Temporal variability in current structure, thermocline and zooplankton of the eastern equatorial Pacific

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Abstract

Major climate regimes of the Pacific Ocean such as ENSO affect physical and biological variables. Thermocline structure, current structure, and zooplankton density are examined in April and/or May of 2003, 2004, and 2005 under different ENSO climate conditions using ADCP, CTD, and neuston net tows. The thermocline depth in May 2003, a year with a lower Oceanic Nino Index, is higher between 0ºN and 5ºN and lower between 5ºN and 10ºN than April 2004 and May 2005 – both months with greater Oceanic Nino Indexes. There is greater eastward current between 10ºN and 15ºN in April 2004 and May 2005 than in May 2003. Zooplankton densities did not show significant differences between the three sampling periods. Long term studies of such physical and biological variables are necessary to understand the impacts of climate.

Introduction

The El Niño/Southern Oscillation (ENSO) is the major inter-annual climate regime of the Pacific Ocean. ENSO is characterized by weakening of the trade winds and warming of sea surface layers in the equatorial Pacific every 4 to 6 years. Normally there is high atmospheric pressure over the eastern side of the Pacific basin and low atmospheric pressure over the western side. This pressure difference drives trade winds that blow from the east to the west driving westward currents such as the north equatorial current which flows between 9 and 18ºN and the south equatorial current which flows between the equator and 8ºS. Warm water piles up on the western side of the Pacific basin depressing the thermocline and nutricline, leading to low productivity in the western basin. During an El Niño event, a shift in the atmospheric pressure pattern called the Southern Oscillation results in high atmospheric pressure over the western basin and low atmospheric pressure over the eastern basin. This pressure change causes trade winds to weaken or reverse and the warm water pool moves eastward as a Kelvin wave, raising sea surface temperature and depressing the normally shallow thermocline and nutricline of the eastern basin, leading instead to low productivity in the eastern basin. Once this Kelvin wave reaches the American continent, it is reflected back across the ocean as a Rossby wave often leading to a La Nina event which is characterized by cooler than normal conditions, high winds, and high productivity in the eastern basin. The frequency and scale of these events can be measured through many variables such as air pressure difference or sea surface temperatures. Figure 1 shows the Oceanic Nino Index which characterizes the relative strength of the ENSO signal using sea surface temperatures (SSTs) measured near the equator in the Pacific ocean. An index value beyond the threshold of +/- 0.5ºC can be considered a warm (El Nino) or cold (La Nina) episode, otherwise the climate is considered to be in a neutral state.

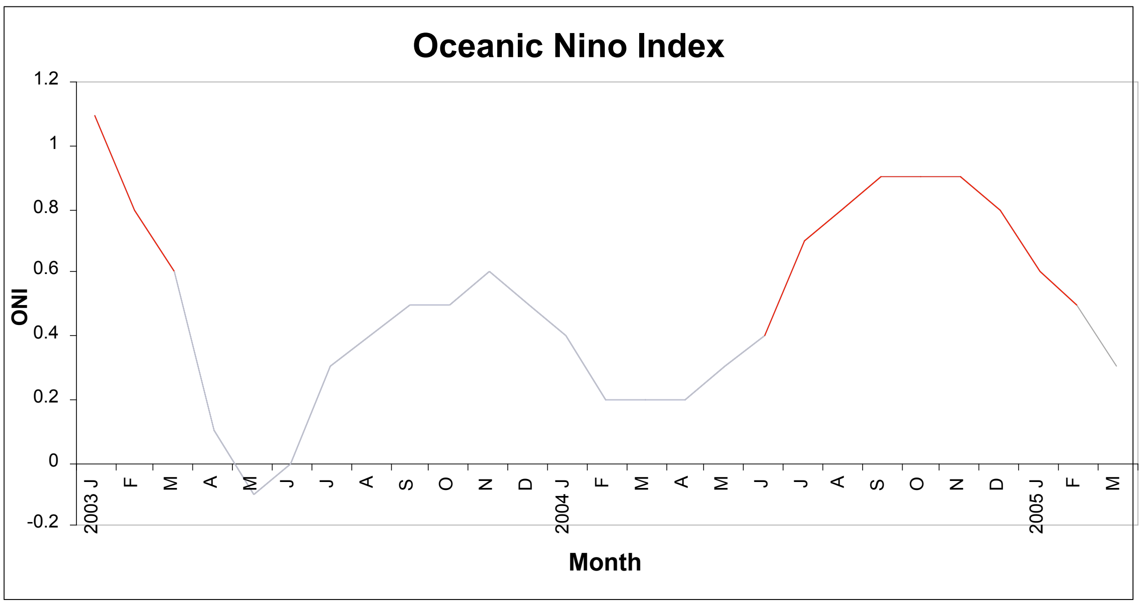

Figure 1. The Oceanic Niño Index (ONI) is the running 3-month mean SST anomaly for the equatorial Pacific and is the standard used by NOAA to identify El Niño (warm) and La Niña (cool) events in the tropical Pacific. May 2003 had a cooler index than April 2004 or May 2005. Data from the NOAA National Weather Service Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml)

