Natural Environment Research Council

PANORAMA

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Earthquake relocation at intermediate-depths using automatically detected teleseismic depth phases

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Abstract

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1. INTRODUCTION

WHAT?

Automatically relocating hypocentral depths of intermediate-depth (40-350 km) earthquakes, using the differential times between P, pP and sP arrivals received at teleseismic (30-90°) sub-arrays.

Array processing techniques are applied to improve the signal-to-noise ratio, and the ability to identify the depth phases.

WHY?

Controls upon intermediate-depth earthquakes remain poorly understood, despite their associated risks to society.

Confidently linking the locations of events to their surrounding geodynamic setting may allow new insights into their nucleation, thus informing hazard assessments.

WHERE?

The Peruvian flat slab section of the subducting Nazca plate is being used as a case study.

The slab provides the opportunity to create a complete regional catalogue, update the slab top, and test slab-bending related earthquake nucleation.

2. METHOD

The approach aims to identify the P arrival and its associated depth phases (pP, sP) for a given earthquake (Fig.1), to calculate their differential times and establish earthquake depth. The approach is entirely automated, and adaptable to any intermediate-depth earthquake dataset worldwide.

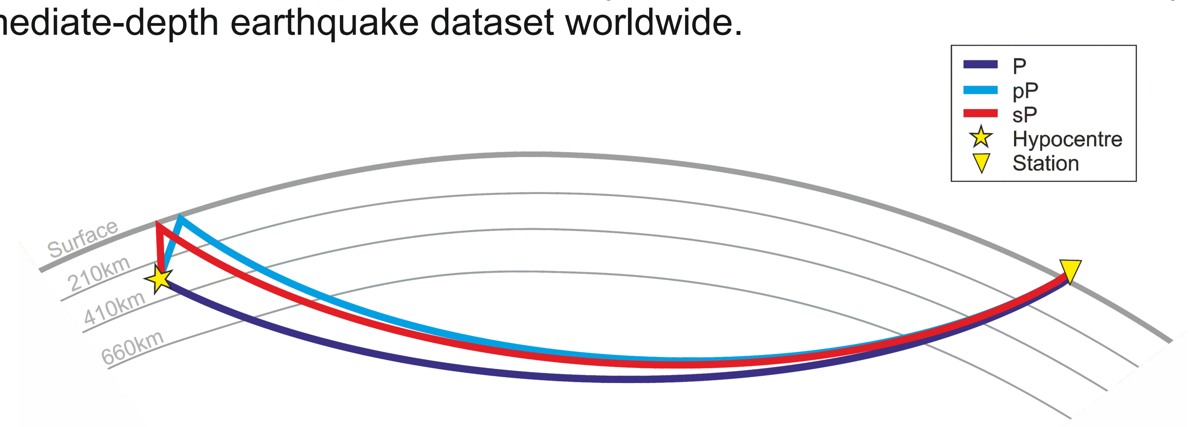


Figure 1. 2D schematic to display the P, pP and sP ray paths from an earthquake hypocentre (star) to a teleseismic receiver (triangle).

+ We aim to leverage the increasing abundance of global seismic stations, by using unsupervised machine learning to assemble teleseismic stations into 2.5° sub-arrays per earthquake (Fig.2). Thus enabling array processing techniques to be dynamically applied to a global teleseismic dataset.

