Summary of PLOO hydrographic observations (2006-2009)

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Introduction

The City of San Diego in collaboration with the Scripps Institution of Oceanography began a study of the hydrographic climate at the site of the Pt. Loma Ocean Outfall (PLOO) in the summer of 2006. The outfall is situated 4.5 miles offshore at a depth of 98 meters (~320') and wastewater is discharged through small ports spaced along ~1 mile of pipeline (diffuser) oriented roughly parallel to shore (see Fig. 1). The diffuser was designed to achieve rapid mixing (initial dilution) with cool ambient waters to achieve entrapment of the sewage field beneath the thermocline thus precluding its rise to the surface. The fate of the PLOO wastefield is primarily affected by the geometry of the diffuser, the rate of wastewater discharge, the temperature stratification of the water column, and currents. Ocean currents mix and transport the wastefield both as it rises, when it is subjected to turbulent initial dilution, and after it has reached its equilibrial depth and ceases rising when it is subjected to further mixing. Therefore hydrographic data at the site of the outfall are critical to assess the dilution and fate of the plume. Current and temperature data can then be utilized in a model of plume dynamics in the near field (zone of initial dilution) to assess rise height, dilution and initial trajectory. The results of this model can then be used in models of regional ocean circulation to determine the fate of the plume in the far field. These model results must then be verified in the field utilizing sophisticated equipment to track the plume. The data briefly summarized in this report represent the initial phase in the three-step process of determining major circulation and temperature stratification patterns, plume and regional circulation modeling, and finally model validation.

Instruments and Study Sites

Patterns of temperature and ocean currents were observed as part of this ongoing study. Hydrographic observations were conducted using current meters (300kHz RDI Acoustic Doppler Current Profilers – ADCPs) and temperature sensors (Onset Tidbits). The current meters use sound to estimate currents at several depth intervals above the bottom. Thermistors were deployed on moorings extending to within a few meters of the surface and were located at four-meter depth intervals. The locations of the current meters and thermistor moorings are shown in Figure 1. Observations were conducted along bottom depths that correspond to the depth of the present diffuser at ~98m and along the bottom depth of the old diffuser (~60m) which was deactivated in 1993.

Findings

Temperature Structure

The degree and depth of stratification indicate the likelihood and depth of wastefield trapping. Stratification is simply the magnitude of temperature change with depth. The thermocline is defined as the depth range where temperature changes are the greatest in the water column. Greater stratification increases the probability that the plume will be trapped below the surface. The depth of the base of thermocline varies seasonally and tidally and is the depth where the plume is most likely trapped beneath the surface.

The general temperature structure and seasonality we observed near the PLOO was consistent with previous observations conducted off San Diego. The water column was seasonally stratified during spring, summer and fall (see Figure 2). Stratification was weaker during winter but exists year round. Bottom temperatures were coolest during the spring/summer upwelling season and warmest during winter. Near surface temperatures were strongly seasonal ranging from 22deg C during summer to 12deg C during winter. The distribution of the base of the thermocline (Figure 3) indicates the most likely trapping depth of the wastefield over the period of observation. The most frequent depth of the thermocline base was ~38m. The base of the thermocline was never shallower than 12 meters, and was deeper than 32 meters 75% of the time, deeper than 44 meters 25% of the time, and deepest at 76 meters. For reference, the maximum depth of the Pt. Loma kelp forest is ~26 meters.

The greatest variation in temperature was observed at seasonal time scales as discussed above, and at tidal time scales. Variation at tidal periods is due to the interaction of the surface tide with the topography of the submarine shelf producing waves that propagate between layers of water having different densities. Density differences in the open ocean off San Diego are mostly due to temperature. These waves are called internal waves and are most energetic at tidal periods producing an internal tide. Internal waves vary in amplitude depending on the density stratification. Wave amplitude increases with decreasing stratification. The greatest variation in temperature and greatest energy due to the internal tide was observed within the depth range of the thermocline. Therefore, the greatest variability in temperature at tidal periods was observed between 25 and 50 meters. The internal tide is an important wastefield transport mechanism during its initial rise producing cross-shore advection of the rising wastefield.

Currents

Modes

Coastal ocean currents that are important for the dispersion of outfall plumes include currents produced by the surface tides and currents at periods longer than tidal periods (greater than 12 hours - subtidal). Tidal currents typically alternate in direction with the semi-diurnal tide off San Diego effectively moving the plume back and forth. Subtidal currents are therefore most important to estimate for determining the footprint of plume visitation.

