Feasibility of Tide measurements at Two Harbors
Sensus Ultra data

Although tide and water-level measurements are made at several locations along the California coast, they are not made at Santa Catalina Island, located 30 km off the coast. For many purposes, tidal measurements made at Los Angeles Harbor are sufficient for understanding the tide at the island. However, for assessing tidal effects of episodic events such as storms, high winds, and tsunamis, the Catalina Marine Society desires tidal measurements at the island, especially at the Wrigley Institute of Environmental Studies (WIES), near Two Harbors. The rough requirements are to measure tide modulation to within 5 cm with a sampling of 20 minutes and with deployment periods on the order of months. Note that absolute water-level measurement is not required.

This note describes an experiment and analysis to obtain tide measurements in an economical manner with volunteer divers. The approach is to submerge a long-recording diving logger off the WIES pier. The logger can be attached securely to the pier pilings in the protective cove and at sufficiently shallow depth to be sensitive to sea-level pressure changes.

We procured a Sensus Ultra (SU) dive logger from Reefnet, a Canadian company. The logger records pressure and temperature at a user-determined sampling frequency. The SU can be configured to start data recording when a user-specified pressure is met or exceeded. It can store 540,000 samples (1500 hours at 10-second sampling period). Its resolution and precision are given in Table 1, and they meet our rough requirements.

After talking with personnel at Reefnet, we understood that the pressure ports must be protected from clogging during long-duration deployments. To mitigate biofouling, we plan to place the SU into a sturdy water bottle filled with fresh water. The bottle will be enclosed with a wire hanger that allows a standard diving weight belt to be threaded to it. When strapped to the pier piling at depth, the bottle will be slightly opened via a hinged, plastic straw-like opening so that the ambient ocean pressure can be communicated to the fresh water in the bottle. In the two sections that follow, we show an analysis of data gathered in a deployment.

Table 1. Sensus Ultra sensor characteristics from Reefnet web site.

Depth resolution	1.27 cm
Depth accuracy	+/- 30.48 cm
Temperature resolution	0.01 ^{o}C
Temperature accuracy	+/- 0.08 ^{o}C

Time-Series Analysis

The instrument as configured above was deployed off the WIES pier at a depth of approximately 6 m. We had set the SU to begin recording at 1111 mBars and to record every 60 seconds. After a three-month deployment from August 25 to December 1, 2012, the instrument was retrieved and its data downloaded. A few sample records are given in Table 2.

Table 2. Example of data downloaded from Sensus Ultra

Year	Month	Day	Hour	Minute	Second	Sample time	Pressure (mBars)	Temperature K
2012	8	25	10	9	24	0	1111	293.97
2012	8	25	10	9	24	60	1111	294
2012	8	25	10	9	24	120	1113	294.03
2012	8	25	10	9	24	180	1114	294.05
2012	8	25	10	9	24	240	1115	294.08

The first 6 values (year, month, day, hour, minute, second) are the start of the data recording, not the time of the recorded datum. The sample time is the time in seconds of the recorded data relative to the start of recording. The last two values are the measured pressure and temperature. Due to the large amount of data, we decimated the data by a factor of 10 to work with sampling period of 600 seconds and converted from time records to dates.

We computed depth from the pressure measurements using the following equation:

$$depth = (pressure - atmospheric\ pressure) \times\ mBarstodepthm$$

We did not measure the atmospheric pressure, but used a constant value of 1013.25 mBar. The conversion factor from pressure to seawater depth was

$$mBartodepthm = {}^{1}/_{100.52}.$$

The entire time series for both depth and temperature are shown in Figure 1. There is no apparent biofouling of the pressure data and the tides are clearly evident. At this time we have no independent verification of the temperature but it has the overall characteristics we expect for this time of year.

