Lithospheric scattering and structure beneath seismic arrays from teleseismic P waveforms

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November 21, 2022

Abstract

Random and small-scale subsurface heterogeneities in velocity and/or density scatter the seismic wavefield when they have scale lengths on the order of the seismic wavelength. Seismic scattering is considered the origin of coda waves. Such inhomogeneities have an important effect on propagating waves, as they generate traveltime and amplitude fluctuations and may be the cause of attenuation or excitation of secondary waves. Understanding the effect of small-scale heterogeneities on the seismic wavefield is important for the characterization of the seismic source (e.g. source parameters of underground nuclear explosions) and to improve our knowledge of the Earth's structure along the raypath. Several approaches and methods have been suggested to study the scattering of seismic waves and characterise subsurface heterogeneities. Here, we apply a combination of the analysis of the incoherent wavefield component and the coda decay with time to a dataset of over 350 teleseismic events (over 20000 traces) recorded at three seismic arrays (Warramunga, Alice Springs and Pilbara) in Australia. This combination allow us to obtain a series of parameters (correlation length, RMS velocity fluctuations of the heterogeneities and thickness of the scattering layer) that give us a measure of the spatial scale and the magnitude of the heterogeneities present in the lithosphere beneath the arrays. This is the first time such a large dataset is used for a study of these characteristics. Our new results show similar structures and scattering strength for Alice Springs and Warramunga, while revealing a different tectonic signature and stronger scattering in the case of Pilbara, possibly caused by the different thicknesses of crust and lithosphere between these regions and its different tectonic history. These stochastic models of the lithosphere are the first step in the development of a technique analogous to adaptive optics which, in this case, aims at removing the effect of the small-scale, near receiver structure from recorded wavefields, thus enabling us to improve our source characterization and to more clearly image the Earth's interior.

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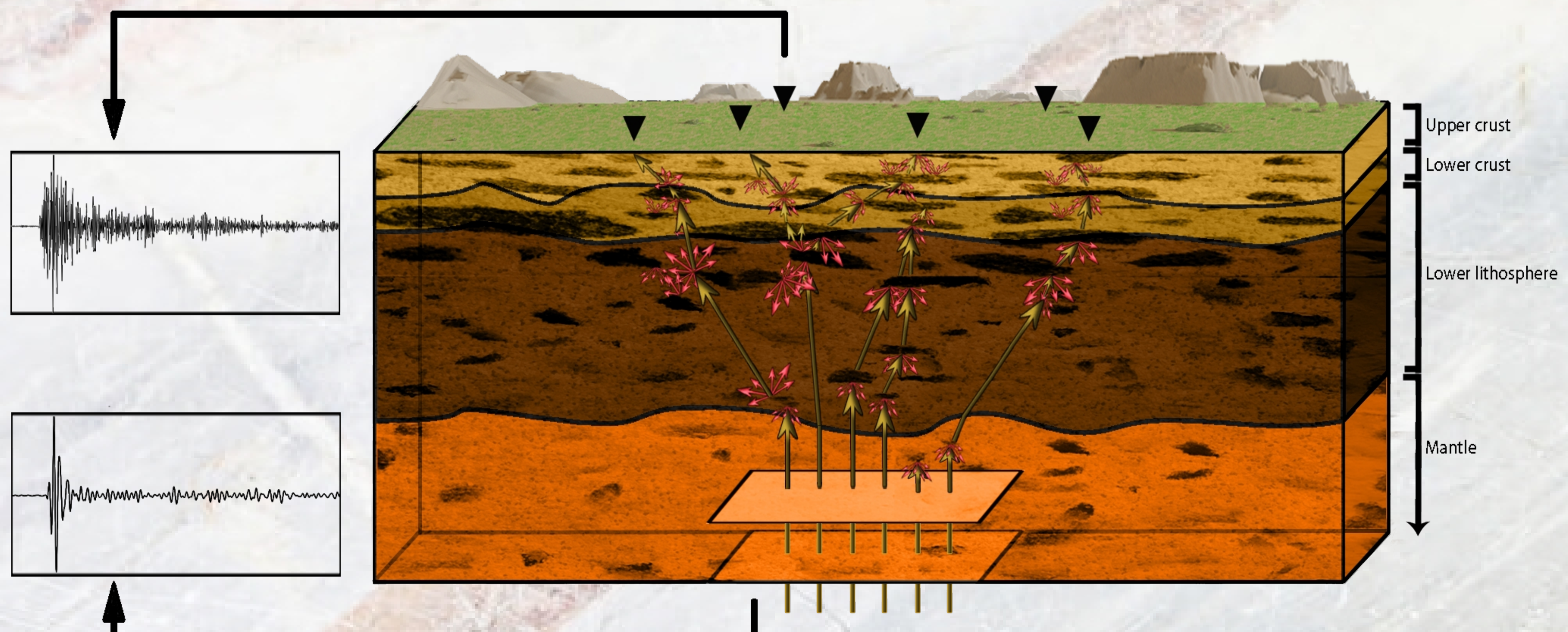
D51-0590