Over the entire three-year observation period, the dominant subtidal circulation pattern (termed mode 1) at the outfall described currents oriented along a NW-SE axis (Figure

4). The current pattern for the first mode was uniform in direction with depth, decreasing in magnitude with depth, and accounted for 69% of the variability in the currents over that period. This is consistent with observations at other coastal locations along the San Diego County coastline. These results indicate that wastewater was most frequently subjected to a water column moving in the same direction at all depths towards the northwest or the southeast. The most frequent direction of mode 1 currents was towards to the NW.

The second major circulation pattern we observed (mode 2) accounted for 16% of the variability. Current patterns for mode 2 were oriented along roughly the same axis as mode 1 but with opposing surface and subsurface currents. Currents below thirty meters were fairly uniform in direction, with pronounced vertical shear between twenty and thirty meters. This type of two-layer flow is also a common vertical velocity structure, since currents driven by local winds often do not extend more than ten meters below the surface, and other remote wind forcing or pressure gradients drive subsurface flows.

The mode 3 circulation pattern, accounting for 10% of variability, was characterized by three-layer flow. Mode 4 circulation was dominated by bottom boundary layer motion, with some depths oriented along a NE-SW axis. Most of the time, the third and fourth current modes would be effectively masked by modes 1 and 2.

Weaker contributions to the overall variability in ocean currents were from modes whose axis was oriented in the NE-SW direction. Such flows were infrequent but could potentially advect the plume shoreward north of Pt Loma. Conditions under which these infrequent patterns occur must be investigated for links with anomalous winds, waves, or other air/sea events.

Seasonality

When grouped into three-month seasonal time periods, there was no identifiable seasonal pattern to the circulation modes. Most often, the mode 1 circulation in a given season matched either the mode 1 multi-year pattern, or the mode 2 pattern. (i.e., the mode 1 circulation for the season typically looks like either mode 1 or mode 2 in Figure 4). However, some shifts do occur. Modes 1 and 2 in Summer of 2009 are similar to the multi-year pattern: uniform current direction with depth in mode 1 and 2-layer flow in mode 2. Then they undergo a 90-degree orientation shift in the Fall, to a mode 1 pattern with a northeast facing axis instead of northwest. Again, this does not appear to be a recurring seasonal pattern.

Implications for the PLOO Wastefield

The two circulation modes comprising 85% of the current variability between 2006-2009 were oriented along NW-SE tilted axes at all depths. The dominant circulation pattern that the plume was exposed to would transport the plume towards the NW or the SE throughout the water column. These patterns are shown in Figures 6 and 7 where currents are oriented northwest and southeast throughout the water column respectively.

Mode 1 currents oriented towards the northwest typically persisted for periods of two to ten days while currents oriented towards the southeast persisted for periods of one to five days. These results indicate that the PLOO plume is transported towards the northwest most of the time. There are also periods that appear to be transitional between mode 1 northwestern and southeastern currents in which the currents are in near opposition between the two halves of the water column (Figure 8). This circulation pattern is much less frequent than mode 1 and the strong shearing between layers increases the dilution rate of the plume in the far field.

Together, current and temperature observations indicate that the PLOO wastefield is trapped deeper than kelp forests depths at least 94% of the time and that the plume is transported towards the northwest most frequently with less frequent excursions towards the southeast. There appear to be infrequent periods when the plume may be advected shoreward north of Pt. Loma but the plume is likely trapped well below the surface during these periods. Future work described below will investigate this possibility.

Future Work

The next steps of the PLOO mapping project will be to develop the near-field mixing model, which will enable the estimation of plume trapping depth and dilution in the zone of initial dilution. These results will then be coupled with a regional circulation model to estimate the footprint of dilution and plume visitation in the San Diego shelf region. These model results will then be validated using a remotely operated vehicle equipped with sensors capable of detecting the plume as well as the density structure off the Pt. Loma shelf to gauge the skill of the models and facilitate their improvement.

