

Deployments of a Deep Submergence Gravimeter

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Abstract—In March 2026, a custom deep-sea gravity sensor was mounted to AUV Sentry and deployed to a 5600-meter depth, operating continuously at constant near-bottom altitude. This integration presents the first AUV-mounted system capable of routine dense near-source gravity mapping of the deep ocean floor. We discuss the technologies developed which enable this, and describe individual deployments. We describe preliminary sensor findings, and outline more comprehensive analysis and engineering for future work.

Index Terms—marine gravimetry, autonomous underwater vehicles, near-bottom geophysics, sensor integration, deep-sea instrumentation, potential fields.

I. INTRODUCTION

AUV-mounted near-bottom gravity data collection enables the detection of density changes in sub-seafloor strata, which may be naturally occurring (mineral deposits, hydrothermal fluids, tectonic features) or otherwise (shipwrecks, pipelines, unexploded ordnance). In contrast to satellite- or ship-mounted devices, sub-sea data collection provides superior resolution of fine-scale features (e.g., in [1], 10-20 km half-wavelength features are resolved, while we obtain better than 100 meters with some filter lengths). Towed systems “possess a number of deficiencies” [2] stemming from their need to remain at a safe altitude and their dependence on the ship.

Prior subsea systems have not, to date, provided the complete set of features needed for deep submergence operation (see Section II): operation at depth with reliable underwater navigation, continuous collection, and reliability under challenging thermal conditions. High-precision gravimetric data have been collected from stationary positions, but this sacrifices spatial data coverage.

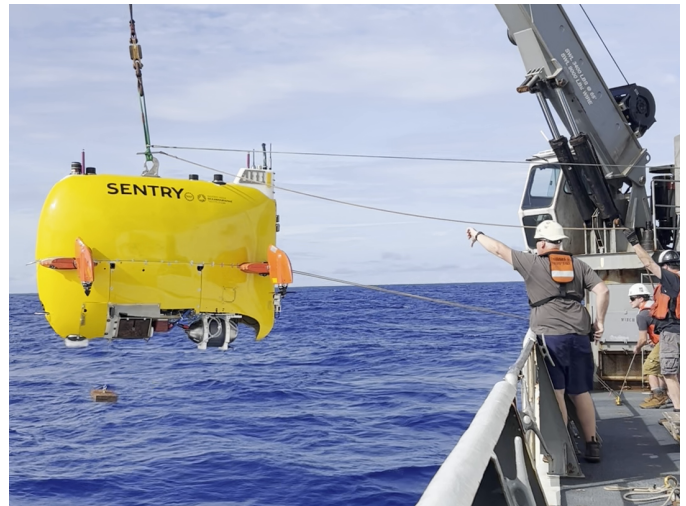


Fig. 1. Sentry being deployed from R/V Thomas G. Thompson. The gravimeter (the DGS AUV-1) is visible as the metal housing mounted to the bottom right.

This paper reports the integration of a custom gravimeter, the DGS AUV-1, with AUV Sentry, its six dives lasting over 24 hours each, and preliminary data. Thus, our contributions are:

- 1) Design and integration of a gravimeter for use at 6000 meters, which is shown to operate at 5600 meters, exceeding the depth rating of prior continuous-operation AUV systems;
- 2) Six at-sea deployments, totaling 186.8 hours in operation, described alongside their operational procedures and findings;
- 3) Preliminary characterization and findings from data processing; and
- 4) A path towards routine facility operation of near-bottom gravimetry for the scientific community.

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II. RELATED WORK

Station-Based Seafloor Gravimetry. Collecting gravity data from a moving platform introduces challenges stemming from platform acceleration. To compensate, researchers have made high-precision seafloor gravity measurements from stationary positions, at the cost of spatial coverage. In [3], the human-occupied vehicle (HOV) Alvin carried a LaCoste-Romberg gravity meter to twenty on-bottom stations along a profile over the East Pacific Rise, reporting a standard error of approximately 0.3 to 0.4 mGal.

