I. INTORDUCTION

A. California Current System

The California current is the eastern boundary current that lies to the west of North America. The California current flows from north, Washington, to south, to the Baja Peninsula and it turns to west from North Equatorial current. The current has the strongest velocities at the sea surface and extends down through the 500 m of the water column with a mean speed of 10 cm/s. The waters coming from the higher altitudes make the California current cool and fresh. However, near the coast the waters are relatively warm and salty due to the California Undercurrent which flows to opposite (poleward) direction of the California Current. The California Undercurrent flows poleward over the continental slope from Baja California to at least Vancouver Island. The undercurrent is strongest at depths of 100-300m from the surface. northwesterly summer winds creates upwelling and brings the colder, saltier water to the surface. southwesterly winds creates downwelling and force California Undercurrent to rise to the surface and create the Davidson Current. The Davidson Current is a poleward, seasonal and surface current. In figure 1 the general view of currents in the North Pacific Gyre is shown.

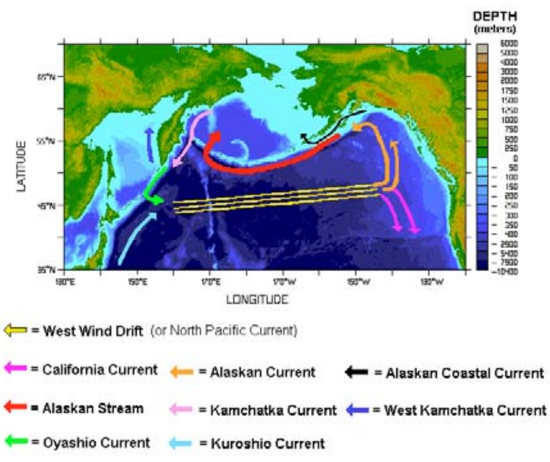


Figure 1

B. Purpose

The main purpose of this project is to calculate the volume transport into or out of the box which is shown in figure 2

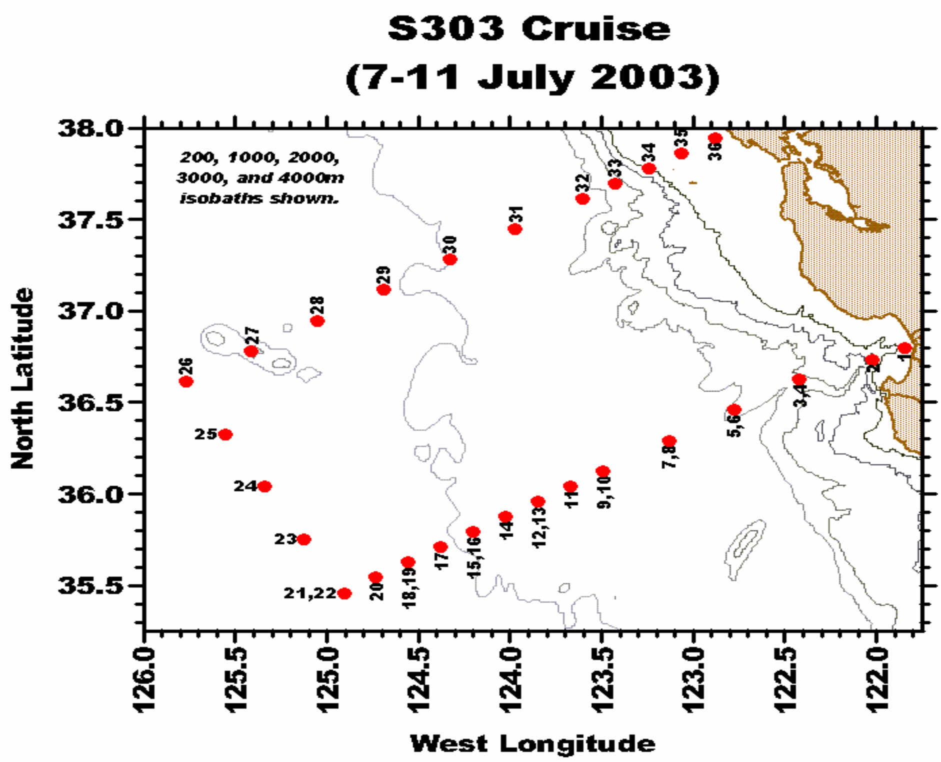


Figure 2

The Volume transport will be analyzed line by line by using geostrophic techniques. The lines between stations 1 and 20, 21 and 26, 26 and 36 are considered as LINE 1, LINE 2 and LINE 3 respectively. Hydrographic features and water masses through the box will be examined and conclusions will be made and discussed according to the analysis.