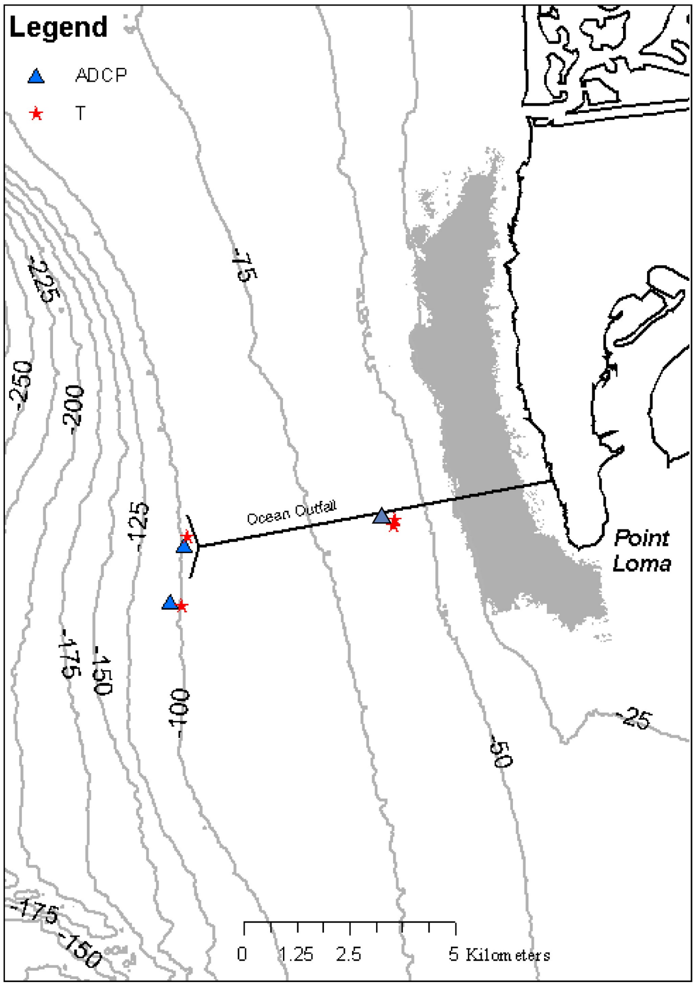

Figure 1. Map of Pt. Loma Ocean Outfall showing locations of hydrographic instrumentation. Blue triangles indicate bottom mounted current meters and red stars indicate location of thermistor moorings.

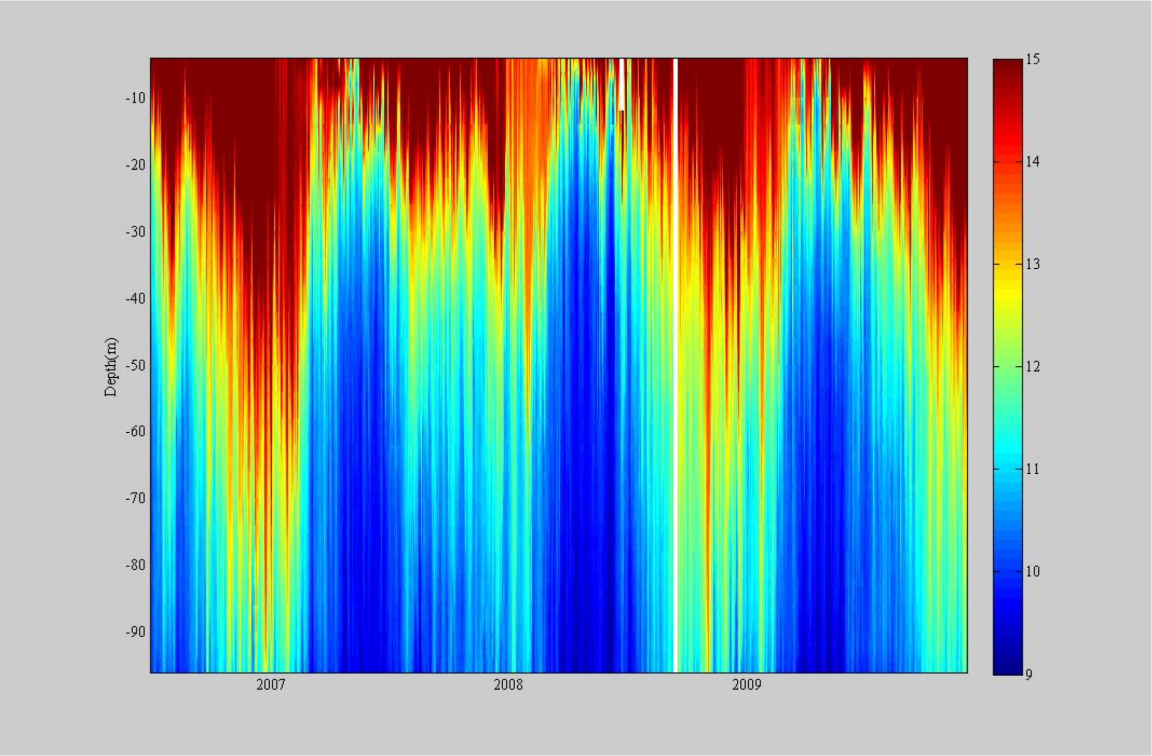

Figure 2. Temperature structure of water column at the PLOO from summer of 2006 to the end of 2009. Color indicates temperatures in degrees Celsius shown on colorbar at right.