On ROVs, the ROVDOG system [4] adapted a Scintrex CG-3M gravimeter (originally intended for on-land use) into a pressure housing with motorized leveling gimbals and quartz pressure gauges for depth compensation. Aided by ROV deployments to concrete seafloor benchmarks, which must be reoccupied to within 3 cm, the system achieved a repeatability of 0.019 mGal using three sensors operated simultaneously. Follow-on work [5] characterized the error budget across repeated surveys and recorded seafloor hydrostatic pressure alongside gravity to constrain benchmark height changes, reporting a time-lapse uncertainty of approximately $3.6 \mu\text{Gal}$. The CG-3M-based housings are rated to 700 or 4,500 meters depending on the pressure case.

These works provide the highest standard of precision for subsea gravimetry, though on a different measurement: static reoccupation repeatability rather than underway noise. However, they sacrifice spatial resolution, as measurements are viable only where a full deploy-and-wait procedure can be followed. As a consequence, surveys or other tasks requiring spatial continuity are not viable. We target this case, and so we seek the highest possible accuracy without sacrificing continuous operation and mobility.

Operation from Crewed or Towed Vehicles. Continuous operation while underway removes the coverage limitation of stationary methods but introduces motion-related error. In another use of HOV Alvin for gravimetry, [6] collected near-continuous near-bottom gravity using a Bell BGM-3 by sampling every twenty to thirty minutes along 8-kilometer transects, with a repeatability of approximately 0.3 mGal. However, the authors note that their resolution was limited by the precision of depth readings from which they computed vertical acceleration.

DVL-aided corrections were applied to subsequent surveys using towed vehicles [7], but vehicle motion while underway remains a limiting factor for crewed platforms. Similarly, towed vehicles inherit noise from the motion of their host ship, must remain at high altitudes for safety, and tie up ship resources for the full length of the survey [2].

AUV-Based Gravimetry. AUV-based deployments have several desirable properties that give them the potential to outperform HOVs, ROVs, and tow frames for subsea gravimetry, as they are better suited for the monotony and endurance of a long-duration survey [2]. Further, measurements of vehicle dynamics highlight AUV Sentry in particular as a desirable platform [8] for this work, thanks to its inherent stability. An

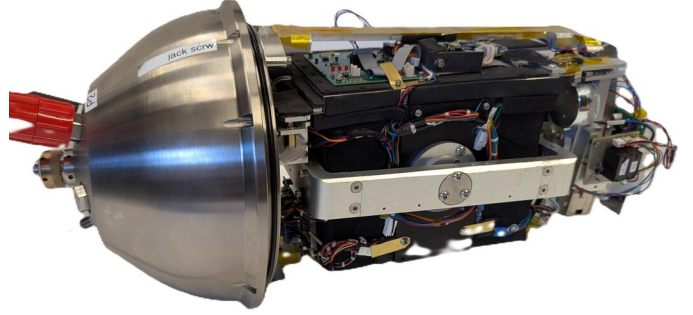


Fig. 2. The DGS AUV-1 Gravimeter, out of its housing.

early attempt to use Sentry for this class of survey encountered inaccuracies from thermal instability [2], and although a solution was developed, it was never validated at sea.

A comparable work prior to our system [9] involved mounting an existing gravimeter within a pressure housing for use aboard AUV Urashima, which completed 11 dives. Like us, they survey at constant speed and altitude and compensate for vertical acceleration using depth measurements from pressure. After these corrections, they report an rms crossover difference of 0.1 mGal. However, their pressure housing is noted to have challenging dimensions to integrate, while we repurpose an existing Sentry housing; they operate only at 1550 meters depth in contrast to our 5600 meter depth and thus avoid many of the thermal issues we encounter; and they are rated to a maximum of 4200 meters while we target near full-ocean depth.

III. DEVICE AND INTEGRATION

A. Gravimeter.

The DGS AUV-1 is custom-built for deep subsea gravimetry by Dynamic Gravity Systems (DGS), based on their AT1M series of shipboard gravimeters (Figure 2). Thus, it inherits a self-leveling 2-axis gimbal and gyro-controlled scalar-specific force meter, with no ITAR-controlled components. Ideally, this system can provide a full global range of 20,000 mGals with 0.001 mGals of resolution (for actual results, see Section VI). However, modifications were necessary to fit the system in a titanium housing suited for on-vehicle use (described next), which limits the gimbal range. Analysis of the accuracy after these changes is promising, but remains ongoing (see Section VI-B).