The mean thermocline and current structure in the central equatorial Pacific along a cruise track from Hawaii to Tahiti between 150 and 160ºN was characterized by Wyrtki and Kilonsky (1984) using data from conductivity-temperature-depth recorder (CTD) for temperatures and zonal geostrophic flow calculated between each pair of stations from mean dynamic height profiles to characterize mean current structure. During this experiment 43 sections were made on 15 cruises over a period of 17 months during April 1979 to March 1980, a period of time that was neither an El Nino year nor a year of cool equatorial temperatures (Wyrtki and Kilonsky 1984). This study provides a baseline for mean thermocline and current structure expected in the central Pacific Ocean from 20ºS to 20ºN. The dominant currents in the Pacific Ocean between the Hawaiian Islands and the equator are the westward flowing north equatorial current which flows between 9 and 18ºN and the eastward flowing north equatorial countercurrent (NECC) between 4 and 9ºN. At the equator between 2ºS and 2ºN is the westward flowing equatorial undercurrent (UC) 40 to 200 meters below the surface which is the most prominent of all eastward flow (Wyrtki and Kilonsky 1984). This present state of knowledge provides a mean picture of current structure during a neutral ENSO state. But how does this current structure change from year to year given slightly different ENSO states?

The impacts of ENSO are also apparent on ecosystem dynamics in the Pacific Ocean. Barber and Chavez (1983) relate the anomalous ocean conditions of the 1982-1983 El Nino to specific biological responses. For instance, normally highly productive upwelling ecosystems in the eastern equatorial Pacific experienced reduced productivity during the El Nino event.

Currents, thermocline, and zooplankton biomass change between Hawaii and the equator during three years (2003-2005) in the spring season (April to May). Because the ENSO climate index of 2004 is similar to 2005, such physical and biological variables are more similar during these two sampling periods than in 2003.

Materials and Methods

Data was collected aboard the *SSV Robert C. Seamans* in the eastern Pacific between Honolulu, Hawaii (21ºN x 157ºW) and the equator during multiple SEA cruise tracks over a three year period from 2003 to 2005 during the months April and/or May. Temperature structure was measured using CTD casts along cruise tracks; see Figure 2 and Table 1 for station locations. Current structure was measured using RDI Instruments OceanSurveyor 75 KHz Acoustic Doppler Flow Profiler (ADCP) during cruise tracks; see Figure 3 for cruise track portion used.

Table 1. Ship's log and GPS locations for CTD station data for cruises S187, S192, and S199.

S187 (May 2003)			S192 (April 2004)			S199 (May 2005)		
log	LatDisplay	LonDisplay	log	LatDisplay	LonDisplay	log	LatDisplay	LonDisplay
126.8	20°37.8' N	156°40.5' W	298.8	18°29.6' N	157°5.5' W	41.1	20°43.8' N	157°43.4' W
274.6	19°38.9' N	156°2.8' W	309.5	18°19.3' N	157°16.3' W	231.0	18°53.0' N	156°57.0' W
344.6	19°38.9' N	156°28.8' W	314.8	18°16.5' N	157°20.6' W	245.0	18°44.2' N	157°5.3' W
402.2	18°0.3' N	157°13.1' W	327.6	18°14.4' N	157°23.0' W	253.1	18°35.7' N	157°13.0' W
554.9	15°16.3' N	157°55.2' W	379.81	17°21.0' N	157°47.9' W	275.7	18°19.6' N	157°0.1' W
692.6	13°2.7' N	158°43.7' W	490	15°24.1' N	158°10.4' W	304.5	17°54.6' N	156°39.4' W
693.3	13°0.1' N	158°46.4' W	615.7	13°22.1' N	158°28.2' W	444.0	17°29.6' N	156°13.6' W
830.1	10°48.2' N	159°35.9' W	664.3	12°28.4' N	158°44.2' W	460.0	15°38.8' N	156°4.8' W
978.2	8°23.3' N	160°9.3' W	679.5	12°18.6' N	158°49.0' W	597.6	13°19.7' N	156°22.5' W
1091.8	6°44.2' N	161°0.7' W	699.3	12°9.2' N	158°49.1' W	730.0	11°5.6' N	156°22.5' W
1325.1	7°3.0' N	161°25.7' W	843	9°37.6' N	159°32.7' W	853.9	8°50.5' N	156°30.8' W
1456.8	8°33.2' N	159°53.0' W	933.5	8°11.6' N	160°3.7' W	943.5	7°6.2' N	156°51.5' W
1600	10°51.0' N	160°32.8' W	946.7	8°6.7' N	160°9.9' W	1040.1	5°23.4' N	157°4.0' W
1710.2	12°5.9' N	160°27.1' W	968.1	7°52.4' N	160°14.0' W	1139.9	3°38.8' N	157°17.9' W
2077.9	16°55.1' N	158°23.5' W	1048.1	6°37.572' N	160°46.150' W	1358.0	3°15.2' N	158°47.7' W
2081	20°29.8' N	156°59.0' W	1139.7	0°19.0' N	161°40.7' W	1831.5	8°37.6' N	161°23.8' W
			1395.6	1°25.4' N	160°53.7' W	2155.9	13°32.4' N	160°14.8' W
			1470.5	0°3.9' N	160°50.4' W			
			1888.1	5°49.8' N	162°6.0' W			
			1989.5	7°48.3' N	162°20.0' W			
			2148.2	10°14.2' N	162°26.6' W			
			2350.2	13°33.6' N	162°46.2' W			
			2604	17°11.7' N	161°16.3' W			

