Testing & Evaluation Report:

Origin 600: Characterizing Ocean Currents and Waves for Coastal Resilience and Ecosystem Function

May 2026

Sonardyne Origin 600 Test and Evaluation: Coupling Acoustic Doppler Current Profiler measurements of currents and surface waves with biogeochemical monitoring at the head of Monterey Submarine Canyon

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Introduction

Knowledge of ocean current patterns and surface wave conditions is important for a wide range of applications in the marine environment. Currents and associated mixing processes deliver nutrients to the surface layers of the ocean, sustaining photosynthetic organisms at the base of marine ecosystems. Currents and surface waves affect the structural integrity, for example, of offshore wind farms and erosional processes along coasts and beaches. Acoustic Doppler Current Profilers (ADCPs) are a versatile technology for obtaining data on waves and ocean currents.

ADCPs use acoustic waves to collect data on water velocity at different levels throughout the water column. Transducers on the ADCP transmit a series of acoustics transmissions, or “pings”, and use the frequency of the sound scattered back to the instrument to calculate water velocity. Data from these pings can be averaged over time to provide information on persistent currents and further processed to provide information on faster motions associated with waves and turbulence.

ADCP technology is well established, yet is continually advancing. The Sonardyne Origin 600 ADCP is an ‘all-in-one’ unit ADCP with an integrated acoustic modem and onboard Edge data processing. The latter works by implementation of a data processing algorithm or ‘app’, and Sonardyne have developed a series of core apps that cater to some typical ADCP use cases. The Waves app calculates a variety of wave metrics, including heights, periods and directional spectra, outputting as a National Marine Electronics Association (NMEA) format string inclusive of background currents information. The QARTOD-QC app performs the series of tests dictated by the Quality Assurance of Real-Time Oceanographic Data (QARTOD; U.S. Integrated Ocean Observing System, 2020) analysis standard for computation of ADCP data quality metrics, outputting in summary via NMEA string or in more detail via a .csv file. The Origin 600 is

Observing System, 2020) analysis standard for computation of ADCP data quality metrics, outputting in summary via NMEA string or in more detail via a .csv file. The Origin 600 is capable of running multiple sampling schedules simultaneously and recording in a high-fidelity A-gram format, which allows for more detailed onboard data storage than the traditional PD0 format.

The technology hypothesis is that ADCP is able to resolve the vertical structure of currents associated with internal waves at the head of a submarine canyon, while simultaneously measuring the characteristics of surface waves.

Methods

The primary objective of the evaluation was to deploy the Origin 600 ADCP in a location of known strong internal wave activity at the head of the Monterey Submarine Canyon. By deploying the instrument near a long-term shore station monitoring system at the Moss Landing Marine Labs seawater intake, the ADCP evaluation was designed to provide new information on currents that are associated with strong variability in biogeochemical parameters such as nitrate, pH and dissolved oxygen. A secondary objective was to obtain a time series of surface wave parameters that could be used to evaluate operational nearshore wave models in a region of complex bathymetry and assess their utility in sediment transport applications. A deployment period of approximately one month was chosen to sample numerous internal wave events, which occur twice per day with the semidiurnal tidal cycle, and a range of regional wind conditions which are known to modulate the strength and propagation characteristics of the internal waves near the head of the Monterey Submarine Canyon (Walter and Phelan 2016) and the surface wave field.

The ADCP was deployed 20 m to the southwest of the Moss Landing Marine Labs (MLML) seawater intake at the head of the Monterey Submarine Canyon (Fig. 1). The location was chosen for its proximity to this long-term oceanographic monitoring site. The head of the canyon is the site of strong internal wave variability (Shea and Broenkow 1982, Walter and Phelan 2016). The ADCP was deployed from March 27 through May 1, 2025 (35 days total).

