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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Preliminary Observations from the 2014 Sand Dunes Experiment

by

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14. ABSTRACT

The Sand Dunes 2014 experiment was international US – Taiwan oceanographic experiment sponsored by the Office of Naval Research (Ocean Acoustics, Physical Oceanography, and ONR Global). This was the primary experiment, following the 2013 pilot effort, designed to focus on acoustic propagation, reverberation, and fluctuations of sound intensity of nonlinear internal waves in a large amplitude sand dune field. The experiment was conducted over an 18-day period in June 2014, with 10 moorings deployed/recovered, operating from 3 Taiwanese research vessels. This report provides technical details of the moorings, quality and quantity of the data collected during this field effort. Further analysis and results will be published as scientific journal articles.

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ABSTRACT

The Sand Dunes 2014 experiment was international US – Taiwan oceanographic experiment sponsored by the Office of Naval Research (Ocean Acoustics, Physical Oceanography, and ONR Global). This was the primary experiment, following the 2013 pilot effort, designed to focus on acoustic propagation, reverberation, and fluctuations of sound intensity of nonlinear internal waves in a large amplitude sand dune field. The experiment was conducted over an 18-day period in June 2014, with 10 moorings deployed/recovered, operating from 3 Taiwanese research vessels. This report provides technical details of the moorings, quality and quantity of the data collected during this field effort. Further analysis and results will be published as scientific journal articles.

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Table of Contents

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List of Figures:

1.0 Introduction

The Sand Dunes experiment is a joint experiment conducted by Taiwan and US oceanographers to observe the effects of nonlinear internal wave interactions with a deep-water sand dune field in the Northeastern South China Sea.

The goal of the acoustics component of the Sand Dunes Experiment was to study the physics of sound propagation and quantify the associated fluctuations of sound intensity of nonlinear internal waves in a dune field. This experiment was conducted over an 18-day period in a ~350m depth region of the South China Sea shelf. This site was very near the area that the previous Asian Seas International Experiment (ASIAEx) and Windy Island Soliton Experiments (WISE), and Non-Linear Internal Wave Initiative (NLIWI) were conducted.

The purpose of this report is to provide the technical details of the moorings and data collected. Additional reports and external papers will document the scientific analysis and discoveries that result from this experiment, and will not be shown here.

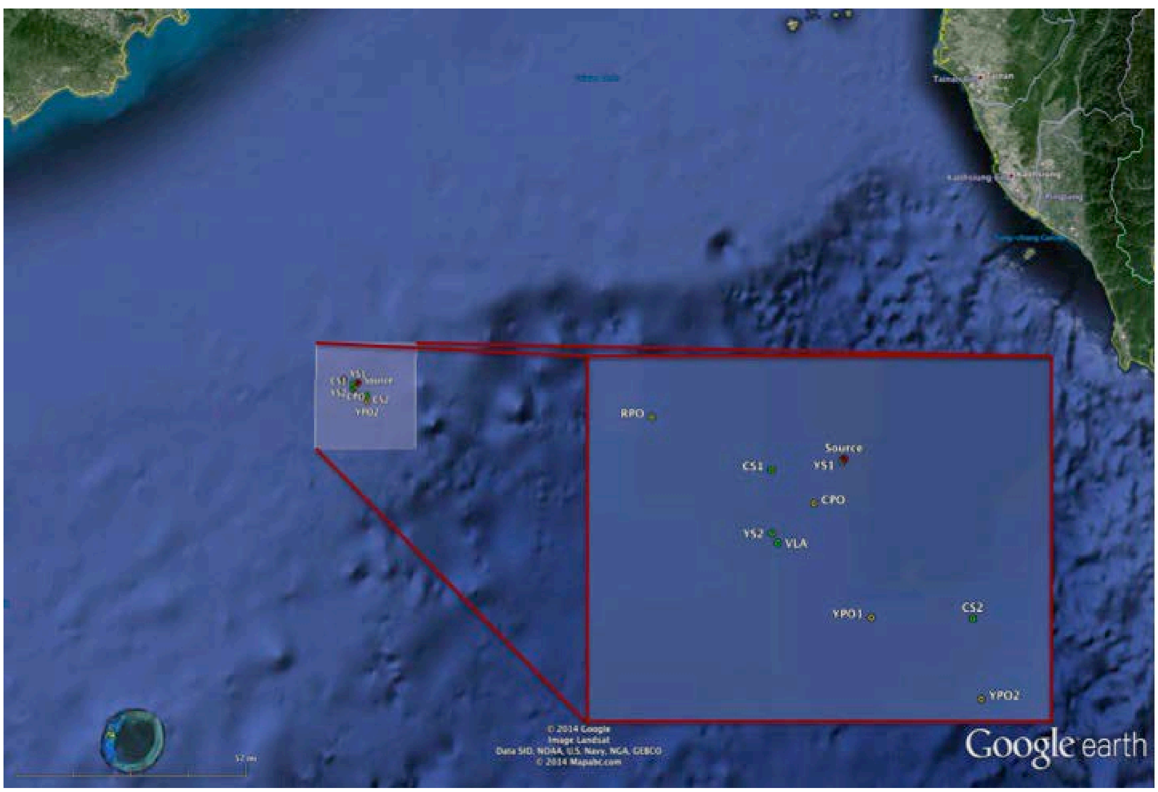

Figure 1. Sand Dunes 2014 experiment area. Taiwan visible in the upper, right corner; Mainland China in the upper left corner, and Dongsha Island (aka. Pratas Reef) in the lower left. Inset shows the relative mooring positions.

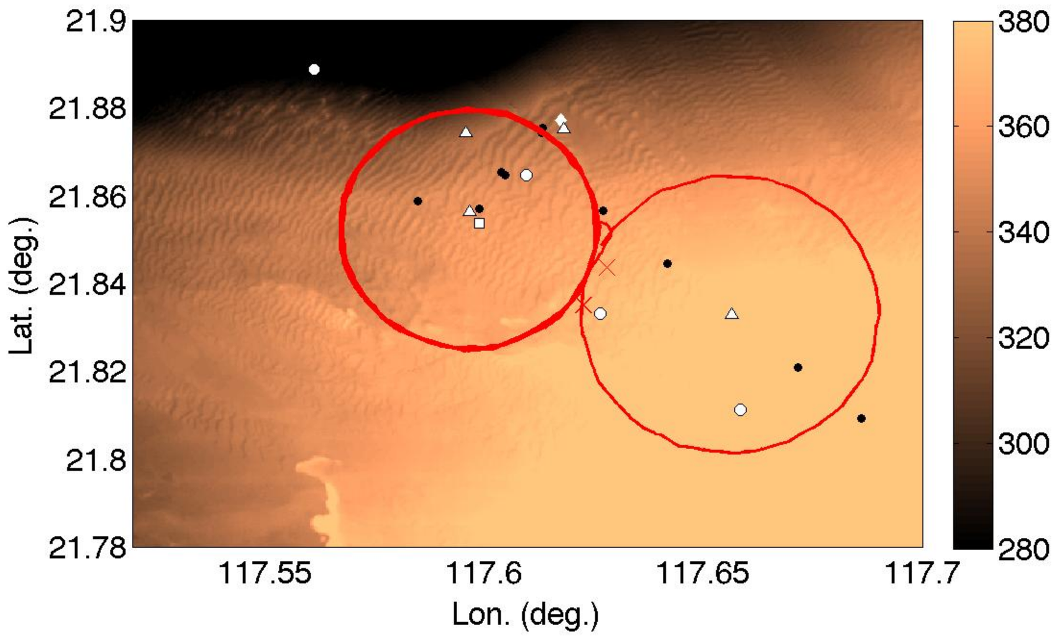

Figure 2. Sand Dunes 2014 Moorings, Cores, and Source Stations, over the 2013 surveyed bathymetry. Moorings shown in white (VLA = square, source = diamond, SHRU = triangles, physical oceanography = circles). Core stations (black circles), lowered source (red 'X'), and towed source (red line) are also shown.

2.0 Ocean Researcher 1 Cruise (31 May–5 June, 2014)

All moorings were deployed from the National Taiwan University research vessel *OCEAN RESEARCHER 1*, cruise #1076, conducted from May 31 – June 5, 2014. In addition to the mooring deployments, multiple CTD / Lowered ADCP (LADCP) casts were performed, and sediment box core samples were taken to provide additional information on the bottom composition of the dunes. In the early hours of June 4, the ship's primary power generator failed. With no backup generator, auxiliary power systems (air conditioning!) were secured, and the captain sought to immediately return to Kaohsiung for safety repairs. After a brief discussion, it was agreed we would deploy the VLA mooring (a day earlier than planned) prior to departing the area June 4th, 01:55 Z. The OR1 science log (compiled by Dr. Ben Reeder) is listed in Appendix 1.

Figure 3. Research Vessel OCEAN RESEARCHER 1

Table 1. Ocean Researcher 1 Science Party

Yiing-Jang Yang	Chief Scientist; Associate Professor Institute of Oceanography, National Taiwan University
Ching-Sang Chiu	Professor, Naval Postgraduate School
D. Benjamin Reeder	Associate Research Professor, Naval Postgraduate School
Chris Miller	Faculty Associate, Research, Naval Postgraduate School
Marla Stone	Oceanographer, Naval Postgraduate School
Keith Wyckoff	Technician, Naval Postgraduate School
Steve Ramp	CEO, Soliton Ocean Services
Fred Bahr	Technician, Soliton Ocean Services
Wen-Hwa Her	Technician, Institute of Oceanography, NTU
Chaing-Chih Shie	Technician, Institute of Oceanography, NTU
Wen-Huei Lee	Technician, Institute of Oceanography, NTU
Cheng-Chia Lien	Research Assistant, Institute of Oceanography, NTU
Chung-Yaung Lee	Student, Institute of Oceanography, NTU
Tien-Siang Ling	Research Assistant Department of Engineering Science and Ocean Engineering, NTU
Chih-Hao Wu	Student, Department of Engineering Science and Ocean Engineering, NTU

Table 2. CTD locations during OR1 cruise

#	Date, time (Z)	Desc.	CTD depth (m)	Bottom depth (m)	Lat (N)	Lon (E)
1	5/31 20:10	RPO	250	257	21° 53.408’ N	117° 33.682’ E
2	6/01 02:05	CPO	327	327	21° 52.442’ N	117° 35.808’ E
3	6/01 10:42	YS1	325	332	21° 52.22’ N	117° 37.05’ E
4	6/02 04:48	YPO2	384	386	21° 48.603’ N	117° 39.459’ E
5	6/02 07:55	CS2	377	379	21° 49.98’ N	117° 39.43’ E
6	6/02 11:58	YS2	340	350	21° 39.601’ N	117° 35.827’ E
7	6/02 14:28	400	390	400	21° 47.611’ N	117° 40.926’ E
8	6/02 16:21	500	490	506	21° 42.457’ N	117° 46.928’ E
9	6/02 17:42	600	582	600	21° 39.601’ N	117° 50.069’ E
10	6/03 08:45	CWE	115	119	21° 55.859’ N	117° 33.390’ E

Table 3. Box Core locations during OR1 cruise

#	Time (Z), June 03	station	Bottom depth (m)	Lat (N)	Lon (E)	Observed composition
1	00:50	NP1	329	21° 52.528’ N	117° 36.808’ E	Coarse sand
2	02:45	T1	349	21° 52.465’ N	117° 36.793’ E	Finer sand
3	04:55	T3	368	21° 51.42’ N	117° 35.93’ E	Sticky mud
4	06:00	T2	356	21° 51.88’ N	117° 36.29’ E	Mud?
5	09:55	NP2	339	21° 51.93’ N	117° 36.24’ E	TBD
6	10:59	NP3	345	21° 51.53’ N	117° 35.09’ E	TBD
7	12:50	CS2A	354	21° 51.395’ N	117° 37.633’ E	TBD
8	14:11	CS2B	365	21° 50.676’ N	117° 38.509’ E	TBD
9	15:48	CS2C	387	21° 49.2557’ N	117° 40.294’ E	TBD
10	17:16	CS2D	392	21° 48.56’ N	117° 41.17’ E	TBD

2.1 Source Mooring

The primary sound source used during the sand dunes experiment was a mechanically tuned, free flooded tonplitz transducer manufactured by Teledyne Webb Research Corporation (TWR) belonging to NPS. This source has a useful bandwidth between 700 Hz to 1.2kHz, and transmits a 100 second linear frequency sweep every 5 minutes.

SeaBird Electronics, Inc., model SBE39 and SBE37 sensors were attached to this mooring to provide additional physical oceanography measurements at a 10 second interval. The SBE39 units measured temperature and pressure, while the SBE37 Microcats additionally recorded conductivity and salinity.

Two Acousonde acoustic recording tags, manufactured by Acoustimetrics, were also attached to this mooring to monitor the source signals and capture reverberation signals.

Acoustic data was recorded with a precise sample rate of 27.33kHz, with an anti-alias, low-pass filter cutoff at 9,292Hz. Auxiliary sampling (compass, accelerometer, temperature, pressure) data on the Acousondes were sampled at a 5 second interval. Acousonde units contain a HighTech HTI-96min hydrophone, with a sensitivity after pre-amplification of -187.6 dB re 1V/µPa, and had a total path gain of +22.47dB.

Table 4. Source Mooring deployment information

Deployed (date/time UTC)	6/1/14, 13:08
Recovered (date/time UTC)	6/18/14
Latitude N (anchor drop)	21° 52.6392' N
Longitude E (anchor drop)	117° 37.0570' E
Magnetic declination	2.93° W on June 1, 2014
Water depth (m)	328 m @ 1500m/s

Table 5. Source Mooring Instrument setup and configuration

Instrument name	Serial Number	Measurement	Depth (m)	Sample interval
SB 37SMP	11684	C,T,P,S	28.0	10s
SBE 39	6360	T,P	57.0	10s
Acousonde	A045	P,tilt, acoustics	54.3	27.33kHz / 5s
SBE 37SMP	11685	C,T,P,S	87.0	10s
SBE 39	1849	T,P	117.4	10s
SBE 37SMP	11686	C,T,P,S	147.4	10s
SBE 39	1800	T,P	178.3	10s
SBE 37SMP	11687	C,T,P,S	207.4	10s
SBE 39	1822	T,P	238.6	10s
Acousonde	A046	P, tilt, acoustics	248.3	27.33kHz / 5s
SBE 37SMP	11776	C,T,P,S	267.2	10s
Source	700-1200 Hz	N/A	307	N/A
SBE 39	1974	T,P	311.0	10s

Table 6. Moored source characteristics.

Start time (UTC)	06 June 2014, 00:00:00
Transmissions	100s every 300s
# cycles	3456 (12 days)
Bandwidth (Hz)	700 – 1200 Hz
End Time (UTC)	18 June 2014, 00:00

Table 7. Source mooring Acousonde setup parameters

Acousonde	A045	A046
Sample rate	27,330 Hz	27,330 Hz
Cutoff Freq	9,292 Hz	9,292 Hz
Depth	54.3 m	248.3 m
RTC Set	05/26/2014 03:32:00	05/26/2014 03:33:00
GPS Sync	05/26/2014 03:35:00	05/26/2014 03:35:00
Start time	06/01/2014 16:00	06/01/2014 16:00
Stop time	06/18/2014 02:22	06/18/2014 02:23:07
GPS Sync	06/18/2014 02:25:00	06/18/2014 02:25:00
Acousonde clock	1983178 s (02:24:58)	1983117s (02:24:58)

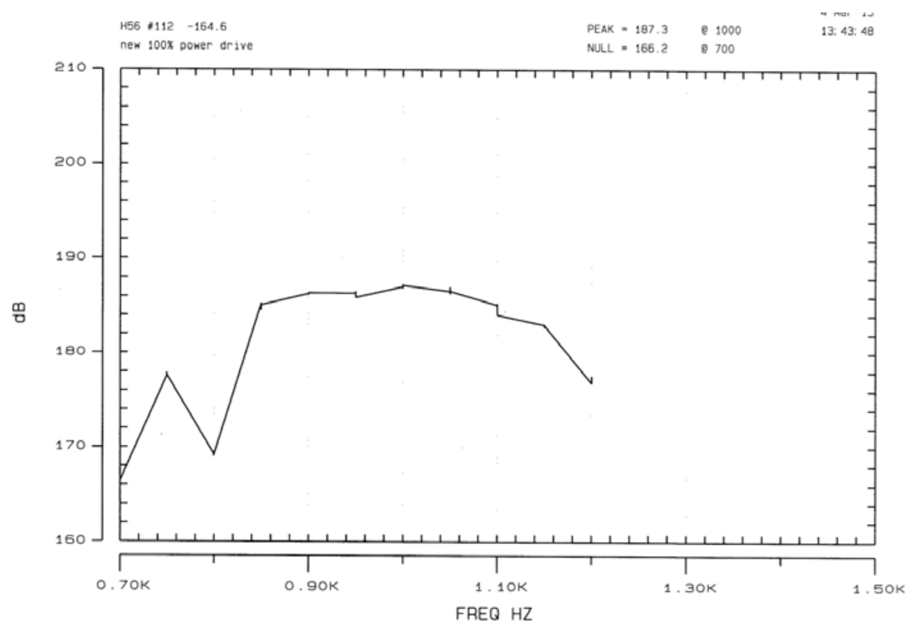

Figure 4. 700-1200Hz tonpiltz frequency response.

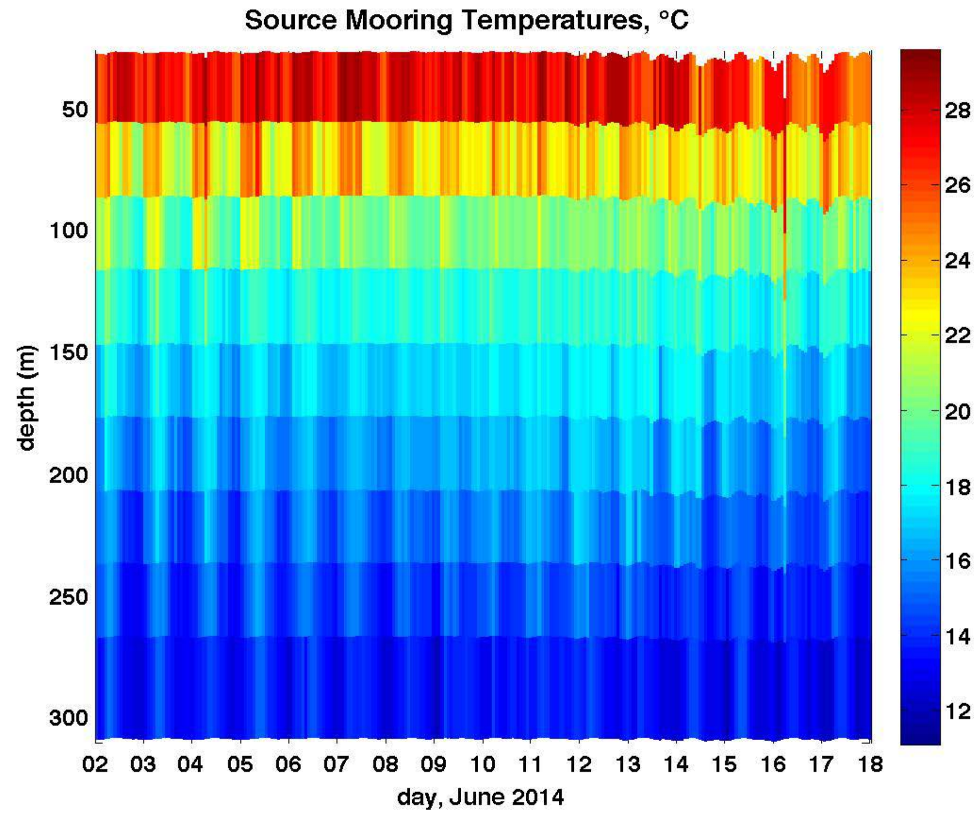

Figure 5. Source mooring temperature time series from all SeaBird instruments.

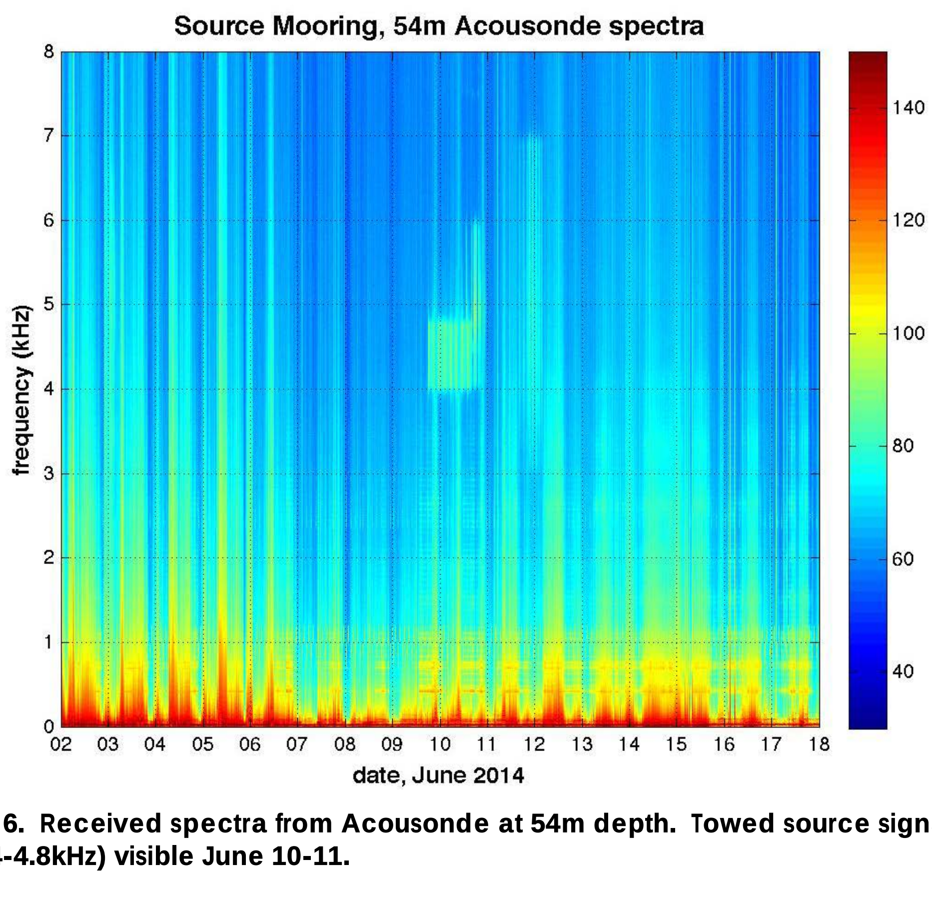

Figure 6. Received spectra from Acousonde at 54m depth. Towed source signals from OR3 (4-4.8kHz) visible June 10-11.

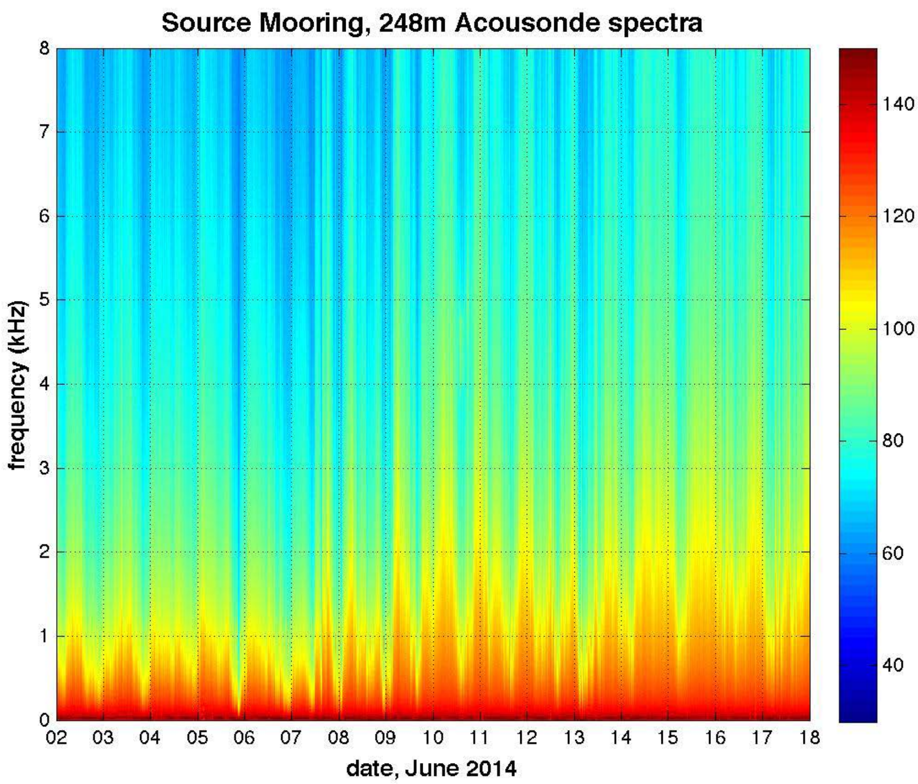

Figure 7. Received spectra from Acousonde at 248m depth.

