AusArray: Toward updatable, high-resolution seismic velocity models of the Australian lithosphere

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SUMMARY

In order to improve exploration success under cover the UNCOVER initiative identified high resolution 3D seismic velocity characterization of the Australian plate as a high priority. To achieve this goal government and academia have united around the Australian passive seismic Array project (AusArray) which aims to obtain a national half degree data coverage and an updateable 3D national velocity model which grows in resolution as data become available.

AusArray unites data collected from the Australian National Seismological Network (ANSN), multiple academic transportable arrays (supported by AuScope and individual grants) as well as the seismometers in schools program. A recent addition has been Geoscience Australia's Exploring for the Future program (EFTF) which has doubled the national rate of such data collection. Extensive quality-control checks have been applied across this combined dataset to improve the robustness of subsequent tomographic inversion and interpretation. The aim being an updatable national velocity reference model with resolution from depths of a few meters to hundreds of kilometres.

The first stage of lithospheric seismic modelling has been the development of P and S body-wave tomography models. An initial earthquake catalogue of ~26,000 events, dating from 1993 to present, has been developed. This is used to estimate first-arrival times using high-performance routines on the National Computational Infrastructure supercomputer facility. Obtained parametric data were then used in non-linear tomographic inversion with a realistic wave propagation scheme. Resulting P and S tomographic images show a strong correlation with major crustal and lithospheric mantle boundaries. Vp and Vs variation patterns are not always positively correlated thereby providing new insights into the architecture of the Australian plate. Integration with resistivity models derived from magnetotelluric data provide insights into the control of minor phase distribution on the imaged architecture.

Keywords: Lithospheric structure, seismic array

INTRODUCTION

Imaging of the Australian lithosphere with broad-band seismic data began in the early 1990s with the deployment of movable seismic arrays such as SKIPPY (van der Hilst et al. 1994, Zielhius and van der Hilst, 1996). During the past three decades, a number of passive seismic experiments have been successfully carried out. The ANU Seismology and Mathematical Geophysics group has deployed a number of independent passive seismological arrays in remote regions of Australia since, focusing specifically on the southeastern part of the continent (e.g. Rawlinson, 2008). The ongoing work continues this effort. At the same time, new seismological imaging methods have evolved leading to numerous Earth models using surface wave data (e.g. Debayle and Kennett, 2000), ambient noise analysis (e.g. Saygin and Kennett 2010) and full waveform inversions (e.g. Fichtner 2009). Since these studies present the application of different methods to different subsets of seismic data the comparison of models is difficult. Development of a national approach to seismic imaging was highlighted as a high priority by the UNCOVER initiate and therefore Geoscience Australia in collaboration with academia and AuScope initiated the national scale AusArray project. Our objective is a national half degree data coverage and an updateable national velocity framework model that can be used to nest higher resolution regional models to inform interpretation of geological and geophysical data for mineral potential assessments, underpin seismic hazard assessments and inform natural resource management. Here we outline our steps towards data assimilation and national body-wave model generation.

METHOD AND RESULTS

All available seismic waveform records from Exploring for the Future deployments, ANSN, and those obtained by universities in field campaigns since 1993 (Figure 1) have been thoroughly QA/QC checked for possible clock errors and metadata correctness. First, all files were associate with their metadata. Then, the time of P-wave arrivals from known earthquakes was estimated and compared to those from neighbourhood stations and theoretical travel-time models to detect implausible travel-time variations. Such variations often reveal errors associated with faulty digitizer clock. Finally, station pairs were cross-correlated to detect small clock drifts. Time periods of stations with questionable data quality were removed from further analysis.

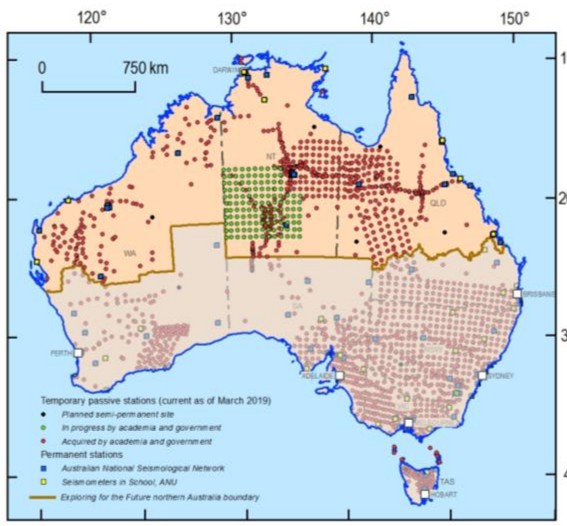

Figure 1. AusArray station locations that include ANSN, current, and legacy passive seismic deployments. The unmasked region of northern Australia depicts the extent of Geoscience Australia's *Exploring for the Future* programme.

After pre-processing, high quality waveforms were used to estimate arrival times of P and S-waves, for an earthquake catalogue of ~26,000 events, using an autoregressive method based on the Akaike Information Criterion (Chen and Holland 2016). Residuals relative to traveltimes predicted from the AK135 1D Earth model (Kennett *et al.*, 1995) are then used in a nonlinear tomographic inversion scheme (Gorbatov et al. 2000) to image seismic velocities.