II. DATA COLLECTION

A. S303 Research Cruise

S303 Cruise was held between latitudes and longitudes shown in figure 2 by research ship R/V Western Flyer in 7-11 July 2003. The R/V Western Flyer is a small water-plane area twin hull (SWATH) oceanographic research vessel measuring 35.66

meters long and 16.15 meters wide. It was designed and constructed for the Monterey Bay Aquarium Research Institute (MBARI) to serve the oceanographic community as a stable platform for deploying, operating, and recovering a tethered remotely operated vehicle (ROV) to a depth of 4,000 meters, conducting hydro-casts (CTD), and other oceanographic activities with state-of-the-art equipment. General ROV operations are, however, the vessel's primary mission.

CTD data was collected at stations to a pressure level of 1000 dbar for offshore stations and to maximum water depth level for onshore stations except stations 3,5,7,9,12,15,18,21, at these stations CTD data was collected to pressure level 200 dbar. The interval between two pressure level is 2 dbar at each station.

B. Equipment

The data used in the analysis was collected by the Current ,Temperature Density equipment and in this equipment is known as CTD in the oceanography glossary.

III. DATA MANIPULATION

A. Geostrophic Method

Most of the information on the subsurface currents are observed by this method. Geostrophic method assumes that there is no friction , steady-state condition and these assumptions result a balance between coriolis force and the pressure gradient force. Geostrophic equation is:

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = v2\Omega\sin\phi = fv$$

Where v is the speed of flow (geostrophic velocity), Ω is the angular speed of rotation of the earth, ϕ is the geographic latitude, ρ is the water density, $\frac{\partial p}{\partial x}$ is the horizontal pressure gradient, f is the coriolis parameter. Total current is the summation of the barotropic flow and the baroclinic flow in the ocean. Geostrophic method gives only the baroclinic component of the total flow, tough geostrophic flow does not represent the actual flow in the ocean. Geostrophic method only gives us relative currents, i.e., the current at one level relative to that another. To convert these relative currents into absolute currents , an absolute current must be determined at some pressure level and usually it is assumed that absolute current is zero at that pressure level called “ depth/level of no motion” or “ reference level “.

B. METHOD

Geostrophic method was used to calculate the geostrophic currents between the stations. First, goepotential anomalies were calculated at each station then geostrophic velocities between the adjacent stations calculated by using the goepotentioal anomalies. The start point of calculations is Moss Landing and the end point of the calculations is Drake’s Bay. The relationship between the geopotential anomalies and the geostrophic velocities is given by the equations below.

$$V_g = V_1 - V_2$$

$$V_1 - V_2 = \frac{\sum(\delta_B x \Delta p) - \sum(\delta_A x \Delta p)}{fL}$$

$$V_1 - V_2 = \frac{\Delta\Phi_B - \Delta\Phi_A}{fL}$$

At least two stations are needed to calculate V_g (geostrophic velocity), A and B represents stations in the equations above. δ is the specific volume, Φ is the geopotantial anomaly, L is the horizontal distance between stations A and B. V_1 is the velocity at a depth and the V_2 is the velocity at the level of no motion. In this project , geostrophic velocities calculated relative to 1000 dbar for offshore stations and relative to maximum depth for onshore stations.

Volume transport was calculated by using geostrophic velocities. The equation for calculating the volume transport is:

$$T_y = \frac{\Phi_B - \Phi_A}{10^4 f}$$

Where T_y is the volume transport but by using MATLAB functions, volume transport can be calculated by integrating the $V_g dxdz$ vertically and horizontally ($\iint V_g dxdz$). The geostrophic velocities and Volume transport were calculated for each line by using MATLAB codes and the Seawater routines, a library of MATLAB computational routines for the properties of seawater. Then the total Volume transport was calculated for the whole box by adding up the results for each line.

IV. ANALYSIS

A. Hydrographic Features

1. Temperature and Salinity Profile of the whole box.

The temperature profile along three lines was plotted in MATLAB. Figure 3 shows the temperature profile for whole box. Temperature, particularly at relatively shallow depths, is one of the most important seawater feature. Salinity and temperature profilers can give very useful information of the water masses.