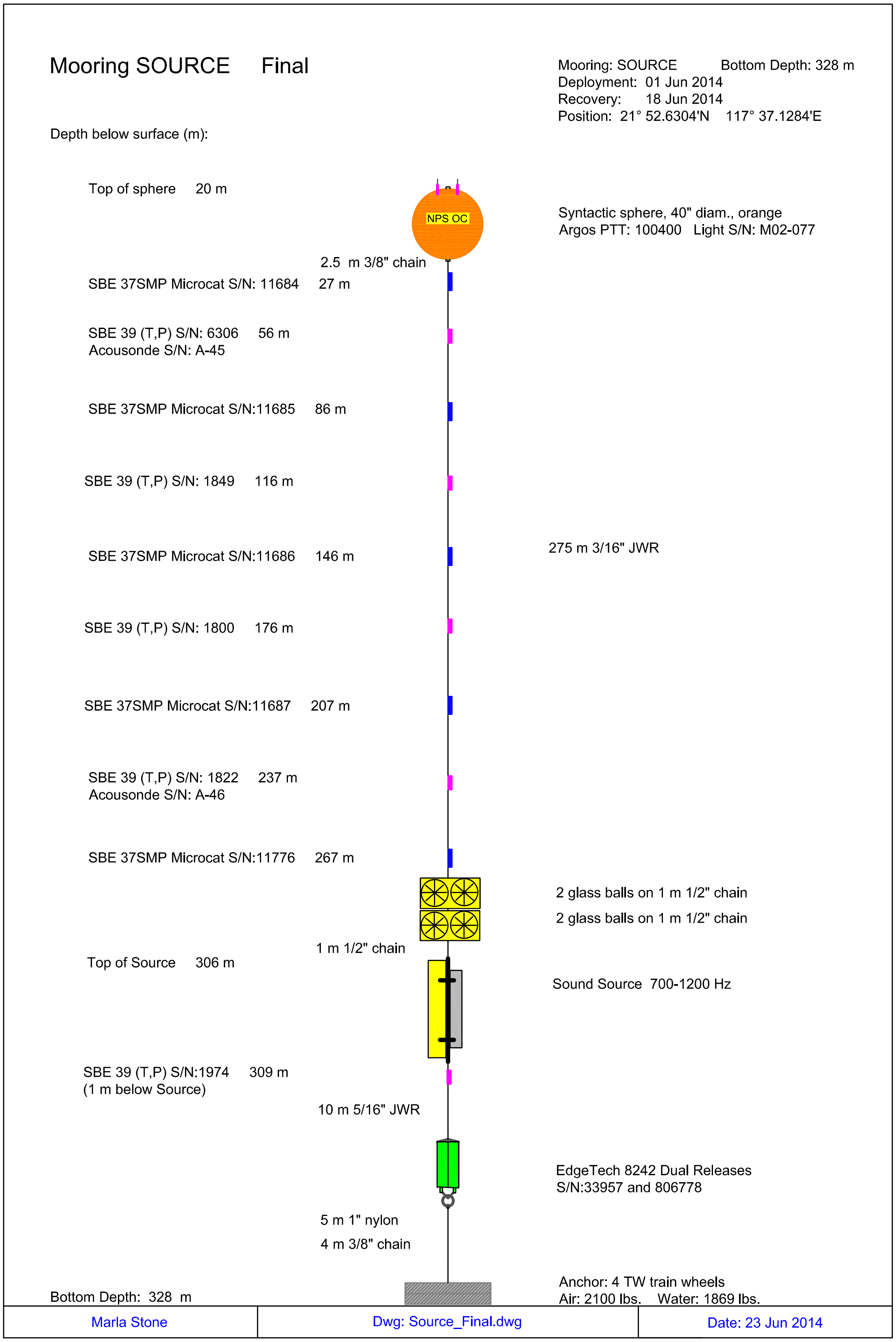

Figure 8. Source Mooring design

2.2 CPO Mooring

A physical oceanography (PO) mooring was located between the source & receiver moorings to provide baseline data for ocean conditions and measurements, as well as the downslope YPO moorings and the upslope RPO mooring.

The physical oceanography moorings were designed to span the water column to provide temperature, CTD, and current time series over the water column. Instrument locations are shown in Table 9, and Figure 10.

Table 8. CPO mooring information.

Mooring	CPO
Deployed (date/time UTC)	1 June 2014
Recovered (date/time UTC)	18 June 2014
Latitude N (anchor drop)	21° 51.8791' N
Longitude E (anchor drop)	117° 36.5866' E
Magnetic Declination	2.92° W on June 1, 2014
Water depth (m)	342 m

Table 9. CPO mooring instrument setup and configuration

Instrument name	Serial Number	Measurement	Depth (m)	Sample interval
RDI WHS-300	0685	ADCP	15	See table 10
SB 37SMP	11699	C,T,P,S	48.37	10s
SBE 39	1473	T,P	79.29	10s
SBE 37SMP	11700	C,T,P,S	109.04	10s
SBE 39	1799	T,P	140.08	10s
SBE 37SMP	11701	C,T,P,S	169.36	10s
SBE 39	3682	T,P	200.84	10s
SBE 37SMP	11702	C,T,P,S	229.81	10s
RDI WHS-300	0344	ADCP	264	See table 11
RDI WHS-300	1830	ADCP	265	See table 12
SBE 39	4515	T,P	287.35	10s
SBE 37SMP	11728	C,T,P,S	305.66	10s

Table 10. CPO ADCP1 (top buoy, looking downward) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 0685
Frequency	300 kHz
Ensemble length	90 seconds
# pings	32 (1 Hz pings, 32 seconds)
Vertical averaging	four meter bins
Start time	15 min after the hour

Table 11. CPO ADCP2 (dual frame, looking up) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 0344
Frequency	300 kHz
Ensemble length	90 seconds
# pings	32 (1 Hz pings, 32 seconds)
Vertical averaging	four meter bins
Start time	15 min 45 seconds after the hour

Table 12. CPO ADCP3 (dual frame, looking down) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 1830
Frequency	300 kHz
Ensemble length	90 seconds
# pings	26 (1 Hz pings, 26 seconds), plus one bottom ping per ensemble
Vertical averaging	four meter bins
Start time	15 min after the hour

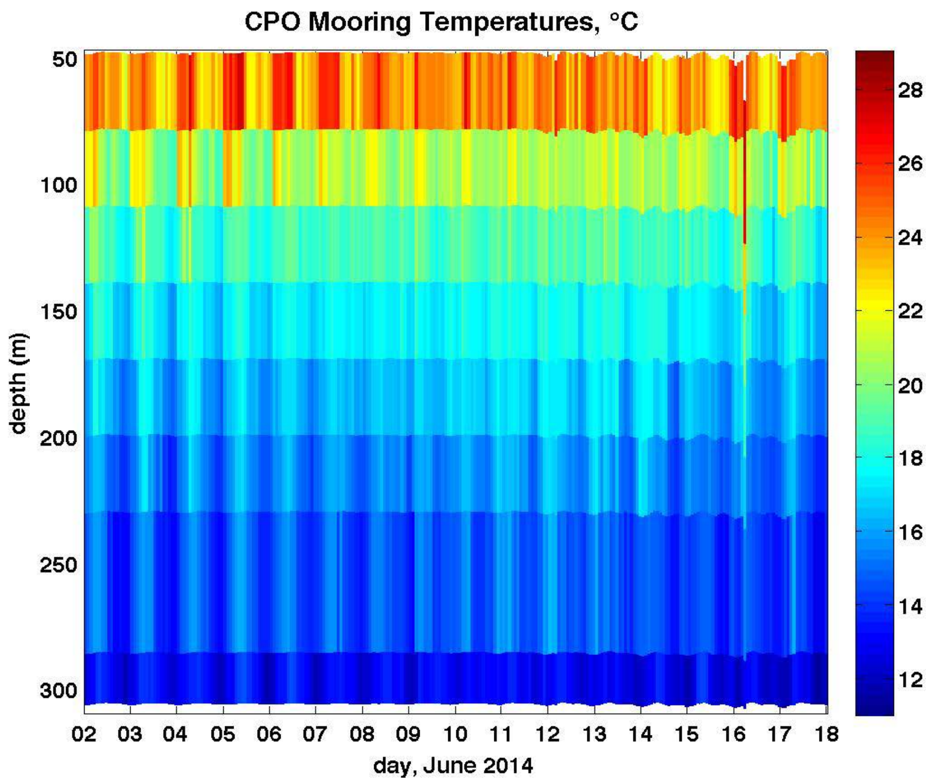

Figure 9. CPO mooring temperature time series from SeaBird instruments.

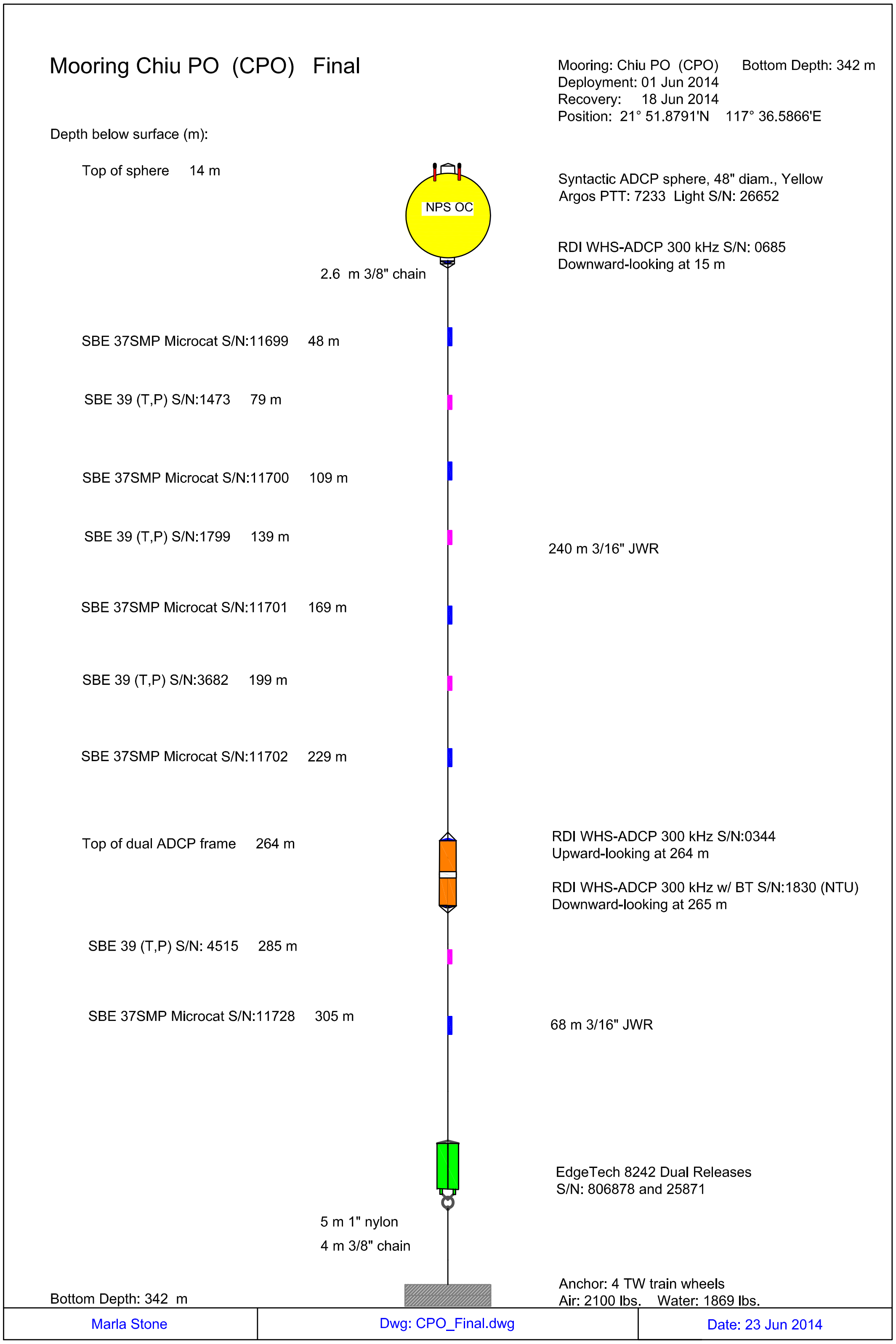

Figure 10. Chiu Physical Oceanography mooring design

2.3 Vertical Line Array (VLA) Mooring

The VLA mooring was actually 3 separate arrays, with respective electronics, deployed in tandem to span the entire water column. The top array was a 32-elment VLA with 5m spacing, the middle was a 16-element with 5m spacing, and the bottom array was an 8 element with 8m spacing. The three arrays were manufactured by High Tech, Inc., and populated with HTI-94-SSQ current mode hydrophones. The hydrophone preamplifiers are current mode, require 12Vdc, 3.12mA (avg.) power and have a maximum signal output of 1.3Vpp (0.5 Vrms) before clipping occurs. The preamplifiers provide a nominal gain of 28 dB, with a hydrophone sensitivity of -198 dB re 1V/µPa for an array element sensitivity of approximately -170 dB re 1V/µPa.

Table 13. VLA Mooring deployment information

Deployed (date/time UTC)	4 June 2014 01:22 GMT
Recovered (date/time UTC)	19 June 2014
Latitude N (anchor drop)	21° 51.14' N
Longitude E (anchor drop)	117° 35.80' E
Latitude N (surveyed)	21° 51.2272' N
Longitude E (surveyed)	117° 35.9392' E
Magnetic Declination	2.92° W on June 1, 2014
Water depth (m)	355 m

Figure 11. VLA Mooring preparations aboard OR1 deck.

Table 14. VLA mooring instruments

Instrument name	Serial Number	Measurement	Depth (m)	Sample interval
MAVS	10308	Current, tilt	32 m	
TUDAS-32	0001	Tilt, acoustics	34.8	1m,
SBE 39	860	T,P	36.8	10s
SBE 39	1529	T,P	77.8	10s
SBE 39	1261	T,P	116.7	10s
SBE 39	5601	T,P	158.0	10s
STARmini	001	acoustics		8kHz
STARmini	003	acoustics		8kHz
SBE 39	1621	T,P	198.31	10s
SBE 39	1756	T,P	238.4	10s
SBE 39	1847	T,P	279.9	10s

There were four independent Data AcQuisition systems (DAQ) recorders digitizing hydrophone data on this array. The DAQ system on the 32-channel VLA was the Teknologic Underwater Data Acquisition System (TUDAS-32), manufactured by Teknologic, Inc. of Seattle, WA. Three older STARmini 8-channel recorders, originally manufactured by Webb Research, were utilized on the other two arrays: The SN001 (NPS) and SN003 (WHOI) systems were wired to the 16-channel VLA, and the SN002 (NTU) system was wired to the 8 channel VLA. The STARmini hardware was upgraded for this experiment from the original 2kHz sample rate to the maximum 8kHz sampling for this experiment, following Perisistor Instruments' example code SPIIIDAQ, with anti-alias filter cutoff frequency changed to 2.1 kHz.

During system initialization & testing at the warehouse, the TUDAS-32 system disks (2 x 500GB SSD drives) were sometimes not visible to the embedded Win95 OS the TUDAS system was running. This resulted in the DAQ software to believe that 0kB of data storage was available (i.e., data disks were full), initiating an immediate shutdown of the system to preserve battery. Unfortunately, this occurred when data had yet to be written. The solid-state disks sometimes take more time to initialize and mount on boot up, and the DAQ software timing did not adequately account for these increased delays. On the off chance that 1 of the 2 disks was not visible to the system start up while deployed, it was decided to delay TUDAS recording until June 9th 00:00 so that a single 500GB drive might record the entire June 9-18, 2014 period when research vessel OR5 would be back on station and deploying the dipped source TL transmissions.

The TUDAS-32 system began data recording June 9, 2014 00:00 GMT. Erratic voltages were observed from the 12V lithium battery pack over the first day of operation (Figure 19). System voltage varied from 12.5V – 10V and back again over periods of hours. Battery voltage dipped below a 10V threshold, initiating a system-shutdown on June 9, 20:38 GMT. This shutdown protocol was in place to preserve clock timing at the end of a deployment, when battery power was failing (not the case during our deployment). This failure is still being investigated. TUDAS-32 data format is described in Table 16.

Table 15. VLA digitizer, programmed settings

	TUDAS-32	STARmini units	
Sample rate	9765.625 Hz	8000 Hz	
Hydrophone gain settings	13 dB	20 dB	
ADC resolution	16 bit	16 bit	
Number of channels	32	8	
Start time	06/09/14 00:00	001	June 3, 2014 23:10:00
		002	June 3, 2014 23:15:00
		003	June 3, 2014 23:05:00
Stop time	06/18/14 00:00	(power dependent)	
Storage capacity	1 TB	120 GB	

Table 16. TUDAS-32 binary data file format

Byte offset	Length (bytes)	Description	format	Value(s)
0	4	header key	ASCII characters	‘ ‘,’h’,’d’,’r’
4	4	Channel count	Int32	32 channels
8	8	Sample Rate	Double float	9,765.625 Hz
16	4	Sample length	Integer	16-bits
20	4	Data key	ASCII characters	‘d’,’a’,’t’,’a’
24-eof	16-bit, multiplexed data [Ch1, Samp1], [Ch2,Samp1], [Ch3,Samp1], … [Ch31,Samp1],[Ch32,Samp1], … [Ch1,Samp2], [Ch2,Samp2]… to end of file			

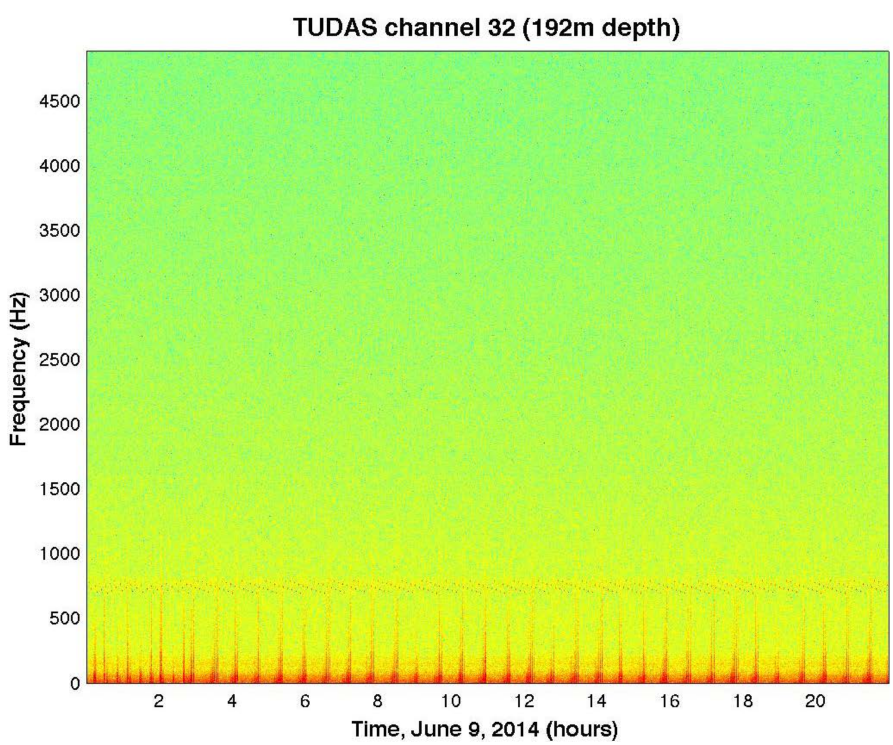

Figure 12. TUDAS Hydrophone #32 (192m depth) acoustic data spectra.

Three Acousonde recording tags were attached to the VLA along the aperture as additional, broadband receiver data at the VLA mooring, as well as provide the auxiliary compass, accelerometer data that might be useful in processing for mooring motion.

Table 17. Acousonde instrument setup for the VLA mooring.

Acousonde	A023	A042	A044
Sample rate	15 kHz	27,330 Hz	27,330 Hz
Cutoff Freq	4,646 Hz	9,292 Hz	9,292 Hz
Depth	280 m	198 m	161 m (+/- 2m)
RTC Set	05/26/2014 03:29:00	06/03/2014 22:50:00	05/26/2014 03:30:00
GPS Sync	05/26/2014 03:37:00	06/03/2014 22:51:00	05/26/2014 03:37:00
Start time	06/09/2014 00:00	06/04/2014 00:00	06/04/2014 00:00
Stop time	06/19/2014 06:06	06/19/2014 06:11:47	06/19/2014 06:30:31
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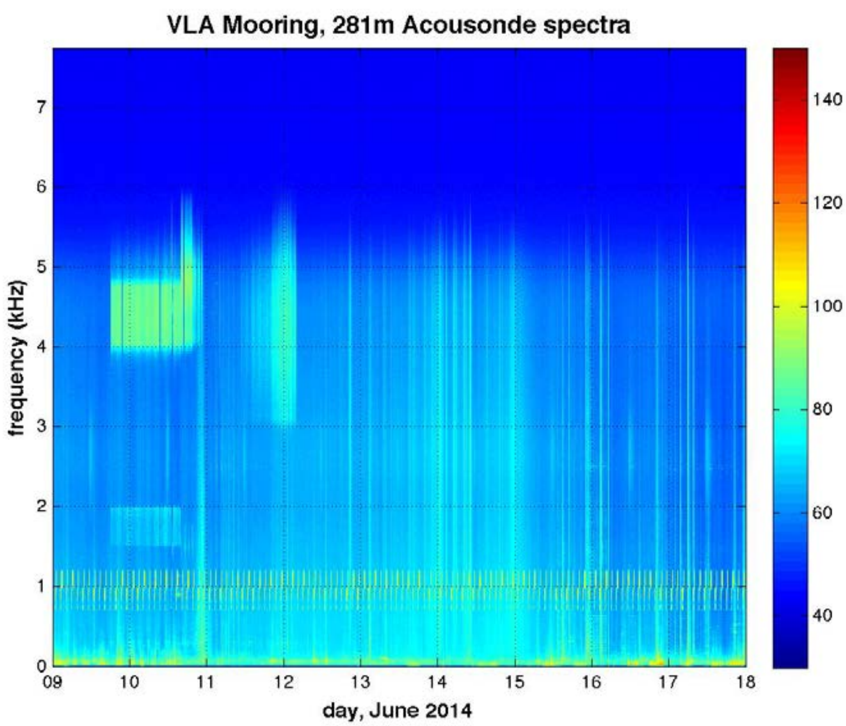

Figure 13. A023 Acousonde acoustic spectra recorded at 281m depth on the VLA mooring, June 9-18, 2014.

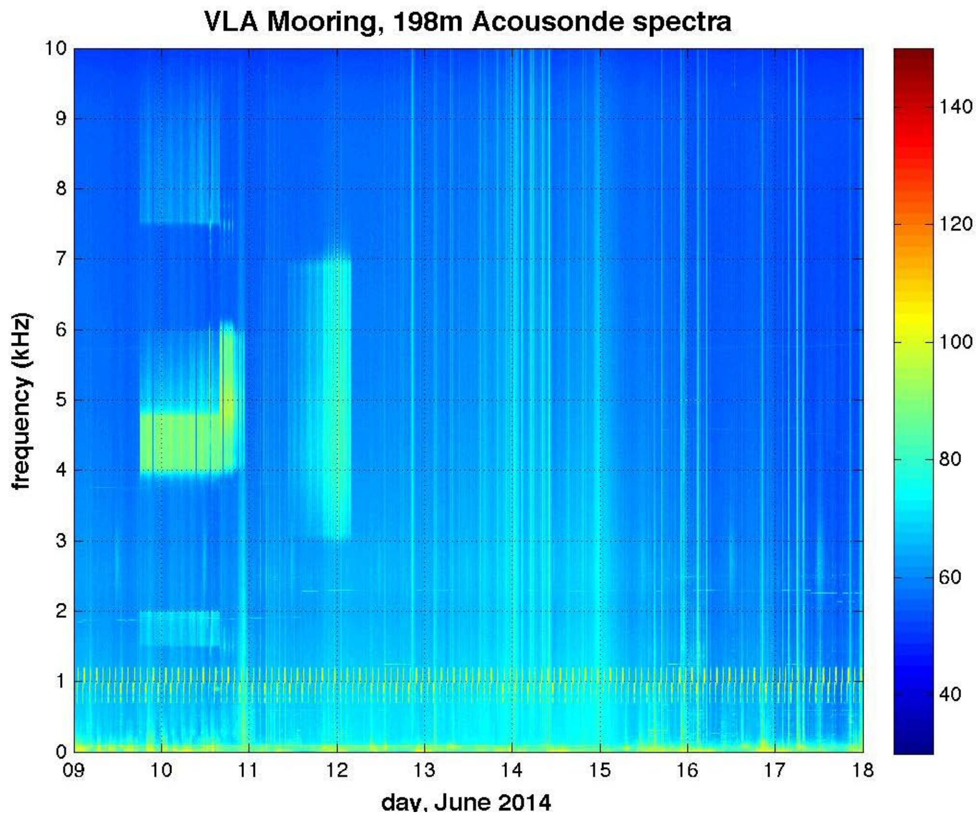

Figure 14. A042 Acousonde spectra recorded at 198m on the VLA mooring.