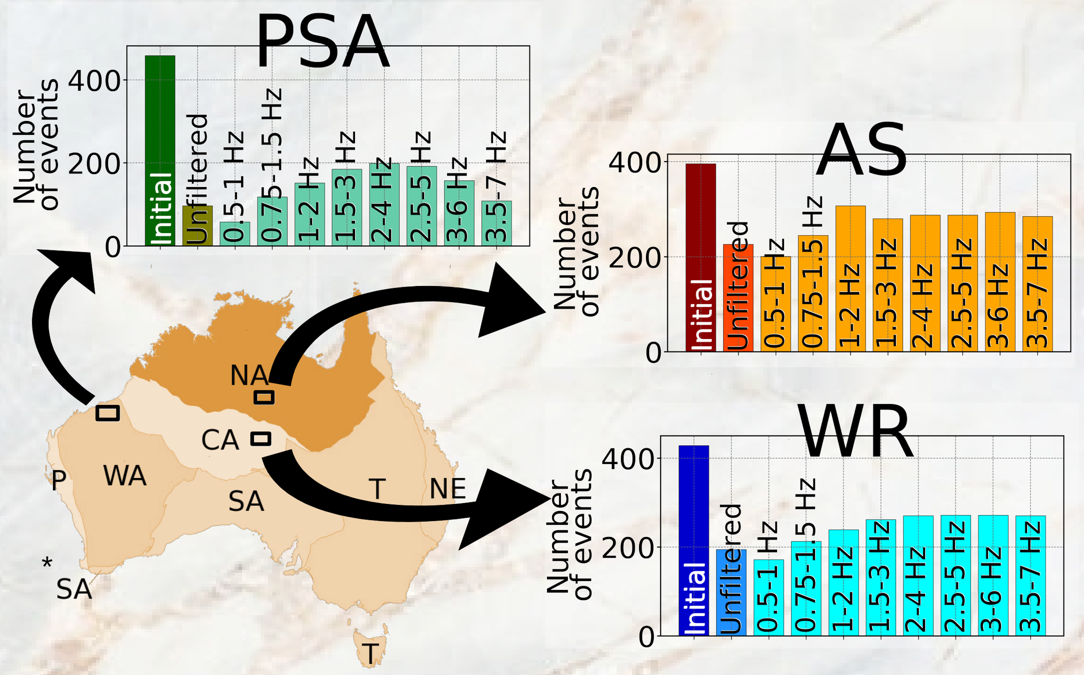
1. Seismic scattering

- Discontinuities and heterogeneities within the Earth's structure reflect, refract and scatter the energy seismic waves carry.
- Inhomogeneities:
  - are more abundant in the crust and upper mantle.
  - the size of the wavelength have the biggest effect on seismic waves.
- Incoherent scattered energy arrives later, and is the origin of seismic codas, whose shapes and amplitudes can vary from station to station.

