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# Cascadia Pilot Experiment Data Report

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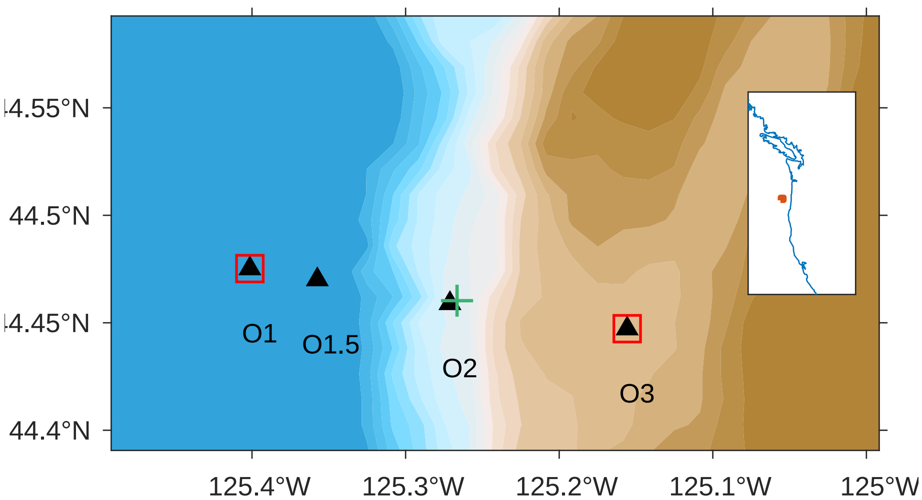
# Cascadia Pilot Experiment Data Report

**April 2017 to November 2017**

**Physical Oceanography Technical Report 37**




by
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Published Online August 21, 2019
http://digitalcommons.uri.edu/physical_oceanography_techrpts/37/

*This research project was funded by the National Science Foundation under awards 1728060 and 1358470.*

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# 1 Setting and Experiment Design

## 1.1 Introduction

This report documents the processing of data collected from an line of inverted echo sounders equipped with bottom pressure gauges and current meters (CPIES) deployed offshore of Oregon in the Cascadia subduction zone region from April to November 2017 (Figure 1). The line consisted of four URI-model CPIES across the continental slope, spanning water depths from 2900 m to 1300 m. From offshore to onshore, the sites were designated O1, O1.5, O2 and O3. The instrument spacing telescoped toward the coast from 3.5 km to 7 km to 9 km. The site locations were chosen to coordinate with a line of benchmark platforms for ocean bottom pressure gauges deployed under NSF's Cascadia Initiative. Additionally, the sites are along a line that ends at the Slope Base site of the OOI Endurance Cabled Continental Margin Array. CTDs were taken at each site on the deployment and recovery cruises. Additionally, two Sonardyne-model PIES (lacking the integrated current meter) were colocated at the deepest and shallowest sites (O1 and O3) for comparison tests. An Aanderaa Seaguard current meter was moored in August 2017 at site O2 because the status of CPIES current meter at that location was uncertain.

The measurements presented here were collected with support provided by National Science Foundation awards 1728060 and 1358470.