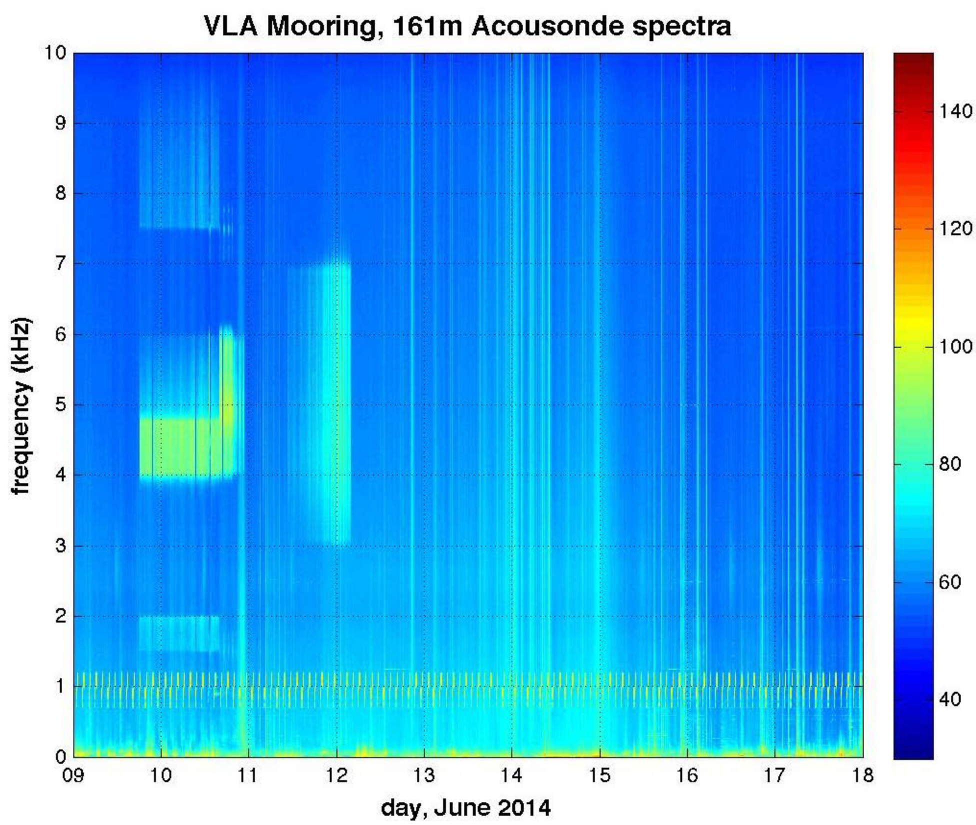

Figure 15. A044 Acousonde spectra recorded at 161m on the VLA mooring.

Sea-Bird temperature/pressure sensors were attached along the VLA mooring (Figure 20) to provide environmental data variability/structure at the acoustic receivers. The pressure sensor data (Figure 17), in addition to compass heading/current data from the MAVS (Figure 18), will also be used to estimate mooring motion and more accurate hydrophone positions during the deployment. During the passage of the largest internal waves, pressure sensor at ~37m was depressed to a depth of 100m! It is clear that the array is compressing during these passages, so a straight line mooring estimate cannot be used to determine hydrophone position for mooring motion corrections.

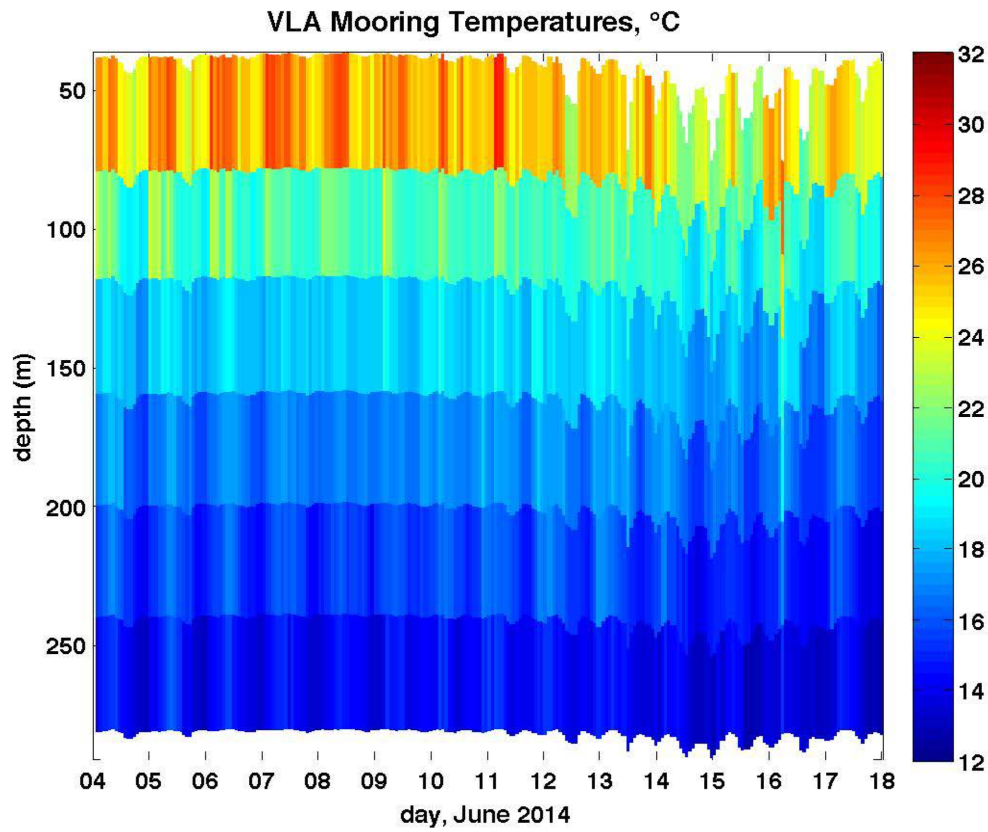

Figure 16. VLA mooring temperature time series from SB39 sensors.

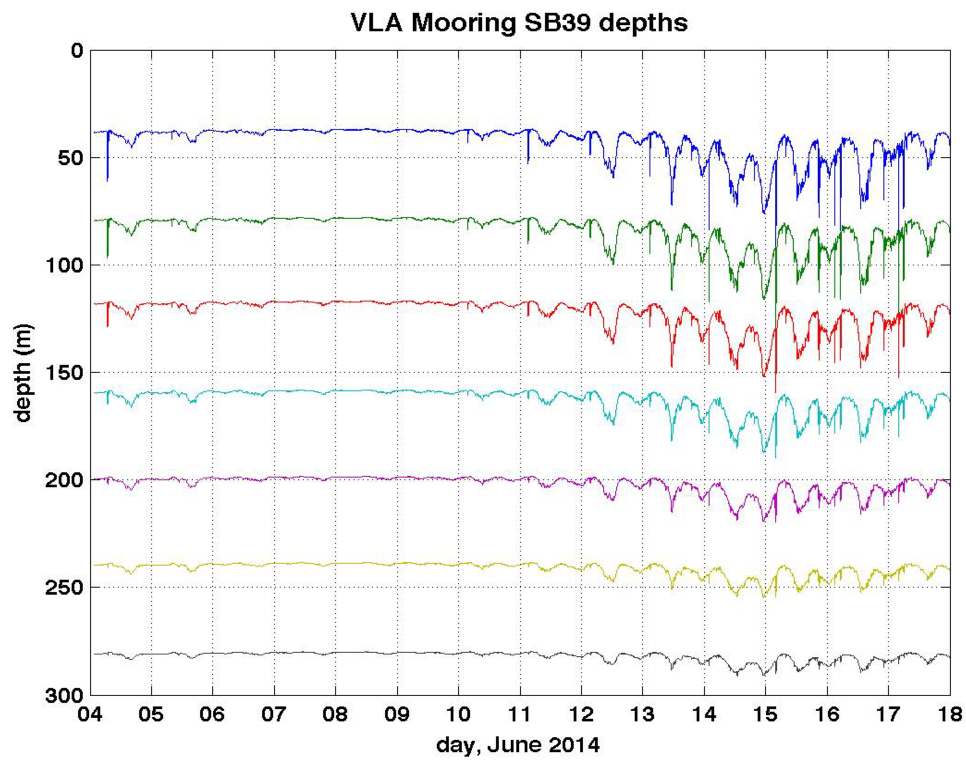

Figure 17. VLA sensor depths of SB39 instruments.

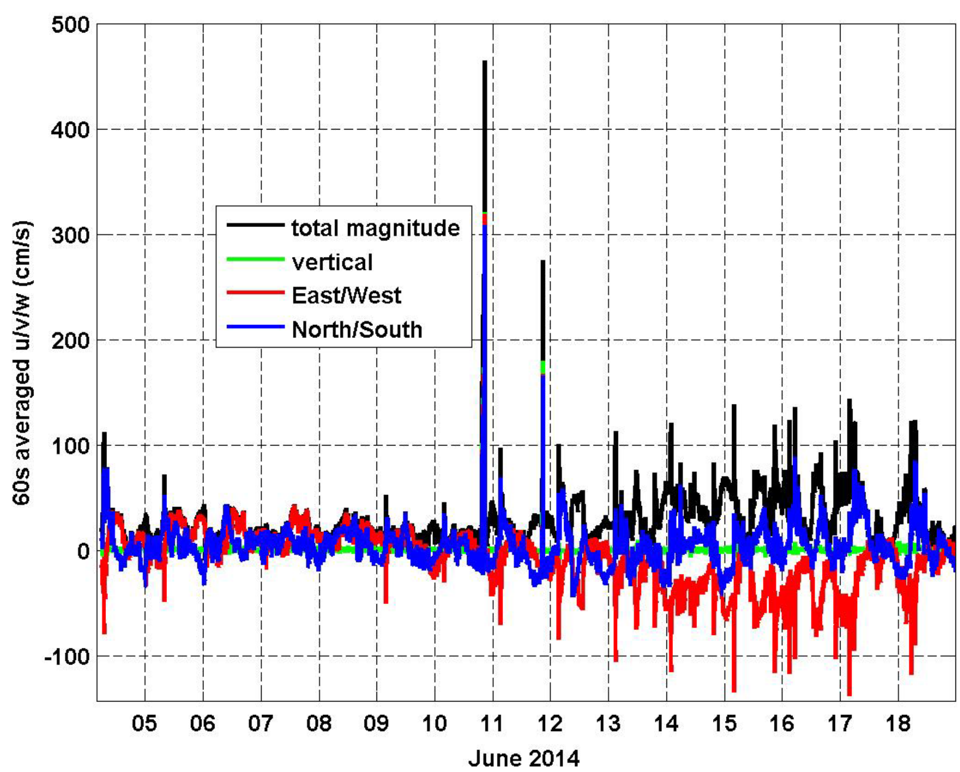

Figure 18. MAVs current meter speeds (cm/s) in the North/South (blue), East/West (red), and vertical (green) directions. Black curve is the combined current vector speed (magnitude).

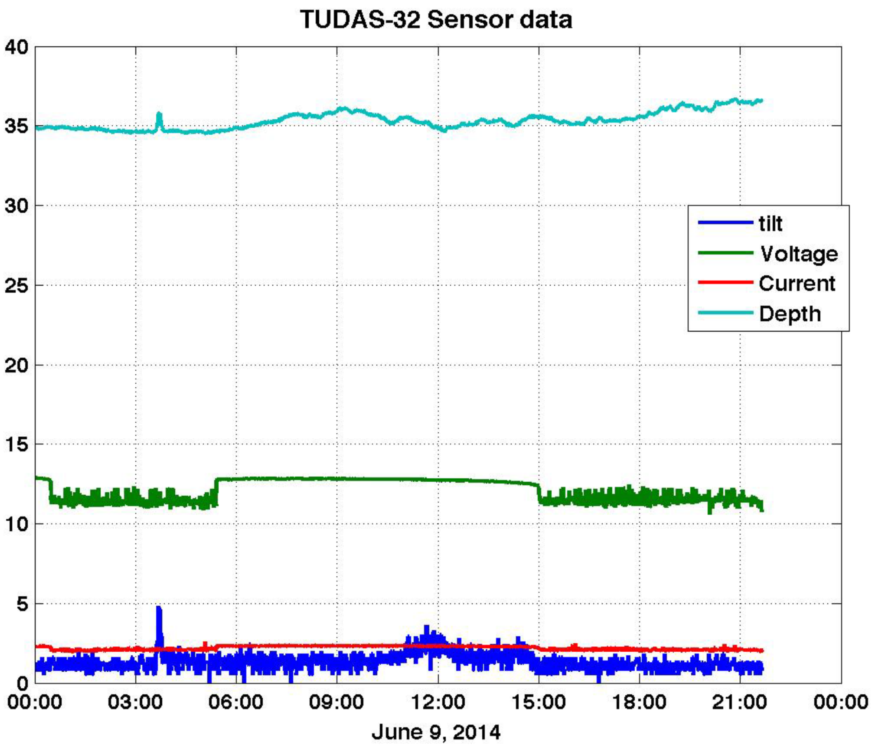

Figure 19. TUDAS-32 digitizer sensor data. Of note is the widely varying voltage (green) measured at the system power, which ultimately dipped below threshold and caused an early shutdown of the system.

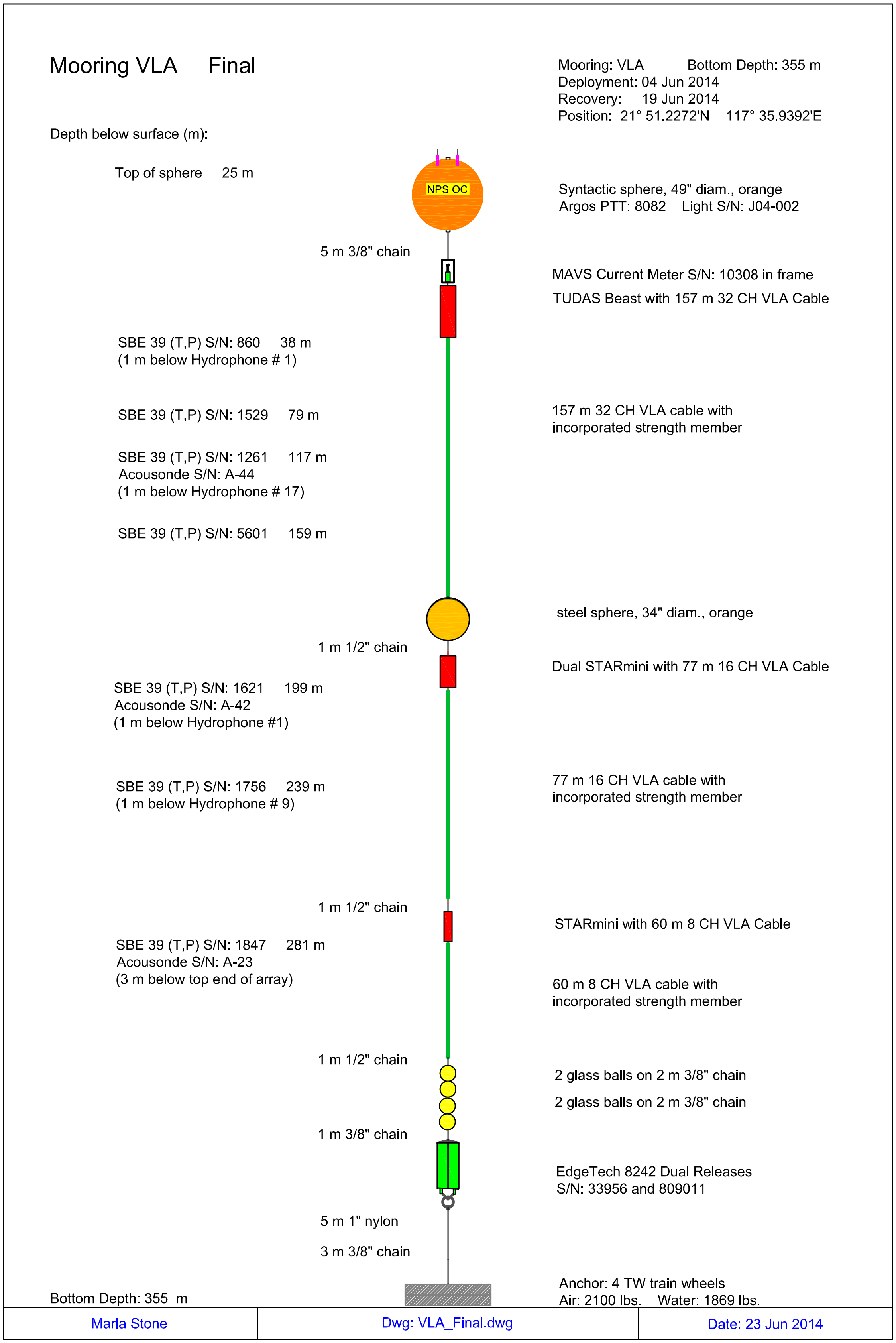

Figure 20. VLA Mooring design

2.4 YS1 SHRU mooring (Source)

A Simple Hydrophone Recording Unit (SHRU) system (SN 920) was moored near the Source Mooring to provide additional acoustic paths for the towed source transmissions, and investigate reverberation data for the source mooring. The SHRU recorders were designed and built by Keith von der Height of the Woods Hole Oceanographic Institution and manufactured by AcodaQ.

The SHRU receiver supports recording from four HTI SSQ94 voltage mode hydrophones, with a nominal -170 dB re 1μPa. The hydrophones were secured to the mooring, beneath the SHRU frame, at 0.6m intervals.

A SeaBird SBE39 temperature/pressure logger (S/N 5648) was mounted to the SHRU instrument frame, whose final timing was 3s faster than GMT time on recovery, and whose pressure information will be used to determine actual hydrophone depths during the deployment. Mean pressure from the SBE39 during deployment was 301.28 dbar, or 299.19 m depth.

Table 18. YS1 mooring deployment information.

Deployed (date/time UTC)	06/01/14 11:37 Z
Recovered (date/time UTC)	06/18/14 07:52 Z
Latitude N (anchor drop)	21° 52.50985' N
Longitude E (anchor drop)	117° 37.0910' E
Water depth (m)	328 m

Table 19. Source SHRU (YS1) system information

SHRU S/N	0920	
Data recorded, UTC	06/02/14 00:00 – 06/19/14 10:57	
Number of channels	4	
Hydrophone 799001	-3m from SB39	302.19 m
Hydrophone 799002	-3.6m from SB39	302.79 m
Hydrophone 799003	-4.2m from SB39	303.39 m
Hydrophone 799004	-4.8m from SB39	303.99 m
Sample rate	9765.625 Hz	
Clock sync (start)	06/01/2014 09:00	0.00 ms (latched)
Clock sync (end)	06/18/2014 11:55:00	10.846 ms slow
Drift rate	633.471 μs/day (slowing)	

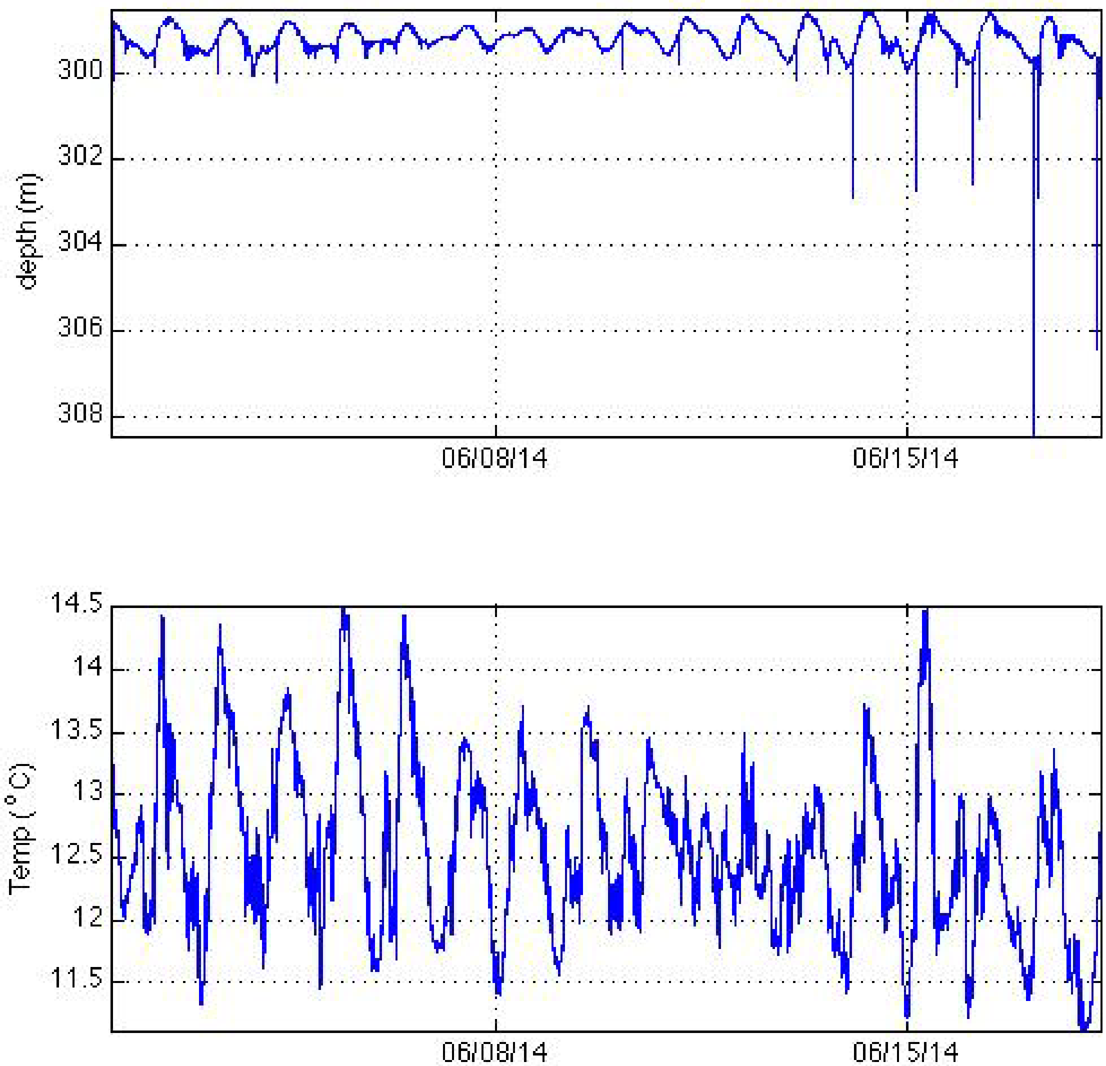

Figure 21. SBE39 Depth/Temperature record for YS1 mooring.

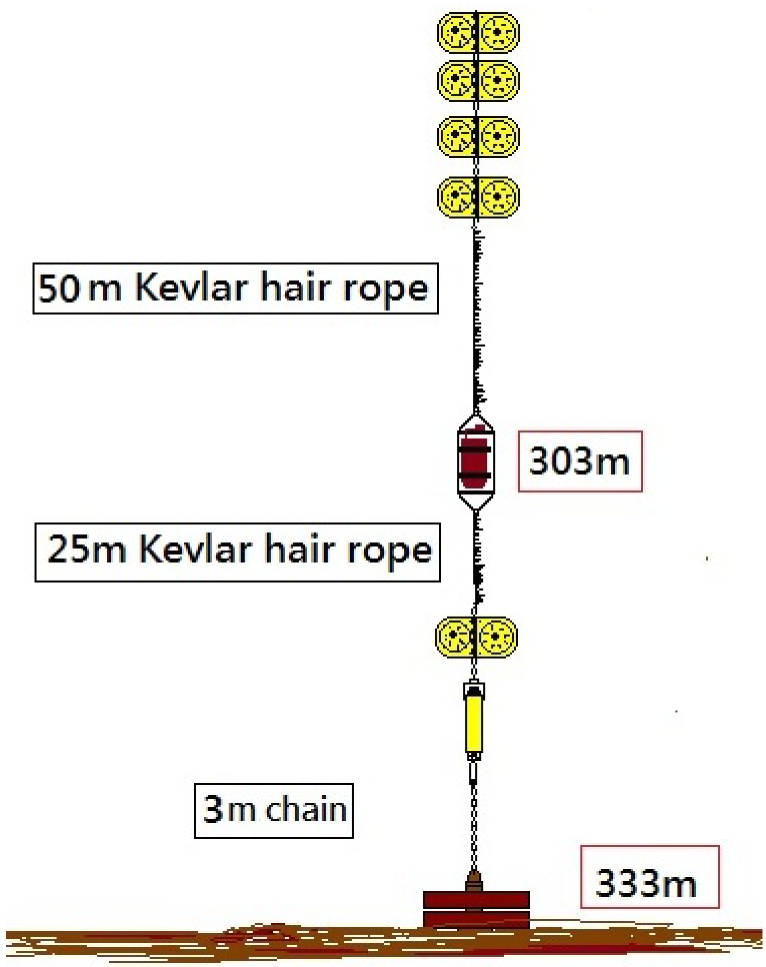

Figure 22. YS1 initial mooring design. 50m Kevlar above SHRU electronics was removed for final deployment to allow mooring close as possible to the source mooring.

2.5 YS2 SHRU mooring (VLA)

The second SHRU mooring, SHRU instrument S/N: 291, was deployed close to the VLA mooring to provide a backup receiver in case there were problems with the VLA digitizers. This unit was deployed with 4 hydrophones over a 20m aperture about the instrument: +10m, +5m, -5m, and -10m, relative to the SBE39 temperature logger (S/N: 6646) mounted on the SHRU frame. Mean depth from the SBE39 over the deployment was 211.18 dbar, or 209.76m.