The object of this study is to determine the stochastic small-scale structure of the lithosphere beneath three seismic arrays, which allows us to quantify scattering strength and compare it with other physical mechanisms that also cause amplitude attenuation in seismic waves.



2. Dataset and Methods



*MAJOR TECTONIC ELEMENTS
CA - Central Australia; **NA** – North Australia; **NE** - New England; **P** – Pinjarra; **SA** - South Australia;
T – Tasman (orogenic system/ fold belt); **WA** - Western Australia. Map modified from Shaw, R.D. Wellman, P., Gunn, P., Whitaker, A.J., Tarlowski, C., and Morse, M., 1996, Australian Crustal Elements based on the distribution of geophysical Domains, (1:5 000 000 scale map; version 2.4, ArcGIS dataset). Geoscience Australia, Canberra.

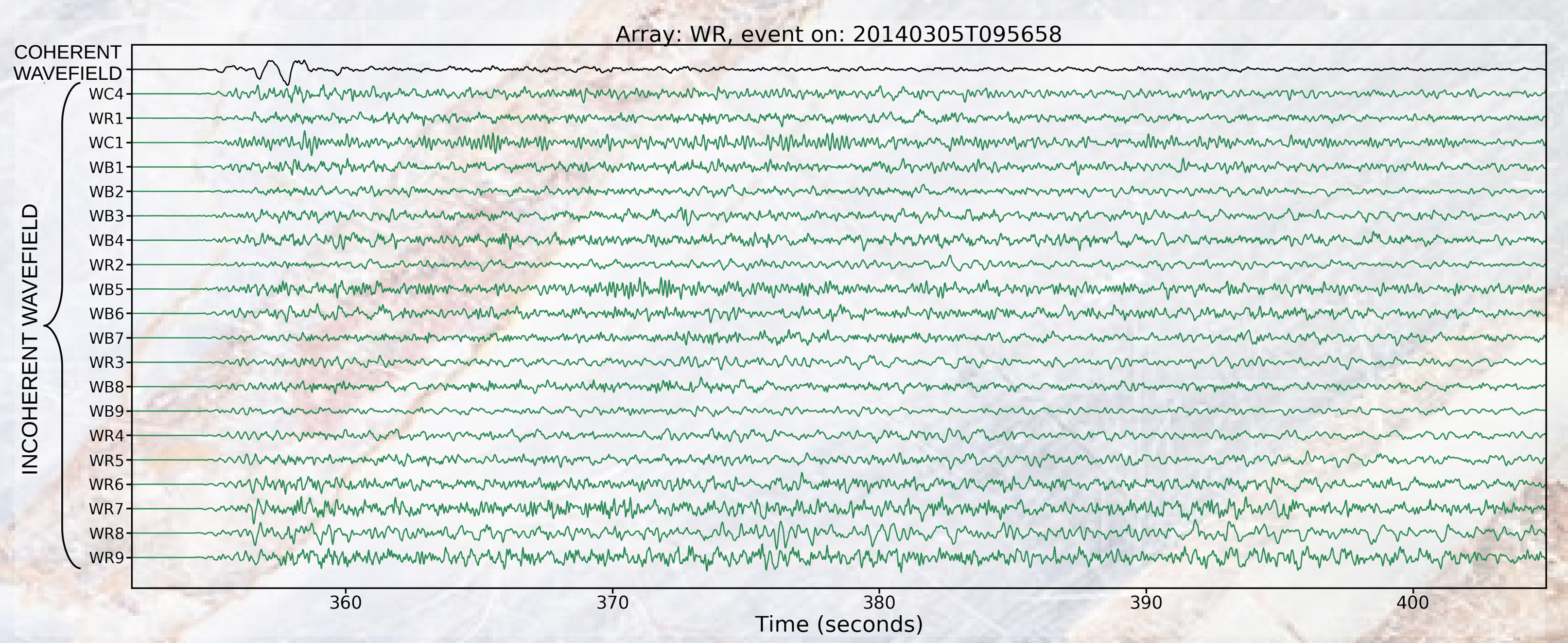
Largest dataset ever used in a study like this. Earthquakes from 2012 to 2017:
- 30º to 80º away from the arrays
- 200 km minimum depth
- Magnitude 5 to 7

