Locating Australian Earthquakes Using the Australian Seismological Reference Model (AuSREM)

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ABSTRACT:

Grids of full 3D seismic travel times are computed for all AU network stations using the Australian Seismological Reference Model (AuSREM), released in late 2012. Location estimates of Australian earthquakes, including five well located (ground truth) events using Australian models, the global ak135 reference model and the full 3D travel times are compared. It is found that the 3D model results in improved or comparable locations compared to those from the local Australian 1D models. Results are also improved compared to using the global model ak135.

Keywords: AuSREM, 3D earthquake locations

1. The AUSREM and the derived travel-times

AuSREM, published by Kennett and Salmon (2012), is a 3D velocity model for Australia defining velocities on two grids, one for the crust and one for the mantle down to a depth of 300 km. In addition, a 2D MOHO depth grid is provided to separate the crust and mantle. The horizontal spacing of these grids is 0.5 degrees in latitude and longitude. The crustal grid has 1 km vertical spacing, the mantle grid 25 km vertical spacing. The model is derived by combining several data sources, such as receiver functions, crustal tomography, refraction/reflection surveys, surface wave tomography and P/S travel time tomography. The MOHO depth data in AuSREM do not cover the entire geographical grid used here (especially the ocean in the corners). These regions of missing data were filled in using extrapolation, so travel times for these regions are non-physical.

3D grids of travel times were pre-computed for all AU network stations used in this study using the Multi-Stage Fast Marching Method (de Kool, Rawlinson & Sambridge, 2006). This method, at the grid resolution used (0.125 degree in latitude and longitude, 5 km in depth), can introduce travel time errors of up to 0.3 seconds for P phases, although on average these errors are much lower. These travel time uncertainties are considerably smaller than those introduced by errors in the velocity model.

Figure 1 shows the travel time differences between the 3D model and the ak135 reference model of first P and S arrivals, for the 3 stations NWAO, WRA and CTA. The sources are at 5km depth. Very large deviations from the ak135 predictions, up to 5 seconds for P travel times and 22 seconds for S travel times are found. The pattern observed is reflective of a very fast region in western Australia, and a slow region in north-eastern Australia. The reality of these large deviations from the ak135 model is borne out by observations. Typically the largest deviations from the ak135 reference model occur for source-receiver distances in the range between 15 and 23 degrees.

2. Location of GT events using the different travel time models

Five ground truth (GT) events (figure 2 and table 1) have been located using 3 travel time models: 1) ak135 travel times, 2) full 3D travel times derived from AuSREM, and 3) local Australian velocity models used for the Geoscience Australia (GA) location. For the first and second models our own location program based on the Neighbourhood Algorithm (NA) (similar to Sambridge and Kennett, 2001) was used. For the third model the location algorithms within the Antelope analysis system (dblocsat2, genloc) were used. In addition, analysis methodology differed between models. For the first two models all well-defined P and S arrivals were used. Results for the third model were taken from the GA database. The normal practise for analysis in this case is to use clear arrivals on nearby stations and to mark more unclear arrivals as associated but non-defining.

In figures 3 to 7, a map of the locations derived by different methods for each event is presented. The individual earthquakes and their estimated locations are discussed in the figure captions. Table 2 lists the distance from the ground truth event for each of the model solutions. These results are also plotted in figure 7.

Table 1 Origin information and ground truth level for the five well-located events used in this study. An estimate of the accuracy of location is given by the GT value assigned to each event. Those origin times marked with an asterisk indicate that this time has been taken from the GA database.

Origin Time	Lat	Lon	Depth	M	Location	Comments
2007-10-09 23:58:40*	-33.9544	117.5319	0.6	4.7	Katanning	GT2 (InSAR)
2010-04-20 00:17:10	-30.7866	121.4892	1.7	5.0	Kalgoorlie	GT2 (Local network)
2012-06-09 14:22:15*	-26.1214	132.1271	4	5.4	Ernabella	GT5 (Surface feature)
2012-11-29 19:21:21	-27.80525	140.7534	4.3	4.0	Innamincka	GT1 (Local network)
2012-06-19 10:53:29	-38.252	146.234	9.4	5.4	Moe	GT5 (Local network)

Table 2 Distances between each of the model locations and each ground truth event location. The models used are: **3D** AuSREM, **Ak135**, local models used to produce the **GA** catalogue.

