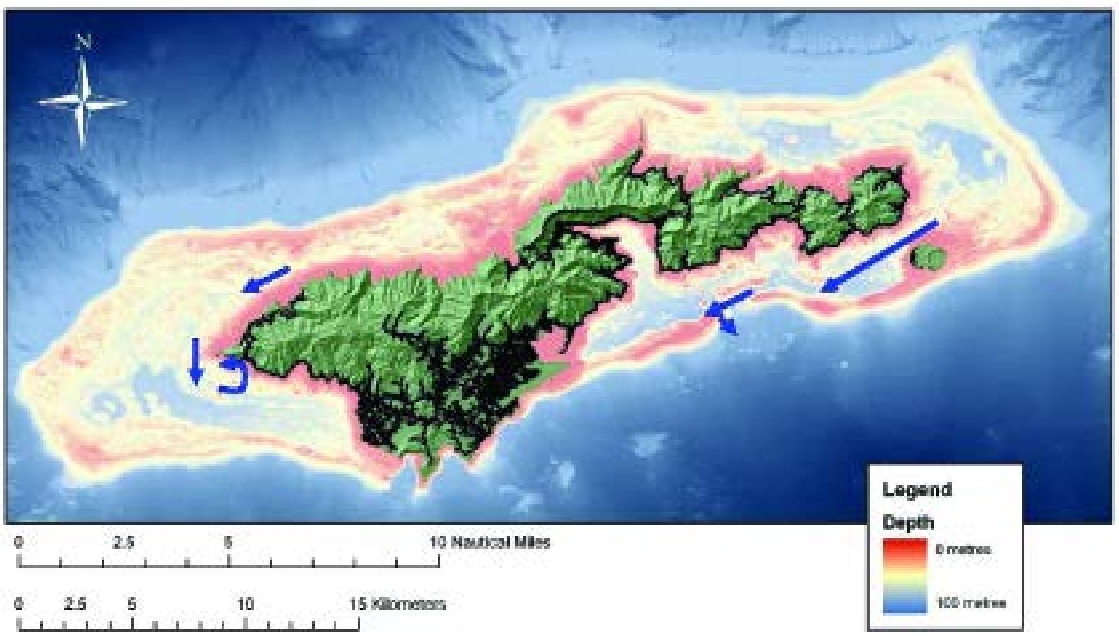
Current Surveys between Potential Marine Managed Areas in American Samoa



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Western Pacific Regional Fishery Management Council
1164 Bishop Street, Suite 1400, Honolulu, HI 96813

A report of the Western Pacific Regional Fishery Management Council
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INTRODUCTION

Very little data exists describing the circulation of ocean currents around American Samoa, particularly on very local scales within bays and around headlands. The purpose of this study is to characterize some of the major currents (velocity, direction, persistence over time), the driving forces (e.g., tidal, seasonal, wind/wave driven) and the impact this will have on larval transport / distribution around the island.

The relative influence of each of the driving forces on the currents is unknown and varies over time. A limited amount of large-scale oceanographic data exists for the islands of American Samoa, as collected by the NOAA Coral Reef Ecosystem Division (CRED – Brainard et al. 2008). The scarce amount of large-scale current data that does exist suggests large-scale currents generally flow from east to west around the American Samoa archipelago; however, these currents meander and it is not unusual for the flow to reverse in direction (e.g., Craig 2008).

Local populations of important fisheries species such as the bristletooth surgeon (*Ctenocaetus striatus*) and the white-cheeked surgeonfish (*Acanthuris nigricans*) are affected by the number of recruits into the population. The bristletooth surgeon has a life span of 36 years and spawns large quantities of larvae every year. An outstanding question is whether adult populations are self-recruiting or whether larvae are imported from outside communities, namely Manu'a Islands and Western Samoa. Data from other areas suggest that some species of reef fish may self-recruit (e.g., Jones et al. 1999), and answering this question for American Samoa will have clear impacts on the development of Fisheries Management Plans (FMPs) and the designation of future marine protected areas (MPAs) in American Samoa.

The MPA Program in the Department of Marine and Wildlife Resources is working with local communities to create a network of no-take areas accounting for 20 percent of the coral reef habitat. This program has information on biological diversity and abundances of various fish species at their priority sites, but they lack information on connectivity between certain sites. The current research was carried out in areas where it was thought that larvae could be retained as well as areas that were identified by the no-take program as potential or newly implemented no-take sites (e.g., Fagamalo and Aunu'u).

As pointed out by Grorud-Colvert and Sponaugle (2009), local variability among sites can lead to spatial differences in fish population replenishment. These authors highlight the importance of characterizing larval supply and recruitment to potential marine reserve sites in order to attempt to identify optimal locations for protection. In the midterm it is proposed that such work will lead to more effective design of marine reserve networks. In this sense, it is anticipated that research that characterizes the small-scale currents at priority locations in Tutuila island will be of great benefit to the managers in American Samoa who are in the process of developing a network of no-take MPAs. Ultimately, this data will be used to feed into a model set up to simulate larval pathways around American Samoa.

The commencement of surveys was delayed as the Department of Marine and Wildlife Resources research boats have been largely out of service for the past 18 months. Surveys have been carried out from three vessels, and a local team of staff have been trained to undertake the surveys independently.

The Pacific Basin Tide

Gary Egbert, at Oregon State University, has used satellite data to infer the tides within the Pacific Basin. His model shows that the main tidal component (M2) is relatively weak around American Samoa. It indicates that the tide moves from north to south past American Samoa with an amplitude of ~0.3m and a weak current (~4cm/s) flowing south during high tide and north during low tide.

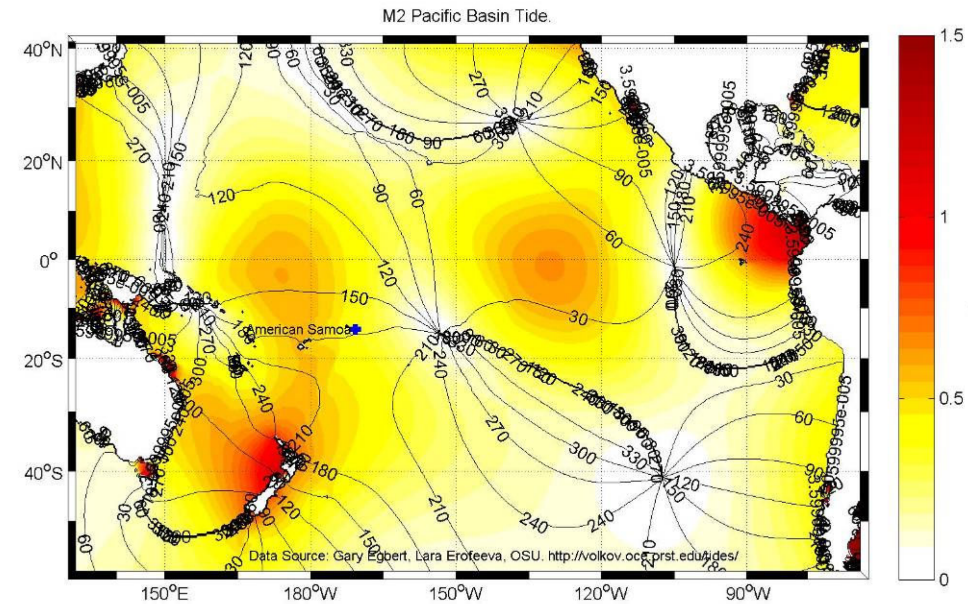


Figure 1. The Pacific basin M2 tide derived from Satellite altimeter data. The colors refer to the amplitude of the M2 tide, and the lines refer to the phase. The M2 tide is the dominant driver of tides in the Pacific.

To date, the successful tidal surveys have fallen on neap tides. Two other surveys were attempted between springs to neaps (8 December 2010) and on a spring tide (2 December 2010); however, bad conditions (probably contributed to by the wind against tide blowing up choppy conditions) forced the abandonment of both of these surveys.

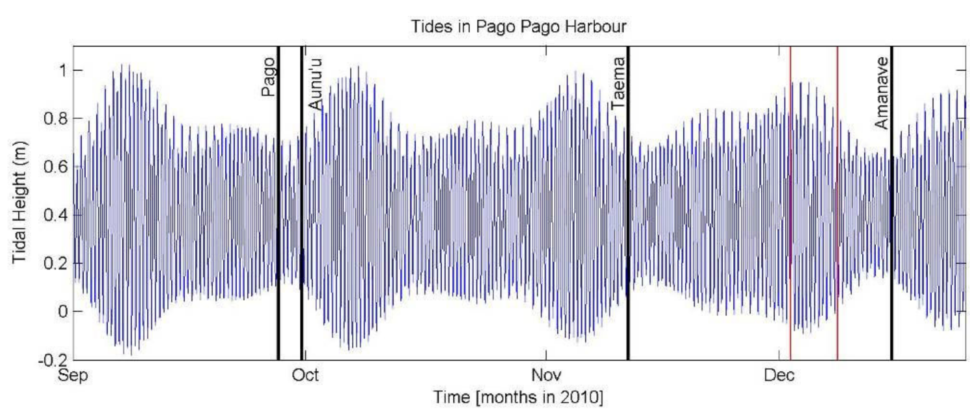


Figure 2. Tides in Pago Pago harbor and the dates of the surveys marked by vertical lines. The black lines mark the successful surveys where almost 12 hours of data were captured. The red lines indicate partial surveys that had to be abandoned.

Winds

The winds measured at the DMWR office in Pago Pago harbor are shown in Figure 3. This indicates that the winds preceding the Pago Pago Harbor and Aunu'u surveys were from a more easterly direction than the winds preceding the other surveys. This would have influenced the locally wind driven currents around the island.

It is important to note that the meteorological station is sheltered by the 611-meter tall Mount Alava ridge to the north.

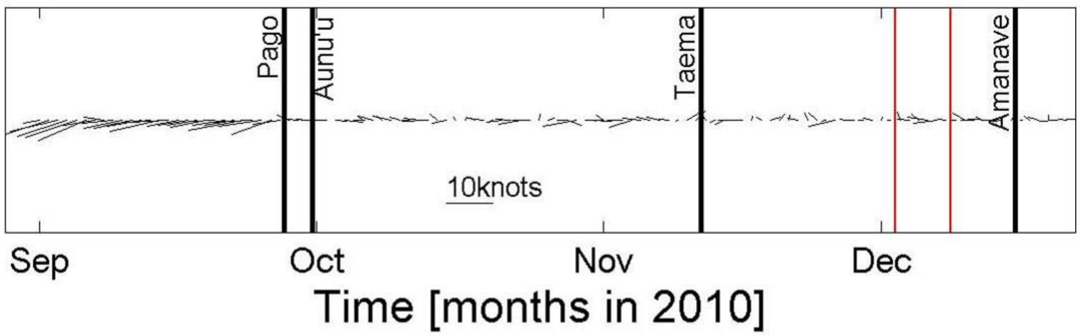


Figure 3. Winds from the DMWR meteorological station in Pago Pago Harbor.

METHOD

A Teledyne RDInstruments 600 kHz Acoustic Doppler Current Profiler (ADCP) was purchased and arrived on the island in May 2010. The 600 kHz model was chosen as it provides high resolution current measurements in the top 40m of the water column using a bottom track feature in total water depths of up to 110m. An ASUS EeePC netbook was purchased along with a Garmin GPS unit for data acquisition and navigation.

An aluminium frame was constructed by a contractor on island and clamps were used to fix this to the side of the vessels. All three vessels were small (2 were Alia fishing boats and the the third was the 25 ft DMWR Boston Whaler). This made weather a significant factor in determining whether surveys could proceed – particularly with prevailing winds coming from the East North East and the choice of sites characterised by strong currents.

The first survey was completed in Pago Pago Harbour to provide valuable flushing time information for the harbour and to allow easy troubleshooting of the equipment during its first use.

Six sites of priority interest for larval dispersal were identified (Figure 4):

- The channel between Aunu'u and Tutuila,
- To the east edge of Taema bank, across Narragansett passage,
- Amanave, around the western tip of Tutuila,
- Fagamalo, the site of DMWRs first no-take MPA,
- The Pola (the Cock's comb), the northern tip of the island near the National Park of American Samoa, and
- Tula, the eastern tip of Tutuila island.

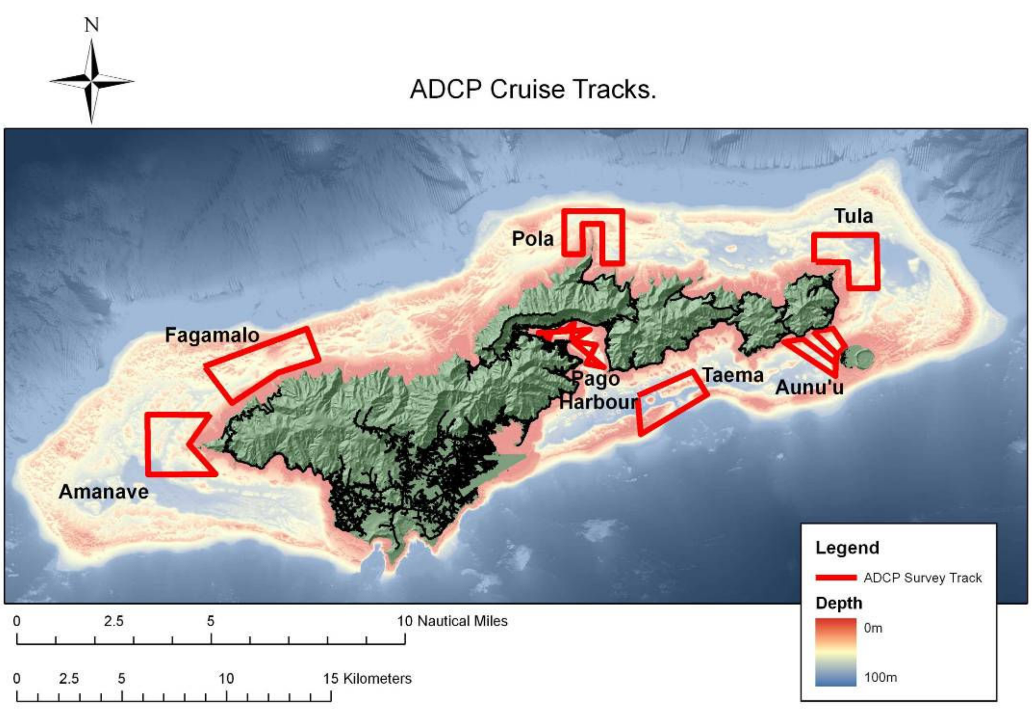


Figure 4. ADCP survey tracks at key locations around Tutuila.

The cruise tracks are 5 to 8 nautical miles long, and the survey vessel can operate at 4 to 6 knots (limited by stresses on the hardware and bubbles degrading data quality). So each track was repeated every one to two hours. Tidal surveys covering at least one M2 tidal cycle (12 hours and 25 minutes) were planned at each site, so a tidal analysis to be performed on the current data enabling the M2 and M4 (6 hours and 13 minutes) components of the current to be separated from the residual flow (Simpson et al. 1990). Due to logistical issues it was difficult to obtain full 12.42 hour tidal surveys at locations away from Pago Pago harbor.

So far, surveys at Aunu'u, Taema and Amanave have produced data suitable for a tidal analysis, which is presented below.

Tidal Analysis Method

The currents from the top 20 meters were depth averaged, then spatially binned onto a coarse grid. Each time the boat entered a grid cell, the data while the boat was in the grid cell was averaged to give one velocity estimate (Figure 5). The east and north components of flow were then resolved into the M2 (12 hour and 25 minute), M4 (6 hour and 13 minute) and residual components following Simpson et al. 1990.

The east and west components were then combined to make an ellipse for each tidal component showing the major axis of tidal flow.

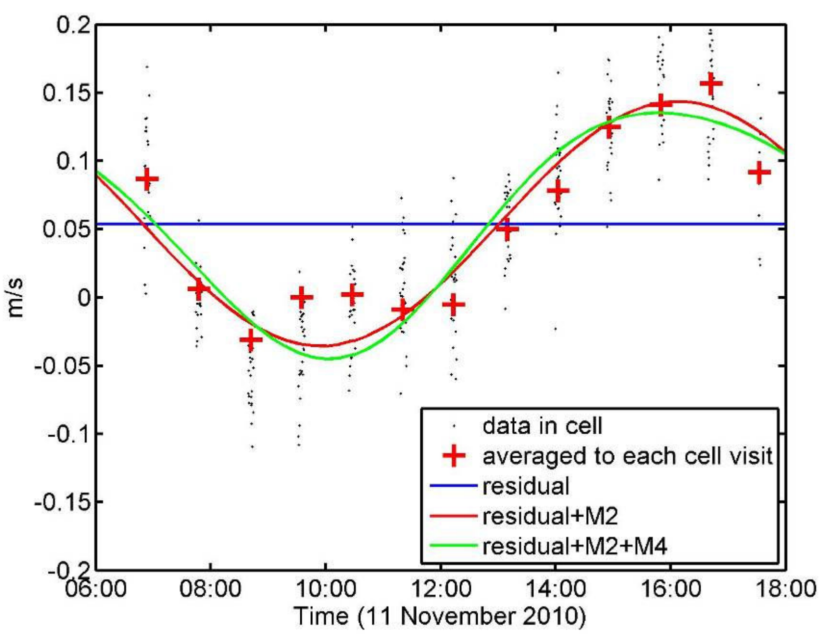


Figure 5. Example of data used for tidal analysis. This data is taken from the easterly component of flow in the most Southwestern corner of the Taema tidal survey. The black dots are all the individual east velocity data points measured every 14 seconds that were taken in this cell. The red cross is the average taken for each time the boat enters this particular grid cell. 12.42 hour (red) and 6.21hour (green) sinusoids are fitted to the red crosses to find the amplitude of those tidal constituents. The residual mean offset flow is included in the regression (blue).

RESULTS

The results from each circuit of the ADCP surveys are shown in the Appendix. Presented in the body of the report are results from the tidal analysis. Green is land, the shades of grey are bathymetry (with 20m contours overlaid) and the scale can be inferred from the vertical (y) axis – 1 minute of latitude is equal to 1 nautical mile.

Tidal ellipses are a way of representing the main axis of tidal flow along with the cross component of flow (i.e., at “slack” water). Away from boundaries or coastlines, tidal flow is rarely 1dimensional and usually moves in ellipses. The black ellipses on the charts below trace this elliptical tide. A legend is located on each graph as the currents vary greatly between the sites.

The red arrow shows the residual (mean) flow that is a background to the periodic tide.

While interpreting these graphs, it is useful to keep in mind that over the course of one M2 tidal cycle, a 0.1m/s tide will have a tidal excursion of 1.4km (0.8 nautical miles) – i.e., a parcel of water (or larvae) will be advected 1.4km in one direction (e.g., during the flood tide) then returned to its original position (during the ebb tide). A residual flow of 0.1m/s will carry a parcel of water 360m (0.2 nautical miles) in one hour.

The blue and green arrows are an aid to the interpretation of the graphs. The blue arrow shows the size of a typical M2 tidal excursion and the green arrow shows an approximate distance the residual flow travels over 12 hours. If either arrow is absent, it means that that component (tidal or residual) is negligible.

The faint pink line is the path of the boat.

The M4 (6 hour and 13 minute) component of the tide is also shown for completeness although the amplitude of this current is usually much smaller than the M2 component.

Aunu’u

The reefs surrounding Aunu’u island have a high biological diversity, making them of interest to marine managers. Although this survey was undertaken during neap tides on September 30, 2010, this survey indicated the tides within Aunu’u channel are very energetic (1 m/s) and aligned with the channel. During the tidal survey, winds were 10 to 15 knots from the east.

At low water (measured in Pago Pago Harbor), the main component of flow is to the northeast, however there is an eddy of return flow to the southeast near Amouli (the yellow hashed area – see also the figures in the Appendix). At high water, the flow is to the southeast, but again there is a “back eddy” of return flow to the north east near Amouli (in the same yellow hashed area).

The residual flow within the channel is not significantly different from 0 m/s.