Teleseismic Fluctuation Wavefield Method (TFWM) + Energy Flux Model (EFM) → **Structural parameters:** *Correlation length:* ***a****, Velocity variations:* ***ε****, Layer thickness:* ***L***

3. Teleseismic Fluctuation Wavefield Method Results

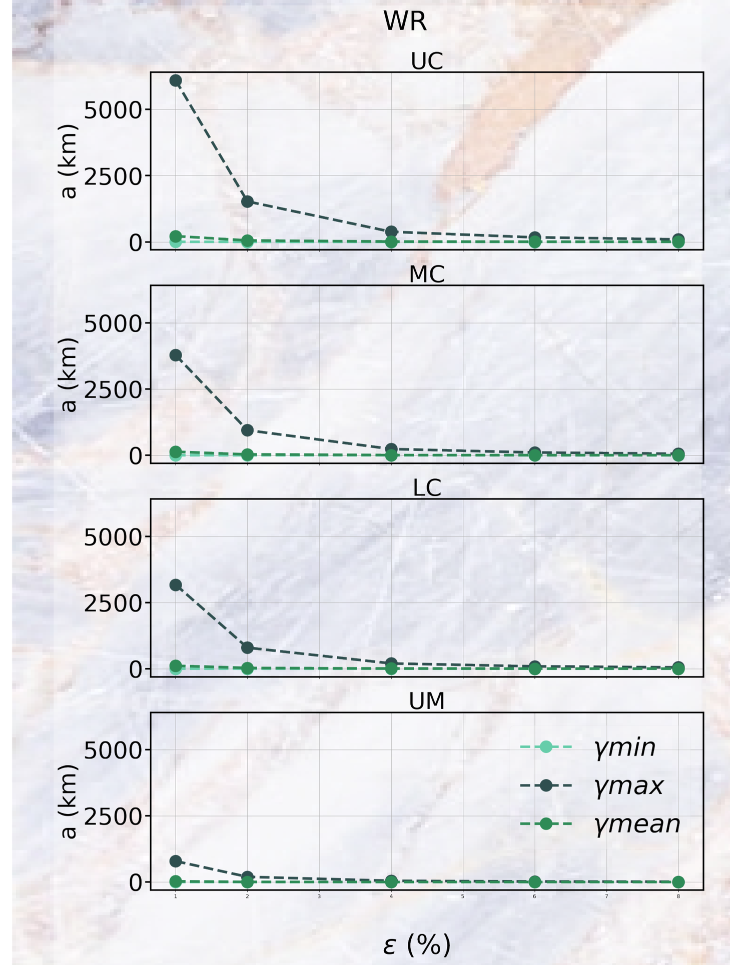
Coherent vs. Incoherent wavefield

The TFWM uses the ratio between the spectra of the coherent and incoherent wavefields to obtain the structural parameters.
The coherent wavefield is obtained by stacking all the traces for a given event and array. The incoherent wavefield for each station is the subtraction of the coherent wavefield from individual traces.



