Reviewer 1:

This is a review of the manuscript “Investigating the D" Reflector Beneath the Indian Ocean with Source Arrays Using GEOSCOPE Stations” by C. Thomas et al.

In their study, the authors search for teleseismic D”-reflected P waves, and claim to have found them for four out of six stations that they investigated. The manuscript is very well written. The seismic evidence for the reported results appears quite weak.

We would like to thank the reviewer for their comments and suggestions, which we hope we have answered below and in the text. Indeed, the D" reflections are weak, but they are often weak also in receiver array studies. We tested the results against synthetics (as shown in Figure 6) and also there the amplitudes of the D" reflections are small; however, they are not there if no reflector is implemented in the model (new Figure S7) as we will show below

Major points:

- This study lacks data supporting the conclusions. This would be understandable if there were simply not more data available, however there are plenty of earthquakes around the currently used source region that could be added, even at depths between 80 and 200 km (Celebes Sea, Papua New Guinea). Additionally, it appears like CASY is also in a suitable distance, and there are more permanent seismic stations in Madagascar besides FOMA, at least one of which has been running longer than FOMA. It is unclear to me why these additional data have not been added.

We did search for events from 1990 to 2024, with magnitudes of 5.6 to 7.5 (larger magnitudes have longer source time functions and were therefore not used). There are in total 145 events in that time range, in three clusters: The one that we used in the first submission; one additional that is further north and we did not use due to the distances being less favourable for our analysis (too far for several stations), less convincing data (i.e. noisier) and more difficult source mechanisms for P-waves; and the last cluster which is drawn out over the western part of Indonesia, leading to unsuitable stacks (the source array is too large). We were initially therefore left with only those events that we collected and of those several events could not be used due to high noise or complicated waveforms and second events close by (in time). We now mention this in the text.

However, based on the comments of reviewer 1, we have re-evaluated the second, northern cluster for additional stations in Antarctica and in the Seychelles/Madagascar but, as before, for the Indian Ocean stations RER, FOMA, AIS, etc, there are only 2-5 usable events per station which is too low a number to stack (despite a larger number to analyse, but they have either complicated waveforms, are too far or contain too much noise). We also now include other stations (CASY, MSEY and MAW) in addition to the previously used stations. We do find a larger number of events for stations CASY, MSEY and MAW and re-analysed events for DRV from the second cluster, and we now show these in the results and new Figure S6. Therefore, we also changed the title of the manuscript, as it not only uses GEOSCOPE stations now.

Search Results

endtime
2024-10-09 23:59:59

maxdepth
150

maxlatitude
3.642

maxlongitude
135

maxmagnitude
7.5

mindepth
80

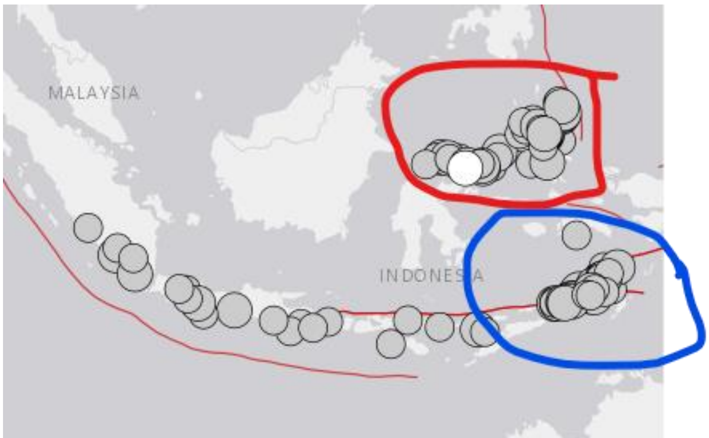
minlatitude
-15.16

minlongitude
101.953

minmagnitude
5.6

orderby
time

starttime
1990-10-02 00:00:00



The red circled cluster provides a very limited number of recordings for the stations in the Indian Ocean (smaller than 7), but we use this now for stations CASY and MAW, as well as MSEY and DRV. The blue circled cluster is the one we used before. The other events are too far from each other to have a suitable array aperture.

