An Overview of the Internal Tidal Bore at the Head of the Submarine Canyon in Monterey Bay

OC 3570 Cruise 21-28 JUL 2003

Project by:

ENS Alicia A. Washkevich, USN

INTRODUCTION:

The Operational Oceanography and Meteorology (OC3570) course took several NPS students on a research cruise aboard the Pt. Sur research vessel. The cruise was broken into two separate legs from 21-14 JUL 2003 and 24-28 JUL2003. Starting in Monterey Bay the group traveled to San Luis Obispo during Leg 1, and in Leg 2 they sailed back up the coast returning to the bay. (Fig. 1)

PURPOSE:

This overview builds on the study of the internal tidal bore from 2-3 FEB 03 by LT Kristen Watts, RAN. A bore is an unsteady flow, often caused by tidal forcing and can be equated to a moving hydraulic jump.[1] Although internal tidal bores may not be visible to the naked eye, they are very real and exist in various regions. The tidal bore in Monterey Bay similarly follows the characteristics of surface tidal bores in a river. For a surface tidal bore to occur, the river banks must converge over a long distance. There must also be a gently rising river bed, thus causing a non-linear propagating wave.[2] Monterey Bay puts a twist the river's surface tidal bore. Due to the converging shape of the submarine canyon at the bottom of the bay and the gradual decrease in depth as one moves inland, the bay is an ideal place for and internal tidal bore to exist.

DATA USED:

During the second leg of the cruise data was collected from 2, 25-hour CTD time series. Each set includes readings from the 27 casts. The first series begins on 26JUL03 at 0302 while the second begins on 27JUL03 at 0459. The data includes temperature

and salinity measurements which may be profiled with depth. Shipboard Acoustic Doppler Current Profiler (ADCP) data was also gathered onboard the Pt Sur. The ADCP transmits at 150kHz and measures the velocity of water from the reflection off the suspended particles in the water column.[3] Finally, six minute mean sea levels were extracted from the NOAA/NOS CO-OPS website for the same date and time range.

MONTEREY BAY BATHYMETRY:

The bathymetry of Monterey Bay is clearly depicted in Figure 2. The submarine canyon generally runs East/West and funnels the water up the rising sea floor toward Moss landing. [4] Figure 2 also shows the locations where the two ADCP time series were collected and will be useful in referencing the U and V components of the velocity. The first series, PBOR1, was measured at 36.79833 degrees West and 121.81566 degrees North. Therefore the data was collected a very narrow portion of the submarine canyon closer to shore. PBOR2 began at 36.79266 degrees West and 121.84033 degrees North at a point farther out in the bay. The canyon is much deeper and wider at this point.

CTD DATA ANALYZED:

From the CTD data collected, plots of Temperature vs. Depth and Salinity vs. Depth were created for each of the two time series data sets. Figure 3 shows the Salinity from CTD Time Series 1. While Figure 4 shows the Temperature from CTD Time Series 1. On both plots it is clear to see the extension of "colder and fresher" water downward in the water column forming a trough. This is a notable trend when describing internal tidal bores[5]. The extension of lower temperatures coincides with the extension of lower

salinity. Both occur at about 207.7 and 208.1 yeardays. One might also note that the 2 trend lines added to the profile have a slightly negative slope. This shows a minor phase lag at each trough. The lower temperatures and salinities dip at the surface of the water column first, then a few hours later the characteristic trough moves to greater depths. However, the "crest" that appears between the two troughs in Figs. 3 and 4 is more linear in alignment. This inconsistency concludes that the internal wave is non-linear.[3]

Yet another notable feature on these graphs is the area of increased salinity and inverted temperature. The salinity here has a magnitude of 34.06 while the temperature is 8 degrees Celsius (one degree warmer than the surrounding temperature). A standard Temperature vs. Salinity graph of the data is included in Fig. 3 to help account for this feature. The T-S diagram shows that the data is real, there are only 2 outliers on the plot, however they do not coincide with the dense water. There is a strong up-canyon flow at this point, therefore there is a possibility that less dense water exists underneath. A further study of the phenomenon would be needed for better understanding.

Figures 5 and 6 show salinity and temperature for the second CTD time series, respectively. As noted in the analysis of Figures 3 and 4 there is a decrease in temperature and salinity throughout the water column noting the presence of an internal bore. At 208.5 and 209.1 the changes are clearly visible. However, in these two figures the trend lines have a greater slope. The trend line on the temperature plot appears to be almost vertical. Still, it is important to remember that the data was collected at different locations within the submarine canyon. Therefore, the linearality of the wave may change slightly across the canyon.

ADCP DATA ANALYSED:

Figure 7 clearly shows the East / West Velocity as measured by the first set of ACDP data. The plot is oriented with a positive East direction. The plot also appears to have a good East / West alignment. The water is clearly depicted moving first toward Moss Landing, then back out toward the Pacific. The oscillation of water flowing in and out is clearly shown on the graph. The submarine canyon acts as a funnel or chute. Therefore some bottom intensification is expected as the submarine canyon will tunnel the deeper water in and out. This intensification, though relatively small, is noted in Figure 7. Figure 8 portrays the North/South Velocity from the "v" component of the ADCP data. One will generally expect a great deal of movement "in and out" (East and West), with very little "up and down" motion. The submarine canyon forms a barrier, therefore the water is restricted in it's ability to maneuver.

Figures 9 and 10 are slightly more complicated. The ADCP is not perfectly aligned East / West; it is slightly oblique to the canyon. Thus is it necessary to try and overlay the two graphs to truly understand the process taking place. Still, both appear to be an exception to the general rule. One would expect some kind of Northeast / Southwest motion. However, these plots clearly show a Northwest / Southeast movement. What may appear as a small rotation in the upper left corner when comparing both graphs may be rationalized when noting the placement of the canyon walls. The southern wall of the submarine canyon is deeper. Therefore, as the water is directed toward Moss Landing it may "spill" over the lip of the southern wall. Thus, the "undisciplined" movement closer to the surface of the column in both the North and South direction could possibly be random "sloshing" of water in both directions. There is

no canyon wall to inhibit such a process in this region. The increased velocity at the surface of the profiles is mostly like caused by the misalignment of the shipboard ADCP with the East/West direction of the submarine canyon. One may note the bottom intensification in Figure 7 also coincides with the unique phenomenon displayed in Figures 3 and 4. There is a particular water mass located at the bottom of the crest that has dennse water moving at a slightly higher velocity.