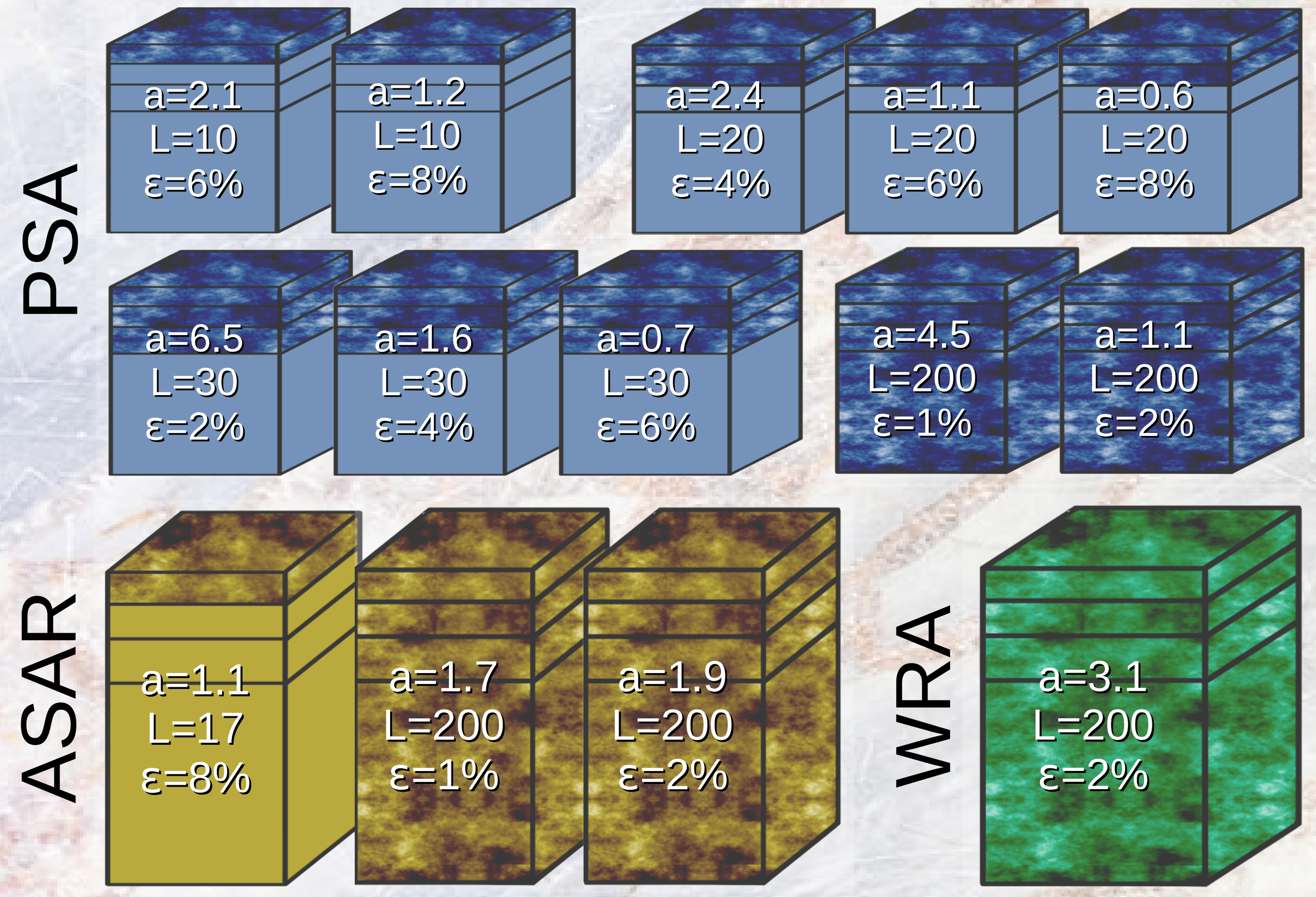
Trade off curves

Correlation length (a) and RMS velocity variations can't be solved separately in the TFWM



