Review of *Distributed optical fibre sensing in physical oceanography: Emergence and future prospects, Garabato et al., 2025.*

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16 October 2025

General Comments

This paper reviews the state of the art for the nascent field of distributed optical fiber sensing (DOFS) as it applies to physical oceanography.

The focus is mostly on presenting case studies showing simple detection of signals and crude classification based on experience, often on short, dedicated cables in near-shore coastal shallow waters, looking at internal waves, temperature, under ice, tidal flow, turbulence, surface gravity waves, and sediment transport. In deep water, signals from tides, storms and currents (below) were detected. These results were exploratory and preliminary and often qualitative, reflecting the nascent state of the field.

While acknowledging this nascent state, I was hoping for more quantitative information and more discussion of what needs to be done to evolve this field. There is a tendency to be overly optimistic as the authors make predictions about future possibilities and capabilities, e.g., "we can measure ocean currents across the ocean", an exaggerated extrapolation from cable strumming signals.

Questions/topics that could be better addressed include: Classification and absolute levels What is the DAS transfer function? How to unravel multiple processes from just one (complex) observable – optical phase and amplitude. As a function of frequency; distance along actual fibers? Importance of knowing the exact cable location vs not? Changes over time? Differences between different fibers in the same cable, or different wavelengths in the same fiber, and adjacent independent observations? Function of gauge length/averaging? Actual SNRs vs expected. Plots of DAS sensitivity/noise floor on top of plots of ambient noise and expected signals as a function of source level and range. What is the beam pattern of individual gauge lengths, and then coherent average of gauge lengths; and over what distance is coherent beamforming practical? Beamforming requires knowledge of local sound speed – how is that obtained? Some DAS systems saturate with strong signals – how to mitigate?

Missing is a discussion of DAS distributed along an entire cable, cross-ocean basin. This is surprising as Mazur is a co-author here, but his work toward this is not reported (and "Repeatered DAS" as proposed by ASN, Rønnekleiv, et al., 2025). Also, while acoustic noise interferometry to infer absolute water sound speed/temperature and velocity above and along the cable, is mentioned, I expected more. I understand these both are both in testing phases, but the combination would be so very significant to truly contributing to global ocean observing (climate, ocean heat content, circulation, sea level) and is one path that deserves strong investigation. It would complement with mutual benefit the point-wise sensors (temperature, pressure, seismic) as being deployed as part of the SMART Cables Network of the Global Ocean Observing System (GOOS).

The authors do acknowledge the non-technical challenges of evolving the DOFS into both a set of useful research tools, as well as into a part of operational ocean observing (e.g., GOOS). A discussion of where DOFS fits within a “system readiness level” framework (both technical and non-technical) would be useful. The scientific research community is well known for its (natural) exuberance and optimism when new measurements techniques are first posed. At the same time, it is under-appreciated what it takes to transition new research observing concepts into useful research and operational systems, especially spanning the scales envisioned.

Specific comments

(line number, text, comment)

Abstract

11 – *and ultra-long-range observations of ocean currents with optical interferometry*. This is referring to cable strumming. Strumming is a curiosity, and industry hates it and does everything possible NOT to have strum. Not something to count on (especially for operational use), opportunistic at best and use of a crude speed is questionable.

Make clear most prevalent form of DFOS at moment is near shore – so could sample global coastal areas.

Applying DAS to the open ocean is in development; unfortunately, the work of Mazur et al is missing.

Make clearer what can be done in telecom cables from shore, and what requires dedicated cable (and thus limited).

13-15 – will need to elaborate on GOOS, Tsunami, operational, global UN structure – all challenges encountered by SMART Cables apply to DOFS too.

There is much reporting on observations of signatures of physical processes, but not on long-term measures, which will come and are necessary.

Introduction

18 - *DOFS entails the repeated firing of coherent light pulses*

Not necessary to be pulses – can be constant power, continuous, broadband coded signals. Trade-offs?

23 *Unravelling the precise relationships*

make it clear that much of the challenge is this “unraveling”

25 *down to O(1 m) and O(1 s), respectively*

should these be smaller and higher frequency – 1 cm and >1000 Hz. I think referenced later?

25 And several years

I don't think phase can be tracked over years. Examples please.

