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Autonomous detection and adaptive sampling of unpredictable carbon flux events monitored by a deep-sea optical sediment trap

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Quantifying, and eventually modelling, deep-ocean carbon storage requires detailed understanding of periods with unusually high activity in the biological carbon pump. "Pulse" events, when large amounts of biological material sink to the deep-sea over a short period of time, are increasing in magnitude, duration, and frequency in the California Current (USA). They can account for a significant fraction of annual deep-ocean carbon storage in this region but remain unpredictable and hard to study. Here we present progress toward targeted study of unpredictable pulse events through monitoring, event detection and command communication by a low-power instrument that then wakes up and initiates physical sample collection by a separate instrument with limited collection capacity. We added on-board image analysis and adaptive event detection to the Sedimentation Event Sensor, an optical sediment trap with acoustic communication capabilities (McGill et al. 2016). After each sample collection, the SES calculated image attenuance and checked for rapid increases in marine snow accumulation. Image attenuance has been shown to correlate with particulate organic carbon flux (Estapa et al. 2024). If the slope of running mean attenuance exceeded a predetermined value, then the SES sent an acoustic "trigger" signal to initiate sampling by a nearby acoustics-enabled conventional sediment trap. This workflow aimed to detect the onset of, and collect during, pulse events. Sampling capacity of the conventional sediment trap was 21 cups, so the overall goal was to develop algorithms that made efficient use of that number of triggers.

Analysis of a prior deployment provided a preliminary sense of scale, variability and patterns in biological carbon pump activity at the test site (outer reaches of Monterey Bay, California, USA, ~900 m depth, May--August, 2023). Using this dataset, we defined pulse events mathematically at a scale amenable to testing engineering developments and developed a triggering algorithm that could indicate pulse event onset. For this study, pulse events were identified retrospectively at the end of a deployment as periods when at least three of the following values exceeded their respective mean + 2 σ for 24 consecutive

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hours: raw image attenuance, 24-h rolling-mean image attenuance, 3-d rolling-mean image attenuance, 5-d rolling-mean image attenuance. We then defined different triggering algorithms for testing: 1) slope-only thresholds, and 2) toggle between two different slope thresholds based on recent triggering rates.

Here we present results from three field trials (2024–2025) totaling over 12 months deployed ~900 m deep, in which the SES successfully detected unpredictable carbon storage events and sent acoustic trigger commands. False positives (triggers when no pulse event occurred) and negatives (missed pulse events) were evaluated.

References:

Estapa, M. L., Durkin, C. A., Slade, W. H., Huffard, C. L., O'Neill, S. P., & Omand, M. M. (2024). A new, global optical sediment trap calibration. *Limnology and Oceanography: Methods*, *22*(2), 77-92.

McGill, P. R., Henthorn, R. G., Bird, L. E., Huffard, C. L., Klimov, D. V., & Smith Jr, K. L. (2016). Sedimentation event sensor: New ocean instrument for in situ imaging and fluorometry of sinking particulate matter. *Limnology and Oceanography: Methods*, *14*(12), 853-863.

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