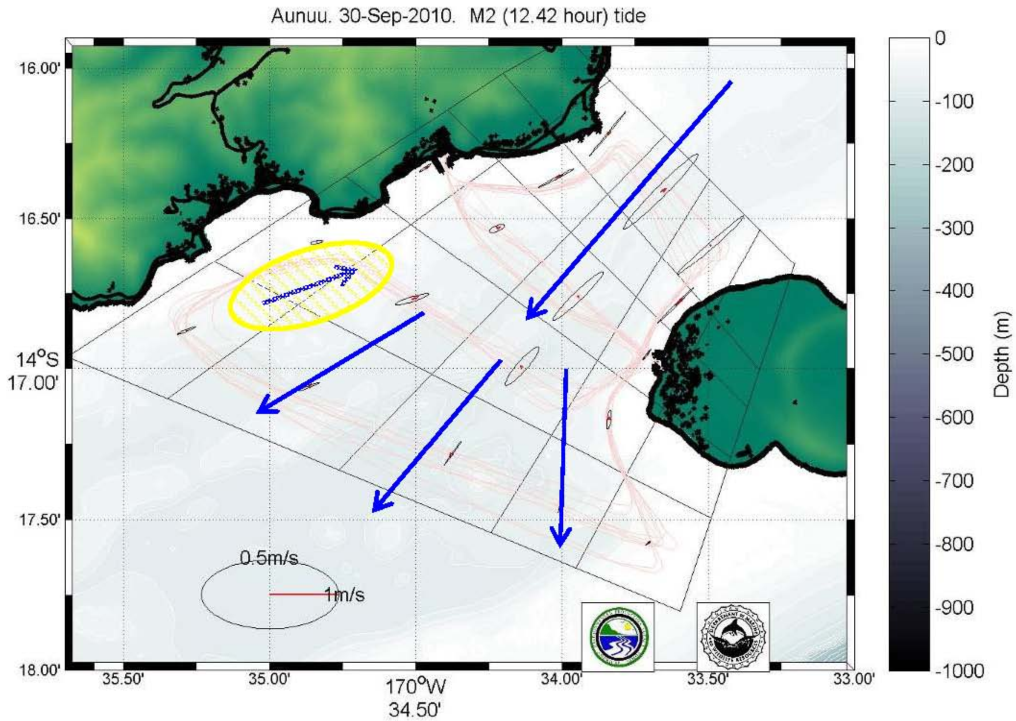


Figure 6. M2 tidal component of flow in the channel between Aunu'u and Tutuila. Although the strong tide in the centre of the channel would carry a parcel of water 14 km over a tidal cycle, the water quickly moves into slower moving water, so the blue arrows get shorter.

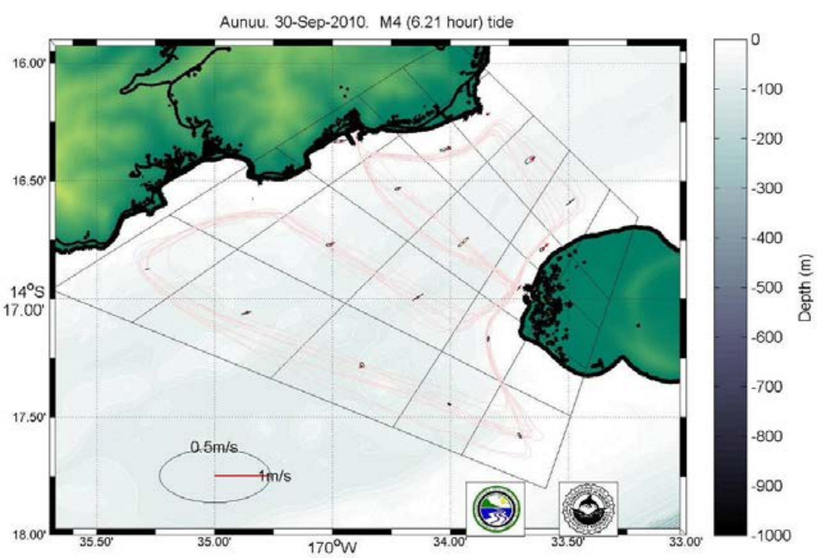


Figure 7. M4 tidal component of flow between Aunu'u island and Tutuila.

Taema

Taema bank rises to ~10 metres depth approximately 1 nautical mile south of Pago Pago harbour entrance. To the east of Taema bank is Narragansett passage, a deep (100m), submerged ava. The survey around Taema bank was performed on November 11, 2010.

Winds during the survey were from the northeast, with a speed of about 10-15 knots. Tidal flow was generally aligned with the coast, eastnortheast to westsouthwest with a magnitude of 10cm/s however there was a noticeable crosscomponent of flow (the ellipses are more open, i.e. not as eccentric), see Figure 8. Strongest flow to the southwest was approximately 2 hours before high tide, while strongest flow to the northeast was 2 hrs before high tide.

The non-tidal component of flow was generally towards the east, at a speed of ~5 cm/s.

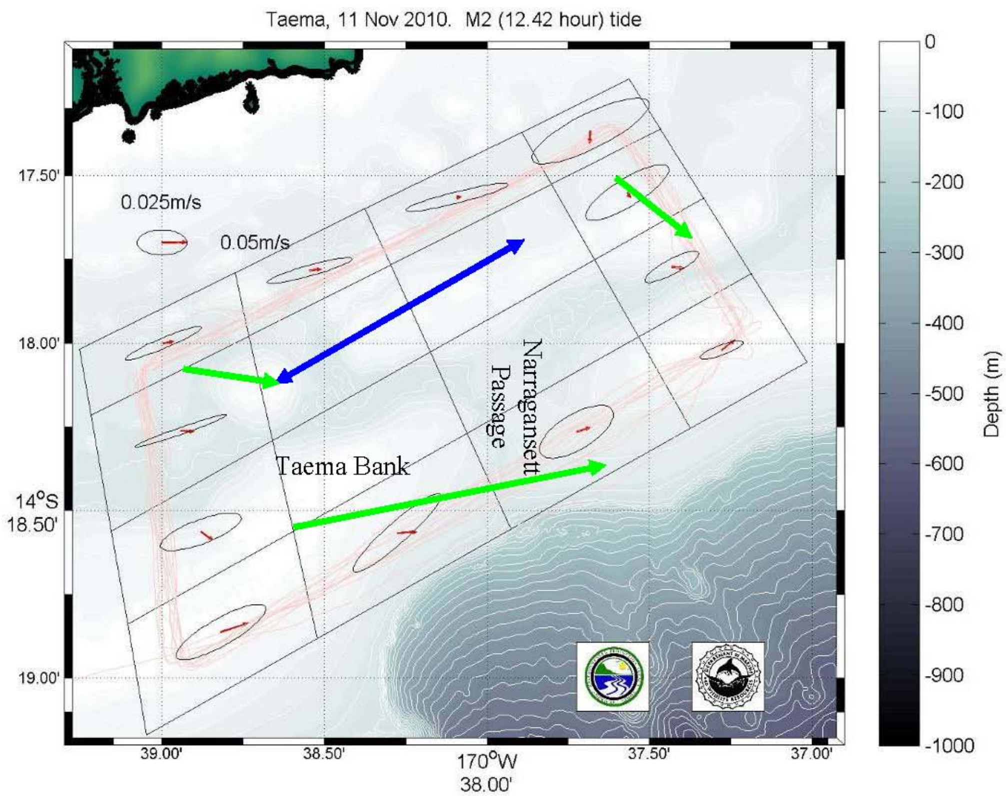


Figure 8. M2 tidal component of flow around Taema bank.

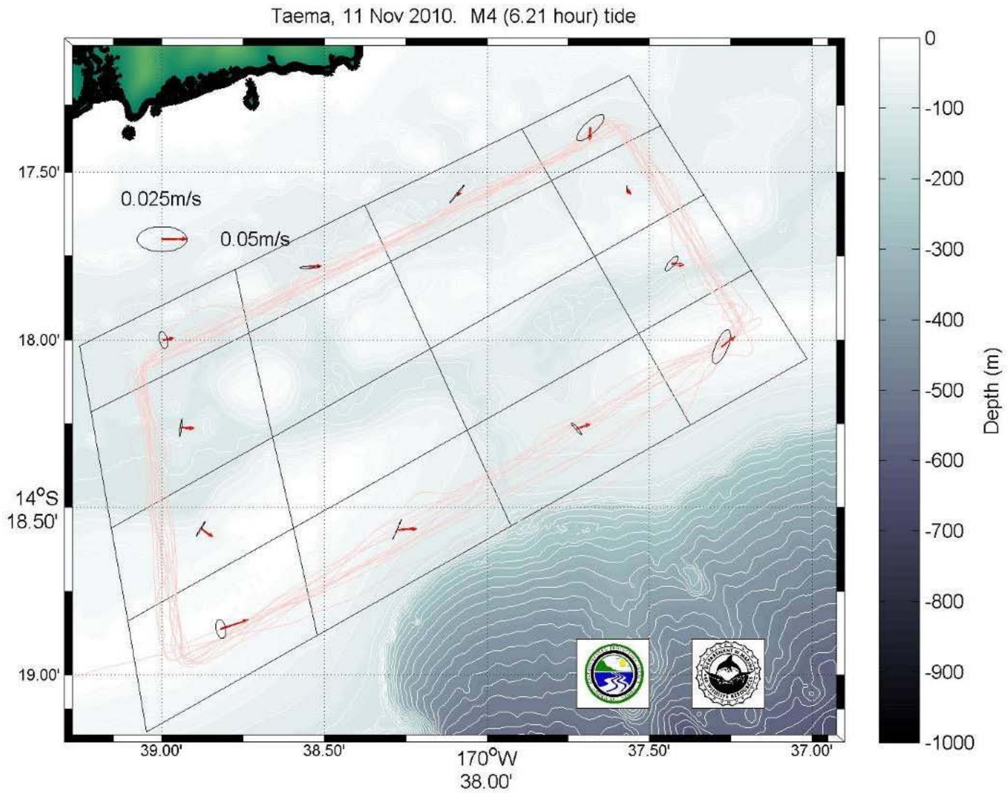


Figure 9. M4 tidal component around Taema bank.

Amanave

Any currents impinging on Tutuila will be squeezed around the edges of the island, intensifying the flow at these locations. Additionally, the presence of a headland jutting out into the flow is likely to cause an eddy (flow separation) on the lee side of the headland. These eddies have the potential to hold larvae close to the island, giving them a chance to settle locally before being lost to the open ocean.

The tidal survey of Amanave could only be carried out over 10 hours on December 15, 2010, so a full tidal cycle was not captured. Winds were calm in the morning and picked up from the northeast later in the day.

The residual flow around cape Taputapu (the western tip of the island) wrapped around the point from the north to the south and at some locations was stronger than the tide. This means that in these locations, the flow never changed direction. This was particularly evident south of the cape, where the residual flows were about 20-25 cm/s while the tidal flow was about 10cm/s.

The strongest flow, when the tide was going in the same direction as the residual flow, was during high tide (measured in Pago Pago Harbor) and had a speed of about 0.3 m/s.

The flow to the south around Amanave set up an eddy in Amanave bay. The s survey track did not capture the eastern edge of this eddy, so it is not yet known if the eddy extends beyond the point at the eastern edge of Amanave bay. Given a characteristic circumference of 4.5 km and speed of 0.1 m/s, water will be travel around the eddy approximately every 12 hours.

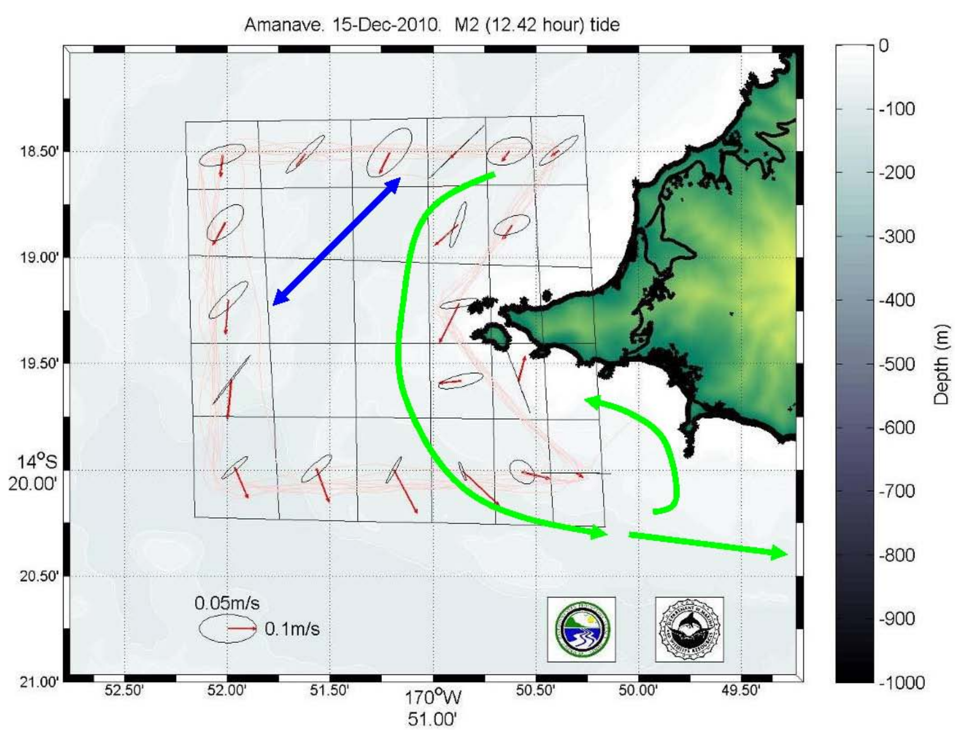


Figure 10. M2 component of the tide around the western tip of Tutuila. The blue arrow indicates a tida excursion, the green arrow is an approximate distance that the residual flow will carry drifters. The gre indicates the position of the eddy in Amanave bay which existed on both phases of the tide.

The M4 tide had a relatively strong signal in this region, probably caused by nonlinear interactions between the residual flow, topography and the M2 tide.

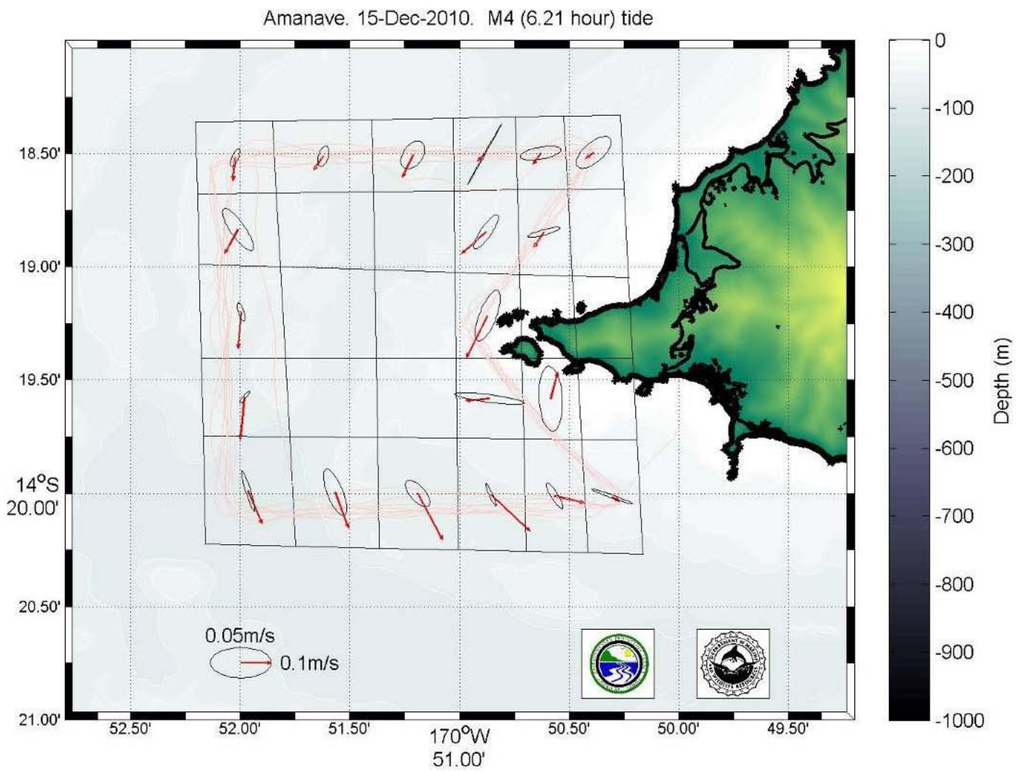


Figure 11. M4 component of the tide around the western tip of Tutuila.

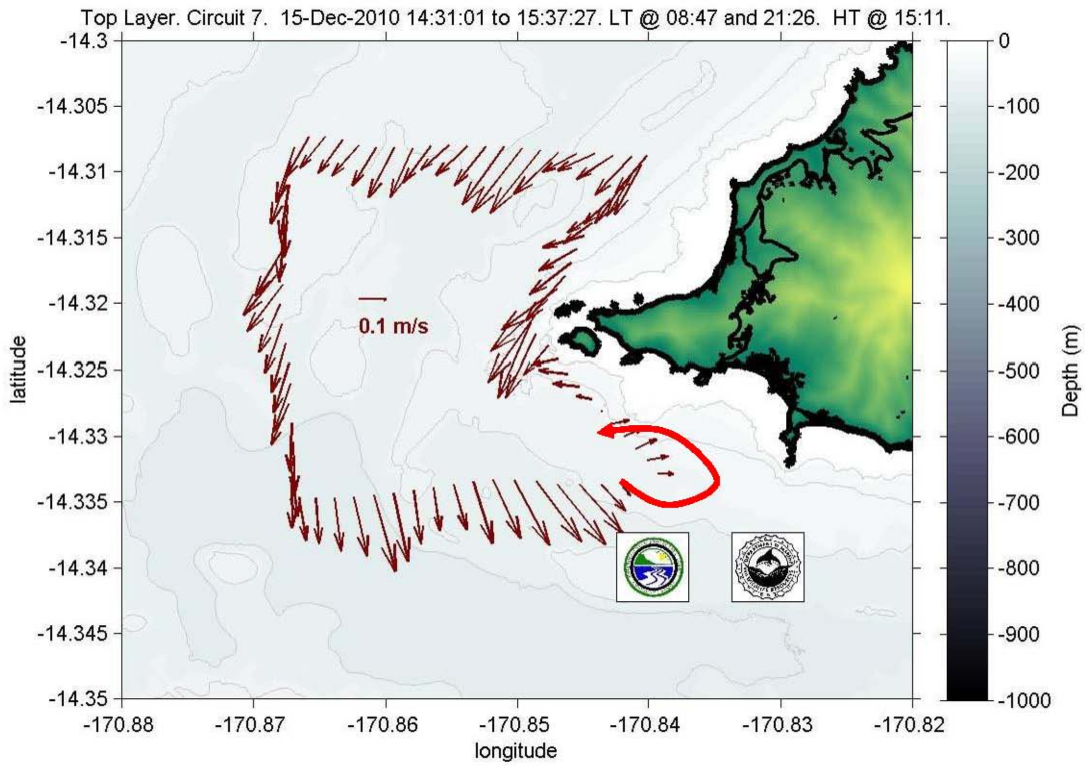


Figure 12. An 'snapshot' of flow around the western tip, showing the eddy to the south of the headland (drawı red arrow).

Pago Pago Harbor

Pago Pago harbor was used as the “proving ground” for the ADCP setup as it is close to shore and problems could be troubleshot relatively easily. It also provided valuable data for estimating flushing within the harbor. The survey was carried out on September 27, 2010.

The tides were small and of the same order as the residual flows (mostly less than 5 cm/s). What little residual flow there was indicated that water in the middle part of the harbor (between Utulei and Aua). The time taken for a parcel of water to circulate around this part of the harbor is approximately 36 hours.