The measured tidal modulations were compared to those measured in LA Harbor by NOAA station 9410660. The NOAA data are recorded every 6 minutes or 360 seconds and the recorded time is in GMT. The distance between the two locations is about 30 km so the time difference in the tides at the two locations should be negligible. We downloaded one month of NOAA data corresponding to the first month of deployment of the SU. We removed the mean value for each time series and subtracted 8 hours from the NOAA data and then plotted them on the same graph. In Figure 2 are shown both data sets for the month and Figure 3 and Figure 4 are temporally-expanded versions that permit examination and comparison in finer detail.

The two series appear to be time aligned and the tidal modulations are within a few cm of each other. Although there are some systematic differences, such as that found for hours 360 to 365, these may be natural phenomena.

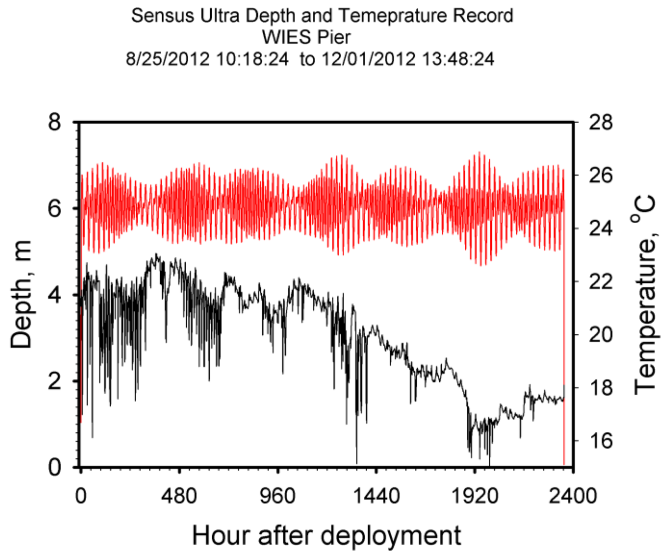

Figure 1. Pressure data converted to meters and temperature for complete deployment.

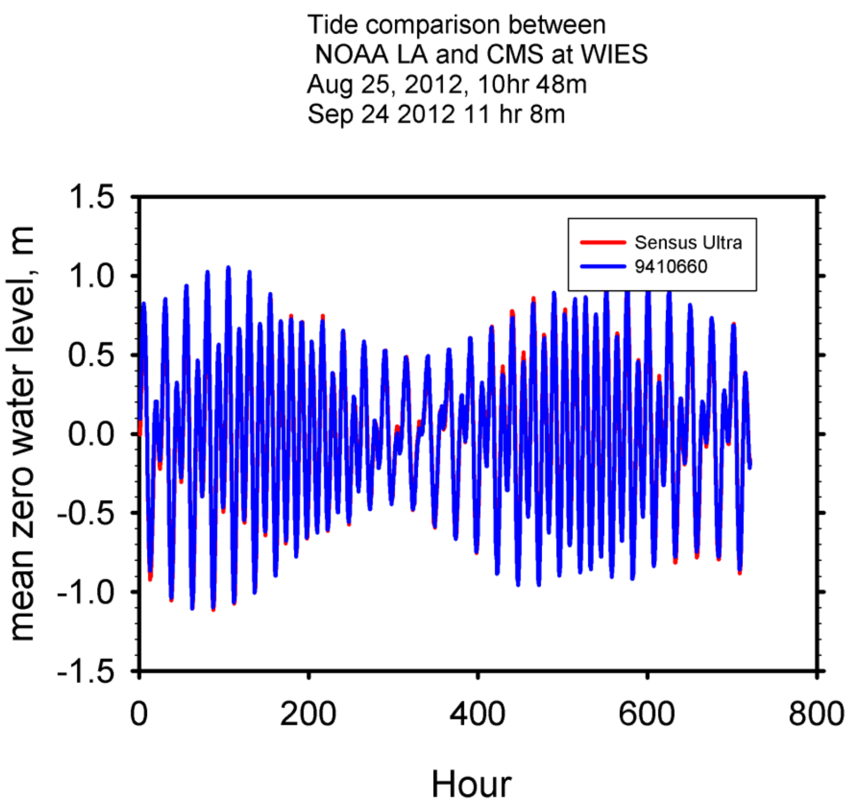

Figure 2. One month comparison of tidal modulations, 720 hours.

