R/V YUNUS-S (Istanbul University) cruise report
November 19-20, 2019
Istanbul – Istanbul

Science party

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Summary

The objective of this cruise was to recover from the Central Basin an instrumented frame deployed during a previous Istanbul University R/V *Yunus-S* cruise, May 8-9, 2019, recover the data recorded by the instruments, do maintenance, and redeploy the frame at another site, in Imrali basin.

The frame was successfully recovered. The RBR/Paroscientific (Digiquartz) bottom pressure recorder functioned properly throughout the 6-month deployment. The other instrument, a Seaguard doppler recording current meter (RCM) equipped with additional sensors, operated properly during the whole period, except for the conductivity sensor. The instrument was at the outlet of a canyon located close to the epicenter of the Sept 26, 2019 Magnitude 5.8 earthquake. Following the earthquake instrumented frame was tilted and recorded hydrodynamic disturbances and an increase of turbidity. The instrumented frame was redeployed at the planned location without incident.

1-Cruise context and objectives

Deployment of Bottom Pressure Recorders on the seafloor of the Sea of Marmara deep basins is required by MAREGAMI project in order to detect and measure resonant frequency oscillations in the Sea of Marmara. These resonant oscillations (also known as seiches) are thought to play an important role in tsunami generation and influence the characteristics of turbidite-homogenite deposition after earthquakes and landslides. In addition, monitoring of bottom water variations in pressure, temperature, salinity, and of bottom currents will help understand the causes of perturbations affecting acoustic ranging measurements performed in Kumburgaz Basin as part of a geodetic experiment (Nov 2014 – Jan 2018) and shall be taken into account for the planning of future geodetic monitoring on the North Anatolian Fault in the Sea of Marmara. This cruise is the fourth deployment performed within the framework of MAREGAMI with the Istanbul University R/V Yunus-S.

The cruise operations were jointly funded by MAREGAMI, a bilateral collaboration project between ANR and TÜBITAK and by EMSO-France Research Infrastructure. Instruments and technical support were provided by CNRS/DT-INSU.

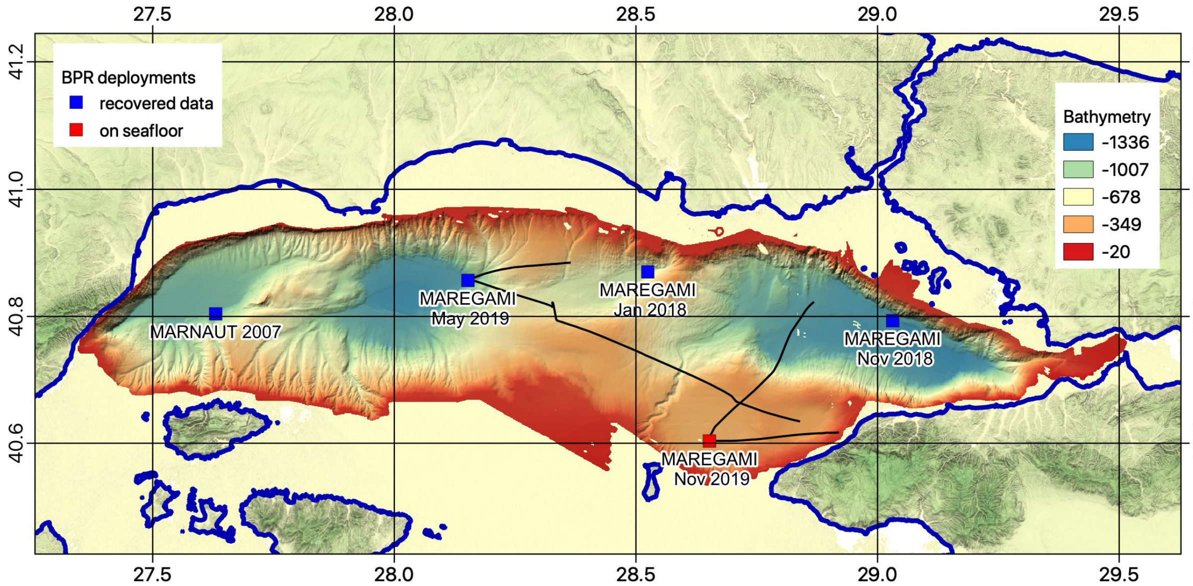


Figure 1*: Ship tracks of YUNUS-S during November 19-20, 2019 cruise and location of BPR deployments. Pressure records were previously obtained in Tekirdağ Basin in 2007-2008 (Marnaut cruise of R/V L'Atalante) Kumburgaz Basin and Çınarcık Basin (R/V Yunus January and November 2018 cruises). This cruise recovered instruments deployed in May 2019 in Central Basin and redeployed them in Imrali Basin. Recovery cruise is planned in May 2019.*

2-Instrumented frame recovery and redeployment

Instrumentation on the frame (Figure 2 and 5) comprises (1) an RBR bottom pressure recorder (BPR) with a Paroscientific 0-2000 m Digiquartz sensor, (2) a Seaguard recording current meter (RCM) equipped with additional sensors: temperature, pressure (tide sensor Aandera 5217), conductivity, oxygen (Aandera optode). The tide sensor is a piezoresistive sensor of accuracy comparable to that of the Digiquartz sensors (0.02% vs 0.01% for Digiquartz), and 0.2 hPa (2 mm) resolution. The sampling interval was set to be compatible with a required minimum battery autonomy of at least a year. The RBR pressure sampling interval was thus set to 5s and the Seaguard RCM to one hour (for all sensors) after a battery failure occurred after only one month during the last deployment. The RBR system was acquired with MAREGAMI funding, the Seaguard RCM was loaned by DT-INSU, as well as the acoustic release systems, a flasher and an Argos beacon. The tide sensor fit on the Seaguard RCM was acquired with EMSO funding.

The frame was equipped with 2 acoustic releases (DT-INSU n° 394 and 853) attached to each end of the anchoring chain for redundancy. The frame was released at the first attempt (11:16 UTC), the frame surfaced 16 minutes later 350 m from port side (ascending speed 1.3 m/s), upside down as implied by the design and was then lifted on board with the side crane.

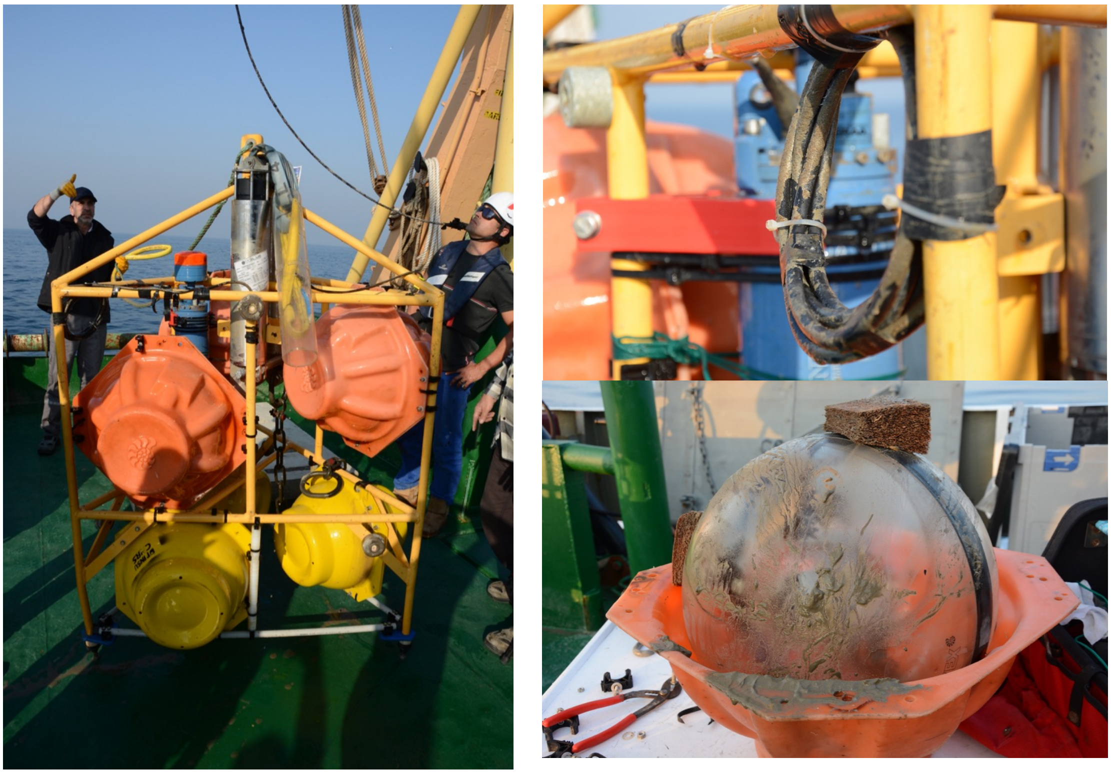


***Figure 2**: Instrumented frame after recovery. (left) one of the flotation spheres was shaken off its binding; (top right) mud caked on the optode connector; (bottom right) mud inside the protection of the detached flotation sphere*

Bottom Pressure Recorder data

The RBR BPR recorded data for the whole duration from recording start shortly before deployment to manual stop after recovery. As expected, power switching from external to internal battery packs occurred 25/08/2019 17:16:00, half-way through deployment period. Clock drift was 3 seconds (slower than UTC) as during the previous deployment. Data exports are available in Ruskin (RBR software) format and in txt format (Table 1).