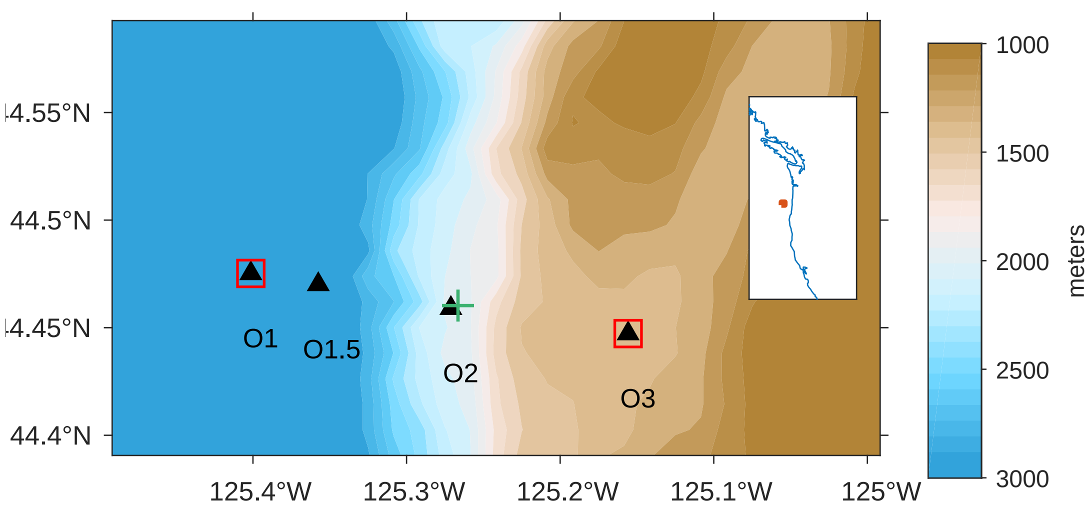


Figure 1: CPIES (solid triangles) and PIES (open squares) site locations offshore of Oregon. The short mooring (green plus), deployed in August 2017, is adjacent to the CPIES at O2. Bathymetry, contoured at 100 m intervals, derives from *Smith and Sandwell* (1997). The location of the array in relation to the US west coast is shown by the red dot in the inset.

## 1.2 Instrumentation

### 1.2.1 CPIES description

A CPIES is a URI manufactured inverted echo sounder (IES) with a Paroscientific pressure sensor housed in a single glass sphere, and an Aanderaa Doppler current sensor (DCS) tethered 50 m above with additional flotation. An anchor stand holds the CPIES stationary at the seafloor. Temperatures are measured by both the pressure sensor and the DCS. The CPIESs were equipped for acoustic telemetry that enabled the data quality to be assessed immediately after the instrument reaches the ocean bottom. Daily pressure, travel time, and current measurements can also be telemetered to a nearby vessel after the CPIES has been deployed for a minimum of three days.

The IES emits 12 kHz sound pulses, and the round trip travel times to the surface and back of the pulses are recorded internally. During this pilot experiment, four acoustic pulses were transmitted every 10 minutes. After recovery, data processing creates a single value ($\tau$ or tau) from the 24 measurements taken during each hour.

The Paroscientific pressure and temperature measurements were taken every 10 minutes, and the CPIES internally corrects the pressure measurements for temperature sensitivity. Model 410k with a rating of 0–10000 psi (about 6800 dbar) sensors were used during this pilot experiment. Because the pressure sensor is inside the glass sphere, the associated temperature measurement is not a direct measurement of seawater temperature.

The DCS measurements of velocity and temperature were made once every 10 minutes. DCS model 3820R (which uses the same current measurement system as the RCM11) was used at all four sites. The DCS temperature sensor is also located inside the metal housing.

### 1.2.2 Sonardyne PIES description

Two PIES manufactured by Sonardyne International Ltd were deployed at the same locations as the CPIES at O1 and O3. The Sonardyne instruments report two travel times (called 'Time of Flight', TOF). A technical bulletin provided by Sonardyne (Technical Bulletin TB15-011 by D. Williams) provided this description of the two TOFs: "TOF1 is calculated using threshold techniques and is better suited for depths up to 2000 meters. TOF2 is calculated using a form of statistical analysis which is better suited for depths greater than 2000 meters." The Sonardyne PIES also includes a Paroscientific pressure sensor and an optional temperature sensor. The pressure sensor also measures its own temperature in order to correct for pressure sensitivity to temperature. The instruments at the two sites were configured differently.

At site O1, a Sonardyne model 8306 Fetch/PIES was deployed. This model uses a glass sphere housing and is held stationary on the seafloor with a fixed tripod frame. For this pilot experiment, a second pressure sensor, manufactured by Presens, was also included. The Presens pressure sensor also measures its own temperature. This PIES was programmed to sample every 5 minutes.

At site O3, a Sonardyne model 8302 PIES was deployed. This model, with a cylindrical housing, was tethered with a 2 m chain strop and equipped with a flotation collar. This PIES was programmed to sample every 10 minutes.

### 1.2.3 Current meter mooring description

An Aanderaa Seaguard RCM DW (also known as a ZPulse DCS) current meter deployed on a short mooring near the CPIES at site O2. The mooring consisted of three glass spheres for flotation at the top, the Seaguard current meter, an EdgeTech release, and a railroad wheel anchor. Wire lengths were chosen so that the current meter would be located 50 m above the seafloor, similar to the current sensor of the adjacent CPIES. The RCM measured current velocity, temperature, and pressure every 10 minutes.