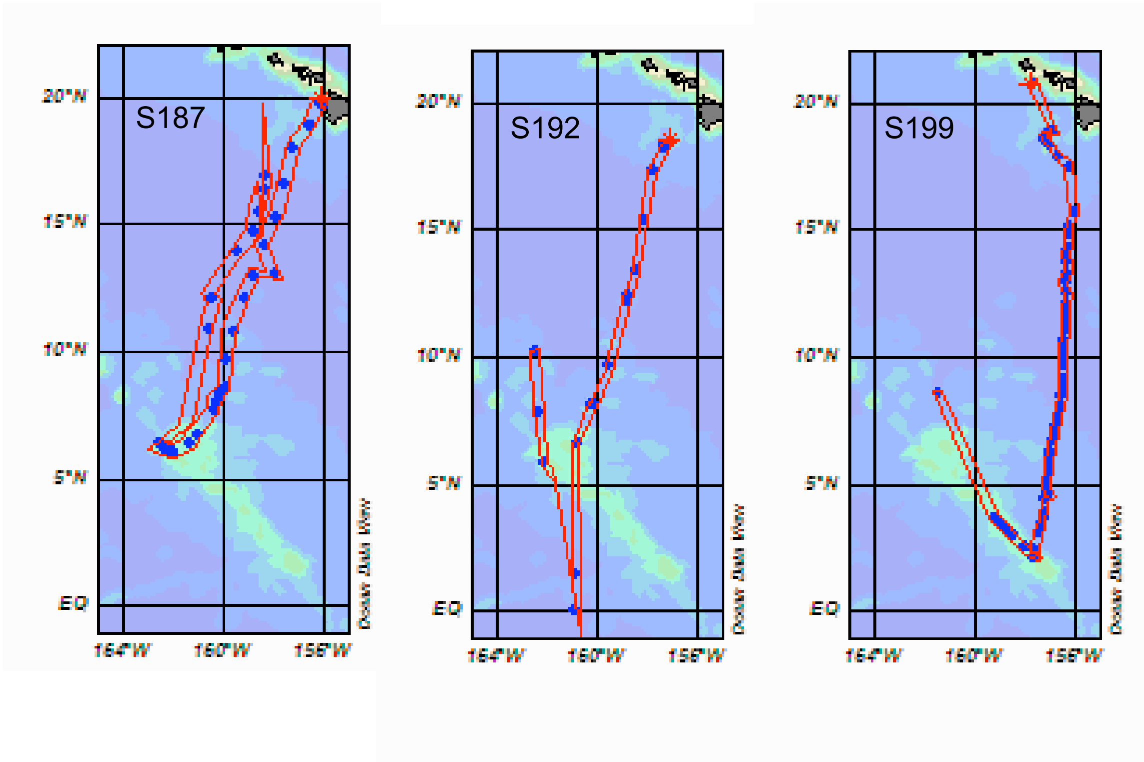

Figure 2. CTD and hydrocast stations for SEA cruises S187 (May 2003), S192 (April 2004) and S199 (May 2005) (see appendix for ship's log and GPS position).

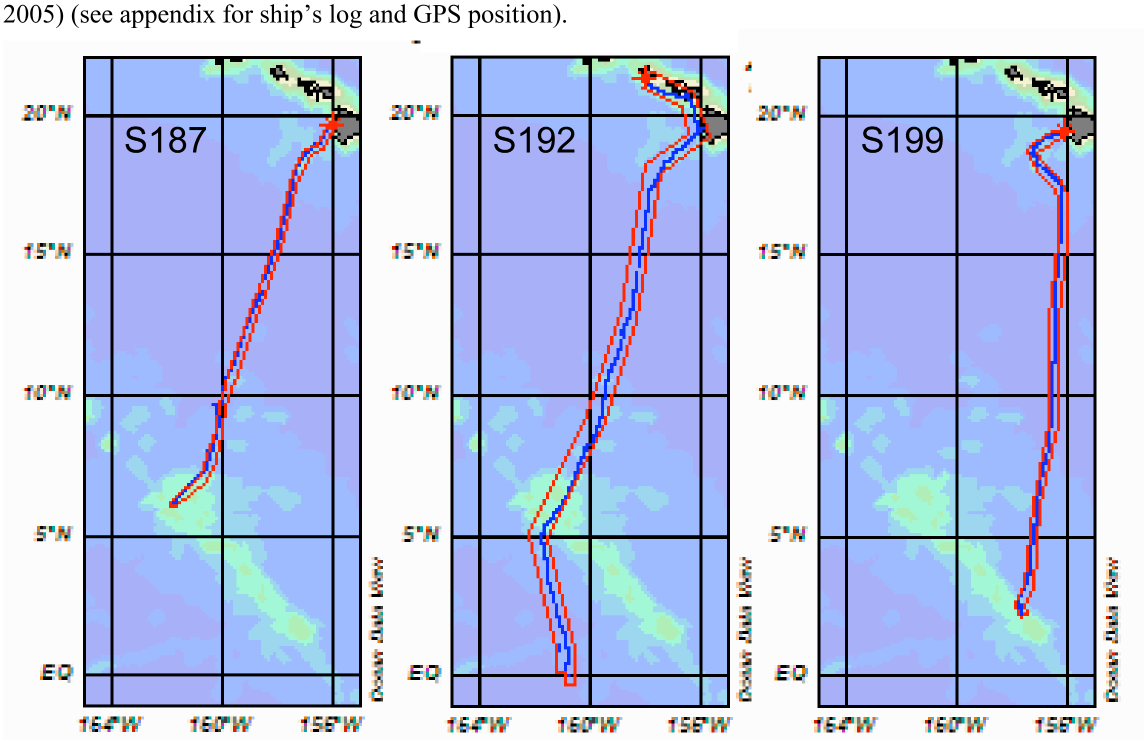

Figure 3. Cruise tracks from cruises S187 (May 2003), S192 (April 2004), and S199 (May 2005) along which ADCP profiles were collected.

