USING DISTRIBUTED FIBER-OPTIC SENSING TO RECORD SANDBAR MIGRATION UNDER CALM AND ENERGETIC CONDITIONS

Hannah Glover, Oregon State University, gloverha@oregonstate.edu
Meagan Wengrove, Oregon State University, meagan.wengrove@oregonstate.edu

INTRODUCTION

Sandy coastlines are continually evolving in response to waves and currents, and predicting the evolution of these dynamic regions depends on collecting accurate measurements of sediment-transport processes. It is especially critical to measure the near-bed and shallow-subsurface processes that drive bedload sediment transport. Bedload-transport evolves over a wide range of spatial and temporal scales, which are challenging to capture with sparse instrumentation. Additionally, processes at the seabed are challenging to measure using existing remote sensing techniques, which primarily capture sea surface signal (Holman & Haller, 2013). Distributed fiber-optic sensing is a rapidly evolving field technique with the potential to provide high-resolution spatial and temporal measurements of pressure and temperature at the seabed. These techniques employ laser scattering to record signals at distributed intervals along a fiber-optic cable, such as a seafloor telecommunications cable. Here, we present observations from the combined use of Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) to record near-bed and shallow subsurface dynamics in a sandy, nearshore environment. The focus of this project is to identify the relationships between strain, temperature, and cable burial, which can be used to track bedform migration.

DISTRIBUTED FIBER-OPTIC SENSING

DAS and DTS are two fiber-optic sensing techniques, which record different cable properties using similar methods. For both, a fiber-optic cable is attached to an interrogator, which emits a laser pulse and records the reflected signal. DAS operates best on single-mode fibers and relies on Rayleigh scattering of the laser by impurities in the glass. The interrogator records the phase change in light, which is linearly related to cable strain (Lindsey & Martin, 2021). DTS operates best on multi-mode fibers and relies on Raman and/or Brillouin scattering of the laser. The intensity of reflected signals provides a relative measurement of temperature, which can be calibrated to absolute temperature by running portions of the cable through temperature-controlled reference baths (Bao & Chen, 2012).

Both DAS and DTS have been used for geophysical monitoring, but their oceanographic applications have been limited. DAS strain has been extensively used for solid-earth research applications, including seismology and the oil/gas industry. The primary limitation in using DAS for oceanography is in converting the recorded strain to hydrodynamically relevant variables, such as dynamic pressure or bed shear stress. Recently, it has been shown that cable strain can be empirically calibrated to dynamic pressure, and DAS can quantitatively record ocean surface waves in the nearshore and on the continental shelf (Glover et al., 2023; Williams et al., 2022). DTS has been extensively used to record subsurface flow and environmental temperature gradients (Selker et al., 2006). Additionally, temperature has been used as a way to estimate depth of burial (Wilson, 1983), and has been extended to DTS applications in fluvial environments to calculate cable burial depth in sediment (Bray & Dunne, 2017). There has been little work done in the combined use of DAS and DTS, especially for nearshore oceanographic or civil engineering applications.

STUDY SITE AND METHODS

In November 2021 to February 2022, DAS and DTS data were collected at the US Army Corp of Engineers (USACE) Field Research Facility (FRF) in Duck, North Carolina, USA. The FRF is located on a barrier island and encompasses ~1 km of linear beach backed by vegetated dunes. The beach is primarily composed of mixed fine and coarse sand, and there is a ubiquitous offshore bar or set of bars (Fig. 1) that migrates seasonally with wave conditions (Anderson et al., 2023).

A custom cable with tightly buffered single-mode and multi-mode fibers was installed along a 1500-m-long cross-shore profile from the dune toe to ~13 m water depth (Fig. 1). It was trenched into the beach and was weighted to self-bury in sand offshore. DAS strain was recorded continuously at 500 Hz on a Sintela Onyx interrogator, with 3.2 m channel spacing (distance between sample points) and 4.8 m gauge length (strain resolution). DTS data was recorded every 10 mins at 1-m intervals using a Sensornet Oryx interrogator. The DTS data were calibrated using a warm bath (~19˚C), cold bath (~4˚C), and ambient loop of cable monitored with RBR Solo temperature sensors.

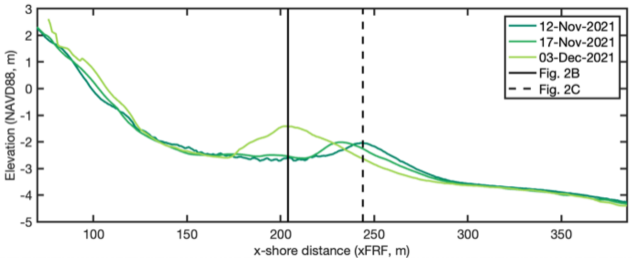

Figure 1 – Bathymetry along the cable path, measured during three amphibious surveys. The vertical lines mark the cable locations of the data shown in Figure 2.