## 1.3 Cruises

The four CPIES and two Sonardyne PIES were deployed in April 2017 aboard the R/V Sikuliaq (Table 1). CTDs were taken at each site. Burst telemetry was taken after each CPIES deployment to assess the on-bottom data quality. The current measurements at site O2 were considered suspect, so arrangements were made to deploy a short current meter mooring during a cruise aboard the R/V Revelle in August that was planning to service the nearby OOI moorings. The CPIES, PIES and short mooring were all recovered in November 2019 on a short two-day cruise aboard the R/V Oceanus.

Table 1: Deployment and recovery cruise information.

| Vessel | Cruise Number | Cruise Dates | Cruise Description |
|---|---|---|---|
| R/V Sikuliaq | SKQ201705S | 26 April – 01 May 2017 | Deploy CPIES, PIES, CTD stations |
| R/V Revelle | | 26 August 2017 | Deploy current meter mooring |
| R/V Oceanus | OC17-11C | 10 – 11 November 2017 | Recover CPIES, PIES, RCM, CTD stations. |

## 1.4 Site locations

CPIES locations, shown in Figure 1, are listed in Table 2 together with the duration of deployment and nominal depth. Serial numbers of the IES, pressure, and current sensors are also tabulated. The corresponding information for the two Sonardyne PIES and the Aanderaa Seaguard RCM are provided in Tables 3 and 4, respectively.

Hydrocasts were taken at the four CPIES sites on both the deployment and recovery cruises with a Seabird Scientific CTD. The station numbers associated with each site are listed in Table 5. The raw data and configuration files are included with the submission to the National Centers for Environmental Information (NCEI).

Table 2: Site designators, instrument serial numbers, deployment and recovery dates, location and bottom depths for URI-model CPIES. For each instrument package, serial numbers are tabulated for the inverted echo sounder (IES), Paros pressure sensor, and Aanderaa Doppler current sensor (DCS). Paros model 410K has a pressure rating to 10000 psi (∼6800 dbar).

| Site | IES SN | Paros Model | Paros SN | DCS SN | Deployment YYYYMMDD | Recovery YYYYMMDD | Latitude (N) | Longitude (W) | Nominal Depth (m) |
|---|---|---|---|---|---|---|---|---|---|
| CPO1 | 109 | 410K | 91523 | 339 | 20170427 | 20171111 | 44° 28.51′ | 125° 24.08′ | 2917 |
| CPO1.5 | 118 | 410K | 92036 | 341 | 20170427 | 20171111 | 44° 28.21′ | 125° 21.45′ | 2924 |
| CPO2 | 121 | 410K | 90551 | 355 | 20170428 | 20171111 | 44° 27.54′ | 125° 16.27′ | 1966 |
| CPO3 | 152 | 410K | 91498 | 757 | 20170428 | 20171110 | 44° 26.84′ | 125° 09.35′ | 1324 |

Table 3: Site designators, instrument serial numbers, deployment and recovery dates, location and bottom depths for Sonardyne-model PIES.

| Site | SN | Deployment YYYYMMDD | Recovery YYYYMMDD | Latitude (N) | Longitude (W) | Nominal Depth (m) |
|---|---|---|---|---|---|---|
| SDO1 | 290797-001 | 20170427 | 20171111 | 44° 28.51′ | 125° 24.08′ | 2917 |
| SDO3 | 295406-004 | 20170428 | 20171110 | 44° 26.84′ | 125° 09.35′ | 1324 |

Table 4: Site designator, instrument serial number, deployment and recovery dates, location and bottom depths for the Seaguard current meter mooring.

| Site | SN | Deployment YYYYMMDD | Recovery YYYYMMDD | Latitude (N) | Longitude (W) | Nominal Depth (m) |
|---|---|---|---|---|---|---|
| RCM518 | 518 | 20170826 | 20171111 | 44° 27.62′ | 125° 15.99′ | 1950 |

Table 5: CTD stations numbers taken at the four CPIES sites on the deployment cruise aboard the R/V Sikuliaq and the recovery cruise about the R/V Oceanus.

| Cruise | O1 | O1.5 | O2 | O3 | Dates of casts |
|---|---|---|---|---|---|
| R/V Sikuliaq | 001 | 002 | 004 | 003 | 27–28 April 2017 |
| R/V Oceanus | 004 | 003 | 002 | 001 | 10–11 November 2017 |

### 1.5 Data returns

Figure 2 summarizes the data returns of the hourly records in time line format. While the temperature data are not displayed, the pressure sensor temperature measurements have the same coverage as the pressure data, and the DCS temperatures have the same coverage as the velocities. Blank (white) spaces indicate missing data. Two large data gaps exist in the hourly currents of CPO2 and the hourly travel times of SDO1 for different reasons.