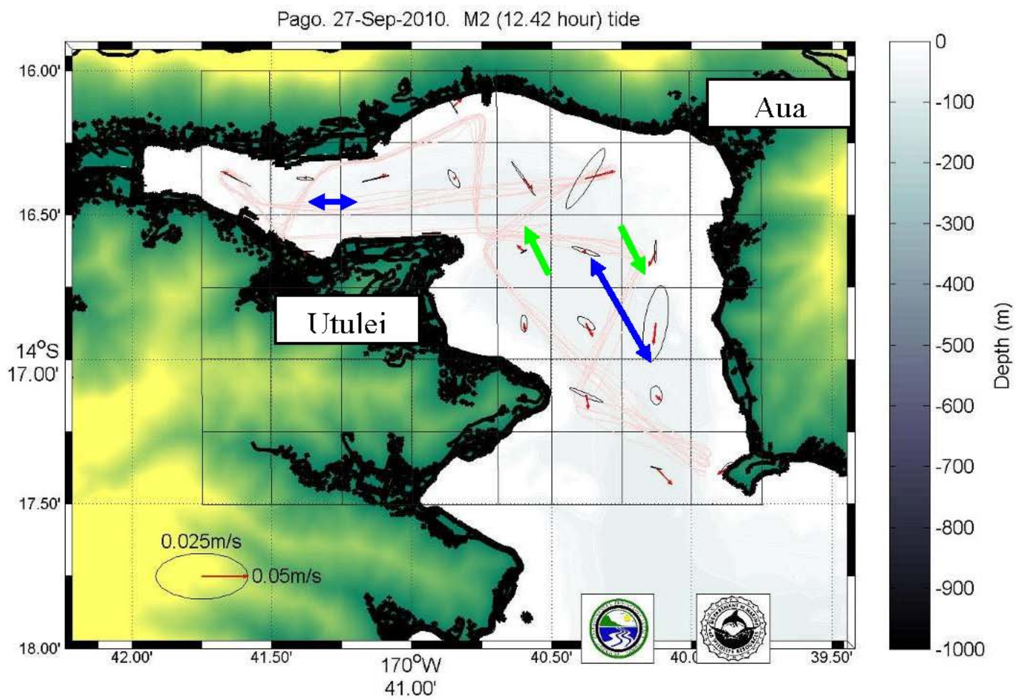


Figure 13. M2 component of tidal flow in Pago Pago Harbour. The blue arrows show typical tidal excursions near the mouth and head of the harbour. The green arrows indicate the weak residual circulation within the harbour.

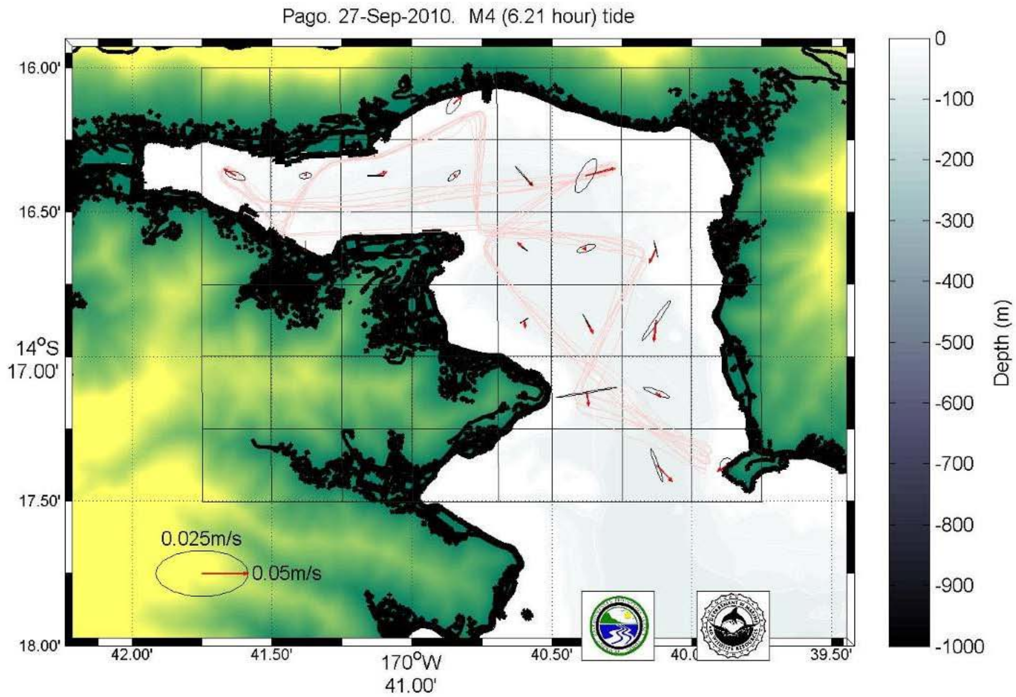


Figure 14. M4 tidal component within Pago Pago harbour.

Fagamalo

Two attempts were made to measure the flow around Fagamalo. Both of these were aborted due to poor weather. Four circuits were made on December 1, 2010, but this was not enough to perform a tidal analysis. The measurements were taken over low water, at which time the currents flowed briefly to the north east. However before and after this, the flow was to the southwest. Extrapolating from the Amanave dataset, it appears that the flow is predominantly to the southeast, but reverses briefly to the northwest during low water.

Nevertheless, some interesting information was gained from the survey, particularly the presence of eddies in the bay encompassing Maloata and Fagamalo and in the bay of Fagali'i. Given a characteristic eddy circumference of 3km and a current speed of 0.1m/s, the water will re-circulate within these eddies approximately every 8 hours.

The complete dataset from Fagamalo is presented in the Appendix.

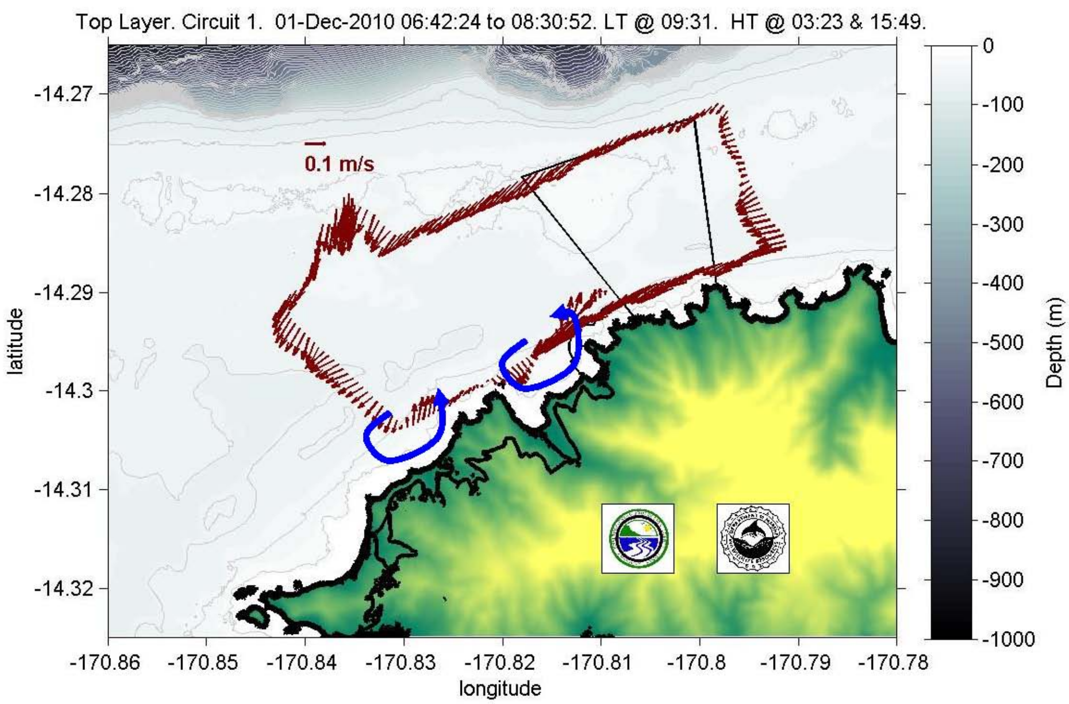


Figure 15. Snapshot of currents near Fagamalo. Top layer here refers to the top 20m.

Tutuila Overview

Because these surveys were carried out weeks apart, it is difficult to assume that the general current patterns around the island have remained steady (e.g., Figure 3); however, rough generalizations can be made with the present data.

The currents generally flow towards the southwest during high tide (Figure 16), and eddies are formed around bays and headlands. There is a particularly strong current in the channel between Aunu'u and Tutuila.

Over low tide, the southwest currents weaken in some places (e.g. the western tip of the island) or reverse (e.g., Taema bank), particularly in the channel between Aunu'u and the mainland where a strong flow towards the northeast is observed (Figure 17). These results are consistent with the basin scale tides shown in Figure 1.

From the data already gathered, it appears that the residual flow on the south side of the island is towards the east and on the western tip of the island is towards the south (Figure 18).

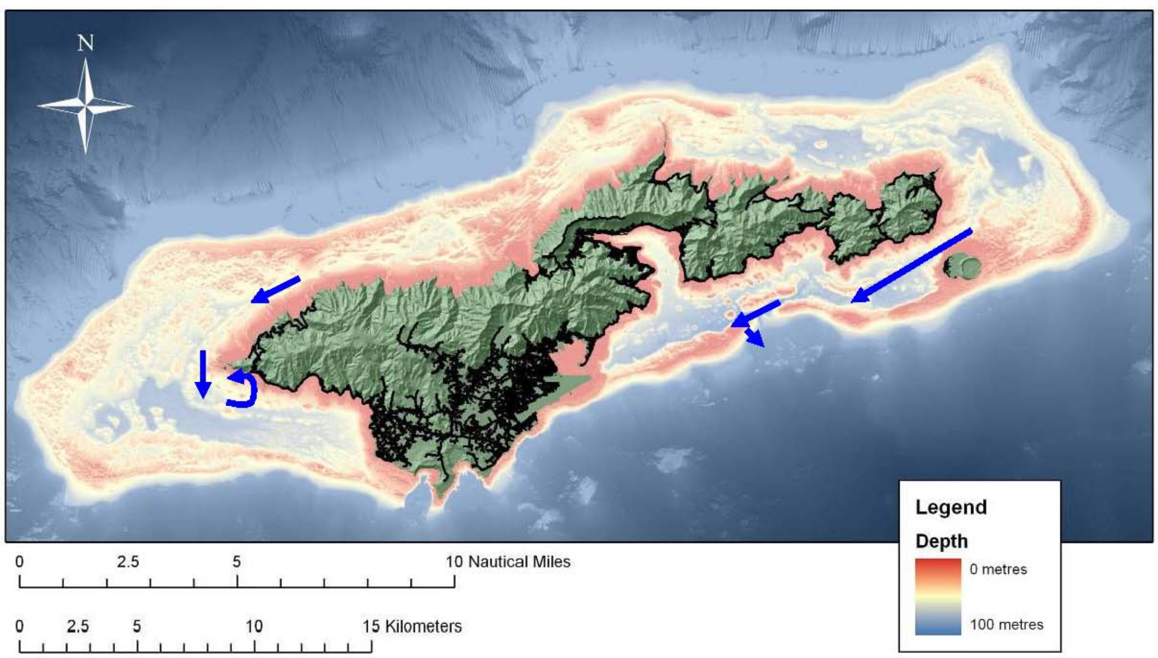


Figure 16. Summary currents around high tide. The currents generally flow towards the west around the island and eddies are set up in bays and around headlands. Particularly strong flow is found in the channel between Aunu'u and Tutuila. The currents flow west past Fagamalo and south around the western tip of the island.

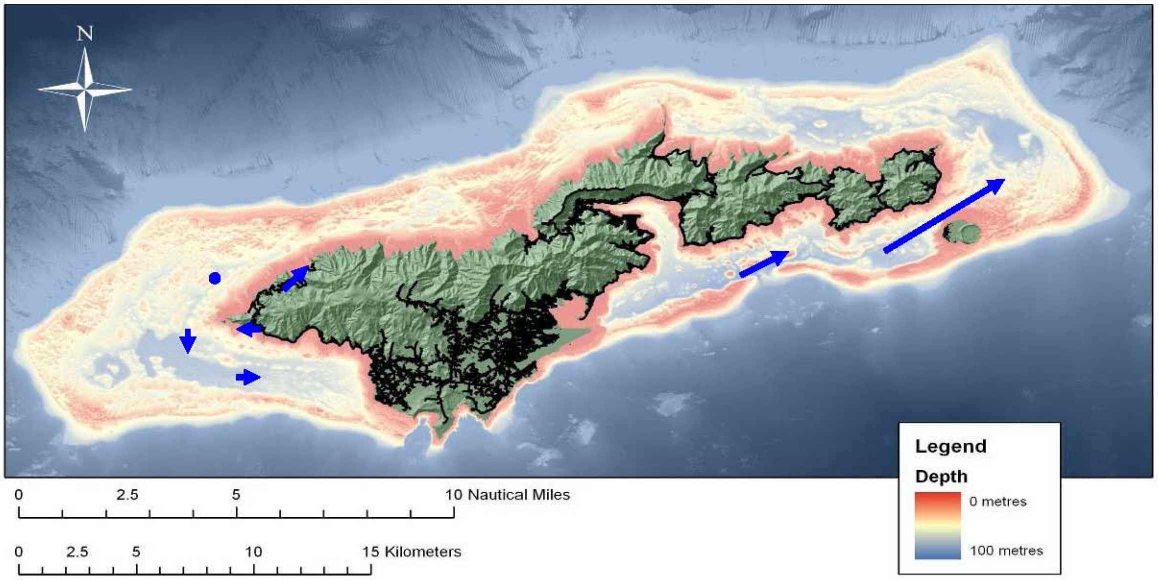


Figure 17. Summary currents around Tutuila over low tide. The strong flow in the channel between Aunu'u island and Tutuila has reversed towards the northeast, as has the flow near Taema bank and Fagamalo. However the current near the western tip of the island still runs to the south.

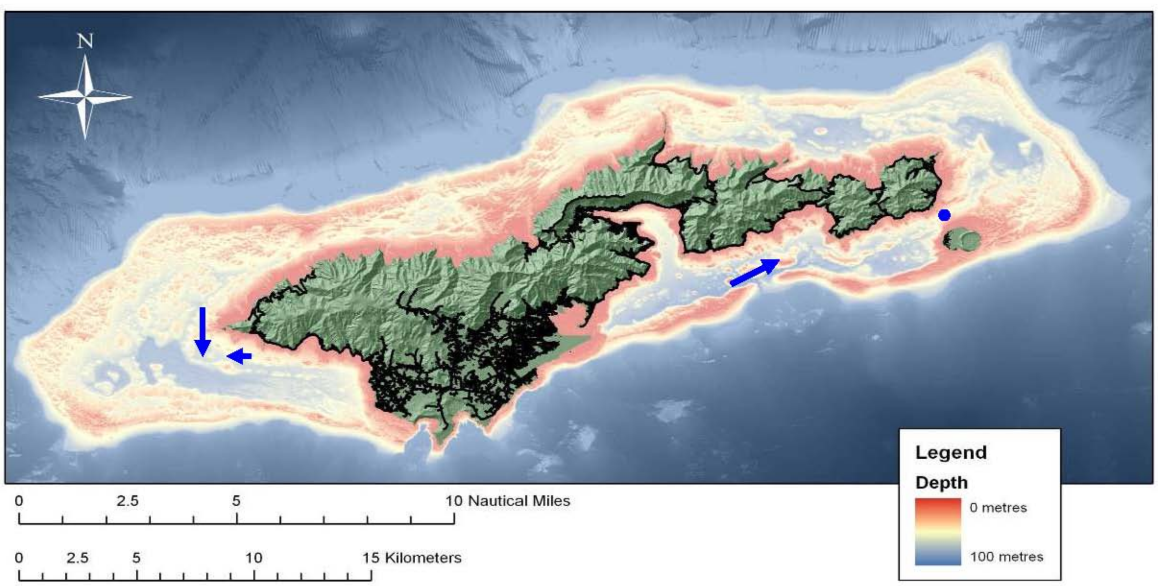


Figure 18. Summary residual flow. Good data so far is only available from the channel between Aunu'u and the mainland, Taema bank and the western tip of the island.

SUMMARY

The nature of these surveys makes it difficult to create an instantaneous (synoptic) picture of the currents around Tutuila. Due to boat scheduling and personnel resources, the surveys are scheduled once per week (with a backup day later in the week). Factoring in weather issues makes it difficult to perform several surveys in a short period of time. This inherently means that oceanographic conditions have enough time to change between the surveys such that the ensemble of surveys cannot be considered as synoptic. For this reason the ADCP surveys are planned over several seasons.

An example of the implications of this is the observed residual eastward current at Taema bank and no observed residual current in the Aunu'u Tutuila channel. If these results were found simultaneously, then it would imply that the residual flow is either being pushed south of Aunu'u or further south into deeper water, or reversing to go west in a counter clockwise eddy.

An important mechanism that these studies are starting to quantify is the potential for local scale topography (bays and headlands) to create recirculating back current eddies. There are likely to be finer scale eddies even closer to the reef and on the reef flat that future efforts using this equipment may be able to capture.

Many eddies are caused by the tide and disappear when the direction of flow reverses. However the eddy in Amanave bay is caused by a residual flow and is likely to remain for long periods of time. Continued surveys are needed at this (and at the other sites) to find out if the flow past the western tip of Amanave is always to the south, i.e., does the residual flow dominate over the tide? If this is the case, then one would not expect to see larvae from Amanave seeding any reefs north of the western tip.

This growing dataset indicates that enhancing spawning stocks in a location such as Fagamalo would be very beneficial to Maloata, Poloa and Amanave and of some benefit to the Aoloau coastline east of Fagamalo. However, enhanced spawning stocks in Amanave may have little benefit to Poloa, Maloata and Fagamalo.

FUTURE WORK

The surveys are still ongoing because of the delayed start to surveying. Two of the sites (Pola and Tula) have not yet been surveyed.

The nature of American Samoa, where there is an oceanic swell coming usually from the east and the vessel is in deep water immediately after leaving port, makes a 25-foot Boston Whaler susceptible to rough weather. Any bubbles entrained under the ADCP transducer block the sound signal from penetrating the water column and a less-than-waterproof cabin exposes other electronic components (e.g., laptop). This makes picking good days for surveying important, which will bias the data. It is hoped that the larger DMWR vessel, the *Pualele*, will be able to operate in a wider range of conditions once it is running.

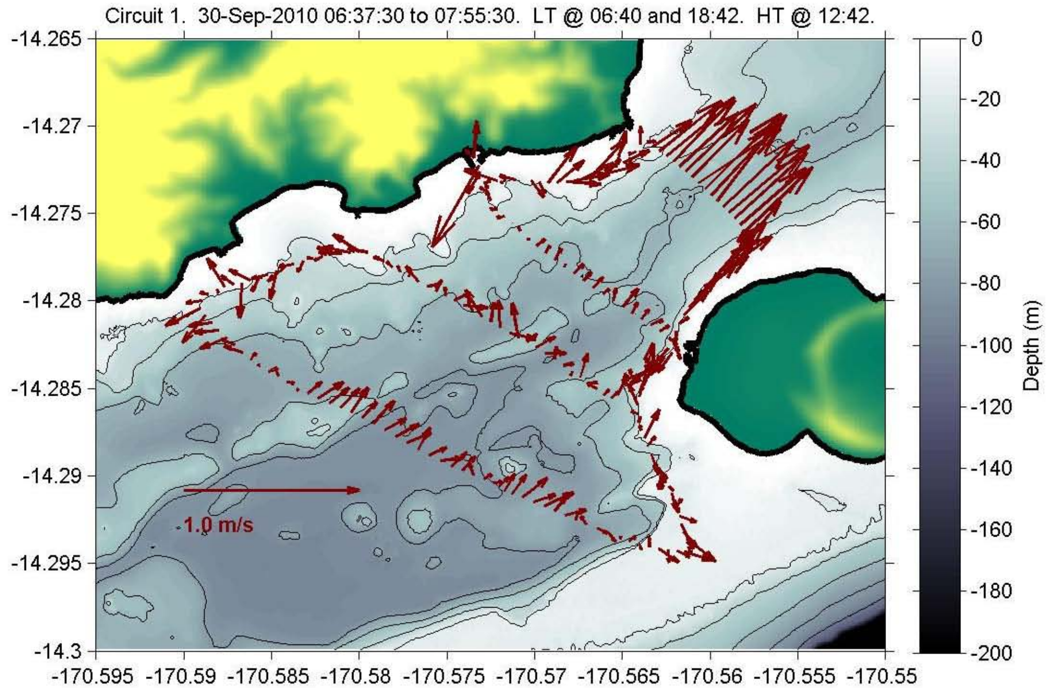
Once this survey work has been completed, it would be useful to attempt using the ADCP in pulse-coherent mode (reduced range, but much greater accuracy) on the reef flat to estimate the residence time of water and larvae before they make it to the reef slope.