B. AUV Sentry.

AUV Sentry is an autonomous underwater vehicle designed, owned, and operated by the National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution

(WHOI) [10]. It operates fully untethered at depths up to 6,000 meters, and is regularly deployed for a variety of scientific operations as part of the facility.

The atypical shape (vertically elongated with actuated fins) permits movement with minimal pitch or roll, even with unusual payloads. For example, while other AUVs may require 20 or even 40 degrees of pitch during standard operation, in our first deployment Sentry kept pitch within 4.25 degrees, with 99% of readings within 2.71 degrees. This makes Sentry an ideal platform for a rotation-sensitive device, further motivating NDSF interest in acquiring this gravimetric capability for the scientific community.

C. Integration.

1) *Mechanical*: A cylindrical titanium housing, approximately 9 inches in diameter, is mounted to an open bay at the underside of Sentry (see Figure 1). This housing is custom-manufactured and pressure-tested to support safe operation to a depth of 6000 meters. All components of the DGS AUV-1 fit within this housing and receive power and thermal management through endcap-mounted bulkheads.

The entire unit rests within a secondary external housing, which connects to Sentry's cooling system. While on-deck, chilled seawater cycles through this housing, running cool water over the pressure housing to maintain temperature. This prevents overheating during sea trials, and minimizes thermal shocks when deployed. This combined is then shimmed to compensate for the roll and pitch bias that Sentry may acquire.

2) *Electrical*: The DGS AUV-1 uses standard serial communications (TTL-level UART, 5v, 57600 Baud). An additional power channel (48V) powers a heater that keeps internal spring components at a precise temperature with known elastic properties (to reduce temperature-dependent error). This heat was kept connected at all times (except for brief moments when its power source was swapped) throughout the approximately month-long deployment period.

3) *Software*: AUV Sentry employs a custom open-source software architecture [11], which was extended to provide control of the DGS AUV-1 through an acoustic tether interface. The on-board INS (Inertial Navigation System, the iXBlue PHINS C5) and depth sensor (Paroscientific 8B7000-I) record acceleration and vertical position data for gravimeter post-processing. A software trigger was added to unclamp internal sensor gimbals once Sentry reached operating depth to minimize stress on the system during deployment.

IV. DEPLOYMENTS AT-SEA

The gravimeter was deployed for 6 dives totaling 186.8 hours, with 162.5 of those hours providing surveying at depth. Surveys targeted the Jurassic Quiet Zone (JQZ) in the western Pacific, which is of interest because of the seafloor's age and relatively weak seafloor magnetic anomaly records, meaning near-bottom surveys are the only viable strategy for data collection.

Each dive started with a set of calibration turns and a repeat gravity track of 250 to 800 meters in length. To maximize

survey time, we powered off non-essential sensing systems, leaving only the gravimeter, three magnetometers, and navigational sensing. Each survey therefore provided near-bottom magnetic and gravity measurements along identical tracks and altitude with a shared navigational solution. Each dive started with a transit which overlapped with itself for the starting kilometer. Survey velocity was reduced to 0.7 m/s to extend endurance. Under this configuration, deployments reached a maximum of 37.9 hours. The maximum depth achieved in this region was approx. 5600 meters, and target altitude was 65 meters.

Deployment 1: No data, intentionally. The first deployment of our work on *R/V Thomas G. Thompson*, cruise ID TN449, occurred in March 2026, and was Sentry Dive 791. The gravimeter was mounted, but the internal gimbal was intentionally left locked. This dive enabled more precise pitch measurements while operating. After recovery, pitch corrections were made by shimming the gravimeter for ideal operation. The dive ran for 29.5 hours, with 25 of those hours spent surveying.

Deployment 2: No data, unintentionally. For Sentry Dive 792, the gravimeter was mounted and unlocked for its first data-collecting deployment, but it stopped recording early in the deployment. After post-dive analysis, we found data suggesting the substantial motion experienced while deploying Sentry at sea via the shipboard crane exceeded an internal limit and put the gravimeter into a safety-locked state that prevented data collection. The dive ran for 37.9 hours, with 33 of those hours spent surveying.