Table 2. Ship's log, and GPS position of neuston net tows for cruises S186 and S187 (2003 data), S192 (2004 data), and S198 and S199 (2005 data).

S186 (April 2003)			S187 (May 2003)			S192 (April 2004)			S198 (April 2005)			S199 (May 2005)		
log	LatDisplay	LonDisplay	**log**	LatDisplay	LonDisplay	**log**	LatDisplay	LonDisplay	**log**	LatDisplay	LonDisplay	**log**	LatDisplay	LonDisplay
23.25	17°8.1' S	149°44.5' W	159.3	20°24.1' N	156°28.0' W	56.9	20°45.5' N	157°19.2' W	49.9	20°31.4' N	157°16.7' W	231.2	18°52.9' N	156°59.9' W
73.5	16°36.5' S	149°19.4' W	263.3	19°48.0' N	156°9.5' W	84.4	19°42.2' N	156°12.5' W	158.5	18°42.0' N	156°56.0' W	240	18°43.5' N	157°5.8' W
199.5	15°16.0' S	148°28.2' W	345.1	18°49.8' N	156°32.9' W	228.3	19°17.2' N	156°14.0' W	203	17°55.6' N	156°48.3' W	253.1	18°36.2' N	157°12.4' W
292.8	14°41.8' S	147°46.5' W	479.2	16°37.0' N	157°34.7' W	298.3	18°28.8' N	157°6.2' W	253.5	17°1.0' N	156°45.1' W	275.7	18°21.6' N	156°58.6' W
344	14°55.0' S	147°0.0' W	625	14°8.0' N	158°18.6' W	336.6	18°3.3' N	157°27.3' W	320.9	16°2.6' N	156°39.5' W	304	17°55.6' N	156°39.8' W
402.25	14°48.65' S	146°27.76' W	748.2	12°5.5' N	159°8.7' W	438.8	16°19.3' N	158°1.2' W	382.2	14°59.5' N	156°30.6' W	344.3	17°30.5' N	156°14.2' W
537.1	14°7.0' S	144°32.0' W	896.4	9°41.0' N	159°56.3' W	490.4	15°22.8' N	158°11.0' W	455	13°56.9' N	156°15.1' W	540.7	14°19.2' N	156°16.1' W
679.9	13°23.96' S	143°1.64' W	1020.3	7°39.6' N	160°21.9' W	565.1	14°16.1' N	158°19.8' W	517.5	13°3.4' N	156°3.3' W	673	12°5.2' N	156°23.5' W
810.4	13°12.7' S	141°11.7' W	NA	5°58.4' N	162°0.2' W	783.9	10°36.8' N	159°22.1' W	561.6	12°22.4' N	155°54.3' W	785	10°2.7' N	156°28.7' W
811.9	13°18.8' S	141°8.1' W	NA	6°20.9' N	162°29.3' W	800	10°18.8' N	159°23.5' W	634	11°6.7' N	155°42.2' W	853.2	8°52.4' N	156°30.4' W
816	13°23.1' S	141°6.6' W	1178.6	16°22.3' N	158°22.8' W	811.8	10°10.3' N	159°28.3' W	717.5	9°51.0' N	155°36.9' W	896	7°55.8' N	156°38.6' W
942.6	12°56.6' S	139°34.9' W				844.2	9°35.5' N	159°32.0' W	782.4	8°42.2' N	155°36.8' W	943	7°7.6' N	156°50.9' W
144.6	11°11.0' S	138°26.6' W				1000	7°21.6' N	160°27.7' W	835.5	7°49.9' N	155°41.9' W	999	6°11.7' N	157°1.6' W
1749.5	5°49.5' S	141°37.9' W				1048.1	6°37.0' N	160°46.0' W	906.6	6°39.8' N	155°43.3' W	1039.8	5°25.0' N	157°4.3' W
1761.5	5°39.9' S	141°41.6' W				1110.2	5°42.9' N	161°21.8' W	965.5	5°48.0' N	155°42.7' W	1075.4	4°44.8' N	157°10.9' W
1767	5°37.9' S	141°42.7' W				1141	5°15.9' N	161°41.4' W	1004.8	5°8.9' N	155°39.2' W	1136.5	3°40.6' N	157°18.1' W
1878	3°59.2' S	142°3.9' W				1396	1°24.5' N	160°55.0' W	1052.3	4°18.5' N	155°34.6' W	1214.9	2°29.8' N	157°38.1' W
2045.2	1°22.8' S	142°46.1' W				1455.8	0°22.8' N	160°50.2' W	1096.8	3°35.2' N	155°36.8' W	1379	3°33.5' N	159°6.5' W
2201.8	0°53.3' N	143°1.5' W				1470.5	0°0.8' N	160°50.6' W	1146.5	2°49.2' N	155°57.0' W	1631.5	5°49.7' N	162°8.3' W
2333	2°58.7' N	143°28.0' W				1499.4	0°17.3' N	161°14.6' W	1199	1°57.4' N	156°22.6' W	1752	7°35.1' N	162°4.5' W
2448	4°51.8' N	143°24.5' W				1854.7	5°37.3' N	162°0.22' W	1320.7	0°3.1' S	156°54.3' W	1831	8°37.8' N	161°24.5' W
2560.8	6°23.5' N	144°13.6' W				1864.6	5°36.2' N	162°0.8' W	1234.3	0°4.6' S	157°5.9' W	1942.4	10°25.3' N	160°52.8' W
2686.1	8°11.1' N	145°28.4' W				1874.4	5°36.8' N	162°3.3' W	1431	1°35.3' N	157°22.6' W			
2789.2	9°26.0' N	146°29.8' W				1888.9	5°47.8' N	162°7.7' W	1500.4	2°55.6' N	157°54.5' W			
2800.5	9°33.0' N	146°37.5' W				1989.75	7°47.7' N	162°19.9' W	1707.5	3°12.5' N	159°12.7' W			
2803.3	9°31.6' N	146°38.6' W				2031.1	8°26.4' N	162°19.1' W	1769.5	4°4.0' N	159°45.5' W			
2899.4	10°40.7' N	147°45.9' W				2036.6	8°25.0' N	162°21.1' W	1815.3	4°0.0' N	160°17.2' W			
3028.5	12°29.1' N	148°56.4' W				2042.2	8°25.6' N	162°25.8' W	1860.9	4°10.3' N	160°27.6' W			
3531.4	19°7.7' N	154°40.1' W				2062.9	8°40.8' N	162°22.5' W	1974.3	4°48.9' N	160°57.1' W			
3541.4	19°8.8' N	154°48.5' W				2110	9°33.2' N	162°21.8' W	2020	5°28.9' N	161°15.0' W			
3549	19°11.10' N	154°51.8' W				2148.3	10°13.7' N	162°27.2' W						
2577.6	19°13.6' N	154°59.8' W				2202.7	11°3.2' N	162°41.8' W						
						2239.5	11°35.6' N	162°27.1' W						
						2305	12°43.7' N	162°44.9' W						
						2350.4	13°33.0' N	162°4.5' W						
						2401.5	14°30.5' N	162°50.4' W						
						2465.5	15°21.8' N	162°26.0' W						
						2499.8	16°12.5' N	162°36.8' W						