In addition to the SHRU receiver, a single hydrophone ocean acoustic datalogger instrument (DSG-ST, manufactured by Loggerhead Instruments) was deployed on this mooring 15m below the SBE39 unit, at a depth of 224.76 m, however the pressure housing failed during deployment and no data is available from this unit.

Table 20. YS2 mooring deployment information

Deployed (date/time UTC)	06/02/14 13:34 Z
Recovered (date/time UTC)	06/19/14 07:37 Z
Latitude N (anchor drop)	21° 51.3887' N
Longitude E (anchor drop)	117° 35.8003' E
Water depth (m)	350 m

Table 21. SHRU 0921 (YS2) system information

SHRU S/N	0921	
Data recorded, UTC	06/02/14 00:00 – 06/19/14 10:58	
SHRU depth	209.76 m	
Number of channels	4	
Hydrophone 799005	10m above SB39	199.76m
Hydrophone 799006	5m above SB39	204.76m
Hydrophone 799007	5m below SB39	214.76m
Hydrophone 799008	10m below SB39	219.76m
Sample rate	9765.625 Hz	
Clock sync (start)	06/02/2014 08:00	1.00s slow
Clock sync (end)	06/19/2014 15:35	1.00192s slow
Drift rate	110.00 μs/day (slowing)	

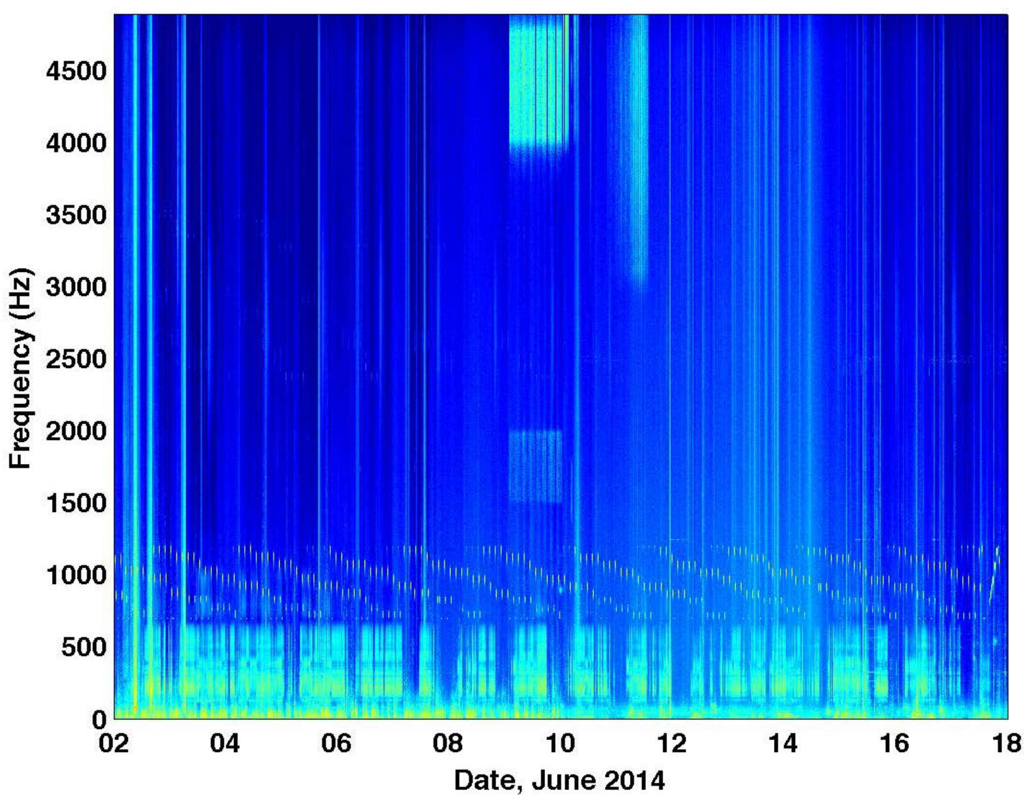

Figure 23. YS2 SHRU hydrophone #1 spectrogram.

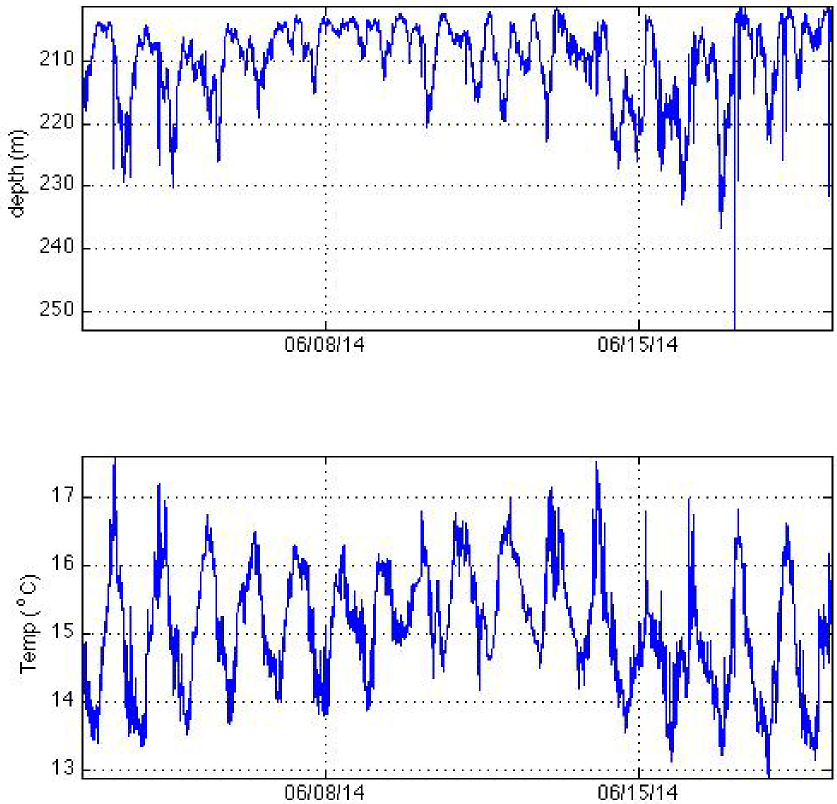

Figure 24. SeaBird SBE39 Depth/Temperature record for YS2 mooring.

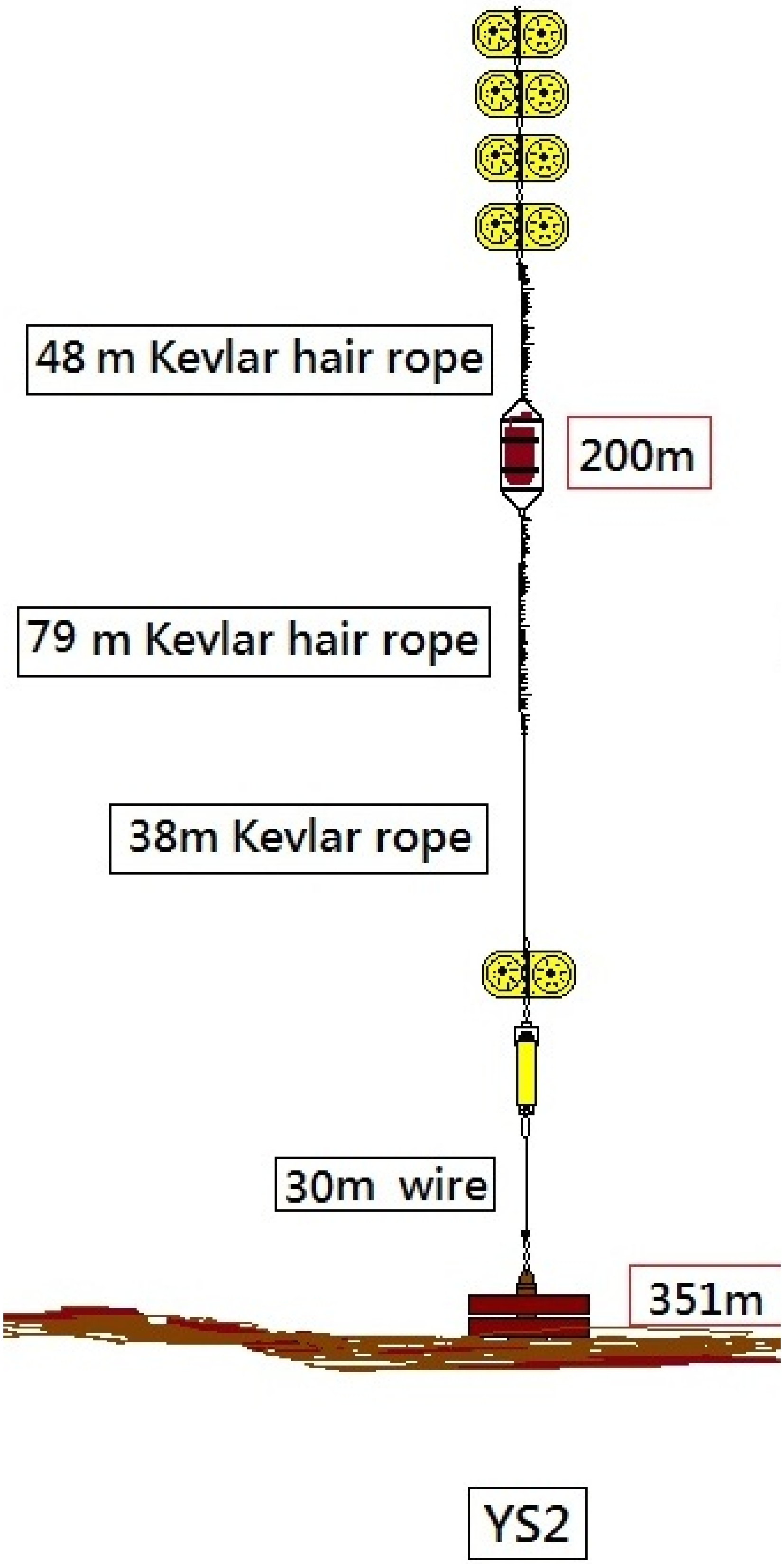

Figure 25. YS2 initial mooring design.

2.6 CS1 SHRU mooring ("Emily")

The CS1 SHRU mooring was deployed on a ridge to the north of the sand dunes field, with the goal to study the three dimensional propagation effects of the source transmissions between the source & vla moorings. This unit was deployed with 4 hydrophones over a 20m aperture about the instrument: +10m, +5m, -5m, and -10m about the SHRU frame. Below the SHRU instrument was faired Kevlar, while the upper phones were attached to standard Kevlar (no fairing). There are significant differences in the received spectra between the top and bottom phones (Figures 27 & 28), that is likely due to cable strum, but needs further investigation. A Seabird SBE39 temperature logger (S/N:6647) was also mounted to the SHRU frame. Mean depth from the SBE39 over the deployment was 201.35 dbar, or 200.0 m.

Table 22. CS1 mooring deployment information

Deployed (date/time UTC)	06/01/2014 02:59 Z
Recovered (date/time UTC)	09/16/2014 23:45 Z
Latitude N (anchor drop)	21° 52.457' N
Longitude E (anchor drop)	117° 35.748' E
Water depth (m)	325 m

Table 23. SHRU 0909 (CS1) system information

SHRU S/N	0909	
Data recorded, UTC	06/02/14 00:00 – 06/17/2014 01:15	
SHRU frame depth	200.0 m	
Number of channels	4	
Hydrophone 752001	+10m (no fairing)	190.0 m
Hydrophone 752002	+5m (no fairing)	195.0 m
Hydrophone 752003	-5m (faired Kevlar)	205.0 m
Hydrophone 752004	-10m (faired Kevlar)	210.0 m
Sample rate	9765.625 Hz	
Clock sync (start)	06/01/2014 (YD 152) 01:33	0.00s (latched)
Clock sync (end)	06/19/2014 (YD 168) 01:34	-29.727 ms
Drift rate	1.651 ms/day (fast)	

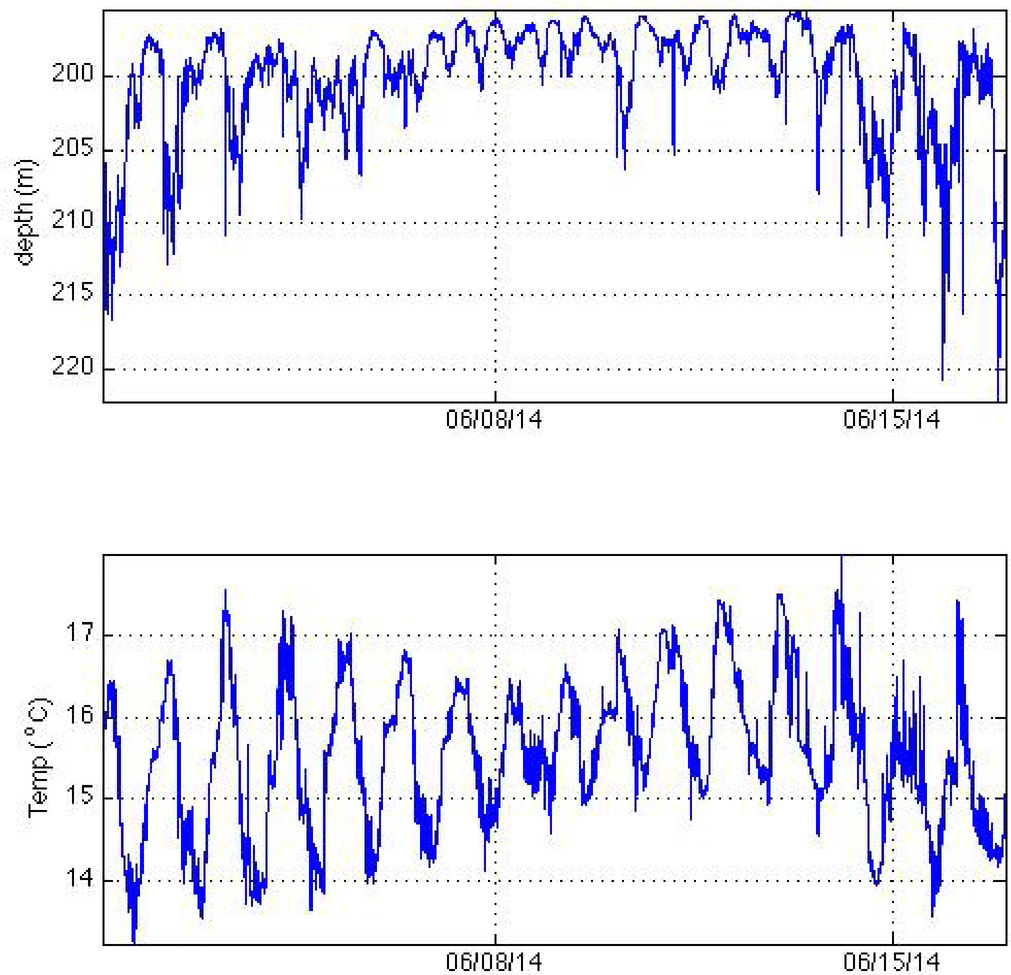

Figure 26. SBE39 Depth/Temperature record for CS1 mooring.

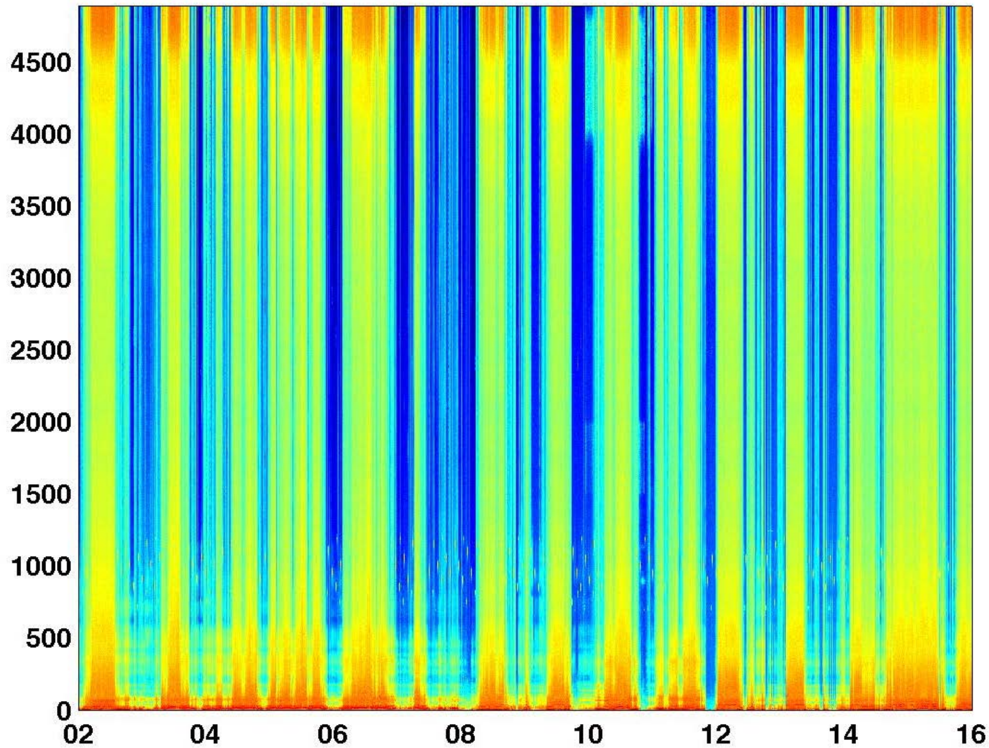

Figure 27. Hydrophone 1 (190 m depth) spectra from CS1 mooring. Horizontal axis is the June 2014 day number (2nd-16th), and the vertical axis is Frequency (Hz).

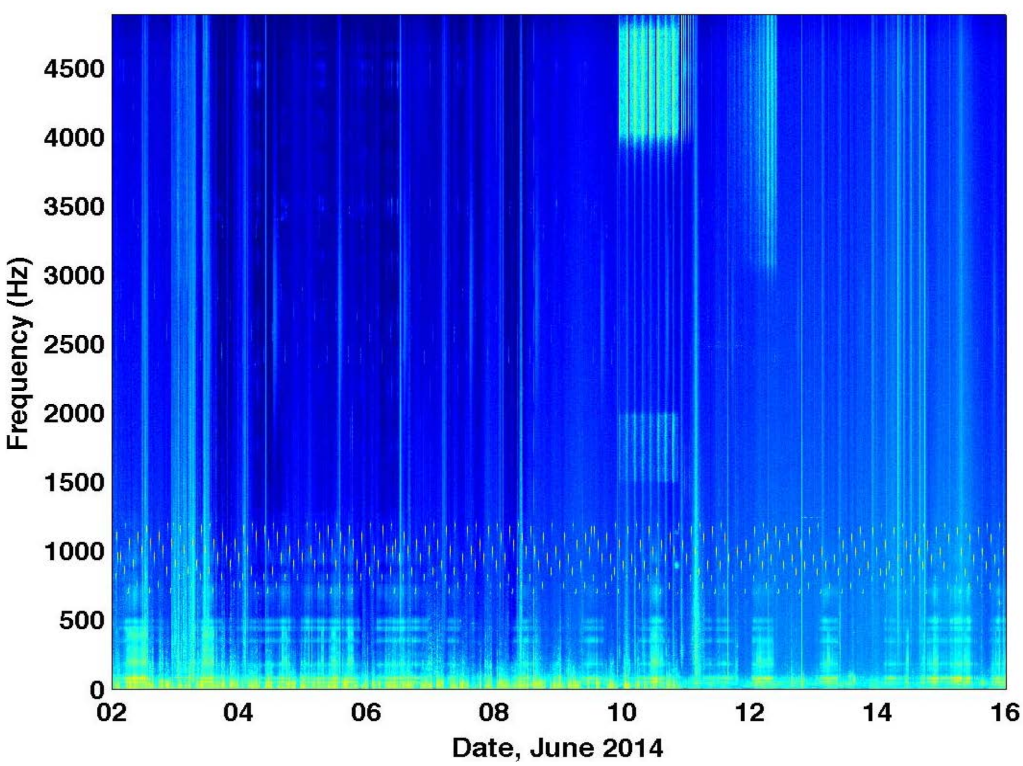

Figure 28. Hydrophone 4 (210 m depth) spectra for CS1 mooring. Same color scale as hydrophone 1, shows a much better signal-to-noise level on hydrophone 4.

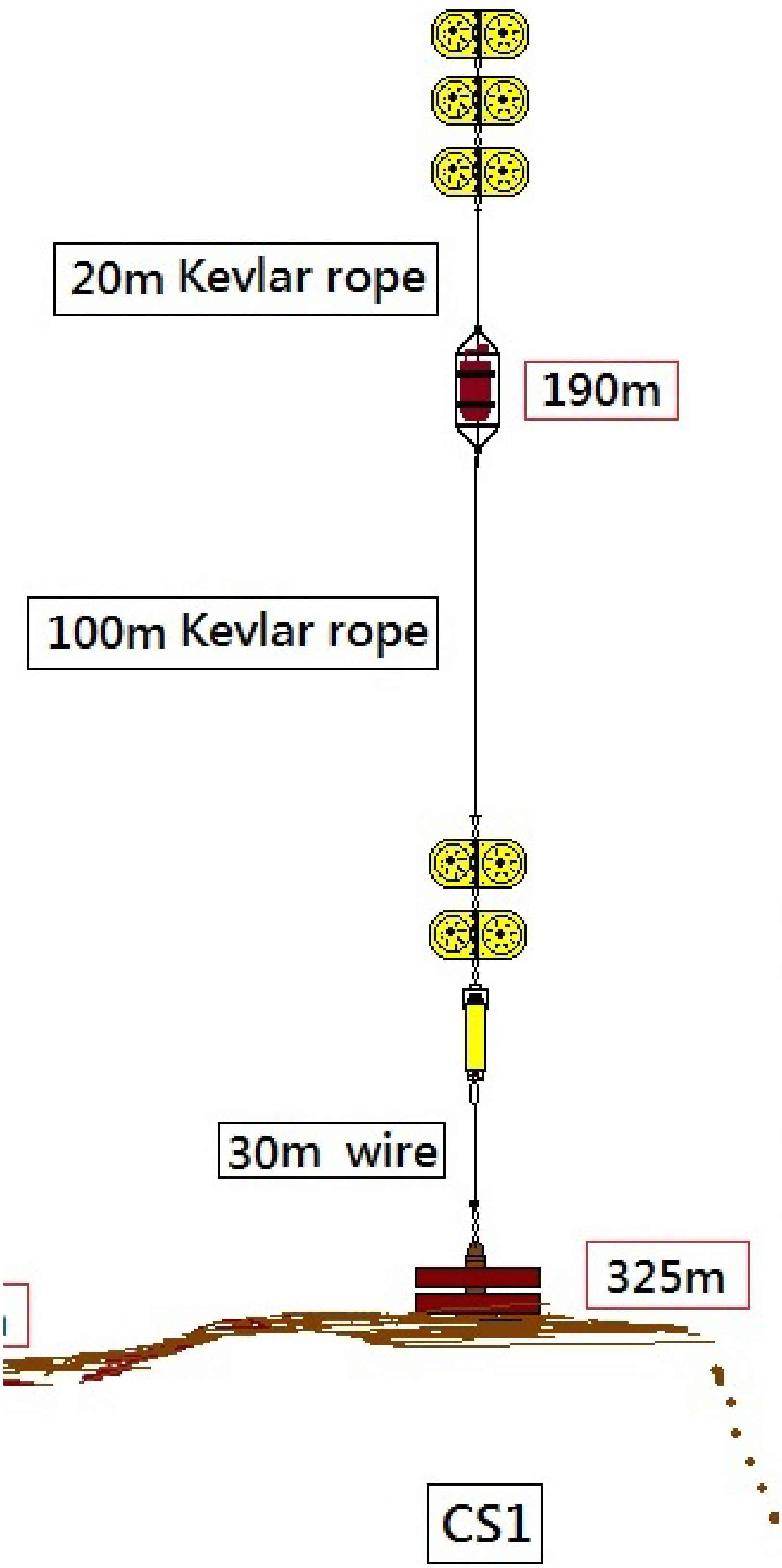

Figure 29. CS1 initial mooring design.

2.7 CS2 SHRU mooring (M-mooring)

The CS2 SHRU mooring was deployed at the same location as the 2013 pilot study main mooring. The purpose of repeating this location was to further refine the geo-acoustic data collected during the May 2013 effort. This unit was deployed with 4 hydrophones over a 20m aperture about the instrument: +10m, +5m, -5m, and -10m about the SHRU frame. A Seabird SBE39 temperature logger (S/N:4520) was also mounted to the SHRU frame. Mean depth from the SBE39 over the deployment was 307.21 dbar, or 305.07 m.