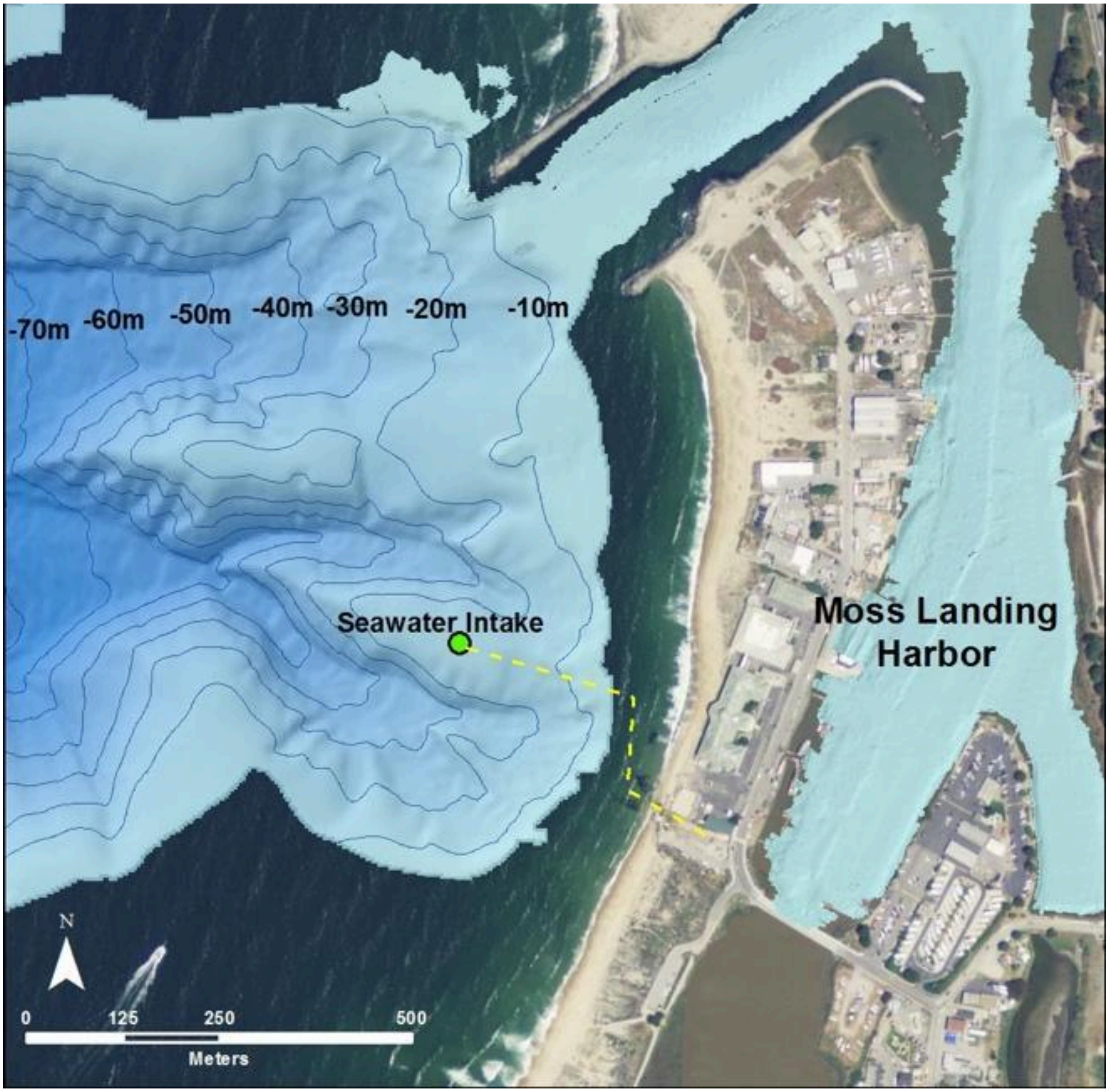

Figure 1. Location of the MLML seawater intake pipes relative to the Monterey Submarine Canyon head and Moss Landing Harbor. The ADCP was deployed 20 m to the southwest of the seawater intake.

The instrument was configured to collect observations of 1) average currents at different vertical positions throughout the water column every 30 minutes (Schedule A), and 2) surface wave characteristics (height, period and direction) every 2 hours (Schedule B).

To address the primary scientific goal of the deployment, Schedule A was designed to resolve current variability associated with internal waves generated by the semidiurnal tide (12.42 hour period) over a range of wind and background stratification conditions during the spring upwelling season. The instrument was programmed to sample at 1 Hz for three minutes every 30 minutes, saving in both PD0 and A-gram formats. The bin size for the PD0 format was set to 0.6 m, giving a theoretical noise floor of 2.6 mm/s for the average current velocity.

Schedule B was designed to achieve the secondary goal of obtaining surface wave characteristics. To acquire enough data to calculate wave statistics, the instrument was programmed to sample at 4 Hz for 20 minutes. To ensure that the instrument had enough internal battery life for the entire deployment, these measurements were acquired every 2 hours. A 5-minute offset was applied to Schedule B to avoid overlap of the two sampling schedules. A-gram bin size was 12mm for both schedules. The more intensive Schedule B observations could also be used to calculate turbulence parameters such as Reynolds stress (e.g. Palóczy et al., 2021), but such detailed analyses are beyond the scope of this report.

The ADCP was mounted on a Mooring Systems, Inc. bottom tripod and deployed from the R/V Sheila B (Figure 2). The deployment location was chosen due to its proximity to the MLML seawater intake, as well as flat and stable bottom topography based on prior bathymetric surveys performed by MLML (Peliks 2025) and pre-deployment observations from scientific divers. About a month before deployment of the ADCP, on February 27, 2025, scientific divers secured five Onset Watertemp Pro temperature loggers sampling at 5-minute intervals onto a line marking the position of the seawater intake at different positions throughout the water column. On March 27, the ADCP tripod was lowered to the bottom using the A-frame and hydraulic capstan on the Sheila B. A temporary float was connected to the deployment line to mark the location of the tripod on the bottom. Scientific divers descended to the bottom, checked that the ADCP was level and functioning, disconnected the surface line, and connected a negatively buoyant ground line from the tripod to the seawater intake structure to aid with recovery.