Zooplankton was collected with a 333μm mesh neuston net and biomass calculated from measured zooplankton volume divided by the area of water towed (meters squared). Statistical analysis was completed with ANOVA test. See table 2 for net tow station positions.

Results

Thermocline structure (Figure 4) is analyzed by visual comparison of color plots. The thermocline is lower between 5ºN and 10ºN in 2004 and 2005 than in 2003. The thermocline between 10ºN and 15ºN is higher in years 2004 and 2005 than in 2003. Between 15ºN and 20ºN the thermocline has less structure in 2004 than in 2003 and 2005.

Current structure (Figure 5) is ana lyzed by visual comparison of color plots. There is greater eastward current between 10ºN and 15ºN in April 2004 and May 2005 than in May 2003 compared to mean current structure characterized by Wyrtki and Kilonsky (1984).

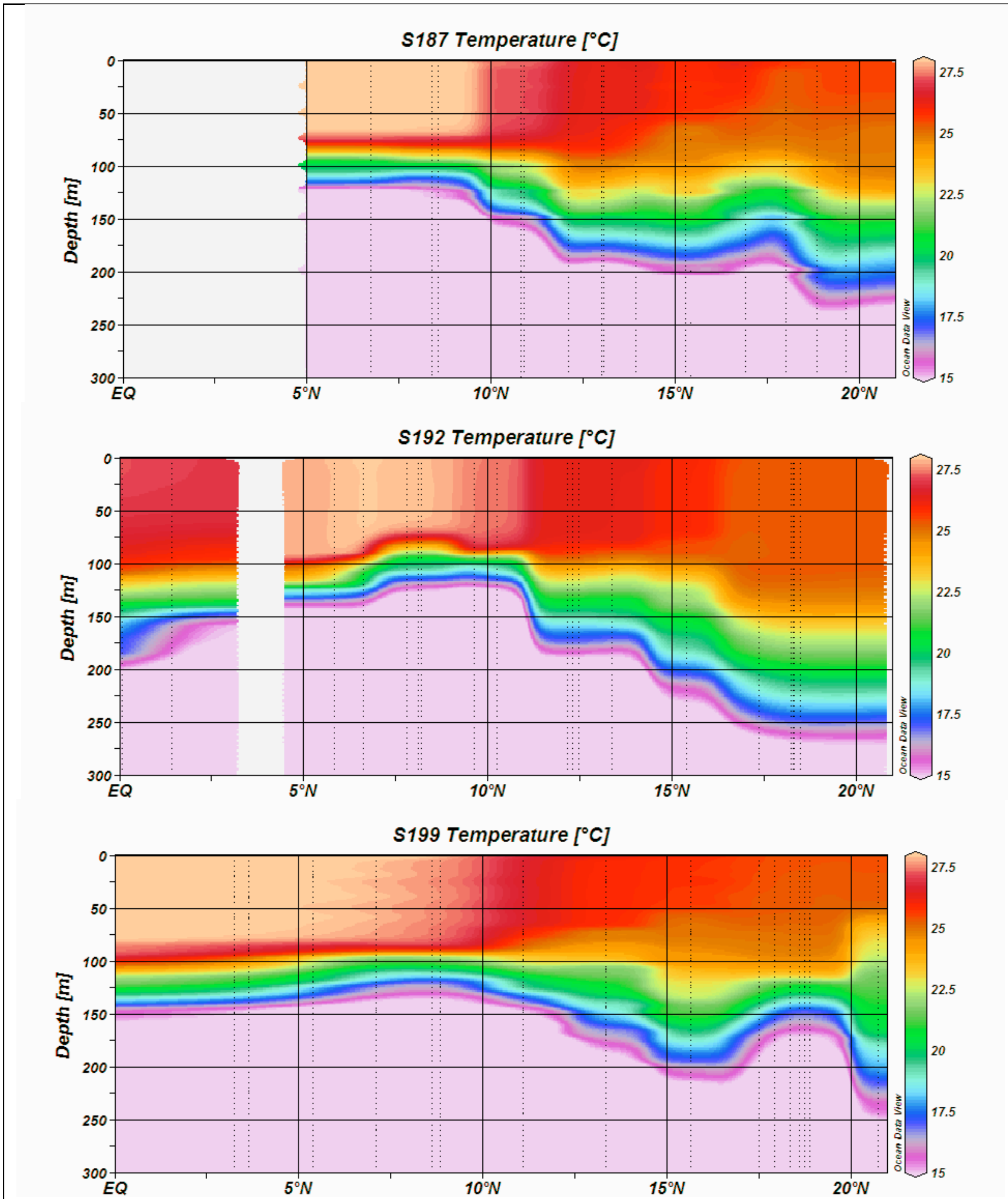

Figure 4. Temperature profiles from cruises S187 (May 2003), S192 (April 2004), and S199 (May 2005)

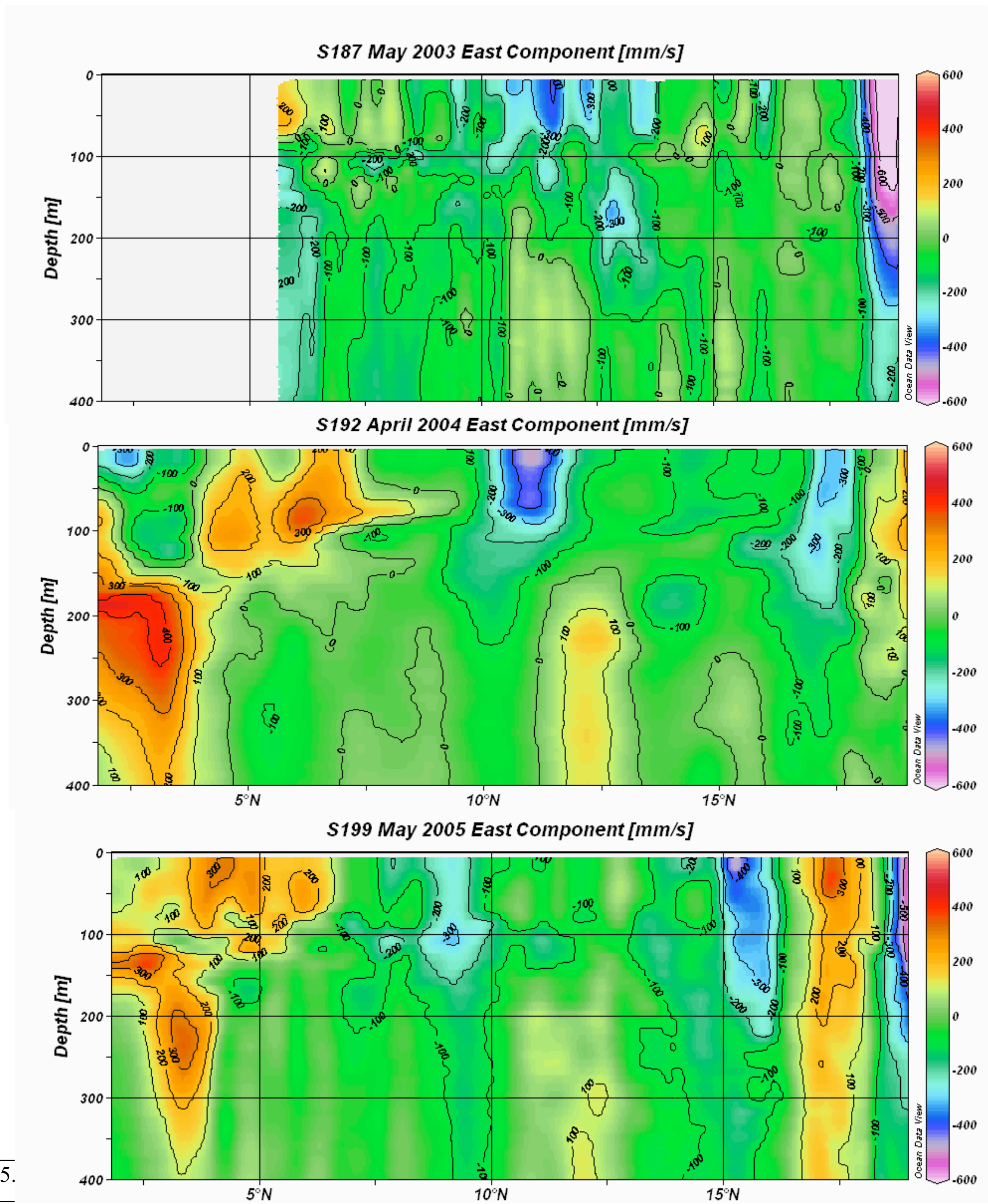
S187 May 2003 East Component [mm/s]
Depth [m]
S192 April 2004 East Component [mm/s]
Depth [m]
5°N
10°N
15°N
S199 May 2005 East Component [mm/s]
Depth [m]
5°N
10°N
15°N
Ocean Data View