The CPIES at CPO2 actually worked properly and collected the current data throughout the whole deployment period. The data gap resulted when the compact flash card was read using an Apple computer. Reading the CPIES compact flash card with a computer running Mac OS/X corrupted the DCS data file of CPO2 and overwrote a portion of it. Fortunately, after considerable effort, most of the data was recovered, leaving only a gap of about 38 days. The same problem also occurred for the DCS data file for CPO1.5. However, in that case, nearly all the DCS data was successfully recovered; only about 1.5 days of velocity data at the beginning of the record were lost.

Fortunately, each CPIES also stores on the compact flash card a file called TELEM.DAT that contains daily values of travel time, pressure, current speed and direction, and yearday. This file was not corrupted when the data was downloaded, so complete records of daily currents are available for the full deployment period. However, the first 4 days of current data at CPO2 were discarded because the speeds were unrealistically high. A stuck compass at the time of deployment is suspected. A comparison of the CPO2 currents with those measured by the RCM confirm that the compass was working properly during their overlapping deployment period.

The Sonardyne PIES at site O1 was incorrectly configured to sample every 5 minutes prior to deployment. Unfortunately, the storage card was not large enough to handle this quantity of data. Thus, no travel time data were collected after the card filled up in mid-August 2017.

## 2 Data Processing

### 2.1 CPIES and PIES

The basic data processing of the URI CPIES was accomplished by a series of MATLAB routines specifically developed for the instruments (*Kennelly et al.,* 2007). The routines were adapted to process the Sonardyne PIES. Travel times, pressures, temperatures, and velocities were windowed and outliers removed (despiked). Hourly values were generated for each variable. Tidal signals and instrumental drifts were removed from the pressure measurements. All hourly variables were low-pass filtered using a fourth order Butterworth filter with a cutoff period of 3 days. The filter was run forward and backward to eliminate phase offsets and the beginning and ending records were excluded to avoid startup transients. The filtered records were subsampled at 12 hour intervals (0000 and 1200 UTC).

Because of the close distances between the CPIES sites, it was highly likely that neighboring instruments would hear one another's acoustic signals. To prevent interference between neighboring instruments during the travel time measurement intervals, the CPIES and PIES were configured