Structural parameters values

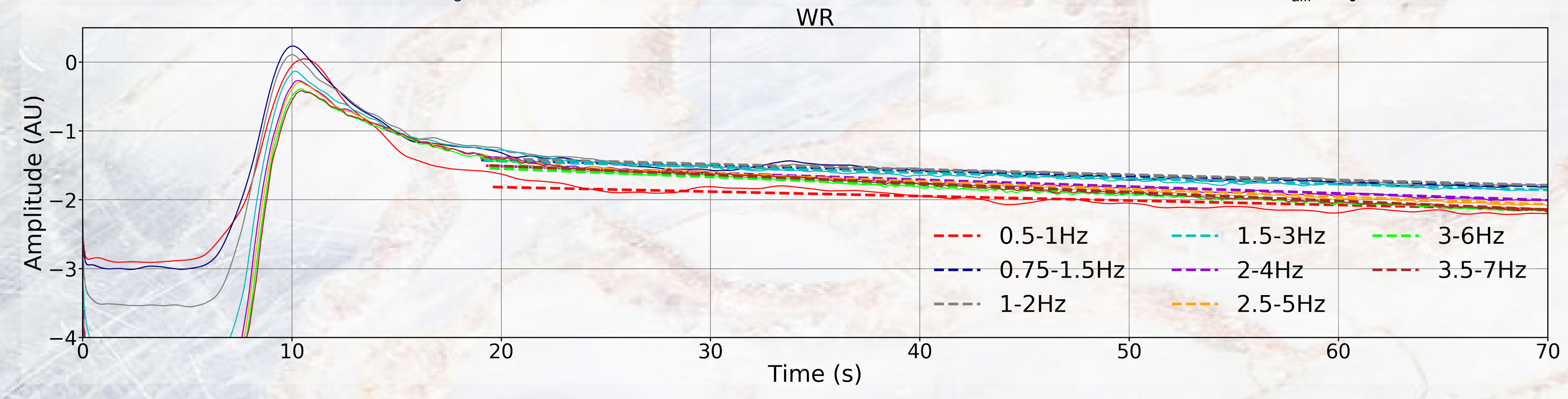
Possible combinations of values of the structural parameters that fit the data for each array. Lengths are given in kilometres.



4. Energy Flux Model Results

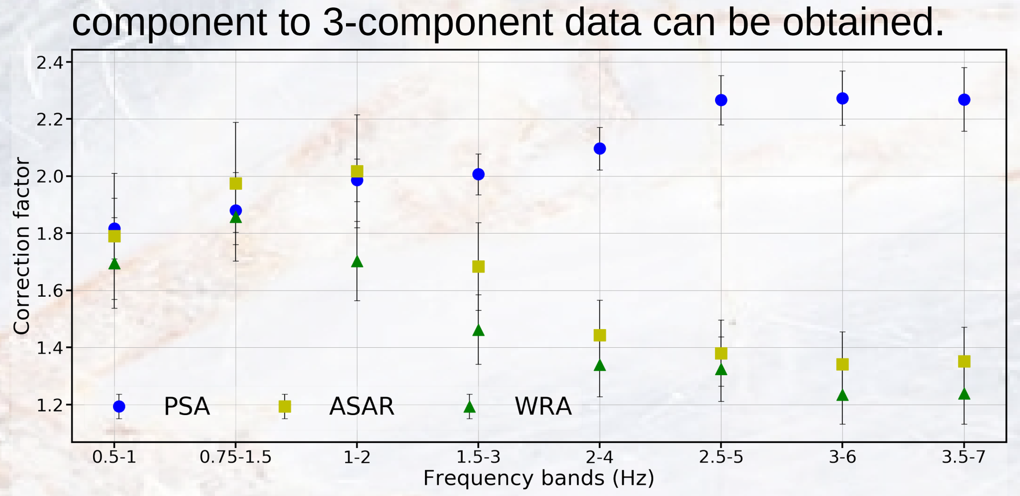
Coda decay fit

A linear function is used to fit the coda decay for each frequency band. A least squares fit of the intercept values allow to obtain scattering Q (Q_s), while the slope ones are used to obtain diffusion and intrinsic Q (Q_{diff}, Q_0).