Recovery of the tripod occurred on May 1, 2025. Scientific divers descended to the bottom, attached a line to a temporary surface float, disconnected the ground line connecting the tripod to the seawater intake, and recovered the temperature sensors. The tripod was then lifted aboard with the A-frame and capstan on the Sheila B. All PD0 and A-gram data were uploaded to a shared Google Drive, along with data from the temperature loggers.

Data analyses were conducted on CSV files generated from the raw A-gram format. Average current velocity (speed and direction) from the Schedule A sampling were provided at five depths which closely matched the vertical positions of the temperature sensors in the water column from 1.6-10.9 meters above bottom (mab). Current speed and bearing (the direction that the flow is moving towards, measured clockwise from North) were converted to eastward and northward components of velocity after adding a 12.65° offset between magnetic and true North in post-processing.

Figure 2. Practice dock-side deployment of the ADCP tripod on the R/V Sheila B.
Photo: T.Connolly / MLML

Ancillary data were acquired from the MLML public data portal. These data were analyzed to demonstrate internal wave effects on nitrate concentrations and to derive a statistical relationship between temperature and density for stratification calculations. Unfortunately, seawater intake data through April 22 are not usable due to an unrelated blockage of the intake pipes, which required cleaning by a commercial dive team.

The potential for turbulent mixing driven by vertical shear of the currents was assessed through analysis of the gradient Richardson number, which quantifies the destabilizing effect of current shear (measured by the ADCP) compared with the stabilizing effect of density stratification (inferred from temperature loggers and seawater density from the seawater intake). The current shear is quantified as $S = \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}$ where u and v are the eastward and northward components of velocity, respectively, and $\frac{\partial}{\partial z}$ represents the vertical gradients calculated from different discrete vertical positions in the water column. Stratification is quantified as the buoyancy frequency $N = \sqrt{-\frac{g}{\rho_o}\frac{\partial \rho}{\partial z}}$ where g is gravitational acceleration, ρ_o = 1024.6 kg/m^3 is a constant background density, and ρ represents seawater density calculated from observed temperature from temperature loggers and a linear regression between density and temperature at the seawater intake. The gradient Richardson number is then calculated as $Ri = N^2/S^2$, with values less than 0.25 indicating conditions where generation of turbulence through shear instability is possible.

The warming or cooling over time associated with internal wave motions is quantified by the change in temperature over time, $\Delta T/\Delta t$. The change in temperature ΔT is calculated as the finite difference in temperature values over a time period of Δt = 3 hours.

Wave characteristics from Schedule B were provided in a separate CSV file. Analyses of wave data focused on significant wave height, average period and average direction. Isolated spikes in significant wave height were removed based on differences between the original data and 3-point running median filter. To demonstrate an application, these data are compared with output at 20 m depth from the nearest transect in the Modeling and Prediction System (MOPS) operational nearshore wave model distributed by the Coastal Data Information Program (CDIP) (O'Reilly et al., 2016).

Results

Data were successfully recorded during the entire deployment period. Current speeds varied between 0-0.6 m/s and higher speeds were observed closer to the surface (Figure 3). The most common observed current directions are towards the south at approximately 180° and towards the north at approximately 0° (Figure 4).

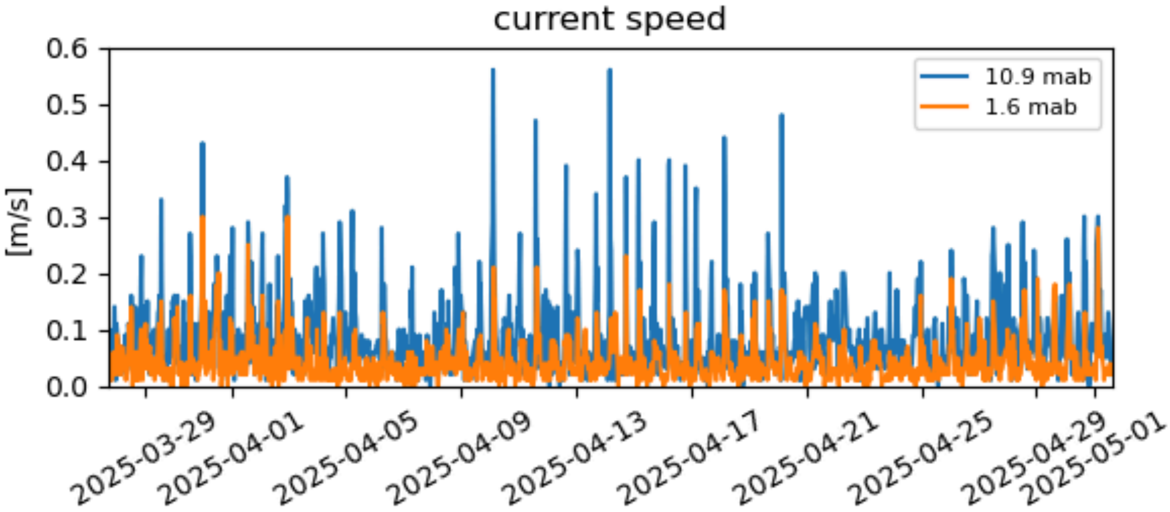

Figure 3. Current speeds near the bottom (1.6 mab, orange) and surface (10.9 mab, blue) throughout the deployment.