MEAN SEA LEVEL PLOTS:

Figures 11, 12, and 13 display U and V vectors at various depths compared with the 6 minute Mean Sea Level data from the NOAA website. Therefore one may see how velocity is related to pressure (mean sea level) and deduce whether the internal bore is a progressive or standing wave. Mean Sea Level data was taken from the NOAA/ CO-OPS website for the Monterey Station : 9413450, and U and V vectors were taken from depths of 71, 87, and 103 meters. In each of the graphs the plots appear to be slightly out of phase, however they both have have the same general trend and oscillation. Therefore the internal bore is passing as a progressive wave. The velocities have a greater intensity at the peaks. Specifically, Figure 11 shows that with increasing depth there is an increased velocity at each peak (the most extreme being 103 m depicted in black). Typically, the deeper water is affected greatly by the walls of the canyon since the water is completely constrained within these barriers.

CONCLUSIONS:

Pineda's discussion "Issues in larval transport by internal tidal bores," states that the passing of an internal bore should result in a strong upslope surge and the pumping of cooler, more saline waters.[6] The aforementioned figures clearly show such trends at

approximately the same day and time. Colder water extends down with a greater saline content at approximately the same time the water is traveling eastward up the canyon toward Moss Landing. Therefore, the previous statement is justified and internal tidal bores exists as marked on Figures 3-6 in the form of a progressive wave.

RECOMMENDATIONS:

This report does show the existence of internal wave and internal tidal bores during the time in which the data was collected. However, this report is merely and overview of the data. One suggestion is to complete and in-depth comparison of the data taken over this summer cruise to that of the data from the 2-3 FEB 03 winter cruise. Also, taking a closer look at the area of high salinity at the bottom of the crest in Figures 3 and 4 may provide some interesting research.

---

[1] G.F. Lane-Serff, D.R. Munday and M.D. Woodward, 'Laboratory experiments of internal bores in non-rotating and rotating exchange flows over sills,' The 2nd Meeting on the Physical Oceanography of Sea Straits, Villefranche,2002.
[2] Linden Software-Tidal Bores: www.linden-software.com/tidal1.html
[3]Watts, K. 'The Internal Tidal Bore at the Head of the Monterey Submarine Canyon: 2/3 February 2003', OC3570 project, Naval Postgraduate School, Monterey, CA, 2003.
[4] www.rdinstrument.com/tips.html

[5] J. Leichter, 'Input of nutrients to reefs in Florida Keys by upwelling,' Wood Hole Oceanographic Institution. www.uncwil.edu/nurc/aquarios/2000/6_2000/expd.htm
[6] J. Pineda. "Issues in larval transport by internal todal bores,' Wood Hole Oceanographic Institution, www.whoi.edu/science/AOPE/people/tduda/isww/text/pineda/pineda.htm

Figure 1

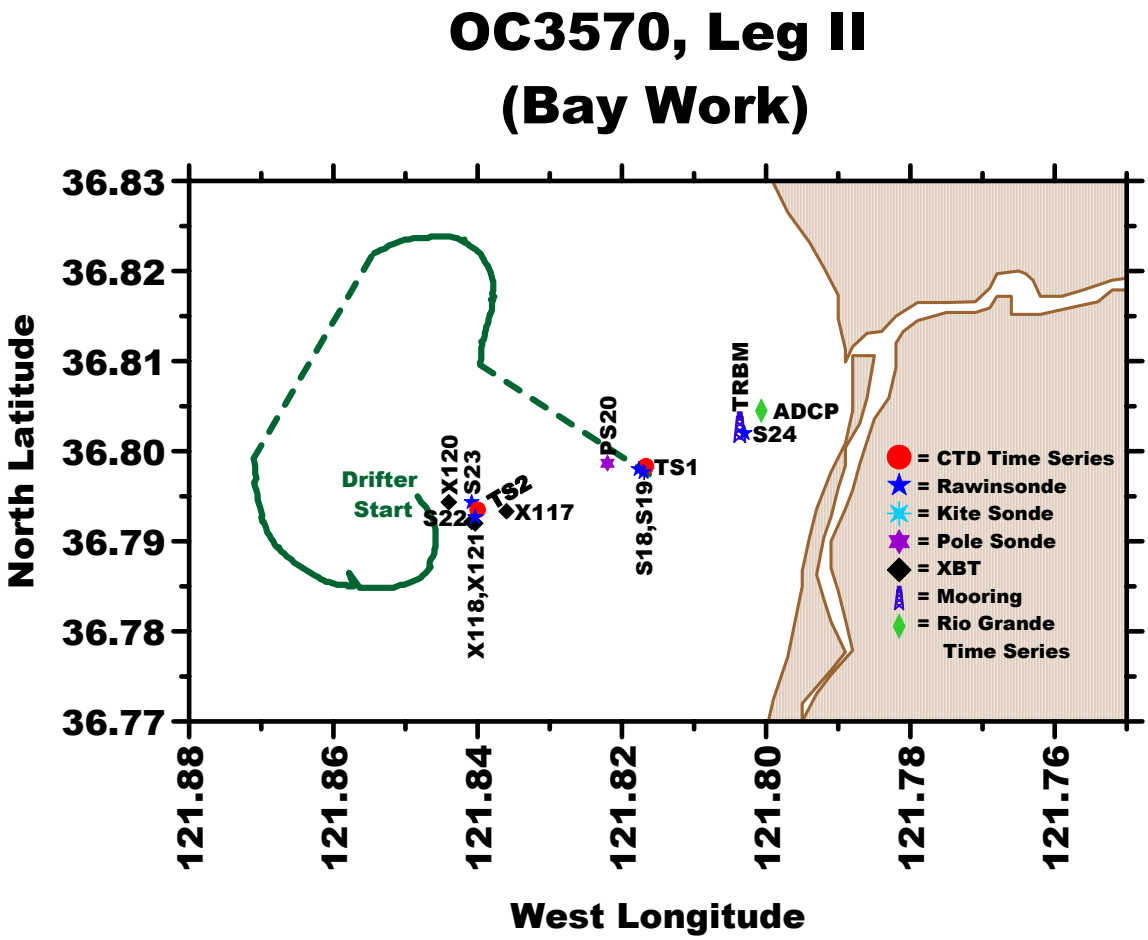

OC3570, Leg II
(Bay Work)
North Latitude
West Longitude
36.83
36.82
36.81
36.80
36.79
36.78
36.77
121.88
121.86
121.84
121.82
121.80
121.78
121.76
Drifter
Start
X120
S23
S22
TS2
X117
X118,X121
PS20
TS1
S18,S19
TRBM
ADCP
S24
= CTD Time Series
= Rawinsonde
= Kite Sonde
= Pole Sonde
= XBT
= Mooring
= Rio Grande
Time Series