After this dive, we modified two operational procedures. First, programmatic control of the gravimeter was exploited so internal clamps would remain engaged throughout deployment and descent to the operating region, becoming unclamped only once the AUV arrested the most severe motion. Second, the acoustic monitoring link was modified to provide intermittent sensor status updates and the ability to reset the sensor. Operator guidelines were updated to include remotely checking for sensor activity and triggering a reboot if needed.

Deployment 3: Data collected through the entire Sentry Dive 793, no intervention required. The dive ran for 34.8 hours, with 30.1 of those hours on-bottom conducting a survey.

Deployment 4: Data collected through the entire Sentry Dive 794. The acoustic link showed that the sensor required a reset, but this occurred during descent through the water column, so no data were impacted. The dive took 30.2 hours, with 28.8 of those hours conducting a survey.

Deployment 5: Data collected through the entire Sentry Dive 795. As with deployment 4, the acoustic link was used to determine a reset was required, and this was performed in the water column with no impact to the data. The dive took 34.3 hours, with 30.0 of those hours on-bottom conducting a survey.

Deployment 6: Data collected through entire Sentry Dive 796, but dive ended early due to unrelated circumstances. The majority of the mission was completed, and gravity data was

otherwise unaffected. Deployment 6 took 20.1 hours, with 15.6 of those hours conducting a survey.

V. PROCESSING

A. Gravity Processing Equations

The DGS AUV-1 is a scalar specific-force meter that measures the desired gravitational acceleration due to the Earth's local mass, along with acceleration from the vehicle's motion. These two sources are indistinguishable, and so inertial corrections must first be computed using Sentry's navigation sensors. The previously described INS, DVL, and depth sensors must be time-synchronized and then provide an essential source of correction. Full-field gravity can first be computed as

$$g_{FF} = g_M + \delta E_{otvos} + r_1 \frac{d^2\theta}{dt^2} + r_2 \frac{d^2\varphi}{dt^2} + CC + g_{Drift} + g_{Offset} + Tidal \quad [1]$$

Free-air gravity can then be computed:

$$g_{FA} = g_{FF} - g_{norm} - \Delta h_g \quad [2]$$

where:

- g_{FF} = full-field gravity, mGal (absolute value)
- g_M = output of the gravity meter, specific force, mGal
- r_1, r_2 = lever arms from the sensor to the vehicle's rotation pivot, m
- θ, φ = vehicle pitch and roll, rad
- δE_{otvos} = correction for the vertical component of the Coriolis (Eötvös) acceleration
- CC = cross-coupling effects from longitudinal and cross-axis accelerations
- g_{Drift} = gravity meter drift compensation
- g_{Offset} = gravity meter offset relative to the absolute gravity at the tie point
- $Tidal$ = tidal gravity compensation
- g_{norm} = normal (theoretical) gravity
- Δh_g = free-air height correction

Precision is further improved by compensating for heater power limitations, which subject the gravity sensor to temperature variations as the housing experiences colder water at depth. The optimum thermostat setpoint for the DGS AUV-1 sensor is 62.3 °C: at this temperature, the sensor exhibits minimal sensitivity to temperature variations. The specific construction of the sensor imposes this value, and the precise calibration is measured as the point that minimizes first-order dependence of measured gravity on temperature:

$$T_c = 0.27796 T^2 - 34.21934 t + 1053.1411 \quad [3]$$

where T_c is the gravity correction (mGal), and T is the internal sensor temperature (°C).

Figure 3 shows this compensation applied to Dive 793, both across the full dive and restricted to the interval after the sensor reached thermal stabilization. The large excursion during descent reflects the temperature drop discussed in Section VI-B; once the vehicle settled into depth-stable operation, the residual correction is small and slowly varying.