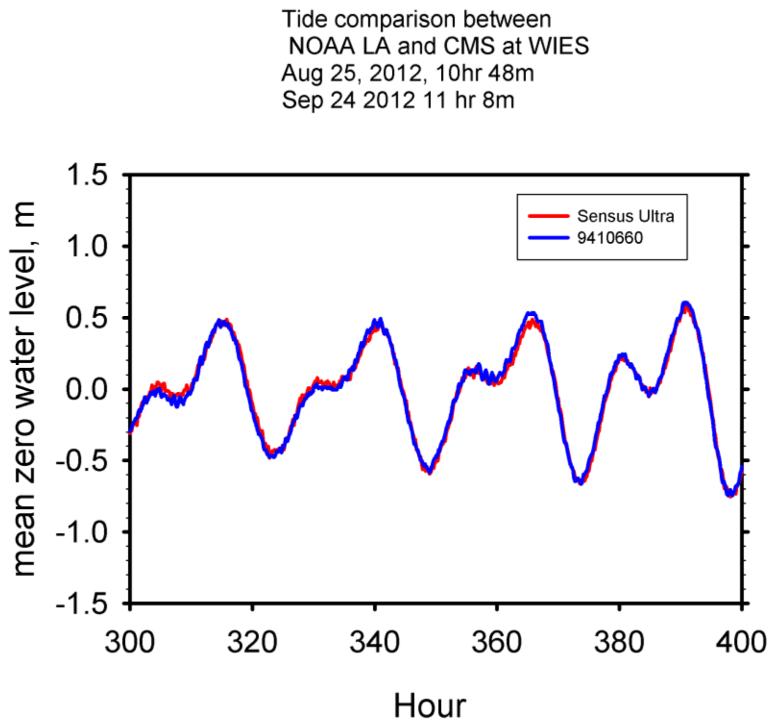

Figure 3. 100-hour comparison.

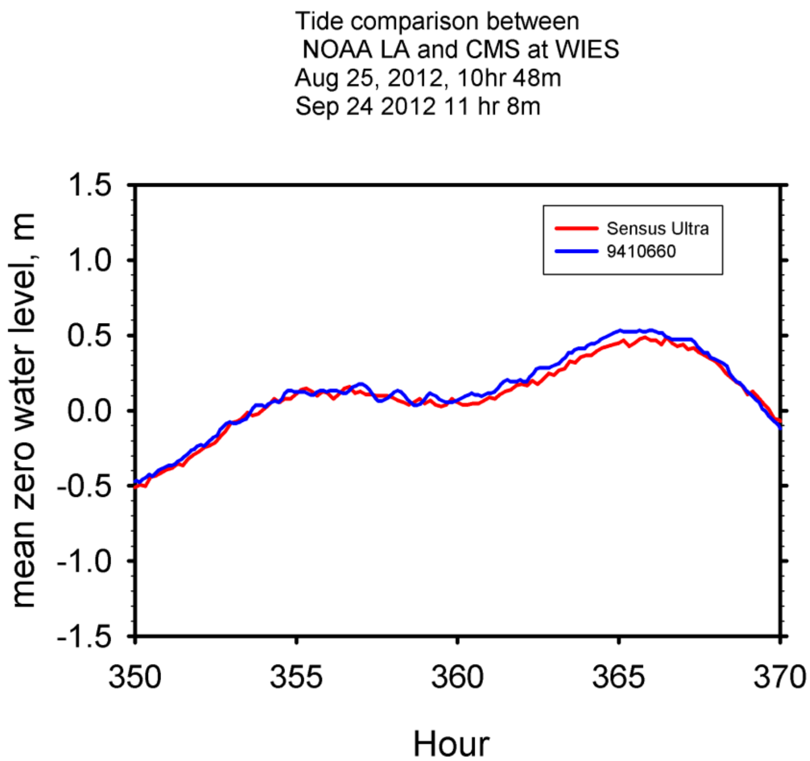

Figure 4. 20-hour comparison.

