Response to Reviewers

We are very grateful to the Editor and Reviewers for their constructive comments and very helpful feedback. Below we outline how we have responded to their comments. Comments by the Reviewers are shown in *blue*, and our responses in black. Line numbers refer to the revised version of the manuscript.

Response to Reviewer 1

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.

We agree with the Reviewer. In response, we now include more quantitative information and discussion (e.g., in section 3.3.4) of what is required to advance the field of DOFS in physical oceanography beyond its current emergent state. We have also toned down our optimism about future capabilities at various stages of the paper, to provide a more measured account of what may be possible.

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?

Thank you for the very helpful suggestions, some of which we have followed. These include:

- DAS transfer function: We have added more details on the challenges of developing an analytical relationship between strain and pressure (lines 663-673). This is an active topic of research at Oregon State University. The transfer function needs to represent the physics of the cable-sediment-water system, which is nontrivial.

- Unraveling multiple processes in DAS records: Typically we do this in frequency space. It's straightforward to filter for the signal of interest. We added a few sentences on this topic (lines 210-214).
- Geolocating cable: we have added citations (lines 636-646); there are two papers that have just come out providing methods for submarine cable geolocation.
- Differences over time/fibres/wavelengths: this information is all related to the transfer function and is mentioned in the new paragraph.

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).

A new section 3.4.2 has been added to the manuscript with a brief introduction to both the long-reach and repeatered DAS approaches to long-range measurements, and some discussion of the potential impacts in physical oceanography of these technologies maturing.

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).

We agree that it would be beneficial to note here how ANI would complement sensors incorporated in SMART Cables, and have now added a discussion of this issue in lines 948-961.

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.

Some text describing the TRL of the systems has been added to the caption of Figure 1, and the accompanying discussion in the main text. This includes separating the measurement systems and the oceanographic applications, which have very different TRLs. Further, the non-technical hurdles to be overcome have been acknowledged in the Introduction.

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.

We agree with the Reviewer that cable strumming should be minimised as much as possible, but as it does occur in some cable sections, it can in principle be used to derived information about ocean flows. We have attempted to clarify this in section 3.4.1.

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

This point is now acknowledged, while noting that several techniques raise prospects for long-range measurements in the future (e.g., in lines 710-711 and 769-771).

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

We have addressed this gap by including a short section on the work of Mazur et al. (section 3.4.2).

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

We now make this distinction explicit through the paper (e.g., lines 324-325).

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

We agree with this suggestion, and have added some relevant discussion through the paper (e.g., in lines 654-662 and 1041-1060).

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

This point is now noted explicitly, including in the new section 3.2.2.

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?

We agree with the Reviewer, and have clarified omitted the use of ‘pulses’ in the relevant sections.

23 *Unravelling the precise relationships*

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

This is now made clear (lines 23-26).

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?

This statement refers to the effective spatial and temporal resolutions of the derived environmental variables. This is now clarified.

25 And several years

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

Phase-OTDR, commonly known as DAS, does not track the absolute optical phase of the laser over years (which would indeed drift, as the Reviewer points out). It tracks relative phase changes between successive measurements at each scattering position along the fibre. Since differential phase is preserved even when absolute phase drifts, long-term stability is achievable. The focus on differential phase is now noted in section 3.3.1. Examples include offshore platforms and pipeline monitoring, where distributed phase-sensitive systems are used for subsea infrastructure, and similar systems in use for monitoring railway lines and other civilian infrastructure projects.

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.

Good point. This is now made clear (lines 27-30).

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?).

Thank you - corrected.

35 *edaphology*

I had to look this up! – soil properties

The wording has been changed to 'soil science'.

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?