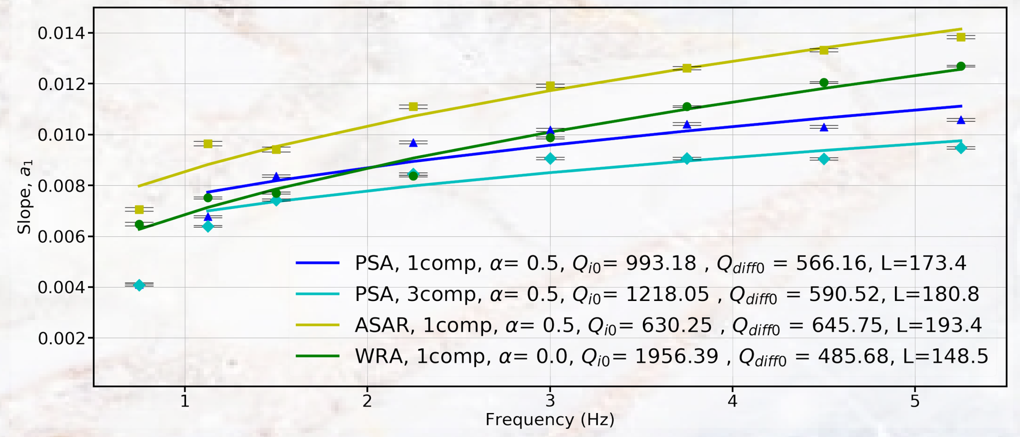


3-to-1 component data correction factor

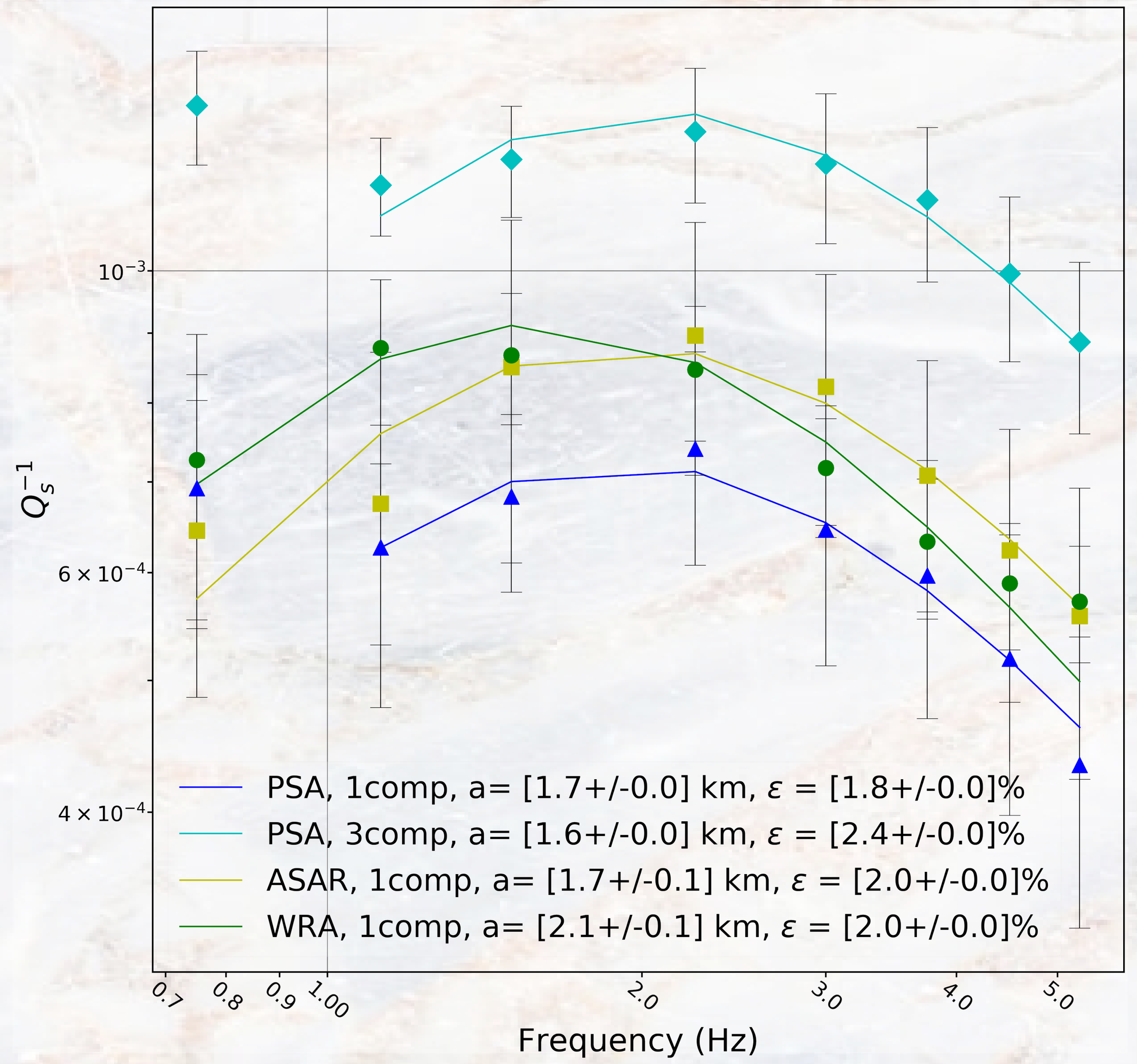
The EFM underestimates the values of the structural parameters when applied to 1-component data. However, a correction factor to convert from 1-component to 3-component data can be obtained.