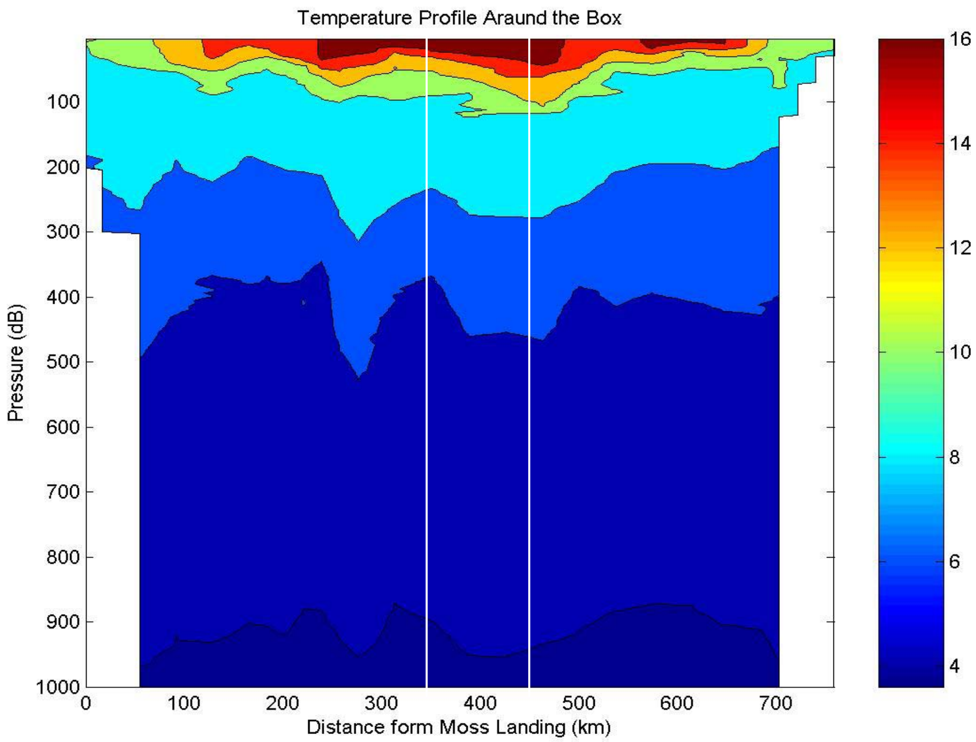


Figure 3: Temperature Profile Around the box

The white lines shows the offshore corners of the box. The horizontal distance is the cumulative distance between the stations from Moss Landing to Drake's Bay. As shown in figure 3 the shallow surface water is relatively cooler than the deep water (upper right and the upper left of figure 3). As explained in part I-A, the northwesterly summer winds cause upwelling near the shore and bringing cooler and saltier water surface. It can be also seen in figure 4 the onshore surface water is relatively saltier than the offshore surface waters. It can be also discerned that California Current (flows form north to south) makes the offshore surface water fresher than onshore surface water.

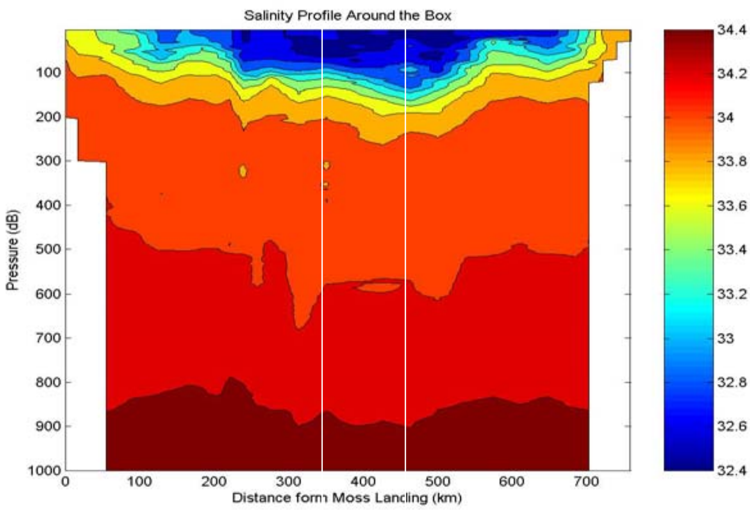


Figure 4: Salinity Profile Around the box

Generally warmer water is less than the colder water, according to this idea, some information about the motion trough the box can be seen in the temperature profile in figure 3. Sea surface temperature getting warmer to offshore which means that more dense water is onshore near the sea surface. For line 1 (distance between 0 and 360 km) the surface flow will be from onshore to offshore and after effect of coriolis force it will turn right (northward) which means into the box also same thing for line 3, the surface flow will be from onshore to offshore then it will turn to right by the affect of coriolis (northward) which means out of the box. (Note: Coriolis force in the northern hemisphere is always tend to change the flow direction to right.).

T&S diagrams gives very good idea to understand the type of water masses in an oceanographic station. Figure 5 shows the T&S diagram for all casts through the box.