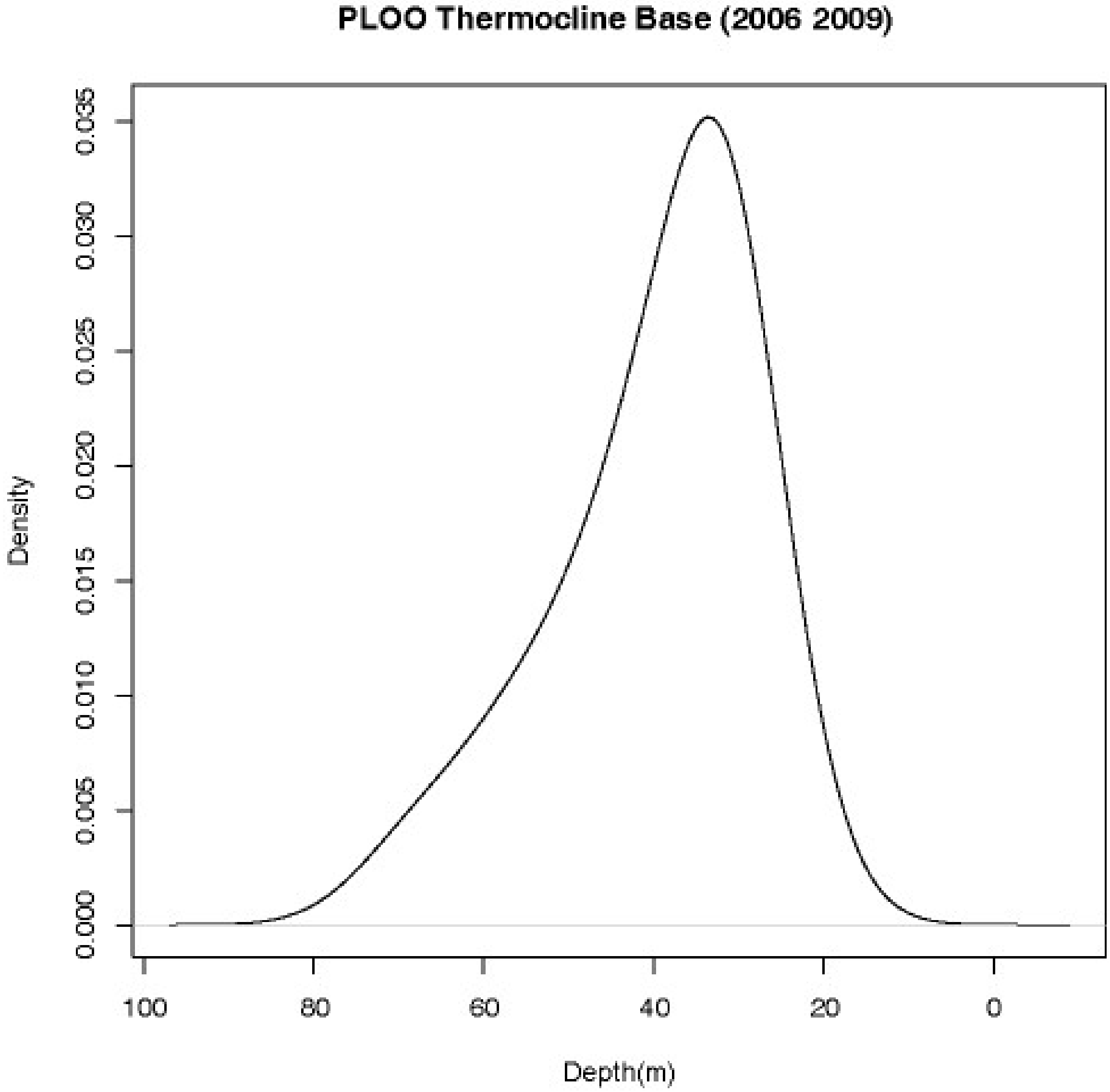

Figure 3. Distribution of the thermocline depth over the course of the observation period.