Table 24. CS2 Mooring deployment information

Deployed (date/time UTC)	06/02/2014 10:16 Z
Recovered (date/time UTC)	09/16/2014 21:35 Z
Latitude N (anchor drop)	21° 49.9806'N
Longitude E (anchor drop)	117° 39.3877'E
Water depth (m)	379 m

Table 25. SHRU #1201 configuration and setup on CS2 mooring

SHRU S/N	1201	
Data recorded, UTC	06/02/14 00:00 – 06/17/14 00:34	
Number of channels	4	
SHRU frame depth	305.07 m	
Hydrophone 752005	10m above SB39	295.07 m
Hydrophone 752006	5m above SB39	300.07 m
Hydrophone 752007	5m below SB39	310.07 m
Hydrophone 752008	10m below SB39	315.07 m
Sample rate	9765.625 Hz	
Clock sync (start)	06/02/2014 07:43	0.00s (latched)
Clock sync (end)	06/16/2014 01:10	38.527 ms fast
Drift rate	2.8066 ms/day (fast)	

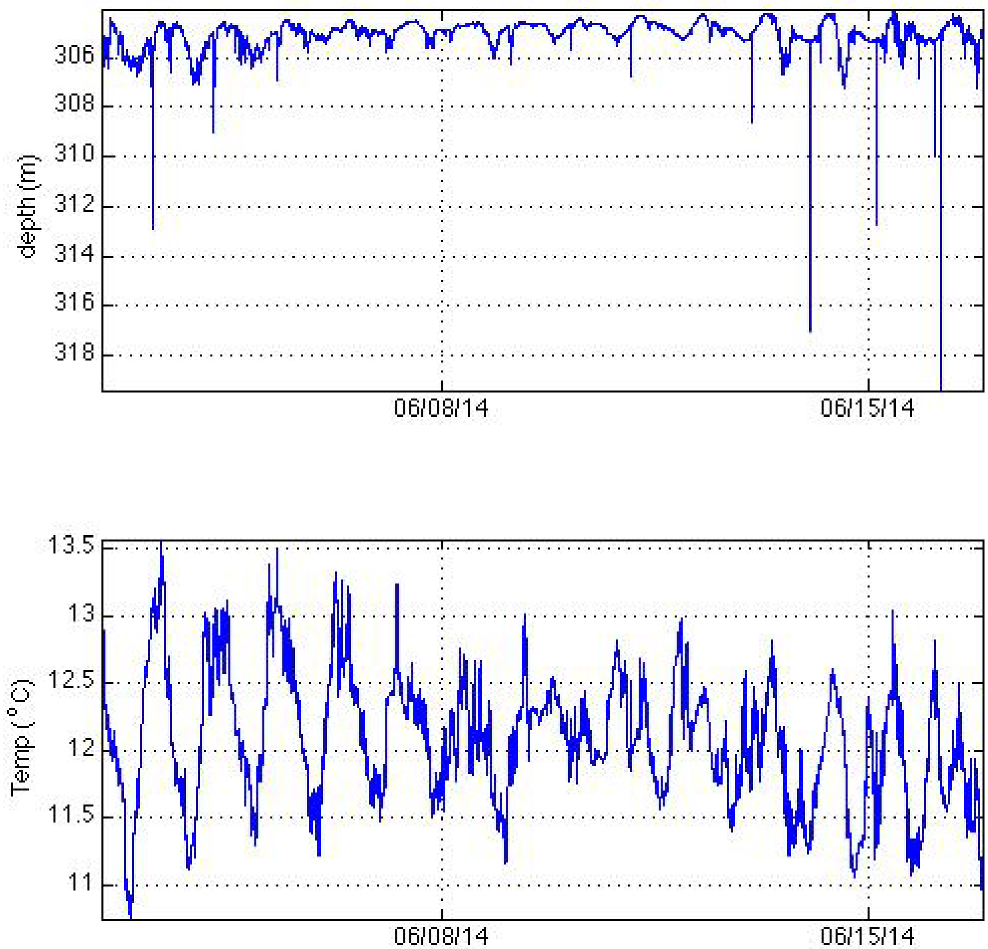

Figure 30. SBE39 Depth/Temperature record for CS2 mooring.

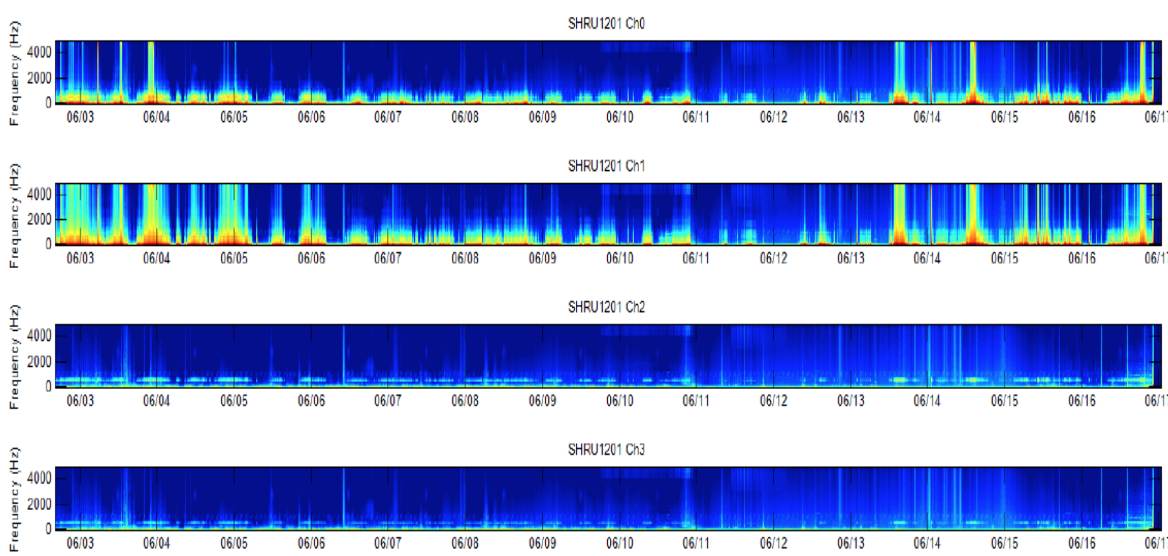

Figure 31. CS2 SHRU hydrophone spectra over June 2-17, 2014 deployment. (top=295m, 300m 310m, bottom=315m). (Figure: Jeff Wu)

In addition to the SHRU receiver, a single hydrophone ocean acoustic datalogger instrument (DSG-ST, manufactured by Loggerhead Instruments) was deployed on this mooring 15m below the SBE39 sensor, at a depth of 320m. This datalogger generated 5,182 data files, covering the span 05 June 2014 – 17 June 2014, at a sample rate of 25.0 kHz. The DSG-ST uses a High Tech, Inc. HTI-96-MIN hydrophone with typical sensitivity of -201 dBV//uPa, and was deployed with a gain of 21 dB. The system should clip at a level of ~180dB re 1uPa.

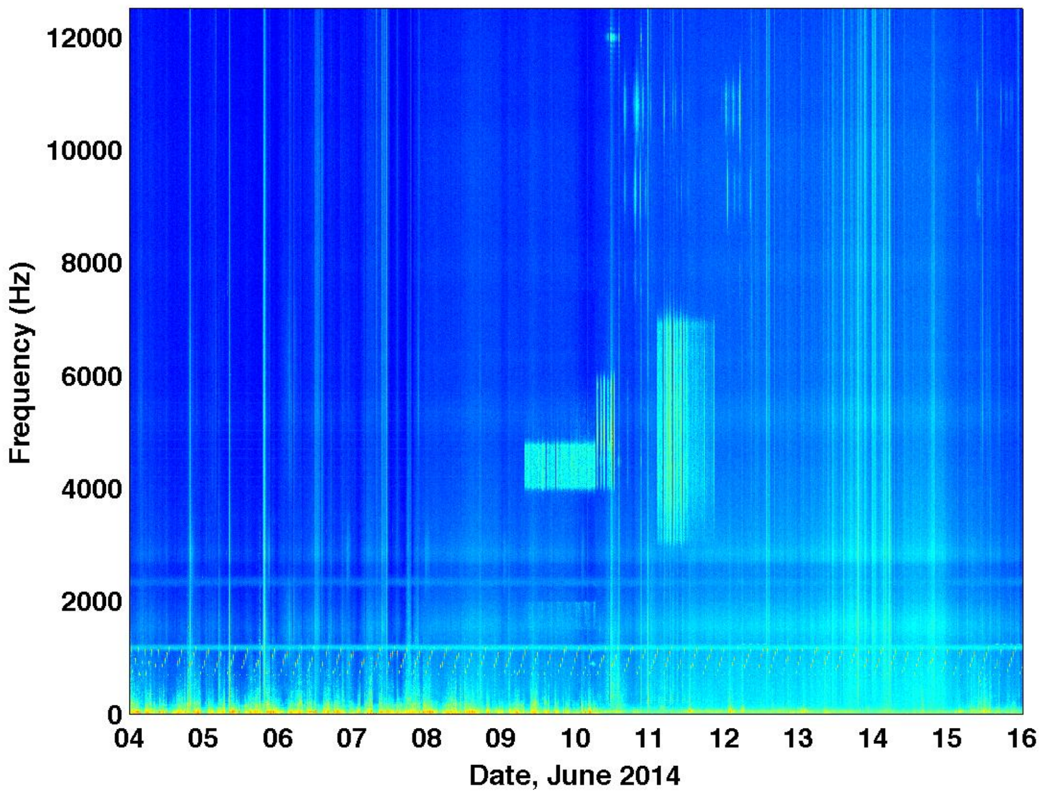

Figure 32 Received spectra from the DSG Datalogger instrument, 320m depth.

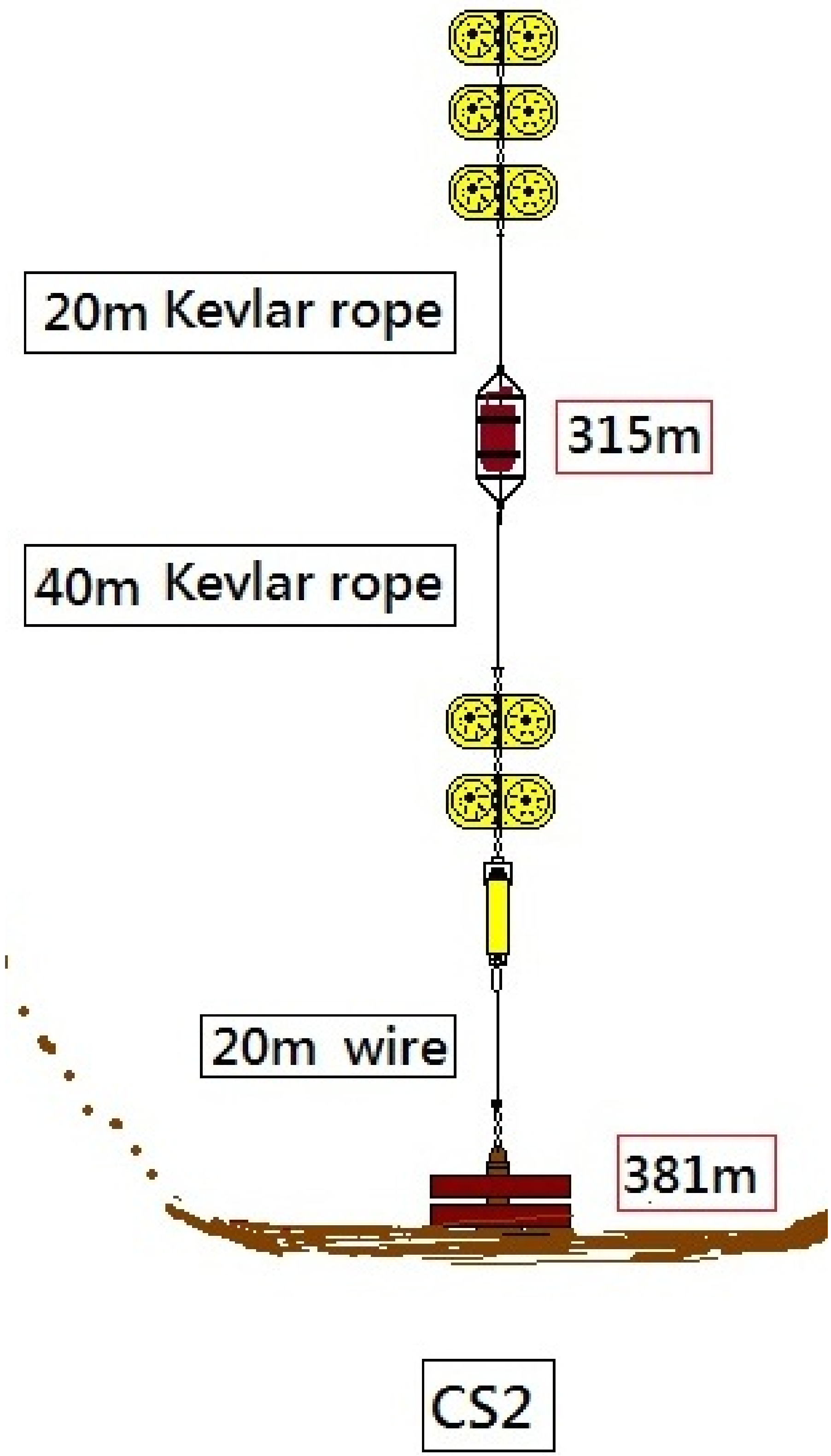

Figure 33. CS2 initial mooring design

2.8 YPO1 & YPO2 moorings

Two physical oceanography moorings were deployed south of the acoustics circle, along the expected arrival path of the internal waves. These moorings were to provide the physical oceanography measurements necessary for understanding internal wave evolution and changes as they progress up the slope, over the sand dune field.

Table 26. YPO1 mooring deployment information

Deployed (date/time UTC)	06/01/2014 03:25 Z
Recovered (date/time UTC)	09/18/2014 Z
Latitude N (anchor drop)	21° 49.998' N
Longitude E (anchor drop)	117° 37.596' E
Water depth (m)	372 m

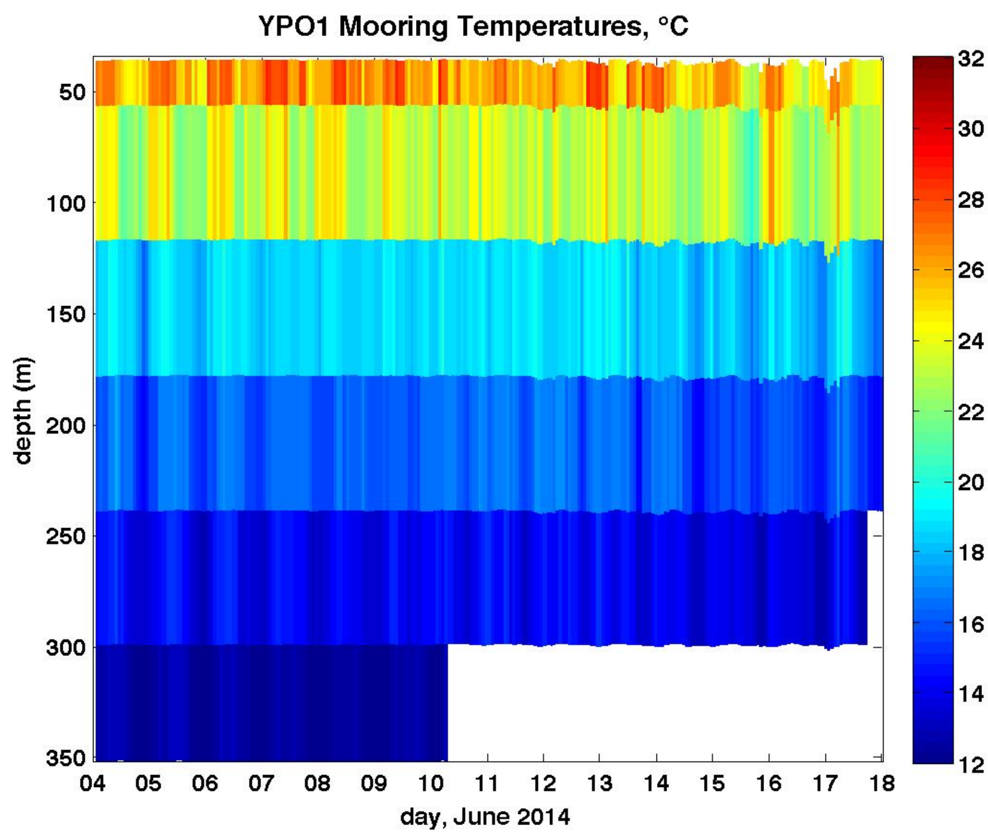

Figure 34. YPO1 Mooring SBE39 temperatures.

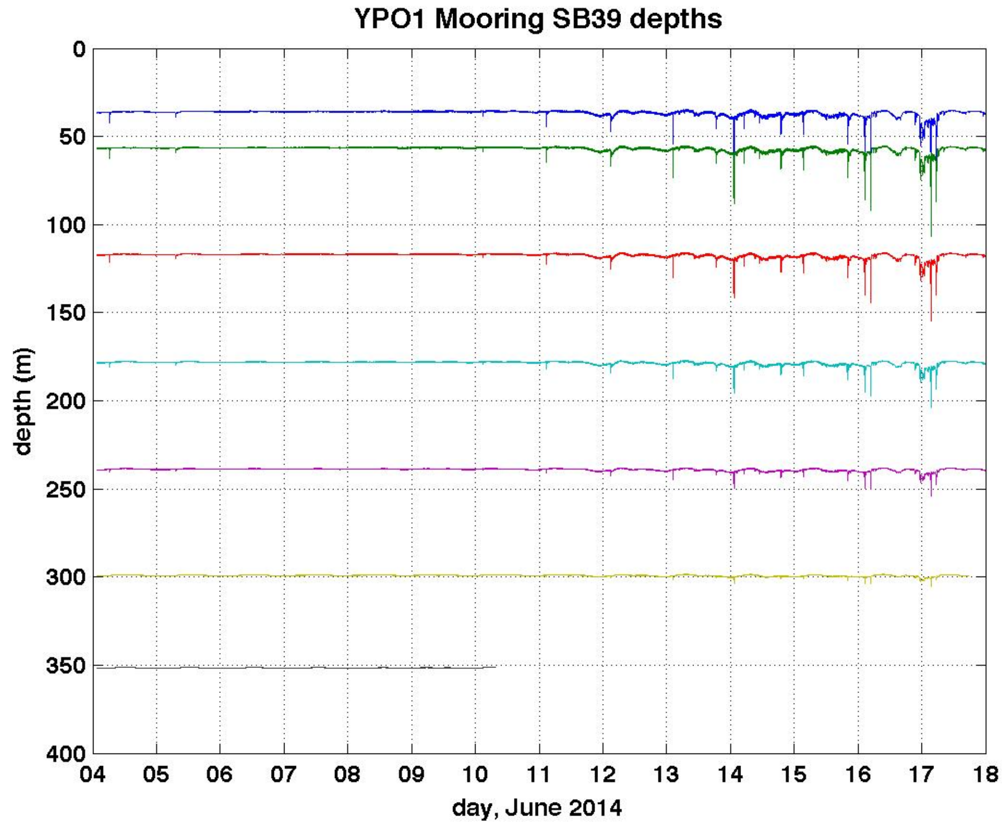

Figure 35. YPO1 SBE39 depth data.

Table 27. YPO2 mooring deployment information.

Deployed (date/time UTC)	06/01/2014 07:06 Z
Recovered (date/time UTC)	09/16/2014 Z
Latitude N (anchor drop)	21° 48.6788’ N
Longitude E (anchor drop)	117° 39.5125’ E
Water depth (m)	386 m

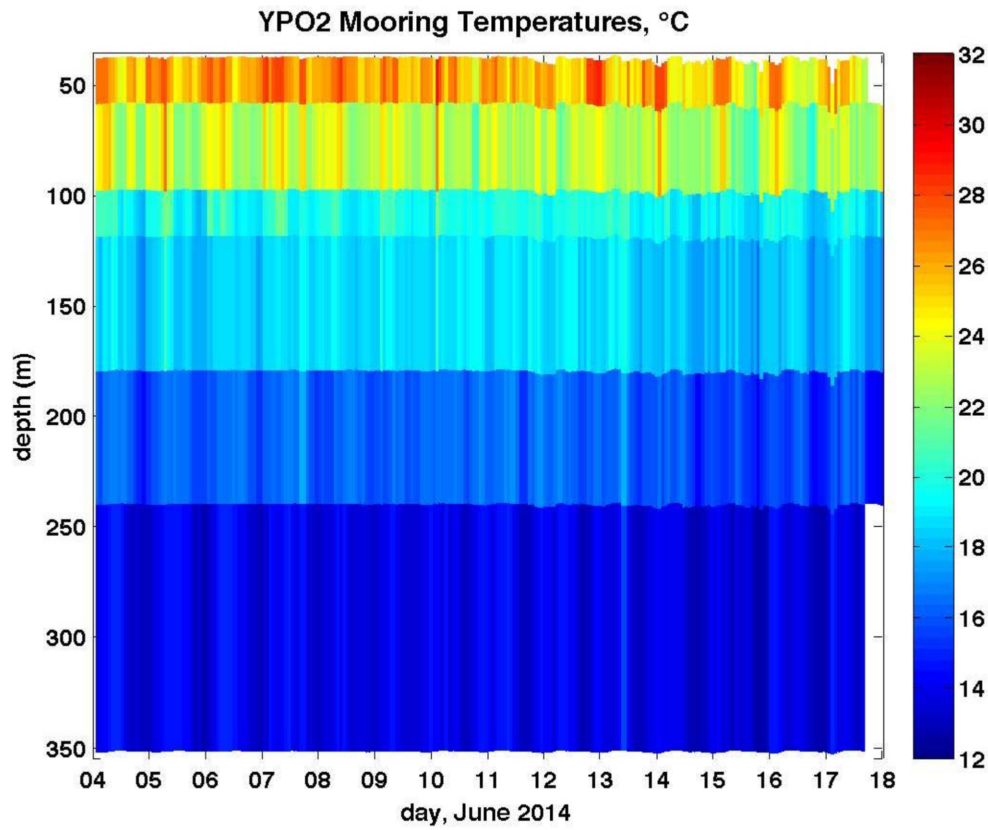

Figure 36. YPO2 mooring SBE39 measured temperatures.

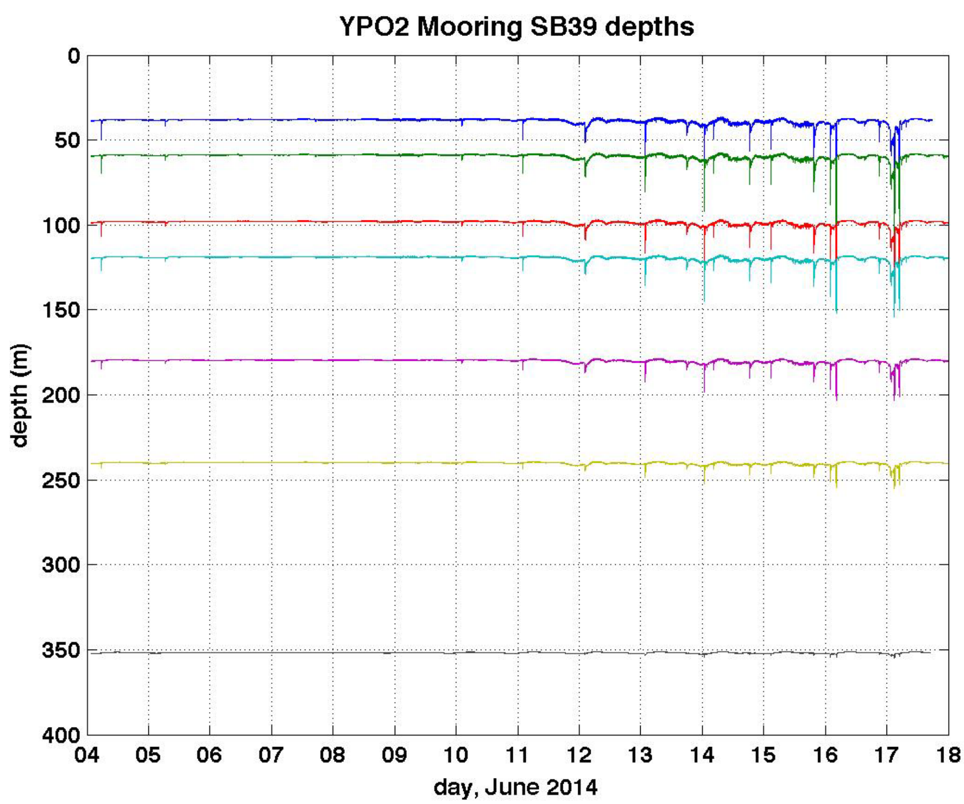

Figure 37. YPO2 SBE39 instrument depths

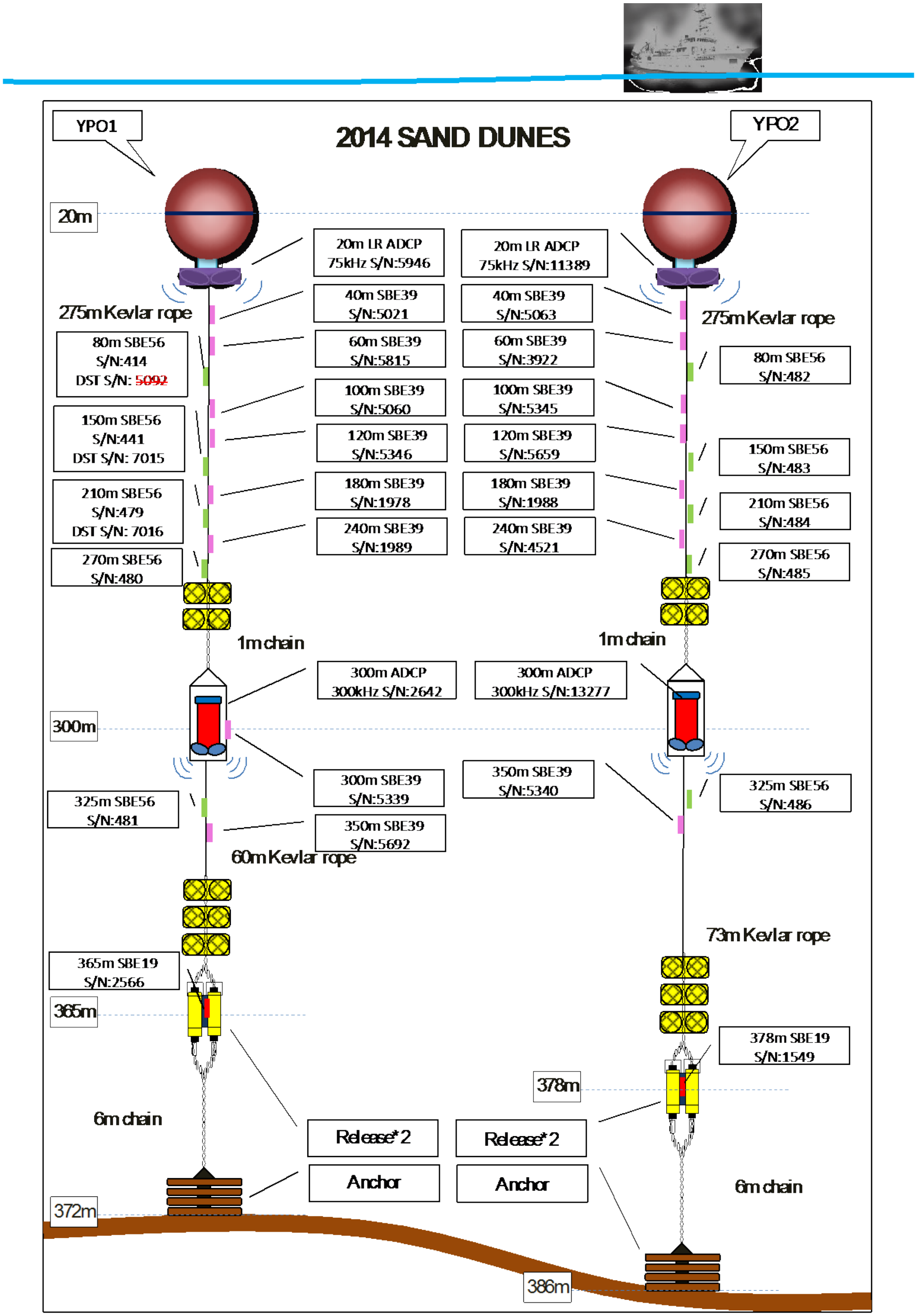

Figure 38. YPO1 (left) and YPO2 (right) mooring drawings (as deployed).

