacific in the 1990s. Among their significant findings were a sharp thermocline in the Central Pacific, as well as a prominent salinity cycle in the north. Additionally, higher surface salinities were found during La Niñas. Temperatures ranged from a high of 27°C for SST during El Niño to a low of 23°C during La Niña, with 20°C isotherm depths ranging from 50m to about 75m. Salinity ranged from 35.2 psu to 34.7 psu but stayed relatively constant throughout.

The depth of the 20°C isotherm (Z20) is another important indicator in ENSO partially because it can be used to monitor equatorial current strength. In the western equatorial Pacific, the Z20 can be used to monitor low-frequency variations of equatorial circulation (Chaen and Wyrki 1981). Kessler (1990) found that Z20 was an effective approximation for thermocline depth in the equatorial Pacific. Wen et al. (2014)

found high positive correlations near the date line between Z20 anomalies and SST anomalies from 1980-1998, with Z20 leading SST. Less clear trends were found after 1999. Notably, during the onset of the 2000, 2008, and 2011 La Niñas, there were strong positive Z20 anomalies. The study finds that thermocline variation is a good precursor for ENSO variations both before and after 1999, even with other characteristics changing after 1999. In addition,

correlations between Z20 and sea level were

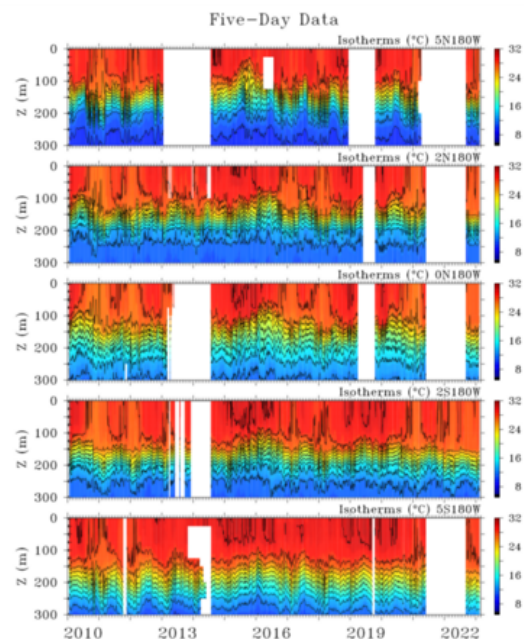


Figure 2: Time-series of temperature with depth at 180 degrees of longitude, at the locations of the TAO moorings (5°N, 5°S, 2°N, 2°S, 0°N). Plot generated on 16 February 2023 using <https://www.pmel.noaa.gov/tao/drupal/disdel/>

found to be reliable in the tropical Pacific between 15°N and 15°S (Rebert et al. 1985).

This study aims to discover the differences in temperature, Z20 and SST between two separate El Nino and La Nina periods for the equatorial Pacific and comparing it to the same measurements during the cruise from February 24<sup>th</sup>, 2023 to March 12<sup>th</sup>, 2023. This study will be conducted using data at about 180° of longitude, near the International Date Line, and between 5°N and 5°S. This study aims to compare the cruise data with El Nino and La Nina to see if it is within expected bounds, and to see whether measured temperature and salinity data from the cruise lines up more with El Nino or La Nina conditions. In this study, salinity will also be examined to find if there are any correlations between the salinity measurements and temperature

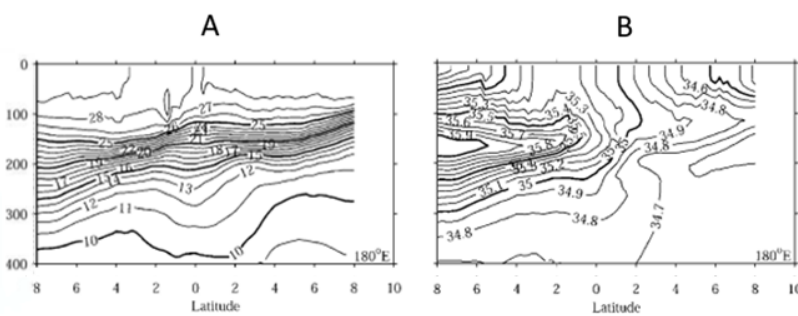


Figure 3: Temperature (A) and salinity (B) with latitude along 180°E. Contour lines of constant temperature and salinity are graphed. (Johnson et al. 2002)