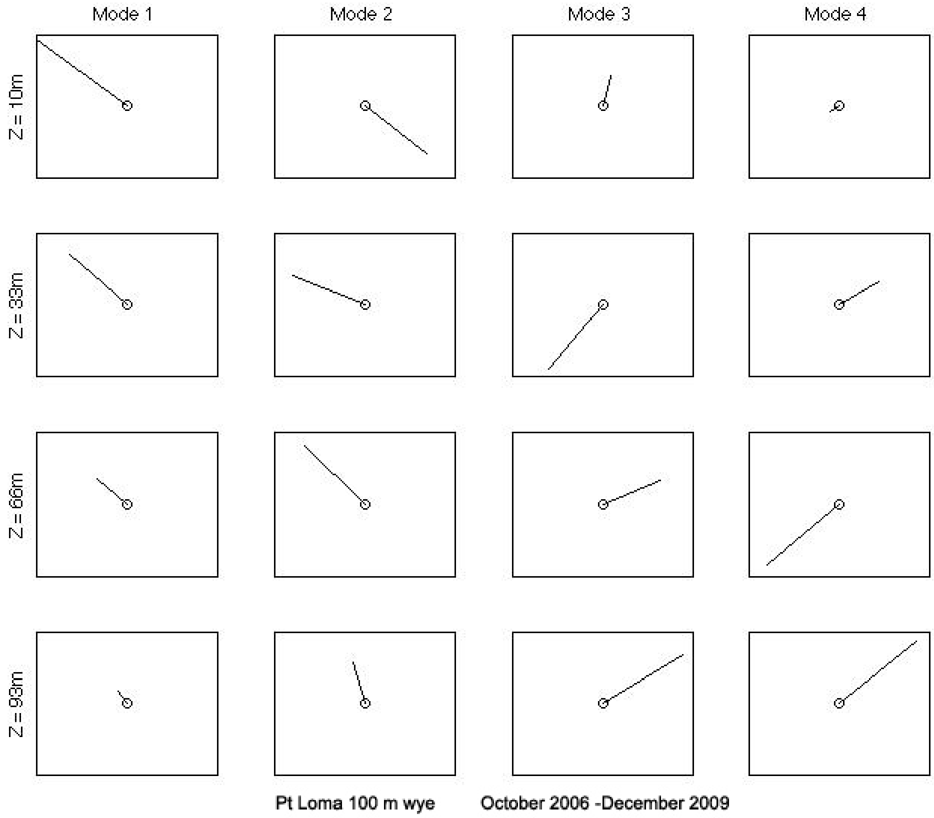

Figure 4. Major circulation modes for the Pt. Loma 100 m wye site, October 2006-December 2009, at depths of 10 m, 33 m, 66 m and 93 m below the surface. Vectors are oriented on a N-S grid and show the major axis of motion, not the dominant direction.