Diffusion and intrinsic Q

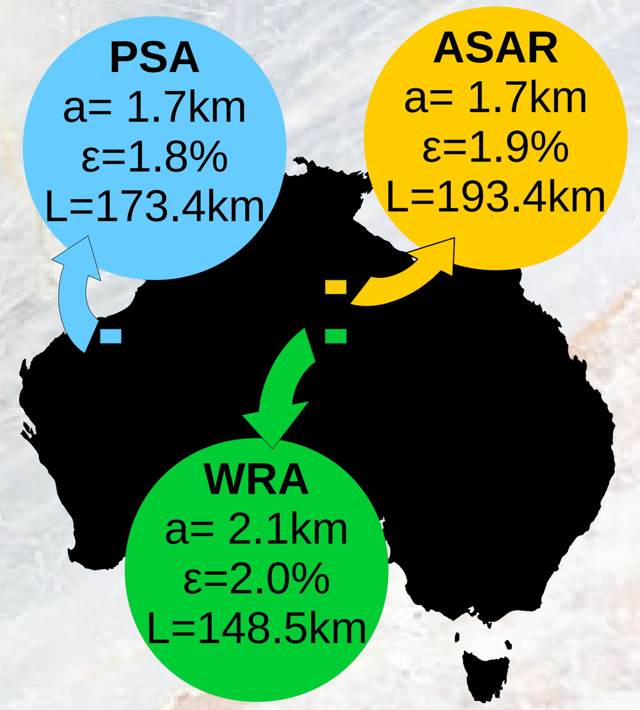


Scattering Q



5. Conclusions

- The structural parameters for all three arrays are similar and in agreement between the two applied methods. They suggest scattering is the main cause of amplitude attenuation of seismic waves and that the lithosphere is the largest contributor of scattered energy for all three arrays.
- The EFM is not able to resolve changes in a multi-layer scattering medium. We will apply a modified Energy Flux model (Korn, 1997) to these data to resolve the differences in crustal heterogeneities.



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References: **1. Shapiro, S.A. and Kneib, G., 1993.** Seismic attenuation by scattering: theory and numerical results. Geophysical Journal International, 114(2), pp.373-391. **2. Korn, M., 1990.** A modified energy flux model for lithospheric scattering of teleseismic body waves. Geophysical Journal International, 102(1), pp.165-175. **3. Korn, M., 1997.** Modelling the teleseismic P coda envelope: depth dependent scattering and deterministic structure. Physics of the earth and planetary interiors, 104(1-3), pp.23-36.