measurements for the upcoming La Niña transition. Z20 seems to have a variance in depth between about 120m and 200m, with slight variations in depth depending on the latitude (Figure 2). The plots have slight spikes or dips at certain times, which is likely due to the impact of El Niño and La Niña. The dips and spikes correlate with when El Niño and La Niña occur, but there are some variations due to being more to the west compared to Niño 3.4. A study by Johnson et al. (2002) averaged data to create average sections at various latitudes, including 180°E (Figure 3). Z20 at 180°E in the study increased going north. For salinity, the graph features a salinity maximum from around 5°S to 8°S. Salinity has a barrier layer between about 7°N and 3°N.

From a graph of SST anomaly made by the Columbia Climate School International Research Institute (Figure 4), there are large increases in temperature shortly after the peak of a

**Historical Nino 3.4 Sea Surface Temperature Anomaly**

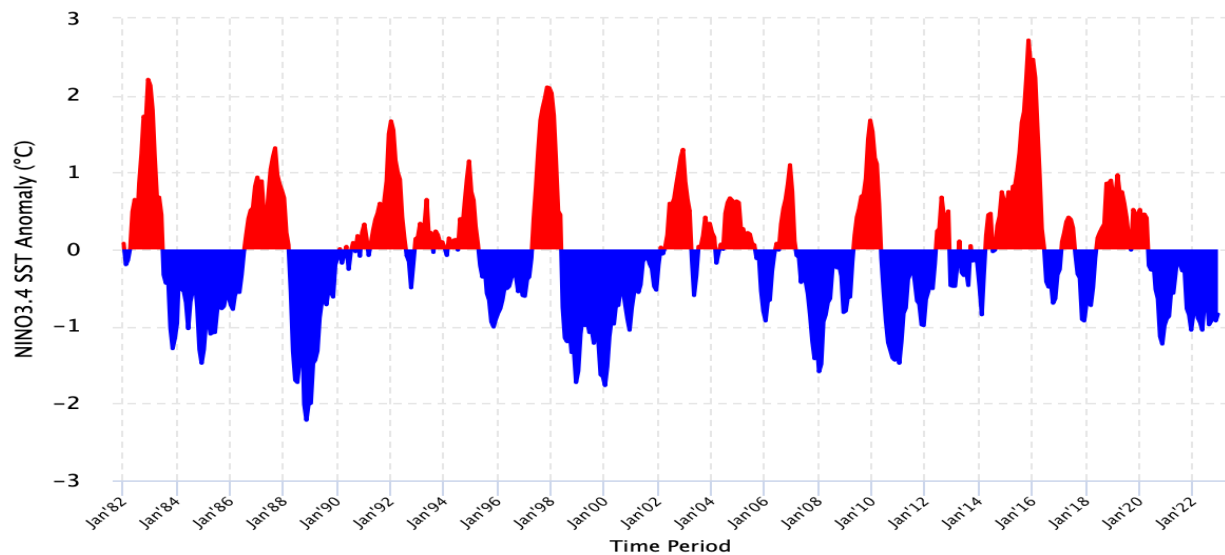


Figure 4: Historical El Niño Sea Surface Temperature Anomalies based on Nino 3.4 (120-170W, 5S-5N). El Niño and La Niña are characterized by having over 0.5 degrees of temperature anomaly. (<https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/> Accessed 10 February 2023)

La Niña event, based on data from Nino 3.4, which is one of the most commonly used indices used to categorize these events. However, since La Niña is still occurring and the time of this study is very close to the predicted end of the La Niña, I hypothesize that for the duration of the cruise there will still be effects on temperature from La Niña around the 200m depth range, which is where the Z20 typically lies. These effects would lead to SST and Z20 values in between La Niña and neutral conditions, but closer towards La Niña conditions.