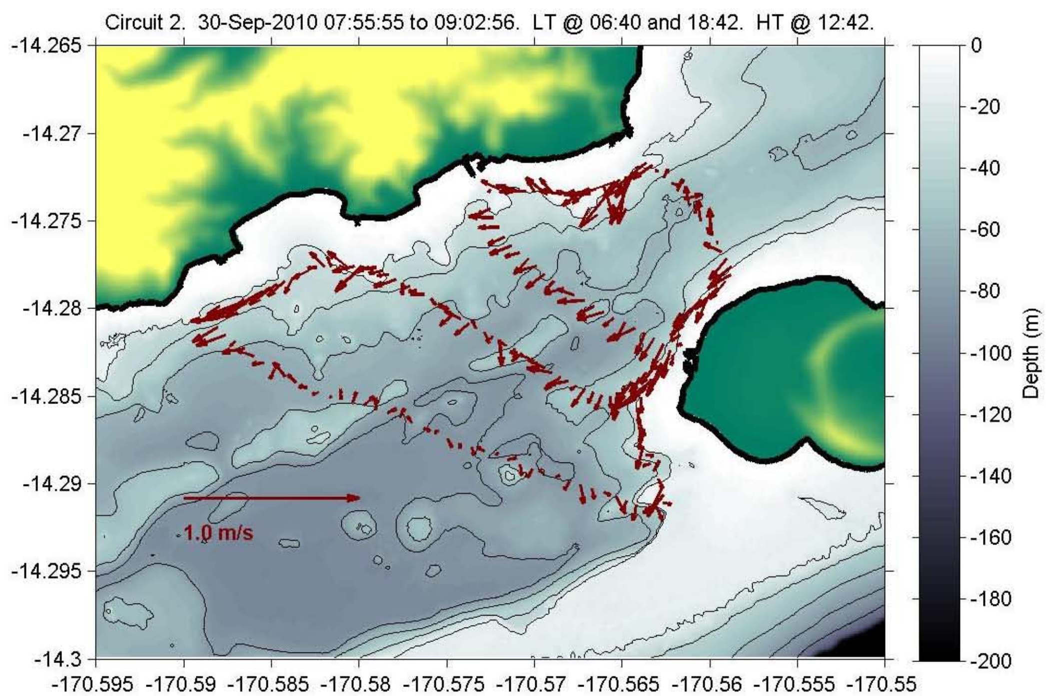
Long time series of currents from the ADCP in a moored configuration are required to distinguish the influence of tides, wind and waves to a higher degree of certainty. Again, it is wise to complete the initial work before leaving the ADCP on an unattended mooring.

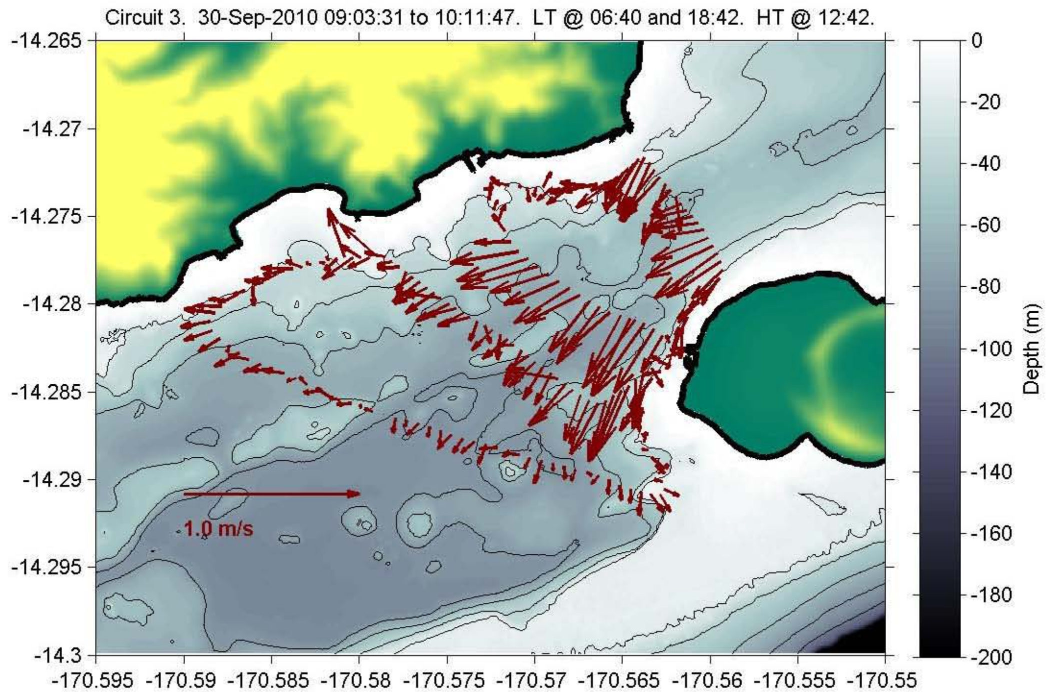
Numerical models (ROMS and ADCIRC) are currently being built to simulate the currents around Tutuila. These models will fill the gaps that the ADCP cannot cover and can be seeded with virtual larvae to gain a more accurate idea of the connectivity between sites.

APPENDIX

Aunu'u Data



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-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
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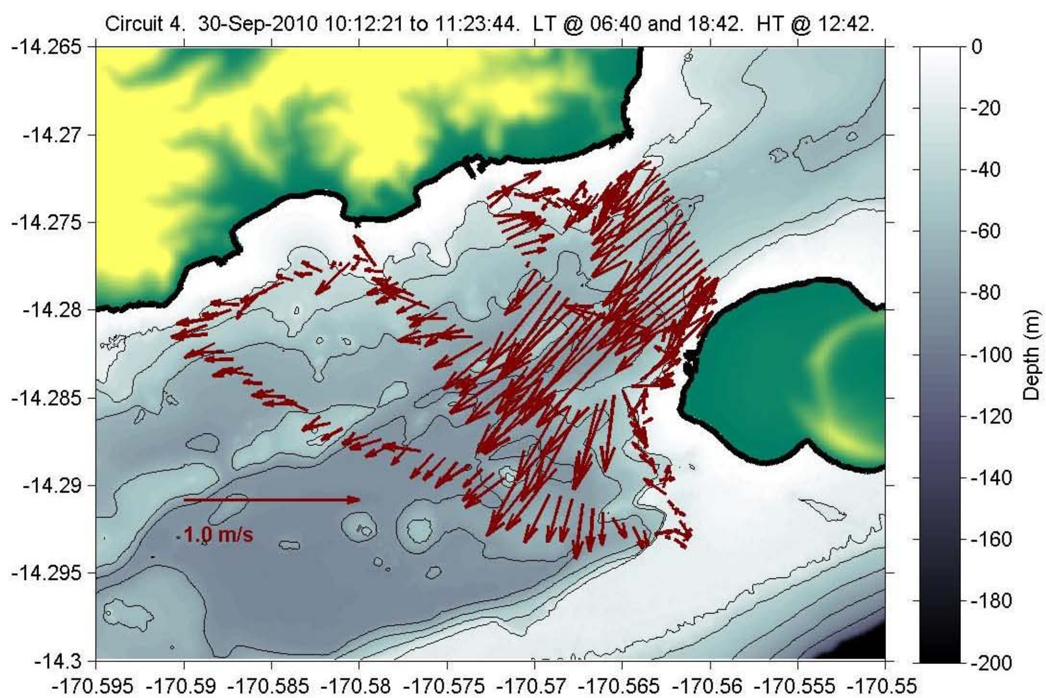
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Depth (m)
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-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
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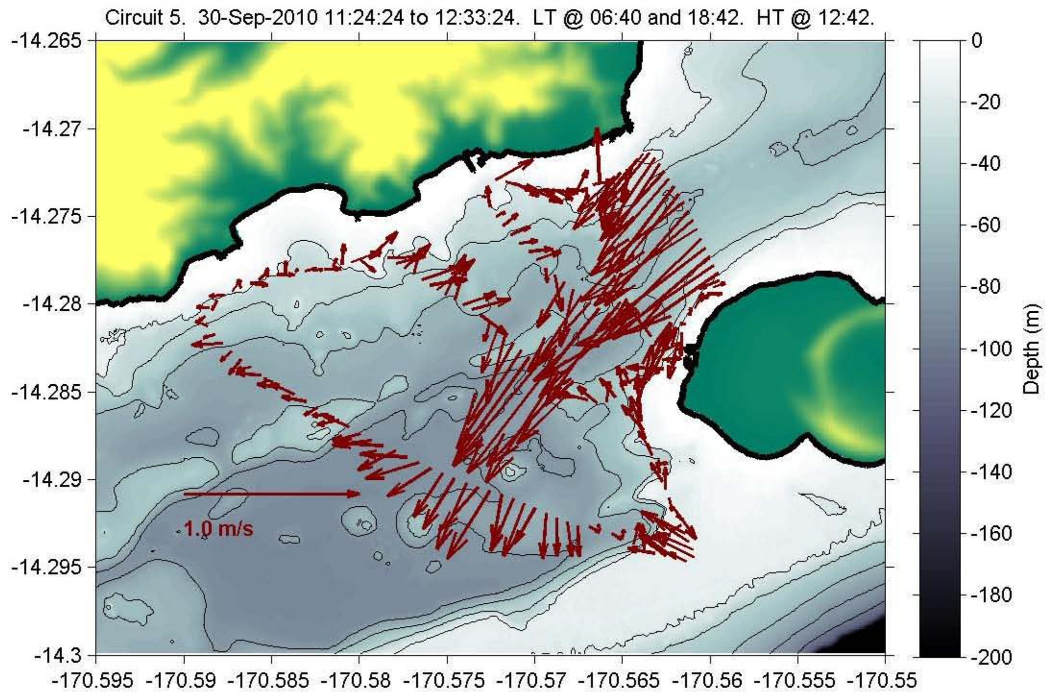

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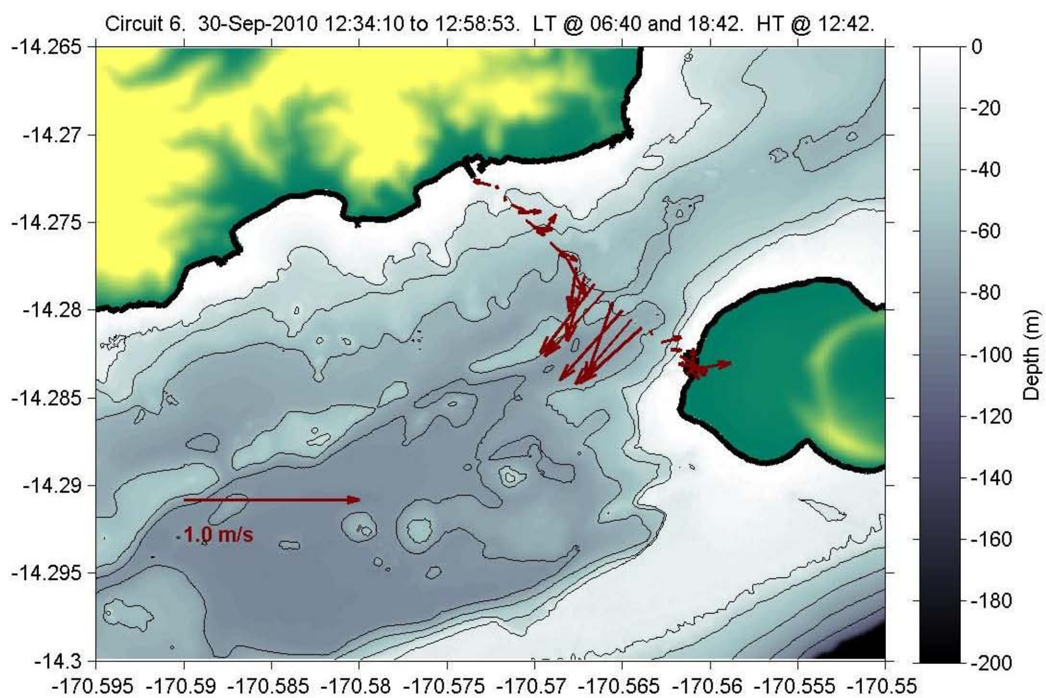
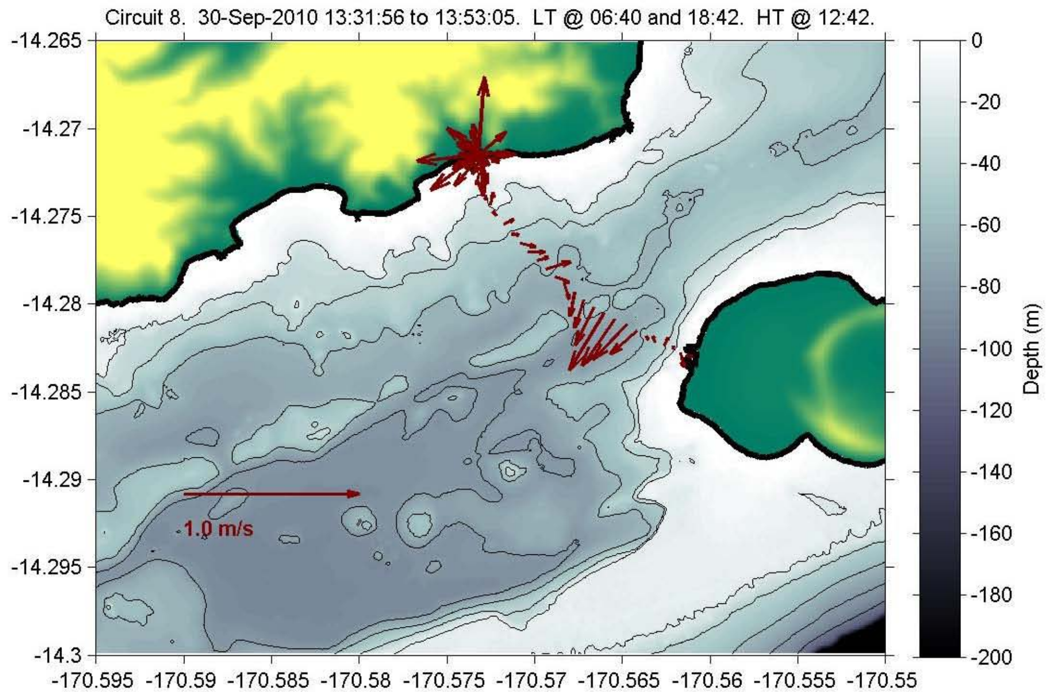
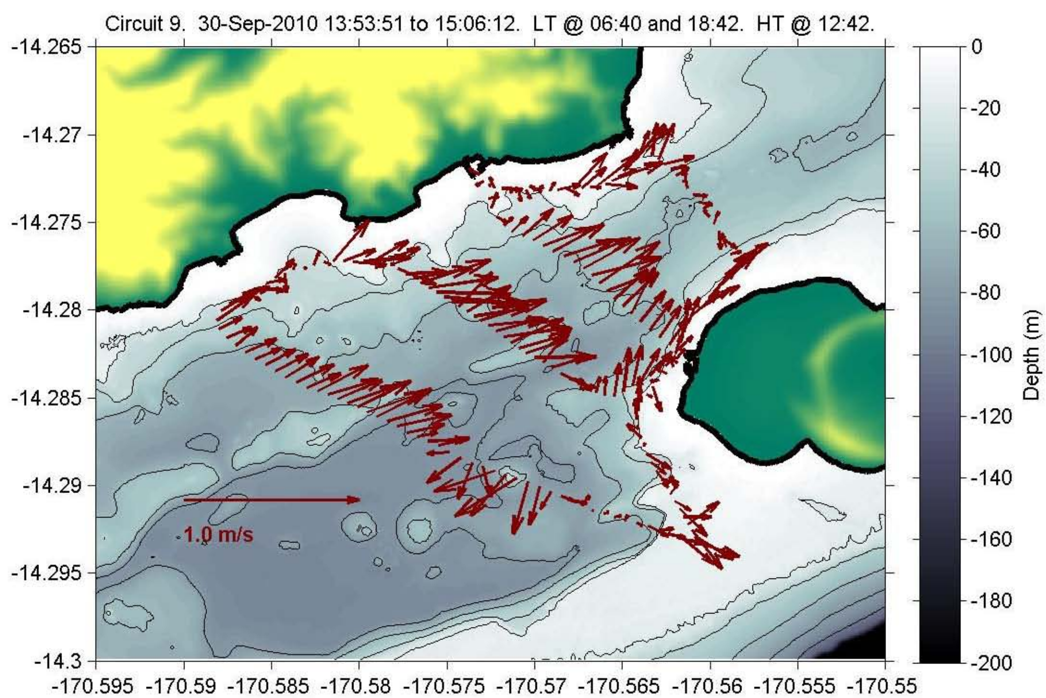
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)



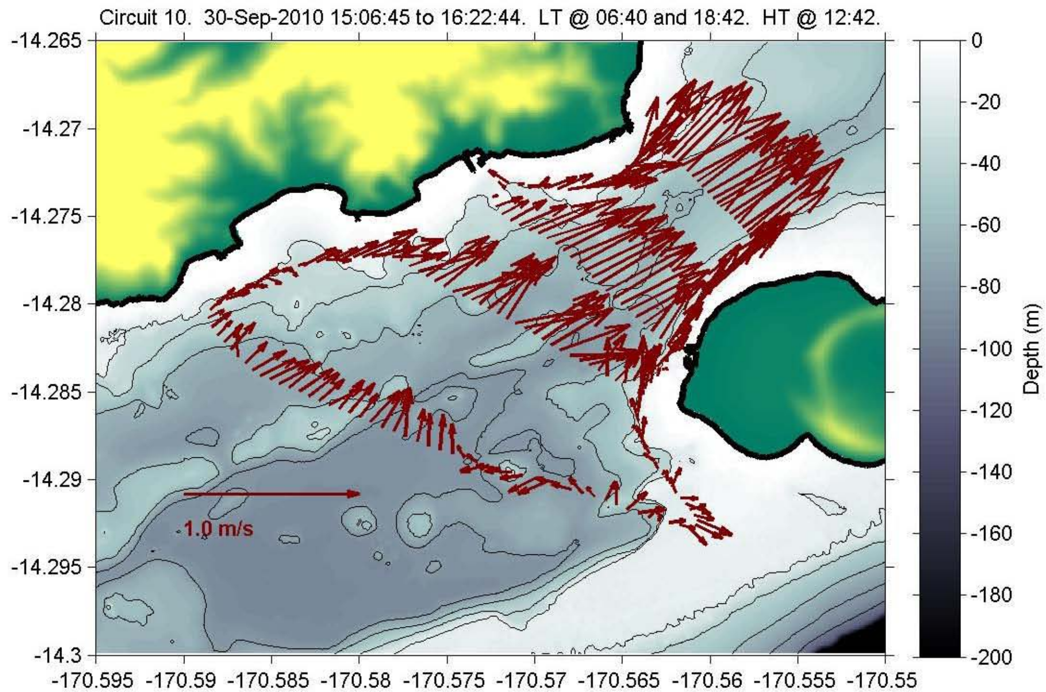
Circuit 6. 30-Sep-2010 12:34:10 to 12:58:53. LT @ 06:40 and 18:42. HT @ 12:42.
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)