2.9 RPO mooring

A physical Oceanography mooring was deployed upslope of the acoustics circle, along the expected propagation path of the internal waves. This mooring will provide the final physical oceanography measurements of the evolution of the internal wave structure, after it passed over the sand dunes and departs the experiment area.

The physical oceanography moorings were designed to span the water column to provide temperature, CTD, and current time series over the water column. Instrument locations are shown in Table 29, and Figure 41.

Table 28. RPO mooring deployment information

Deployed (date/time UTC)	06/01/2014 00:10 Z
Recovered (date/time UTC)	09/16/2014 Z
Latitude N (anchor drop)	21° 53.334' N
Longitude E (anchor drop)	117° 33.676' E
Water depth (m)	262 m

Table 29. RPO mooring instrument setup and configuration

Instrument name	Serial Number	Measurement	Depth (m)	Sample interval
SBE 37SMP	4847	C,T,P,S	26	10s
RDI WHS-300	3109	ADCP	27	See table 25
SBE 56	487	T	45	10s
SBE 39	6308	T,P	60	10s
SBE 56	488	T	75	10s
SBE 39	5649	T,P	91	10s
SBE 37SMP	4848	C,T,P,S	104	10s
RDI WHS-300	6742	ADCP	105	See table 26
SBE 56	489	T	124	10s
SBE 39	5727	T,P	139	10s
SBE 56	490	T	154	10s
SBE 39	1474	T,P	169	10s
SBE 37SMP	4849	C,T,P,S	183	10s
RDI WHS-300	3771	ADCP	184	See table 27
SBE 56	491	T	198	10s
SBE 56	492	T	228	10s
SBE 37SMP	4820	C,T,P,S	243	10s
SBE 39	1735	T,P	256	10s

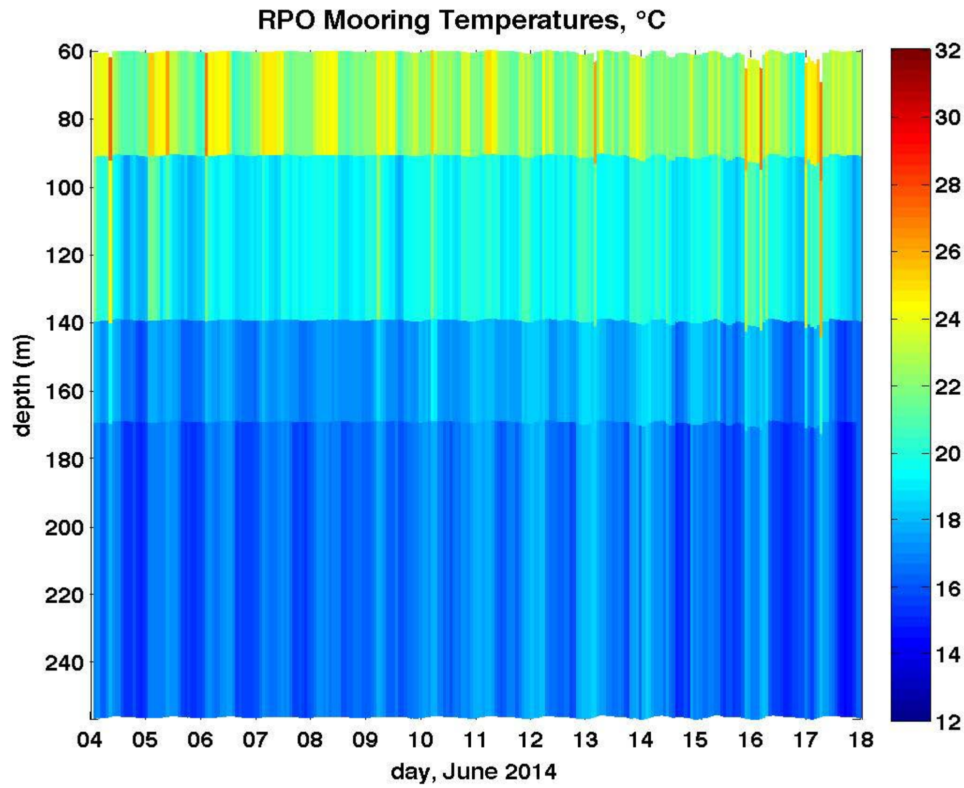

Figure 39. RPO Mooring temperatures from SBE39 sensors

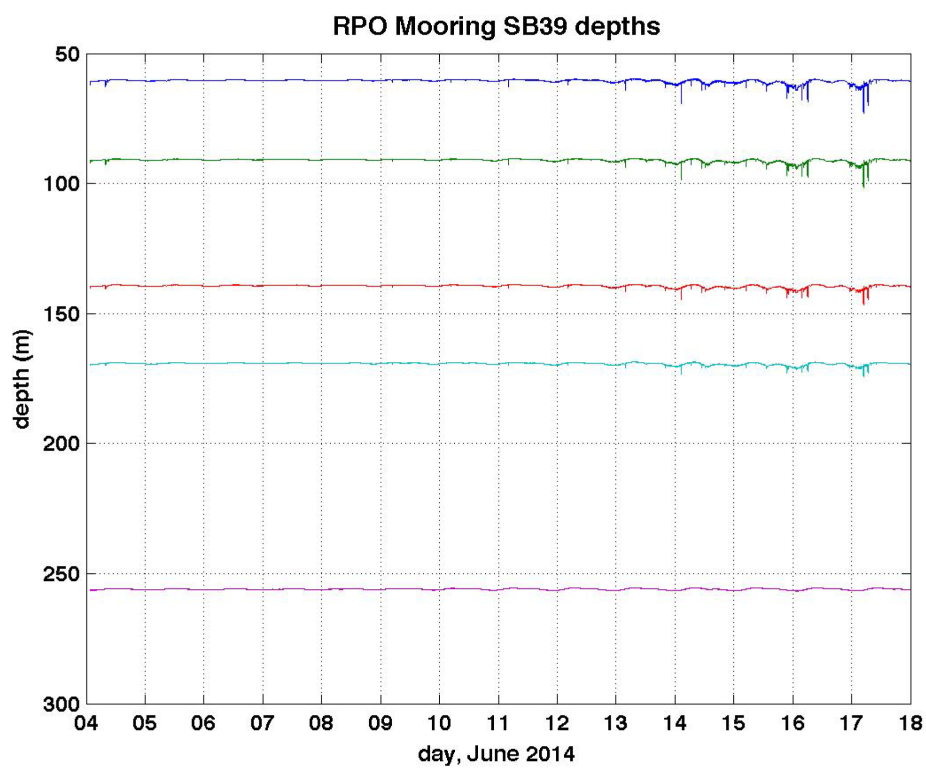

Figure 40. RPO mooring depths measured at SBE39 instruments

Table 30. RPO ADCP1 (top frame, looking downward) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 3109
Frequency	300 kHz
Ensemble length	90 seconds
# pings	32 (1 Hz pings, 32 seconds)
Vertical averaging	four meter bins
Start time	15 min after the hour

Table 31. RPO ADCP2 (middle frame, looking down) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 6742
Frequency	300 kHz
Ensemble length	90 seconds
# pings	32 (1 Hz pings, 32 seconds)
Vertical averaging	four meter bins
Start time	15 min 45 seconds after the hour

Table 32. RPO ADCP3 (lower frame, looking down) setup parameters

Manufacturer	Teledyne RD Instruments
Model number	WHS-300, S/N: 3771
Frequency	300 kHz
Ensemble length	90 seconds
# pings	26 (1 Hz pings, 26 seconds), plus one bottom ping per ensemble
Vertical averaging	four meter bins
Start time	15 min after the hour

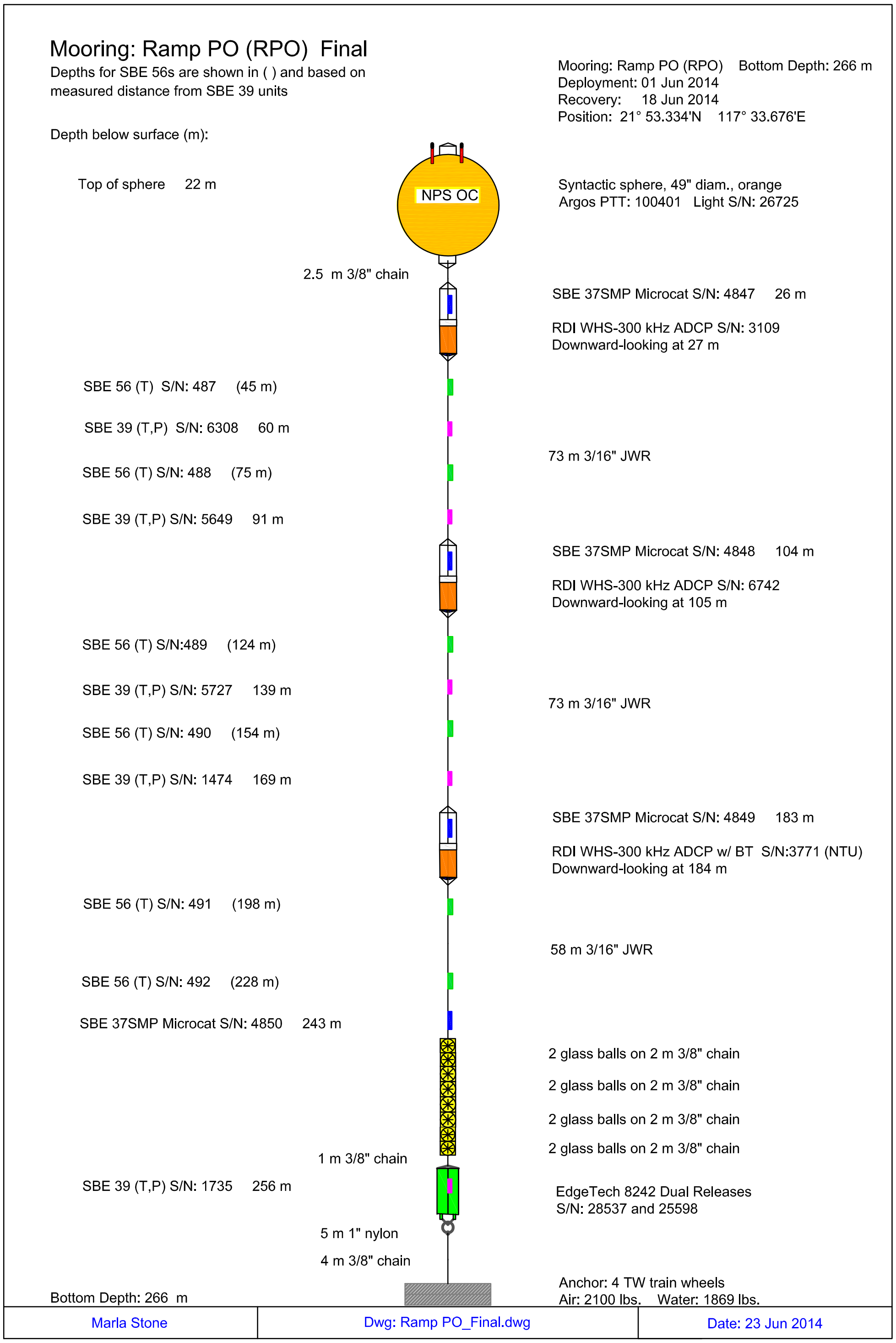

Figure 41. RPO mooring design

3.0 Ocean Researcher 3 cruise (June 9-13, 2014)

The research vessel Ocean Researcher 3 (OR3) is a smaller research vessel operated by the National Sun Yat-Sen University (NSYSU) and was used as the towed source platform for the Sand Dunes 2014 effort. Due to its smaller size, and limited fresh water capacity, it is a useful vessel for survey operations but is not suited for larger scale mooring operations.

Table 33. Ocean Researcher 3 Science Party

Linus Y.S. Chiu	Chief Scientist, Assistant Professor National Sun Yat-sen Univeristy
Ssu-Yu Chen	Student, NSYSU
Kuang-Yun Li	Student, NSYSU
Ming-Mou Hsien	Student, NSYSU
Chien-Hung Chen	Student, NSYSU
Chun-Cheng Huang	Student, NSYSU
Han-Jung Yeh	Student, Department of Engineering Science and Ocean Engineering, NTU

3.1 Towed Source Operations

The OR3 was equipped with a TR201a mid-frequency transducer, mounted in a tow wing body, and was the primary source for the radial transmission loss measurements about both the VLA mooring and CS2 mooring locations. In addition to the towed source measurements, the OR3 continued to survey the bathymetry over the acoustic experiment area to help determine if (any) volume transport was observed in the sand dune field since the 2013 survey.

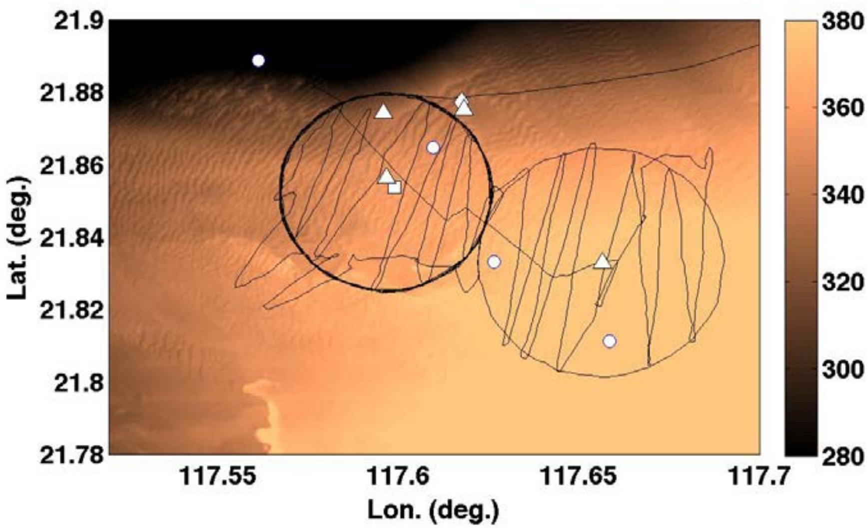

Figure 42. OR3 cruise track. Towed source circles about the VLA (white square) & CS2 SHRU (white triangle, middle right) mooring.

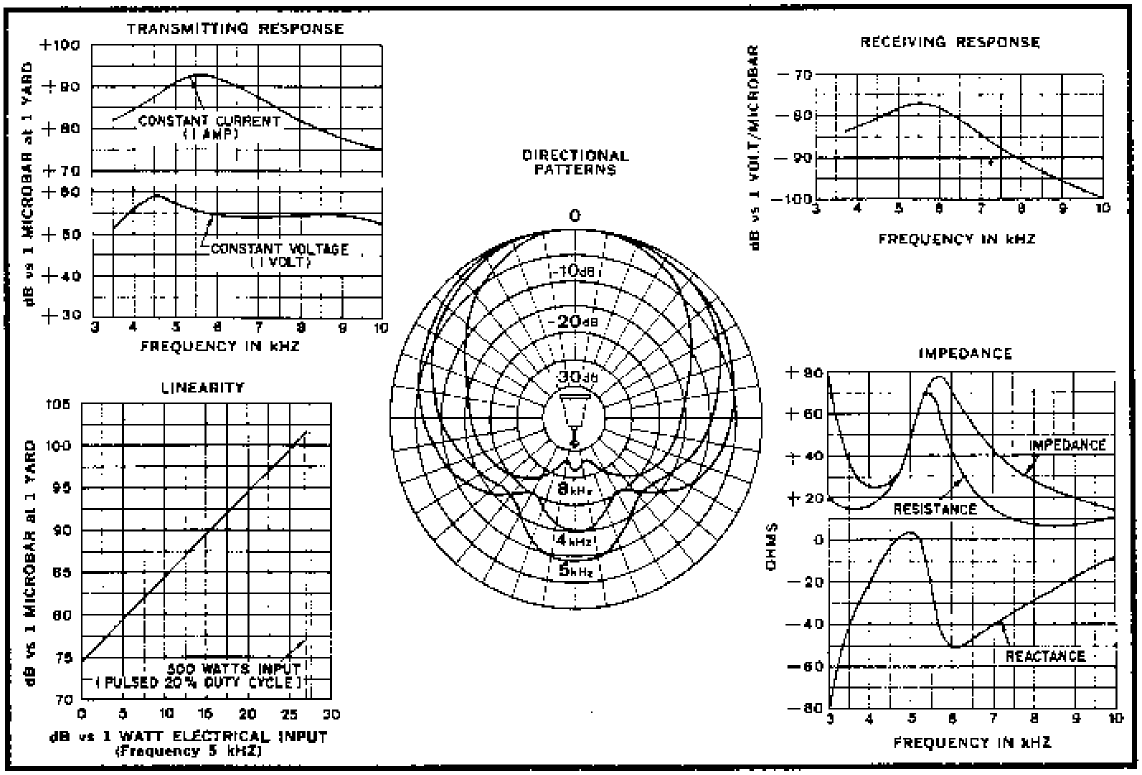

Figure 43. Towed source transducer (TR201a) characteristics.

Towed source operations about the VLA mooring began June 9, 2014 18:00 and secured June 10, 2014 ~19:20 GMT, having performed 8.5 circles about the primary receiver mooring. One additional circle was performed about the CS2 mooring (2013 "main mooring" site) on June 10, 2014 ~19:40–23:30 to gain additional geo-acoustic data at this location. Table 34 lists the transmission times and waveforms, logged by the OR3 in Taiwan local time (GMT+8).

Table 34. OR3 Towed Source Transmission Types, Signal Details

Transmission Sequence	Start time	End time	Period (s)	Signal details
LFM Seq 1	6/10/14 02:05 L 6/9/14 18:05 Z	6/10/14 16:28 L 6/10/14 08:28 Z	3	500ms, 1.5-2.0kHz LFM 220ms, 4-5kHz LFM
LFM Seq 2	6/10/14 16:32 L 6/10/14 08:32 Z	6/10/14 23:53 L 6/10/14 15:53 Z	3	1.0s, 1.5-2.0kHz LFM 220ms, 4-5kHz LFM
COM/M	6/10/14 23:53 L 6/10/14 15:53 Z	6/11/14 07:45 L 6/10/14 23:45 Z	Fig 46	4-6kHz BW, 40.88s M-seq 1-2kHz M-seq
Geo-acoustic	6/11/14 18:41 L 6/11/14 10:41 Z	6/12/14 11:57 L 6/12/14 03:57 Z	3	100ms, 3-7kHz LFM 200ms, 3-7kHz LFM

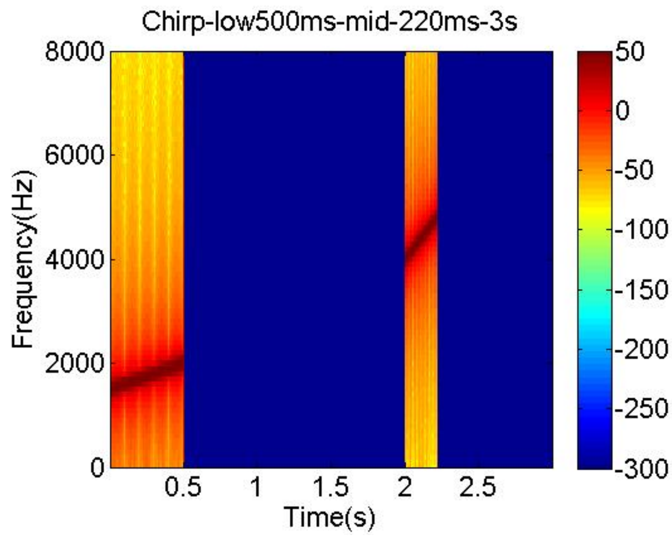

Figure 44. OR3 towed source signal for "LFM Seq 1". 1.5-2.0kHz, 500ms LFM, followed by 4-5kHz, 220ms LFM, repeated every 3 seconds.

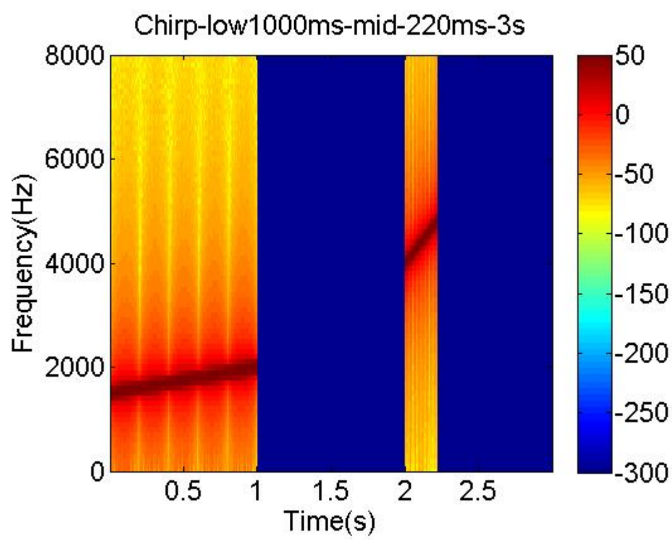

Figure 45. OR3 towed source signal for "Experiment 2". 1.5-2.0kHz, 1s LFM, followed by 4-5kHz, 220ms LFM, repeated every 3 seconds.

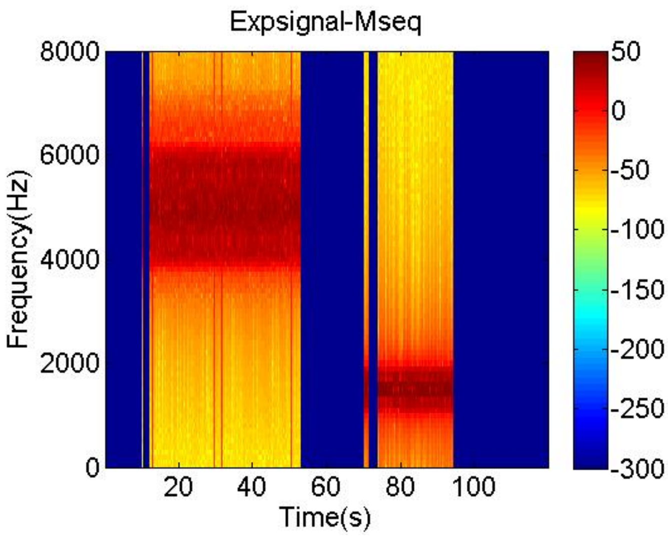

Figure 46. OR3 towed source signal for "COM/M".