	Location Error (km)		
Event	**3D**	**Ak135**	**GA**
Katanning	4.4	14.0	2.6
Kalgoorlie	8.3	12.6	8.3
Ernabella	4.8	14.2	13.4
Innamincka	4.0	10.2	10.6
Moe	2.3	3.3	7.5

3. Location of Australian Earthquakes 2010 to 2013

Events from the GA Australian catalogue for the last three years (July 2010 to August 2013) were extracted and relocated using the AuSREM model and the neighbourhood algorithm. The stations and arrival times used in the location were taken from the GA database, so the same set of arrivals, as used in the GA catalogue, were used in this comparison. This means that the stations used were in most cases located at local and regional distances from the epicentres.

Analysis of these results is focussed upon a region near Koorda where many earthquakes were available for comparison. The results are shown in figure 9 where it is observed that the locations using the AuSREM model and the neighbourhood algorithm (blue) are more tightly clustered than those from the GA catalogue (yellow). Time residuals for both P and S arrivals for the various models are shown in figure 10. The results of GA analyst procedures are seen in Figure 10 where the S time residuals for GA locations rarely exceed two seconds.

4. Discussion

In this study events were relocated using the AuSREM model and the neighbourhood algorithm. Therefore, interpretations need to consider both the effects of the model and the location method. With regards to the results of the relocation of the 5 ground truth events, Figure 8 shows that the AuSREM model results in better locations for 3 of the 5 events, with the remaining 2 events having comparable locations. Locations using the AuSREM model used all well-defined stations and P and S arrivals in comparison with the locations from the GA database which generally used nearby stations. The use of P and S arrivals from a broad distance range provides confidence in the accuracy of the travel times derived from the AuSREM model. The 5 ground truth events form a small data set that do not evenly sample the continent, however the results do show promise for the routine use of a single continental scale travel-time model.

For the comparison of Australian earthquakes in the Koorda region for the period 2010 to 2013 identical arrivals were used for both locations. These events are in the main small and nearby stations are used. The tightening of the epicentres is thought to indicate the difference in location methods.

5. Conclusions

The use of continental scale travel times from the AuSREM velocity model can potentially improve location accuracy when using the Australian network.