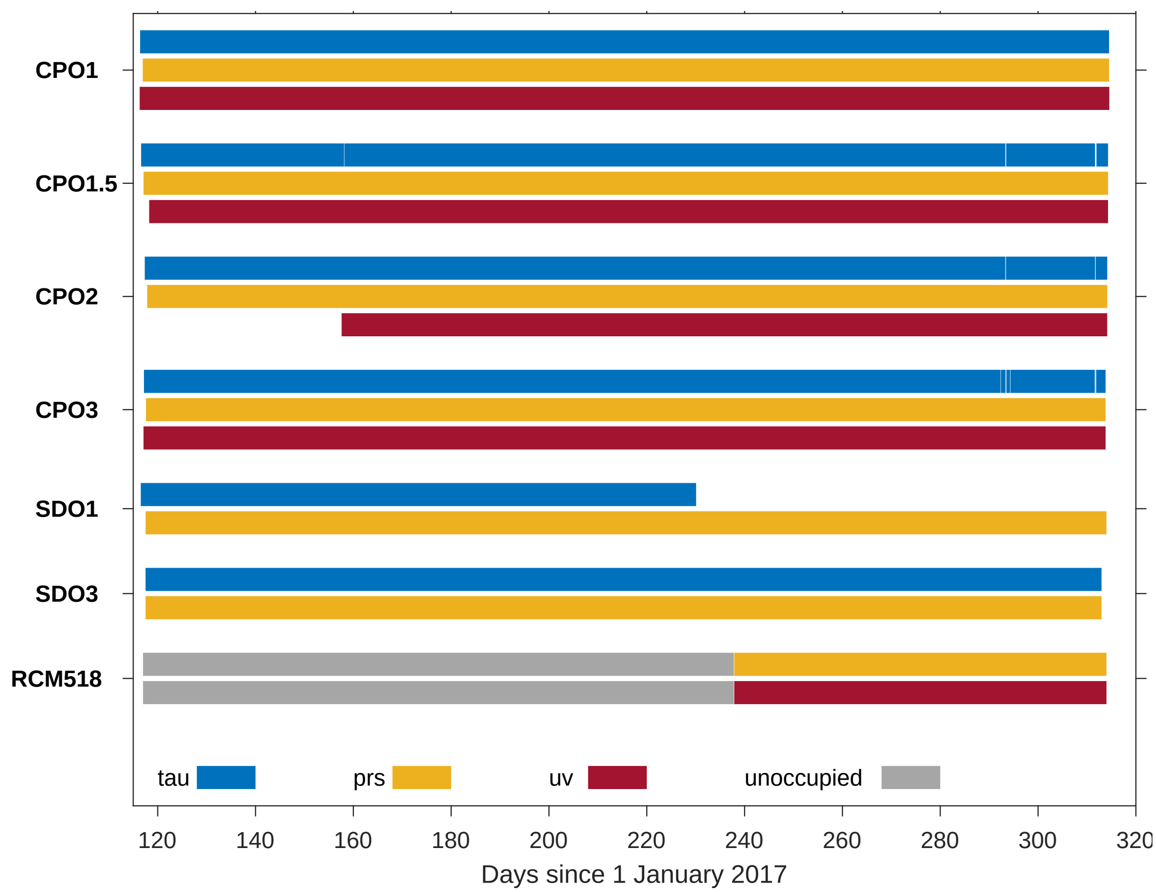


Figure 2: Data returns for the hourly records of travel time (blue), pressure (orange), and velocity (red). White spaces indicate missing data. Gray lines indicate the time period prior to the current meter mooring deployment when the site was unoccupied.

with staggered start times. The clocks were adjusted to begin sampling after true UTC by the number of minutes listed in Table 6.

### 2.1.1 Vertical acoustic travel time, $\tau$

For the URI CPIES, a single representative travel time measurement was determined from a burst of 24 pings taken during each hour using a modified quartile method. Each burst of $\tau$ measurements is windowed twice to remove outliers and reduce measurement noise. The representative $\tau$ for each hour is then determined as the average of a few measurements surrounding the first quartile value of the remaining $\tau$ measurements. Details of the method are provided in *Kennelly et al.* (2007).

For the Sonardyne PIES, a simple averaging method was used to determine each hourly $\tau$ value. Both methods used internally by the PIES s to calculate TOF yielded travel times with very little scatter. Therefore, after removing large outliers, representative $\tau$ values were obtained by simply averaging $\tau$ measurements during each hour. For SDO1, with a 5-minute sampling interval, typically 12 $\tau$ values were averaged. For SDO3, with a 10-minute sampling interval, typically 6 values were averaged. Hourly $\tau$ values were obtained separately for both TOFs recorded by the Sonardyne PIES.

### 2.1.2 Pressure

Hourly pressures were obtained by averaging the 6 measurements taken each hour. For SDO1, which was programmed to sample every 5 minutes, 12 measurements were averaged to create the hourly values.

Semidiurnal and diurnal tidal constituents were determined using the response analysis method (*Munk and Cartwright,* 1966) and the generated tidal record was subtracted from the hourly pressures. The amplitudes and phases of the eight major constituents for the CPIES at sites O1 and O3 are listed in Table 7. The tidal amplitudes are the same at the two sites, separated by only 19.5 km, and the phases differ by less than 0.5 degrees. The tides were added back to the dedrifted pressure records for the submission to NCEI.