Table 1 - Time series acquired by RBR BPR

Data export	First record	Last record	Comments
052665_20191119_1359.rsk	2019-05-09 05:56:14	2019-11-19 14:02:29	From before deployment to after recovery
052665_20191120_0508.rsk	2019-11-19 14:07:14	2019-11-20 05:09:19	On board, Clock UTC. Failed to record from 2019-11-20 01:50:29 to 05:06:19

To test the possibility of calibrating the 0 of a Digiquartz sensor during a cruise, an atmospheric barometer (VAISALA PTB330TS) was brought on board the ship. The accuracy of the barometer is 0.1 hPa at lab temperature. It was set to record pressure every minute from 19/11/2019 07:09:18 to 20/11/2019 10:45:18 UTC. Raw pressure records, uncorrected for clock error, are available as ASCII csv and column tabulated files (2019-11-19_7_09.csv, 2019-11-19_7_09.m70, 2019-11-19_7_09.txt). While on board the ship, the RBR was set horizontally in the same position as on the frame (lettering up, horizontal flat spot) and recording (Figure 3).

Seaguard RCM

The Seaguard RCM was found operating. Clock drift was < 1 min. The battery voltage (7.17 V) was close to nominal and in fact had increased during the deployment. The CTD conductivity sensor malfunctioned during the entire deployment yielding anomalously high values (> 60 mS/cm), beyond measuring range. Other sensors worked correctly except for one of the temperature sensors (#119) that continued drifting randomly. The new oxygen optode sensor yielded satisfactory data but drifted slightly between before deployment (99.648 saturation on board) and after (95.909 saturation on board).

Table 2 – Time series acquired by SeaguardRCM

Data export	First record	Last record	Recorded sensors
YUNUS_nov_19_data.txt YUNUS_nov_19_data.xlsx	2019-05-09 11:57:46	2019-11-19 11:57:46	Temperature #119, DCS #146, Conductivity #788, Tide #393, Oxygen Optode #3127

Repairs and redeployment

The device obviously suffered from the occurrence of the Sept 26, 2019 Magnitude 5.8 earthquake. The links attaching one of the flotation spheres to the frame below the optode sensor were broken and the sphere slided along the vertical metal tubes during recovery (Figure 2). In addition, mud was caked on the device in various places: on the frame feet, on the acoustic releasers, on the optode connector, and mud was also found inside the plastic protection of the slided flotation sphere. Data from the Seaguard RCM tiltmeter indicate that the frame was tilted by more that 60° after the earthquake so that parts of it may have been dragged on the seafloor. However, it apparently straightened itself after a few hours and, besides the detachment of one flotation sphere, was largely unscathed. The flotation sphere was reattached in place. The batteries of the Seaguard RCM and RBR BPR were replaced and instruments reset with the same settings as before: 5s sampling interval for the RBR BPR, one-hour recording interval for the Seaguard RCM, set in burst mode with 150 Doppler current sensor pings and 10 minutes Tide sensor pressure averaging.

***Figure 3**: Instrumented frame before redeployment. (left) RBR sensor; (center) Seaguard Z-pulse sensor with X Y orientation and transducer number indicated.*

Deployment was done without difficulty. A lifting tackle and the warping head of a winch were used to lift the frame/ballast assembly overboard and two ropes passing through slots in the concrete slab allowed lateral stabilization. The assembly weight was then transferred to the acoustic release device attached to the main winch cable (Figure 4). The Seacatch releasable hook was not available this time but this only brought minor changes in the operations as the aramide link used to hoist the frame already needed to be recovered manually while the frame was hanging overboard on the main winch cable.

Water depth at the target deployment site is 406 ± 5 m according to multibeam maps while the shipboard sounder indicated 404 m. The device was first lowered at about 1 m/s down to 350 m wire out. At this point, acoustic range to the acoustic device on the cable (n° 1973) was measured at 388 m (assuming 1500 m/s sound speed). The device was then lowered at 0.5 m/s, while interrogating acoustic device n°1973 every 10s. Touch down occurred between 07:52:13 and 07:52:25 for an acoustic range of 427 m. The device acknowledged execution at 12:52:55 after first release order. Effective release was verified by checking acoustic range to acoustic devices n°853 and n°394 on the frame and to n°1973 on the wire while wiring in. The location of the frame on the bottom was then determined by triangulation (Figure 6 and Table 3). Two acoustic range measurements (assuming velocity 1500 m/s) were performed at each of three points 470 m WSW, ESE and N from the target point. The frame location thus determined was 40 m NW of ship position at release, with an acoustic immersion of 429 m and a theoretical wire out of 431 m. The position of the device is 20 m from the target location in a N153° azimuth, on the floor of Imrali Basin (Figure 6).

Figure 4*: Deployment setup. (Left) complete view of hoisting assembly with hook and tackle used for lifting the device overboard and acoustic releaser on steel wire for used for lowering and deploymentat the seafloor; (Right) detail of hook assembly*

3-Navigation

Location of remarkable points (Table 3) and detailed navigation maps for Day 1 (May 8, 2019) (Figure 5) and Day 2 (May 9, 2019) (Figure 6) and are given here after.

Table 3 – Remarkable points

Point	Lat	Lon	Lat	Lon	Depth	Comment
MRG BPR1	40.8703	28.5244	N 40° 52.218'	E 028° 31.464'	805 m	previous BPR location
MRG BPR2	40.7934	29.0312	N 40° 47.604'	E 029° 01.872'	1225 m	previous BPR location
MRG BPR3	40.8568	28.1523	N 40° 51.408'	E 028° 09.138'	1184 m	recovered BPR
Tri1 (BPR4)	40.6018	28.6470	N 40° 36.108'	E 028° 38.819'		triangulation point
Tri2 (BPR4)	40.6020	28.6567	N 40° 36.122'	E 028° 39.401'		triangulation point
Tri3 (BPR4)	40.6081	28.6519	N 40° 36.484'	E 028° 39.115'		triangulation point
MRG BPR4	40.6035	28.6521	N 40° 36.212'	E 028° 39.126'	406 m	relocated position