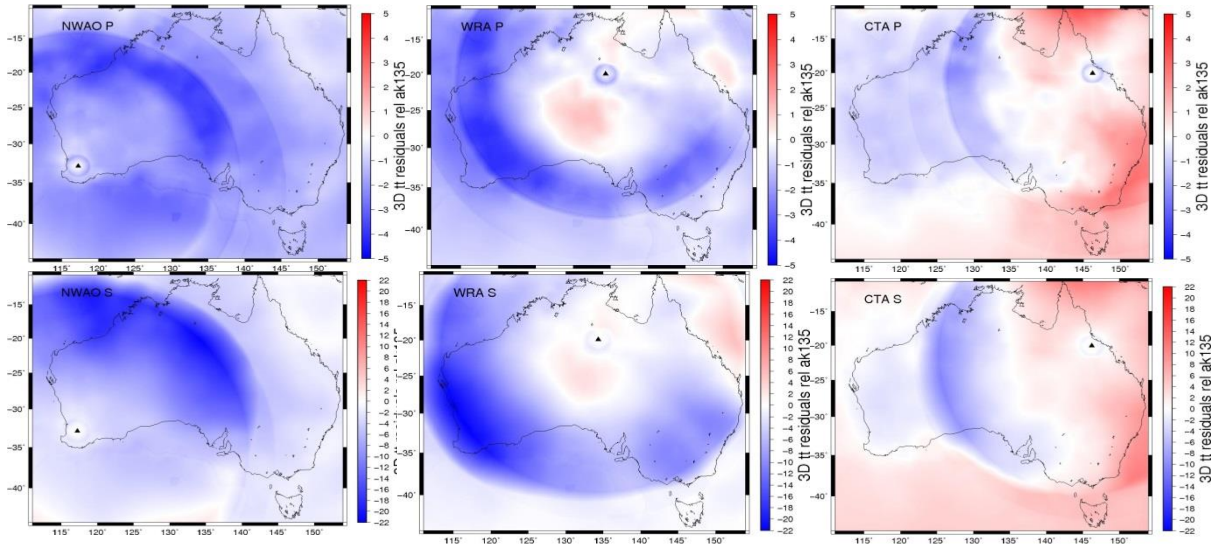

Figure 1. Example travel time residual distribution for the first P and S arrivals computed in 3D through the AuSREM model, relative to ak135. Results are plotted for the 3 IMS stations NWAO, WRA and CTA. The approximate concentric structure in the P residuals around the stations represent the Pg-Pn transition at ~ 2 degrees, the radius at which Pn starts to dive into the mantle (~14 degrees), and first P bottoming below the 410 and 660 discontinuities (~ 18 and 23 degrees). A similar but less pronounced structure is seen for the S times. Note the very fast mantle below the west, and the slow mantle below the north-east