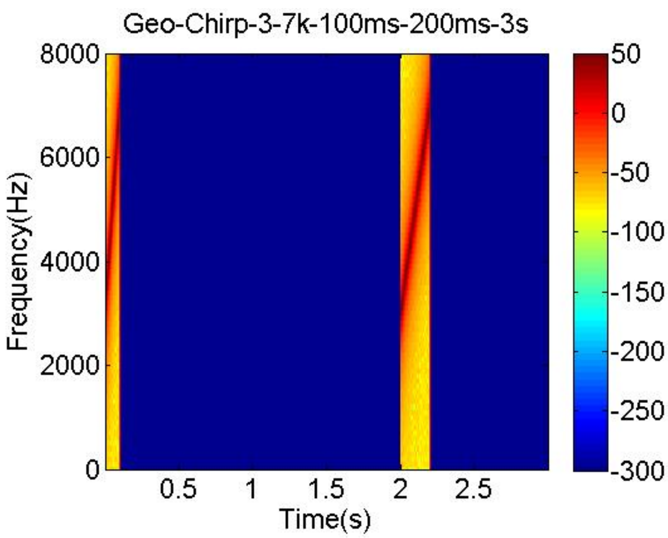

Figure 47. OR3 geo-acoustic survey signals. 3-7kHz LFM chirps, of 100ms and 200ms length, repeated every 3 seconds.

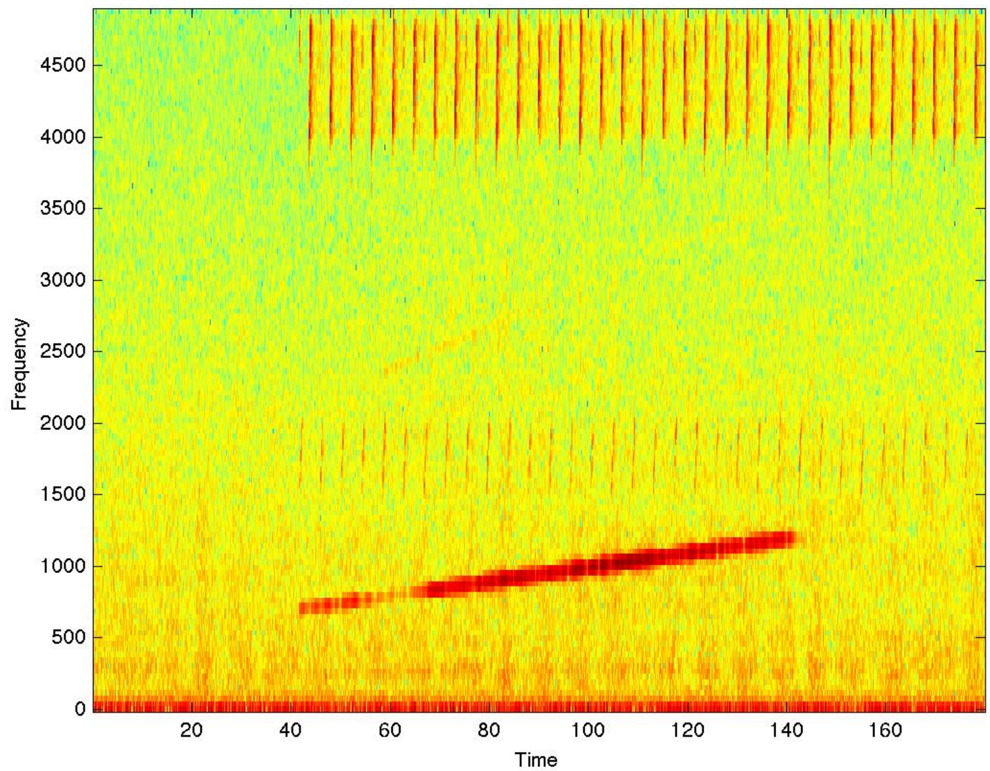

Figure 48. VLA hydrophone data spectrum at XYZ m depth. 7-1200 Hz LFM (moored source), 1500-2000Hz (LF towed source) and 4000-5000 Hz (HF towed source) are shown.

4.0 Ocean Researcher 5 cruise (10-21 June 2014)

The Ocean Researcher V (OR5) cruise was conducted June 10-21, 2014. Operated by the Taiwan Ocean Research Institute (TORI), the OR5 is the newest research vessel in Taiwan, and equipped for long-term research studies. Built in 2012, the OR5 is 72.6m in length, with a 15m beam and gross tonnage of 2,967t. This cruise was hampered by tropical storm HAGIBIS, which passed directly over the experiment area. With the seas and winds too large for “over the side” operations, the captain circuited the storm from June 13-15 in a wide arc to the south to avoid the storm area. OR5 science log is provided as Appendix 2 (compiled by Dr. Ben Reeder).

Primary objectives for the OR5 cruise are: bathymetry transect surveys along the internal wave propagation path over the course of the experiment; lowered source stations for radial and distant TL measurements; internal wave sampling with the LADCP package; and mooring recoveries.

Figure 49. Research Vessel OCEAN RESEARCHER V

Table 35. Ocean Researcher V science party

Yiing-Jang Yang	Chief Scientist; Associate Professor Institute of Oceanography, National Taiwan University
Ching-Sang Chiu	Professor, Naval Postgraduate School
D. Benjamin Reeder	Associate Research Professor, Naval Postgraduate School
Chris Miller	Faculty Associate, Research, Naval Postgraduate School
Marla Stone	Oceanographer, Naval Postgraduate School
Keith Wyckoff	Technician, Naval Postgraduate School
Steve Ramp	CEO, Soliton Ocean Services
Fred Bahr	Technician, Soliton Ocean Services
Wen-Hwa Her	Technician, Institute of Oceanography, NTU
Chaing-Chih Shie	Technician, Institute of Oceanography, NTU
Wen-Huei Lee	Technician, Institute of Oceanography, NTU
Cheng-Chia Lien	Research Assistant, Institute of Oceanography, NTU
Chung-Yaung Lee	Student, Institute of Oceanography, NTU
Wei-Chun Hu	Research Assistant, Department of Engineering Science and Ocean Engineering, NTU
Tien-Siang Ling	Research Assistant Department of Engineering Science and Ocean Engineering, NTU
Chih-Hao Wu	Student, Department of Engineering Science and Ocean Engineering, NTU

4.1 Lowered Source Operations

The OR5 cruise had planned extensive lowered source operations, using a mechanically tuned, free flooded tonplitz transducer manufactured by Teledyne Webb Research Corporation (TWR). This source has a useful bandwidth between 500 Hz to 700 Hz, and transmitted a 30 second linear frequency sweep every 5 minutes. The lowered source transmission circle will provide additional low-frequency bandwidth to the OR3's towed source circle.

In order to provide flexibility during the source operations, the OR5 multi-purpose winch wire was spliced at the slip-ring connection to provide the 4-wire connectivity for SAIL loop and reset communications with the sound source while deployed.

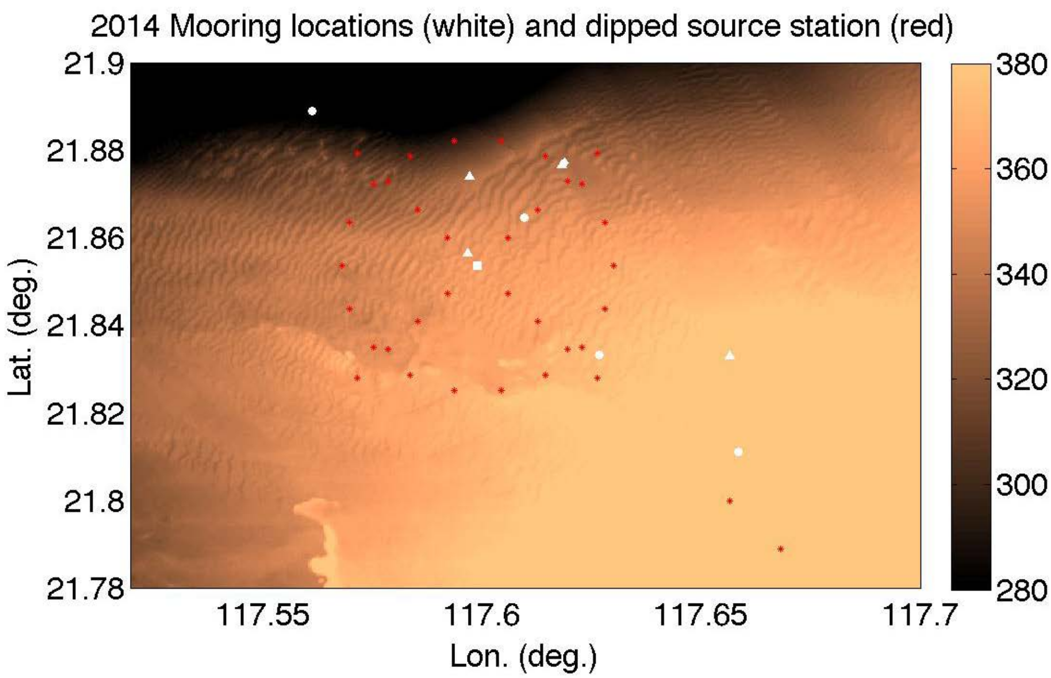

Figure 50. Planned acoustic stations (red) for 2014 Sand Dunes experiment. VLA (white square) is the central mooring for the experiment, with SHRU receivers (white triangles), PO Moorings (white circles) and source (white diamond) moorings also shown. Mechanical problems with source prevented dipped source stations from being completed.

Transmissions	100s every 300s
Bandwidth (Hz)	500 – 700 Hz

Unfortunately, the tropical storm HAGIBIS severely impacted our ability to execute the lowered source station plan. By June 12, the seas were too severe for lowered source operations, and we weren't able to get back on station to resume until June 15th, several days after the VLA mooring STARmini units stopped recording (battery capacity bench tested at 12 days; lasted 10.5 & 11.5 days deployed).

Table 36. Lowered source (500-700 Hz) transmission stations.

Station	Depth	Latitude	Longitude	Start	Period
LS07	50m	21° 50.113' N	117° 37.370' E	6/15/14 13:25 Z	15
LS07	250m	21° 50.113' N	117° 37.370' E	6/15/14 14:05 Z	15
LS06	50m	21° 50.617' N	117° 37.681' E	6/15/14 15:25 Z	15
LS06	250m	21° 50.617' N	117° 37.681' E	6/15/14 16:00 Z	15

Prior to the lowered source station #6, it was noted that the spherical ITC transducer ball was hanging lower in the resonator tube. At station LS#5 it was further noted that the linear actuator was 100% open, much farther than normal operation, and the ITC transducer was free hanging in the resonator tube, with no securing mounts. With the transducer "out of tune", the feedback loop forced the actuator to continue to open past the stops. On deck the source did not mechanically respond to any "move sleeve" commands issued to the actuator. With no spare parts, and bad weather conditions, the source was boxed and lowered source operations ceased.

After the moored source was recovered on June 18th, the 700-1200 Hz source was used in place of the 500-700 Hz, to repeat the few dipped stations that had been occupied to provide a different bandwidth for TL comparison. Transmitted one 100s 700-1200Hz LFM sweep every 180 seconds.

Table 37. Lowered source (700 – 1200 Hz) transmission stations

Station	Depth	Latitude	Longitude	Start	Period
LS07	250m	21° 50.108' N	117° 37.352' E	6/18/14 03:00 Z	80
LS07	250m	21° 50.108' N	117° 37.352' E	6/18/14 0700 Z	5

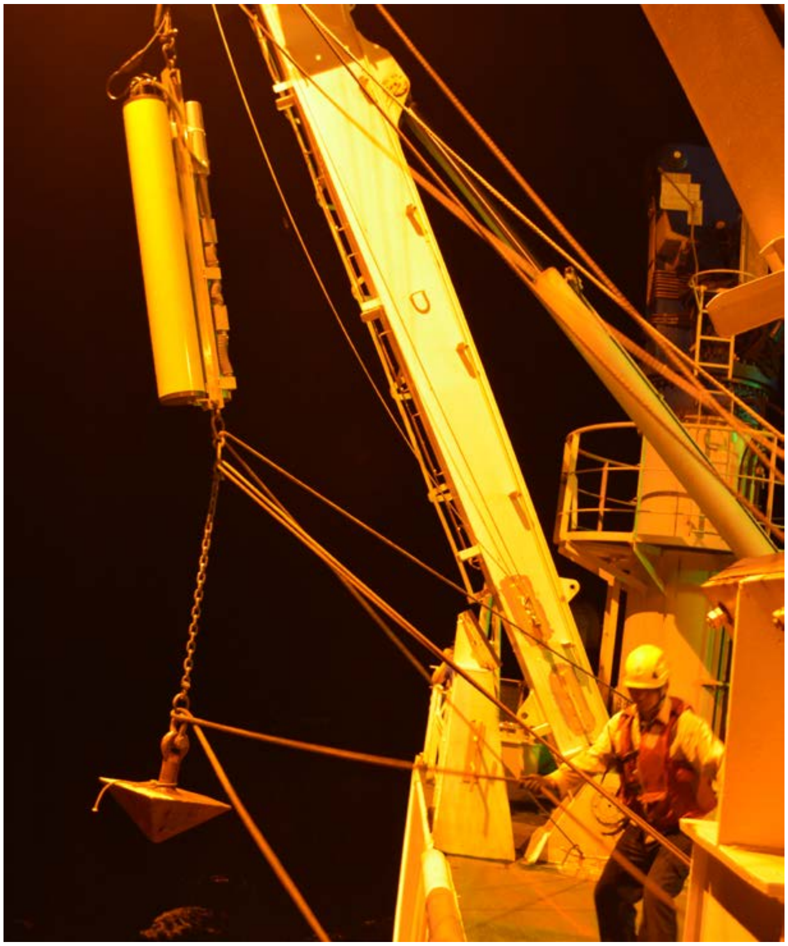

Figure 51. Lowered source deployment.

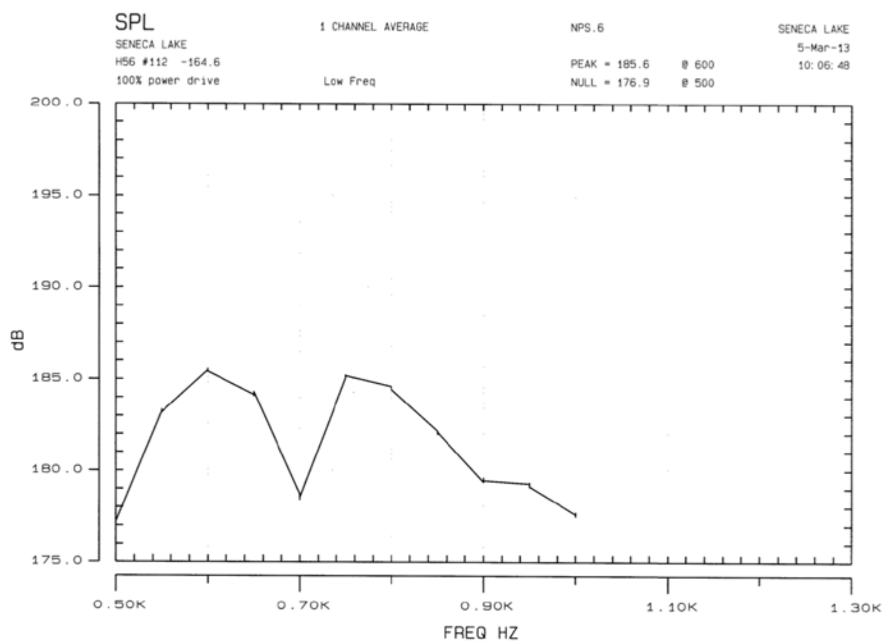

Figure 52. Lowered source (Sweeper 500-700 Hz) measured source level calibration curve.

4.2 Autonomous Sources

Three expendable, autonomous vehicles were also deployed during the OR5 cruise as a backup to the lowered source operations, as we expected a very busy cruise schedule, with many conflicting schedules.

These vehicles use dead reckoning navigation, using only magnetic heading, motor speed, and depth programing for each time duration to navigate a pre-programmed route. As these vehicles have no onboard positioning, it is expected that the will experience increasing position error as time goes by, as they will be affected by ocean currents and internal waves during their run.

These vehicles provided a critical stopgap to the lowered source mechanical failure, and foul weather that we encountered during the cruise. With a robust architecture, these systems are “release and relocate”, and could be deployed with the ship underway to the next waypoint or in bad weather conditions where other operations were not possible.

All vehicles were programmed to broadcast a 1.25 KHz, 150dB continuous wave (CW) tonal for 58 seconds of every minute, followed by a 2 second linear frequency modulated sweep from 1,250 – 3,000 Hz each minute. These vehicles have a run time of approximately 10 hours (power limited).

Table 38. "Circle" autonomous source (#98053) deployment

Latitude	21 51.989’ N
Longitude	117 35.1196’ E
Launch Time	06/12/14 (YD 163) ~13:00 GMT

Table 39. "Circle" autonomous source (#98057) deployment

Latitude	21 51.989’ N
Longitude	117 35.1196’ E
Launch Time	06/15/14 (YD 166) ~18:35 GMT

Table 40. 2km "Circle" source geometry

Duration	Heading (T)	Depth	Speed	Description
43 min	135	30 m	3 kts	4km diameter, SW past VLA
132 min	360 circle	30 m	3 kts	2km CCW circle @ 30m
132 min	360	60 m	3 kts	2km CCW circle @ 60m
66 min	180	30 m	3 kts	2km ½ CCW circle @ 30m
43 min	135	30 m	3 kts	4km diameter, CW past VLA
300 min	135	30 m	6 kts	Continue long range TL

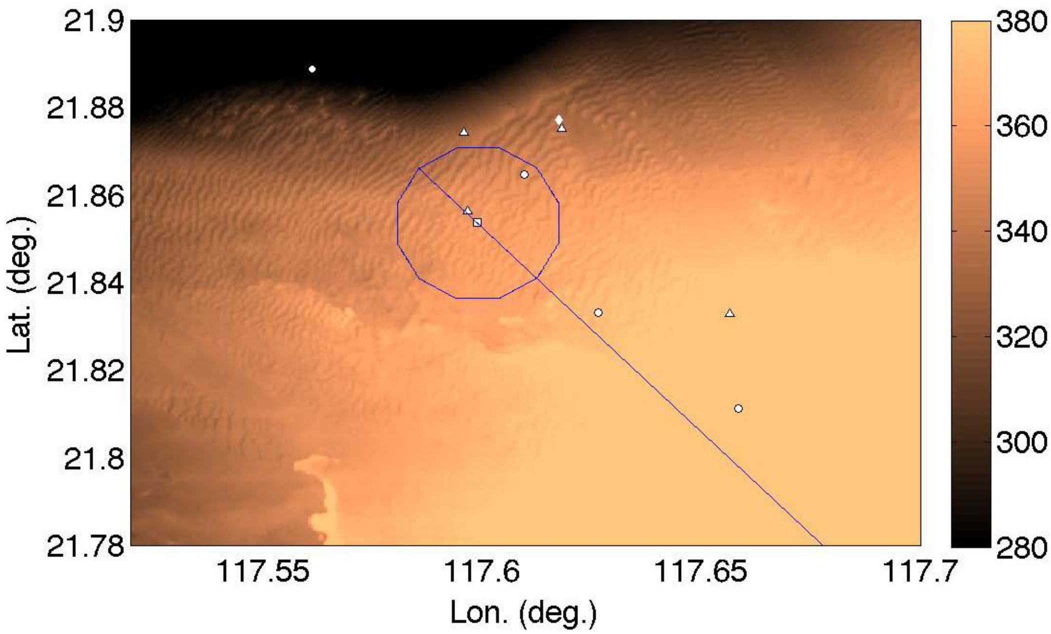

Figure 53. "Circular track" vehicle programming. Vehicle was deployed upper northwest, and ran southwest past the VLA (white square), before circling the VLA mooring counter-clockwise 2.5 times before once again running past the VLA and continuing southwest for a long baseline TL run.

Table 41. "Cross" autonomous source (#98058) deployment

Latitude	21 51.735' N
Longitude	117 36.038' E
Launch Time	06/17/14 (YD 163) ~03:00 GMT

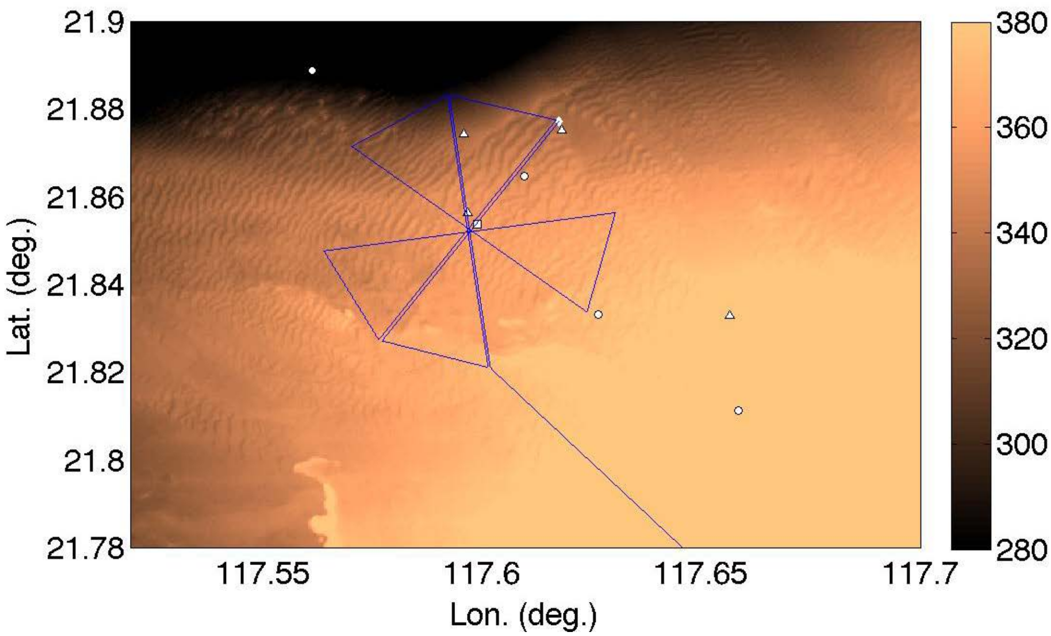

Figure 54. "Cross" track vehicle programming. Vehicle deployed near the source

mooring location, and passed along the source-CPO-VLA track (heading 217) for 1.25 hr, ran 14 min CCW along the circle, headed north past the VLA, etc.. After the 6th crossing of the VLA, the vehicle exited the experiment area along heading 135 at 8kts.

Table 42. "Cross" vehicle geometry

Duration	Heading (T)	Depth	Speed	Description
75 min	217	30 m	3 kts	4km diameter, SW past VLA
14 min	105	30 m	6 kts	Transit circumference (CCW)
75 min	352	30 m	3 kts	4km diameter, N past VLA
14 min	240	30 m	6 kts	Transit circumference (CCW)
75 min	127	30 m	3 kts	4km diameter, SE past VLA
14 min	15	30 m	6 kts	Transit circumference (CCW)
75 min	262	30 m	3 kts	4km diameter, W past VLA
14 min	150	30 m	6 kts	Transit circumference (CCW)
75 min	37	30 m	3 kts	4km diameter, NE past VLA
14 min	284	30 m	6 kts	Transit circumference (CCW)
75 min	172	30 m	3 kts	4km diameter, S past VLA
300 min	150	30 m	8 kts	Outbound TL, 1.3kHz CW

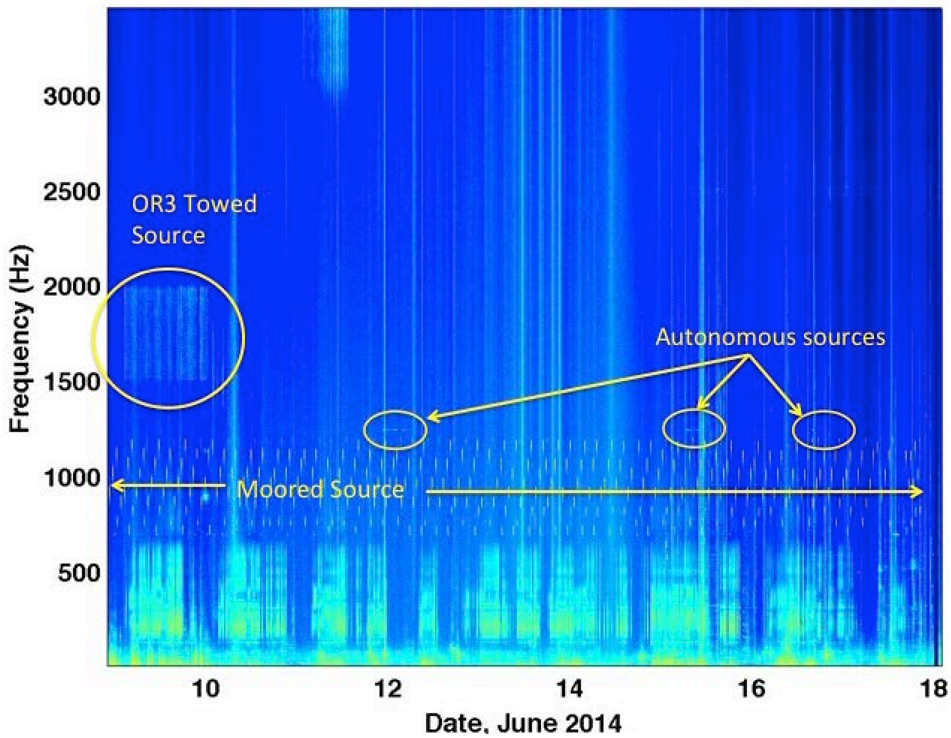

Figure 55. Spectrogram from YS2 (VLA SHRU) phone 1 showing the OR3 towed source (June 9th, 1.5-2kHz), moored source (700-1200Hz, throughout), and autonomous source (1250Hz CW seen June 12, 15, 17).