Power-Spectral Analysis

Power spectral analysis can detect subtle sensor responses. We computed and compared power spectral densities (PSDs) for the SU, Los Angeles and San Diego harbors' data. We computed the spectrum by first decimating the SU data to 6 min samples, the same sampling frequency of the NOAA data. Using data for the three stations covering the same interval, we subtracted the mean value for each station, Fourier transformed and squared the result to compute the PSD. The full spectrum for the SU data is shown in Figure 5 and an expanded view of the lower frequencies to emphasize the diurnal and semidiurnal tides, $1.1574 x 10^{-5}$ Hz and 2.3148×10^{-5} Hz, respectively, is shown in Figure 6. The full spectrum in Figure 5 indicates a curious sensor roll-off at approximately 0.0009 Hz corresponding to a period of 18 minutes or less.

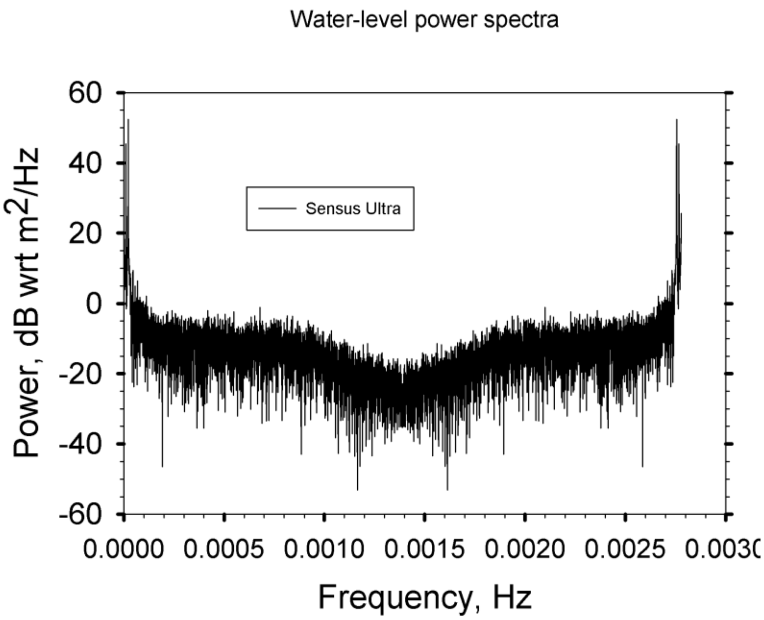

Figure 5. PSD of SU data.

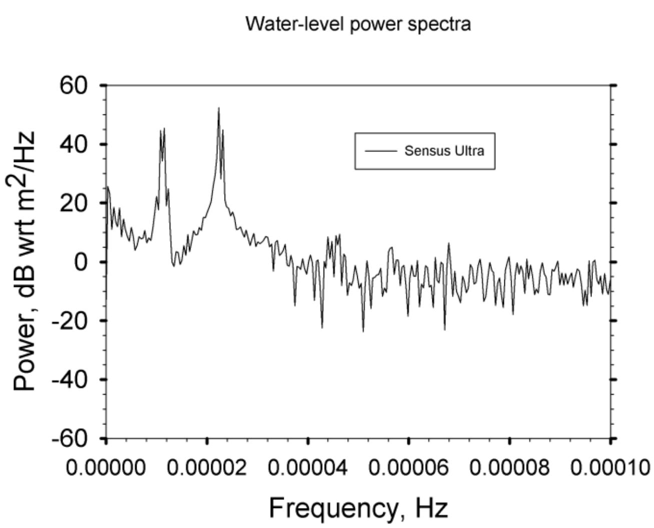

Figure 6. Expanded view of low-frequency portion of SU PSD.