Figure 5.

Zooplankton biomass density (ml/m^3), the latitude, and time of net tow are listed in Table 3 and Figure 6 displays the zooplankton density at each latitude. ANOVA test p-value between 2005 and 2003 is 0.94 and between 2005 and 2004 is 0.74 (Table 4), thus there is no significant difference between the amount of zooplankton collected in net tows between 2005 and the previous two seasons. It is evident in Figure 6 that there is a difference between the levels of zooplankton density at night versus day due to Diel vertical migration.

Table 3. The density (ml/m^3) of zooplankton at latitude (ºN) and time of sample. fir 2003 (cruises S186 and S187), 2004 (cruise S192), and 2005 (cruises S198 and S199).

2003						2004						2005					
S186	night		day			S192	night		day			S198	night		day		
LAT	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**
0	0.024946	0:40	19	0.0022	17:34	19	0.00486	0:02	20	0.00432	11:33	17	0.0036	0003	20	0.0012	1210
3	0.013364	1:05	19	0.0092	5:30	18	0.002538	0:05	19	0.00108	15:30	13	0.001	0006	18	0.000063	1532
4	0.068818	0:54				16	0.00162	0:18	18	0.000675	12:04	12	0.004	2140	17	0.00054	1222
6	0.06007	0:30				14	0.00054	0:22	15	0.00135	11:07	7	0.0032	2235	16	0.0008	0103
7	0.0058	0:42				10	0.00216	21:02	10	0.014399	5:07	5	0.00094	0022	14	0.0012	1154
8	0.021541	22:08				10	0.00432	1:19	6	0.004527	10:03	4	0.095	2230	13	5.4E-06	1233
8	0.032292	0:00				7	0.0054	0:16	5	0.007139	11:26	2	0.0081	0006	11	0.00054	1208
8	0.008393	2:07				5	0.025198	0:19	1	0.007199	11:04	0	0.015	2234	8	0.00003	1232
10	0.0006	0:30				0	0.038157	0:23	0	0.009719	10:29	1	0.00405	0005	6	0.00026	1150
12	0.0097	1:00				0	0.071	23:40	5	0.035	5:03	2	0.0216	0343	5	0.003	1151
19	0.0034	20:13				5	0.024	20:02	5	0.010799	11:22	3	0.015	0013	3	0.0017	1200
19	0.0084	20:20				5	0.023398	1:15	7	0.004	11:04	4	0.0124	0014	1	0.0057	1208
S187	night					8	0.019	21:50	8	0.009	6:00	4	0.01	2358	0	0.012419	1418
LAT	**DENSITY**	**TIME**				8	0.009	2:00	8	0.011	11:32	4	0.0011	0004	4	0.005	1157
19	0.0152	0:22				9	0.023	0:16	10	0.0043	10:51				5	0.002	1151
18	0.00162	1:05				11	0.0074	22:52	11	0.0015	9:54	S199	night		day		
16	0.0104	22:39				12	0.0086	23:05	13	0.0011	11:04	**LAT**	**DENSITY**	**TIME**	**LAT**	**DENSITY**	**TIME**
14	0.0013	22:52				14	0.003	22:51	15	0.002	11:12	18	0.010	2012	18	0.019	0619
12	0.0036	22:20				16	0.0111	23:03				14	0.004	0022	18	0.001	0934
9	0.0016	22:36										12	0.002	0020	18	0.002	1418
7	0.027	21:51										10	0.021	0:05	17	0.008	0630
5	0.013	22:40										7	0.020	2355	17	0.007	1617
6	0.0157	3:30										6	0.030	0003	8	0.002	1049
												4	0.028	0037	7	0.117	1058
												2	0.014	0008	5	0.003	1051
												3	0.055	2330	3	0.004	1043
												7	0.029	2245	5	0.056	1943