All of the pressure sensors in the CPIES and PIES exhibited instrumental drift. The processing code was used to least-squares fit a linear-exponential curve to each detided pressure record. The drift curves are plotted in Figure 3. Dedrifted pressure records were generated by subtracting fitted

Table 6: Clock offsets from true UTC for the CPIES and PIES. Offsets are specified in minutes. Negative values indicate that the actual sampling times lag behind true UTC.

| Site | SN | Offset |
|---|---|---|
| CPO1 | 109 | -07 |
| CPO1.5 | 118 | -05 |
| CPO2 | 121 | -03 |
| CPO3 | 152 | 00 |
| SDO1 | 290797-001 | -04 |
| SDO3 | 295406-004 | -02 |

Table 7: Tidal constituents at at the offshore and onshore CPIES sites separated by less than 20 km. Amplitudes (H) are in decibars; phases (G) are in degrees.

| Site<br>SN | Amplitude<br>Phase | O1 | K1 | Q1 | P1 | M2 | K2 | N2 | S2 |
|---|---|---|---|---|---|---|---|---|---|
| CPO1 | H | 0.26 | 0.42 | 0.05 | 0.14 | 0.82 | 0.06 | 0.17 | 0.23 |
| 109 | G | 219.64 | 235.24 | 212.78 | 234.21 | 225.15 | 251.52 | 200.82 | 250.35 |
| CPO3 | H | 0.26 | 0.42 | 0.05 | 0.14 | 0.83 | 0.06 | 0.17 | 0.23 |
| 152 | G | 219.54 | 235.07 | 212.47 | 234.07 | 224.65 | 251.06 | 200.46 | 249.88 |

drift curves from the measurements.

#### 2.1.3 Temperature

A quartz crystal with temperature sensitivity is incorporated into the Paroscientific pressure sensor. Because the pressure sensor is located inside the glass housing of the CPIES, it does not provide an accurate measurement of the in situ water temperature. However, the temperature measurements can be used to examine the temporal variability. Therefore, the pressure sensor temperatures were averaged to create hourly values. Typically, it takes between 12 and 24 hours for the temperature inside the housing to equilibrate with the surrounding water. Temperature and pressure measurements taken prior to reaching equilibrium were discarded.

The temperature sensor associated with the DCS current sensor is not in direct contact with the surrounding water either. It is inside the metal housing, but it reaches equilibrium more rapidly than the Paroscientific temperature sensor. Typically only the first hour of post-launch data were discarded.

#### 2.1.4 Currents

The CPIESs measured near-bottom currents every 10 minutes. The measured current directions have not been adjusted for magnetic declination. Additionally, the measured speeds are based on the default sound speed value of 1500 m $s^{-1}$ used by the DCS. More accurate speeds could be obtained by multiplying them by a speed of sound scale factor, where the scale factor is the ratio of the true sound speed to the default value. The eastward ($u$) and northward ($v$) components were averaged to produce hourly values.

#### 2.1.5 Daily currents

The URI model CPIES internally process the measured travel times, pressures, and currents at the end of each day to create daily values which are written to a separate file on the compact flash drive for later retrieval via telemetry to a nearby research vessel. Because the current meter data files for CPO1.5 and CPO2 were corrupted during the data downloading process, the daily current speed and direction are included with the submission to NCEI in order to provide complete velocity records for the full deployment period at the four CPIES sites.