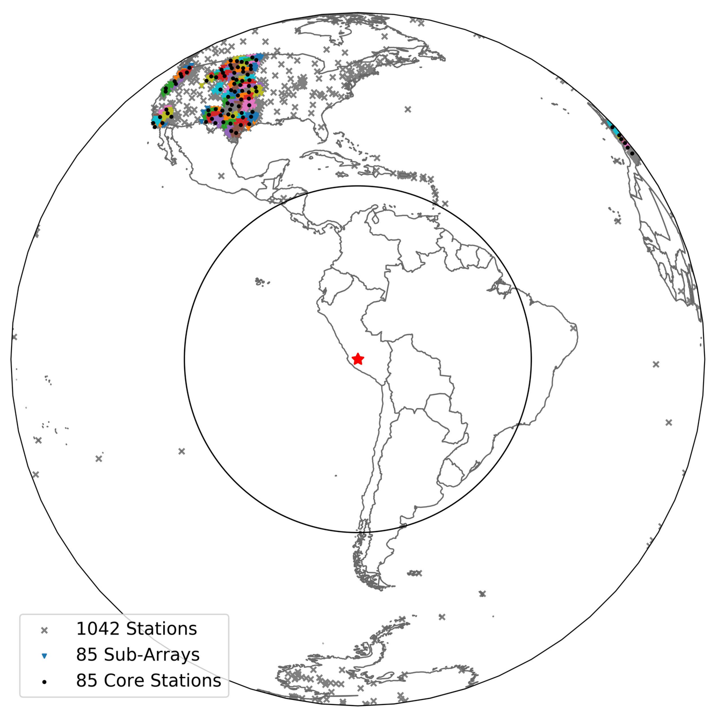


Figure 2. Global plot illustrating the location of Mw 6.1 earthquake from 23/5/2010 (red star), locations of available teleseismic station data (grey cross), stations grouped into sub-arrays (coloured traingle) and their core stations (black circle).

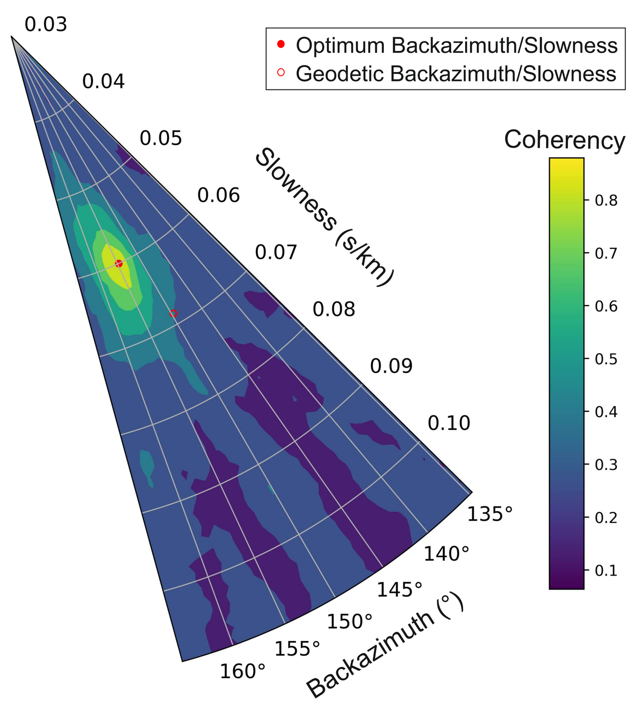


Figure 3. Polar plot showing the maximum P arrival coherency per tested backazimuth and slowness during beamforming. Example from a sub-array at 49.203° epicentral distance from the Mw 6.1 earthquake, 23/5/2010.

+ Each sub-array is processed, with poor quality traces removed via a cross-correlation check. Remaining P arrivals are beamformed using a slowness and backazimuth grid search (Fig.3).

+ The beam with the greatest P arrival coherency indicates the optimum backazimuth and slowness values for the sub-array. These are used to form an optimum phase-weighted beam from the sub-array traces for picking.

+ Vespagrams are created to assess phase arrival coherency, and aid phase picking (Fig.4). Poor quality vespagrams, hence poor sub-arrays, are discarded.

+ Remaining sub-arrays are automatically picked using the envelope of the optimum phase-weighted beam and a threshold-based method (Fig.4). Peaks with a significant prominence, and amplitudes greater than the dynamic threshold - calculated from the distribution of the beam amplitudes - are picked.

+ Picks are assigned a phase, or discarded, based upon expected differential times. The picks must also demonstrate a signal-to-noise ratio larger than 5 to be preserved.