Figure 2

Monterey Bay Bathymetry

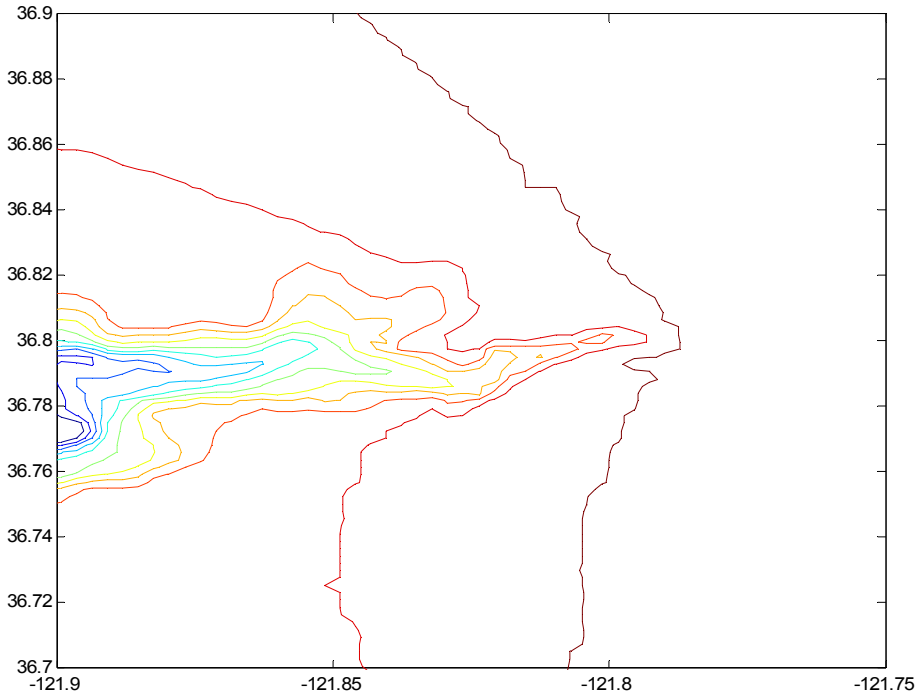


Figure 3:

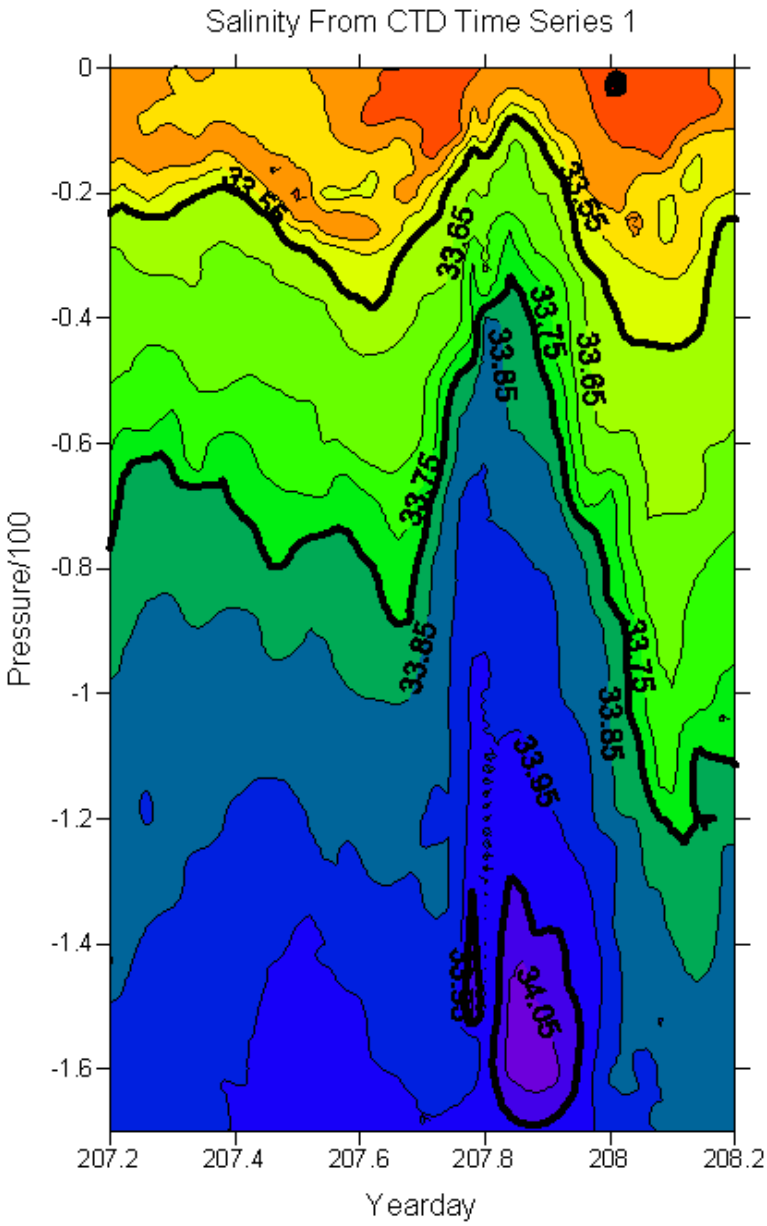

Salinity From CTD Time Series 1
Pressure/100
Yearday
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
207.2
207.4
207.6
207.8
208
208.2
33.55
33.65
33.75
33.85
33.95
34.05