Additionally, temperature variations within the housing introduce internal pressures which affect the apparent specific

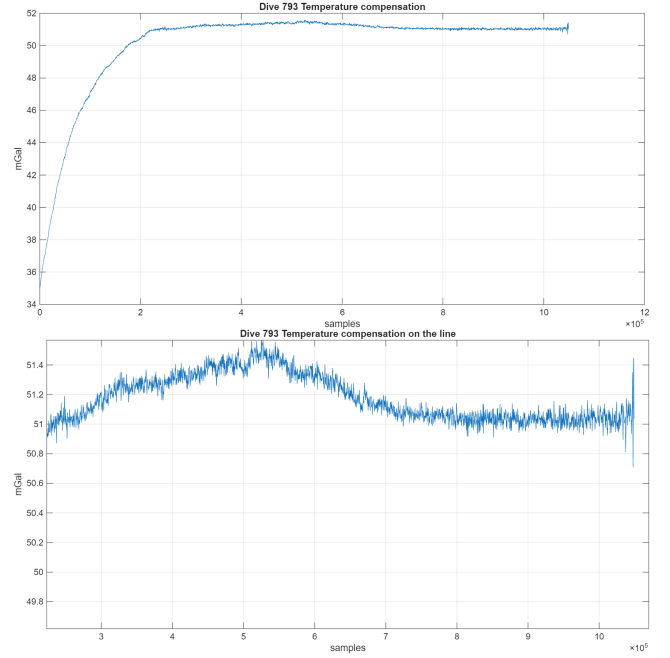


Fig. 3. Temperature compensation for Sentry Dive 793

force. This effect is driven primarily by changes in buoyancy acting on the sensing mass. For the DGS AUV-1, it is compensated using the following empirical relationship:

$$\Delta g = -5.4 \Delta T \quad [4]$$

where Δg is the change in apparent specific force (mGal), and ΔT is the change in internal sensor temperature (°C). The coefficient -5.4 mGal/°C is sensor-specific and derived from calibration; this correction accounts for thermally induced pressure effects not eliminated by operating at the thermostat setpoint. Figure 4 shows this correction applied to the Dive 793 dataset.

B. Time Synchronization

Because the navigation-derived corrections are subtracted from a signal that also contains the vehicle's kinematics, the two data streams must share a common timebase; even small misalignments appear as elevated noise or residual bias in the computed solution. The gravimeter and navigation clocks were not synchronized, and the temperature decrease at depth caused the sensor's acquisition frequency to deviate slightly from nominal. We estimate both a constant delay and a frequency offset in post-processing by maximizing the cross-correlation between the sensor output and the navigation-derived corrections over windows of approximately one hour, which resolves fixed offsets and slow drift separately. Figure 5 shows the resulting estimate over a dive; the gravity data are then resampled onto the navigation timebase.