The Station FOMA on Madagascar is already too far, as explained in the text, the other stations on Madagascar are similarly too far. But we tested all these stations again with the new clusters but had not much more luck. We tried additional stations on La Réunion, on Mauritius, we also used the stations of the RHUM-RUM Experiment and every other station that could be downloaded from IRIS and other open data centres. Unfortunately, there are no more good data for the Indian Ocean that we were able to find. We have added more information to the text explaining this.

We also tried to find more receiver array data but could only find an additional 5 combinations that are located in the northern part of our study area and (as the events and receiver arrays we showed before) approximately confirm the values by Young and Lay 1987 (shown as grey diamonds in Fig 9).

- I appreciate that the authors are trying to squeeze out subtle signals from their data. I believe that such approaches are very important, but many studies have shown that some of the subtle signals that have traditionally been interpreted in terms of mantle structure are due to finite frequency effects. To convince me that the interpreted signals are real, I will need to see that they are not visible in synthetic seismograms that include realistic heterogeneity, i.e. for an input model that includes 3D tomography in the mantle. I am aware that this test cannot be conducted down to 1Hz, but synthetic seismograms down to periods between 5 to 10s are quite common these days.

We appreciate the comment and have generated synthetic data (with AxiSEM3D) for one source array, using a tomography inversion as input for the mantle and processing those data as we do for the real data. The test is shown in new Figure S7. There is no reflector visible, but the wavelength was large (>6s), so the upswing visible before PcP is part of PcP wave. At shallower depths the amplitude does not cross from positive values to negative (or vice versa), which would be the criteria for a reflection.

Minor points:

- Non-technical summary: consistently use earthquakes instead of sources; I do not believe non-experts know what the plane wave assumption is.

  This might be the case, thanks. We tried to reword this sentence

- Line 55: exhibits -> exhibit

  corrected

- Line 57: Yu and Garnero (2018) is not technically a review paper.

  True. We deleted "review by"

- Line 95: Comma in front of and.

  Corrected

- Figures 5, 6, 8: The color bar appears to be incorrect as the plots only show specific color levels. Only showing a few discrete color levels can be misleading. I believe it would be better to present these plots with more gradual color (as the color bar indicates but is not implemented).

  The contours are filled for every contour interval. Using gradual changes in the figure would make it messier as contour intervals would not be clearly visible. But the reviewer is right, it could lead to misunderstandings. We therefore changed the colour bar instead, to make amplitude intervals clearer.

- Discussion and conclusion: Please streamline. There is no need to repeat everything that you have written before.

  We have re-written the Discussion and shortened the conclusion to be more concise. Thanks

- D" has also been suggested to be anisotropic – are there any correlations to previous anisotropy detections?

  We did already mention a bit of this in the discussion: South of Australia there is a detection of D" anisotropy (Usui et al., 2008). To our knowledge there is little else in the Indian Ocean at the moment. Wolf et al. (2023) do show a compilation of anisotropy in D" and they also find little evidence or inconclusive results for the Indian Ocean in the literature (Rao et al., 2017 and Creasy et al., 2017). We added this in the text.

- Code availability: Seismica states “Seismica requests authors to not only provide access to their data, but also to the scripts and computer codes that were used to process and analyze these data. The most convenient way to meet this requirement is to combine the data and the corresponding scripts/codes in the same self-contained repository. Seismica recognizes that not all computer codes or scripts are central to a study, but codes or scripts that are important should be provided with clear documentation, or a compelling explanation for their absence. In the case of specialized hardware requirements, it suffices to provide the relevant codes with an additional note on the hardware restrictions.” Please provide all codes in a repository according to these guidelines.

  Seismic Handler is openly available including all scripts. The data are also openly available from IRIS. The migration is carried out in Matlab, the script for the migration are now placed in a repository (ZENODO) with the reference and doi given in the manuscript.

Recommendation: Resubmit for Review

Reviewer 2:

The manuscript investigates the D" discontinuity beneath the Indian Ocean using seismic P-wave reflections recorded at GEOSCOPE stations. Given that the D" layer beneath the Indian Ocean is underexplored but potentially significant for understanding mantle composition and dynamics, it is commendable that the authors have made considerable efforts to extract weak reflection signals from limited event and station coverage. The manuscript is generally well-written and easy to follow, though the sparse data coverage and high noise levels raise concerns about the reliability of the findings. My detailed comments are outlined below:

1. Amplitude Discrepancy: The amplitude of PdP is theoretically expected to be lower than that of the core-reflected PcP, due to the low velocity contrast across the D" discontinuity, as demonstrated by the synthetic tests (Figures 6d and 7). However, the observed PdP amplitude is comparable to or even stronger than PcP, as shown by the amplitude-depth profiles (Stations RER and PAF) (Figures 5 and S5). Additional interpretation is needed to clarify this discrepancy.