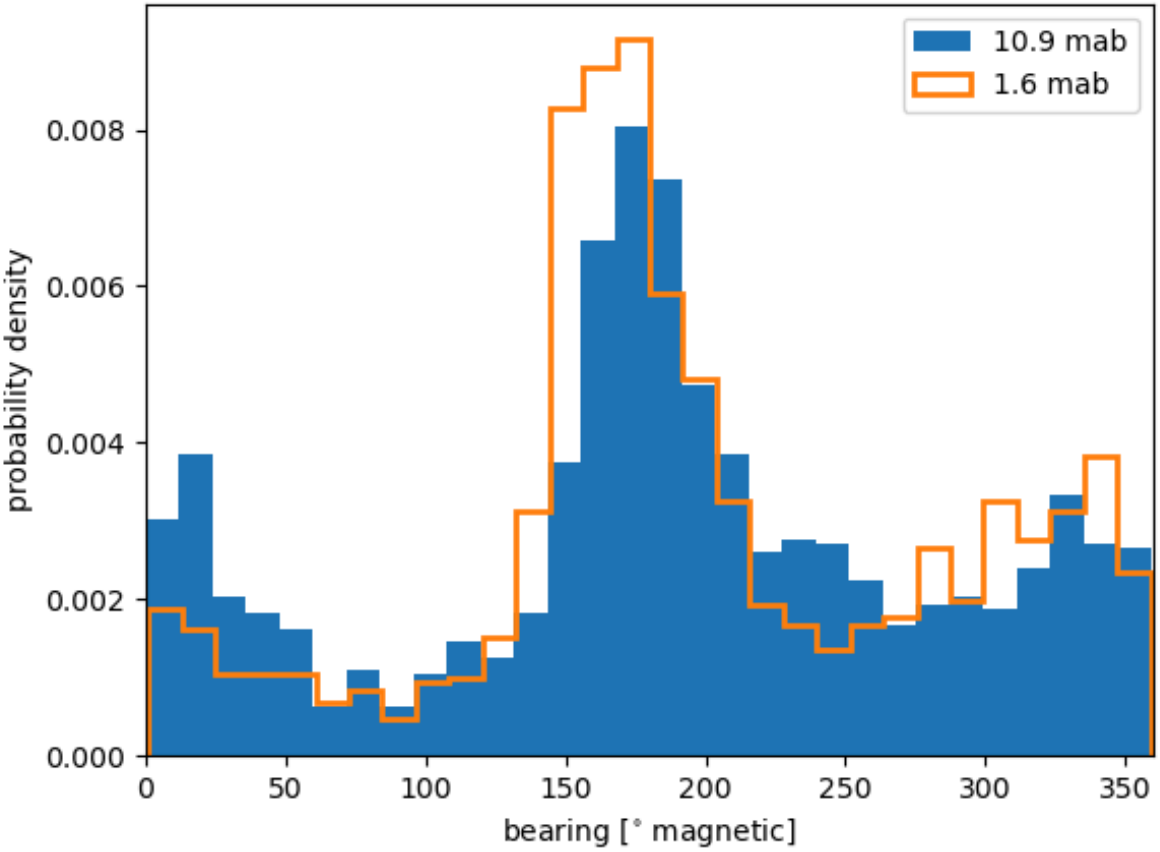

Figure 4. Probability distributions of current direction near the bottom (1.6 mab, orange) and surface (10.9 mab, blue) throughout the deployment. These directions represent the direction the current is flowing towards, clockwise from magnetic north (add 12.65° for directions relative to true north).

A closer look at a four-day period at the end of the deployment (April 27-May 1) shows that the frequent oscillations between high and low currents speeds are due to the influence of internal tidal currents. Semidiurnal (twice per day) oscillations are observed in nitrate at the MLML seawater intake, temperature throughout the water column, and current velocity recorded by the ADCP (Figure 5). High nitrate concentrations correspond with periods of cold water near the bottom. As the water cools and nitrate concentrations increase, temperature stratification develops throughout the water column. Periods of relatively slow cooling are followed by abrupt warming and a transition to weaker stratification and low nitrate concentrations. The ADCP data show that the abrupt warming events are typically preceded by bursts of northeastward velocity, and often followed by rapid transitions to southward flow. In contrast, the slow cooling periods are associated with relatively weak velocities.