Figure 4:
Temperature from CTD Time Series 1
X=Yearday
Y=Pressure/100

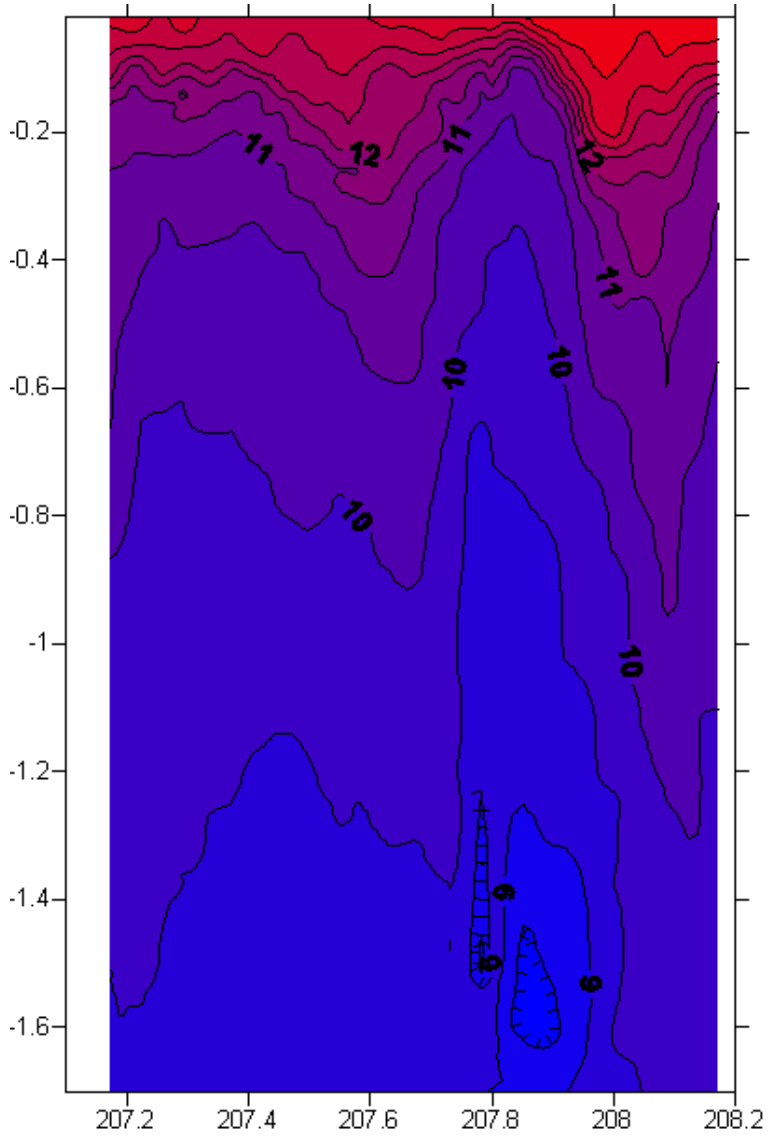


Figure 5:
Salinity from CTD Time Series 2
X=Yearday
Y=Pressure/100

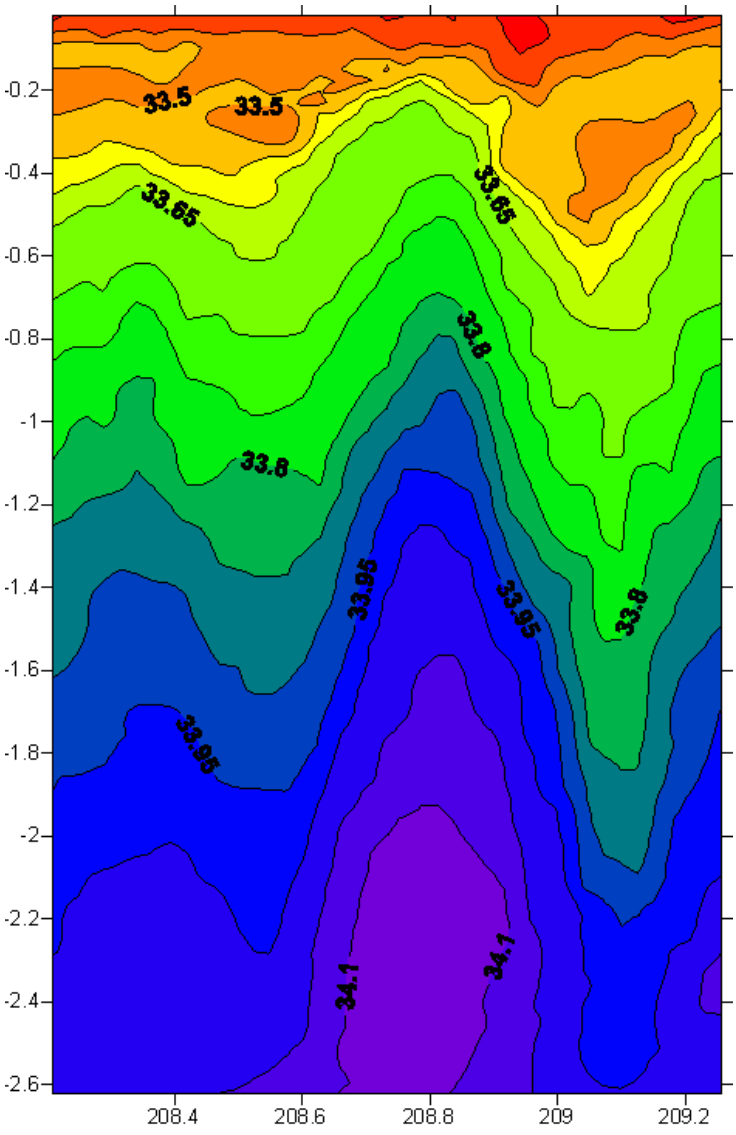


Figure 6:
Temperature from CTD Time Series 2