   The amplitude of PdP depends on the impedance jumps across D" and in our models we assume a higher velocity within D" (as also found in other regions, see Wysession et al., 1998 and Lay 2015). The synthetic data, as the reviewer pointed out, confirm this and the D" reflection stacked amplitudes should be smaller than PcP. In many of our results we do find this - see also the new results, although we clip the amplitude depth profile at the CMB. This clipping could be one reason for the amplitude of the PcP apparently being smaller than PdP, since we do not stack for depths lower than the CMB but the wavelet of PcP developing to its full extend after the first onset. Another possibility is that the time window, in which we measure the maximum amplitude for shifted traces for each grid-point could be too small. We have re-run the migration for a larger time window for station RER and the PcP now shows up with an amplitude as we would expect it. The results are now replacing the previous amplitude-depth profiles for RER. For station PAF, the results are very difficult to interpret, as pointed out in the manuscript before. And even with changing start times and larger time windows, we cannot get a better result. This measurement therefore is unreliable and we now mention this explicitly in the text.

2. Uncertainties in the height of the D" discontinuity: The detection of PdP and PcP is not quite reliable, as suggested by the source normalization and vespagram analyses (Figure S2; Figure 4). The uncertainties in the height of the D" discontinuity should be quantified.

   As we mentioned in the text, the depth is variable (we now give the values, i.e. 20-30km) but since the PcP depth varies by approx. the same amount, the thickness of the D" layer can be recovered as shown in the synthetics. We now mention the error of the depth measurement, while in the remaining manuscript, we still use the thickness rather than depth. The error due to variable velocity within D" could lead to an apparent change in thickness of the D" layer, based on our synthetic tests, we give an error of 30km, we now mention this as well.

3. Ambiguity in Interpretation: The statement "Since all of our reflection points are found within this high velocity region, we suggest that our imaged reflections are detecting the top of the subducted lithosphere" (Lines 546-548) needs clarification. What is the relationship between the top of the subducted lithosphere and the D" discontinuity? This is confusing, especially since the manuscript predominantly focuses on the D" discontinuity.

   It is often assumed that the discontinuity found at top of the D" region is due to subducted lithosphere. It is also possible that it is due to alignment of minerals due to the flow of the lithospheric plate along the CMB. We have clarified this in the text, both in the introduction and the discussion.

4. Lengthy Descriptions: The manuscript includes extensive descriptions of data processing, which are helpful but may be overly detailed for the main text. Consider moving some of these details to the supplementary materials. The conclusion is also somewhat lengthy and could be more concise.

   We have re-written/shortened the discussion and conclusion and moved some of the processing descriptions into the supplementary material (i.e. the source normalisation methods).

5. Lines 243-250: "We also tried the ID approach...". The seismic traces normalized by Iterative deconvolution are not provided in manuscript and Supplementary material.

   As this approach failed, due to the reasons provided in the original manuscript, we did not show an example. We now state more clearly that this approach did not yield results, but we keep the description, as we think is a useful information for other researchers.

6. Lines 472-475: "We did identify an arrival...300 km above the CMB... D" reflector 190 km above the CMB". The arrivals resulting from "300 km reflector" are not

marked in the source vespagram (Figure 8). Further discussion is required for the origin of the double discontinuities ("300 km" and "190 km") above the CMB.

This is a misunderstanding due to our wording. We apologize. We only find one reflector at 190 km above the CMB. We have now re-worded that sentence

7. Lines 548-549: "Our amplitude-depth profiles suggest a small signal for PdP ... (Figures 5, 8, and S4)". "Figure S4" is the principle of migration images and amplitude-depth profiles. "Figure S4" should be "Figure S5".

   Indeed, thanks. Corrected.

Recommendation: Revisions Required