Power spectra were similarly computed for the Los Angeles Harbor and San Diego Harbor data. The spectra were smoothed over 51 points and plotted together in Figure 7. Between 0.0003 and 0.0008 Hz, the SU spectrum is approximately level at -10 dB. If we take this as the noise floor, then the noise yields the uncertainty of 0.0167 m slightly larger than the value listed in Table 1. By comparison, the NOAA spectra have a noise floor of -20 dB, yielding an uncertainty of 0.005 m. The frequency roll-off in the SU spectrum imply that high-frequency, 0.0014 Hz, tidal modulations could be measured at 1/3 their true amplitude.

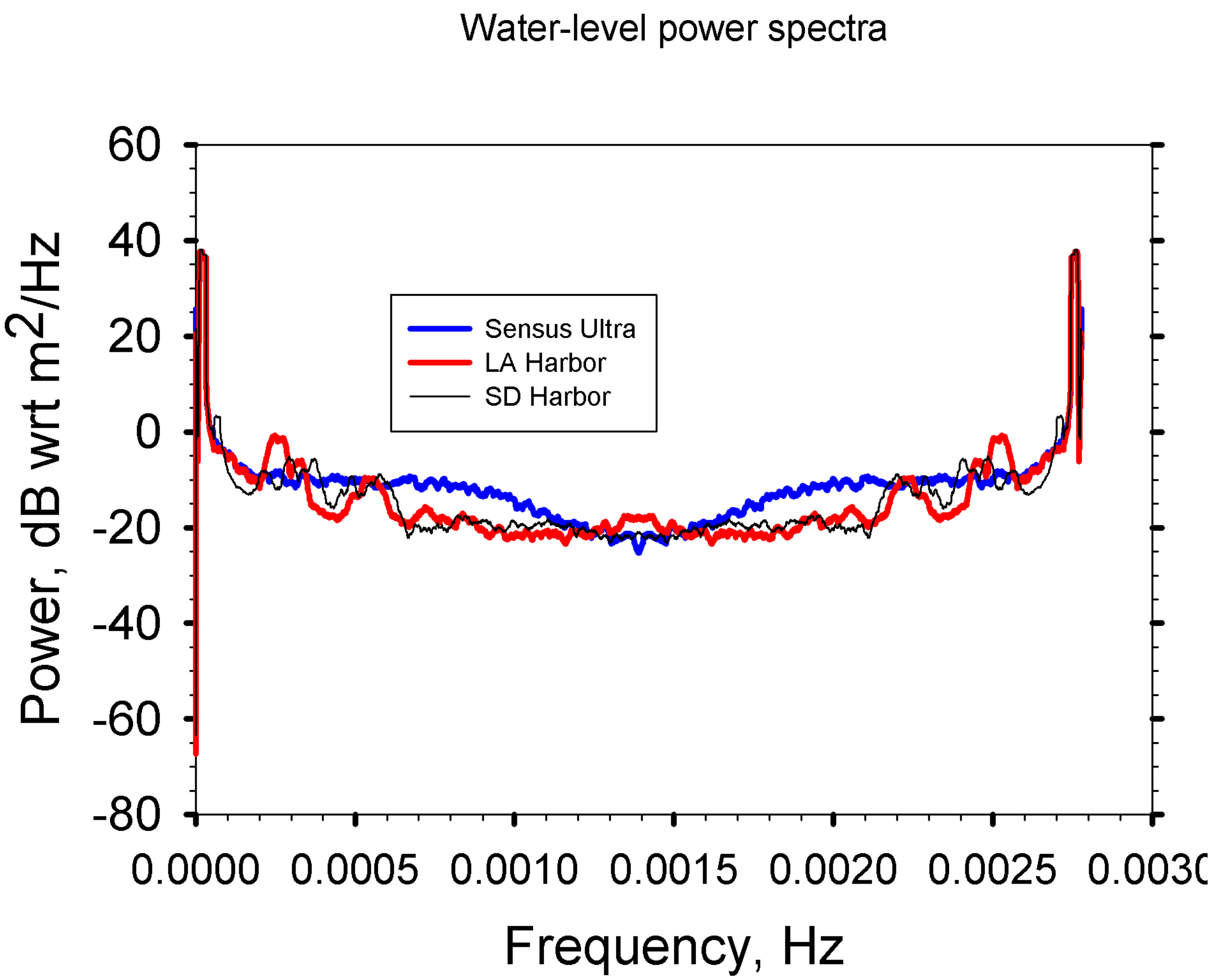

Figure 7. Smooth LA, SD and SU power spectral densities.