X=Yearday
Y=Pressure/100

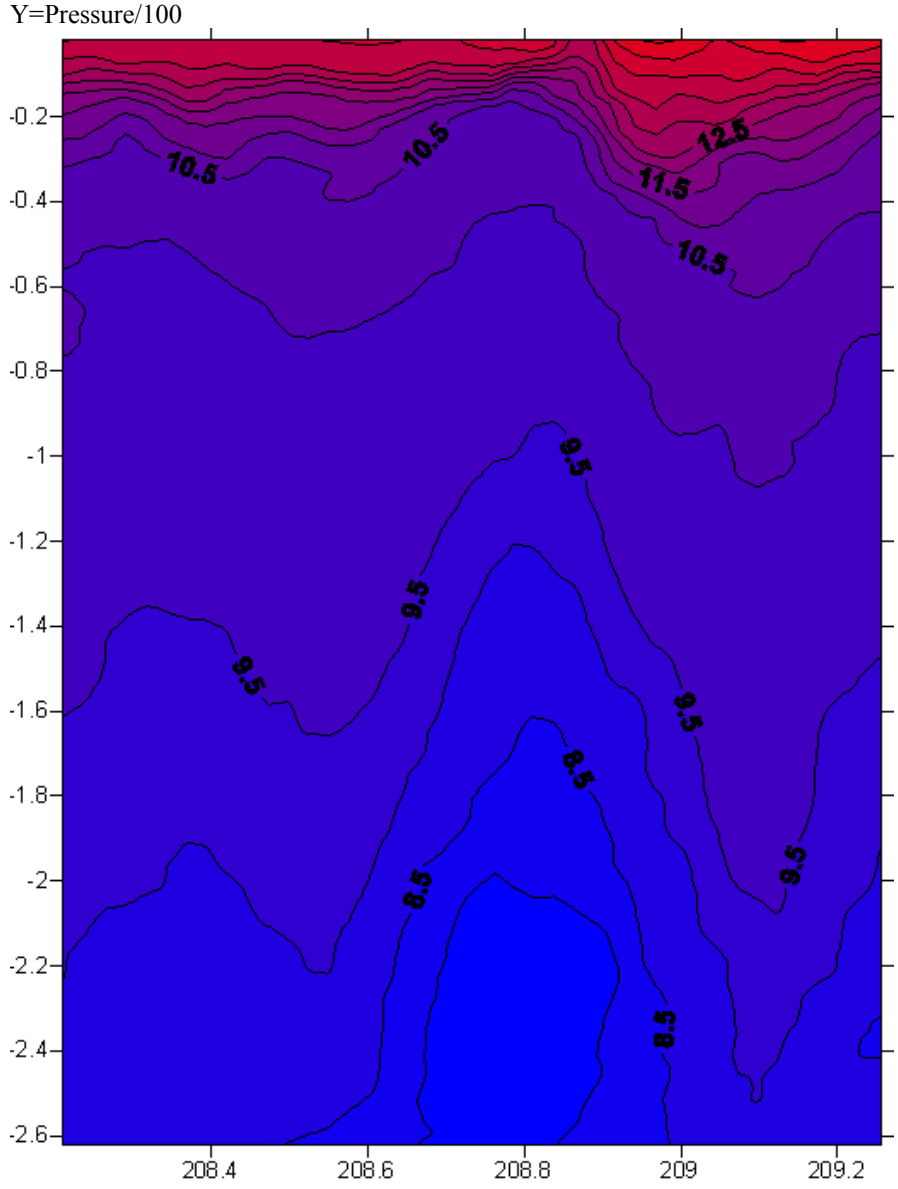


Figure 7:
Positive East

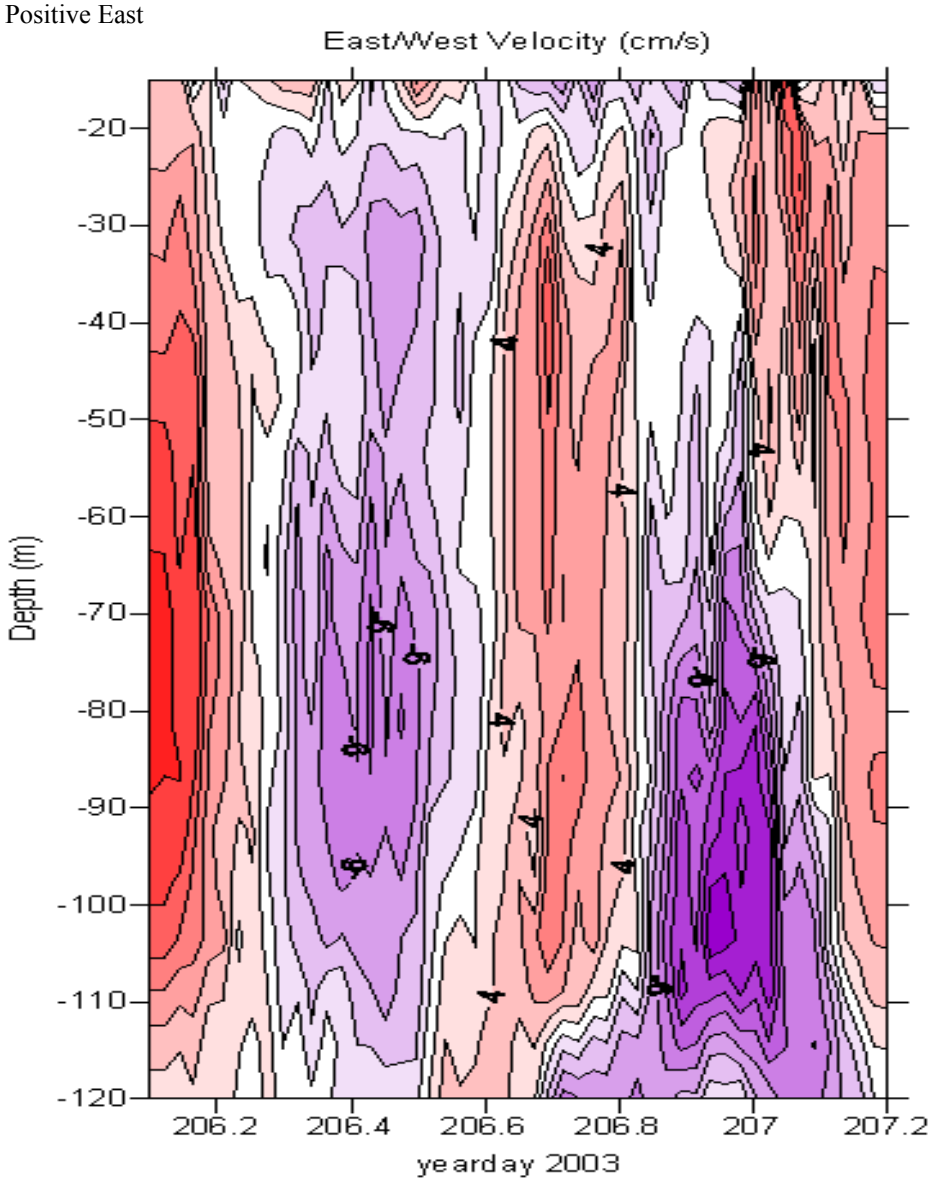


Figure 8:

North / South Velocity Shipboard ADCP PBOR 1
X=Yearday -1
Y=Depth (m)/100
Positive North

