

Response #1 to Anonymous reviewer 1 on manuscript submitted to OS “Monitoring surface gravity wave variability with State of Polarization sensing on a subsea telecommunication cable” by Pelaez Quiñones et al.

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We appreciate your constructive comments to improve the quality of our manuscript. Please find below a point-by-point reply to the matters raised in your review (*italics* are used for citing the reviewer’s comment). Specific changes proposed for a revised version of the manuscript are indicated in [brackets]:

- On the Minor, general comments:

1. “I really appreciated the whole discussion around S_1 towards the end of the paper, but still cannot understand why the Authors chose to monitor this parameter alone. Can they discuss this point? Concerning the lines between 432-434 and Appendix D, if I understood correctly, the Authors state that each variation affecting the Stokes vector positioned where one parameter is minimized, has maximized sensitivity on that parameter. This is true as, for example, the sphere’s poles lying on S_1 are the points where this parameter is less sensitive. By monitoring one Stokes parameter alone, anyway, there could be another “fading” condition, where $S_1 = 0$, as stated in lines 440-443. This would completely hide variations induced by external events and, since they are extremely slow, maybe for a long period of time. Would employing a full polarimeter allow for a complete and increased sensitivity of SoP? Are there some other SoP-derived parameters that could be used to increase sensitivity? Coherent receivers’ SoP estimate would provide for the whole Stokes vector.”

Reply:

- The implementation of the S_1 parameter alone is basically a limitation of the available receiver used in our experimental set-up, as it was designed to detect relative variations of that specific parameter only. This is largely due to its inherent design simplicity and cost-effectiveness (the anatomy of the SoP sensor is described Sec 3.1). For a revised version, we intend to be more emphatic on this and change L101-2 to: “... and was designed to analyze the S_1 Stokes parameter [alone owing to design simplicity and low cost. Thus, this work will exclusively focus on this parameter].”
- Indeed, as you suggest, a full polarimeter would likely allow for a more complete monitoring of SoP variations through the other 3 Stokes parameters. For instance, “sensitivity gaps” could potentially be addressed by combining the time series of the different parameters in a way that environmental signals that are “missed out” by one parameter could be recovered from another one. This may effectively improve the stability of the SoP sensitivity over time and perhaps even increase it. However, this is yet to be rigorously evaluated and outside of the scope of our manuscript since we have not yet studied how particular combinations of these parameters could produce a tentative, additional parameter with improved performance. At some point, we tested a commercial polarimeter measuring all Stokes parameters, but it unfortunately proved unreliable for continuous logging and storage-limited for long time acquisitions, so basically unsuitable for the long-term campaign that we managed with our own SoP receiver.

- Based on your suggestion, we propose the following addition to the sentences in L439-443: “... systems combining all Stokes vectors are likely to provide a higher degree of [stability and] linearity in the SoP response [as environmental signals that are randomly ill-recovered by some Stokes parameter(s) could be detected more properly by at least another.]”

2. *“This sensing system is currently non-coexisting with telecommunication data. Despite the large number of interesting results the authors presented, I see few advantages to deploying the SoP monitoring system alone (i.e., installing the entire submarine fiber-optic cable just for SoP sensing), other than for telecommunication purposes. The S 1 time evolution is very difficult to interpret: a dataset consisting only of SoP data, without all the other sensors, would probably have been impossible to interpret as the authors did in this work. Given the mention of SoP monitoring with coherent transceivers that the Authors do around line 535, do they see this kind of system deployed in a “standalone” manner, or jointly working with the telecom system? In more practical terms, do the Authors see any added value in monitoring SoP alone, in this context? Would environmental data from sensors be needed to properly exploit their full potential?”*

Reply:

- The presented dataset was acquired on a pair of looped dark fibres (with no other coexisting data) of an active telecommunication cable (other fibres inside the same cable were simultaneously used for telecommunication during the experiment). However, it is in principle also possible to use fibres with coexisting internet for sensing since natural SoP fluctuations are also carried by standard telecommunication signals, as described in the second paragraph of Sec. 5.3.
- We agree that deploying a long subsea cable for monitoring SoP alone can be complex and costly. The possibility of joint work with telecom systems is thus often advantageous and generally sought as these are long-term installations typically requiring little or very sporadic maintenance. On the other hand, SoP is one out of several fibre-optic sensing systems (e.g. DAS, DTS, DSTS,...) that are compatible with the same FO cables, each system with their own capabilities, applications and potential to complement one another. Thus, depending on the application, practical constraints (size of a cable, cost-effectiveness), specific study region, among others, there could be suitable cases for sensing-dedicated cable deployments (e.g. in narrower areas where continuous, real-time and/or long term monitoring is important, where robust sensors are desired due to harsh conditions, or on some of the cases as suggested in L535-8). Especially if one considers that, although already installed, the general access to privately-owned cables can be restricted and/or expensive.
- Existing ground truths currently remain critical if rigorous interpretations related to absolute magnitudes are sought with FO sensing, but not necessarily so for more relaxed analyses in terms of measurand accuracy. For example, with SoP data alone we have shown that it is possible to identify surface gravity wave events and anomalies based solely on their characteristic frequency band and dispersive trends, as shown in Fig 4. It’s hard for us to tell at this point whether a more detailed knowledge on the response of SoP and future advances will be sufficient to turn SoP into a popular stand-alone sensor. Alternatively, hybrid architectures (e.g. SMART cables with built-in conventional sensors) might eventually close the gap between fully telecom and fully FO-sensing cables.

3. *“Imagine using several fiber cables to monitor SoP, for example, exploiting coherent*

telecommunication hardware, in different areas. To my understanding, each cable installation is different. The Authors underline this in several parts of the paper (e.g., lines 375-380, Sec. 5.2, and 6), and it looks truly critical to have the fiber sensitive to different kinds of events. It seems to me that, if the cables are not deployed for sensing purposes, but “randomly” installed for telecommunications, it is a very long and complicated process to understand what SoP can “see”, and kind of impossible to do it without the aid of external sensors. My question is then: how difficult is it to scale this over the submarine communication network? It seems extremely complex and long. Could there be a situation where SoP data are almost completely silent because, for example, the cable is not that loose or suspended, and nothing couples to it? Do the Authors envision some future ad-hoc installations to maximize the sensitivity to certain kinds of events (and maybe minimize it for others)?”

Reply:

- We agree that cable installations can differ to variable extents in coupling, burial, geometry, et al that could make their response sensitivity and data quite different in terms of signal content (this could also results from uniformly calibrated sensors in different geographical regions, exposed to different kinds of environmental conditions and events) and in some cases, even preclude any signal of interest from being detected as you suggest, e.g. if the cable is simply too deep to measure SGWs. Relatively straight-forward limitations like the latter example could be extrapolated for most cables from a few reference measurements.
- At the moment, the detailed, quantitative sensitivity of each cable relies heavily on reference sensors and is normally assessed empirically via ground-truthing as there is a lack of predictive models for the sensitivity of a given cable. What could make the process particularly long and complicated is a lack of available data from calibrated monitoring probes sufficiently close to parts of the cable, as these would have to be deployed and retrieved for that purpose. The situation is not aided by the fact that detailed information about deployed telecom cables is often inaccessible, so scaling doesn’t appear so simple at the moment. However, if relative event recognition alone is sought without absolute measurand quantification, the scaling seems less daunting. As an example, arrays of several telecom cables have been proposed to extend the coverage of seismic networks and to estimate source regions of earthquakes, without implying that their magnitudes can always be recovered accurately from cables alone. Some of the aforementioned practical generalities and considerations are discussed in Secs 5.3 and 5.4 in the manuscript.
- Certainly, ad-hoc installations with higher sensitivity to certain events (e.g. close to the water surface for gravity waves) are quite possible but it seems difficult to foretell reliably (or positively) about their future as long as the cables used for FO-sensing remain limited to those owned by private companies if the latter don’t see prioritizable commercial interests in such applications.

- On the Figures:

Figure 4. The plot shows a very interesting match not only between the SoP acquired and the different data coming from the sensors, but also with the models. Nevertheless, I found it difficult to read, particularly the spectrogram: the overlap between plots hides some features. I am aware of the fact that it will probably take more vertical space, but would the Authors consider, to enhance clarity and visualization, vertically stacking the line plots in 4a, easing the spectrogram? Maybe overlapping the in-situ data with the models only. In this way, the time correspondence

would be preserved, and the spectrogram would be easier to read, sacrificing space for text.