Typically, hollow-core air-guided fibres confine most of the optical power within an air core. They still provide sufficient distributed backscatter for DAS because the guided mode has a non-zero evanescent overlap with the surrounding microstructured glass, similar to how higher-order modes in standard SMF generate Rayleigh scattering through partial cladding penetration. Furthermore, the photonic-bandgap, or anti-resonant cladding, consists of thin glass webs and tubes whose nanoscale variations in thickness, curvature and refractive index act as natural distributed scatterers, especially in the presence of the high air–glass index contrast. These structural perturbations generate a weak but stable Rayleigh-like background that the interrogator can detect across long distances. Backscatter levels can also be intentionally increased using femtosecond-laser-induced micro-modifications, allowing hollow-core fibres to be engineered specifically for DAS applications while retaining their advantages of ultra-low loss and reduced nonlinearities. However, for Raman and Brillouin scatterings, which are used for measurements of slowly-varying temperature and strain, the fact that there is only a small proportion of the light travelling in the glass in hollow-core air-guided fibres will severely lower the intensity of backscatter signal. We prefer not to include this level of detail in the manuscript, but can do so if requested by the Reviewer.

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.

We agree - this has now been clarified through the manuscript.

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.

Thank you - we agree and now mention this at several relevant stages of the manuscript.

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)

This is now clarified in the new discussion of GOOS starting on line 1041.

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.

Discussion of the TRL of various oceanographic applications has been added to the Figure 1 caption and accompanying text.

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.

The interplay between the telecommunications and sensing industries can impose practical constraints on DOFS system design, because the available fibres, lasers, connectors, wavelengths and manufacturing ecosystem are largely inherited from telecom. At the same time, one of the most critical developments that enabled modern interrogators—the introduction of coherent OTDR—originated squarely within telecom, where it was developed to characterise fibre properties more sensitively than amplitude-only reflectometers. When the oil and gas industry later required distributed measurements in deep boreholes, where electronics cannot survive, this coherent-detection technology provided exactly the foundation needed to transform telecom diagnostic tools into high-performance distributed sensors. Thus, telecom constrained the platform, but simultaneously supplied the core-enabling technology, while energy-sector applications provided the impetus that pushed coherent OTDR into its modern sensing form. This point is now acknowledged in lines 114-115.

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.

Coherent/heterodyne detection is fundamental in modern DOFS interrogators. The backscattered field is optically mixed with a reference (LO - local oscillator), often frequency-shifted (via an AOM/EOM: acoustooptic/electrooptic modulator) to an intermediate frequency; the resulting electrical beat encodes the optical phase and any apparent Doppler shifts, which are retrieved by I/Q demodulation and DSP (digital signal processing). Frequency shifting simplifies detection (removes DC, 1/f problems), preserves sign information for ±phase/frequency shifts, and enables robust phase tracking and unwrapping over long measurement intervals. This is now noted in lines 145-148 .

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

This is now noted in lines 153-155. Rayleigh scattering in optical fibres arises from microscopic (~nm–tens of nm) random density and refractive index fluctuations in the silica, which are much smaller than the wavelength of light (λ ≈ 1550 nm). This satisfies the classical Rayleigh criterion (scattering centres << wavelength). The scattering is elastic, preserving the photon's frequency, and produces the distributed backscatter used in OTDR and DAS.

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?

In distributed fibre sensing, "spatial resolution" refers to the fibre segment length over which backscatter is integrated, typically set by the pulse duration. Each fibre segment behaves as a line of coherent scatterers, producing a dipole-like angular pattern with a null perpendicular to the fibre and a peak along its axis; the angular width scales approximately as λ/L, where λ is the optical wavelength and L is the segment length. For typical optical wavelengths (~1.5 µm) and metre-scale spatial resolution, this angular lobe is extremely narrow (~µrad), so in practice (1) the free-space angular pattern does not limit detection; (2) spatial resolution is the meaningful metric for sensing; and (3) the dipole/cosine pattern is primarily a theoretical illustration and does not constrain system performance. We prefer not to include this level of detail in the manuscript, but can do so if requested by the Reviewer.

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.

DOFS inherently measures a path-integrated signal along each spatial segment (commonly referred to as spatial resolution), which provides a continuous sensing capability along the fibre and avoids the "blind spots" that can occur with discrete point sensors. The segment averaging acts like a boxcar filter, reducing aliasing and smoothing small-scale variations. However, this averaging also imposes a fundamental limit on spatial resolution: variations occurring on scales smaller than the segment length (or spatial resolution) cannot be uniquely resolved, so the exact location or profile of sub-segment features cannot be recovered. Thus, DOFS combines the advantage of continuous coverage with the trade-off of limited sub-segment localization. This point is now made in lines 198-202.