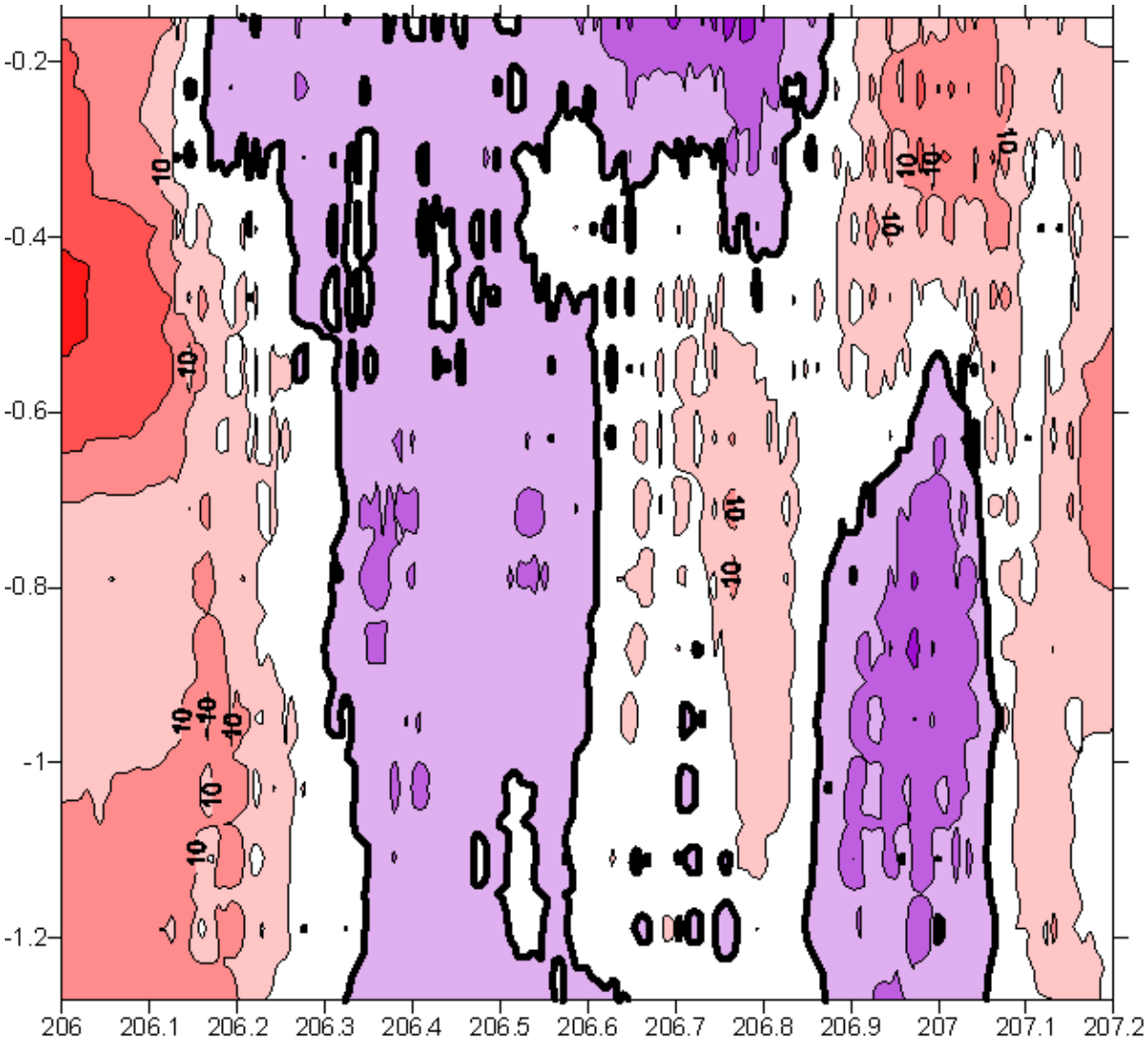


Figure 9:
East / West Velocity Shipboard ADCP PBOR 2
X=yearday-1
Y=Depth(m)/100
Positive East

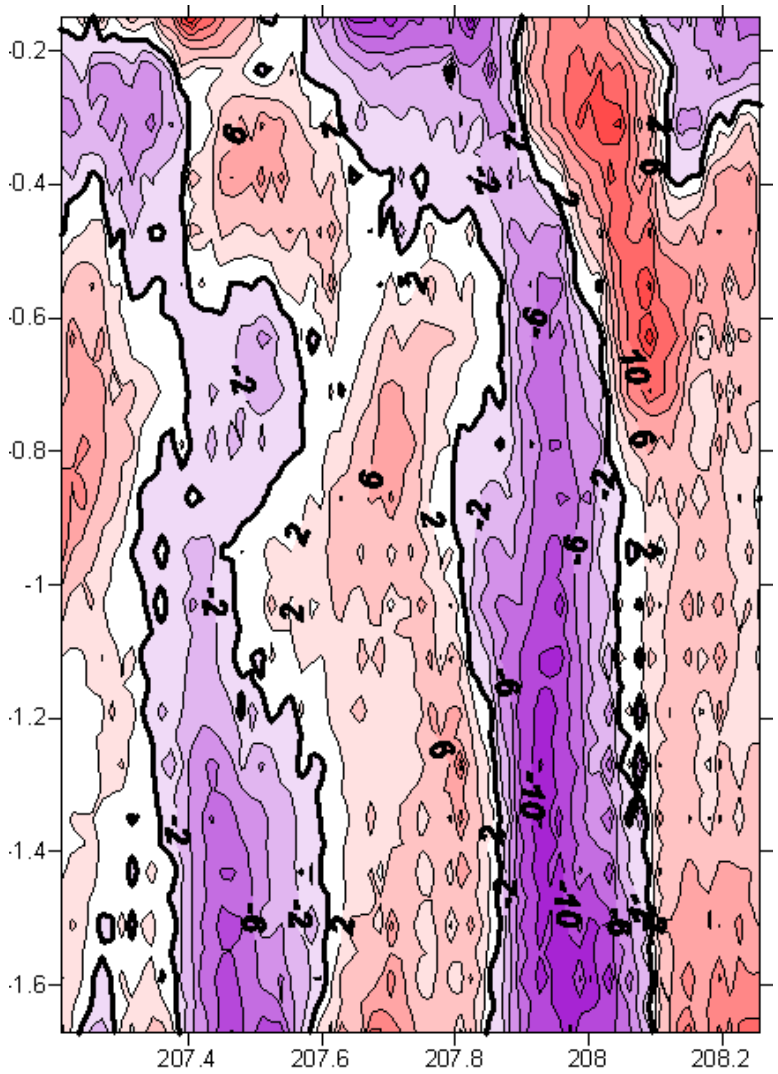


Figure 10:
North / South Velocity Shipboard ADCP PBOR 2
X=yearday – 1
Y=depth(m)/100
Positive (North)