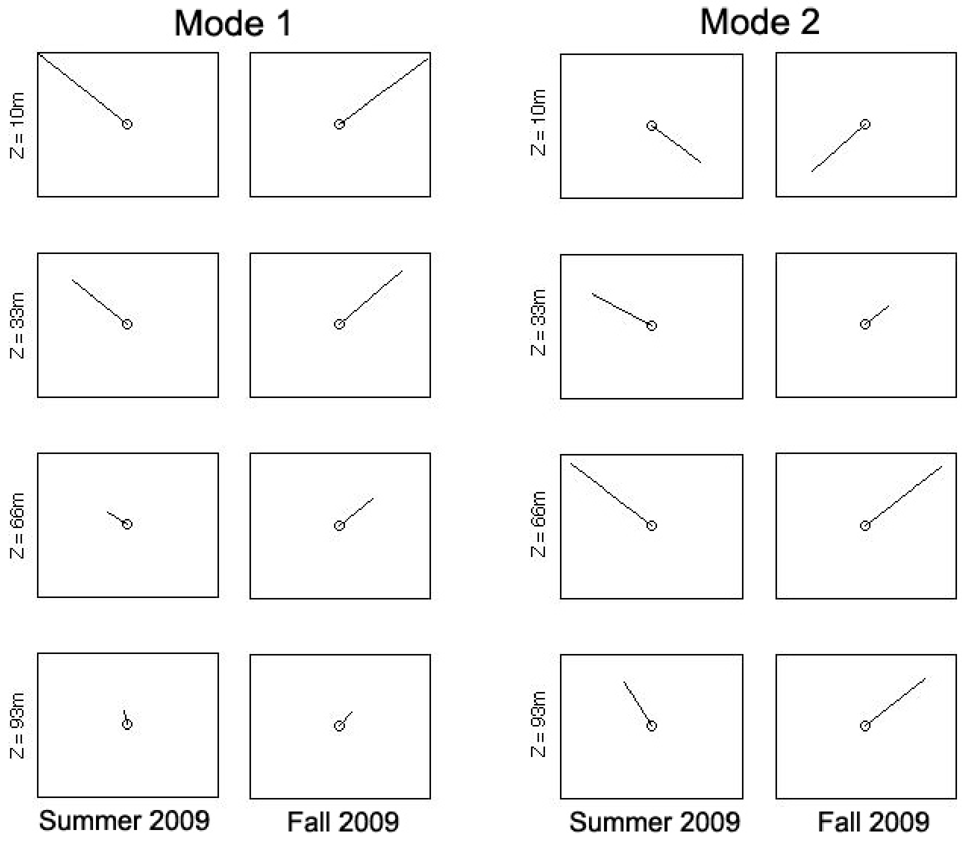

Figure 5. Major modes of circulation at Pt Loma 100m wye. Shown are modes 1 and 2, for summer and fall of 2009. Vectors are oriented on a N-S grid and show the major axis of motion, not the dominant direction.

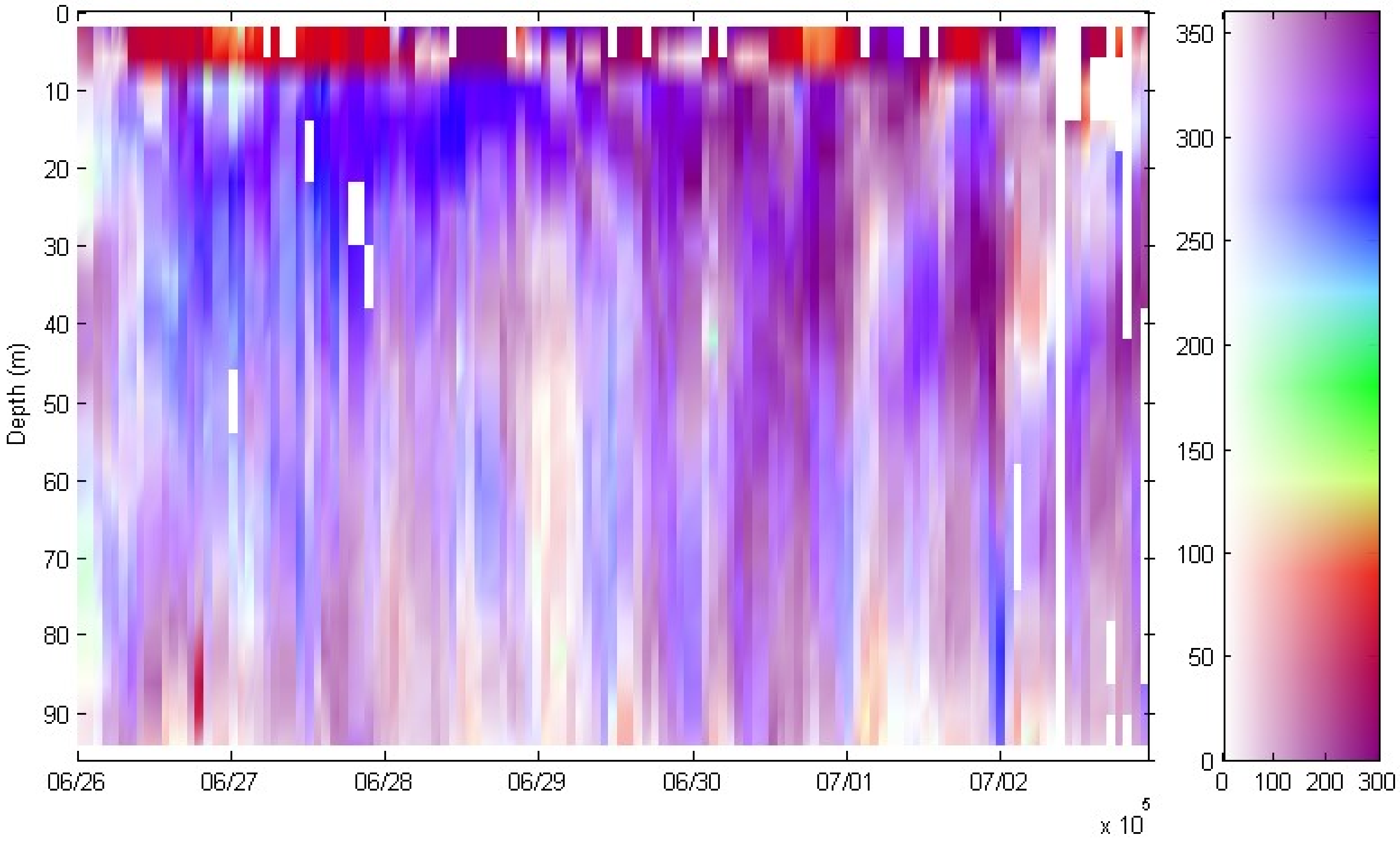

Figure 6. Most common circulation pattern of mode 1 currents in which currents at the outfall are oriented to the north and northwest throughout the water column. This observation period is for currents the last week of June and first week of July 2007. Color indicates compass direction that currents are going towards and shading strength indicates current speeds indicated on the colorbar at right. Velocity units are millimeters per second - for reference a one-knot current is 500 mm/sec.