Reply:

- Our suggestion: to overlay only the full spectrum peak periods from the in-situ and model data, as these seem to be the ones that provide the best match with the data anyway.

Figure 6. It seems like the legend in the grey box containing the numbers 10 and 1 (dotted line) is not explained in the text. Am I missing something? If not, please add the proper details to the manuscript.

Reply:

- The last sentence in the caption indicates that the dotted lines correspond to contour levels in kPa, but this could be easily overlooked. For more clarity, we suggest for the last sentence: “Pressure values and dashed contours [(labels in grey box)] in kPa”.

Figure 7. I found it confusing to label the plots with $S 1'$, when the actual plotted value is the RMS $S1'$. I think it would enhance clarity to rename labels. I am referring, for example, to Fig. 7e: in the text, it is specified (lines 313-314) “Fig. 7e depicts the entire normalized, hourly RMS time series of $S 1'$ alongside...”, but the labels just show $S 1'$. Stokes parameters can have (also, as shown in Fig. 3) negative values. By labeling Fig. 7e with $S 1'$ only, it looks a bit odd.

Moreover, the triangles mentioned are basically invisible. I am not sure if it makes sense to highlight the data gaps or just mention them in the text and keep the same marker.

Reply:

- We agree. The labels have been renamed to indicate that these plots of Fig 7 are in fact RMS values and not the original time series.
- For more clarity, the triangles can be highlighted more clearly, as we agree that these are rather transparent and small as they are.

- On the Specific comments and typos:

1. Lines 30-35. I am aware that the concept of birefringence is very well known, but it would benefit the clarity of the paper, particularly to readers outside the photonics area, to maybe add some references.

Reply:

- We suggest the following addition at the end of L30-35: “[Birefringence variations in the optical fibers induced by environmental perturbations dominate the SoP signal (Mecozzi et al., 2021). This birefringence arises from strain-induced anisotropy, i.e., differential changes in the refractive index along orthogonal axes of the fiber. These anisotropic perturbations lead to relative phase (or time) delays between light components oscillating along different polarization axes, ultimately resulting in a net evolution of the SoP as the environmental straining conditions change]”

2. Lines 50 to 55, when talking about surface gravity waves (SGW). In contrast to

birefringence, SGW phenomena are not known to telecommunication readers. I know that the journal is outside that area, but since the subject treated is quite transversal, I think it would enhance the paper to provide a short definition and/or some references.

Reply:

- We suggest the following textbook as a general reference: {Massel, S. R.: Ocean Surface Waves: Their Physics And Prediction, chap. 4, Advanced Series On Ocean Engineering, World Scientific Publishing Co Pte Ltd, 3 edn., 2017} in L46: "...monitor ocean waves, [i.e. surface gravity waves (SGW), Massel, 2017]."

3. Can the Authors cite something related to the V-shape of the SGW, referred to between lines 180-183?

Reply:

- Certainly, we propose to add these two references as examples:
 - Ferretti, G., Zunino, A., Scafidi, D., Barani, S., and Spallarossa, D.: On microseisms recorded near the Ligurian coast (Italy) and their relationship with sea wave height, Geophysical Journal International, 194, 524–533, <https://doi.org/10.1093/gji/ggt114>, 2013
 - Colosi, L., Pizzo, N., Grare, L., Statom, N., and Lenain, L.: "Observations of Surface Gravity Wave Spectra from Moving Platforms", Journal of Atmospheric and Oceanic Technology, 40, 1153 – 1169, <https://doi.org/10.1175/JTECH-D-23-0022.1>, 2023

4. Line 336. Fig. 8k seems not to exist. Is this a typo?

Reply:

- Yes, this must be changed to Fig. 8h instead. Thank you.

5. Please check the acronyms used. It seems to me that sometimes they are not defined.

Reply:

- We have double-checked, and except for electromagnetic (EM), all remaining acronyms seem to be properly defined in the main text and in the appendix table.

6. Please mention that R^2 is the determination coefficient.

Reply:

- We have checked, and the caption of Fig. 7 currently reads: "...with linear regression (including determination coefficient R^2 and p-value of t-distribution..."