27 Seafloor cables have a long history of use for observations of along-cable average or integrated oceanic variables.

Must be much clearer that there are extremely few examples – those given – temperature – no longer done (stopped in 1962) and Florida – difficult requiring constant calibration.

28 measurements of average seafloor temperature are available since 1906 (Hansen – 1906-1962

not "available since 1906", stops in 1962 – last telegraph cable (strictly passive?).

35 *edaphology*

I had to look this up! – soil properties

40 *developments include: air-guided fibres, which provide substantially lower energy loss than conventional fibres*

This begs the question, if the light is propagating in air, what is producing the backscatter?

44 thereby facilitating the application of DOFS approaches to the existing global cable network. This stands in contrast to the usage of cables for fixed ocean observatories, such as in the SMART (Science Monitoring and Reliable Telecommunications) initiative (Howe et al., 2022).

One should understand that DOFS and SMART are complementary, each measuring different observables (measurands) and/or ocean and earth variables; each can help the other. At a superficial level, DOFS is distributed with low sensitivity and relative, and SMART is also (sparsely) distributed but with very accurate absolute sensors.

Much of DOFS has been focused mainly on geophysics and not climate – anxious to see evolution of DOFS to climate/ocean/physO per this paper.

Also, both SMART And DOFS are fixed (stationary). The use of the word "observatories" is associated with dedicated science systems, local in geographic coverage, like NEPTUNE and DONET. SMART is focused on measuring Essential Ocean Variables, geophysics, and early warning on the global scale in a long-term sustained operational sense that supports both operations and research (i.e., GOOS)

Figure 1 caption

The colour of each pictogram denotes the *readiness level*

Need to quantify or give example in terms of NASA technical readiness level (TRL). In text need to back these up.

"Demonstrated, preliminary, expected" need explanation. My thinking is these are associated with TRLs <=3. To reach full operational status requires TRL 9, typically needs a decade, irrespective of the early optimism. One should include more than “technical” but also the non-technical issues and challenges all the way through using the data effectively.

125 Thus, the specifics of the interplay between the telecommunications and sensing industries can place some practical constraints on the design of DOFS systems.

Another crucial relatively recent development that led directly to “interrogators” was the introduction of coherent optical time delay reflectometry for measuring fiber properties (and breaks, improving on amplitude only devices) and, for sensing, driven by the need of oil and gas (i.e., fracking) for ways to measure in deep boreholes where electronics fail.

141 The properties of the returned light (e.g., intensity, polarisation, phase, propagation time, optical spectrum and coherence) are measured

Is optical heterodyning involved – mixing the outgoing light (as a ref) with the backscattered light to obtain a non-optical-frequency phase signal? Is there any frequency shifting of the reference light to handle +/- phase(apparent frequency shift)? If so, say so and show in diagram.

151 Rayleigh scattering, a form of elastic (i.e. preserving the incident photons’ energy or, equivalently, frequency) scattering caused by microscopic, random density fluctuations in the fibre’s glass structure.

Say scattering cross section << wavelength of light

185 • Spatial resolution.

What about angular resolution? – what is the beam pattern of a 1-d fiber segment as a function of length of segment and frequency/wavelength of the signal of interest? Cosine response, dipole shape with a null broadside and a peak endfire?

195 spatial resolution of the sampling. Conversely, the localisation of point sensors can lead to information being undetected between sensor positions.

Note that OFS averaging (path integral) along the segment is an advantage – smaller scale features are averaged out, and aliasing is reduced (box car filter). But it is a path integral along the fiber, and it is impossible to back out signal variations along the fiber.

197 • *Temporal resolution.*

Probably the only “higher” frequencies of interest here are either for ocean soundscapes or for the noise interferometry purposes mentioned below.

Need to clarify. Phase (and amplitude), PS and PaS, etc, are “measurands”. Derived quantities like strain and temperature are “variables” – correct?

279 The Stokes and anti-Stokes backscatter intensities (PS and PaS, respectively) are determined along the fibre length d from time-of-flight measurements of the backscattered light. The free parameters in Eq. (3) – γ*,* $C(t)$ *and* $\Delta\alpha(d', t)$ *– are established by in situ calibration. Both single-ended and double-ended (returning) cable configurations can be used, the latter requiring fewer calibration measurements.*

Describe what calibration consists of? how difficult? How frequent?