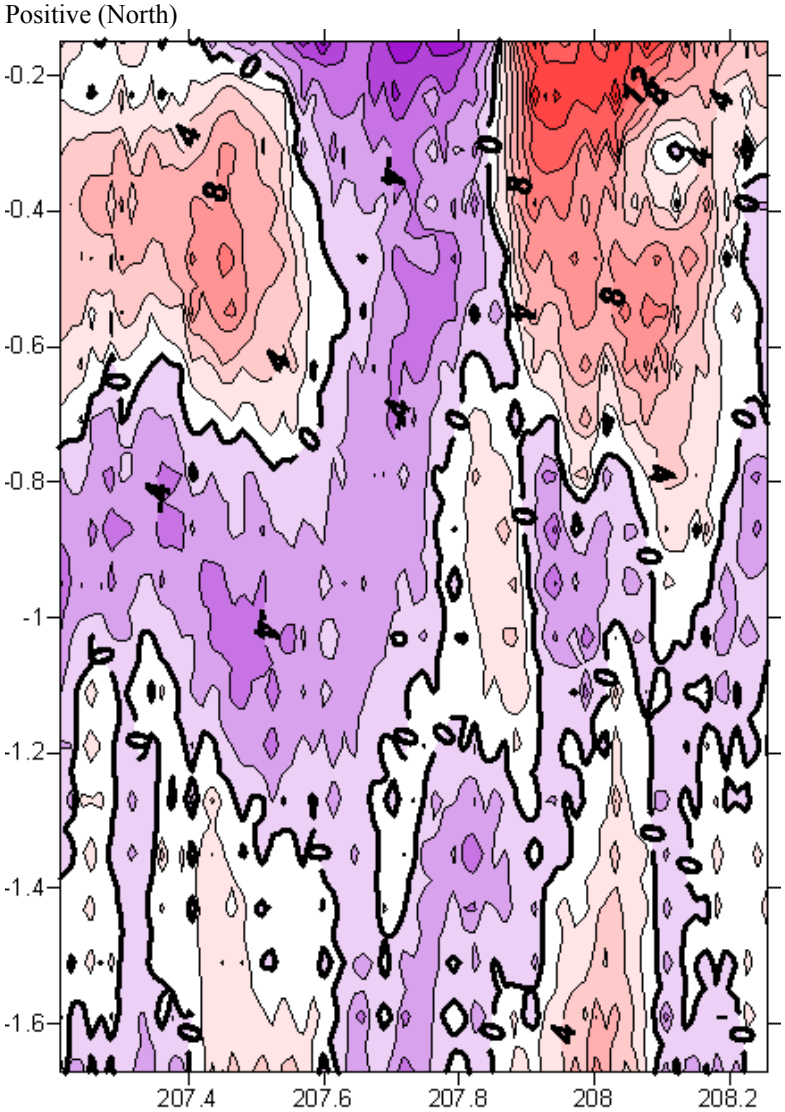


Figure 11:

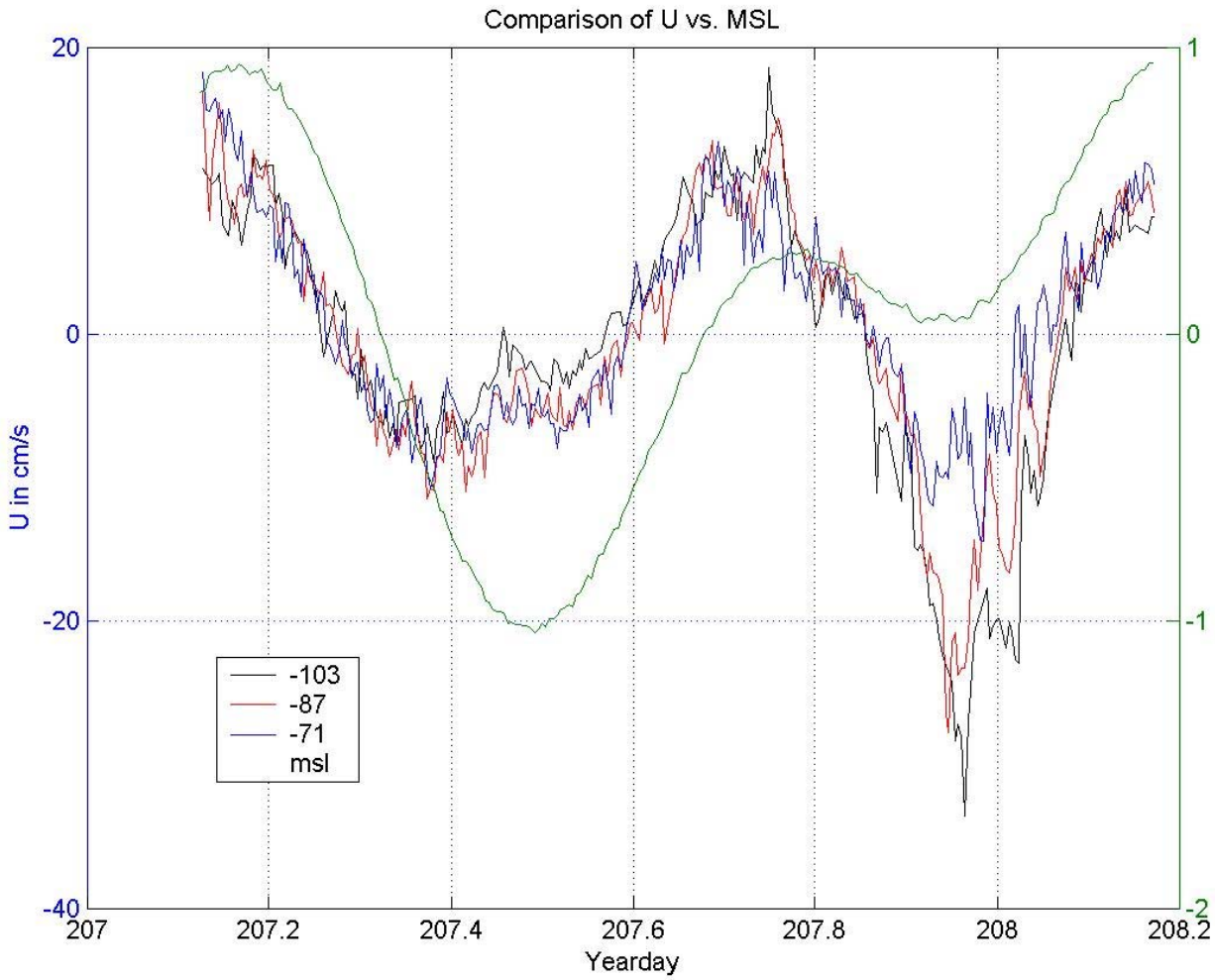

Comparison of U vs. MSL
20
0
-20
-40
1
0
-1
-2
U in cm/s
207
207.2
207.4
207.6
207.8
208
208.2
Yearday
-103
-87
-71
msl

