M1/M2 BUOY DATA:

OCEAN TEMPERATURE ANALYSIS

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Background:

The purpose of this paper is to discuss sea surface temperatures in the Monterey Bay area. Two data sets, compiled over a ten-year period, were collected using buoys M1 and M2 located in the Monterey Bay (see Fig. 1). The goal is to determine if any annual or seasonal variations exist in the region and discuss any differences between the two data sets.

Introduction:

The California coast, in particular, Monterey Bay area, has received considerable oceanographic attention due to its unique topography and dynamic ocean environment. This region, strongly influenced by the process of coastal upwelling, has led to numerous studies of sea surface temperatures, nutrient concentrations, and phytoplankton. This discussion will only focus on the sea surface temperatures. Monterey Bay is a deep (>1000m), non-estuarine embayment in that is broadly open to the coastal ocean. Coastal upwelling occurs along eastern ocean margins when equatorward winds act in combination with the Coriolis force to move surface waters offshore, drawing deeper water to the surface near the coast. This upwelled water occurs as a cool band along the coast, typically several 10's of km wide, separated from warmer offshore waters by a variable series of fronts, plumes and eddies.

Monterey Bay Aquarium Research Institute (MBARI) initiated a program of semi-monthly time-series cruises to stations within and offshore of Monterey Bay. MBARI deployed two OASIS moorings, M1 and M2, in and offshore of Monterey Bay in 1992. The M1 and M2 moorings anchored in 1000 and 1800 m of water, respectively,

allow continuous observations in order to characterize and understand climate and ocean variability.

M1 Buoy Data

The M1 buoy sampling contains data from 1990 to 2000 with intermittent gaps or holes in 1991 and 1997. The data contained ocean temperatures from the surface on down to 300m (see Fig. 2). M1 temperature time series (see Fig. 3) clearly shows the highest ocean temperatures occurring once a year in the wintertime. The exception to this occurs in 1999, when the maximum temperatures appear in the fall. This is more than likely the result of El Nino occurring in 1998, which forced an extreme maximum spike in the time series and disrupting the annual pattern. On the contrary, lowest ocean temperatures occurred in and around the summertime.

Principal component analysis (see Fig. 3) reveals that 86.66 percent of the variability of M1 occurs in the first mode. The second mode accounts for 8.34 percent, followed by a mere 3.15 percent in the third mode. Knowing this, one can achieve a reasonably good understanding of the ocean environment simply by looking at the first principal component.

M2 Buoy Data

The M2 buoy sampling contains data from 1992 to 2000 with small gaps or holes in 1993, 1996, 1998 and 1999. Again, the data contains ocean temperatures from the surface on down to 300m (see Fig. 4) and generally cooler deeper temperatures are seen from 1993-1997. M2 temperature time series (see Fig. 5) shows similar results to M1, with maximum temperatures happening in the wintertime with 1999, being an exception to the rule. Concurrently, the minimum temperatures are present in the summertime.

Principal component analysis (see Fig. 5) reveals that 74.33 percent of the variability of M2 occurs in the first mode. The second mode accounts for 17.75 percent, followed by a 5.13 percent in the third mode. This still shows the majority of variability occurring in the first mode, however, there is almost twice as much in the second mode than was seen in M1.

M1 and M2 Combined:

Combining M1 and M2 data sets (see Fig. 6) reinforces the previously mentioned annual variability of higher temperatures in the winter and cooler temperatures in the summer. Here, only data that appeared in both M1 and M2 data was analyzed. The first mode contains 78.12 percent, followed by 10.14 percent in the second mode, and 4.33 percent in the third.

In meshing the two data sets and calculating the mean and standard deviation (see Fig. 7), a couple of interesting results appear. First, the mean for M1 shows slightly cooler temperatures in the upper 80m than its counterpart, M2. The resulting warmer upper layer temperatures for M2 lead to a more stratified ocean than M1. One reason for this could be that buoy M1 lies on top of a stronger upwelling region and therefore more sensitive to changes in the upwelling regime leading to generally cooler temperatures. The offshore M2 mooring lies at the eastern edge of the California Current and is not as affected by coastal upwelling. Accordingly, the standard deviation plot shows M1 having a much stronger variability than M2.

Averaging the two data sets together allows one to compute the geopotential anomaly (see Fig 8), or steric height. This process simply adds all the depths together then subtracts the difference giving an average height variation over time. As expected

with the warmer temperatures observed in the winter months, higher heights are present. Similarly, lower heights are observed in the summertime.

Analysis on a monthly time series from 1994-1999 (see Figs 9-14) demonstrated secondary seasonal variations. 1994 saw a peak of upwelling in February and October. 1995 demonstrated strong upwelling during the month of April, followed by a sharp drop thereafter. Additionally, there were higher than average temperatures throughout the fall season. This event presents itself a few times during this time series. The year 1996 opened up with a significant drop in the month of February followed by a return to warmer temperatures in March, then transitioning to cooler values of summer. Obviously, 1998 was marked by El Nino, which forced higher than normal temperatures in the winter, followed by a cooler than normal year of 1999. A possible reason for this seasonal variability in the transitional months could be due to wind reversals in the bay. Wind reversals result in onshore advection of warmer water into cooler inshore regions thus decreasing effect of upwelling.

Conclusions:

In summary, there was a general trend of warming temperatures in the winter and cooling temperatures in the summer due to the effects of upwelling. The bulk of the variability in the ocean is seen in the first principal component of the M1/M2 thermistor string. M1 showed slightly cooler temperatures in the upper 80m than M2, which could be to M1 residing over a stronger upwelling region. Buoy M2 is less affected since it lies on the eastern edge of the California Current. As a result, M1 showed a much greater variability than M2 as it was not as stratified. As expected, higher geopotential anomalies were seen in the wintertime due to warmer temperatures and vice versa.

During the mid 1990's, there was a gradual shift to a later onset of upwelling before El Nino in 1998 disrupted the pattern. The longer these studies are conducted, the greater chance of determining any large scale features such as global warming and predicting El Nino events.