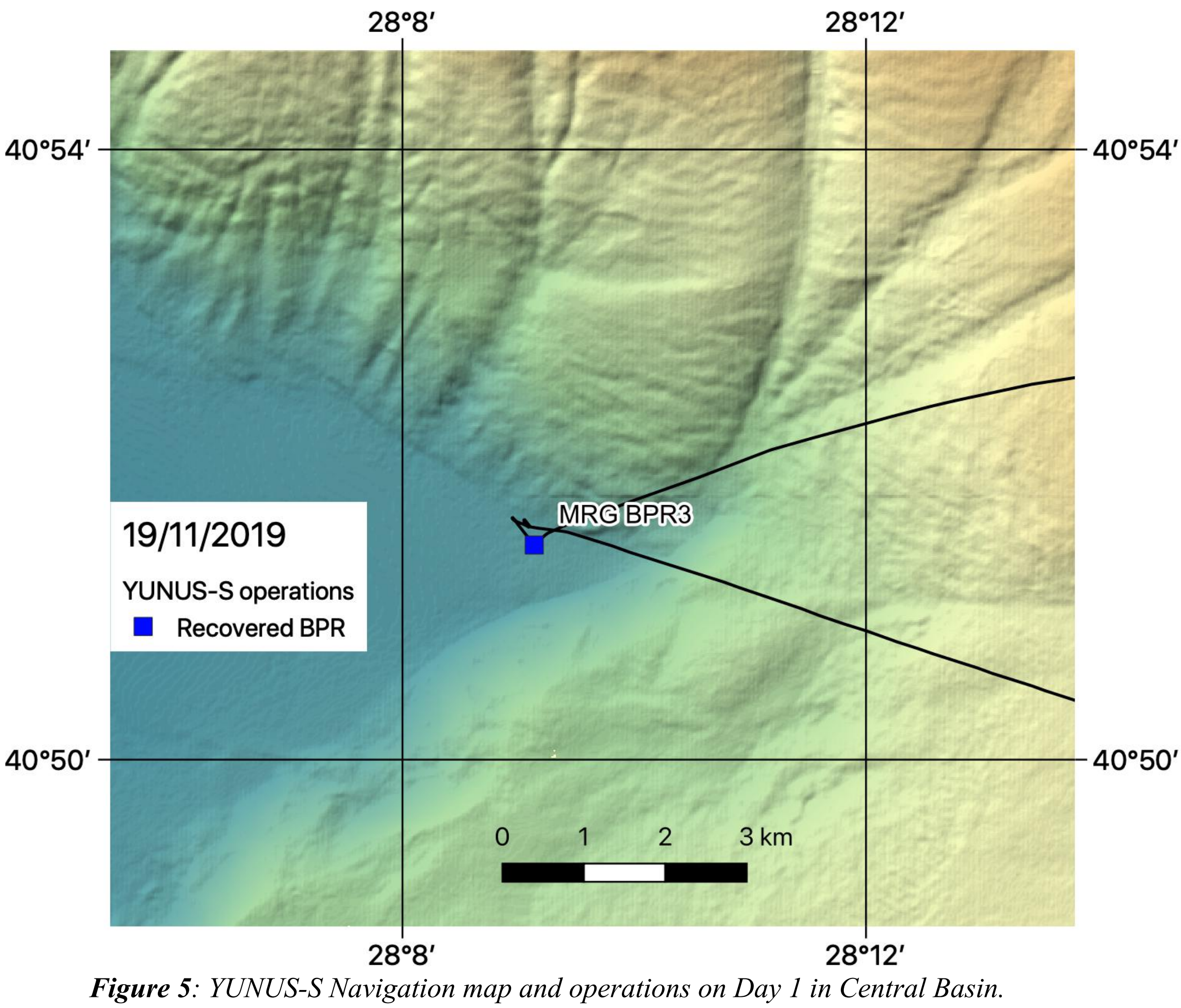


Figure 5*: YUNUS-S Navigation map and operations on Day 1 in Central Basin.*

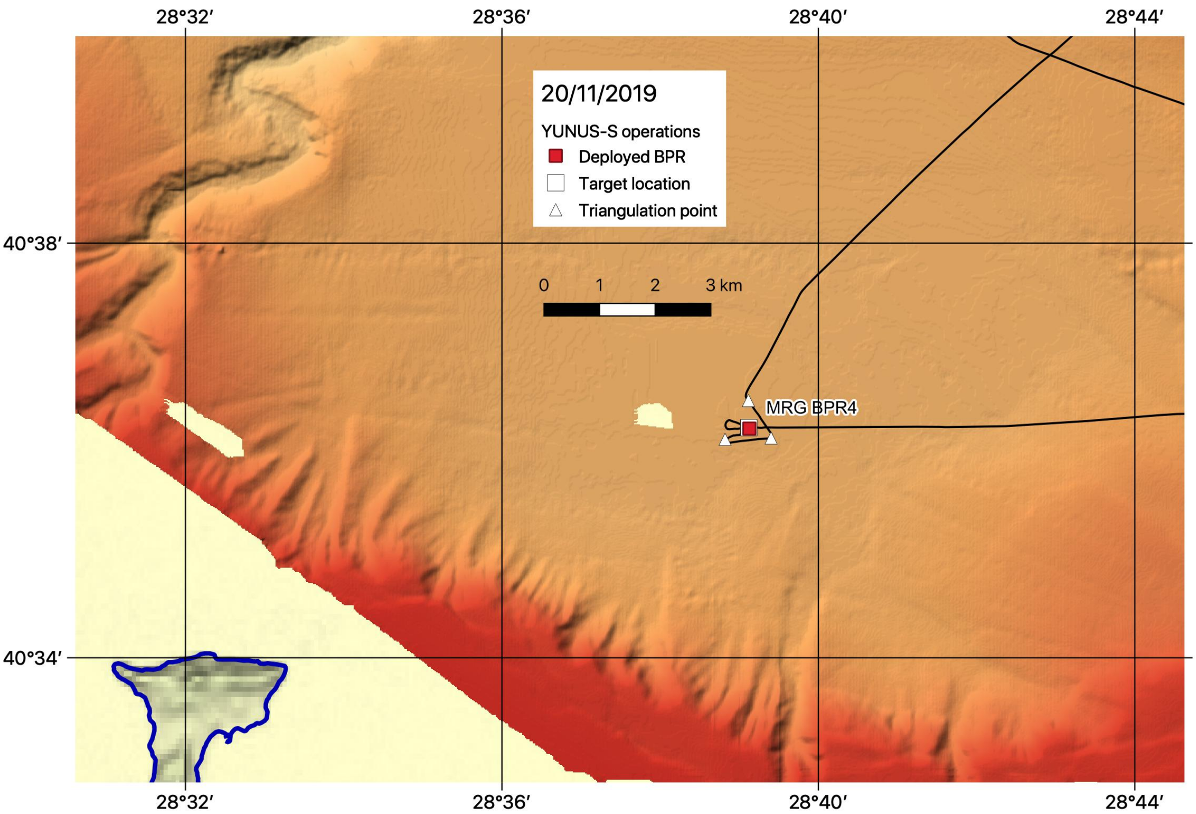


***Figure 6**: YUNUS-S Navigation map and operations on Day 2 in Imrali Basin.*

4- Operation timeline

Wind conditions were 0-2 on Beaufort scale
Local time is UTC+3

Time (UTC)	
19/11/19	**Tuesday**, wind conditions 1 on Beaufort scale
6:00	Leaving Haydarpaşa port
6:15	refueling
6:41	Set computer to GMT (should have been done before starting OpenCPN)
6:50	En route to BPR 3, range 37.8 NM
7:08	Synchronization of Vaisala PTB – clearing memory
7:09	Start PTB recording, sampling interval 1 min. Patm 1024.87
7:57	9.24 knts, course 261°, ETA 11:02
9:50	8.61 knts, course 261°, ETA 11:13
10:06	Restart OpenCPN because of conflict between computer clock and GPS clock. Computed lock should be set before starting OpenCPN – Tracking on
11:09	8;66 knts, course 249°, 0.55 NM to target (BPR3)
11:16	Acoustic releaser #394 released
11:17	Acoustic range 1119 m
11:18:15	Acoustic range 1084 m
11:23:40	Acoustic range 686 m – ascending velocity 1.23 m/s
11:29:18	Acoustic range 356 m, horizontal distance to seafloor location 280 m, N142°
11:32:18	Device seen on surface, front port side
11:56:43	Device on board. A lot of mud on feet frame, flotation spheres, acoustic release systems and optode connector. One of the spheres is loose and dropped down.
12:04	8.21 knts, course 107° to Esenköy
12:40	Seaguard on, clock 12:39 – end recording
13:13	Stopped at sea – Seaguard data recovered – battery at 7.17V at recovery
13:50	8.74 knts, course 111° to Esenköy
13:59	RBR plugged, recovering data (25.62 MB)
14:05:18	RBR clock lags 3 s at 14:05:15 –> UTC sync
14:07	RBR data saved as 052665_20191119_1359 (.rsk & .zip) First switch to internal power occurred at 2:17 25/08/2019
16:18	Stop GPS tracking (diner)
18:44	Change Seaguard and RBR batteries – Check Seaguard memory card: 512 MB, available 499.5 MB
19:29	Start Seaguard recording

Time (UTC)	
20/11/19	**Thursday**, wind conditions 2 on Beaufort scale
4:25	Seaguard recording – in pressure container
4:37	RBR not working, stopped at 2019-11-20 01:50:29
5:07	RBR hard reset (batteries removed) – recording resumed
5:09	Data download, file 052665_20191120_0508.rsk
5:11	Stop recording

5:12	UTC sync
5:13	Start RBR recording 20/11/2019 05:13:55 -> scheduled end 01/12/2020 08:28:10, sampling interval 5s Power source USB (external), internal power 12.17 V
5:15	Check : unplug and replug USB (OK)
5:23	OpenCPN running, tracking enabled
5:24	8.32 knts, course 266°, range 12 NM to BPR 4 deployment point, ETA 07:00
5:29	RBR connected on USB, recording
5:43	RBR pressure vessel closed, ready for deployment
5:48	Seaguard and RBR on frame, frame ready for deployment.
5:55	Lifting frame briefly to check stability
5:58	Check Vaisala PTB – recording – Patm = 1021.55 hPa
6:04	Checking acoustic releaser for winch cable hook #1973
7:00	On site, ready for deployment without SeaCatch quick releasse
7:13	Frame overboard – TV crew filming
7:16	RBR in water (Seaguard Z-pulse out of water)
7:20	Sounder 404–405 m, drifted 0.1 NM West, RBR and Seaguard in water, frame hanging
7:27	TV crew done, lowering device to 100 m
7:31	Wire stopped at 100 m, 0.21 NM from target (BPR4), getting back on site
7:43	Back on site, start lowering to 370 m at 1 m/s. 20 m offset between Acoustic Range and Wire Out. Instruction to stop at 350 m
7:47	Winch stopped at 350 m WO, #1973, AR 388 m (+7 m to base of frame)
7:50	Lowering slowly (0.5 m/s) AR 390 m
7:52:13	AR 426 m
7:52:25	AR 427 m, Touchdown
7:52:55	Release executed 40° 36.1949'N, 028° 39.1070' E, wiring in
7:54:29	Check Beacon #394 (on frame) 429-430 m
7:55	Check Beacon #1973 (on hook) 367 m #394 diagnostic value: 5134 vertical (8.75 V)
7:59	#853 AR 444 m, diagnostic value: 5111 vertical (8.66 V)
8:00	Acoustic release #1973 back on board
8:09	Triangulation point 1: 40°36.1082N, 028°38.8194E AR 638 (640) m
8:15:52	Triangulation point 2: 40°36.1216N, 028°39.4014E AR 601 (603) m
8:21:40	Triangulation point 3: 40°36.4833N, 028°39.1152E AR 559 (663) m
8:25:30	Transit back to Istanbul
8:40	8.36 knts, course 031° ETA 11:40 (14:40 local time)
10:28	Trying to connect computer to Vaisala PTB 330. Stop OpenCPN GPS tracking
10:40	Connection problem solved with VirtualBox USB filter set with USB 2.0 driver and serial port off
10:52	Vaisala PTB330 data downloaded, files 2019-11-19_7_09.m70 .txt & .csv
10:58	Stopped recording, Vaisala memory emptied
10:59	Navigation, Seaguard, RBR and Vaisala data saved on LaScie (XFAT) HDD
11:04	Vaisala and all equipment packed
12:08	Photos saved – In port at Haydarpaşa

5- Data distribution and initial assessment

Data from RBR BPR, Seaguard RCM, and Vaisala PTB are temporarily available at the OSU Pytheas Owncloud server[1] in ascii and in matlab binary format and explanation of variables in matlab files is given in Table 4, 5 and 6. Seafloor data will be distributed through the OSUPytheas ERDDAP server[2] as for the previous deployments. The instruments on the frame recorded a series of disturbances following a magnitude 5.8 earthquake that occurred Sept 26, 2019 at 10:59 UTC.