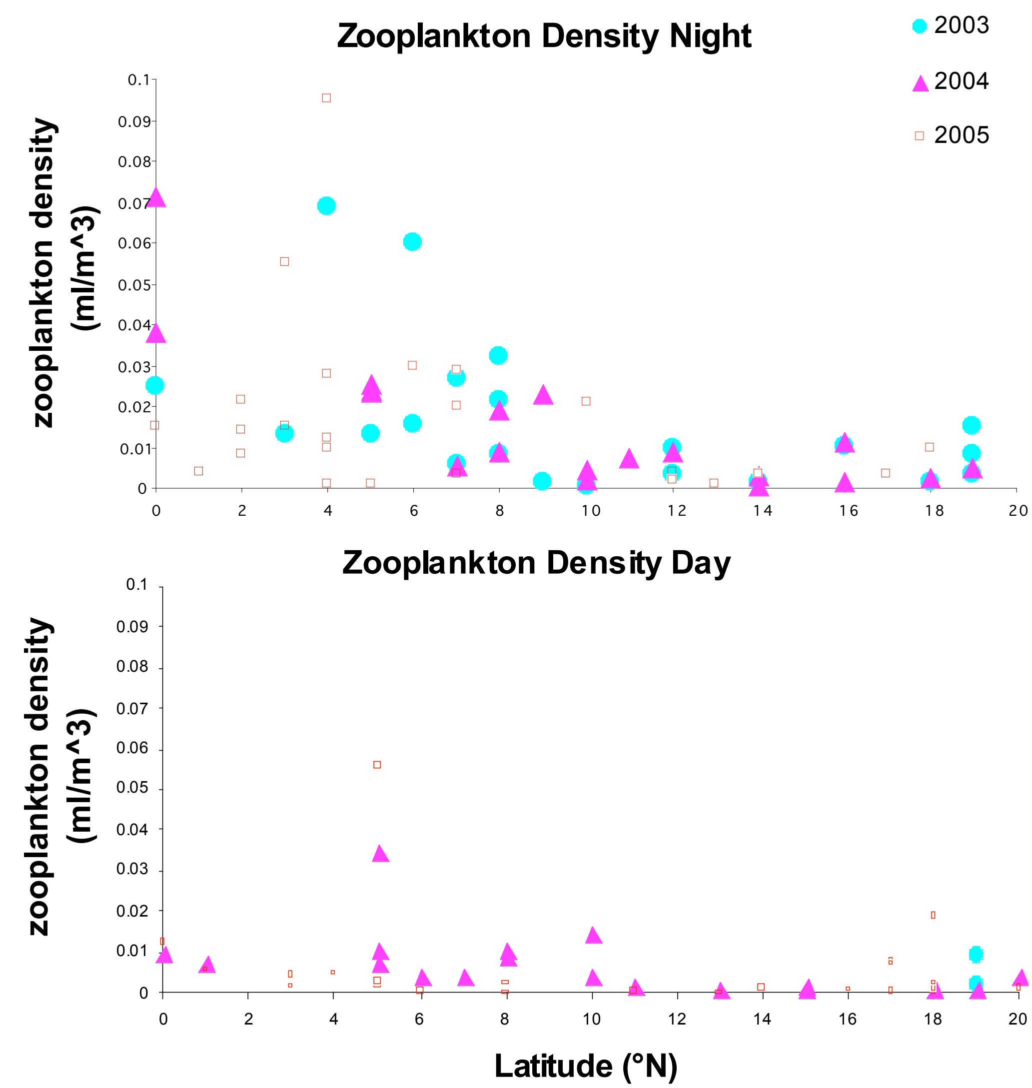

Figure 6. Zooplankton biomass density from 2003 (dots), 2004 (triangles), and 2005 (open squares).

Table 4. ANOVA test results

Groups	Count	Sum	Average	Variance
2004	19	0.284289	0.014963	0.000296
2005	24	0.40699	0.016958	0.000439

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.22E-05	1	4.22E-05	0.112276	0.739276	4.078546
Within Groups	0.015418	41	0.000376			
Total	0.01546	42				

Groups	Count	Sum	Average	Variance
2005	24	0.40699	0.016958	0.000439
2003	21	0.346743	0.016512	0.000336

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.23E-06	1	2.23E-06	0.005708	0.940129	4.067047
Within Groups	0.01681	43	0.000391			
Total	0.016812	44				

Discussion

The greater thermocline structure in 2005 and 2003 than in 2004 between 15ºN and 20ºN is most likely due to eddies that form in the lee of the Hawaiian Islands at these latitudes. The apparent shift to a lower thermocline between 5ºN and 10ºN and the apparent shift to a higher thermocline between 10ºN and 15ºN is during the more El Nino-like years than the more La Nina-like year (Figure 1).

Much of the current structure apparent in the visual plots may be due more to the snapshot in time that was taken along the cruise track. Much of the structure apparent in Figure 5 may be a result of ephemeral eddies rather than portray a true mean structure. Furthermore, the Ocean Nino Indexes (Figure 1) for each of the three sampling periods are not that drastically different. A more dramatic change in current structure may be noticeable during a stronger ENSO signal, emphasizing the importance of long term studies of the effects of climate change on currents.

Zooplankton biomass data is limited; a more thorough sampling may show noticeable differences between a slightly more La Nina year and a slightly more El Nino year. However, all three of the years sampled were relatively neutral ENSO conditions, perhaps a stronger ENSO climate perturbation is required before a significant difference in zooplankton biomass density can be noticed. It is this point that underlines the importance of long term studies in the Pacific in order to better understand the effects of the ENSO climate phenomenon.

Conclusion

This study sampled physical and biological variables in the eastern equatorial Pacific Ocean during the same season over three different years to examine how different ENSO strengths might affect these variables. Visual plots of thermocline and current structure are different – a difference that may be due to different ENSO signals, but could also be due to limited sample size. The zooplankton biomass density did not show any difference between sampling periods. Because the ENSO signal was relatively neutral during each sampling period, major differences are difficult to observe. However, this study provides baseline information that may be compared to stronger ENSO signals in the future.

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