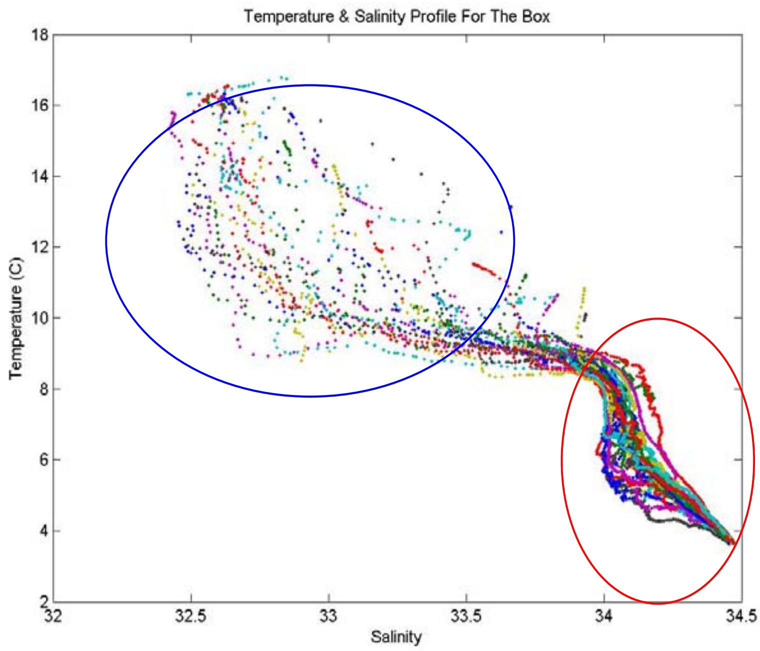


Figure 5: T&S Diagram Around the box

For deep water it can be seen (red circle in figure 5) that there is a mixing of two different water masses. There is a water mass warmer and saltier at the upper right side of the red circle which is coming from the equatorial currents and there is another water mass colder and fresher which is coming from the arctic currents. These two different water mass are strongly mixing in the red circle. The gradient of water masses is smoothly changing in the red circle. For the upper side of the box there are different types of water masses occur and this area is indicated with blue circle and there is very weak mixing in this area.

2. Spiceness for whole box

Spiceness is another way to look at the water masses in an oceanographic area. If the density lines plotted in the T&S diagram , the spiceness lines would be perpendicular the density lines and it can be discerned the gradient of water masses in each depth. The spiceness was calculated by the MATLAB program created by Prof. Collins Curtis and plotted for the whole box. Figure 6 shows the spiceness at each depth and at each station. For deep water (below 400 dbar), notice the air masses are changing with a smooth gradient and for shallow water (above 100 dbar), the water masses are changing with strong gradient.

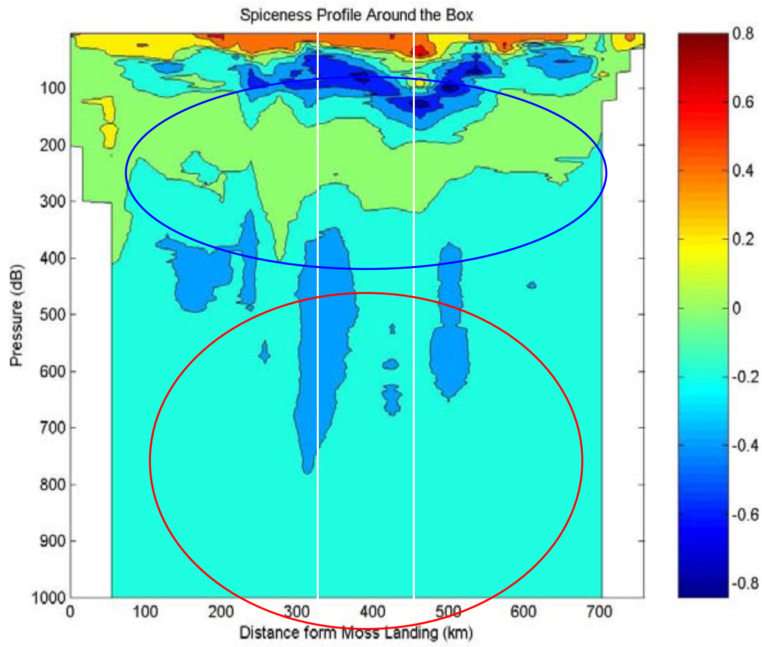


Figure 7: Spciness Around the box

3. Density Profile

Density Profile gives a very nice picture to figure out the motions in the ocean. Figure 8 shows the density profile for each station at each depth.

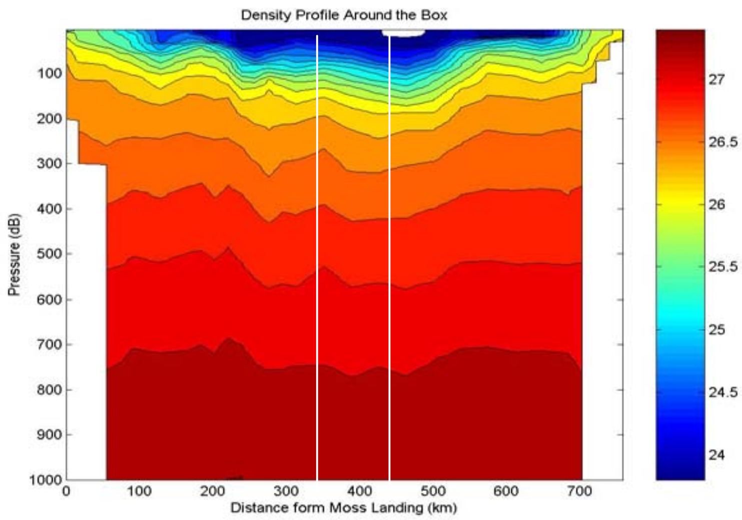


Figure 8: Density Profile Around the box

As explained in temperature and salinity profile, it can be seen upper level (above 150 dbar level) strong flows which is into the box in the left side of figure 8 and out of the box on the right side of the box .At the 250th km of the line 1 there is a strong density gradient which creates strong flow into the box and there is an outflow from the box at the and of the line 1below 200 dbar.