5-1-RBR pressure and temperature records

The RBR Bottom Pressure Recorder provided 6 months of useable data (Figure 7). The pressure record indicates that the device landed on the seafloor 2018-11-13 12:55:09. Pressure stabilizes in 20s (at 12:55:29) and there is no indication of subsidence, unlike during the deployment in Çınarcık basin. The instrument recorded the last point prior releasing from the seafloor at 2019-11-19 11:16:34. Clock drift during deployment was estimated 3s (slow) during this 6-month deployment as during the previous one, but not corrected. The pressure record is disturbed after a magnitude 5.8 earthquake that occurred Sept 26, 2019 at 10:59 UTC and these disturbances include a permanent offset. These disturbances taken aside, the amplitude of recorded pressure variations is 25 hPa crest to crest (equivalent to 25 cm of water) and thus lower than during previous deployments. Tidal amplitudes are less than 10 cm and involve ≈12 hours and ≈24 hours dominant periods. Higher frequency oscillations have an amplitude of about 1 hPa (1 cm) and "white" noise level is ±0.1 mm (±Pa). Bad P or T records occasionally occur and where automatically detected and removed using a 3-point median filter, setting a maximum difference of 5 hPa between raw signal and median-filtered pressure signals and a maximum difference of 0.1°C for the temperature record. Temperature appears to be stable within 0.01°C except for some fluctuations in May and June as well as after the earthquake.

Table 4 – Variables in BPR Matlab files

Name	**Type**	**Comment**
Time	datetime array	Time in datetime format Time.TimeZone='UTC' Time.Format='yyyy-MM-dd HH:mm:ss.S'
Timestring	cell array	Time as character string
elapsed_days *or* elapsed_hours	double array	time elapsed since first record in file days(Time-Time(1)) *or* hours(Time-Time(1))
Period	double array	Pressure sensor measured period in ps
Period1	double array	Temperature sensor measured period in ps
BPRpressure	double array	Pressure in dBar (10 kPa)
BPRtemperature	double array	Temperature in °C

5-2-Seaguard data logger

[1] https://nuage.osupytheas.fr/s/oL96q5gNaPtkHHc

[2] https://dataset.osupytheas.fr/geonetwork/srv/fre/catalog.search#/metadata/7175f88e-cde6-4a67-ada5-1e44a687156f

The Seaguard data logger acquired data at the seafloor every hour over the whole deployment interval while the RBR PBR was also operating. The *pressure and temperature* time series acquired with the various sensors are compared in Figure 10. Before the Sept 25, the earthquake the average offset between the Digiquartz and the Aandera tide sensors is 116 hPa, 4 hPa larger than the offset measured during the previous deployment, 112 hPa (Digiquartz values being higher), determined during the first month. During the 4.5 months of deployment between May 9 and Sept 26, there is no significant relative drift of the 2 sensors, and variations of pressure offset after the earthquake may be attributed to the tilting of the device. In order to compare the records from both sensors the pressure measured by the RBR was averaged over 5 minutes every hour to match the Seaguard recording schedule. For the time period before the earthquake the rms of the difference between these two time-series (after removal or 116 hPa offset) is 0.3 hPa (Figure 11). The high frequency fluctuations of the Tide sensor pressure data without averaging during the previous deployment were somewhat larger (±0.5 hPa). The Seaguard data logger recorded temperature variations with 4 different sensors: a specific temperature probe, and temperature sensors on the conductivity meter, on the tide sensor and on the oxygen optode. As during the previous deployment, the temperature probe yields very poor results with random drifts and jumps. The CTD temperature is stable, but with a noise amplitude of ± 0.01 °C, appears too noisy to resolve short term natural variations. The tide and optode sensors provides the best temperature records, with variations consistent with that recorded by the temperature sensor of the RBR BPR, but with static offsets between instruments. The average temperature measured from the beginning of the deployment to the time of the earthquake are 14.7074°C for the tide sensor 14.7143°C (+0.0059°C) for the CTD sensor, 14.7158°C (+0.0074°C) for the oxygen sensor, 14.7262°C (+0.0178°C) for the Digiquartz sensor. Also, the Digiquartz of the BPR sensor is an internal sensor that has a slower response to short term seawater temperature variations and may thus average out rapid variations.
The *oxygen optode* sensor recorded a progressive decrease from 50 µM at the begining of the deployment to about 35 µM at the end (corresponding to 16 and 11 % saturation). The probe displayed some drift over the measurement period as the saturation measured in air varied from 99.648% saturation (286.783 µM at 20°C) before deployment to 95.909% (281.633 µM at 19.1°C) after, but this cannot explain the trend recorded at the seafloor. Moreover, rapid variations between 35 µM and 55 µM are observed over the first 33 days, and these correlate with temperature variations. This finding may be put in perspective with CTD profiles performed at the same location June 2, 2007 during Marnaut cruise that identified above the seafloor a layer of water of slighly higher temperature, salinity and oxygen concentration (14.52°C, 38.678, 44.5 µM) relative to the water mass above (14.48°C, 38.669, 26.7 µM) with a transition occurring between 1060-1125 m. This perturbation observed in 2007 was only observed locally at two CTD stations near the canyon outlet, but not in the central part of the basin. Water at higher temperature, salinity and oxygen was found between 200 m and 80 m depth, beneath the halocline. This suggests cascading events could occur seasonally within the deep-water mass.
The *current meter*, set 1.5 m above seafloor, recorded small currents of less than 5 cm/s during most of the deployment. Three excursions where recorded, one following the earthquake lasted less than a day and two later events of slightly longer duration occurred around Oct 14 with maximum current speed 9.5 cm/s and around Nov 8 with maximum current speed 7 cm/s. During these later events, the current varied in direction with time, and is westward when speed is maximum. These events are associated with small temperature variations. Some smaller variations of current (up to 5 cm/s) observed early in the deployment may relate with oxygen and temperature variations, but this is not immediately interpretable from the time series plot. Interpretation of currents following the earthquake is complicated by tilting of the instrument. From its landing to about 25 minutes after the earthquake the device had negligible tilt (1.3° on

X-axis, -0.8° on Y-axis, with X-axis in a N139° azimuth). For a period of 9 hours after the earthquake from 11:57:46 to 20:57:46 the device recorded a large but fairly stable tilt of -65° of the X-axis and +19° of the Y-axis, with X-axis in a N160° azimuth. After that, the device apparently straightened itself and the tilt parameters recorded remained moderate and stable -11.5° for the X-axis and 5.3° for the Y-axis with X-axis in a N105.3° azimuth for the rest of the deployment. After recovery, tilt recorded while the device was on deck was negligible: 0.099° on X-axis and 1.086° on Y-axis (weather was good ☺). A tilt correction was automatically applied by the instrument firmware to the recorded current data and the current measurements performed when the instrument was strongly tilted required reprocessing. However, it may be noted that the highest current speeds (exceeding 20 cm/s) were recorded around the time when the device when back to its upright position, not when it capsized. Currents then decays to background level (≈2 cm/s) in 8 hours. The exact timing of events could be determined more precisely by analyzing the data from the RBR BPR, that recorded pressure with a 5 s sampling interval (see **section 6**).
The backscattered signal strength of a Doppler current meter is a proxy for water turbidity. Background signal strength was -40dB or less during most of the deployment. Values between -13dB and -20dB where recorded after the earthquake when the instrument was tilted. After the instrument straightened itself, a maximum value of -7.6 dB is recorded and backscatter decays back to background value in 3 days.
The *conductivity sensor* yielded aberrant values (> 60 mS/cm) during the whole deployment for unknown reasons. However, it had operated properly during the previous deployment.
Graphs of most environmental parameters (current speed and direction, backscatter signal strength, temperature, pressure) are included in an XLSX file (YUNUS_may_19_graphs.xlsx) available on OSU Pytheas Owncloud server.