## Methods

This study data was collected from March 3<sup>rd</sup>, 2023 to March 7<sup>th</sup>, 2023 aboard the R.V. Thomas G Thompson on a transect through the Equatorial Pacific. High resolution temperature and salinity measurements with depth used in this study were taken using Sea-Bird SBE-9+ CTD. The measurements used were taken from 5 degrees N to 5 degrees S near the International

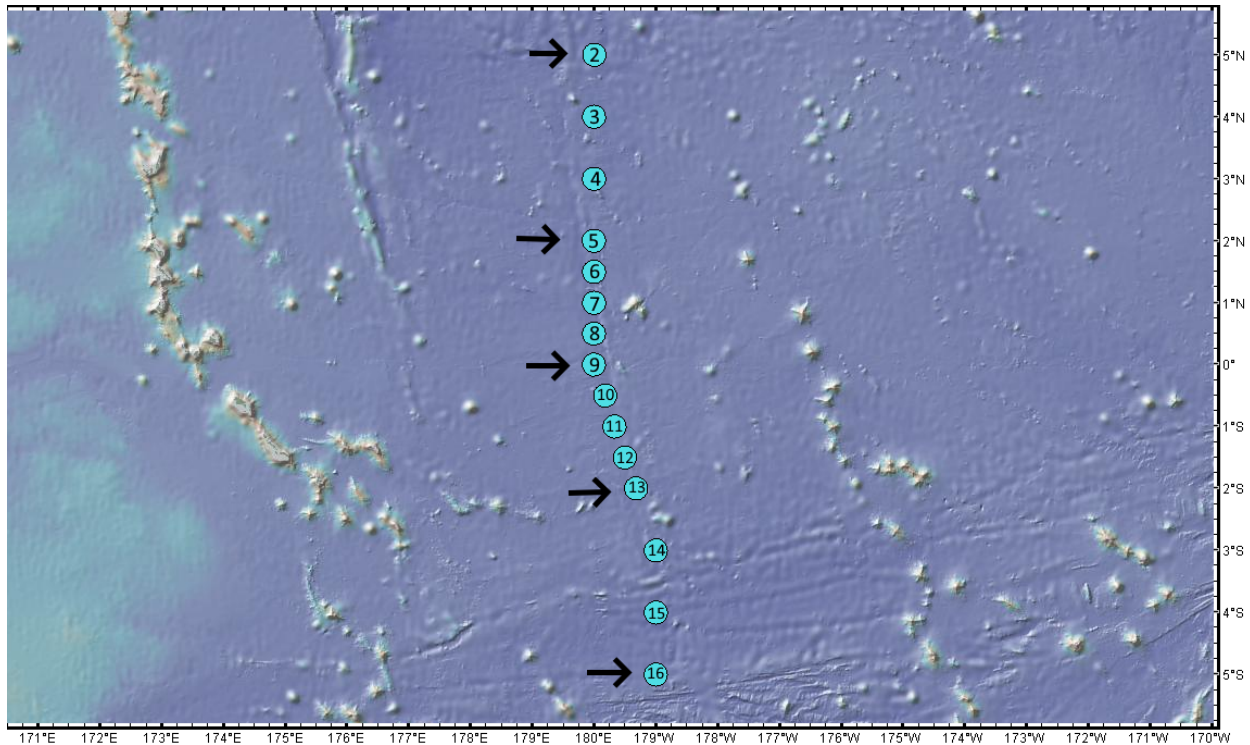


Figure 5: Transect of stations for CTD samples to be taken at, numbered 2-16. Stations are placed between 5°N and 5°S, with stations at every degree from 5°-2° north and south and every half a degree from 2°N to 2°S. Marked with a black arrow are stations sharing the same latitudes as TAO moorings.

Date Line with casts taken at 5°, 4°, 3°, 2°, 1.5°, 1°, 0.5°, and 0° both north and south of the equator. (Figure 5). The CTD was lowered down to 1000 meters before being brought back up and temperature, salinity, and depth were taken continuously on the downcast. Temperature was converted into potential temperature and potential density was calculated from the temperature, salinity, and pressure data. Data was collected and processed into CNV files, which were then able to be used for analysis by loading, grouping, and plotting in Python.