B. GEOSTROPHIC VELOCITIES AND VOLUME TRANSPORT

The goeostrophic velocities and the volume transport were calculated line by line by using the method described before.

LINE 1

The geostrophic velocities and the volume transport trough line 1 is shown in figure 9.a and figure 9.b respectively.

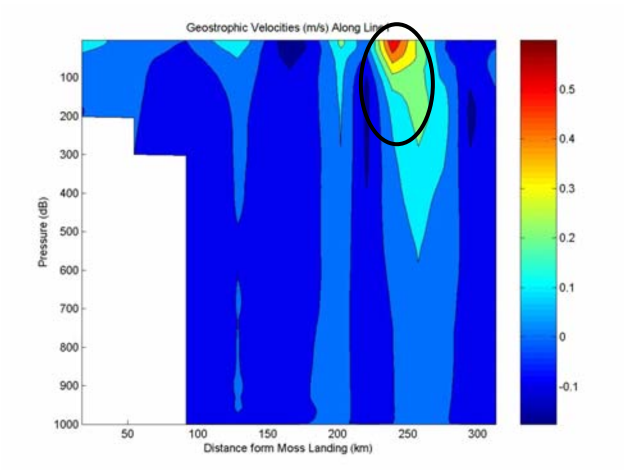


Figure 9.a: Geostrophic Velocities Along Line1

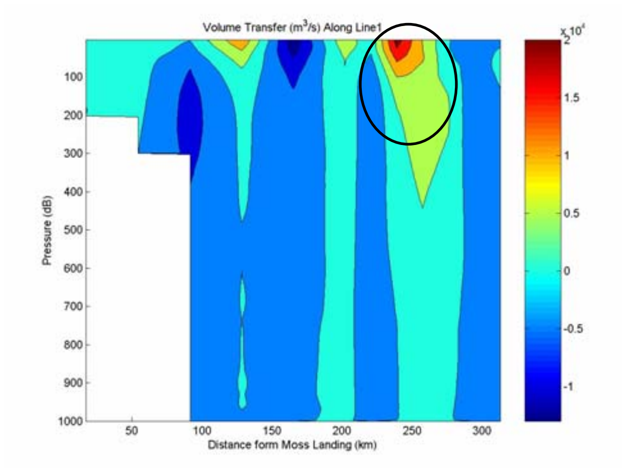


Figure 9.b: Volume transport Along Line1

From figure 9.a , strong positive geostrophic velocity at the distance of 250 km from Moss Landing can be discern and figure 9.b proves that there is volume transport into the box at the distance 250th. km. from Moss Landing. These two plots also verify the result that I concluded for the density profile. Generally we can see that there is an inward volume transport along Line 1. According to the results calculating by geostrophic method in MATLAB, total volume transport for line 1 is 1.5480 Sv.

LINE 2

The geostrophic velocities and the volume transport trough line 2 is shown in figure 10.a and figure 10.b. respectively. Line 2 is offshore line and all the geostrophic velocities are calculated relative to 1000 dbar through this line.