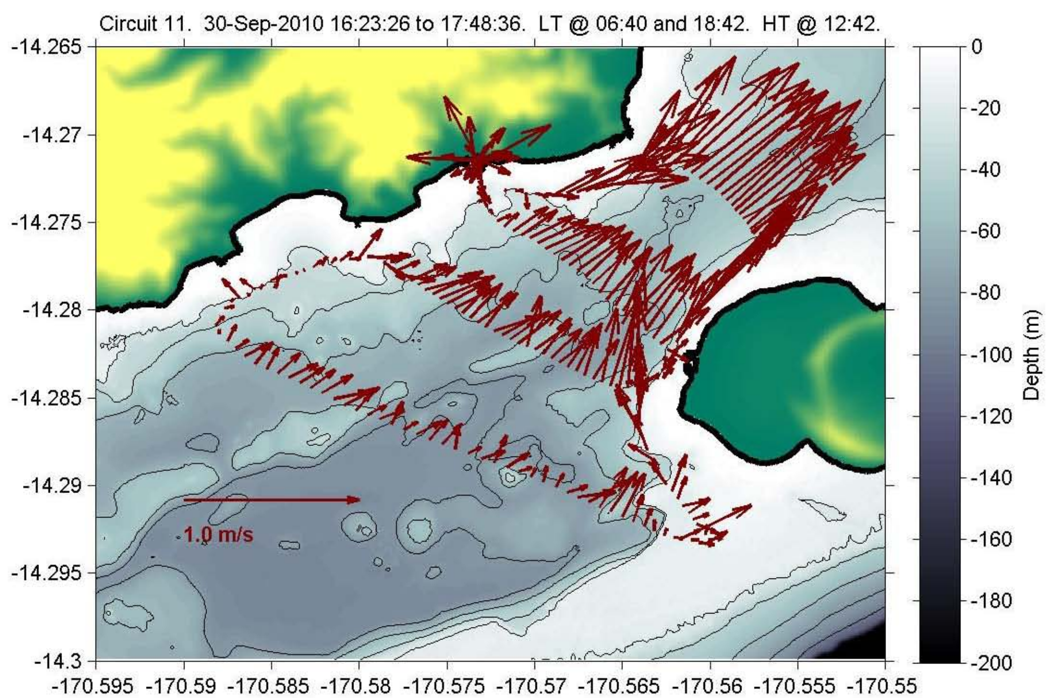


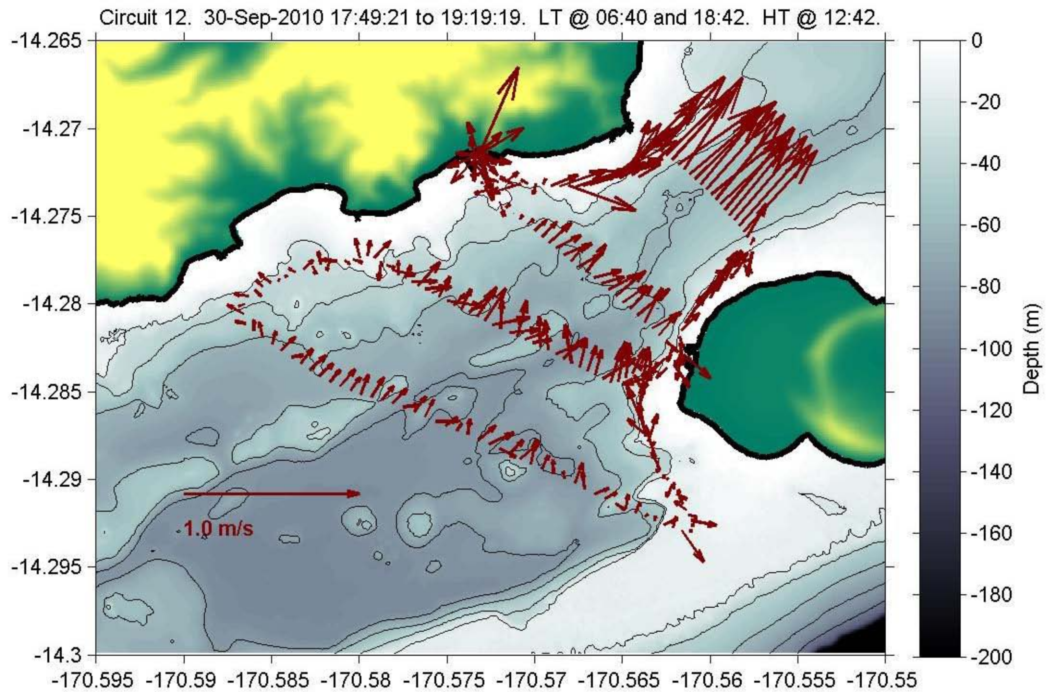
Circuit 8. 30-Sep-2010 13:31:56 to 13:53:05. LT @ 06:40 and 18:42. HT @ 12:42.
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)



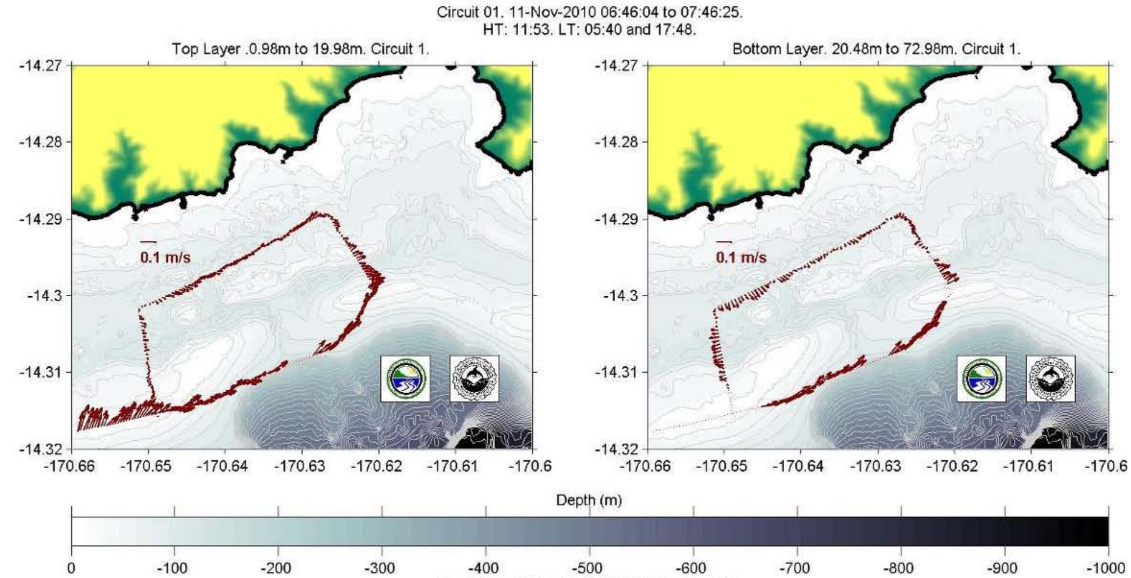
Circuit 9. 30-Sep-2010 13:53:51 to 15:06:12. LT @ 06:40 and 18:42. HT @ 12:42.
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)

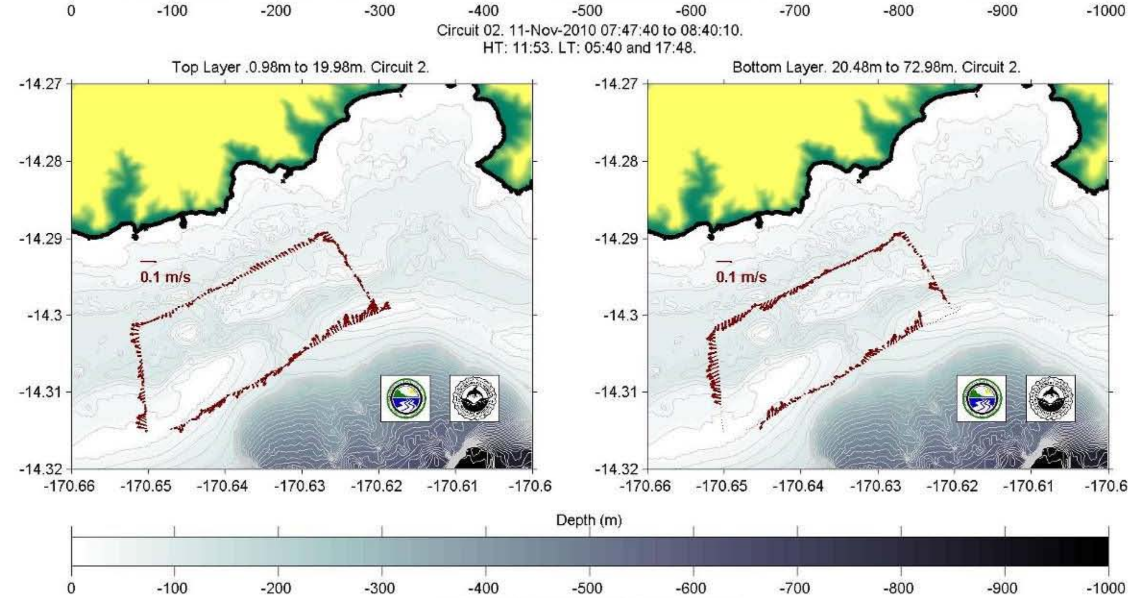

Circuit 10. 30-Sep-2010 15:06:45 to 16:22:44. LT @ 06:40 and 18:42. HT @ 12:42.
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)

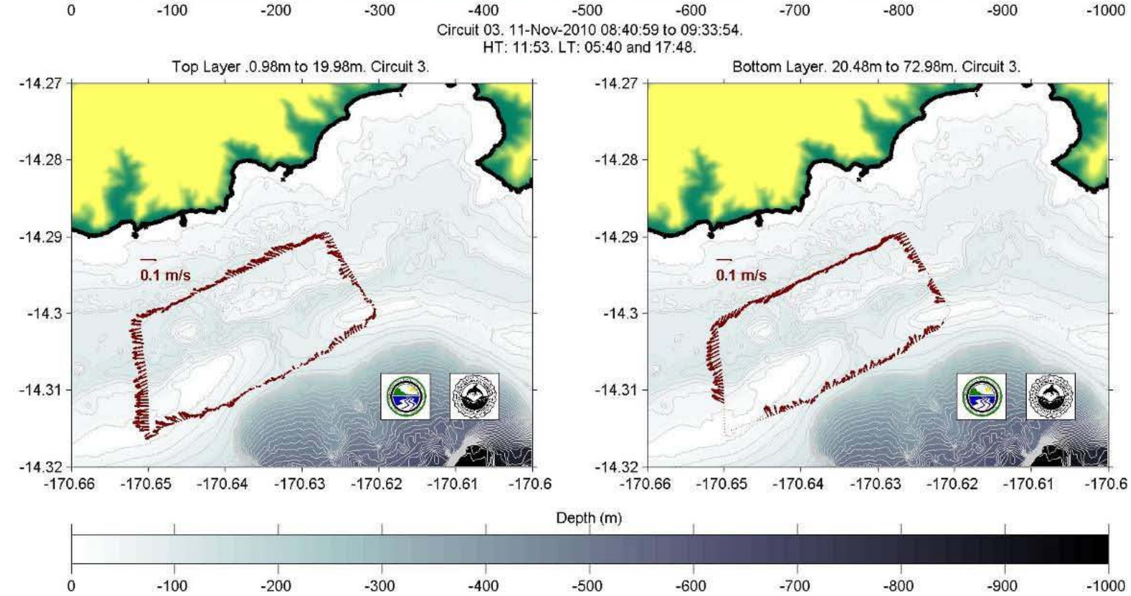

Circuit 11. 30-Sep-2010 16:23:26 to 17:48:36. LT @ 06:40 and 18:42. HT @ 12:42.
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
1.0 m/s
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
Depth (m)

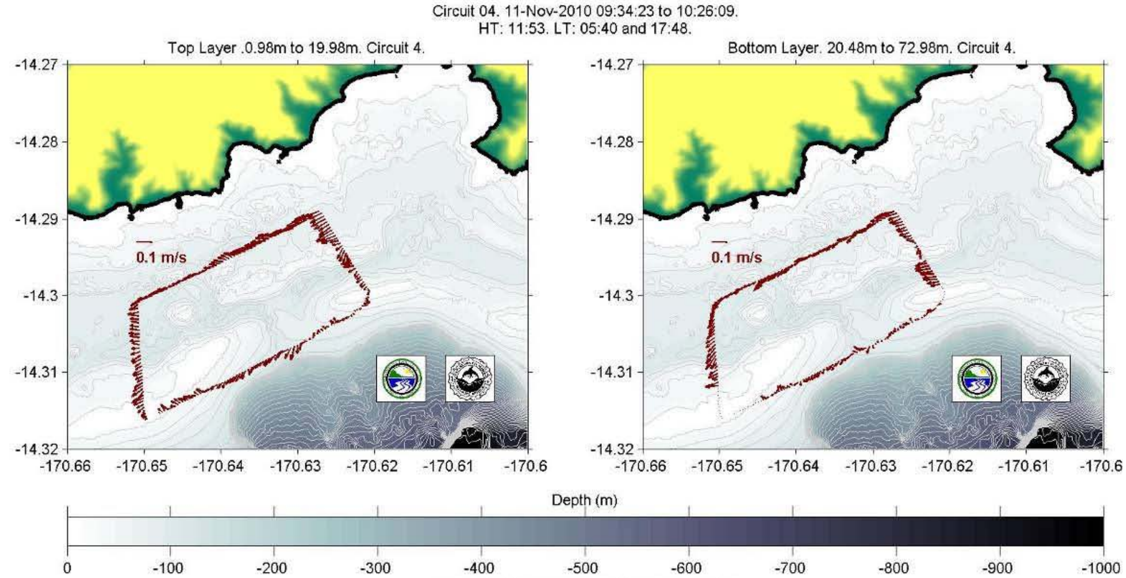

Circuit 12. 30-Sep-2010 17:49:21 to 19:19:19. LT @ 06:40 and 18:42. HT @ 12:42.
1.0 m/s
Depth (m)
-14.265
-14.27
-14.275
-14.28
-14.285
-14.29
-14.295
-14.3
-170.595 -170.59 -170.585 -170.58 -170.575 -170.57 -170.565 -170.56 -170.555 -170.55
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200

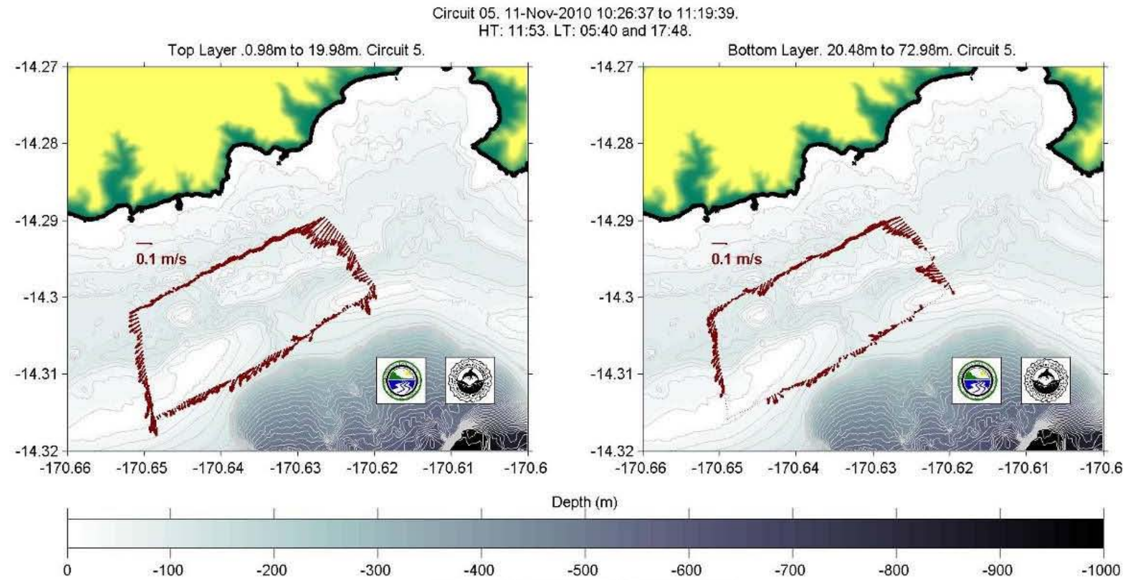
Taema Data

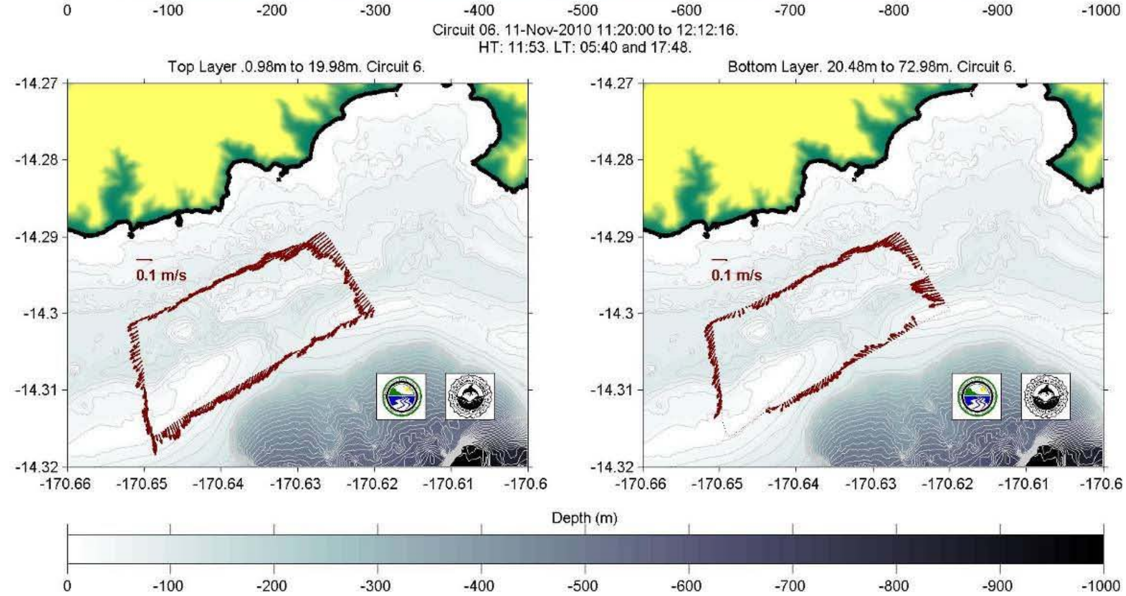

Circuit 01. 11-Nov-2010 06:46:04 to 07:46:25.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 1.
Bottom Layer. 20.48m to 72.98m. Circuit 1.
0.1 m/s
-14.27
-14.28
-14.29
-14.3
-14.31
-14.32
-170.66
-170.65
-170.64
-170.63
-170.62
-170.61
-170.6
Depth (m)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000

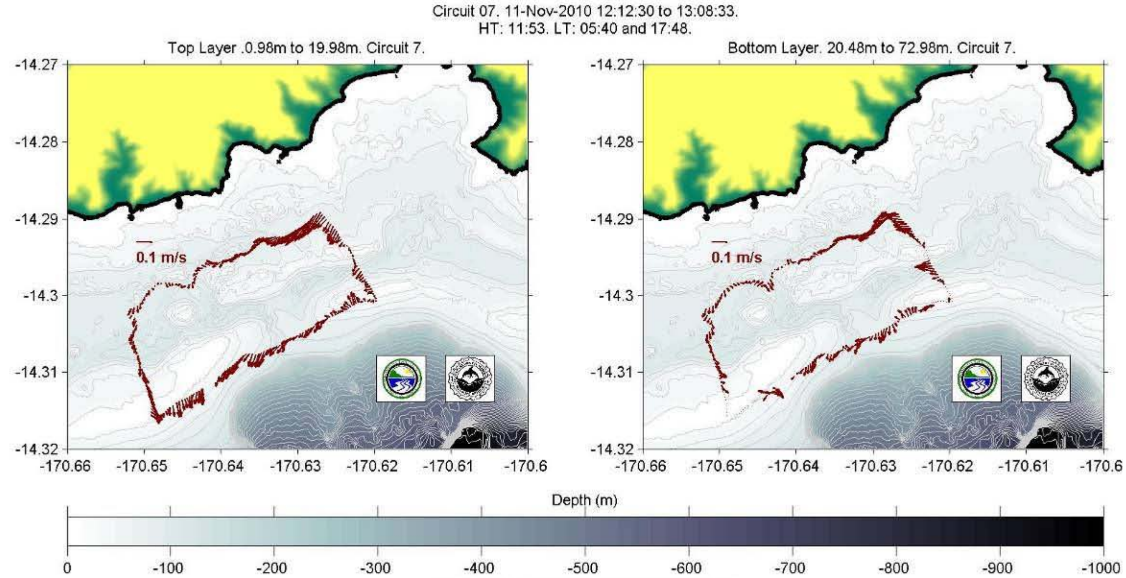

Circuit 02. 11-Nov-2010 07:47:40 to 08:40:10.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 2.
Bottom Layer. 20.48m to 72.98m. Circuit 2.
0.1 m/s
Depth (m)