Table 5 – Variables in Seagard RCM Matlab file (Nov_2019_RCM.mat)

Name	Type	Comment
Time_RCM	datetime array	Time in datetime format Time_RCM.TimeZone='UTC' Time_RCM.Format='yyyy-MM-dd HH:mm:ss.S'
Timestring_RCM	cell array	Time as character string
BatteryVoltageV	double array	Battery Voltage (V)
		Temperature Sensor #119 parameters
TemperatureDegC	double array	T (°C)
		Doppler Current Sensor #146 parameters
AbsSpeedcms	double array	Current absolute speed ($cm.s^{-1}$)
DirectionDegM	double array	Current direction (° wrt magnetic north)
Northcms	double array	Current north-south component ($cm.s^{-1}$)
Eastcms	double array	Current east-west component ($cm.s^{-1}$)
HeadingDegM	double array	Instrument Heading (° wrt magnetic north)
TiltXDeg	double array	Instrument tilt in X direction
TiltYDeg	double array	Instrument tilt in Y direction
SPStdcms	double array	Single Ping Standard deviation ($cm.s^{-1}$)
StrengthdB	double array	Signal strength (dB)
		Conductivity Sensor #788 parameters
ConductivitymScm	double array	Conductivity ($mS.cm^{-1}$), measured
TemperatureDegC1	double array	Temperature (°C), measured
SalinityPSU	double array	Salinity (PSU), derived

Densitykgm3	double array	Density (kg.m^{-3}), derived
Soundspeedms	double array	Sound speed (m/s), derived
		Tide sensor #393 parameters
PressurekPa	double array	Pressure (kPa), measured
TemperatureDegC2	double array	Temperature (°C), measured
TidePressurekPa	double array	Pressure (kPa), 300 s average
		Oxygen Optode sensor #3127 parameters
O2ConcentrationuM	double array	O_2 concentration (μM), measured
AirSaturation	double array	O_2 saturation wrt air (%), derived
TemperatureDegC3	double array	Temperature (°C), measured

Faulty data are outlined in grey.

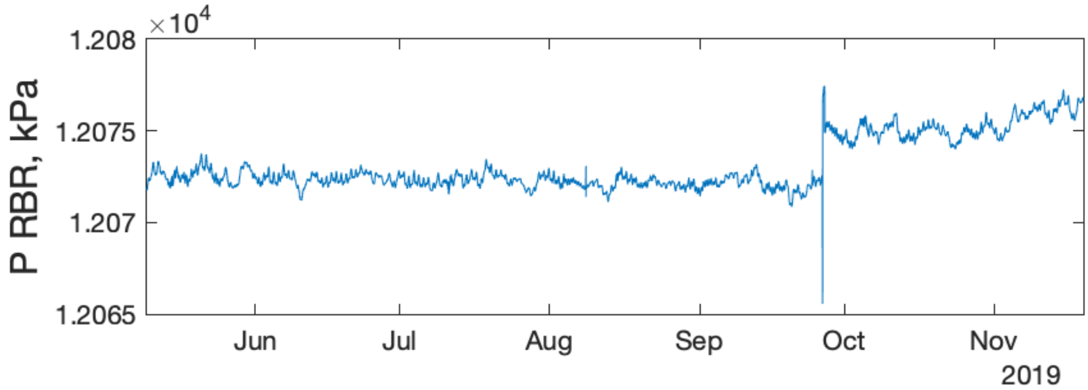
5-3-Vaisala shipboard atmospheric pressure record

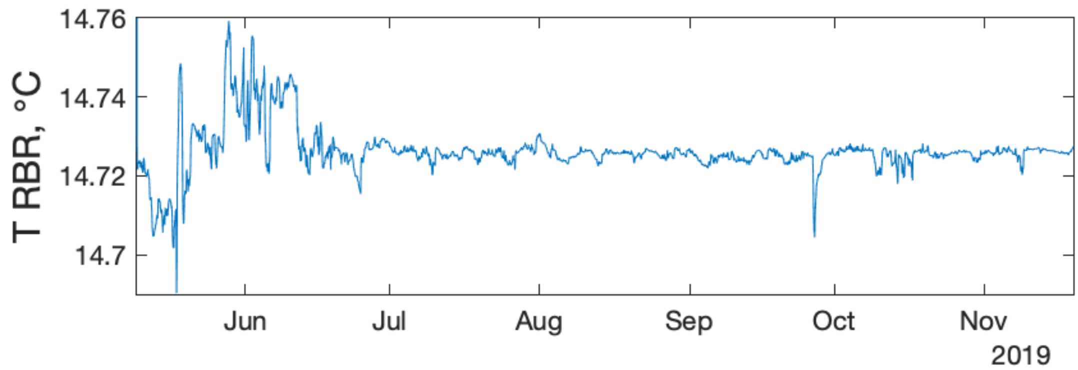
The Vaisala PTB and RBR BPR were re-synchronized to UTC on board. The Digiquartz pressure gauge displays variations due to its sensitivity to temperature variations and to acceleration as well as to non-linear drift resulting from the sudden pressure change upon instrument recovery. About 7 hours after recovery a stable pressure of 1095 hPa is recorded by the RBR BPR while temperature is also stable at 20.12°C and Vaisala PTB indicates 1022 hPa. The BPR value is thus 73 hPa above PTB. This may be compared with the offset between instruments measured 12 hours after recovery in May 2019, of 69 hPa at 16.75°C and the 72.5 hPa offset at 20.25°C measured before deployment in Nov. 2018. This suggests that relative drift over one year is less than 1 hPa, but that the temperature correction of the Digiquartz pressure sensor is not fully satisfactory. The Seaguard RCM only recorded one pressure value after recovery in Nov 2019, 1022.11 hPa at 19.10°C while the PTB recorded 1023 hPa and one before deployment in May 2019, 1015.09 hPa at 20.04°C while the PTB recorded 1013 hPa. In Nov 2018, the device recorded 24 values over 2 hours, 1027.7±0.4 hPa at 15.25±0.3°C while the PTB recorded pressure progressively increasing from 1027 to 1028 hPa. It thus appears that the tide sensor has better consistency at atmospheric pressure with the Vaisala PTB

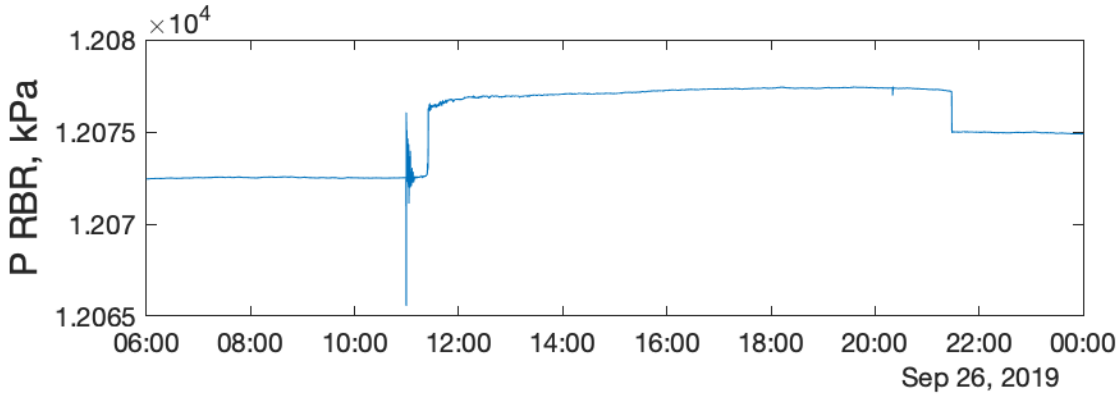
Table 5 – Variables in PTB Matlab file (2019-05-08_7_50.mat)

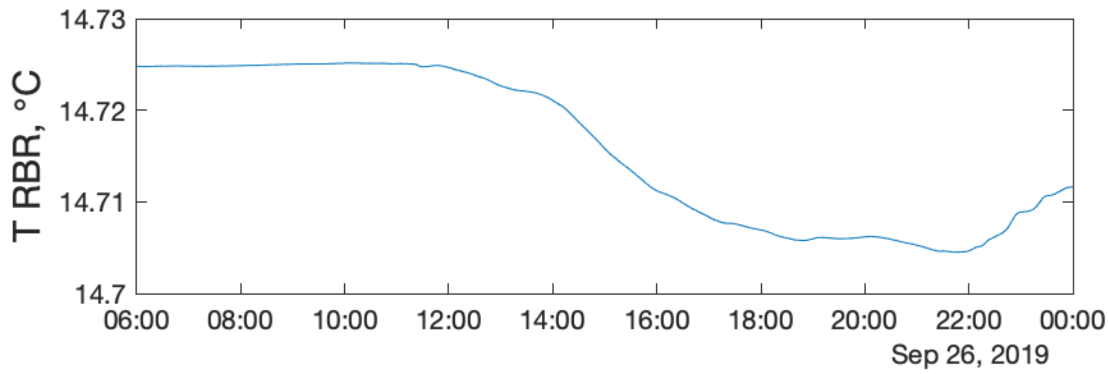
Name	Type	Comment
Time_PTB	datetime array	Time in datetime format Time_PTB.TimeZone='UTC' Time_PTB.Format='yyyy-MM-dd HH:mm:ss.S'
Timestring_PTB	cell array	Time as character string
P_hPa	double array	Atmospheric Pressure in hPa (mBar)

***Figure** 7: (On following page) Bottom pressure and temperature records from RBR BPR. Anomalous single values were removed using a 3 point median filter (medfilt1): (top) complete usable pressure record (upper middle) complete usable temperature record, (lower middle and bottom) zooms showing pressure and temperature variations related to Sept 26, 2019 earthquake that occurred at 10:59 UTC. The excursion March 20 06:35:21 likely corresponds to a M5.7 earthquake near Acipayam at 06:34:27, 370 km away.*