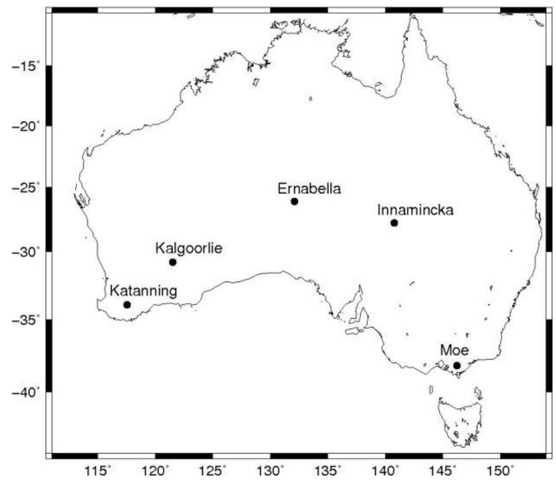

Figure 2. Location of the 5 GT events on the Australian continent

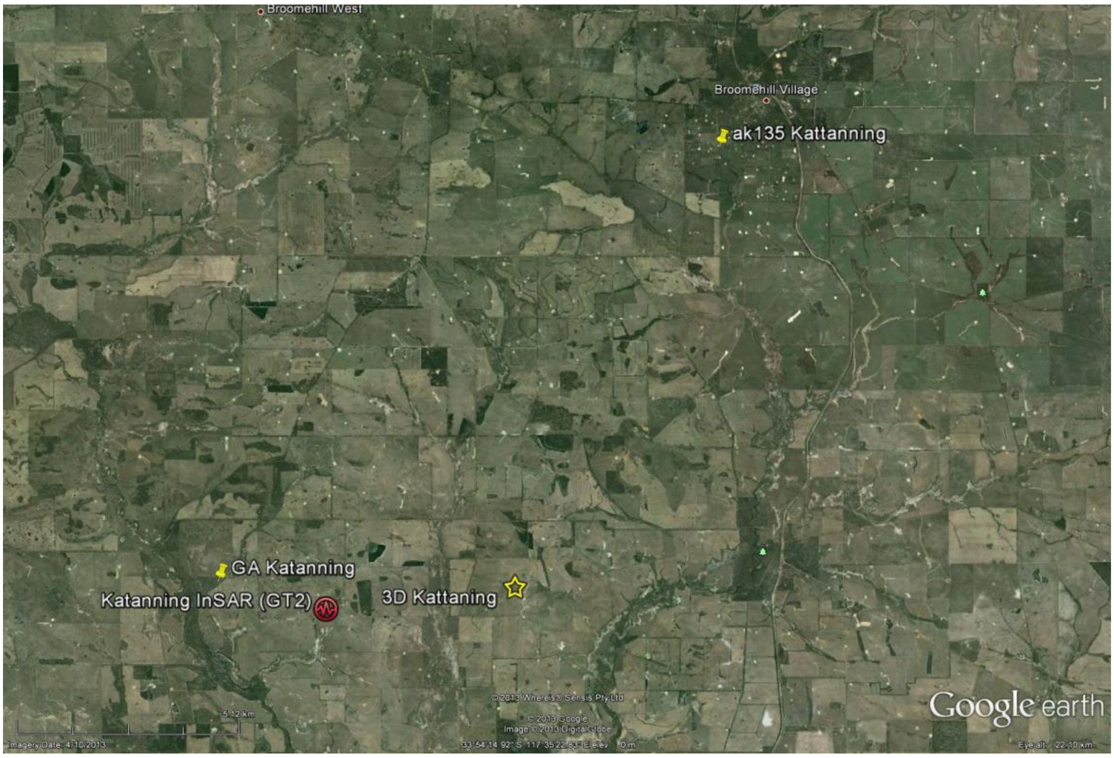

Figure 3. Katanning: This mb4.0 earthquake was accurately located using InSAR surface deformation measurements. Location errors are d(ak135)=14.0 km, d(3D)=4.4 km and d(GA)=2.6 km.