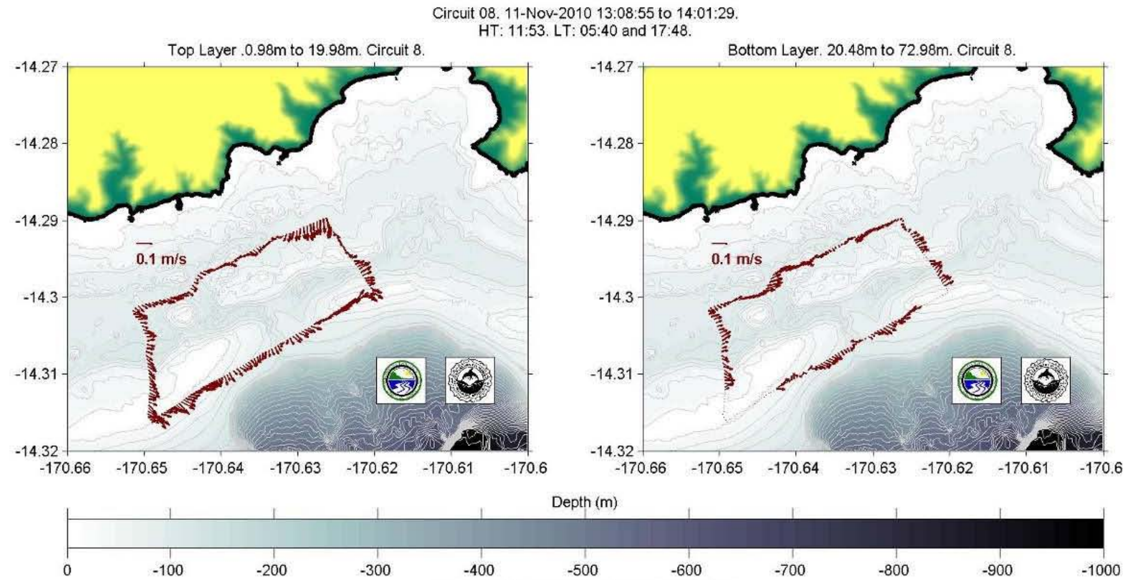

Circuit 03. 11-Nov-2010 08:40:59 to 09:33:54.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 3.
Bottom Layer. 20.48m to 72.98m. Circuit 3.
0.1 m/s
Depth (m)

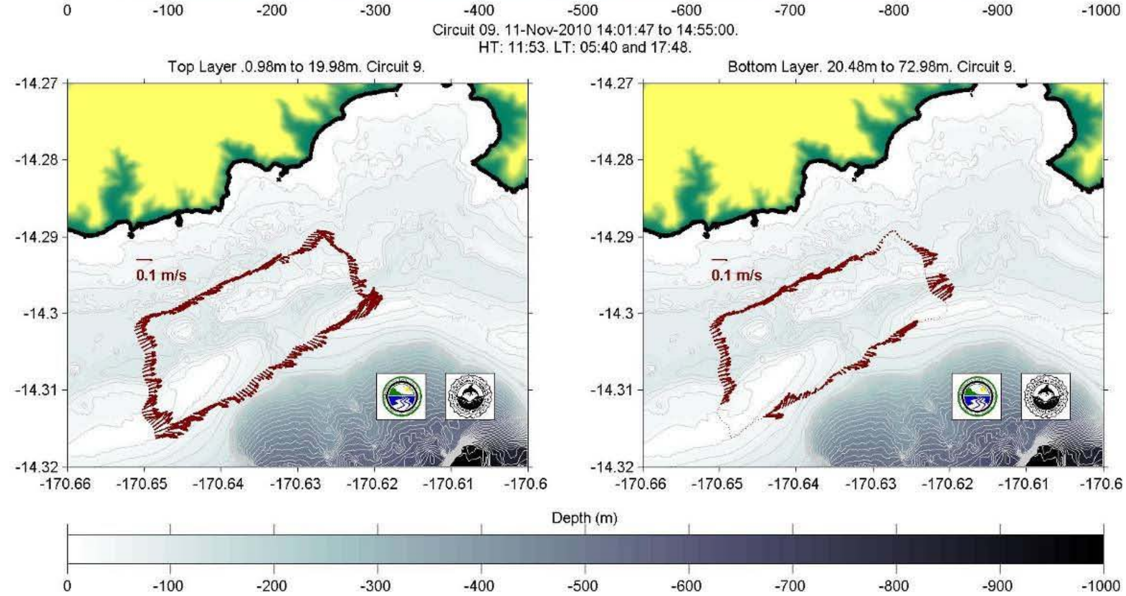

Circuit 04. 11-Nov-2010 09:34:23 to 10:26:09.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 4.
Bottom Layer. 20.48m to 72.98m. Circuit 4.
0.1 m/s
Depth (m)

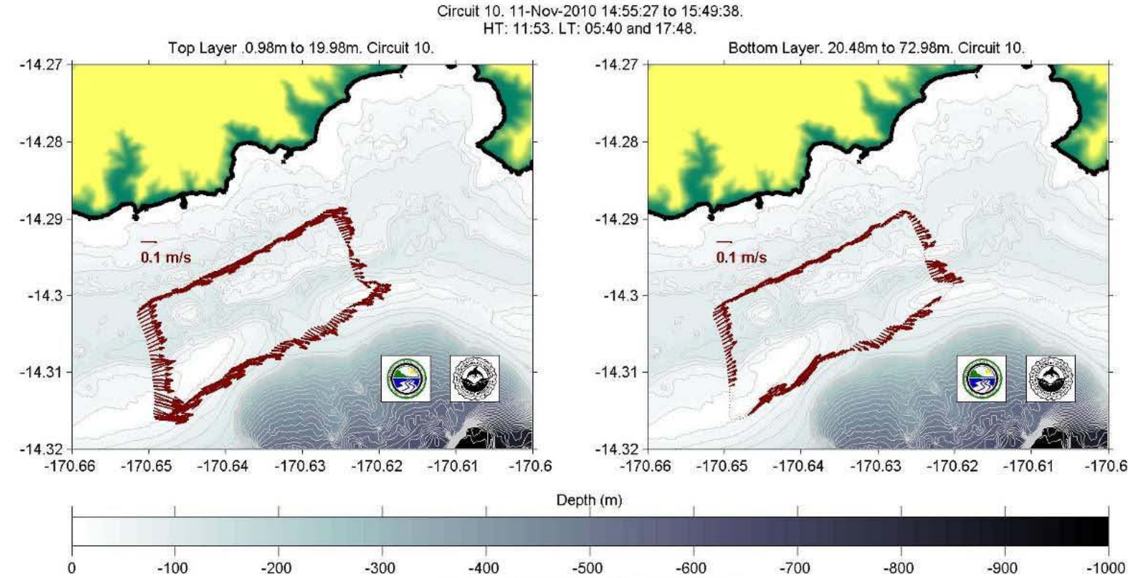

Circuit 05. 11-Nov-2010 10:26:37 to 11:19:39.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 5.
Bottom Layer. 20.48m to 72.98m. Circuit 5.
0.1 m/s
Depth (m)

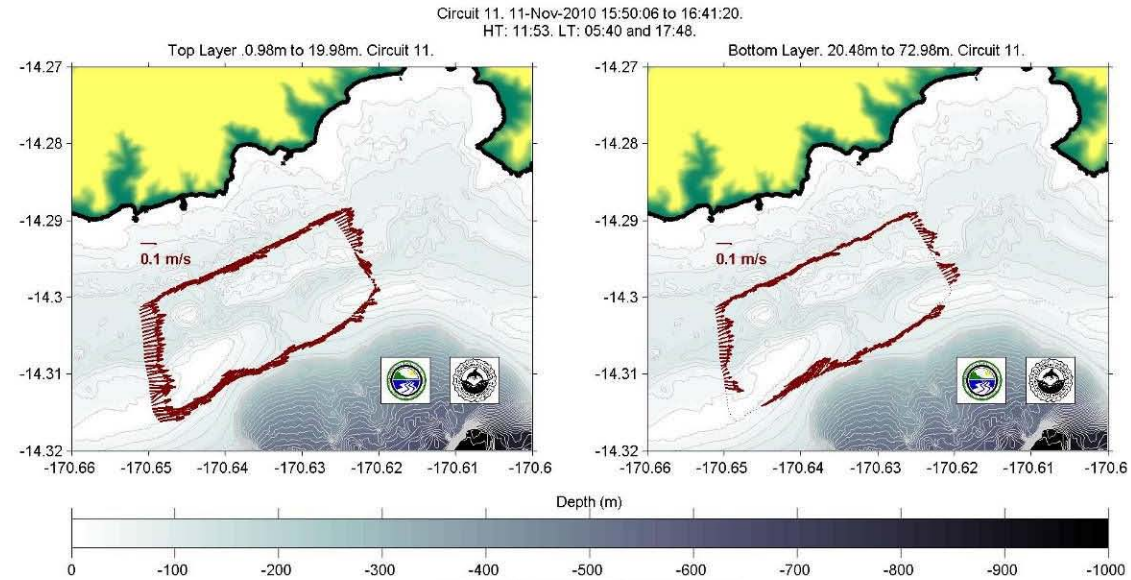

Circuit 06. 11-Nov-2010 11:20:00 to 12:12:16.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 6.
Bottom Layer. 20.48m to 72.98m. Circuit 6.
0.1 m/s
Depth (m)

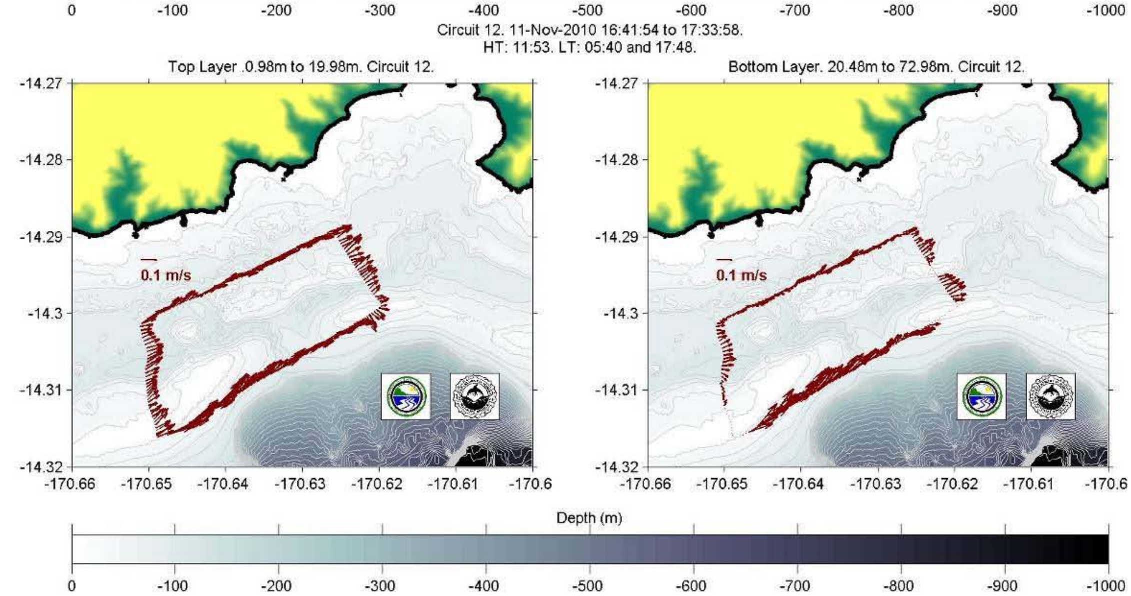

Circuit 07. 11-Nov-2010 12:12:30 to 13:08:33.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 7.
Bottom Layer. 20.48m to 72.98m. Circuit 7.
0.1 m/s
Depth (m)


Circuit 08. 11-Nov-2010 13:08:55 to 14:01:29.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 8.
Bottom Layer. 20.48m to 72.98m. Circuit 8.
0.1 m/s
Depth (m)

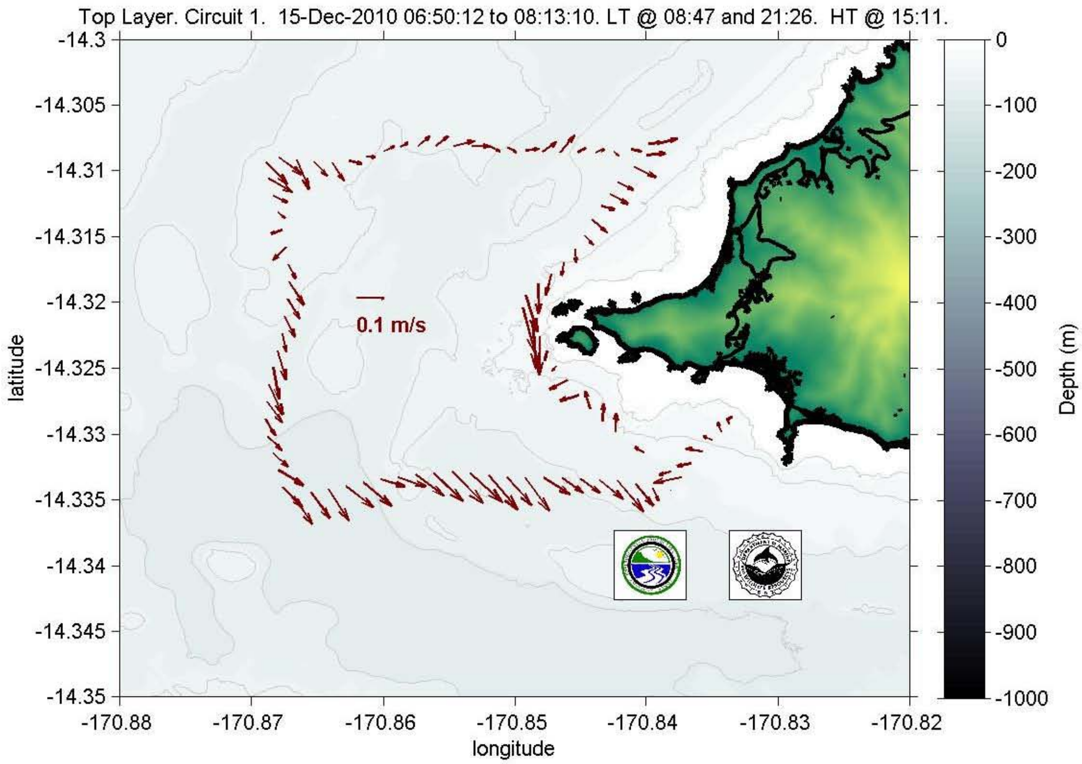

Circuit 09. 11-Nov-2010 14:01:47 to 14:55:00.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 9.
Bottom Layer. 20.48m to 72.98m. Circuit 9.
0.1 m/s
Depth (m)

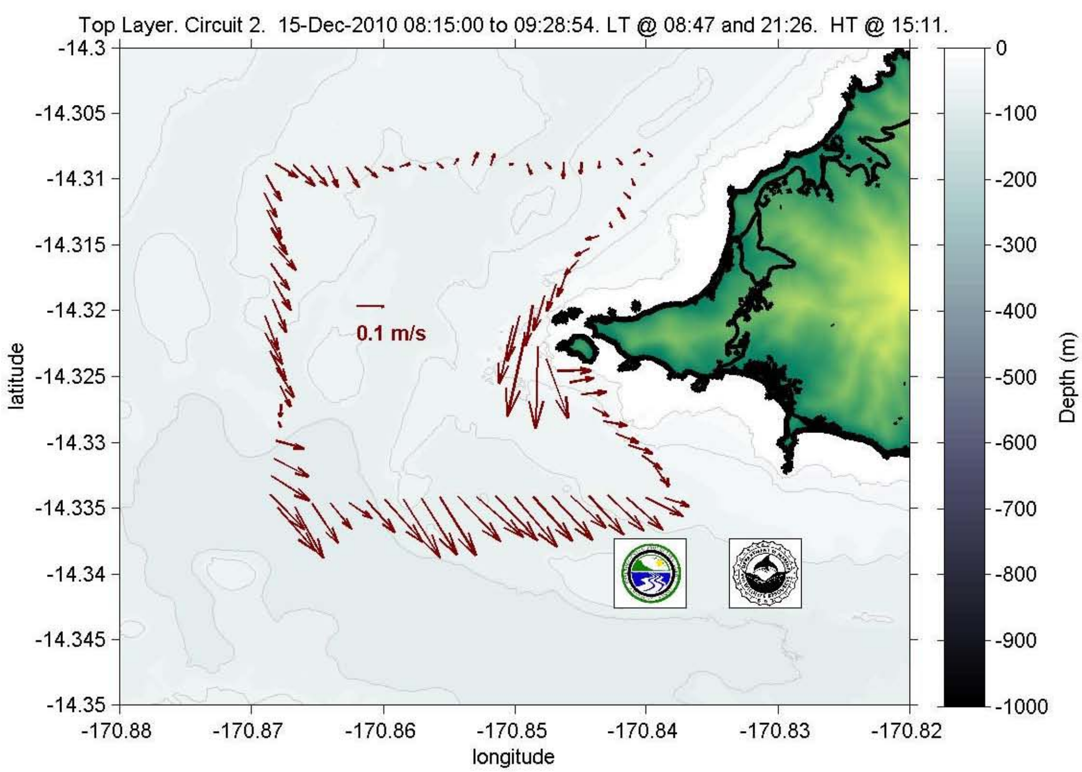

Circuit 10. 11-Nov-2010 14:55:27 to 15:49:38.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 10.
Bottom Layer. 20.48m to 72.98m. Circuit 10.
0.1 m/s
Depth (m)

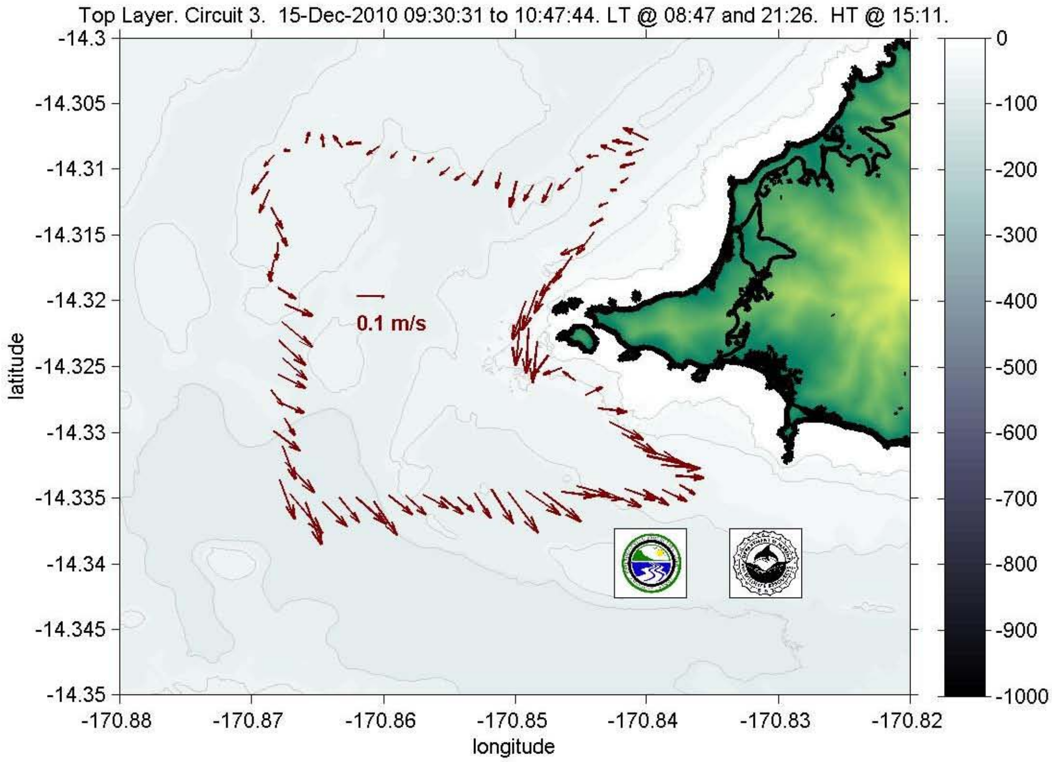

Circuit 11. 11-Nov-2010 15:50:06 to 16:41:20.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 11.
Bottom Layer. 20.48m to 72.98m. Circuit 11.
0.1 m/s
Depth (m)