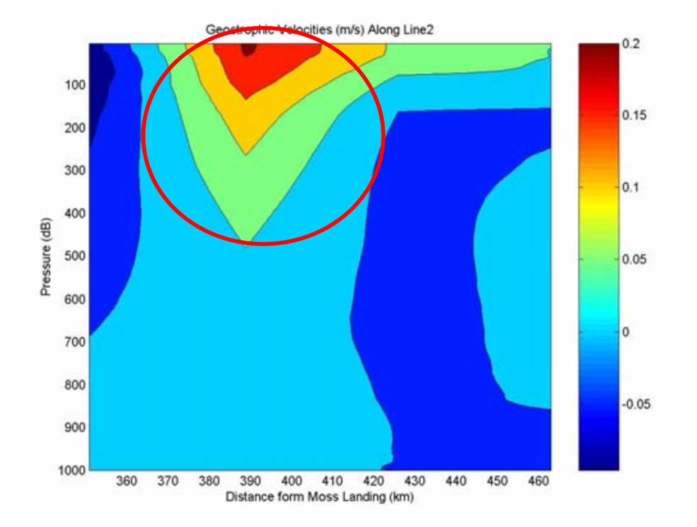


Figure 10.a : Geostrophic Velocities Along Line2

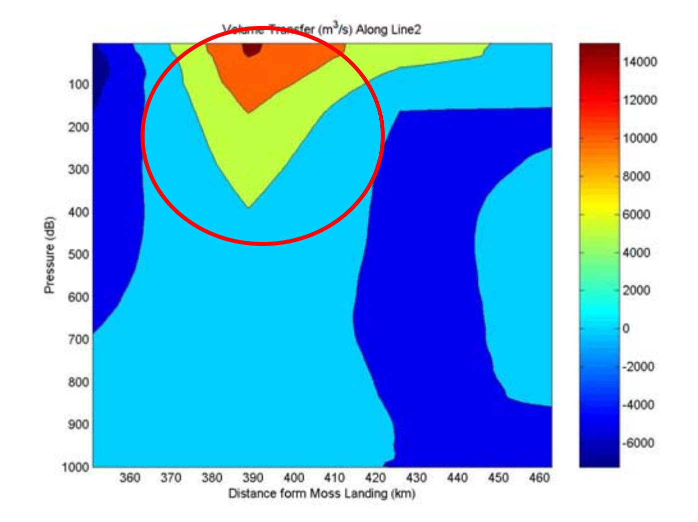


Figure 10.b : Volume Transport Along Line2

It can be seen the volume transfer into the box is stronger than the volume transfer out of the box while positive geostrophic velocities stronger than the negative geostrophic velocities. According to the results calculating by geostrophic method in MATLAB total volume transport for line 2 is 1.8391 Sv.

LINE 3

The geostrophic velocities and the volume transport trough line 3 is shown in figure 11.a and figure 11.b. respectively.

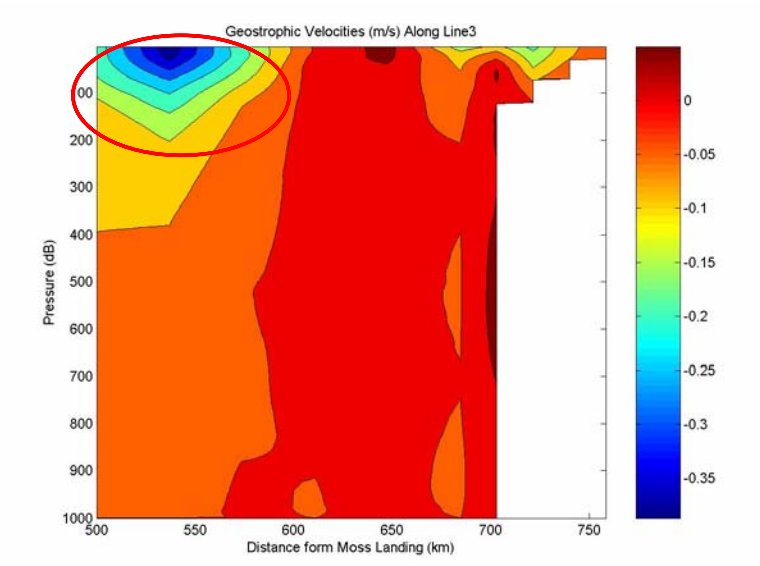


Figure 11.a : Geostrophic Velocities Along Line3

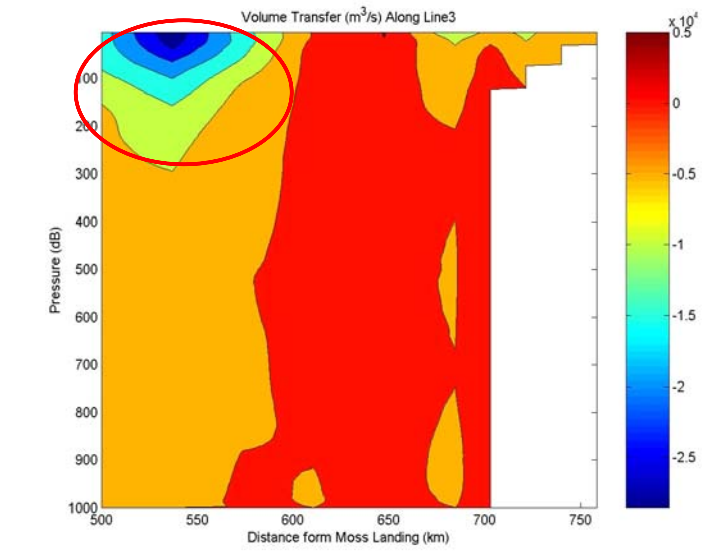


Figure 11.b : Volume Transport Along Line3

Strong negative geostrophic velocities are dominant especially in the circled area in figure 11.a, and negative volume transport out of the box is dominant in figure 11.b at the same place as in figure 11.a. Along line 3 outflow from the box is dominant which means loss of mass from the box and it verifies the comments that I made while analyzing the hydrographic features. According to the results calculating by geostrophic method in MATLAB, total volume transport for line 3 is –4.0185 Sv. Figure 12 shows total volume transport between the stations (from Moss Landing to Drake's Bay).