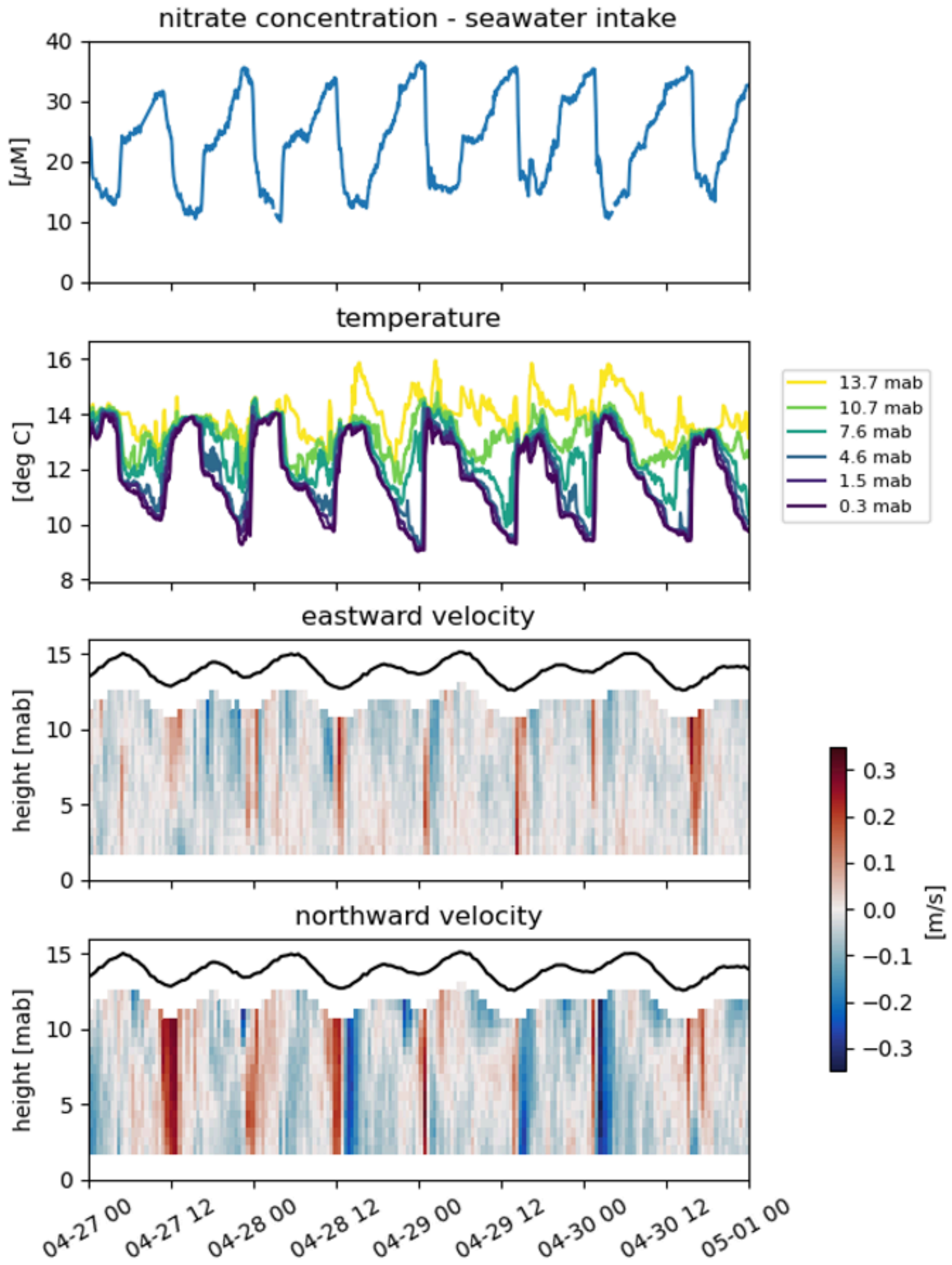

Figure 5. Time series of nitrate at the MLML seawater intake (first row), temperature observed at six locations throughout the water column (second row), eastward velocity (third row) and northward velocity (fourth row).

Differences in velocity between vertical levels (Figure 5, bottom rows) indicate the presence of current shear, which can destabilize the water column and create turbulence. Active turbulent mixing associated with the internal waves could be contributing to the weak stratification observed during the warm phases of the internal tide. This possibility is further investigated through analysis of the gradient Richardson number, Ri (described above in the methods) near the bottom between 1.6 and 4.7 mab. Low values of Ri < 0.25 indicate that current shear is strong enough to overcome stratification and create turbulent mixing (Figure 6). Comparing trends in Ri with the change in temperature over time, $\Delta T/\Delta t$, indicates that these low values mostly occur during the warming phase of the internal tide when $\Delta T/\Delta t$ is positive. During cooling periods (negative $\Delta T/\Delta t$), strong stratification and weak shear combine to suppress this mechanism of turbulence generation. These patterns of Ri variation are broadly consistent with past observations of "non-canonical" nearshore internal bores in southern Monterey Bay (Walter et al., 2012).