We implement an adaptable irregular grid-mesh for parameterisation of the subsurface (Figure 2). In contrast to previous studies (*e.g.* Burdick *et al.*, 2008), we vary grid-size based on the results of resolution testing (Yao *et al*, 1999; Hejrani et al., 2014; 2017). Increases in data coverage with each model update will increase the model resolution and, consequently, decreases the model cell size. Our tomographic models have a lateral cell-size of 0.5 by 0.5 degrees beneath dense arrays, expanding to 5 by 5 degrees in areas with reduced data coverage.

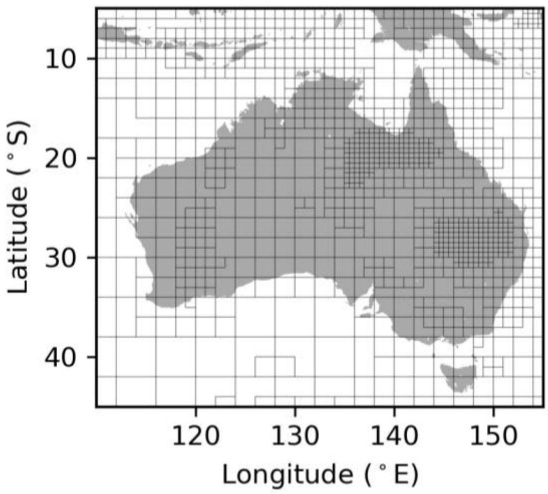

Figure 2. Example of an irregular grid-mesh used in tomographic modelling. Grid-size is adapted to the current model resolution.

Results

At this stage high-resolution results are currently available in the vicinity of the dense arrays across the Northern Territory-Queensland border (Figure 1). In this region the inferred seismic velocities show a strong correlation with major crustal boundaries (Figures 3 and 4). Lower seismic velocities, for both Vp and Vs, are observed beneath the Paleoproterozoic-Mesoproterozoic Mount Isa Orogen (Figures 3 and 4). These features are also correlated with deep electrical conductivity anomalies (Wang, 2014), and positive magnetic, gravity, and heat flow anomalies (Bacchin *et al.*, 2008; Hasterok and Gard, 2016; Milligan *et al.*, 2010).

We observe variations in seismic velocity coincident with the North Australian Craton indicating it has a heterogeneous internal structure. We also note a divergence in the correlation between Vp and Vs. Such differences likely map variations in composition (e.g. Gorbatov and Kennett 2003, Yuan 2015, Skirrow et al., 2018). Comparison of tomographic image variations with resistivity maps derived from magnetotelluric surveys may help to explain if these inconsistencies are thermal or compositional in nature.

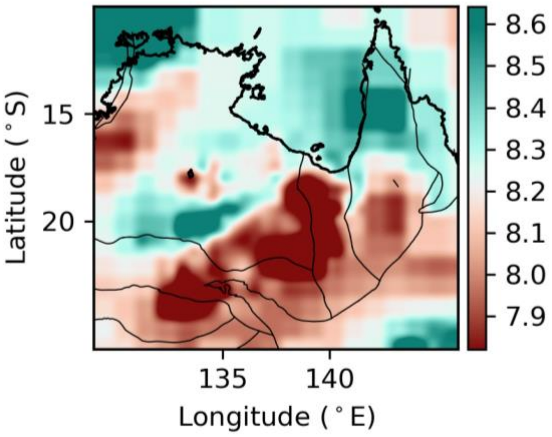

Figure 3. P-wave velocity (km/s) structure at 185 km depth. Thin lines are crustal boundaries, from Korsch and Doublier (2014).

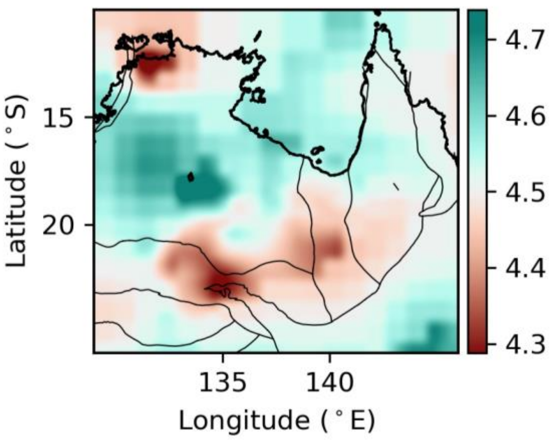

Figure 4. S-wave velocity (km/s) structure at 185 km depth. Thin lines are crustal boundaries, from Korsch and Doublier (2014).

CONCLUSIONS

Dense seismic arrays have enabled tomographic imaging of the Australian lithosphere. Inferred P and S-wave velocity structures correlate with major crustal boundaries. Vp and Vs variation patterns are not always positively correlated, and these deviations may provide new insights into the architecture of the Australian plate.

Our results represent an initial step in the goal to produce a high-resolution 3D seismic model of the Australian lithosphere. Our tomographic models will be progressively updated as new arrays are deployed, advances in inversion techniques are incorporated, and data from older and new arrays is processed through QA/QC algorithms. Future integration of these models with other geophysical observables will bring new insights into the structure and composition of the Australian lithosphere.

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