×10^4
1.208
1.2075
1.207
1.2065
P RBR, kPa
Jun
Jul
Aug
Sep
Oct
Nov
2019


14.76
14.74
14.72
14.7
T RBR, °C
Jun
Jul
Aug
Sep
Oct
Nov
2019


×10^4
1.208
1.2075
1.207
1.2065
P RBR, kPa
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Sep 26, 2019


14.73
14.72
14.71
14.7
T RBR, °C
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Sep 26, 2019

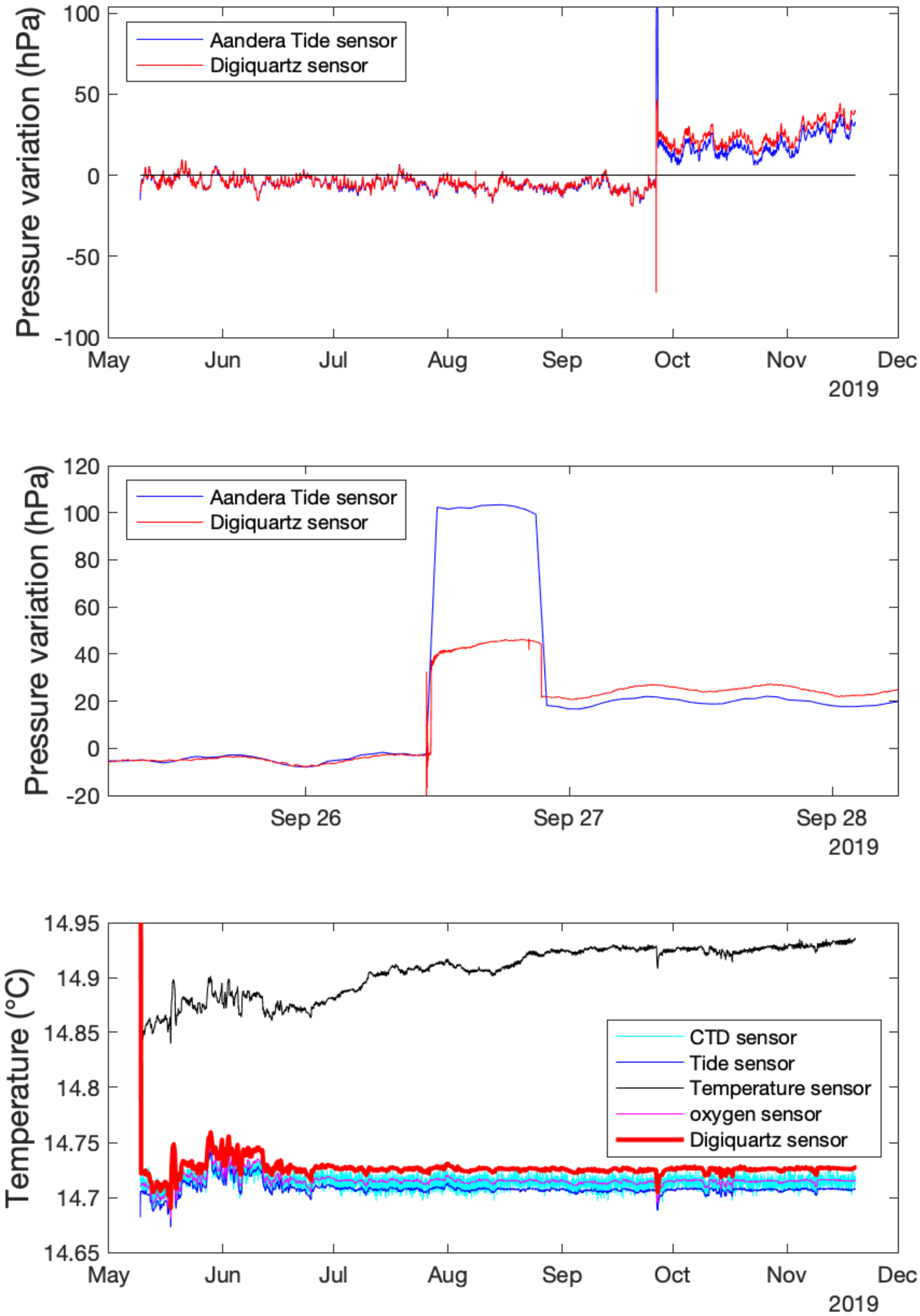


Figure 8: *Comparison of pressure and temperature records obtained at the seafloor with the various sensors fit to the Seaguard and RBR data loggers*

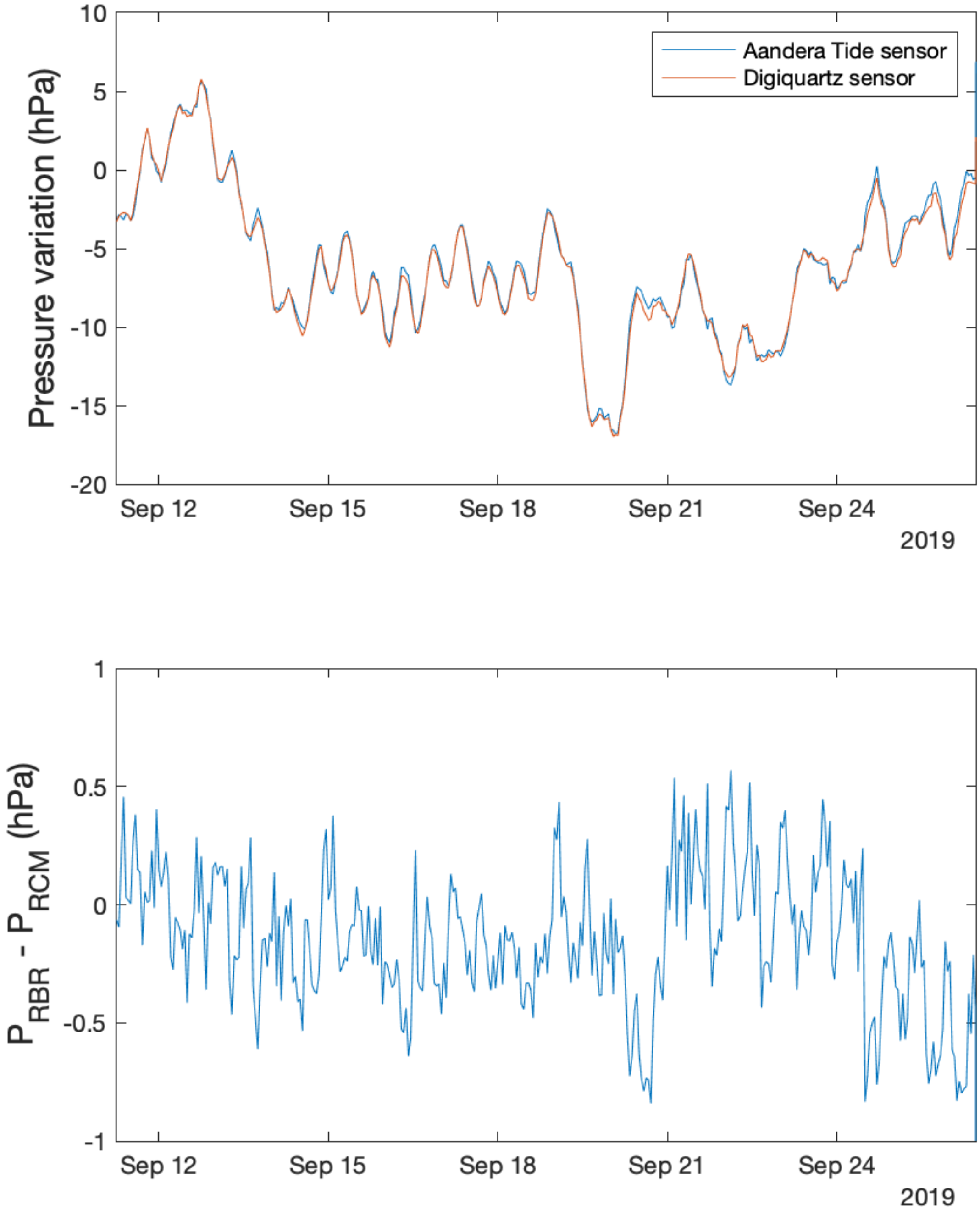


***Figure 9**: Comparison of pressure time series obtained at the seafloor with the the Seaguard RCM and RBR Digiquartz systems with the same averaging duration (5 minutes) and recording interval (1 hour). Averaging is done during acquisition for the RCM, and on time series originally sampled at 5s for the RBR.*