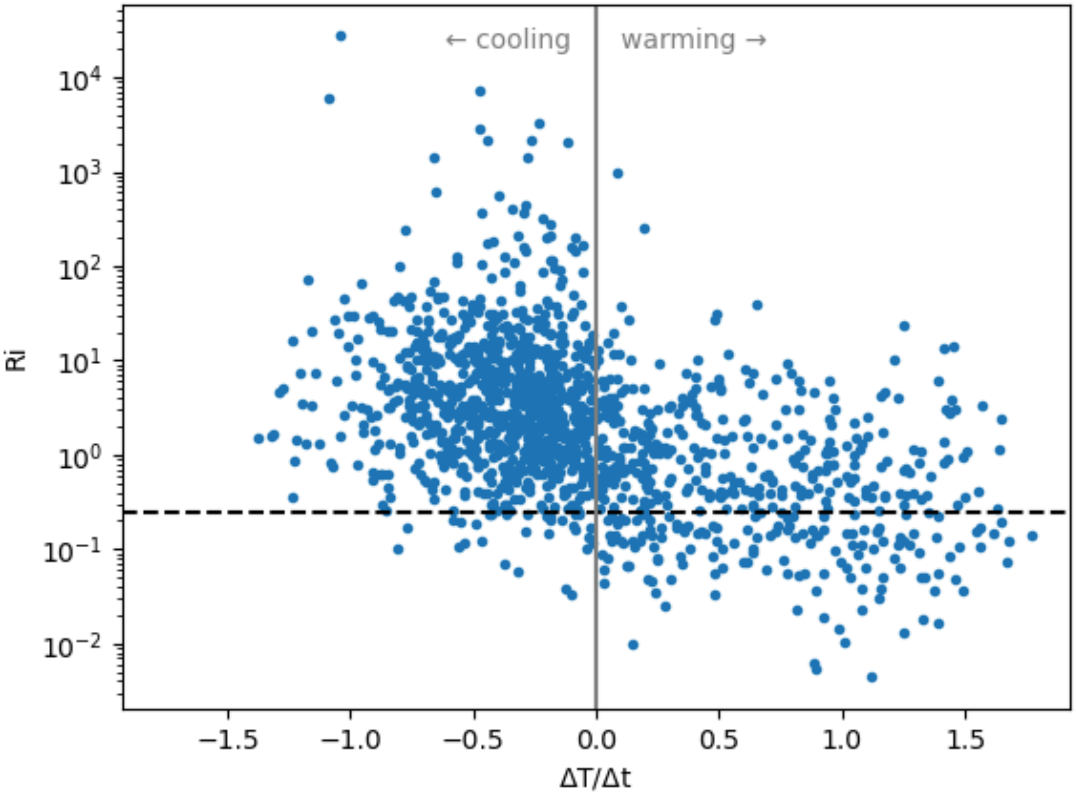

Figure 6. Values of the gradient Richardson number, Ri, compared with the change in temperature over time, $\Delta T/\Delta t$ (units of °C per hour). The horizontal black dashed line indicates Ri = 0.25. Values below this line indicate conditions favorable for shear-driven turbulence. The vertical gray line indicates $\Delta T/\Delta t$ = 0 at 1.6 mab. Higher values indicate that the water is warming over time, while lower values indicate that the water is cooling over time.

Although the primary scientific objective of this deployment was to resolve tidally driven internal wave motions (periods of about 12 hours), the ability to program multiple schedules allowed for co-located observations of surface waves with much shorter periods of less than 20 seconds. Several events with significant wave heights of 1-2 m were observed during the deployment (Figure 7). Average wave periods range from 3-10 s and wave directions are generally from the west (about 270°) aside from one southwesterly event early in the deployment. Since the beach faces a direction of 284° (the shore normal direction), these waves would tend to drive sediment transport towards the north-northwest along the coast, towards the harbor mouth and the center of the canyon axis. These observations are qualitatively consistent with known patterns of sediment transport and the idea that the canyon acts as a sink for sediment originating in the southern portion of Monterey Bay (Thornton 2016). Comparison with the CDIP MOP model indicates that this operational model does reasonably well in reproducing the height, period and direction of the observed waves during most time periods except the one southwesterly event.