In addition to data collected during this study, data from previous years was used to assess how the data from the study compares to prior El Niño and La Niña events. The data used was Tropical Atmosphere Ocean (TAO), found on <https://www.pmel.noaa.gov/tao/drupal/disdel/>. For comparison, 5-day average data of temperature with depth was used along 180 degrees of

longitude, using stations at 5°N, 2°N, 0°N, 2°S, and 5°S. Additionally, 5-day averages of Z20 from the TAO data was used in order to generate a graph.

## Results

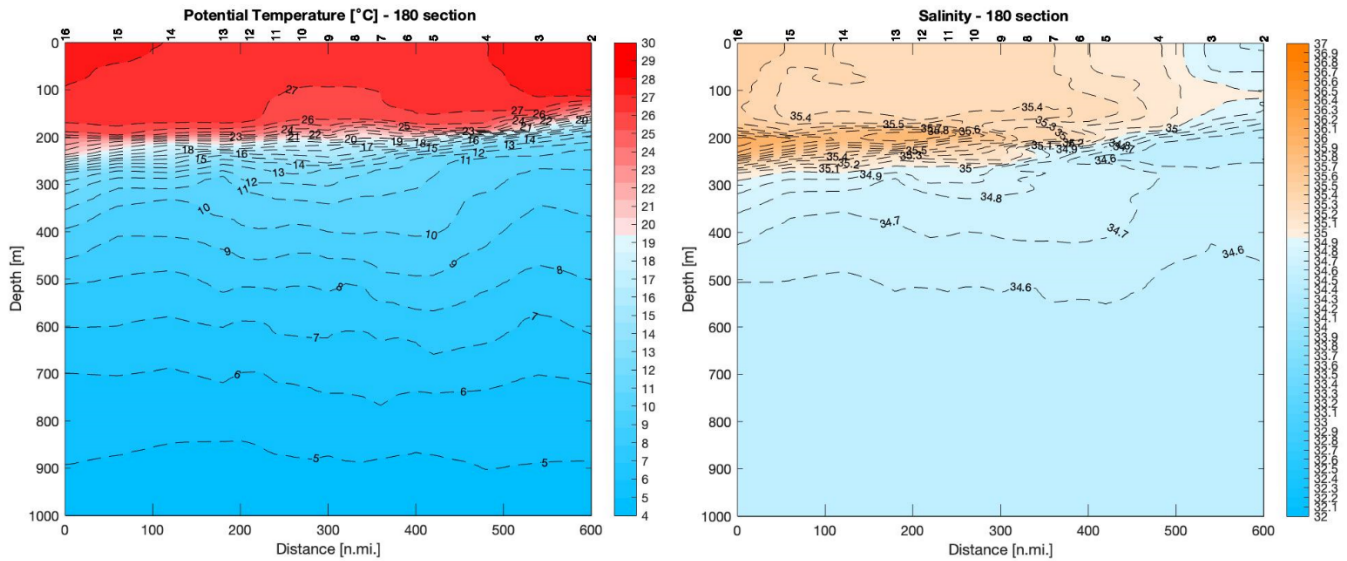


Figure 6: Vertical sections of potential temperature and salinity on the cruise section. Lines of constant temperature and salinity are included in the graphs. Potential temperature follows a red to blue color gradient, with white at 20°C. Station numbers are marked at the top of each plot. Graphs generated by Mark Warner.

Temperatures stay relatively constant throughout the latitudes, with shallower 20°C depths at more northern latitudes (Figure 6). Salinity is higher closer to the surface above 300 meters and has a general increase towards the south. Sharp changes in salinity were found at both 5°N and 4°N of latitude (Stations 2 and 3), with a large increase followed by a decrease about 10 meters deeper. A salinity maximum was found at more southern latitudes, with peaks of over 36 PSU found at 1°S, 4°S, and 5°S. (Figure 6)