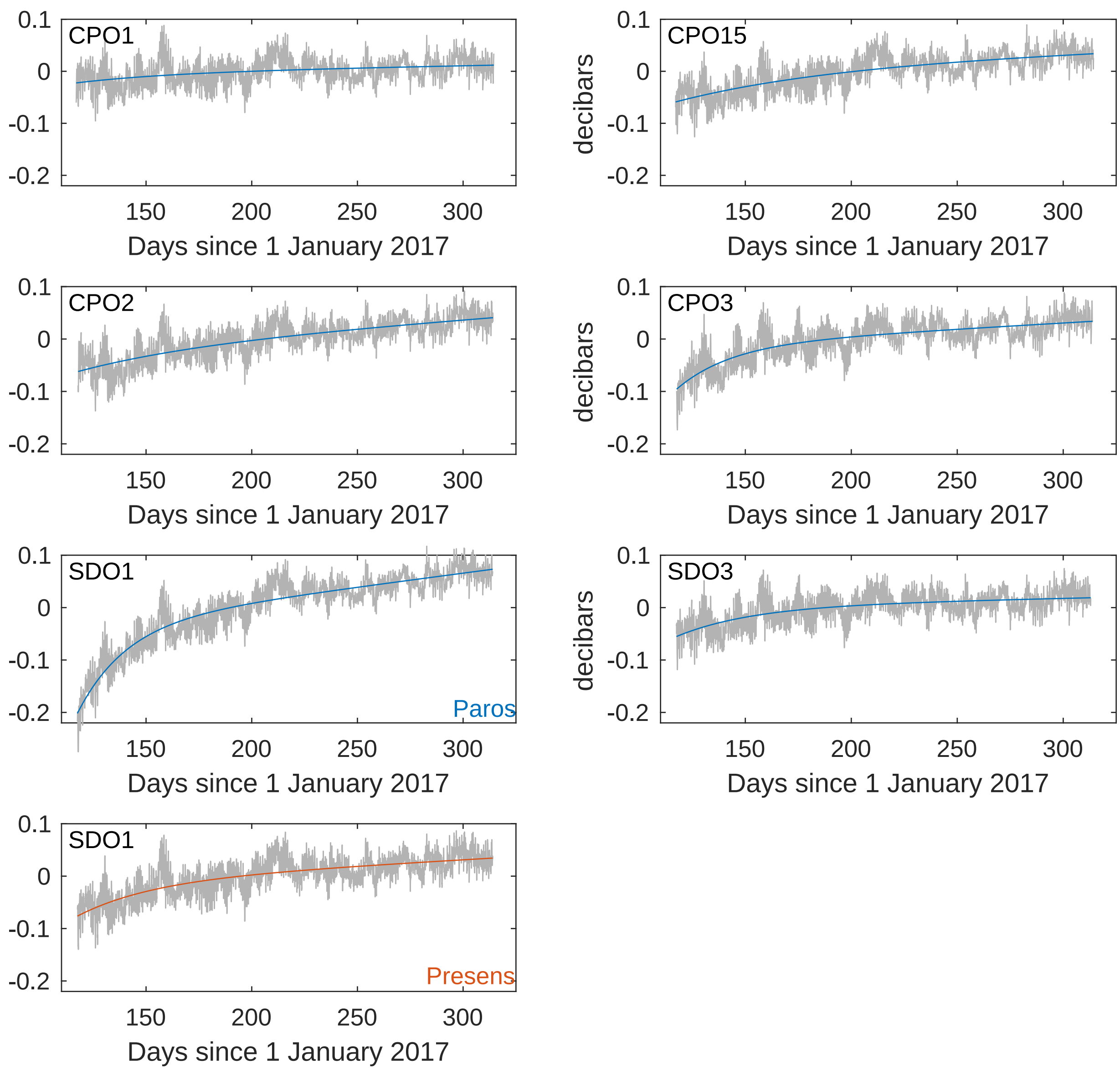


Figure 3: Instrumental pressure drift curves (colored lines) fitted to the hourly detided pressure records (gray lines). The Sonardyne PIES at site O1 was outfitted with two different model pressure sensors. Drift curves were fitted to both pressure records separately.

The daily averages of $u$ and $v$ are calculated internally by the CPIES as follows. At the end of each hour, the velocity components are sorted and windowed in two stages and the median hourly values are stored in a 72-element array. At the end of each day, just prior to midnight, the CPIES applies a *Godin* (1972) filter to $u$ and $v$ individually to remove the semi- and diurnal tides. The detided average velocities, centered on the previous 72 hours, were converted to polar coordinates prior to be saved in TELEM.DAT.

Similarly to the hourly current data, the daily current directions have not been adjusted for magnetic declination and the daily speeds are based on the default sound speed setting used by the DCS.

### 2.2 RCM current meter

Minimal processing has been performed on the data collected by the current meter on the short mooring at site O2. The RCM measurements were taken at 20 minute intervals. Hourly averages have not been calculated. The current directions have not been been adjusted for magnetic declination. The current speeds are based on the default sound speed setting of 1500 m $s^{-1}$ used by the RCM.

## 3 Acknowledgments

We gratefully acknowledge the crews of the R/V Sikuliaq, R/V Revelle, and R/V Oceanus for their efforts during the deployment and recovery cruises. We are especially grateful to Dr. Deborah Kelley and James Tilley of the University of Washington for deploying the short mooring for us on the cruise to service the OOI Cabled Array instruments.

The success of the URI CPIES is due to the instrument development and careful preparation done by Erran Sousa, Laura Reed, and Dan Holloway.

We acknowledge Sonardyne International Ltd for providing two models of PIES to demonstrate their performance capabilities side-by-side with the URI CPIES. We thank Chris Hammersley for preparing and deploying the instruments and Chloe Kennard for helping to recover them.

This work was supported by the National Science Foundation under awards 1728060 and 1358470.

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