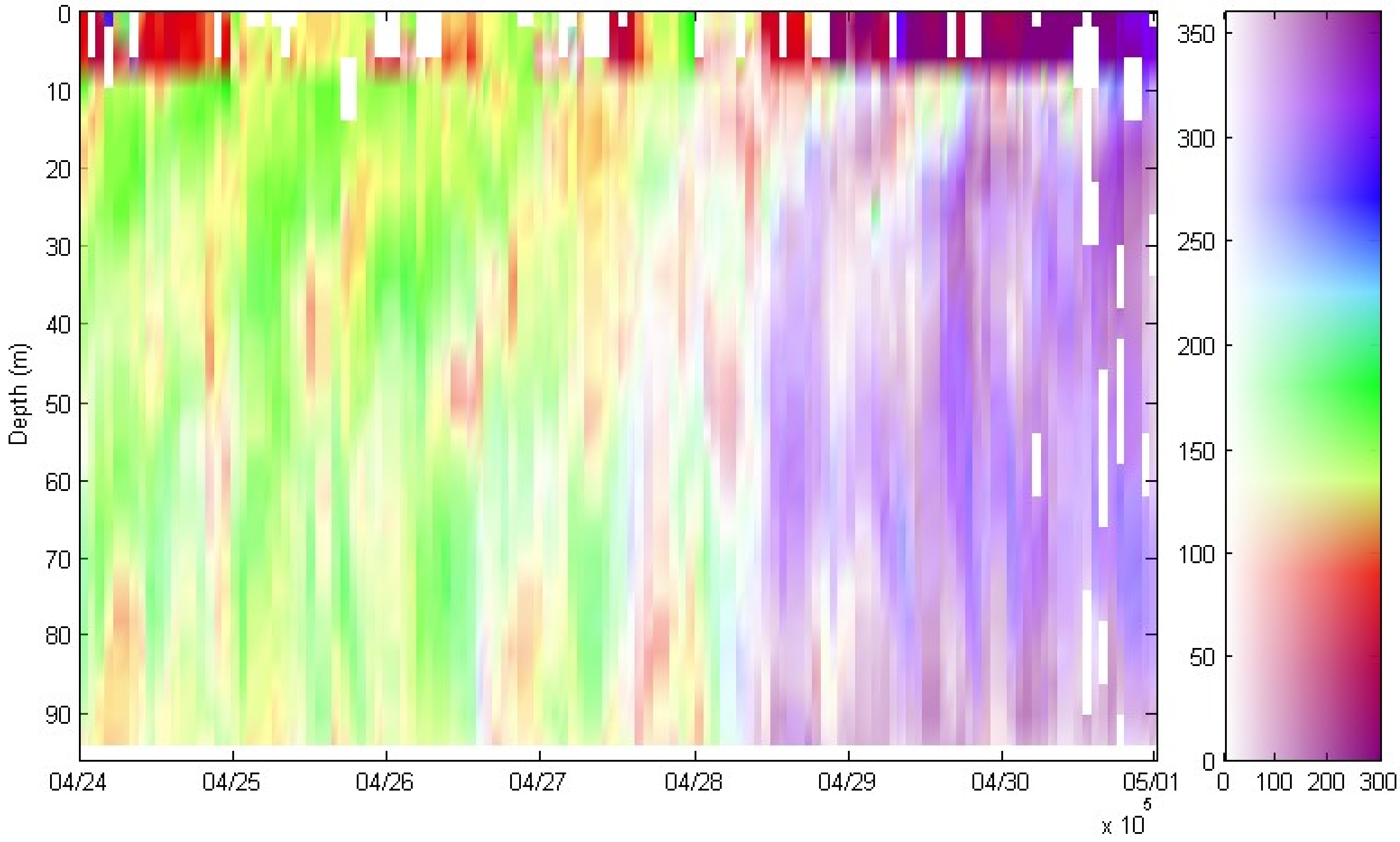

Figure 7. Less common circulation pattern of mode 1 currents in which currents at the outfall are oriented to the south and southeast throughout the water column. Currents returned to the more common northwest direction on April 28. This observation period is for currents during the last week of April 2007. Color indicates compass direction that currents are going towards and shading strength indicates current speeds indicated on the colorbar at right. Velocity units are millimeters per second - for reference a one-knot current is 500 mm/sec.