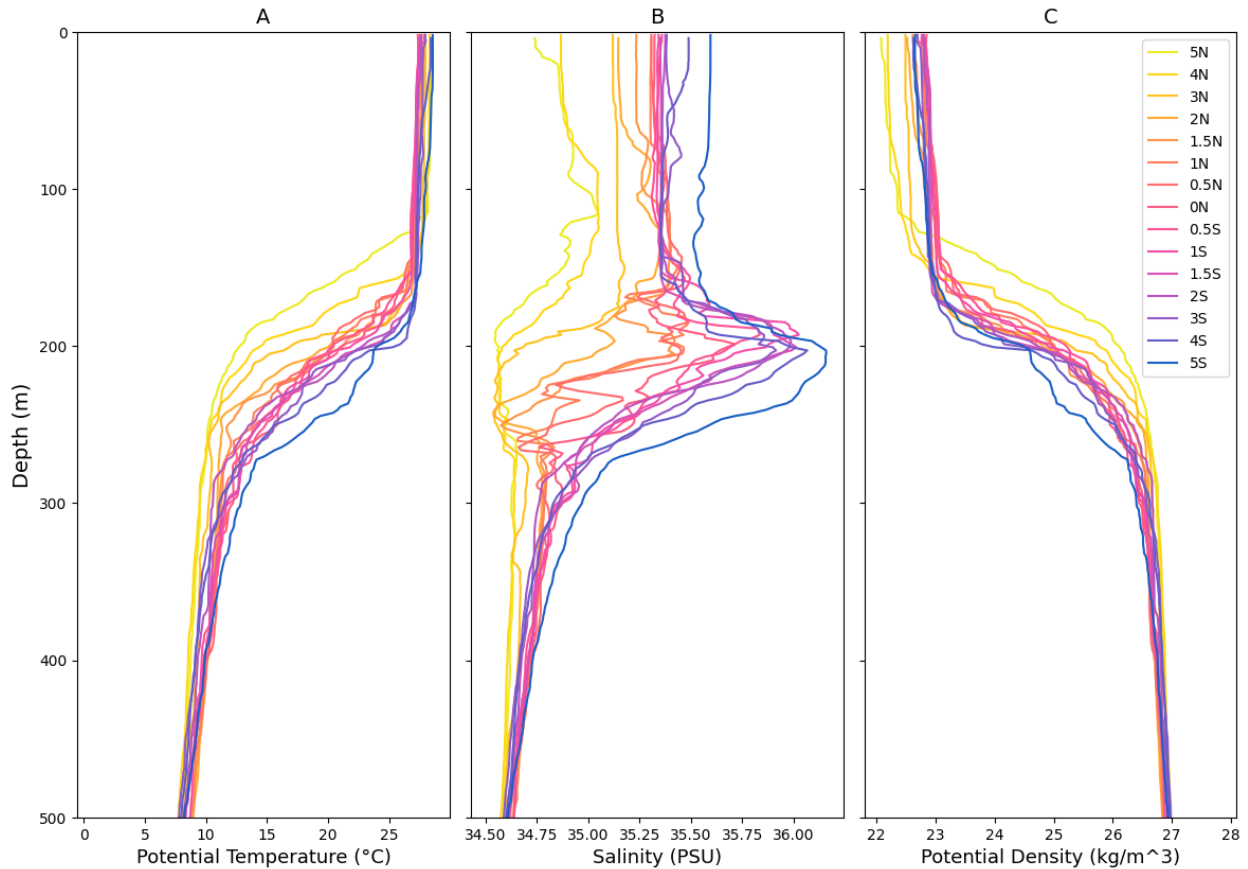


Figure 7: Vertical profiles of A) potential temperature, B) salinity and C) potential density from Stations 2-16, between 5N-5S using cruise data.