4.3 Automated Information System (AIS) Vessel data

An AIS antenna/receiver was installed onboard the OR5 to record passing vessel traffic during the experiment. While this data does not represent a complete picture of all vessels in the experiment area (limited receiver ranges, OR5 leaving the experiment area during the tropical storm HAGIBIS, and vessels which have turned off or are lacking AIS transponders), it should provide some insight to additional sources of noise during the investigation of the data.

An initial plot (Figure 54) shows that 6 distinct vessels (in addition to the OR3 and OR5) that passed within 2km of the VLA mooring between June 11-19, 2014. No vessel data exists before the June 11 arrival of the OR5 at the experiment area, and a data gap between June 13-16 exists when the OR5 exited the experiment area during the Tropical Storm HAGABIS passage.

Table 43. Vessel traffic passing within 5km of VLA

Vessel Name	Type	Length x bredth	Gross tonnage	Flag
OCEAN LADY	Bulk carrier (Cargo)	295m x 46m	94863	Hong Kong
CSL TRAILBLAZER	Bulk carrier (Cargo)	178m x 26m	18241	Bahamas
OCEAN BEAUTY	Bulk carrier (Cargo)	180m x 30m	23264	Hong Kong
FRANBO PROGRESS	General Cargo	115m x 19m	7350	Panama
FU KUO 5	Fishing	Not available	Not available	Taiwan
JIN SHENG FENG	Fishing	Not available	Not available	Taiwan

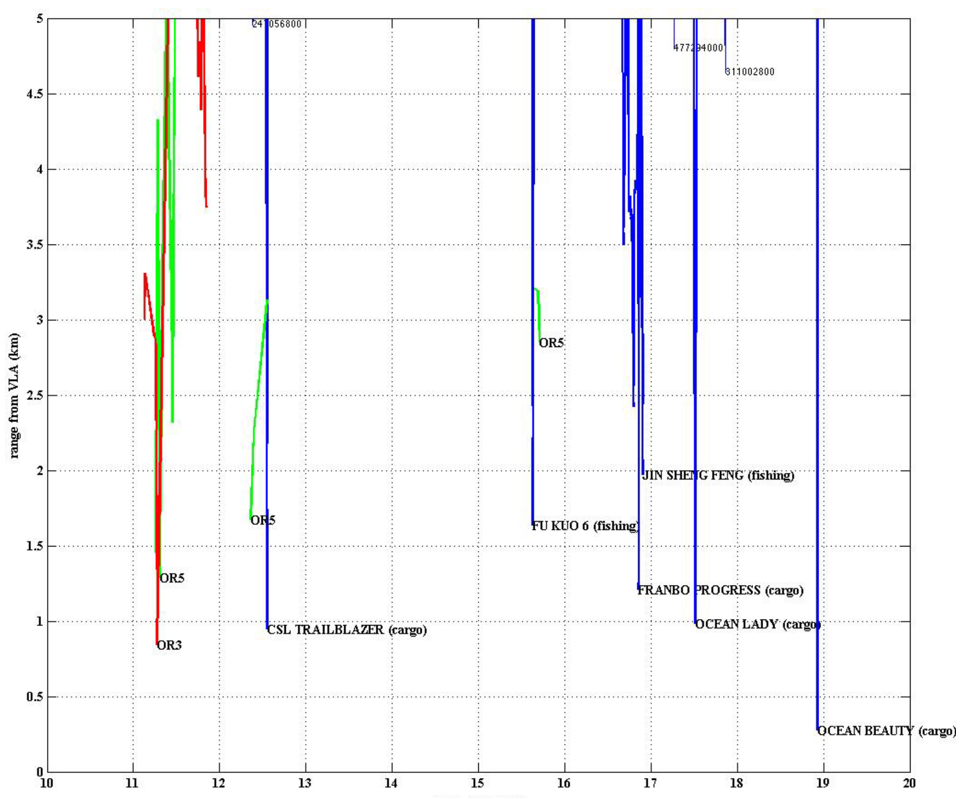

Figure 56. Closest Point of Approach (CPA) of vessel traffic within 5km of the VLA mooring.

5.0 Acknowledgements

The authors would like to thank Drs. Bob Headrick and Kyle Becker of the Office of Naval Research, Ocean Acoustics division, and Dr. Woei-Min Lin of ONR Global, for their financial support, dedication and belief in this project. We would also like to acknowledge Taiwan's Ministry of Science and Technology support of the project, and the mutually beneficial scientific collaborations of our Taiwanese colleagues.

We would also like to thank the captains and crews of the research vessels: OCEAN RESEARCHER 1 (OR1), OCEAN RESEARCHER 3 (OR3), and OCEAN RESEARCHER V (OR5). Their skill and professionalism allowed all moorings to be deployed, and 100% of all gear recovered, despite very hot weather conditions; mechanical failures; and the passage of a tropical storm, all of which conspired to reduce our available working days on board.

Special thanks go to the technical staff which made this data collection possible: Wen-Hwa Her, Chiang-Chih Shie, Wen-Huei Lee, Marla Stone, and Keith Wyckoff; as well as the hard work of Cheng-Chia Lien, Chung-Yaung Lee, Tien-Siang Ling, Chih-Hao Wu, and Wei-Chun Hu.

Author's note: As this report was finalized for submission, the authors were informed of the loss of the R/V OCEAN RESEARCHER V. The vessel sank in the Taiwan Straight on 10 October 2014, during Typhoon Vongfong. We join with our Taiwan colleagues in mourning the loss of life, and vessel during these difficult times.

Appendix 1: OR1 Cruise Log

Underway cruise log documented by Dr. Ben Reeder. All times Taiwan local (GMT + 8)

May 31

1015 L Underway from Love Pier, Kaohsiung
1203 L Spotted a set of underwater dunes on the EK500 only ~20 nm from KS
1845 L First beautiful sunset over a very calm sea; very reddish color
1914 L Crossed over the head of the submarine canyon IVO of Taiwan Bank; ~20 fishing vessels on our stud side
1924 L The crew thinks the fishermen are out here for small squid; they haven't turned on their lights yet; These are Taiwanese fishermen; mainland China fishermen are not allowed to fish starting June 1 for one month(?).
1930 L Crossing what looks to be the head of a larger submarine canyon
1950 L Heading 250; not seeing the western canyon wall yet; Looks like we're heading too far to the south of the shelf break to see the western wall

June 1

0410 L CTD near RPO complete; reached about 7 m from bottom
0500 L Getting set up to deploy RPO
0600 L Saw our first set of waves pass through; looks like another wave is coming
0610 L Ship repositioning to set up for the deployment; dunes apparent on the EK500
0630 L Current generally from the south, setting up to slowly transit along the 262 m isobath to deploy RPO at 262 m
0810 L RPO deployed @ 21 53.334 N 117 33.676 E, water depth 262 m
0841 L Schools of small fish seen on EK500 (strong echoes on 120 kHz data, but weak echoes on 38 kHz)
1005 L CTD near CS1 complete; reached about 2.6 m from the bottom; seen on EK500; GoPro attached
1059 L CS1 deployed @ 21 52.442 N 117 35.832 E, water depth 325 m
1130 L Nice wave IVO CPO with clear turbulence in the center; could it be an A wave? Apparent refraction to the left and right due to subducted warm water by NLIW; Causes energy to refract away from center of the beam; less energy scattered back to transducer
1245 L The 120 kHz EK500 data shows changing echo level as the ship moves over the dunes About 5-6 dB a short distance above the seabed.
1353 L CPO deployed @ 21 51.8791 N 117 36.5866 E, water depth 348 m
1400 L Commenced zig-zagging along the Src-VLA transect to try to identify/locate the trough between source and receiver; Crew taking a rest during heat of day
1500 L Fish schools apparent at both freqs on the south side of the transect, ~325 m water depth, fish at ~225 m depth
1800 L Finished surveying along the acoustic transect; decided to move the Src, YS1 and VLA positions south to the next trough. Provides slightly deeper water to match the mooring design depths and places them in an apparent meandering trough
1935 L YS1 deployed (Source SHRU) @ 21 52.50985 N 117 37.0910, water depth 328 m
1945 L The not-so-deep scattering layer has migrated towards the surface

2108 L Source mooring deployed @ 21 52.6392 N 117 37.0570 E, water depth 328 m

June 2

1125 L YPO1 deployed @ 21 49.998 N 117 37.6 E, water depth 372 m

1312 L CTD IVO YPO2 complete, MAVS10320 mounted sensor up, data file = 'Data-10320-20140602-YPO1', EK500 shows bio-layer near bottom

1506 L YPO2 deployed @ 21 48.6788 N 117 39.5125 E, water depth 386 m

1623 L CTD near CS2 completed; spent 5 min 3-6 m off bottom, MAVS10320 mounted sensor-down ('Data-10320-20140602-CS2), started recording @ ~100 m depth. Looks like the CTD passed through a Mode 2 wave on the downcast (evident on EK500 and the difference in T b/w down/upcasts on CTD). Strong bio-layer above the bottom

1812 L CS2 deployed @ 21 49.9806 N 117 39.3877 E, water depth 379 m

2038 L CTD near YS2 completed; no MAVS

2122 L YS2 deployed @ 21 51.3887 N 117 35.8003 E, water depth 350 m

2300 L CTD @ 400 m water depth @ 21 42.611 N 117 40.676 E

June 3

0053 L CTD @ 500 m water depth @ 21 42.457 N 117 46.926 E

0219 L CTD @ 600 m water depth @ 21 39.601 N 117 50.069 E

0850 L NP1 box core on dune crest north of ac. transect close to Source, water depth = 324 m, coarse sand @ 21 52.528 N 117 36.805 E

1045 L T1 box core in dune trough along ac. transect close to Source, water depth = 336 m, finer sand than NP1, @ 21 52.445 N 117 36.793 E

1255 L T3 box core in dune trough in ac. transect close to VLA, water depth - 352 m, sticky mud with grit, @ 21 51.42 N 117 35.93 E

1400 L T2 box core in dune trough in center of ac. transect, water depth = 347 m, mud????????????, @ 21 51.88 N 117 36.29 E

1500 L CW01 (Chase Wave #01): Heading NW to get ahead of a wave that passed the ship a little while ago; nice overturning in the wave; MAVS, camera and LADCP ready to go

1515 L Passed the wave, good signature on the EK500, now up on the shelf in about 120 m of water; OOD is inexperienced, BB#0332-0334

1518 L EK500 BB#0335 shows an enhanced area on the 120 kHz below the NLIW that is climbing the slope—the reddish area ?=? suspended sediment/biology?

1531 L On station (120 m), CTD going into the water, looks like there should be some good suspension events in the MAVS data

1630 L CW01 complete

1037 L NP2 box core on dune crest north of center of ac. transect, water depth = 339 m, @ 21 51.93 N 117 36.24 E

1138 L NP3 box core on dune crest north of ac. transect close to VLA, water depth = 345 m, @ 21 51.53 N 117 35.89 E

2100 L CS2-A box core, 4 km bearing 310 deg from CS2, water depth = 354 m, @ 21 51.395 N 117 37.633 E

2135 L CS2-B box core, 2 km bearing 310 deg from CS2, water depth = 365 m, @ 21 50.677 N 117 38.510 E

2300 L CS2-C box core, 2 km bearing 130 deg from CS2, water depth = 387 m, @ 21 49.257 N 117 40.294 E

June 4

0100 L CS2-D box core, 4 km bearing 130 deg from CS2, water depth = 392 m, @ 21 48.56 N 117 41.17 E

0400 L One out of two ship's generators is down; deploy VLA, then return to KS one day early

0922 L VLA deployed @ 21 51.14 N 117 35.809 E, water depth = 355 m

0955 L VLA mooring survey complete; heading back to Kaohsiung.

Appendix 2: OR5 Cruise Log

Underway cruise log documented by Dr. Ben Reeder. All times Taiwan local (GMT + 8)

June 10
1315 L Underway from Love Pier, Kaohsiung
1600 L MBES calibration south of Kaohsiung

June 11
0930 L MBES survey of the PO transect from RPO to YPO2 (XBT's, CTD). MBES survey of acoustic transect between Source and VLA
2100 L Piston core @ 21 52.2477N 117 36.7237E — came up empty
2300 L MBES survey of top half of the VLA circle

June 12 Winds NE 30-35 kt, Seas NE 2-4 m, too rough for dipped source ops
0800 L CW01: Lowered package with CTD, LADCP, camera, MAVS @ 21 42.4597N 117 46.9291E, Water depth ~ 510 m
1000 L LP recovered to download data (not MAVS)
1030 L LP deployed, same location
1300 L LP recovered, didn't see any waves (maybe large swell overwhelmed them to the point that they were not observable
2200 L Deployed one EMATT and one sonobuoy (77) @ 21 51.989N 117 35.1196E

June 13
AM: winds/seas down from yesterday as LP system develops to our south, temporarily weakening the gradient; Winds 060 25-30 kt, Seas 2 m (swell down, more wind waves now as LP moves NE)

0740 L CW02/B2: NLIW passed ship @ '500 m' station (seen on 120kHz) but not seen on radar ahead of time. Repositioning upslope to deploy LP ahead of the wave
0920 L LP in the water, heading down to the bottom, water depth ~ 400 m, @ 21 46.250N 117 39.877E
0925 L NLIW passing by now; LP not all the way to the bottom yet, ~180-190 m depth when the trough passed ship. DP system creates bubble wash over echosounder; have asked bridge to try to maintain station w/o DP, not sure if we're on it right now, but the 120 kHz looks pretty good, as though we're not on it right now; the large signatures before the wave is due to the ship turning and using DP once we reached the station;
0950 L LP on deck; heading to position close to VLA
1015 L Overtaking the wave; SOG ~11 kt, COG ~340; good imagery of wave on 120 kHz
1045 L LP in the water near VLA @ 21 50.816N 117 35.418E, water depth ~ 340 m 3rd mate on watch on bridge; currently using DP with ship broadside to the wind (hdg=NW, winds=NE); hopeless….
1105 L Can't maintain station; DP system needs GPS, GPS signal intermittent due to wx; thrusters overloading; appears crew is too dependent on DP system. Note sure if the wave passed or not; no clear radar or echosounder picture
1115 L Ship decided the wx is too rough for CTD/LP ops; recovering LP.

2000 L Captain decided to move to the west to avoid "TD" in Taiwan wx fcst; "TD" based on single observation on Dongsha Atoll; TD fcst has it moving NNW, weakening and dissipating; fcst shows very weak gradient across northern SCS; conditions here will likely not get any worse than they already have been; CW and JMA shows no TS warnings in the SCS and we've been experiencing TS-force winds for a couple of days already; we're crossing the T heading west; better to stay here or move south a short distance as conditions dictate; JTWC has not called it a TD yet b/c the models tend to want to make small instabilities dynamical this time of year

June 14 Transited 160 nm to the west; plan now is to head S/SE and follow the storm back around; on DP in the middle of nowhere JTWC now has called it a TS, along with JMA; TS heading north slowly at 4-5 kt, fast max sustained winds in ctr of 45 kt we're seeing 30 kt of wind from the north, shifting NW through the day

June 15 AM: now south of Dongsha, heading NE, 120 nm from VLA, 25 kt of wind from the SW, by the time we get back to the VLA, the conditions should be acceptable for wave chasing, dipped source ops TBD

1300 L Trans-basin wave passing by; Steve says it's an A wave; shiploc 20 40.6N 117 26.28E, hdg 030 @ 8 kt

2125 L LS07, transmitting @ 50 m, secured at 2155L, lowering to 250 m
Seas look to be 2-3 m swells with some wind waves and white caps, winds 20-25 kts out of the south, fcst to decrease
Ship is relatively steady, with the stern moving up and down 1-2 m with occasional 2-4 m movement due to the swell

2205 L LS07, transmitting @ 250 m, secured at 2235L, recovering LS and moving to LS06

2325 L LS06, transmitting @ 50 m, secured at 2355L, lowering to 250 m

2340 L Ship took a couple of sizable rolls

June 16

0000 L LS06, transmitting @ 250 m, secured at 0030L, recovering LS and heading to LS05

0120 L LS05, source is dead; spherical transducer loose, wedge mounts are lost, actuator appears jammed, recovered; Done with LS; moving towards RPO to deploy EMATT

0240 L Launched an EMATT IVO 21 52.15N 117 35.04E; this one is programmed to do 2.5 circles and then out along the PO transect. Commencing MBES survey of the circle until 0600 to chase waves

0630 L CW03/B5: MAVS on the LP; on DP near CPO

0650 L LP in the water IVO CPO @ 21 51.734 N 117 36.339E; WD=345 m, doing yo-yo's until a wave comes through Wx: seas down to 1-2 m swell coming from the W and SW, some white caps, winds SSW 20 kt

1100 L I was in the rack, so I'm not sure I believe him, but Steve claims a 60 m B wave came through with the LP on the bottom!!

1215 L Recovering the LP to dumb data and move over to the Source; the plan is: as soon as we see the A wave on radar, through the 'rose' EMATT in the water, then run back over to this same location IVO CPO and put the LP back down to the bottom; I'm leaving the MAVS on the LP for the duration; they're programmed to record for 24 hours

1300 L A 50 m wave passed by but Steve says it's not the A wave we're looking for

1330 L There's a wave coming on radar, but Steve says it's still not the wave we're looking for, so we're heading south to check it out

1930 L All we've seen are baby waves, no big ones, Steve hypothesizes that the A wave did not appear b/c there are times when the A wave is not generated at the largest tide in the center of the tidal cycle b/c there may be a critical value above which the flow is too strong over Luzon Ridge such that the wave is too turbulent and dissipates immediately; Pulled the MAVS and downloading data from the period of the big wave this am. Re-did the anchor surveys on 2-3 moorings

June 17

0620 L CS2 recovered

NOTE: the bottom two phones were faired (hairy kevlar) but the top two phones were not (JWR); strum??

0700 L R/V Dong Fang Hong 2 about 12 nm away; loosely interpreted, "red sun rises in the east" (?)

0745 L CS1 recovered

0830 L Heading NW to run over the wave that went by earlier this morning; overtaking the wave, there appears to be some overturning of sediment/biota in the lee of the wave as we pass over it from the rear, the 'turbulent plume' is about 40 m tall, the moored ADCP's are collecting data in 2 m bins, so the moored data should be able to see the structure of the 'bolus'; water depth is ~250 m; we need to deploy the LP at this location on a wave; there's a bio-layer at about 210-220 m, so the bolus may be composed of both sediment and biology; near the shelf break, the wave looks a lot like the EK500 data collected in 2007 at the shelfbreak; there's actually 2 waves relatively close together; Steve names this the A5' wave that we saw in deeper water earlier this morning; A5' is the 'weaker beat A wave #5'; the radar data shows local refraction of the wavefront due to the wave going over the 'corner' of the shelfbreak

0945 L reversed course, going over to a pt IVO the source, echosounder shows the 'bolus' still there, sediment/biota still suspended, dispersing

1000 L MAVS mounted on CTD carousel, programmed to record for 24 hours starting at 1030L

1100 L EMATT (criss-cross tracks centered on VLA) deployed IVO Source; moving to LP station for incoming wave

1130 L CW04/A6: On station IVO CPO; LP in the water and descending; wave coming in looks like "The one we've been waiting for" Cross-talking freqs on the MBES and ship's ADCP are secured; DP is secured;

1210 L 80 m IW trough just passed the ship; ship's ADCP: surface currents NW 1.7 kt, CTD wire tending to the ESE with large wire angle; LP started ~5 m off the bottom, slant range as high as 100 m; pressure signal says 20 m vertical displacement; 2-3 large features under the IW, probably due to refraction, not suspended sediments, would be good to model; Chris Miller noticed that the two striation/featues occur directly over two sand dunes, so the features could be due to a combination of refraction and then scattering by the dunes; surface currents pushing the ship to the NW, skewing the echosounder image of the wave (stretched out)

1215 L some bubble subduction on the lee side of the trough

1230 L ship has drifted 1.3 nm from original position; have decided to continue drifting until the next wave passes

1300 L ship is putting a few turns on to maintain position **without DP**; ship's hdg is SE, wire angle is near vertical

1305 L decided to recover the LP, dump data, reset the ship to original position, redeploy LP before the next wave

1340 L fish schools on echosounder

1415 L LP is back in the water IVO CPO; we may have skipped over the biggest wave, based on what's on the radar

1431 L Ship is drifting NW; large wire angle; passed over a sand dune with no dispersive signature like before when the IW was passing over the dunes; the other striations in this picture are due to temporary DP operation

1440 L Asked the bridge to put a few turns on so we don't drift so far and the incoming wave can actually reach us; this will also decrease wire angle (wire is tending forward when drifting backward with ship hdg SE)

1452 L Making about 0.5 to 1 kt to the SW, wave is closing

1500 L Got turns on for 1-1.5 kt now;

1515 L The waves that appear on the radar don't materialize as expected; wonder if the waves are weak and break apart. Done with the waves for the day; recovering the LP;

1600 L Started a new MBES survey of the circle; started a new MBES file; to ensure we have a good, clean MBES dataset in good wx. Will finish the circle survey by the end of the cruise;

2145 L Up on the shelf break to do one core in 120 m water depth where we caught a wave on the OR1 cruise; need to sample the sediment here, on the steep slope in 250 m water depth and one near RPO; the concept is that all the sediment comes from the continent, over the shelf, down the slope and to the basins, so we're sampling the sediment in these three locations to see how they compare, and to use in connection with the AT data

2230 L Gravity core came back empty

June 18

0445 L CW05/A7?: On station IVO RPO, water depth = 220 m, LP in water @ 21 53.572N 117 33.969E

0505 L LP 5 m off the bottom; ship is to maintain position without DP, cross-talking MBES and ADCP freqs secured

0515 L LP lowered to 3 m from the bottom; small angle tending toward the stern; ship has turns on to keep position

0520 L echosounder shows a layer going down slowly; multiple waves on radar coming in;

0525 L echosounder: looks like some bugs may be riding the wave down for their morning depth excursion; hard to tell whether it's the wave or not, maybe just the morning diurnal migration?

0538 L total excursion so far is about 60-70 m; more waves coming in;

0610 L a series of smallish waves…..

0620 L looks like there are waves coming from two directions: SSE and S (from

Dongsha?)
0645 L Done; recovering; moving to Source mooring for recovery at 0800 L
0800 L Popped the release on the source mooring
0845 L Still maneuvering to recover the mooring……
0850 L Snagged the ball
0941 L Source mooring recovered
0950 L Chris is preparing the Acousonde, SBE-39 and source for dipped source ops at the SE corner of the circle (LS07)
1050 L Source is in the water, heading down to 250 m @ LS07 @ 21 50.108N 117 37.352E
1100 L Transmitting 100 sec on, in 3 minute periods; ship on DP
1225 L Ship on DP, but the NW'ly surface current is sweeping the bubbles back and away from the echosounder transducer, so we now have secured the ship's ADCP and MBES cross-talking freqs;
1230 L radar shows waves, but none seem to be coming through on the echosounder
1145 L a large wave is coming by; large band of breaking waves passing the ship; bubbles are being sub ducted under the ship and showing up on the echosounder; these bubble signatures are more gradual than what typically happens when the DP bubbles cause problems, but with the changing currents with wave passage, these signatures are likely a combination of both sources of bubbles; transmitted for 1.75 hours before the entrance of this wave
1400 L water column appears to be quite stable (only small oscillations); one more hour…..
1440 L D'oh! Looks like another wave! About 50 m amplitude; observable outside; large bubble signatures on echosounder
1514 L Source emits secured; hopefully, the last wave passed the VLA before now……..
1545 L Source out of the water
1637 L Source SHRU recovered
1813 L CPO recovered
1900 L Finishing rest of circle with MBES, then the PO transect

June 19

0715 L RPO recovered; preparing for the VLA recovery
1246 L VLA recovered
1755 L YPO1 recovered
1800 L Steaming to the SW along the ~400 m isobath to try to find some other sand dunes; will be back at YPO2 in the morning. Found two locations with dunes, updated in plot_bathy_scs.m

June 20

0730 L YPO2 recovered
0800 L Steaming SE to the 500 m isobath, then turning SW to steam along the ~500 m isobath to look for sand dunes; we may deploy the LP later this afternoon when a big wave comes through
1400 L Found some dunes along the track and have updated the plotting routine to mark them on the chart (plot_bathy_scs.m)
1430 L CW06/A?B?: MAVS on the LP and recording now, in anticipation of catching an incoming wave

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