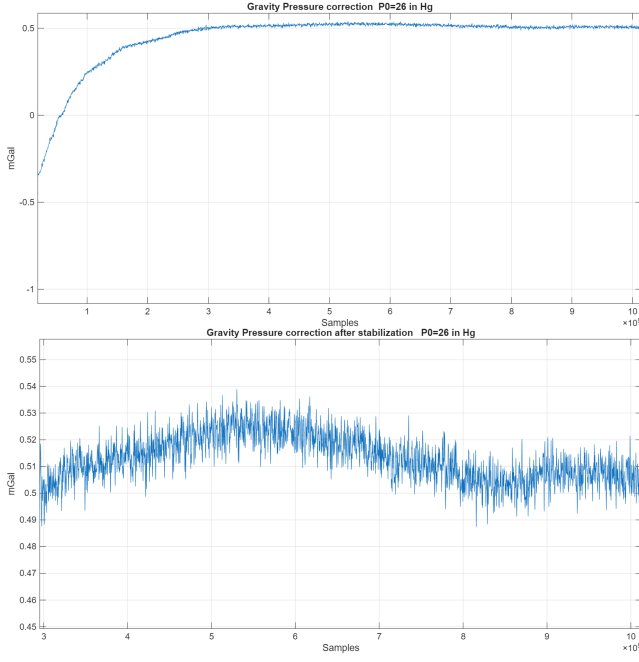


Fig. 4. Pressure correction applied to the Dive 793 dataset

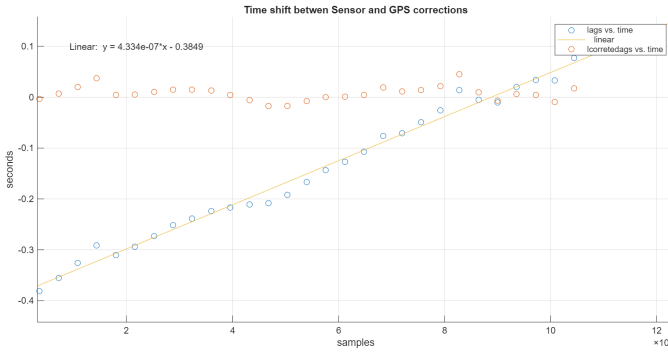


Fig. 5. Estimated time shift between sensor and navigation data over the dive

VI. RESULTS

A. Free-Air Noise

The raw vertical acceleration, the main correction term, is obtained by double differentiation of the depth signal and contains higher-frequency components than those in the original sensor data. Because vertical acceleration serves as the primary correction term, this frequency-response mismatch distorts the solution and can degrade overall accuracy. Figure 7 compares the frequency content of the raw vertical acceleration with that of the raw sensor signal, showing the mismatch directly.

This mismatch can be reduced by applying longer filters. A Kalman smoother can more effectively mitigate the noise introduced by depth measurements, assuming the autonomous underwater vehicle (AUV) exhibits bounded velocity variations. This approach permits more efficient filtering without sacrificing filter length or target detectability. Figure 6 presents

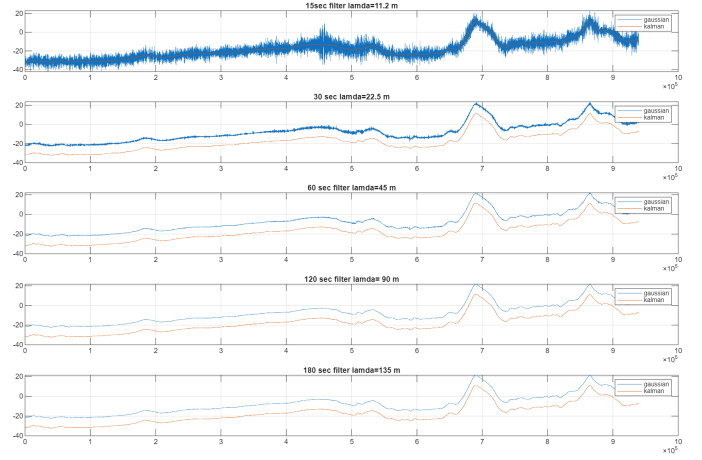


Fig. 6. Free-air gravity solution for Gaussian and Kalman filters at varying filter lengths

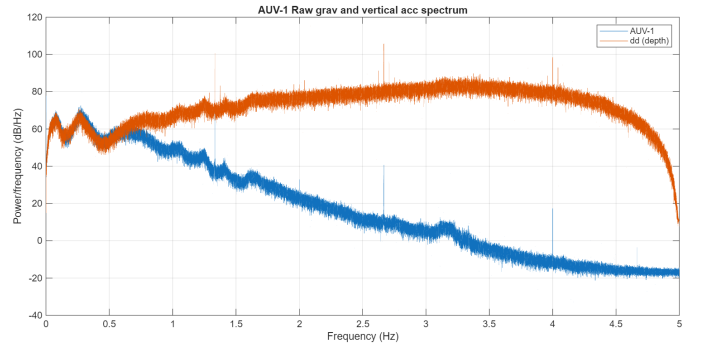


Fig. 7. Frequency content of the raw vertical acceleration compared to the raw sensor signal

the solution for the entire dive using both Gaussian and Kalman filters at several filter lengths.

Table I summarizes the estimated noise levels for the Gaussian and Kalman filters at each filter length, along with the corresponding spatial wavelength at a nominal AUV speed of 0.7 m/s. The noise was estimated from a subset of the free-air data (approximately 10,000 samples). We fitted a linear trend to the gravity data in this segment and used the standard deviation of the residuals as the noise estimate.

The Kalman filter consistently outperforms the Gaussian filter at short-to-moderate filter lengths, converging to a noise floor of ≈ 0.07 – 0.18 mGal for filter lengths of 60–120 s (42–84 m spatial resolution).