Potential temperature shows a trend of deeper thermoclines with more southern latitudes, with some exceptions in the middle latitudes, like 1°N, 0°N, and 1°S. Temperature ranges were relatively consistent between the latitudes, being between about 7-29°C in the upper 500 meters. Salinity showed similar trends as in the previous graph, with an increase in salinity at 100m and a decrease in salinity at about 150m. The salinity maximum can be more clearly seen in this graph, with much higher salinity in the southern latitudes. Potential density shows lower densities at northern latitudes and shallower pycnoclines. (Figure 7)

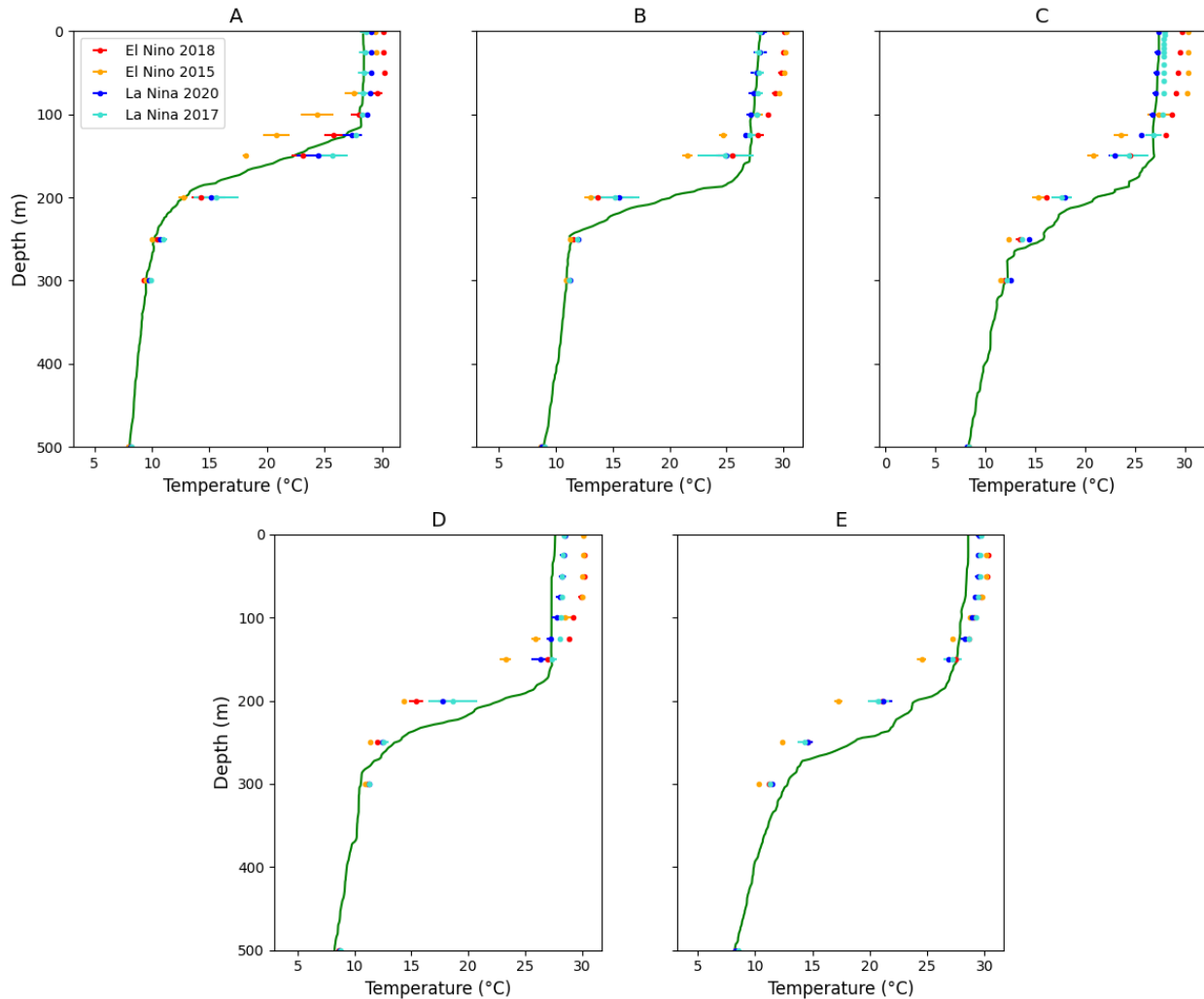


Figure 8: Comparison of cruise data to TAO array data at 5N (A), 2N (B), 0N (C), 2S (D) and 5S (E). Plotted points are of peak El Niño and La Niña months, averaged at each depth with a 5-day average. Error bars of standard deviations are included. Cruise data is plotted as a line in green. Data from <https://www.pmel.noaa.gov/tao/drupal/disdcl/> Accessed on April 6, 2023.