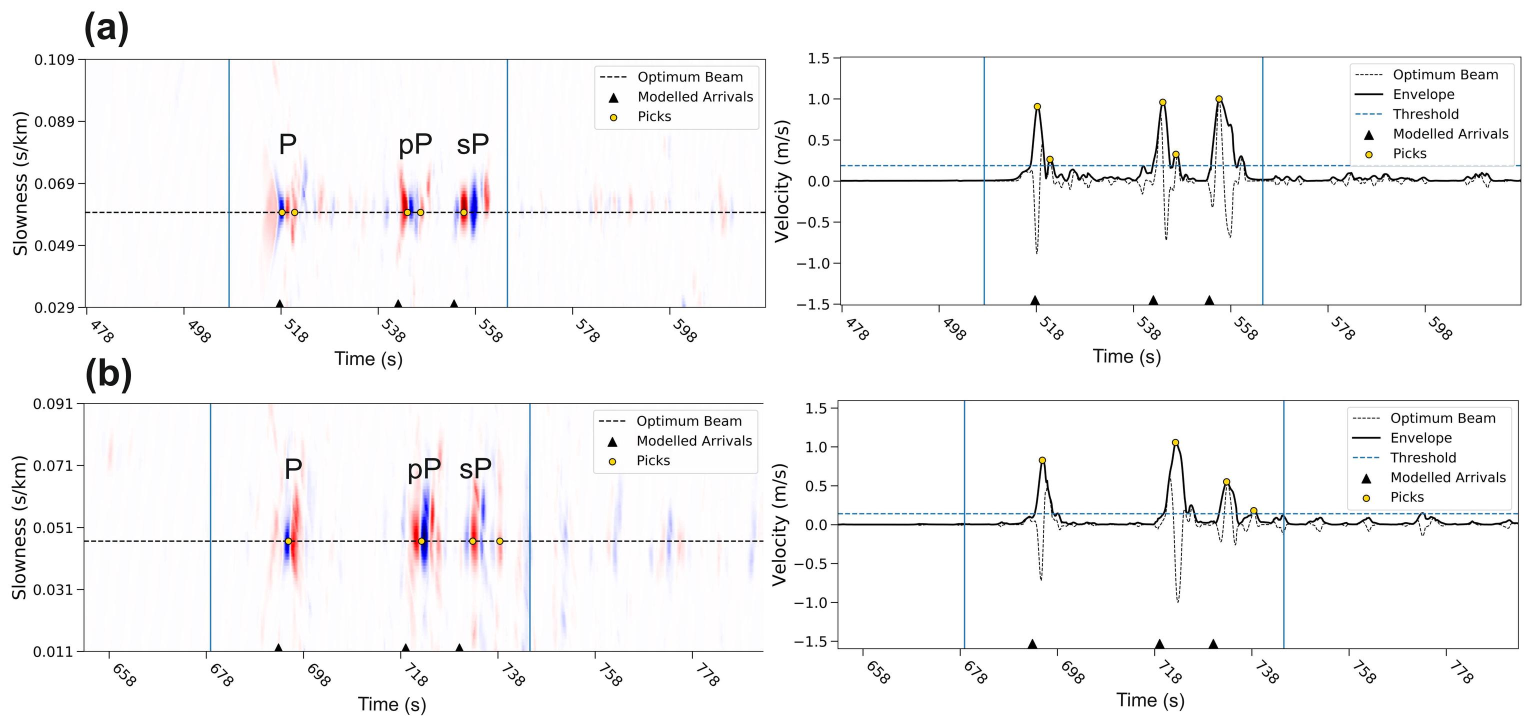


Figure 4. Vespagram (left) and optimum phase weighted beam (right) plots used for automatic picking. Examples from sub-arrays at (a) 49.203° and (b) 75.477° epicentral distance from the Mw 6.1 earthquake, 23/5/2010.

+ Differential times between the final P, pP and sP phases are calculated and used in conjunction with a velocity model (currently using ak135 [1]) to determine earthquake depth.

+ A depth is ascertained per sub-array (assuming there are picked arrivals). The assemblage of sub-array depths are regressively filtered and used to determine a final depth for the earthquake hypocentre (Fig.5).