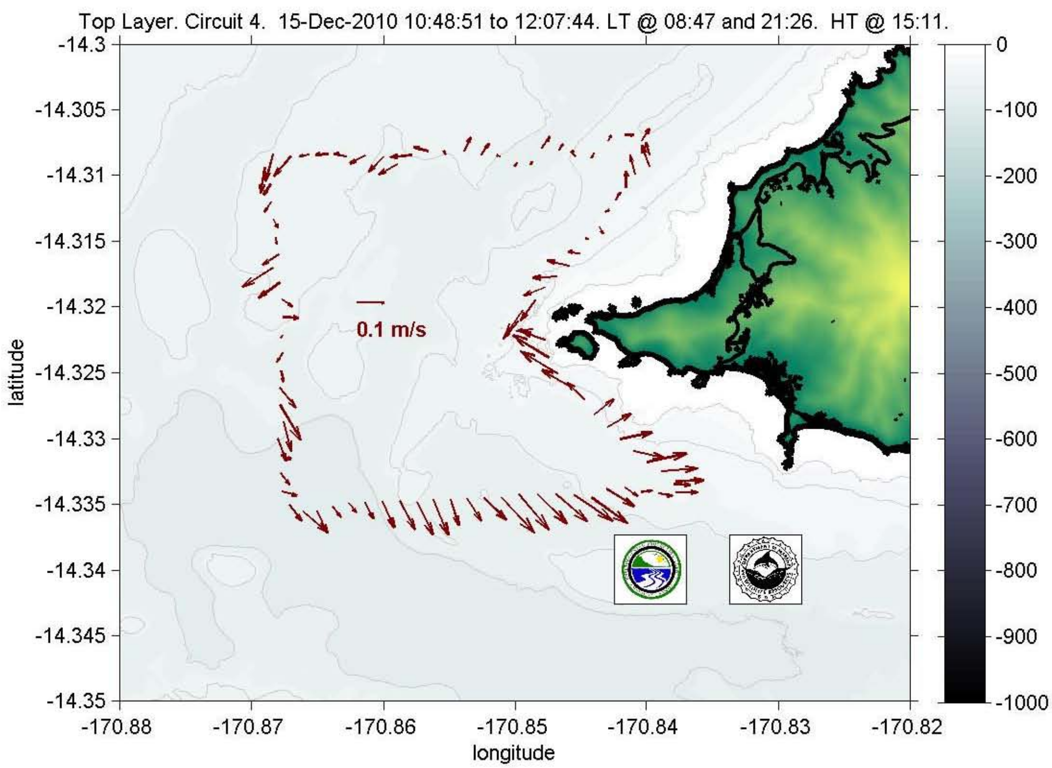

Circuit 12. 11-Nov-2010 16:41:54 to 17:33:58.
HT: 11:53. LT: 05:40 and 17:48.
Top Layer .0.98m to 19.98m. Circuit 12.
Bottom Layer. 20.48m to 72.98m. Circuit 12.
0.1 m/s
Depth (m)

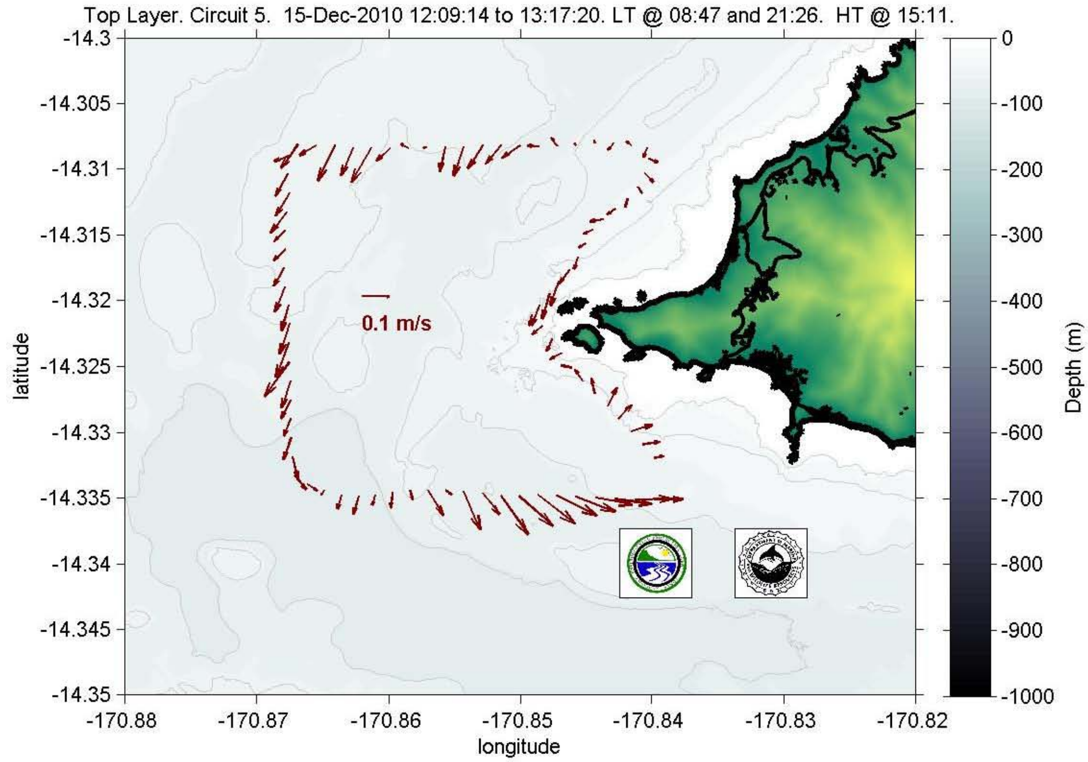
Amanave Data



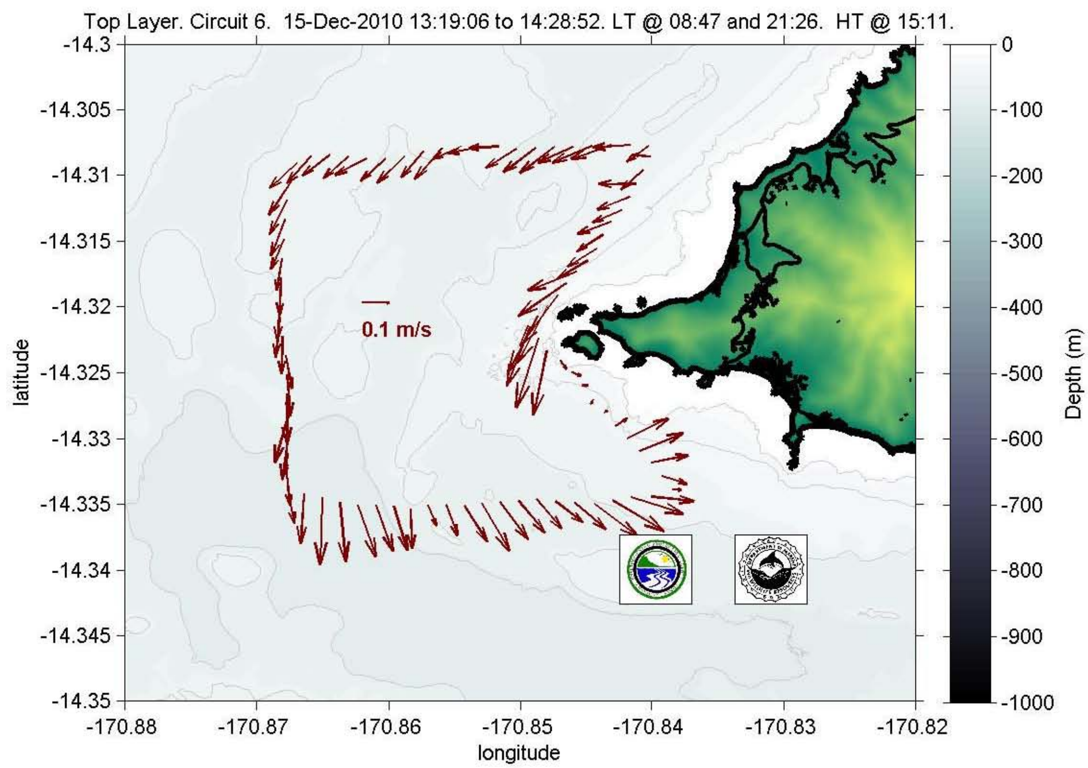



Top Layer. Circuit 3. 15-Dec-2010 09:30:31 to 10:47:44. LT @ 08:47 and 21:26. HT @ 15:11.
0.1 m/s
latitude
longitude
Depth (m)
-14.3
-14.305
-14.31
-14.315
-14.32
-14.325
-14.33
-14.335
-14.34
-14.345
-14.35
-170.88
-170.87
-170.86
-170.85
-170.84
-170.83
-170.82
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000

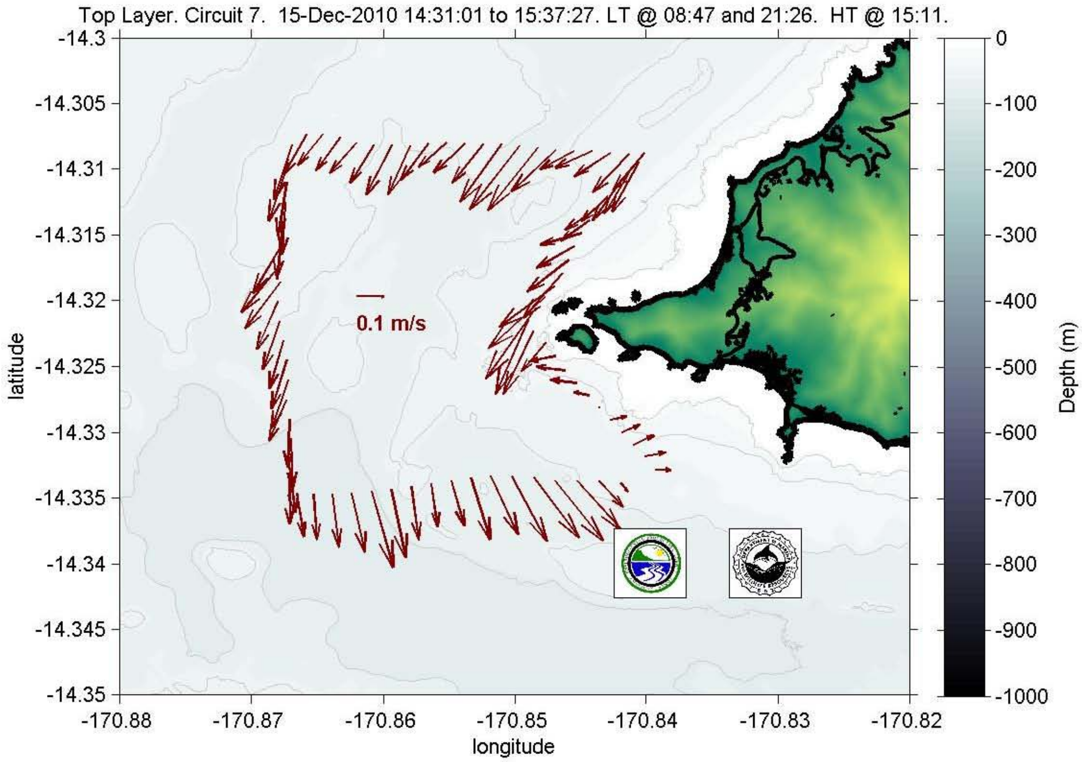

Top Layer. Circuit 4. 15-Dec-2010 10:48:51 to 12:07:44. LT @ 08:47 and 21:26. HT @ 15:11.
0.1 m/s
latitude
longitude
Depth (m)
-14.3
-14.305
-14.31
-14.315
-14.32
-14.325
-14.33
-14.335
-14.34
-14.345
-14.35
-170.88
-170.87
-170.86
-170.85
-170.84
-170.83
-170.82
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000

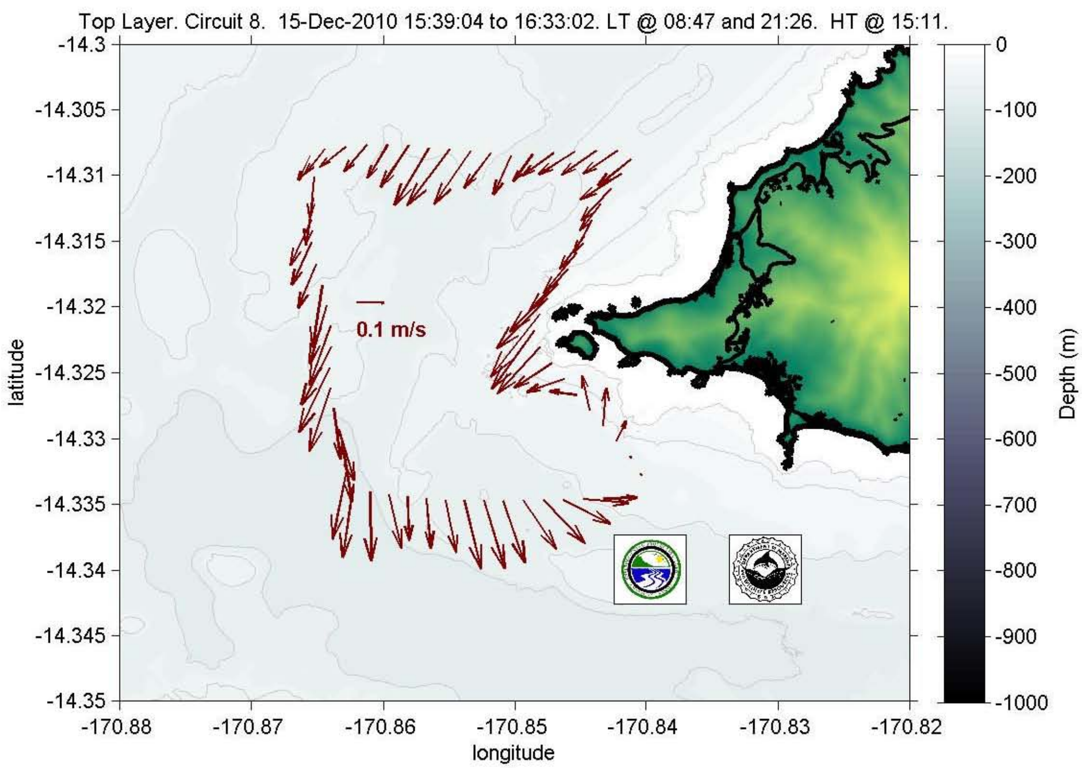


Top Layer. Circuit 5. 15-Dec-2010 12:09:14 to 13:17:20. LT @ 08:47 and 21:26. HT @ 15:11.
latitude
longitude
0.1 m/s
Depth (m)

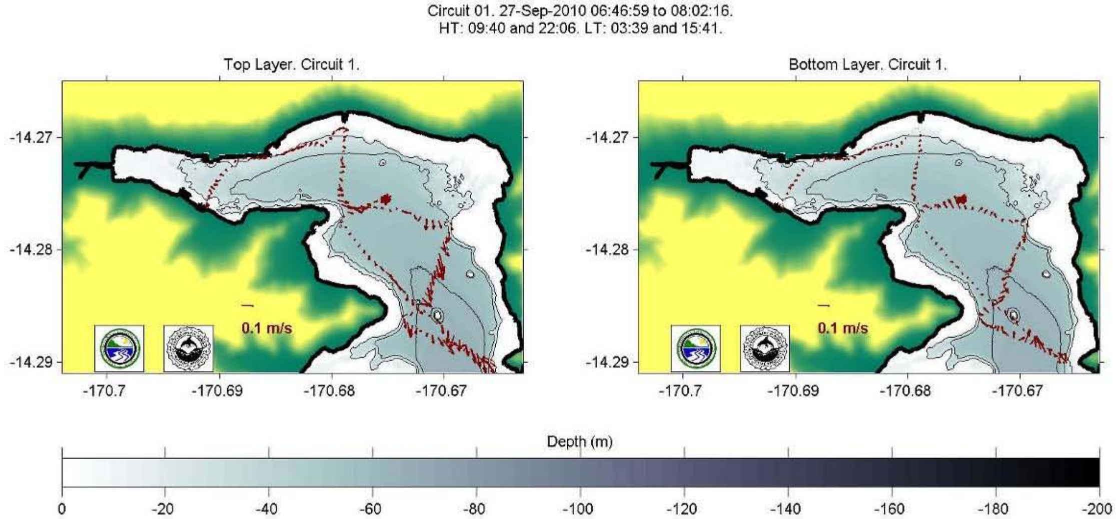


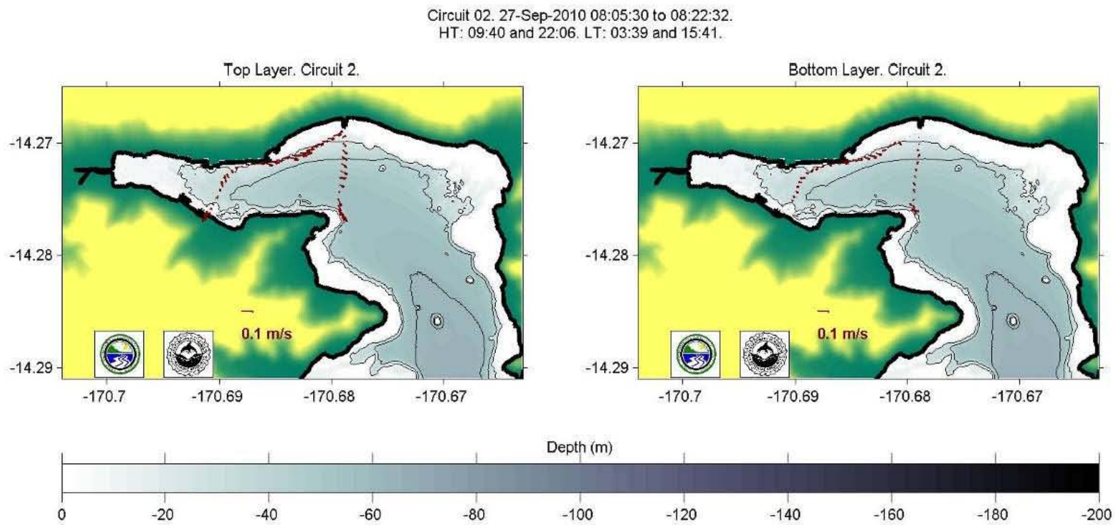
Top Layer. Circuit 6. 15-Dec-2010 13:19:06 to 14:28:52. LT @ 08:47 and 21:26. HT @ 15:11.
latitude
longitude
0.1 m/s
Depth (m)

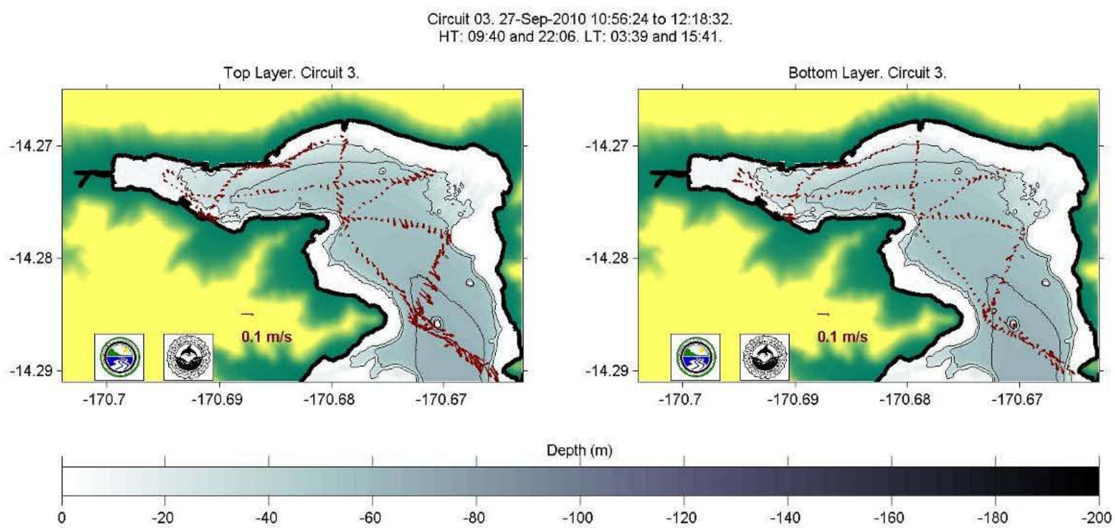

Top Layer. Circuit 7. 15-Dec-2010 14:31:01 to 15:37:27. LT @ 08:47 and 21:26. HT @ 15:11.
0.1 m/s
latitude
longitude
Depth (m)
-14.3
-14.305
-14.31
-14.315
-14.32
-14.325
-14.33
-14.335
-14.34
-14.345
-14.35
-170.88
-170.87
-170.86
-170.85
-170.84
-170.83
-170.82
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000