The cruise data is generally similar at the surface to the TAO data for the La Niña periods, being between 26-28°C and are lower in temperature compared to the El Niño periods, where the surface temperature becomes around 30°C. The thermocline is sharper and slightly shallower during El Niño years compared to the La Niña years (Figure 8).

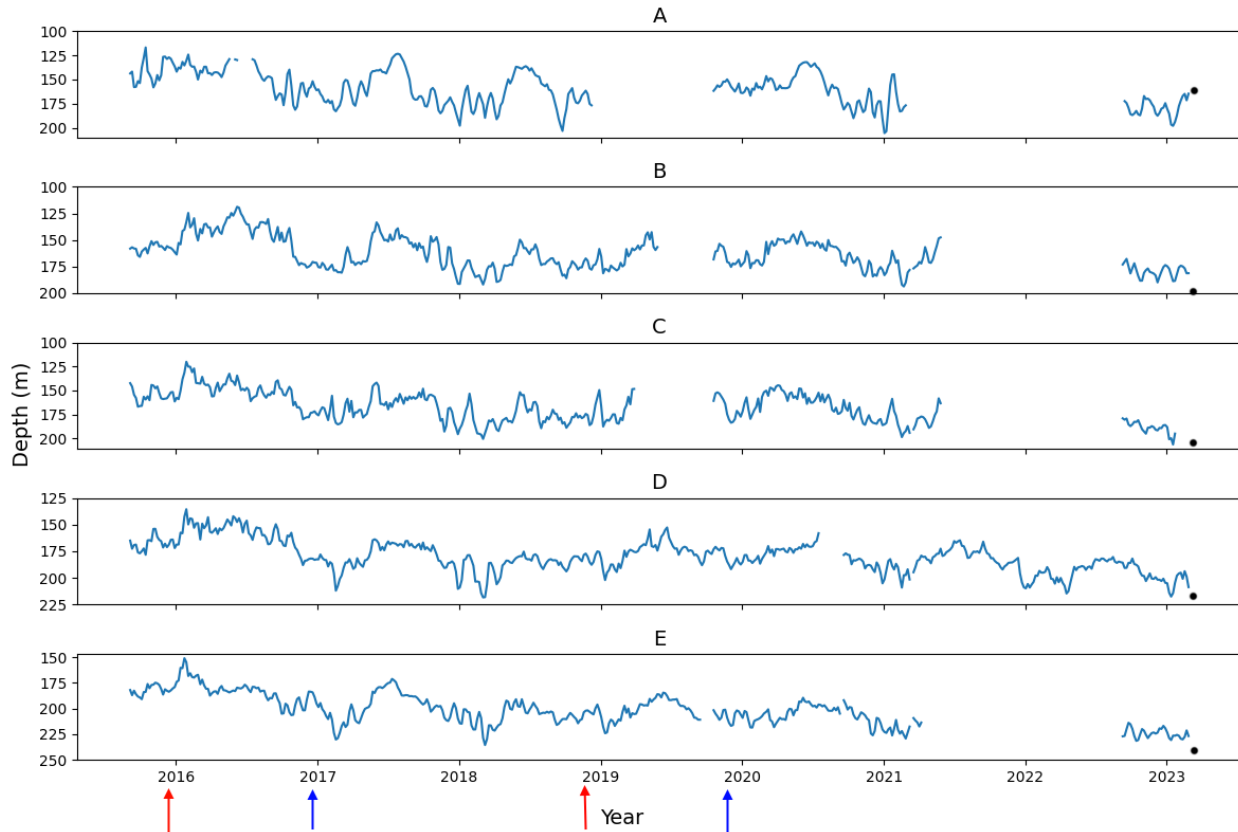


Figure 9: Z20 at latitudes of 5N (A), 2N (B), 0N (C), 2S (D) and 5S (E) from a 5-day average. Approximated Z20 from cruise data is plotted as a black dot. Approximate dates of El Nino (red) and La Nina (blue) are marked by arrows. Data from PMEL NOAA at <https://www.pmel.noaa.gov/tao/drupal/disdell/>.