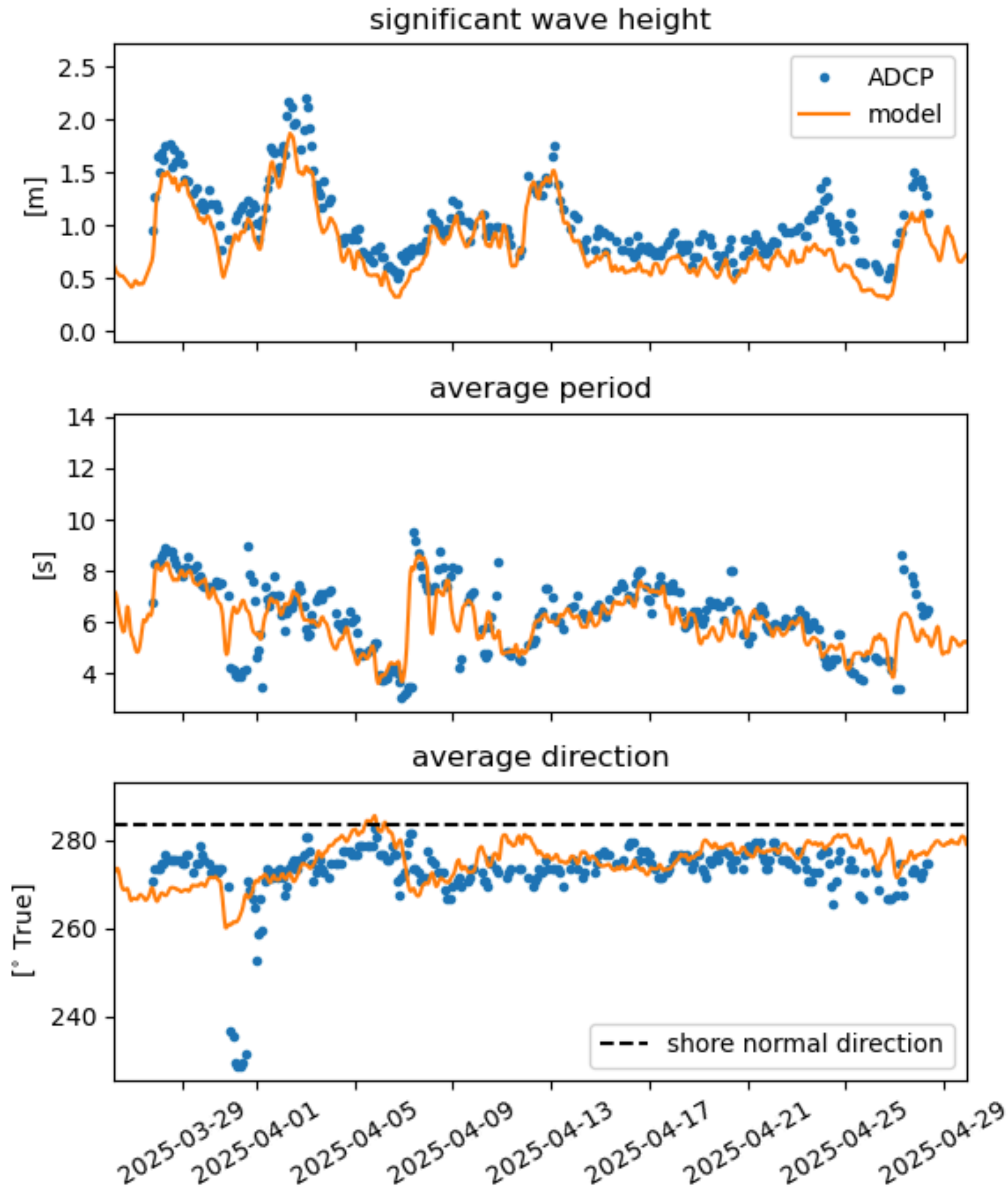

Figure 7. Significant wave height (top row), average wave period (middle row) and average wave direction (bottom row) throughout the deployment as measured by the Origin 600 ADCP (blue) and as generated by the CDIP MOP model (orange).

Overall, the technology performed as expected. The instrument was successful in collecting useful data on internal waves and surface waves at the head of Monterey Submarine Canyon. Several unique aspects of this particular ADCP unit aided in the operation and scientific analysis:

- The large data capacity (1 TB) and proprietary A-gram format allows for adjustment of vertical bin spacing in post-processing instead of being confined to a fixed choice before deployment. This is useful in the gradient Richardson number calculations (Fig. 6) where past experience has shown that too small of an *a priori* choice can lead to noisy results.
- The ability to program multiple schedules allowed for study of two different physical processes: internal waves with periods of about 12 hours and surface waves with periods of about 10 seconds.
- The rechargeable battery eliminated the need for user replacement of battery packs and associated concerns with o-ring damage and flooding.

Note that we did not test the ability to retrieve data with an acoustic modem during deployment due to a short deployment window.

Discussion

From a scientific perspective, the technology was successfully used to collect new data on currents associated with internal waves near the head of the Monterey Submarine Canyon. An interesting result is the north-south orientation of the velocity bursts associated with the rapid warming phase of the internal waves, directed predominantly parallel to shore. These patterns indicate that the internal wave motions are strongly influenced by the complex local bathymetry (Figure 1) and facilitate exchange of water between the canyon and the continental shelf, consistent with prior velocity observations on the north side of the canyon head (Walter and Phelan, 2016). The results provide further support for the idea that shear-driven mixing is an additional mechanism for nutrient transport during warming phases, as suggested by Walter and Phelan (2016).