DGS AUV-1 free-air gravity was compared qualitatively against surface ATIM-17 gravimeter data, Sandwell satellite-derived gravity, and gravity forward-modeled from bathymetry along each track. The DGS AUV-1 signal reproduces the long-wavelength trend and major anomalies seen in these independent estimates, reasonably indicating that the sensor and processing chain are performing as expected. We examine the three optimal dives and compare them with surface ATIM-17 gravimeter data, Sandwell satellite-derived gravity, and gravity forward models from the along-track bathymetry. We

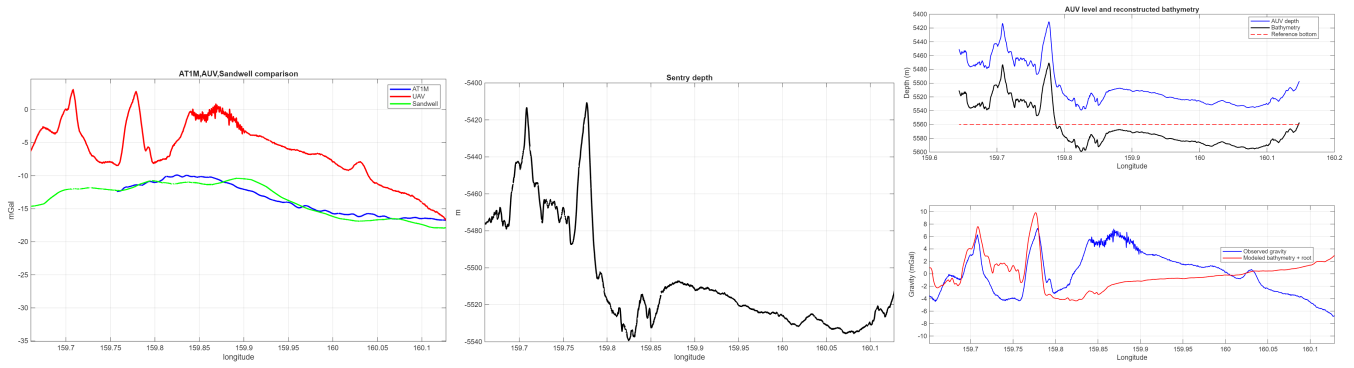


Fig. 8. Dive 793 free-air AUV-1, AT1M-17, and Sandwell gravity comparison

Filter time (s)	λ , m @ 0.7 m/s	σ Gaussian (mGal)	σ Kalman (mGal)
15	10.5	18.596	0.569
30	21	1.564	0.232
60	42	0.268	0.182
120	84	0.075	0.072
180	126	0.046	0.054

TABLE I
FREE-AIR NOISE VS. FILTER LENGTH AND EQUIVALENT SPATIAL
WAVELENGTH, GAUSSIAN VS. KALMAN SMOOTHING.

focus on dive 793. We observe these in Figure 8.

Figure 8 shows this comparison for Dive 793. Because no repeat or intersecting lines were flown at survey altitude beyond the self-overlap described in Section IV, this agreement supports the processing chain rather than establishing an absolute accuracy figure.

B. Discussion and Future Work

Although we corrected many sensing artifacts in post-expedition data analysis, our test program identified several operational and instrumentation challenges that may affect data quality and should be addressed in future deployments. Nevertheless, these are addressable engineering or deployment concerns and not critical flaws in the sensor itself.

Improved thermal management is required (insufficient heater power causes a temperature drop as Sentry descends). Due to poor temperature control within the sensor, the AUV data-acquisition clock ran approximately 0.2 s/day slower than nominal during each of the dives conducted. To overcome this, we resampled and interpolated the AUV data onto the same timebase as the navigation data. Poor temperature control also caused the sensor's internal temperature to drop by roughly 5 °C as the vehicle approached the seafloor. We corrected this in post-processing; once the vehicle returned to depth-stable ("in-line") operation, temperature variation decreased.

Vertical acceleration substantially affects the measurement, but the INS helps correct this in post-processing, along with pitch corrections. Roll corrections and cross-coupling corrections were found to be negligible due to the relatively smooth motion of AUV Sentry. After corrections and data filtering, our preliminary analysis shows Kalman-filtered noise levels reach 0.232 mGal at 21-meter spatial resolution, and 0.072 mGal at 84-meter resolution.

Mechanical clamping issues remain to be resolved. Sensor's pitch limitations imposed by fitting the sensor into currently available housing may be improved but likely still require relatively constant altitude deployments if brought to other platforms.

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