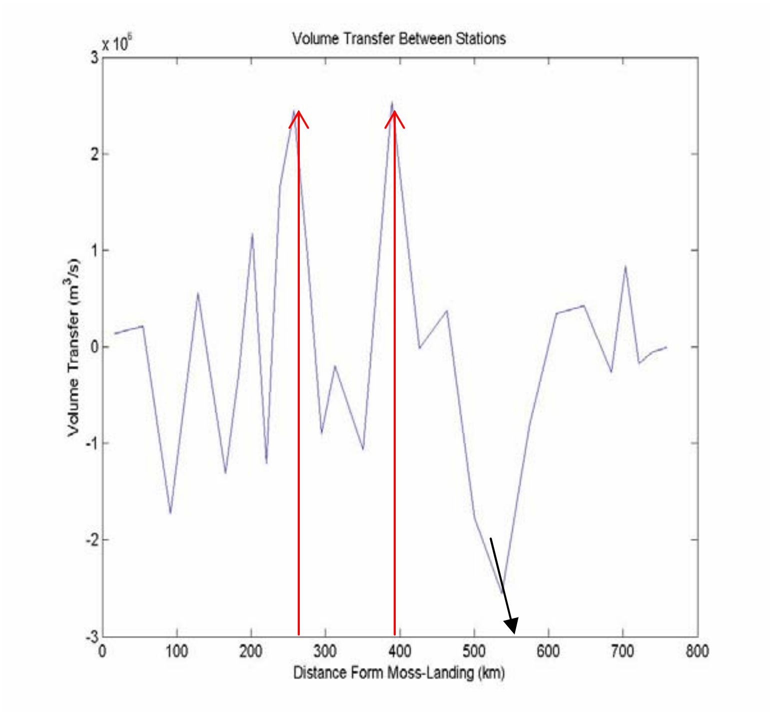
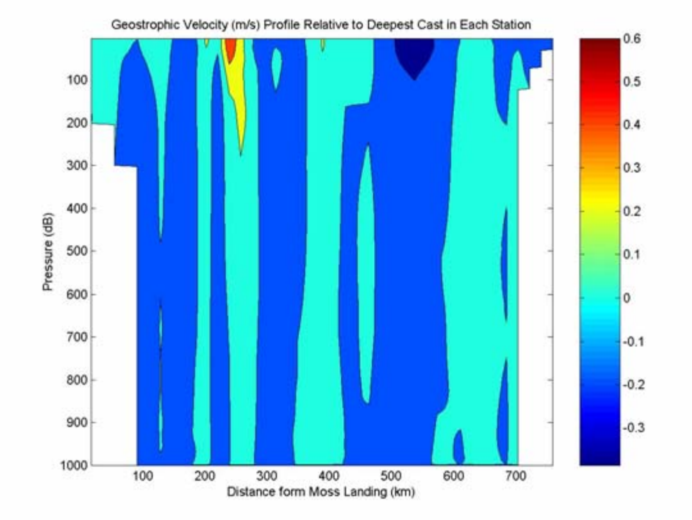


Figure 12: Total Volume Transport Between stations

In Figure 12, maximum total volume transport into the box can be seen at the distance of 250 km.(in line1) and 410 km (in line 2). The maximum volume transport out of the box is at the distance of 540 km (in line 3) and these results are matching with the results that were discerned from the contour plots.

Figure 13 a. and 13.b shows the total geostrophic velocities and the total volume transport at each depth and in each station respectively.



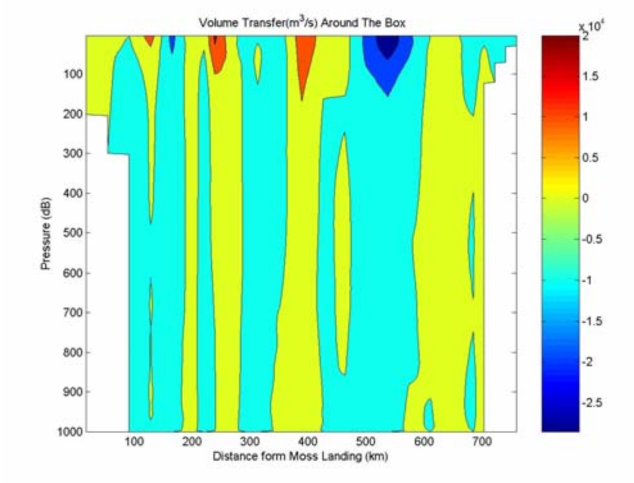


Figure 13.a: Geostrophic Velocities Around Box

Figure 13.b : Volume Transport Around Box

Total Volume transport around the box is almost zero, but the result from the geostrophic method which is calculated in the MATLAB environment is not zero. **The total volume transport around the box is –0.6314 Sv.** There is a volume loss for the box according to this result.