180 2.3 Implementation factors of DOFS

What about including considering sensitivity relative to (geophysical) ambient noise levels?

Would be nice to show beam patterns for a range of gauge lengths, signal frequency and wavelength and direction.

241 *For example, the specific settings of these cables can be unclear,*

Instead of settings, use “as laid route coordinates” – and/or physical configuration (burial or not, armor, etc)?

275 - So, are Ps and Pas measurands? How is in situ calibration done – from one end or needed along all the cable? would appear to useful primarily for short distances. Not suited for deep ocean using existing cables – correct?

290 waves (Pinkel et al., 2023). These studies demonstrated the capability of Raman-scattering DTS systems to observe coherent structures with frequency and wavenumber aperture that is difficult or impossible to achieve with traditional approaches.

Should mention that the two examples use dedicated cables and are for small scale physO research topics. If using telecom cables (dual use), one would need to use light frequencies outside of the telecom spectrum and of course get access/permission.

395 Because strain and temperature perturbations are both observed through a single measurand (i.e. optical phase), the two quantities are not necessarily straightforward to separate in field data.

Resolving this ambiguity is one of the major challenges of DAS. The result of a separation procedure should include an error covariance matrix that reflects the remaining ambiguity.

405 – from the Stringys reference:” the relationship between the strain and the dynamic properties of the surrounding oceanic environment is less conclusive. This limitation results in uncertainties in for example, the applicability of the assumptions underpinning Equation 4, the stability of the derived coefficients, and the optimal conventional measurements required to calibrate those parameters. This work constitutes an initial assessment of the above relationship and motivates a dedicated observational campaign to rigorously and comprehensively characterize the DOFS methodology presented here for a wider range of oceanic environments.”

Agreed. Inferring velocity from signals related to drag (quadratic, ~speed^2 along cable) can be problematic. For ocean observing purposes, it is necessary to have a reliable, well understood observable that can be assimilated into an ocean model. Not clear that this can be done. But, as the authors state: *motivates a dedicated observational campaign to rigorously and comprehensively characterize the DOFS methodology*

416 - *For example, the horizontal strain amplitude of the solid-Earth tides is typically ≲ 50°ø10−9 m m−1 (e.g., Berger and Wyatt, 1973), which, by Eq. 8, is equivalent to a 0.005 K temperature signal in DAS data*

Deep ocean temperature fluctuations are <milli K to 10s of mK; thus possibly ambiguous with solid earth tide signals.

Why is the paper “Trans-Oceanic Distributed Sensing of Tides Over Telecommunication Cable Between Portugal and Brazil” by Meichen Liu et al not referenced?

445 - *the response of DAS temperature measurements is highly dependent on the fibre optic cable construction and state of burial, which may be unknown*

This would imply every cable will be unique requiring special data treatment that could be done in a research mode, but perhaps an impediment to widespread use.

457 - *drift of DAS phase at long periods can be significant.*

This would seem to preclude validity of long-term temperature measurements without validation/calibration (that perhaps SMART point sensors could provide and/or occasional ship CTD/AUV measurements of opportunity).

460 – Bottom boundary layer. Perhaps OFS and SMART measurements in the BBL will motivate physical oceanographers and ocean modelers to at least attempt to include BBLs explicitly in models. This would reduce the large representation errors that are added to instrumental errors in the process of assimilating data into ocean models.

481 - *temperature fluctuations. The first of these works (Spingys et al., 2024a) –*

may be some overlap here with above text (line 405)

499 - often called vortex-induced vibrations (VIV). In this approach, the frequency of the induced vibrations is linearly related to the speed of the flow past a suspended section of cable and the diameter of the cable,

VIV in a cable is anathema to cable operators as it implies the cable has been improperly laid, likely resulting in abrasion and chafing and ultimately failure. May be interesting from a research point of view, but to claim is as contributing to “measuring ocean velocity” is a stretch.

529 Thus far, these DAS-derived measurements of waves have been generated by empirically calibrating strain to seafloor pressure using in situ point measurements from traditional seafloor and sea-surface instrumentation.

Calibration would have to be factored into any operational system. Is calibration needed at multiple points along a cable? (see line 557). Repeated over time?