Z20 depths from the cruise data were at the lower end compared to the TAO data for 2N, 0N, 2S, and 5S, but were closer to the average at 5N. In general, deeper isotherm depths were found following peak La Nina periods, while shallower isotherm depths were found following peak El Nino (Figure 9).

## Discussion

A salinity maximum was found from the cruise data from around 1-5°S. This is a similar finding to the Johnson et al. (2002) paper, where the salinity maximum was found south of the equator at 5-8°S, but the salinity maximum there was found further south than in the cruise data. The sharp increase in salinity leading into a decrease at 5°N and 4°N indicates a barrier layer. A

barrier layer was also found between 3-7°N in the Johnson et al. paper, which is also similar to what was found on the cruise, but there is no way to tell how far the barrier layer would have continued northward if the cruise data had a larger range of latitudes. The Johnson et al. (2002) paper was mostly conducted during neutral conditions averaged over multiple cruises, which may have been the reason for the slight differences in where both the salinity maximum and barrier layer were found.

Density at southern latitudes were found to be lower than the northern latitudes, but the pycnocline went deeper as latitude went towards the north. This is due to the salinity maximum south of the equator being deeper than the thermoclines for the more northern latitudes as well as a deeper thermocline for latitudes north of the equator. The extreme changes in salinity at the salinity maximum also lead to southern latitudes having a slightly sharper density change than the northern latitudes. The barrier layer in the north could be a part of the cause for a shallower pycnocline, as the salinity would cause the density to have significant changes at a shallower depth. The salinity maximum in the south was part of a reason for the deeper pycnocline, as a majority of the increase in salinity was at deeper depths, around 200m or deeper.

Deeper thermoclines going southward was a common trend between the cruise data, Johnson et al. (2002) paper, and TAO dataset. In general, the thermocline for La Nina periods were slightly deeper than El Nino periods, but the thermocline for the cruise data seemed to lie deeper than the La Nina periods from the TAO data. The surface temperatures support my hypothesis that the cruise data would be similar to La Nina conditions. Z20 was generally shallower for both the cruise and the Johnson et al. (2002) paper in the more northern latitudes, being about 150m at 5°N and deeper in the southern latitudes, around 250m at 5°S. From the Z20 TAO data, the cruise data matches very closely to the La Nina cycles in the TAO data, where the

Z20 deepens in the later end of a La Nina. This supports my hypothesis of the cruise data being similar to a typical La Nina, as the depths for Z20 found during the cruise are much more similar to a La Nina than an El Nino. However, Z20 depths found on the cruise were anomalously deep, being either as deep or deeper than the deepest points on the TAO data, which may have been caused by the three consecutive La Ninas.

## **Conclusions**

Understanding the ENSO cycle and the variance within it is important for predicting future changes in climate and knowing the expected changes from an El Nino to a La Nina. Because of the variety of global large-scale changes, the ENSO cycle can impact, knowing the range of variance within it is crucial in understanding the results of changes in water mass properties. For this study, my prediction was that the data collected on the cruise would be similar to La Nina conditions, with similar Z20 depth and surface temperatures. The data from the cruise ended up with similar conditions at the surface to La Nina conditions, with Z20s and thermoclines closer to the La Nina conditions than the El Nino conditions, compared to the TAO data. However, the cruise data still had significantly different Z20s and thermoclines. A salinity maximum was found in southern latitudes of around 1-5°S and a barrier layer was found in northern latitudes at around 4-5°S, which were latitudes similar but not exactly the same as a previously conducted study. However, the conditions in this study and the previous study were different as well, so this was expected. As a follow up, it would be helpful to work with a dataset with a larger variety of depths at the mixed layer, as the TAO dataset had few points in mixed layer depth, making it hard to compare accurately.

## **Acknowledgements**

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