V. CONCLUSION

According to the conservation of mass the total volume transport in any box in the ocean should be zero, in other words the total inflow must balance the total outflow otherwise San Francisco will be flooded.

Total volume transport that is found in the analysis is – 0.6314 Sv. and this is not zero but very close to zero. During the analysis the wind stresses weren't taken into account. The wind stresses play very important role in volume transporting, Ekman divergences due to wind stresses is very important and should not be ignored especially for smaller boxes or micro scale calculations near the shore.

As mentioned before , the results of the analysis are based on the geostrophic method and during the analysis it is assumed that there is no motion at 1000 dbar . level for offshore stations and no motion at the maximum level of depth for onshore stations. This assumption might not be true because there is a motion at these level even if these motions too weak these may affect the results. Figure 14 shows the potential density anomaly distribution at 1000 dbar. versus stations.

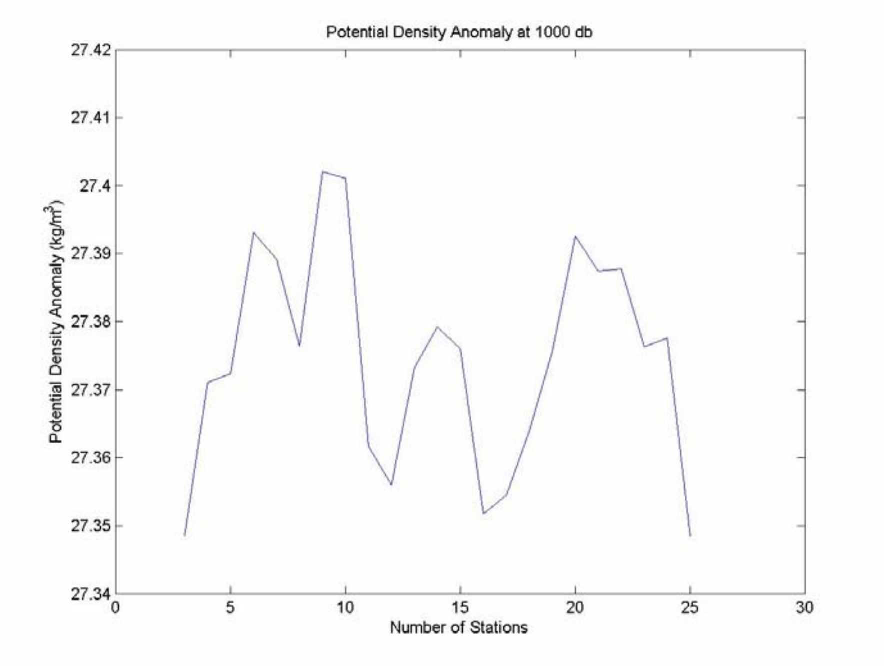


Figure 14: Potential Density Anomalies at 1000 db

In Figure 14 it can be discerned that there is very small density gradient between the stations at 1000 dbar. level and it shows us there is a small motion at that level which can create error in the analysis.

The measurements in the box were taken down to 1000 dbar. depth but in the box the actual depth is greater than 1000 dbar. as shown in figure 2. There could be flow into the box from the deeper levels than 1000 dbar. but this is not very likely.

The total volume transport for the box which is done by the student cruise in leg 1 is found approximately –6 Sv. by using the geostrophic method and this is a bigger value than S303 cruise box total volume transport –0.6 Sv . S303 cruise box is much bigger than the student cruise box. It can be concluded that the geostrophic method works better for larger scales and we have to be careful that when we are using the geostrophic method in analysis for smaller box and near the shore but it is not a rule of thumb because, other effects like strong undercurrent in the deep water may occur and these undercurrents create strong motion at reference level.

In the analysis, tidal effects was ignored. Tidal effects play very important role in the shallow water .

Finally , total volume transport found by the analysis can be acceptable with small errors. –0.6314 Sv. is assumed to be a very good result for geostrophic method. The geostrophic velocities calculated in this project can be compared with the ADCP velocities and the difference could give the differences between actual and relative flow.

VI. REFERENCES

1. CSIRO Marine Laboratories report 222,Sea Water , a Library of MATLAB Computational Routines for the Properties of sea water.

2. Data Analysis Methods in Physical Oceanography, Emery & Thomson

3. Descriptive Physical Oceanography, Pickard & Emery

4. Processing of Oceanographic Station Data by JPOTS Editorial Panel

5. Introductory Dynamical Oceanography, Pond & Pickar

6. Monterey Bay Aquarium Research Institute web site (www.mbari.org)

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CONSERVATION OF MASS ANALYSIS

MURAT ELGE

LTJG. TU,NAVY

09/18/2003