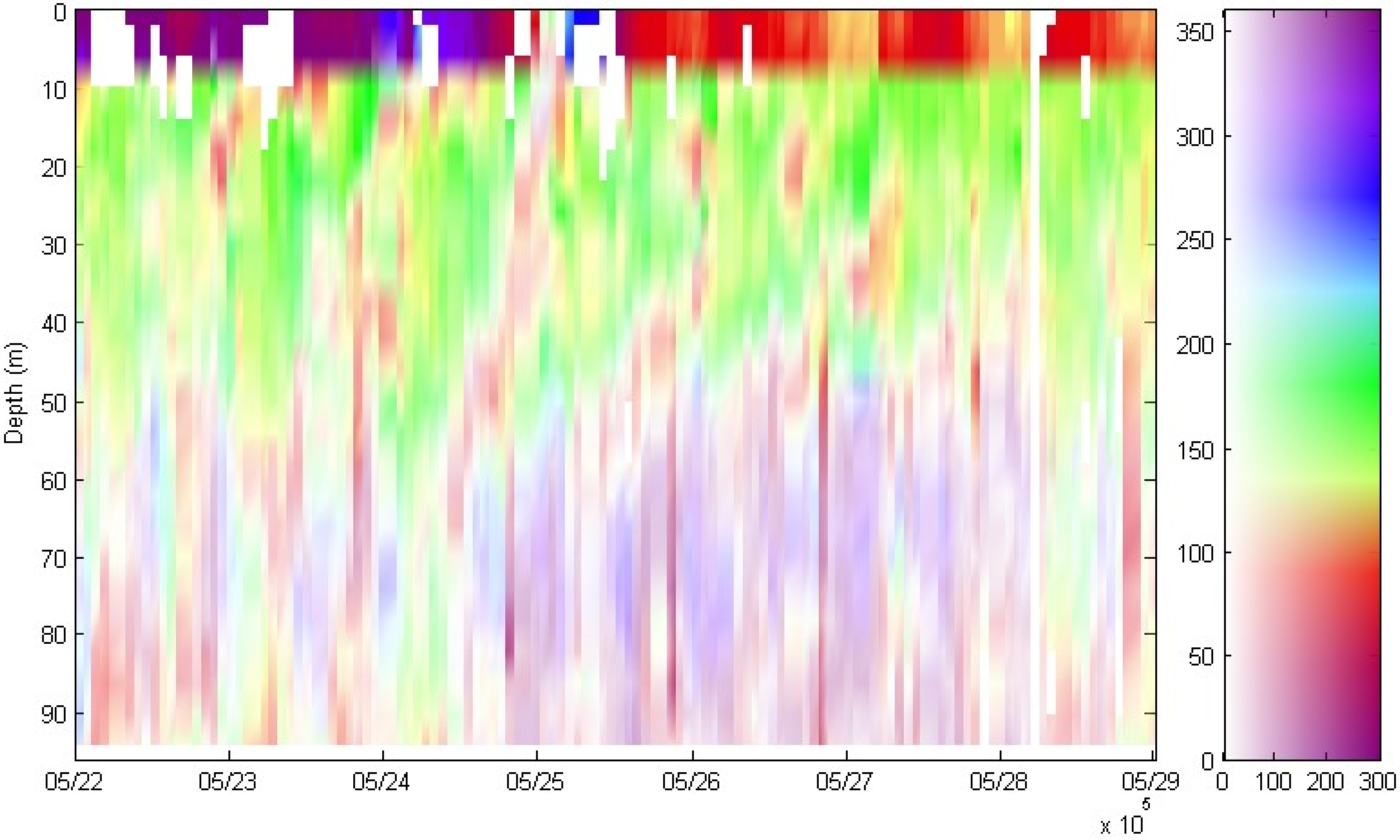

Figure 8. Typical mode 2 current pattern in which currents at the outfall are vertically sheared (2 layer structure) with currents in near opposition between lower and upper portions of the water column. Currents returned to the more common northwest direction on April 28. This observation period is for currents during the last week of May 2007. Color indicates compass direction that currents are going towards and shading strength indicates current speeds indicated on the colorbar at right. Velocity units are millimeters per second - for reference a one-knot current is 500 mm/sec.