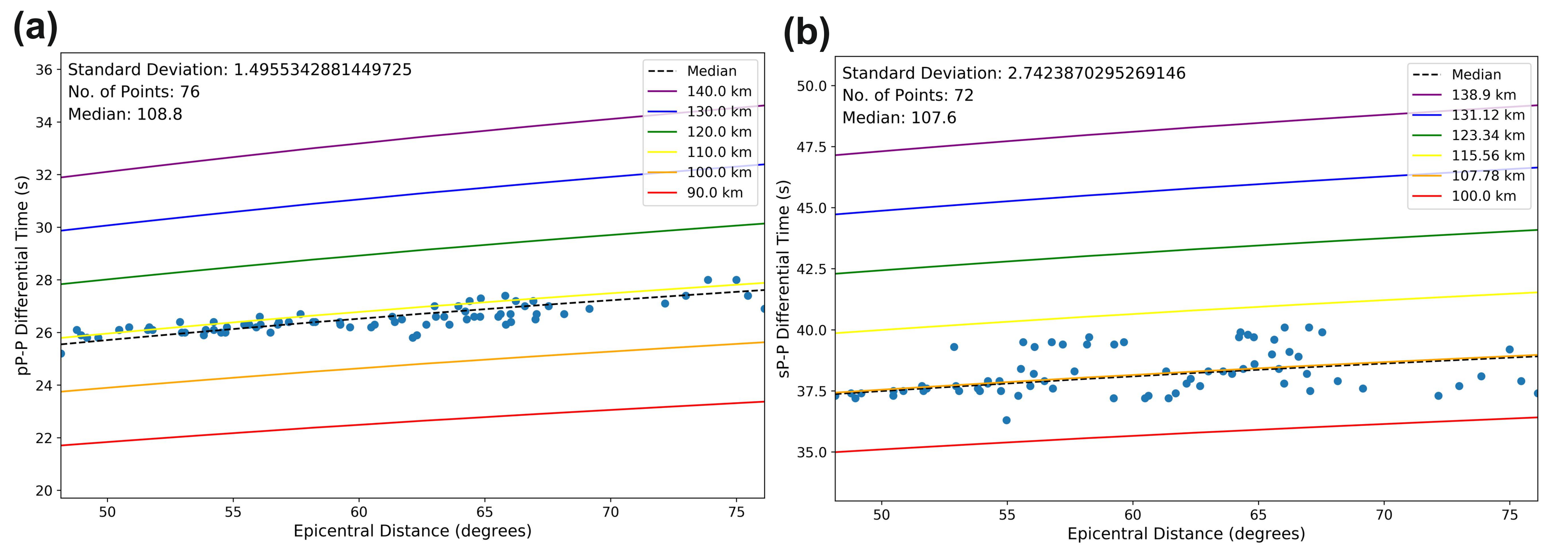


Figure 5. Plots of differential times versus epicentral distance for pP-P (a) and sP-P (b), with coloured lines indicating modelled differential times for given depths. Each dot indicates a result from one sub-array.

3. RESULTS

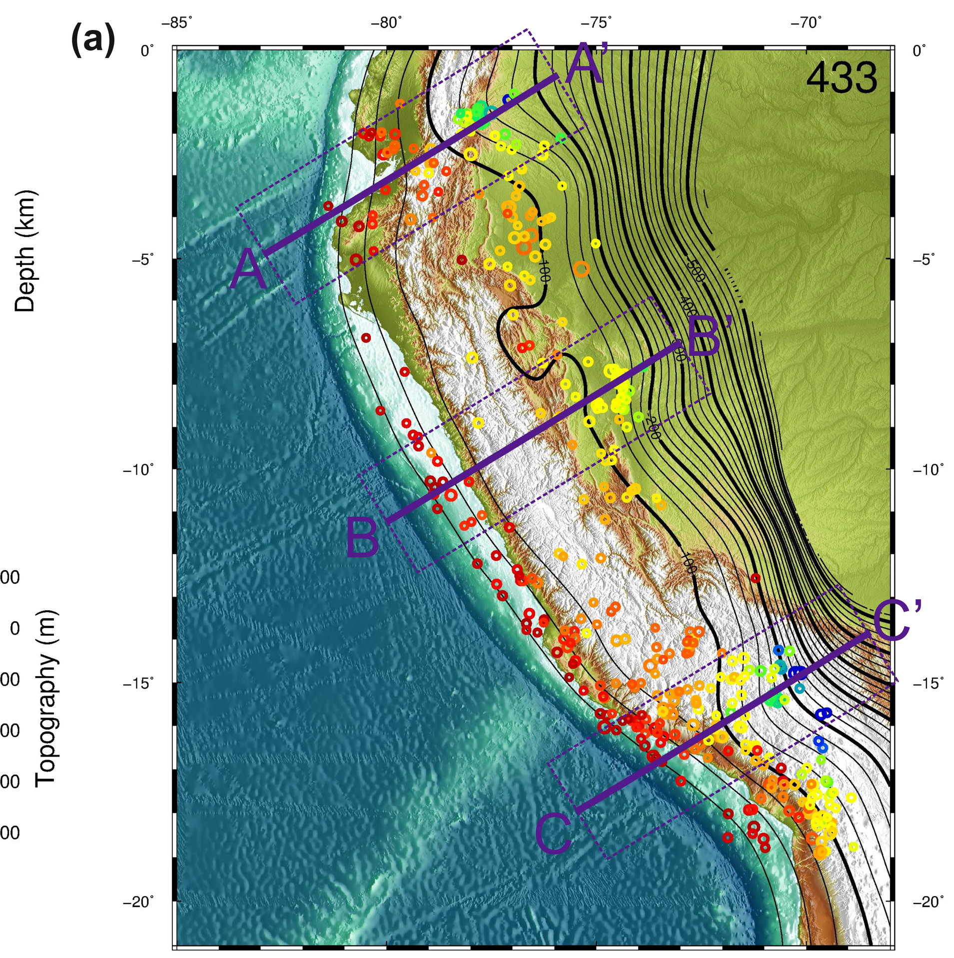
+ For Peru, 502 earthquakes from 1995 to present day have been processed.