Top Layer. Circuit 8. 15-Dec-2010 15:39:04 to 16:33:02. LT @ 08:47 and 21:26. HT @ 15:11.
0.1 m/s
latitude
longitude
Depth (m)
-14.3
-14.305
-14.31
-14.315
-14.32
-14.325
-14.33
-14.335
-14.34
-14.345
-14.35
-170.88
-170.87
-170.86
-170.85
-170.84
-170.83
-170.82
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000

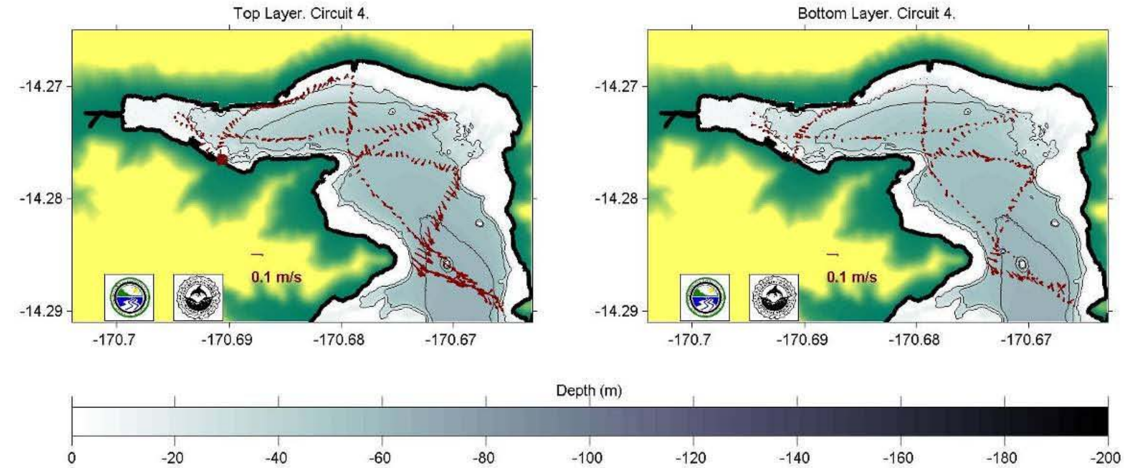
Pago Harbor Data



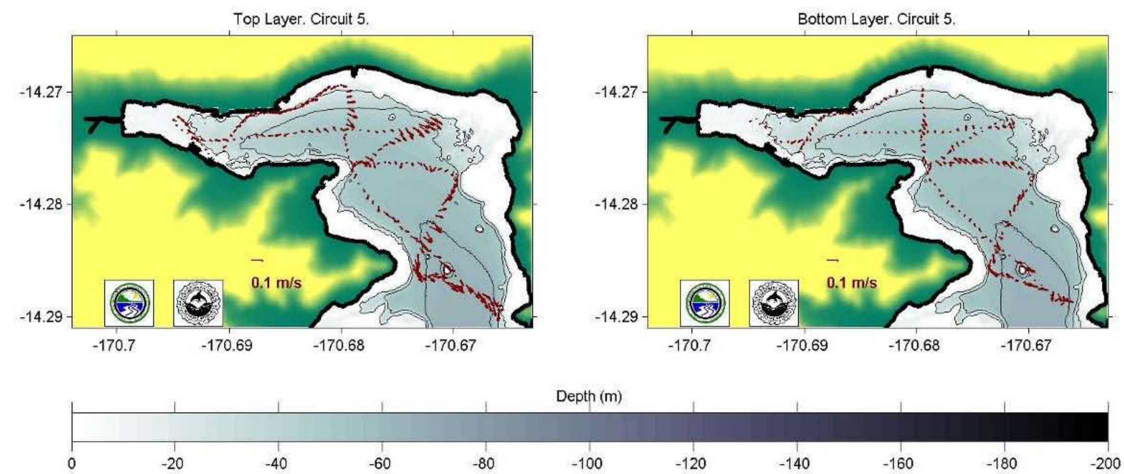




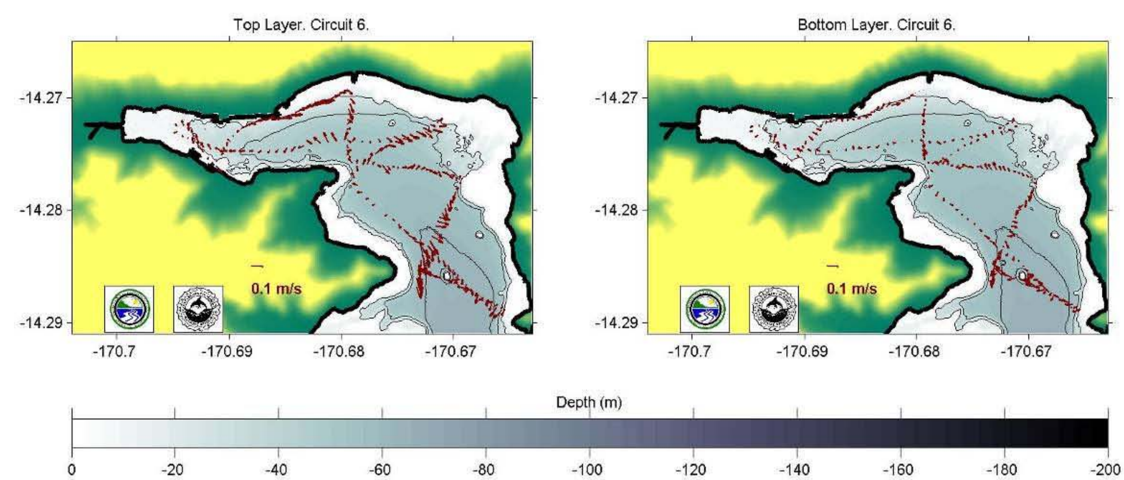
Circuit 04. 27-Sep-2010 12:19:09 to 13:36:21.
HT: 09:40 and 22:06. LT: 03:39 and 15:41.

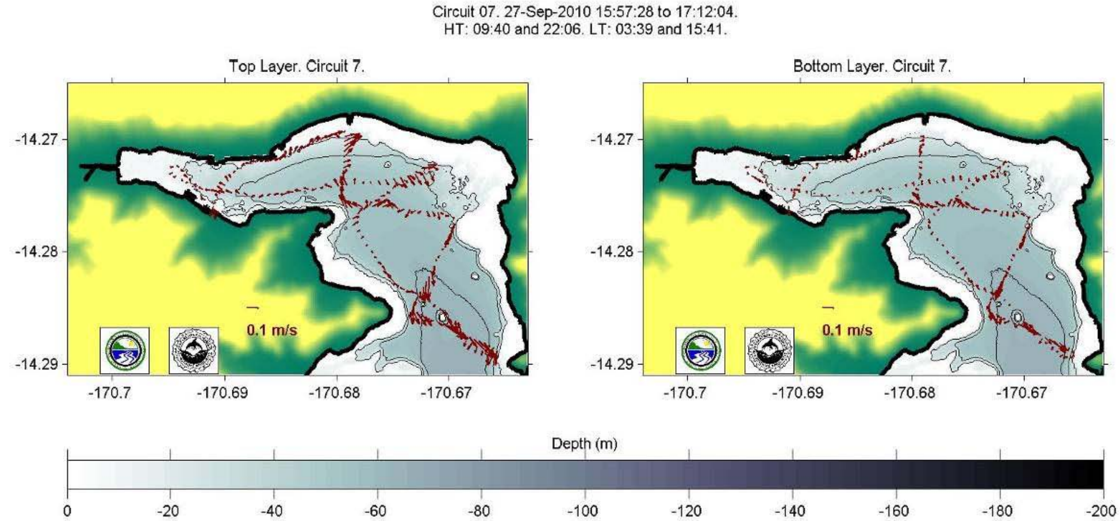


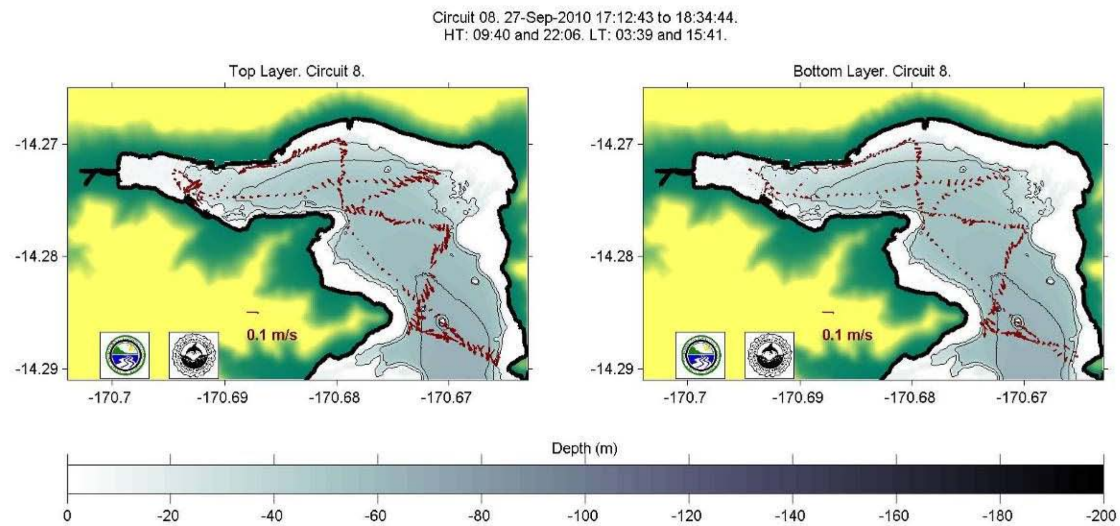
Circuit 05. 27-Sep-2010 13:37:38 to 14:45:33.
HT: 09:40 and 22:06. LT: 03:39 and 15:41.



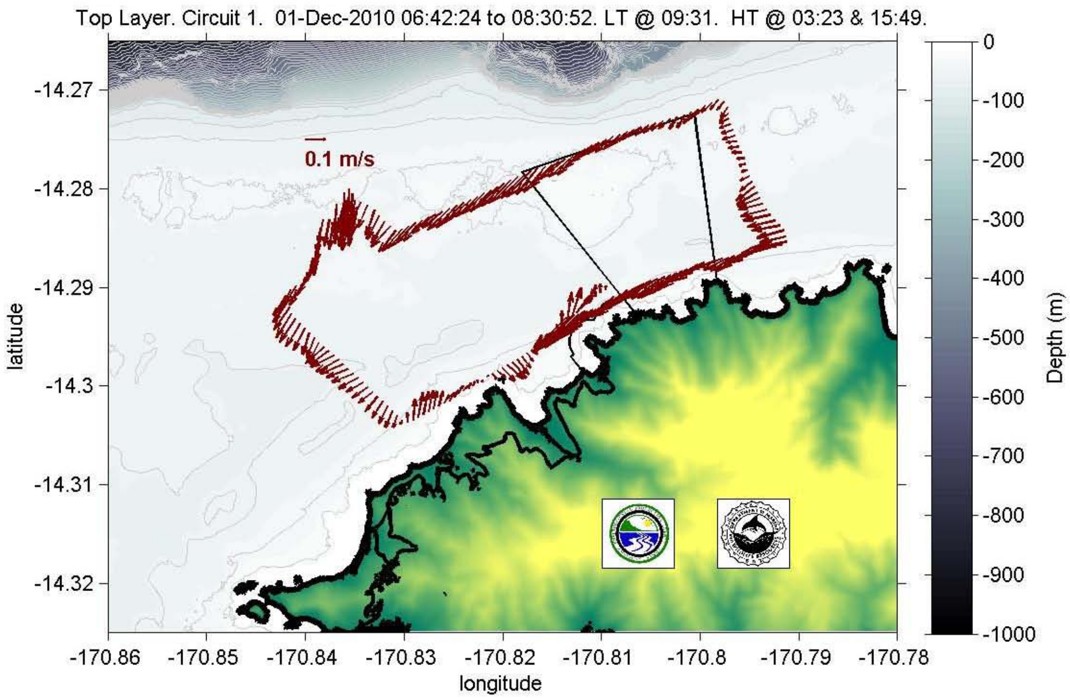
Circuit 06. 27-Sep-2010 14:46:18 to 15:56:47.
HT: 09:40 and 22:06. LT: 03:39 and 15:41.

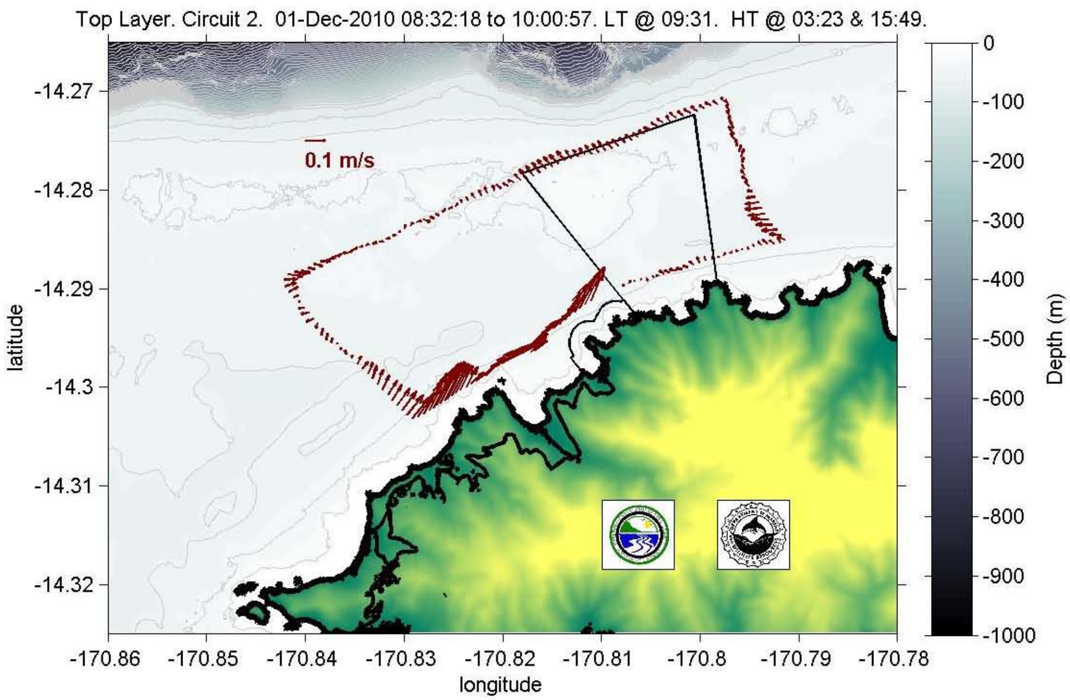



Circuit 07. 27-Sep-2010 15:57:28 to 17:12:04.
HT: 09:40 and 22:06. LT: 03:39 and 15:41.
Top Layer. Circuit 7.
Bottom Layer. Circuit 7.
0.1 m/s
-14.27
-14.28
-14.29
-170.7
-170.69
-170.68
-170.67
Depth (m)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200

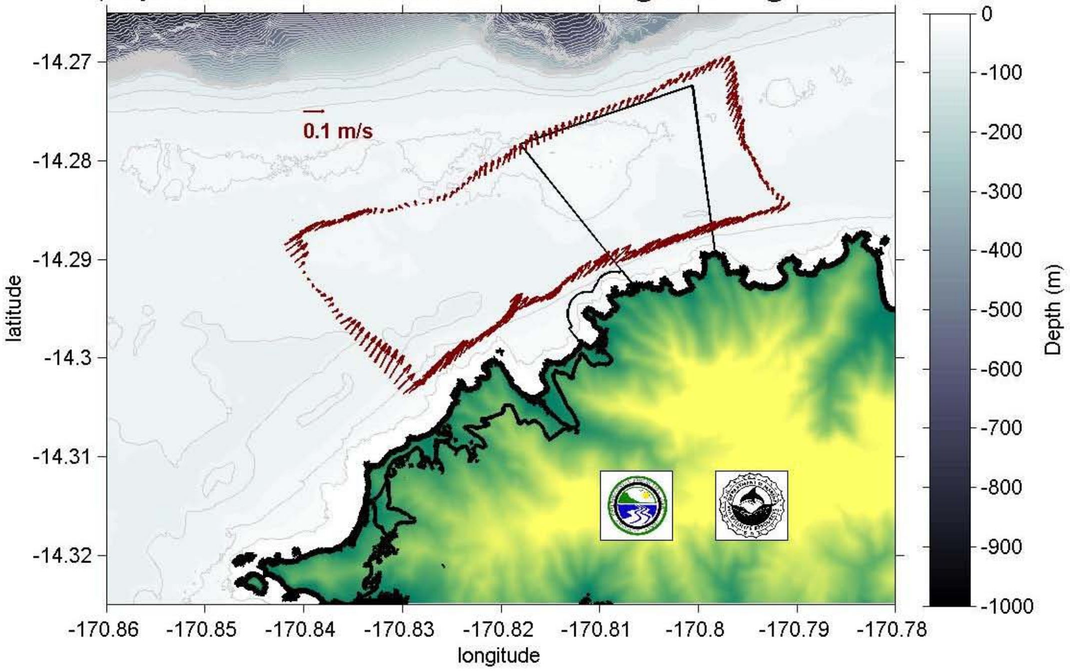

Circuit 08. 27-Sep-2010 17:12:43 to 18:34:44.
HT: 09:40 and 22:06. LT: 03:39 and 15:41.
Top Layer. Circuit 8.
Bottom Layer. Circuit 8.
0.1 m/s
-14.27
-14.28
-14.29
-170.7
-170.69
-170.68
-170.67
Depth (m)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200

Fagamalo Data

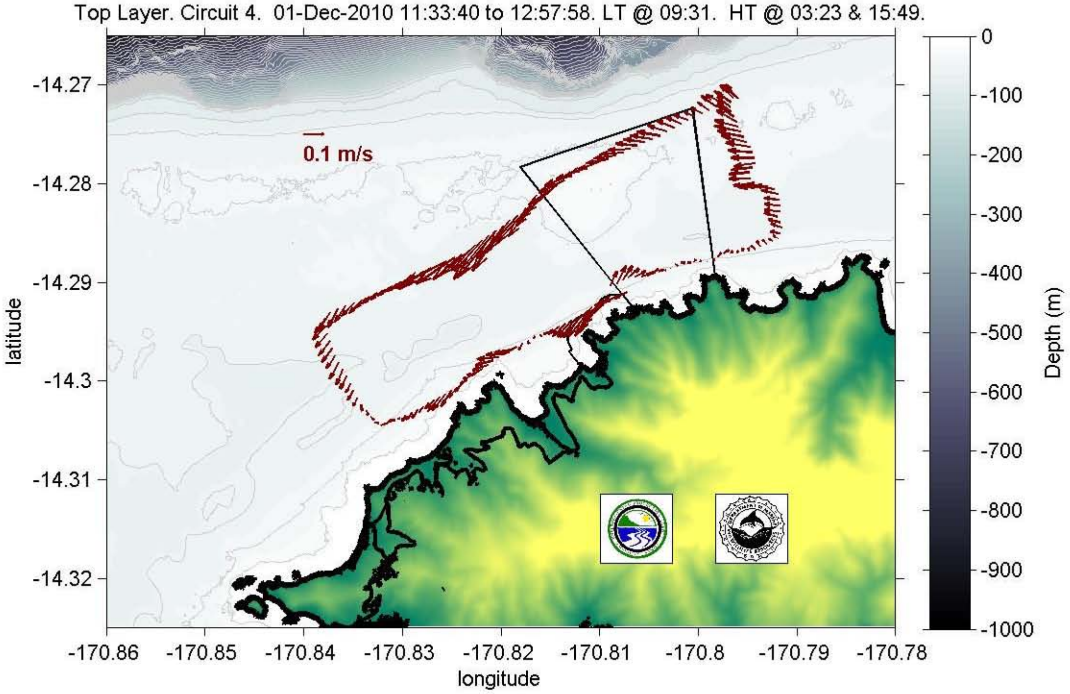




Top Layer. Circuit 3. 01-Dec-2010 10:02:00 to 11:32:23. LT @ 09:31. HT @ 03:23 & 15:49.



Top Layer. Circuit 4. 01-Dec-2010 11:33:40 to 12:57:58. LT @ 09:31. HT @ 03:23 & 15:49.



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