197 *• Temporal resolution.*

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

This is now elaborated upon within the 'Temporal resolution' bullet point.

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

In optical fibre sensing, the primary measurands are optical quantities - such as phase, intensity, wavelength, spectrum and polarization - while physical variables like strain, temperature, or pressure are derived through modelling and calibration. We have now ensured consistency on this use of terminology through the paper.

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 Δα(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?

A description of DTS calibration procedures is now provided in lines 310-321.

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.

There are several aspects to this good point by the Reviewer:

1. Sensitivity. Whereas sensitivity to strain can be defined by the interrogator, the issue is how this translates to the sensitivity to pressure waves. The transfer function relating pressure waves to strain on the fibre is likely to depend on the specifics of the cable. Factors influencing the presssure/strain transfer function include the level of armouring of the cable, how the fibre is integrated in the cable (straight tube as is typical telecommunication cables or part of the screen as in some energy cables, for example) and whether the fibre is loose or surrounded by gel. Some attempts at calibrating the transfer were shown in Bouffaut et al. (2025) - https://pubs.aip.org/asa/jasa/article/157/4_Supplement/A92/3353922/From-strain-to-pressure-evaluation-of-Distributed.

2. Directionality. Studies mainly in the boreseismic and active surface seismic communities have established the relationship between angle of incidence of the wave relative to the fibre axis and also the wavenumber filtering effects. For P-waves, the sensitivity is at a maximum for waves travelling parallel to the fibre axis, falling off to near zero for waves impinging orthogonally to the fibre axis. The physical interpretation for this effect is simple: the DAS signal is a measure of the strain applied to the fibre and a wave arriving orthogonally to the fibre axis will move the fibre sideways from its axis while applying essentially no strain.

3. Wavenumber filtering effects. In a phase-measuring DAS system, the recorded signal is integrated over a gauge length. For a fixed gauge length, as the acoustic wavelength is increased from a value far larger than the gauge length, the measured signal increases until a half-wavelength is equal to the gauge length. At this point the response is at its maximum - the DAS has integrated a half-cycle of the displacement. Any further reduction results in a subtractive contribution of the second half of the acoustic wave until a minimum (null) response is reached when the acoustic wavelength is equal to exactly one acoustic wavelength. The same argument applies when the gauge length is equal to integer multiples of the gauge. Seen in the wavenumber domain, therefore, the DAS response is a wavenumber filter which notches at multiples of the inverse of the gauge length.

4. Angular effects of the wavenumber filter. The wavenumber response picture described so far relates to waves travelling parallel to the fibre axis. As the wave angle of arrival deviates from the fibre axis, the apparent velocity of the wave, as it impinges on the fibre, increases, leading to a shift of the notches in the wavenumber response to higher wavenumbers.

While a comprehensive discussion of these effects is beyond the scope of our review and perspective article, we now acknowledge several of them in section 2.3.

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)?

Amended as suggested by the Reviewer (lines 260-263).

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?

The Reviewer is correct. These points are now clarified in this subsection.

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.

This point is now clarified in lines 322-325.

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.

We agree with the Reviewer, and note that separating temperature from strain is important and discuss both the technical and practical reasons why this is challenging in section 3.3.1. As the Reviewer points out, uncertainty estimation would constitute an important element of a strain/temperature separation procedure. However, as no such procedures have yet been demonstrated, we believe that proposing novel separation techniques is beyond the scope of this review.

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*

A sentence has been added to this section highlighting that this result is only from one location and its wider applicability is unknown (lines 566-568).

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

The characteristic amplitude of deep-ocean temperature fluctuations is now mentioned in lines 495-497.

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

Thank you for pointing out this omission. The paper is now cited.

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.

This caveat is now noted within the DAS discussion in section 3.3.1.

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).

This potential synergy is now acknowledged at various stages of the paper.

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.

We fully agree with the Reviewer.

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

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

This overlap has been removed.

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.

While we agree that, in general, cable operators prefer to avoid spanning sections of cable for the reasons that the Reviewer highlights, it is not the case in real applications that operators are able to completely avoid spanning sections. Indeed, there is published work showing spanning or hanging sections of cables and their impact on ocean sensing applications (e.g,. Mata Flores et al, 2023, Loureiro et al, 2025). Other data sets not yet published and conversations across the community (both academic and industry) indicate that hanging segments of seafloor cables seem to be a fairly common feature, so we believe worthy of inclusion here.