The semidiurnal region of the smoothed spectra is shown in Figure 8. We find that the San Diego semidiurnal tide is largest, followed by the Los Angles tide and then the SU measured tide, all within 0.5 dB of each other. We expect the tide at WIES where the SU was deployed to be the least as it farthest from the continent, though we have no quantitative information on how much less it should be. The peak differences translate to about a 6% difference in tidal height between San Diego and WIES and a 3% difference between Los Angeles and WIES and also Los Angeles and San Diego.

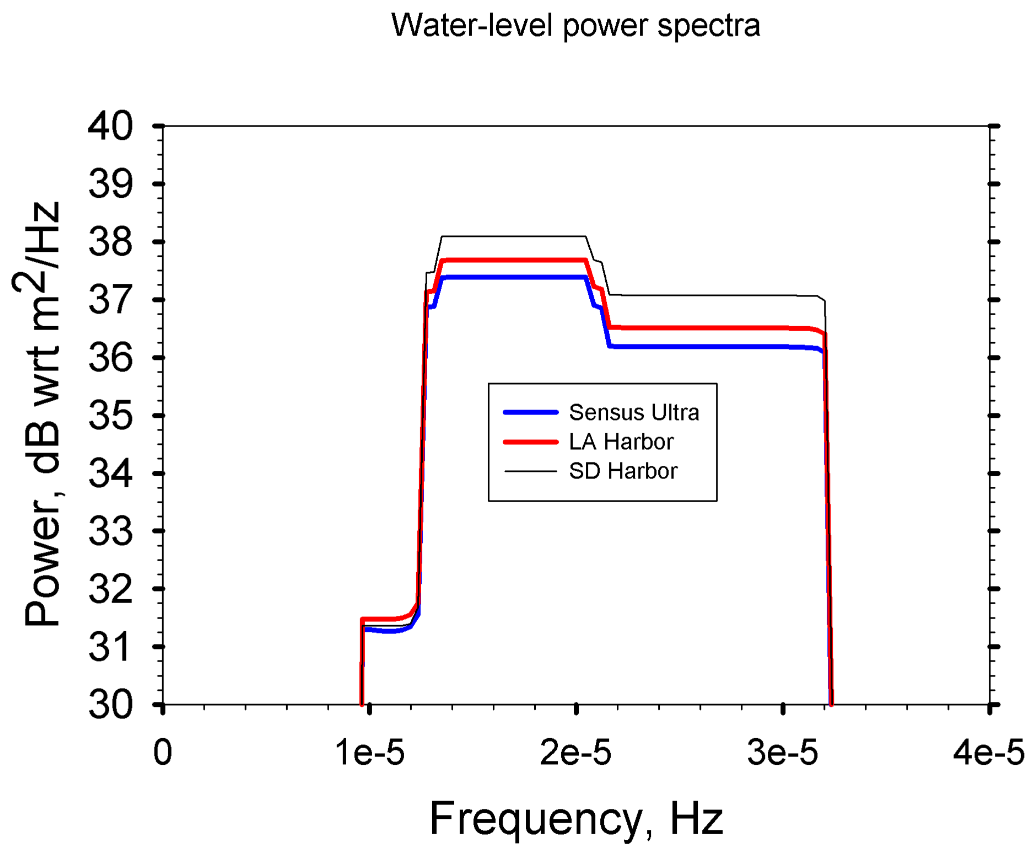

Figure 8. Comparison among LA, SD and SU.

Summary

We conclude that the SU and its deployment method meets the requirements of the CMS for tidal data.