Figure 12:

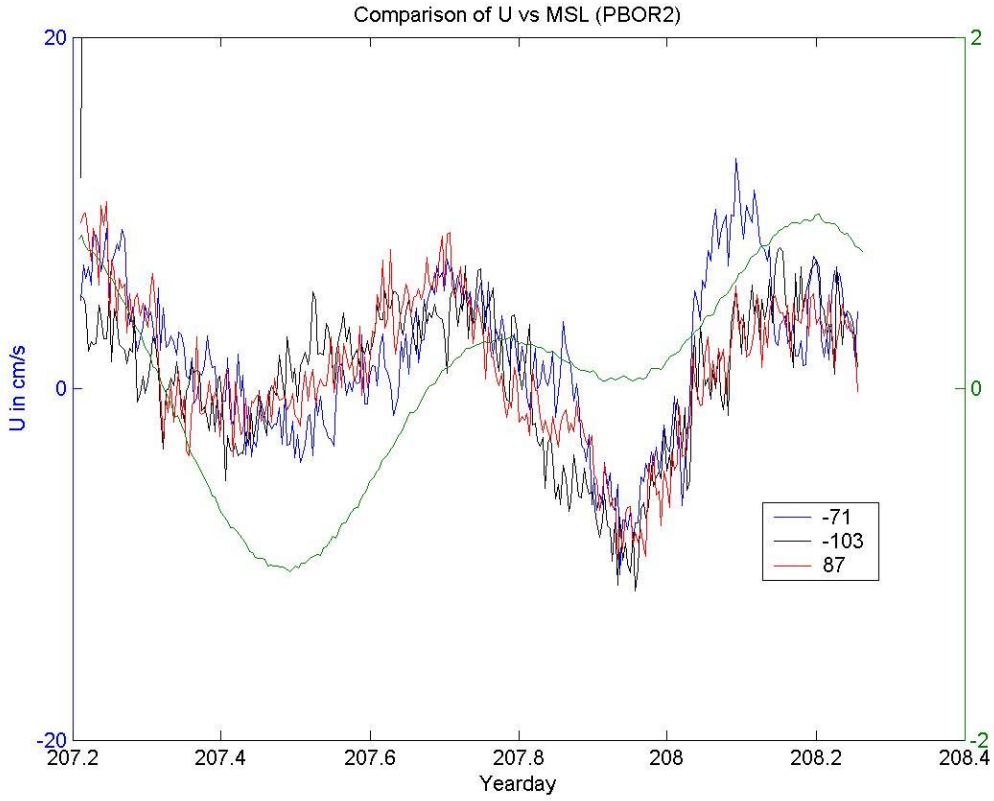
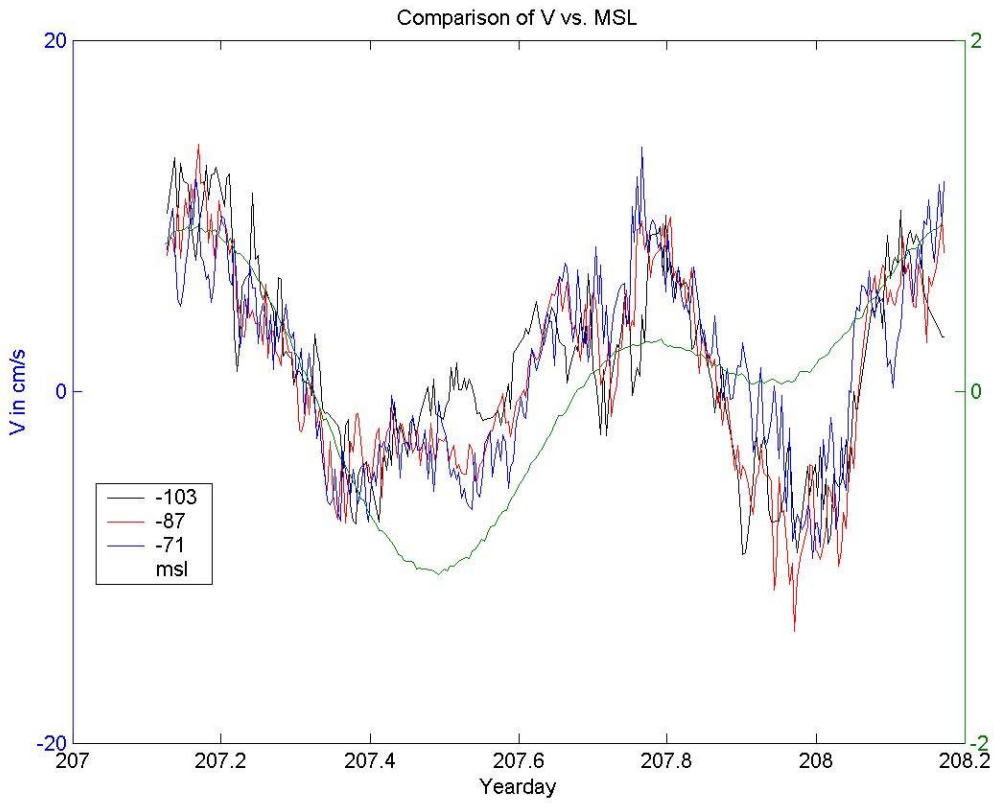

Comparison of U vs MSL (PBOR2)
U in cm/s
Yearday
20
0
-20
2
0
-2
207.2
207.4
207.6
207.8
208
208.2
208.4
-71
-103
87

Figure 13:


Comparison of V vs. MSL
20
0
-20
2
0
-2
V in cm/s
207
207.2
207.4
207.6
207.8
208
208.2
Yearday
-103
-87
-71
msl