+ 433 earthquakes have been successfully, automatically relocated in depth (see Fig.6 illustrating the preliminary catalogue).

+ The new earthquake catalogue indicates opportunity to investigate new slab features, and update the regional slab model.

+ As differential times between pP-P and sP-P are the main output of the approach, alongside the corresponding sub-array geometric centres, alternative depth inversions (including in 3D) and regional velocity models could be applied.

+ Success has also been observed for alternative tectonic settings, the approach corroborated the depth (~31 km) of an intraplate earthquake in Algeria determined by Wimpenny (in prep).



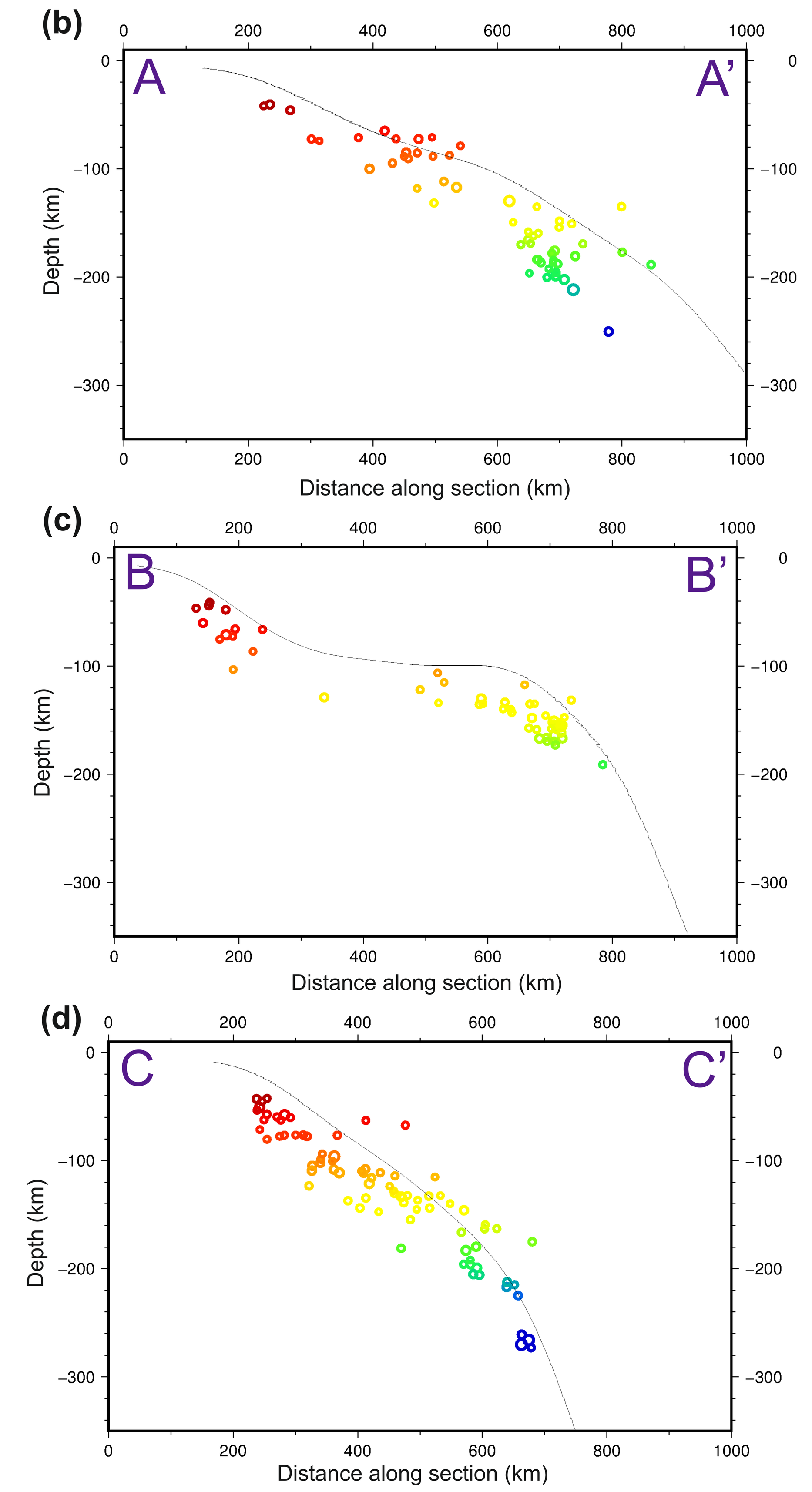


Figure 6. Intermediate-depth seismicity in Peru. (a) map of the Peruvian flat slab, with Slab2 contours and cross-section locations (including 125 km margins) [2]. (b-d) seismicity plotted on the cross-sections seen on a), and the location of the Slab2 model surface [2]. Earthquakes are colour-coded by depth and sized

4. CONCLUSIONS

+ A global distribution of stations can be automatically sorted into sub-arrays to enable array processing techniques upon intermediate-depth teleseismic data.