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?

We have added more detail about the requirements for calibration due to changes in signal magnitude between channels (lines 636-646). It is better to have multiple ground-truth sensors, especially if the water depth changes enough to alter the wave spectra. The number of ground-truth points will depend on the research goal and the study site.

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

We unfortunately don’t have space to include example figures of every hydrodynamic phenomenon that has been observed with DOFS. We now provide citations to papers that explore tsunami detection in detail. We added a few sentences highlighting both the potential and the challenges of developing an operational early-warning system using DAS (lines 654-662).

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.

We have added more details on the challenges of developing an analytical relationship between strain and pressure (lines 663-674). This is an active topic of research at Oregon State University. The transfer function needs to represent the physics of the cable-sediment-water system, which is non-trivial.

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.

We have added a sentence here to highlight that these are early developments and more work is needed to fully understand the detected signals. The potential to use DOFS for acoustic measurements of ocean properties is discussed in section 4.3, and we prefer to keep that discussion there.

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.

We agree with the Reviewer. This work is now included in new section 4.2.

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.

We agree! These systems are now referenced in lines 777-780.

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.

Direct salinity sensing is not possible with standard DOFS mechanisms. However, high-fidelity DAS measurements can provide acoustic travel-time or phase-velocity information that, when combined with DOFS-derived temperature and pressure (via Raman/Brillouin channels), may allow indirect inference of salinity through the seawater sound-speed relation. In practice, accuracy, coupling, environmental stability, and telecom-cable constraints currently limit the feasibility of routine salinity estimation using shared-use subsea DOFS deployments. These points are now made in lines 808-820.

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).

We agree. We have added a brief discussion of this point in lines 937-941.

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)

We have added a clarification of the Reviewer's point in lines 925-927. We are not considering SMART cables and the Portuguese Atlantic CAM a form of DOFS, so we do not feel it is beneficial to mention this here. We do however acknowledge that SMART cables can complement DOFS/DAS measurements, and refer to our addition in lines 948-960.

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.

We agree, and have aimed to tone down our enthusiasm accordingly through the paper.

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).

We agree. The SMART exemplar is now mentioned in this context (lines 1035-1036 and 1041-1060).

Response to Reviewer 2

I would like to thank the authors for their impressive effort in preparing this manuscript. It offers a comprehensive overview of the emergence of distributed optical fibre sensing (DOFS) in physical oceanography, spanning its technological foundations, current applications, and future prospects. The clarity of the writing and the breadth of expertise represented by the co-authors make this a highly valuable contribution to the community.

We thank the Reviewer for their kind words and very helpful feedback.

That said, I believe the paper could be further strengthened by addressing several additional aspects:

1) Given the societal importance of tsunamis for coastal hazard mitigation, it would be very useful to include a discussion of how DOFS might contribute to tsunami detection and early warning. This could cover both the potential (e.g., DAS for detecting seismic signals or water pressure changes) and the technical/logistical challenges.

Thank you, great suggestion. We now include a short discussion of this issue in lines 654-662.

2) While the manuscript touches on the global ocean observing system, it could go further in outlining how DOFS might be synergistically combined with established tools (Argo floats, gliders, moorings, satellites). Highlighting complementarities and possible data assimilation strategies would strengthen the long-term perspective.

We agree with the Reviewer. The potential synergies with established observational tools and data assimilation efforts are now acknowledged (lines 1041-1060).

3) One important issue for the uptake of DOFS in oceanography is how to handle the large volumes of data it produces. A short section discussing data storage, sharing, standardization, and processing frameworks would add depth to the practical implementation considerations.

We agree with the Reviewer on this point too. We have touched on these issues in lines 1041-1060, and have added a new appendix to showcase the type of novel data frameworks that could be deployed to handle the large DOFS data volumes.

4) The paper might benefit from a more explicit reflection on the costs of DOFS deployment versus its scientific and societal benefits. This could include discussion of scalability — from localized experiments to basin-scale networks using existing telecommunication cables.