Ground-truth measurements of pressure, water velocity, temperature, and bulk wave statistics were provided at 4.5 m, 6 m, and 11 m water depths by Nortek Acoustic Wave and Current profilers (AWACs) maintained by the FRF. Bed change along the cable path was recorded in monthly, amphibious bathymetric surveys. Bathymetry was also monitored with Argus camera imagery and the cBathy algorithm.

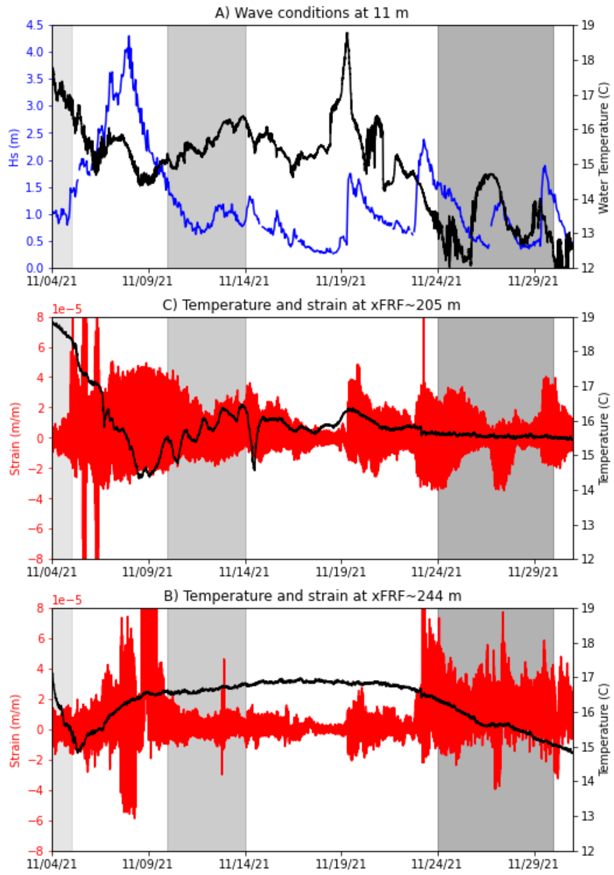

Figure 2 – Example wave and cable data from November 2021. A) Significant wave height and surface water temperature. B) Strain and temperature at xFRF~244 m. B) Strain and temperature at xFRF~205 m. Shading highlights the three time periods discussed below.

PRELIMINARY RESULTS

A wide range of wave conditions were recorded during November with significant wave heights of 0.4-4 m and peak periods of 3-18 s (Fig. 2A). The cable strain signal was dominated by the dynamic pressure due to propagating waves, and strain magnitude varied with wave climate (Fig 2B,C). This strain was empirically converted to pressure and was successfully used to calculate wave height and period (Glover et al., 2023).

Temperature in the water column varied between 12-19 ˚C (Fig. 2A), while the temperature of the cable only varied between 14-19 ˚C (Fig. 2B,C). During the first 2 days, the cable temperature was most consistent with the water temperature. It is likely that the cable was not fully buried in the bed and was directly exposed to the water. The weight of the cable would have promoted self-burial with the passing of an event that stirred the surface sediments (i.e. a moderate storm).

After Nov. 5, the cable temperature appears to reflect burial depth. In the section of the cable under the sand bar (Fig. 2C), the temperature remained relatively constant despite significant changes in water-column temperature. This cable section was likely insulated by the overlying sediment, and the temperature only decreased to match the water column once this cable segment was exposed by onshore migration of the sandbar (Fig. 1). At a section of cable initially onshore of the bar, cross-shore position ~205 m, the cable temperature initially varied with water temperature. However, the temperature variation decreased as the sandbar migrated over that cable section, later in the month. The strain signal on the cable also varied slightly with burial depth. For example, the average strain magnitude increased at cross-shore position around ~244 starting around 23 November, when the sandbar had begun migrating onshore. This increase in strain suggests that the cable was recording the attenuation of pressure with depth in the sediment. In the future, these temperature and strain signals will be used to directly calculate cable burial depth.

CONCLUSIONS

Distributed fiber-optic sensing has the potential to record seabed processes at unprecedented spatial and temporal resolutions. These methodologies can be especially useful in collecting measurements during energetic conditions, when traditional instrumentation could be damaged. However, many uncertainties remain in relating fiber-optic strain and temperature signals to sediment-transport processes.

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