+ Array processing boosts signal-to-noise ratios of depth phases to an extent where they can be automatically picked using a threshold-based approach, and the phases identified using expected differential time comparisons.

+ Differential times for pP-P and sP-P are inverted for depth to create a preliminary earthquake catalogue for the Peruvian flat slab. Figure 7 illustrates the current success rates of the approach, and the ability to extend testing into smaller magnitudes.

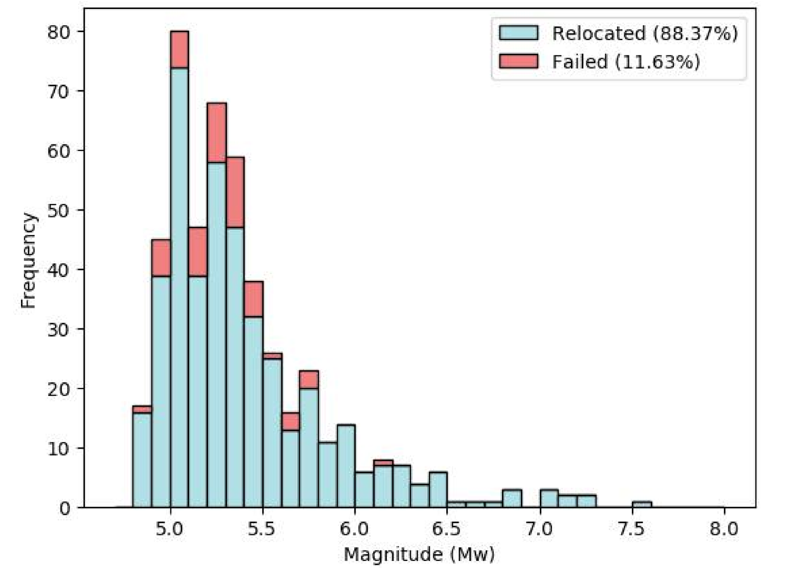


Figure 7. Histogram demonstrating the number of successful relocations per magnitude of earthquake tested for the Peruvian flat slab.

+ The final catalogue for Peru will allow earthquake nucleation and the geodynamic processes of the flat slab subduction to be investigated, in order to inform hazard assessments for populations residing on the overlying crust.

REFERENCES

[1] Kennett, B.L.N., 2005. Seismological tables: ak135. Research School of Earth Sciences, Australian National University Canberra, Australia, pp.1-289.

[2] Hayes, G. P., Moore, G. L., Portner, D. E., Hearne, M., Flamme, H., Furtney, M., and Smoczyk, G. M. (2018). Slab2, a comprehensive subduction zone geometry model. Science, 362(6410):58–61.