Good suggestion. Some of these issues are now acknowledged in the new discussion in lines 1041-1060.

5) The manuscript could benefit from a discussion of how uncertainties in the precise seafloor position of fibre optic cables affect DOFS measurements. For example, in regions

where cable routing data are incomplete or proprietary, how much error does this introduce in the interpretation of physical oceanographic variables? Moreover, does the impact of this uncertainty differ depending on the scientific purpose (e.g., temperature monitoring versus current or seismic detection)? Clarifying this issue would help readers better understand the reliability and limitations of DOFS-derived datasets.

We thank the Reviewer for highlighting the importance of cable-position uncertainty. We agree that incomplete or proprietary routing information can introduce ambiguity in the interpretation of DOFS measurements, particularly for applications that rely on precise spatial context. We have added some discussion of these points (lines 260-277 and 643-646) clarifying how positional uncertainty affects different classes of DOFS observables and scientific use cases, and where such uncertainty is more or less critical.

Response to Marc-Andre Gutscher

Dear colleagues, (I am not a reviewer of this submission - just an interested member of the community of this nascent field)

I have a specific comment about the introduction and about the authors' choice to discuss (only) three distributed fiber optic sensing techniques, (1) DTS (Distributed Temperature Sensing), (2) DAS (Distributed Acoustic Sensing - sometimes referred to by some as dynamic strain sensing or vibration sensing) and (3) ultra-long-range observations of ocean currents with optical interferometry.

The authors have omitted an important technique, namely DSS (Distributed Strain Sensing) using BOTDR (Brillouin Optical Time Domain Reflectometry) which is sensitive to both strain and temperature changes (which makes it a bit more difficult to disentangle the two signals).

My co-workers and I have established a three-year time series using BOTDR on a network of commercial telecom cables in Guadeloupe (over cable distances up to 65 km) and we are confident that we observe both seasonal (interannual) temperature signals (with an amplitude of 3°C) as well as strong mechanical strain at specific morphological locations (shelf breaks, canyons etc.), most likely caused by seafloor currents here.

This work has just been accepted for publication in Geophysical Research Letters (Decision Letter from the editor received 17 Oct. 2025). Here below are the title, the authors and the abstract:

Monitoring Long-term Seafloor Water Temperature Changes Using Fiber Optic Sensing on Submarine Telecommunication Cables

M.-A. Gutscher, G. Cappelli, L. Quetel, M. Philippon, J.-F. Lebrun, C. Nativelle, S. Vitalis-Simon, and E. Autret

Abstract

Monitoring of ocean temperatures is crucial for climate studies, ocean circulation modeling and assessing potential ecosystem impacts. However, obtaining observations from the subsurface ocean is difficult and costly. We present a three-year time series of distributed fiber optic sensing (sensitive to temperature changes and strain) obtained at 3 to 6-month intervals, using a network of telecommunication cables in Guadeloupe (Lesser Antilles). We demonstrate that this technique can track seasonal and annual seafloor water temperature changes to within 0.1°C , in a well-mixed, shelf sea environment. We observe a marine heatwave, with a temperature increase of +1.5°C between 2022 and 2024 at the sea-floor, causing coral bleaching with 30% mortality. These trends are confirmed by satellite observations of the Sea Surface Temperature (SST) in the same location. This successful demonstration, in a shallow-water environment, opens the path forward for widespread use of submarine cables for long-term environmental monitoring of the seafloor.

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Given that your manuscript, currently under discussion / review at EGUsphere for the journal Ocean Science, is a general overview paper about the prospects of different distributed fiber optic sensing techniques for physical oceanography, I thought you would like to be aware of this work in press. FYI - preliminary results have been presented at conferences in the past, like the SSA Vancouver Meeting in Oct. 2024, the EGU Meetings in Vienna in April 2024 and April 2025, and the One Ocean Science Conference, in Nice in June 2025.

Marc-Andre Gutscher (Brest, France), a scientist who works on DSS / BOTDR (Brillouin Optical Time Domain Reflectometry)

We are very grateful to Marc-Andre Gutscher for pointing out this omission. We have addressed it by including a new subsection on DSS / BOTDR and an illustrative figure. Giuseppe Cappelli has been brought in as a co-author to strengthen this new component of the manuscript.