The physical dynamics of nutrient transport are ecologically important since internal waves can provide a sustained source of localized nutrient delivery to the nearshore portions of Monterey Bay during time periods when wind-driven upwelling is weak. The orientation of the currents observed during this study suggest that internal waves exchange water with the continental shelf to the south, supplying pulses of nutrient-rich water during cooling phases and drawing well-mixed and nutrient-poor water back into the canyon during warming phases. It is anticipated that these data will be useful in future studies of nutrient dynamics and cross-shelf exchange in the nearshore regions of Monterey Bay, and in interpreting long-term monitoring data collected at the MLML seawater intake.

The deployment also provided information on surface waves, which are also influenced by the complex canyon bathymetry. The data indicate that an operational wave model captures the important aspects of the wave field and support its use in future studies of sediment transport and erosion processes in the nearshore region near the canyon head (e.g., Peliks, 2025).

User feedback

The findings of this evaluation were shared with potential ADCP users and physical oceanographers and feedback was collected to better understand the use-cases of the Origin 600 ADCP. In general, the ability to collect both ocean current profiles and surface waves provides coastal engineers the unique ability to characterize nearshore coastal dynamics relating to both sediment transport and coastal resilience. Physical forces present continuous impacts on coastal infrastructure (e.g. jetties, piers, bridges, etc) and natural resources (e.g. cliffs, reefs, beaches). Thus, using tools to accurately characterize, model, and forecast future impact scenarios with additional climate-driven impacts aids coastal managers in decision-making. Likewise, better understanding of the physical oceanography along the coastal fringe lends support to along-shore and cross-shore sediment transport, accretion, and erosion. Lastly, as in the case of the Monterey Canyon head, oceanographic dynamics can promote biological hotspots with deep, nutrient-rich water being advected closer to the surface driving primary productivity.

End users highlighted several features of the Origin 600 as meaningful advances over conventional ADCP deployments. The ability to run multiple simultaneous sampling schedules was viewed as a valuable improvement, addressing the longstanding trade-off between sampling frequency, battery endurance, and the timescales of the processes being studied. End users noted that the large onboard memory capacity compares favorably with conventional ADCPs. Additionally, the integrated acoustic modem with the option to apply QARTOD quality control was identified as particularly valuable for a range of stakeholders and for event-driven response scenarios. The ability to spot-check data in the field while the instrument remains deployed presents a major operational upgrade relative to conventional ADCP systems. Finally, users appreciated the function of being able to adjust vertical bin spacing - post-deployment - enabling users to calculate velocities that better match the process of interest.

Take-home messages for information end-users and technology users

- The Sonardyne Origin 600 was successfully used to collect data on internal waves and surface waves at the head of the Monterey Submarine Canyon.
- The warming phases of the internal waves are associated with strong currents that likely drive vigorous exchange with the nearby continental shelf and turbulent mixing.
- Additional measurements of surface wave characteristics were compared with an operational wave model, with potential applications to future studies of sediment transport.

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References

O'Reilly, W. C., C. B. Olfe, J. Thomas, R. J. Seymour, & R. T. Guza (2016). The California coastal wave monitoring and prediction system. *Coastal Engineering*, *116*, 118-132. https://doi.org/10.1016/j.coastaleng.2016.06.005

Palóczy, A., J. A. MacKinnon, and A. F. Waterhouse (2021). Subtidal to supertidal variability of Reynolds stresses in a midlatitude stratified inner shelf. *Journal of Physical Oceanography* 51.4: 1091-1111. https://doi.org/10.1175/JPO-D-20-0140.1

Peliks, M. (2025). Assembly and Field Testing of a Shallow-Water Multibeam System for High-Frequency, High-Resolution Bathymetric Surveys: A Case Study at Monterey Canyon Head. *Moss Landing Marine Labs Master's Thesis*. https://digitalcommons.csumb.edu/caps_thes_all/1990

Shea, R. E., & W. W. Broenkow (1982). The role of internal tides in the nutrient enrichment of Monterey Bay, California. *Estuarine, Coastal and Shelf Science*, *15*(1), 57-66. https://doi.org/10.1016/0272-7714(82)90036-1

Thornton, E. B. (2016). Temporal and spatial variations in sand budgets with application to southern Monterey Bay, California. *Marine Geology*, *382*, 56-67. https://doi.org/10.1016/j.margeo.2016.10.004

U.S. Integrated Ocean Observing System, 2020. QARTOD - Prospects for Real-Time Quality Control Manuals, How to Create Them, and a Vision for Advanced Implementation. 22 pp. DOI: 10.25923/ysj8-5n28, https://cdn.ioos.noaa.gov/media/2020/10/Prospects-for-RT-QC-manual_5.2.pdf

Walter, R. K., Woodson, C. B., Arthur, R. S., Fringer, O. B., & Monismith, S. G. (2012). Nearshore internal bores and turbulent mixing in southern Monterey Bay. *Journal of Geophysical Research: Oceans*, *117*(C7). https://doi.org/10.1029/2012JC008115

Walter, R. K., & P. J. Phelan (2016). Internal bore seasonality and tidal pumping of subthermocline waters at the head of the Monterey submarine canyon. *Continental Shelf Research*, *116*, 42-53. https://doi.org/10.1016/j.csr.2016.01.015

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