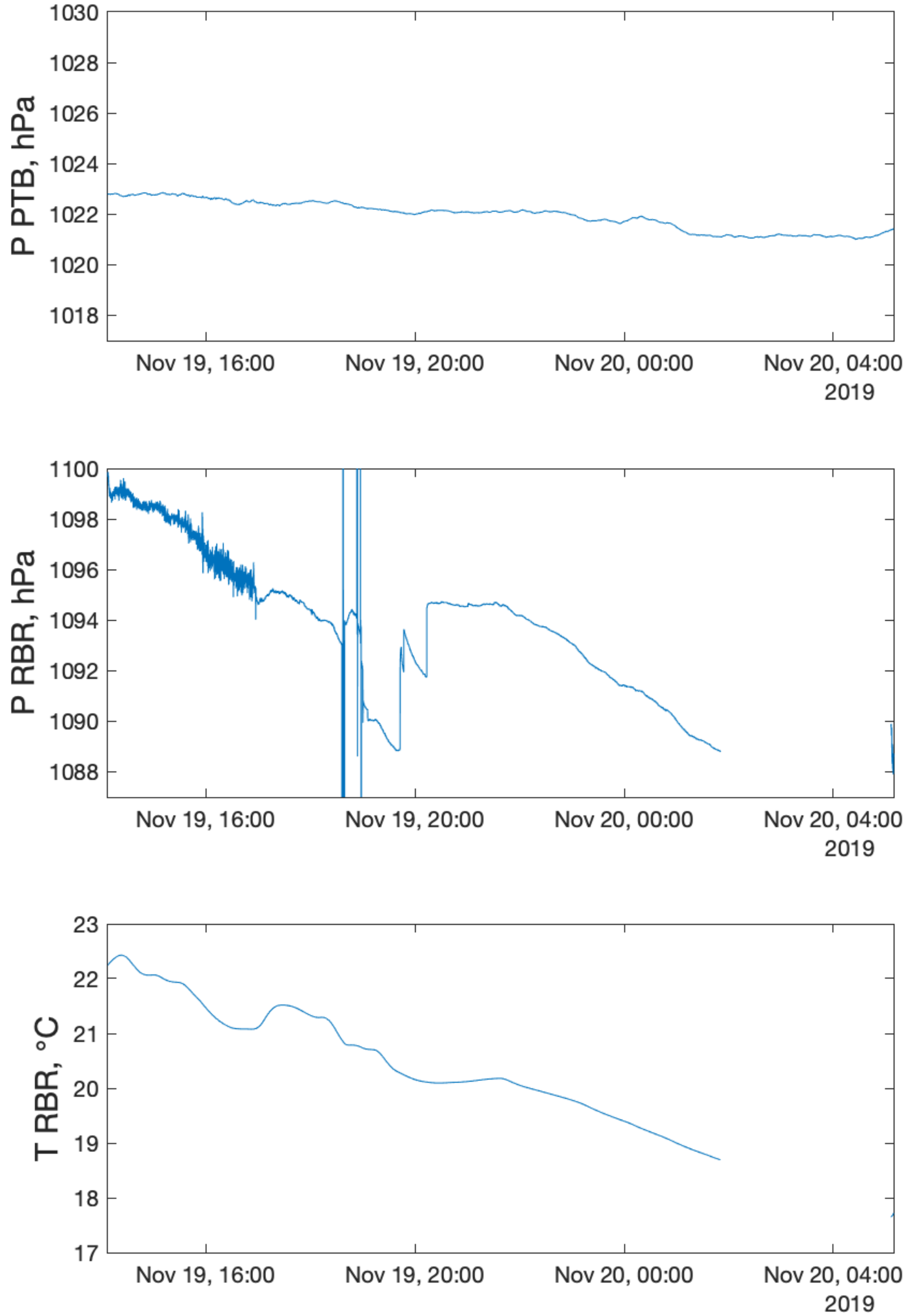


***Figure 10**: Records acquired on the ship. (top) Vaisala PTB record; (middle) RBR Digiquartz pressure record; (bottom) RBR temperature record.*

5- Sequence of events following the Sept 26, 2019 earthquake

The seismic wave train from the earthquake is first recorded by the Digiquartz pressure sensor as a pressure drop of 65 hPa between 10:59:19 and 10:59:24 followed by oscillations (Figure 7). Considering that the clock drifted 3s during the deployment, and assuming linear drift, the clock was probably 2s late at the time of the earthquake (10:59:24 clock time should be 10:59:26 UTC). During the previous deployments sudden pressure variations followed by oscillations where found to be associated with earthquakes. Pressure sensors are sensitive to pressure variations caused by P-wave. At wavelengths shorter than water depth, pressure amplitude is related to acceleration amplitude by $P=(T/2\pi)(v_p\rho).a$ where T is the period, v_p is the P-wave velocity in water and ρ is water density. For an ascending wave, if the height of the water counn is small compared with the wavelength, pressure amplitude no longer depends on period: $P=H.\rho.a$. For the sampling interval of 5s used in this setup, the shortest period that would not be aliased is T = 10s, for which the wavelength would be 15 km, >10 times 1200 m depth. In this case P = 12 MPa/g. Digiquartz sensors are also intrinsically sensitive to acceleration, but to a lesser extent, 160 hPa/g for an instrument with 20 MPa range according to the calibration report. The pressure variations caused by the P-wave propagating in water is thus probably the largest contribution to the signal. The negative polarity of the first arrival is consistent with the epicenter location (NE of instrument) and the focal mechanism (right lateral on an EW plane). However, the waveform may be difficult to interpret because of the long sampling interval.

Twenty-five minutes after the earthquake, a new disturbance of the pressure sensor is observed at 11:23:39. The pressure progressively increases by 30.9 hPa in 15 seconds between 11:24:44 and 11:24:59 and then stabilizes. At 11:57:46 the Seaguard RCM tiltmeter records a tilt of -65° of the X-axis and +19° of the Y-axis, with X-axis in a N161° azimuth. The variations of recorded pressure may thus be attributed to the tilting of the instrument. Ten hours later, the device apparently straightens itself in about 5 seconds, between 21:28:29 and 21:28:34 as indicated by a rapid pressure variation. After that, the tilt parameters recorded are moderate and stabilize at -11.5° for the X-axis and 5.3° for the Y-axis, with X-axis in a N105.3° azimuth.

At this stage of the data analysis there are still ambiguities regarding the interpretation of the tilt data. First of all, tilts larger than 45° are beyond the normal operational range of the instrument, and therefore may not be reliable. Second, the tilt polarity (positive tilt upward or downward) is not indicated in the manual. The tilt polarity, however, has no influence on the current correction. This correction is applied assuming that true current is in the horizontal plane and that the instrument measures its projection in the plane where the transducers are measuring the X and Y velocity components. The instrument was set to upstream pinging mode, which means that it only retains values from sensors measuring positive Doppler effects. A tilted instrument with one sensor facing downward toward the seafloor will thus only be able to measure currents facing the opposite sensor. It follows from the record that sensor 1 (oriented 160°) was most probably the sensor facing down. In this interpretation, the floatation sphere that was detached and filled with mud is also on the downward facing side of the instrument. The corresponding convention is with negative tilt down. The orientation of the instrumented frame with this convention is shown on Figure 11.

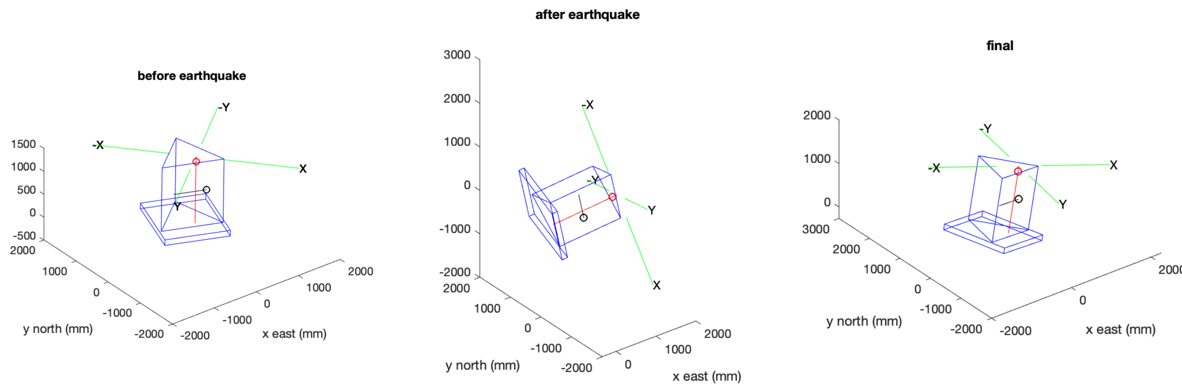


Figure 11: *successive orientations of the instrumented frame calculated from tilt parameters. The concrete slab and metal frame are in blue. The RBR BPR is in black with its pressure port indicated as a circle. The Seaguard Z-axis is in red and the location of the Tide sensor indicated as a red circle. The orientation of the beams of the Doppler current meter and extent of the measurement cells (between 0.5 m and 2 m from sensor) are indicated in green.*

During the 10 hours when the instrument remained strongly tilted, it recorded currents varying in both in speed and orientation. Some precautions are needed when interpreting these data. It may be considered that the current component measured by transducers 2 or 4 along the Y-axis, oriented N200°, is accurate as the tilt along this axis is less than 20° and the measurement cell remains above the bottom. On the other hand, the X-component may not be reliable as a current flowing northwestward will not be detected and the tilt correction performed assuming the current is horizontal is very large. However, data indicate that both current direction and speed varied during this time interval (Figure 12). There is no doubt that current direction varied as the current measured along the Y-axis changed sign several times (Figure 13). Assuming raw measurement and tilt corrected measurements bracket the actual current speed, four current pulses, ranging from 5 cm/s to about 50 cm/s occurred, the last one being the strongest. The current in the first 2 hours after the earthquake apparently remained small, at most 5-6 cm/s. Unless some short burst of current occurred that was missed because of the 1 hour sampling interval, it appears unlikely that strong currents caused the device to tilt. Liquefaction of the sediment beneath the device is also unlikely because the tilting of the instrument occurred 25 minutes after the earthquake. A mud flow originating from the basin slopes thus appears as a more likely cause. On the other hand the current in the 20-50 cm/s range recorded before the device straightened up is strong enough to cause erosion of mud or sand deposits. It may thus be hypothesized that erosion freed the device from the mud. The flotation spheres on the upper part of the frame and the concrete ballast at its base exert a couple that should keep it stable in an upright position unless the system is loaded with sediment. Once the system got back in an upright position, it recorded a current consistently flowing westward and progressively decreasing from 20 cm/s to background level (2 cm/s) in 9 hours.