564 Although the exploitation of DAS for tsunami monitoring holds significant promise, further technical developments are required – particularly in accessing lower frequencies and establishing quantitative comparisons with more established geophysical approaches.

Would be good to show the (one?) example of a tsunami observation, given the importance of that for early warning

570 - Future work should also address the development of analytical relationships

between recorded strain, pressure, and cable characteristics (Lindsey et al. 2019).

Correct. Not clear how much progress has been made along these lines since 2019.

597 - *3.3 Ultra-long-range observation*

608 - *In those tests, the authors demonstrated the cable-based detection of ocean-bottom currents at distances up to several thousand kilometres from the coast.*

Again, to claim measuring ocean currents based on totally unknown cable strumming/geometry is a gross stretch.

The observable length scales in this case are repeater separations or larger - > 50 km. Physical Oceanography should focus on can the OFS detect signatures of the ocean mesoscale or larger and use multiple diverse/crossing cables to do a tomographic inversion of the data (path integrals along the individual segments of multiple cables), much as Marra originally proposed. Like ocean acoustic tomography which has similar sampling characteristics.

647 4 Prospects of DOFS in physical oceanography

Where is the work of Mazar, a co-author of this paper – showing DAS capability along an entire cable. E.g., M. Mazur et al., “Real-time in-line coherent distributed sensing over a legacy submarine cable”, in Optical Fiber Communication Conference, Optica Publishing Group, 2024, Th4B–8.

And the work by ASN: Range-scalable distributed acoustic sensing with EDFA repeaters demonstrated over 2227 km, Erlend Rønnekleiv, et al, 2025.

This is a serious omission.

650 Expected that the reliability, accuracy and physical interpretability of these DOFS observations will develop rapidly over coming years, as targeted intercomparison exercises with standard oceanographic instrumentation, and other DOFS ground-truthing experiments, are increasingly performed both in the field

Should reference the two SMART systems to be deployed in 2027, both with OFS capability (in a research mode): Atlantic CAM (4000 km, 20 sensor nodes, connecting Lisbon, Azores, Madeira in a ring), and the Tamtam system connecting New Caledonia and Vanuatu (400 km, 4 nodes). These will be perfect test beds for intercomparison.

659 *4.1 Can DOFS measure ocean salinity?*

It is hard to imagine incorporating such special fibers exposed to sea water in the context of sharing commercial telecom cables. In any case, the biofouling/biofilms and longevity would be a major concern.

750 - *The issue of coupling continues to be a challenge for all DOFS, and is a topic of significant ongoing research in DAS-related seismology*

Agreed. This is a critical to convert from measurands to variables of interest in a quantitative way, rather than just descriptive observations of process signatures without absolute/trustworthy units.

800 changes in ANI inter-segment travel times would likely be independent of the details of the cable geometry and amplitude transfer response as only changes in travel times are used (as long as enough signal to get distinct cross correlation peaks). However, if signals from active sources are received on DAS (or other) elements, then absolute positions become important. Guessing a bootstrap method would be needed to get precise positions (<1 m).

822 Using DOFS for ocean acoustic thermometry would not only dramatically expand the geographic coverage of measurements compared with sparse traditional receivers but could also lead to more robust estimates of temperature trends courtesy of averaging over multiple channels along a fibre optic cable.

It has been suggested that with just a few shore-connected active sources, the Portuguese Atlantic CAM with SMART and OFS – with many crossing ray paths, would be able to produce real time 3-d maps of sound speed/temperature.

Note that ocean acoustic thermometry (single paths) is just a simplification (degenerate?!) form of ocean acoustic tomography (multiple paths crossing at multiple angles)

854 much remains to be learned on the physical interpretation of DOFS observations. This is essential to state – OFS for physO is still very much in a nascent research mode, grappling with trying to convert its measurands into useful data. Need to realistically manage expectations and timeframes and not oversell.

884 Overcoming these challenges will require a collaborative, international approach across academia, business and government, so as to generate a mutually beneficial system

The DOFS community can benefit from the groundwork of the JTF SMART Cables initiative and the establishment of the SMART Cables Network as an Emerging Network of the UNESCO-IOC/WMO Global Ocean Observing System (GOOS).