The strength of the backscattered signal can be used as a proxy for turbidity. The Seaguard RCM emits in the 1.9-2 MHz band corresponding to a wavelength (λ) of 0.75 mm. Considering that Doppler backscatter current meters have maximum sensitivity for particles of diameter $D = \lambda/\pi$ ($k.a$=1 where k is wavenumber and a particle radius) and can detect particles down to diameter $D = 0.08\ \lambda$ (or $k.a > 0.25$), for with backscatter power is less than 1/10 of peak backscatter power (Guerrero et al., 2011, 2012), the seaguard RCM should be mostly sensitive to the presence in suspension of sand size particles (more than 63 µm). The background backscatter amplitude level is -40dB before the earthquakes and increases to the -20 dB to -13 dB range after the earthquake which implies sand sized sediment was put in suspension soon after the earthquake although the local current speed remains relatively low (about 5 cm/s at most). The signal strength values recorded while the system was tilted may be difficult to interpreted quantitatively. After the device went back to near vertical position, signal strengh reaches a maximum of -7.6 dB, that correspond to an amplitude ratio of 42 and an intensity ratio of 1800 compared to base level. With the Z-Pulse sensor used, similar signal strength levels are typically reached in highly turbid water such as in the Elbe estuary downstream of Hamburg (personnal communication from Anders Tengberg, Aandera). Deep sea deployments are more typically in the -60 to -40 dB range. Backscattered signal strengh then progressively decays to background levels in 3 days.

These observations provide some insight on the complex sequence of event that followed the earthquake at this location and lead to suggest the following scenario. After the passing of the seismic wave, triggering of instability on slopes adjacent to the instrument caused mud flows that spread on the basin floor causing bottom water turbidity. These flows can explain the tilting of the instrument 25 minutes after the earthquake. The base of the nearest slope is about 400 m north of the instrument, which would imply a minimum velocity of the mudflow of 20 cm/s to reach the device location in 25 minutes. Widespread instability on slopes north, north-east, and west of the device may have resulted in several turbidity currents of variable orientation that reached the device location over the following 10 hours. During this period, successive current pulses tend to increase in strength over time, eventually reaching a speed of the order of 50 cm/s and causing enough erosion to free the device from the accumulated mud. The current then stabilizes in a westward direction and decays progressively over the next 9 hours, which suggests the tail of a turbidity current flowing in the canyon ENE of the deployment site has been recorded. The hours-long delay between the earthquake and the passing of the fastest current over the instrument may hypothetically correspond to the time for the head of a turbidity current to travel from its source to the location of the instrument. The length of the canyon between the device location and the canyon heads at shelf break is about 15 km. Assuming some instability was triggered at the canyon head at the time of the earthquake and the resulting current reached the device location 10 hours later, the average speed of the head of the turbidity current along the canyon would be 42 cm/s. This estimation is in fair agreement with the range of measured current speed. The progressive build up of currents over a 10 hours period may reflect that turbidity currents have been triggered at various depths and distances from the site and that those triggered further away reached the site after a longer delay but having gained more strength on their downhill path due to the larger height difference. The three day decay of the backscatter signal strength may reflect the settling of sand size particles, which in fact could mainly correspond to sand size flocks, that were suspended in the water column after all these events.

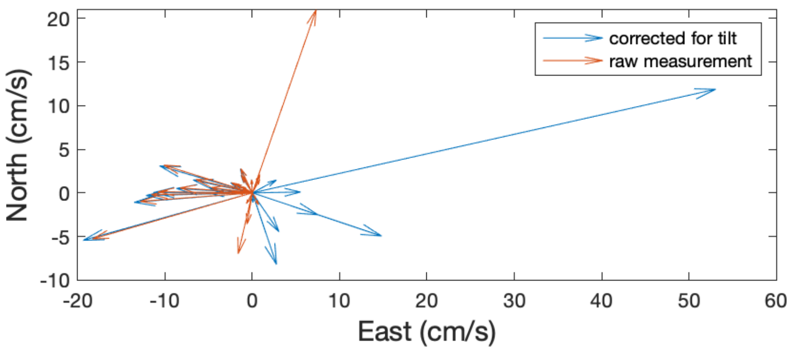


Figure 12: *Arrow plot of currents recorded every hour after the Sept 26 earthquake. Tilt correction was applied assuming current is always horizontal (parallel to bottom). Raw measurements represent the projection on the horizontal plane of velocities measured in the instrument plane*

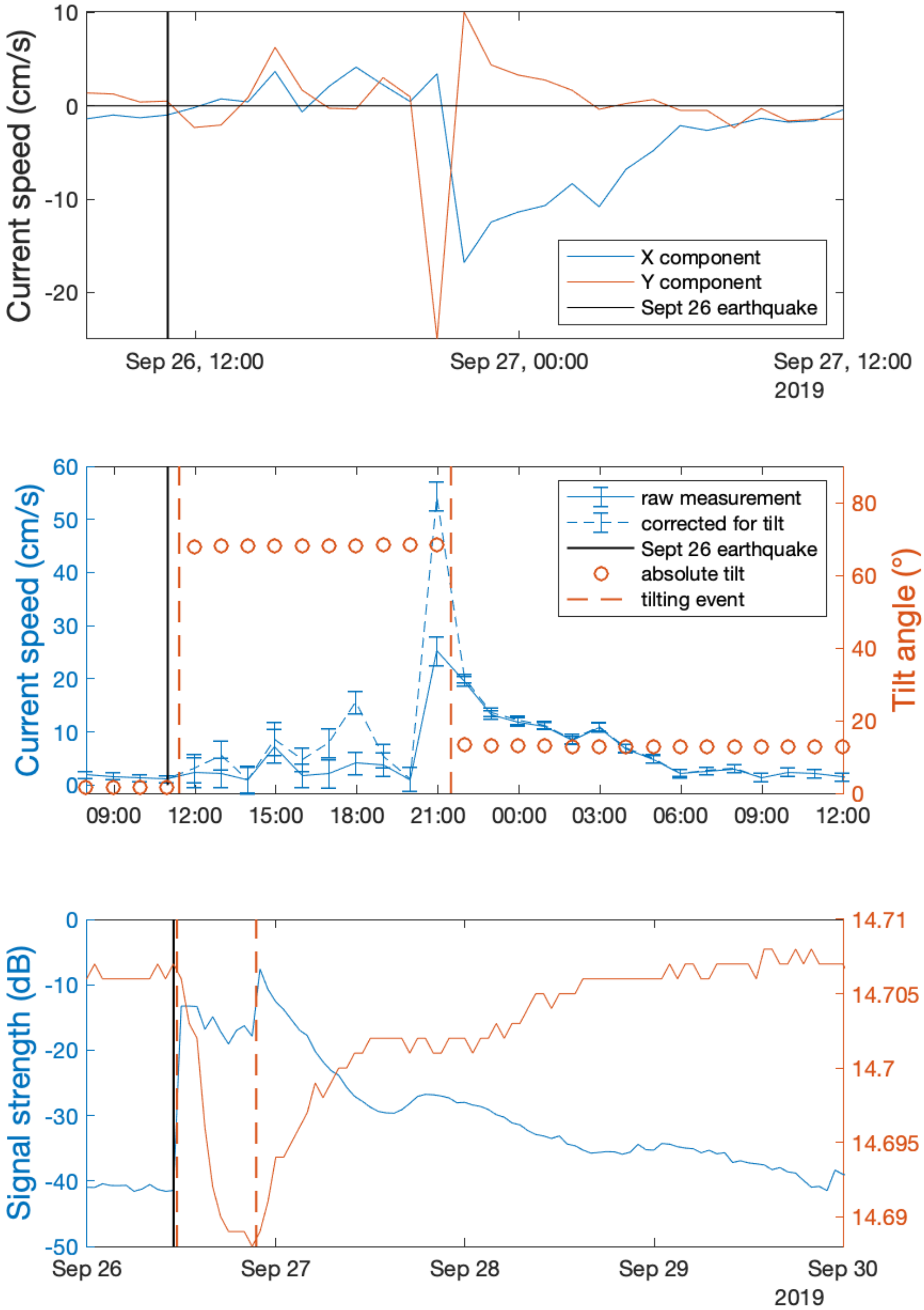


Figure 13*: Current meter record of the Sept 26 earthquake. (top) X and Y current components measured in the instrument reference frame. (middle) current speed estimated from raw measurement and by applying tilt correction. The instrument remained strongly tilted more than 10 hours before getting back to uprightl position. (bottom) backscattered signal strengh and temperature records.*