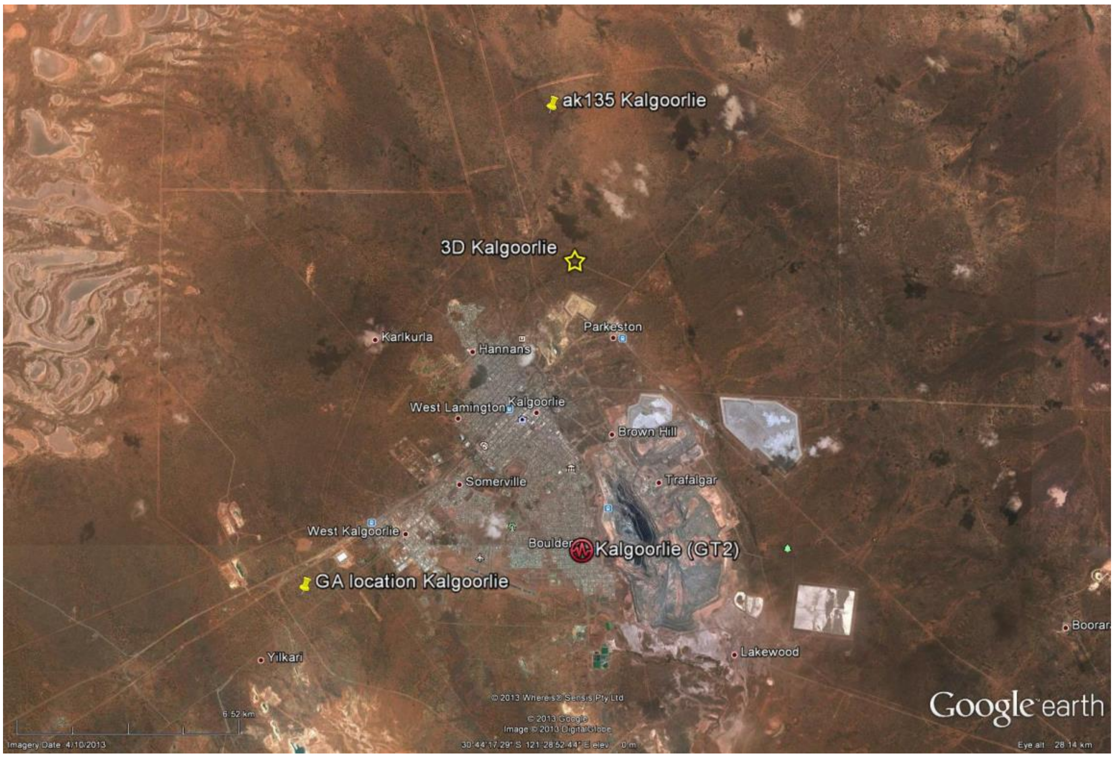

Figure 4. Kalgoorlie: This mb5.0 earthquake was well located using a local mine monitoring network. Location errors are d(ak135)=12.6 km, d(3D)=8.3 km and d(GA)=8.3 km. Using only P and S phases on 7 stations < 6 degrees distant this improves to d(ak135)=9.6 km and d(3D)=4.5 km.

Figure 5. Ernabella: For this Mw5.3 earthquake ground truth was obtained using an observed surface rupture. Location errors are d(ak135)=14.2 km, d(3D)=4.8 km and d(GA)=13.4 km.

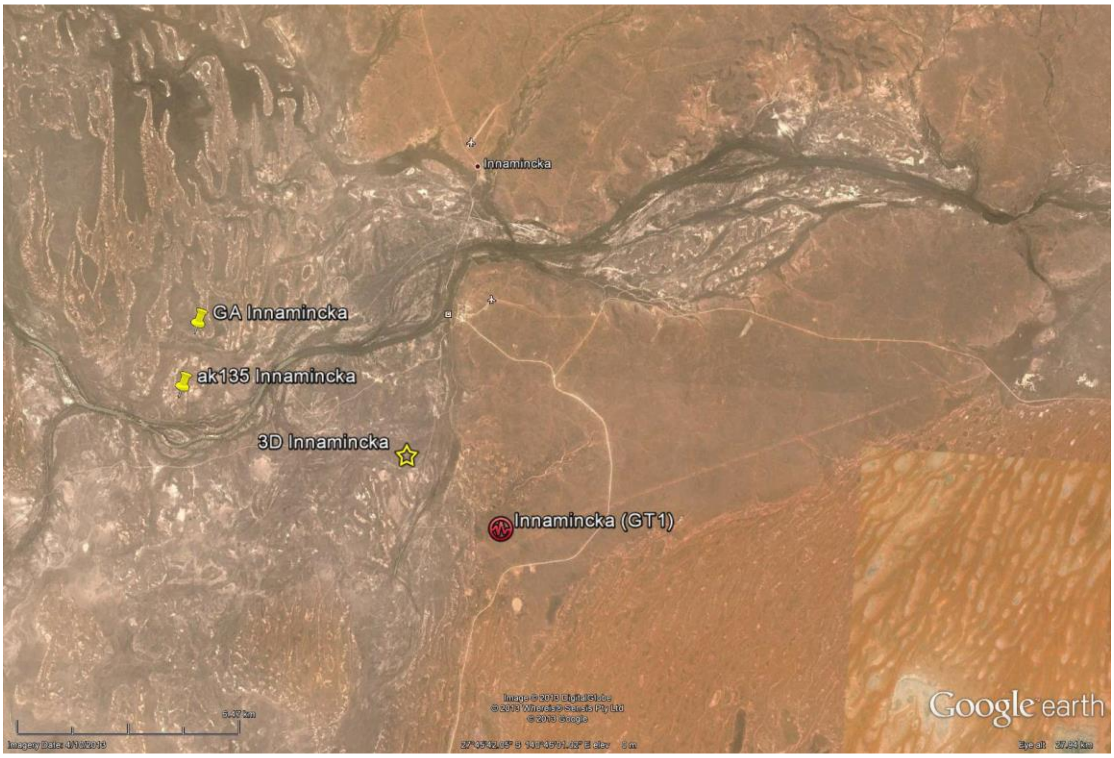

Figure 6. Innamincka. This mb4.0 earthquake was located accurately by the local monitoring network of a geothermal project. Location errors are d(ak135)=10.2 km, d(3D)=4.0 km and d(GA)=10.6 km.

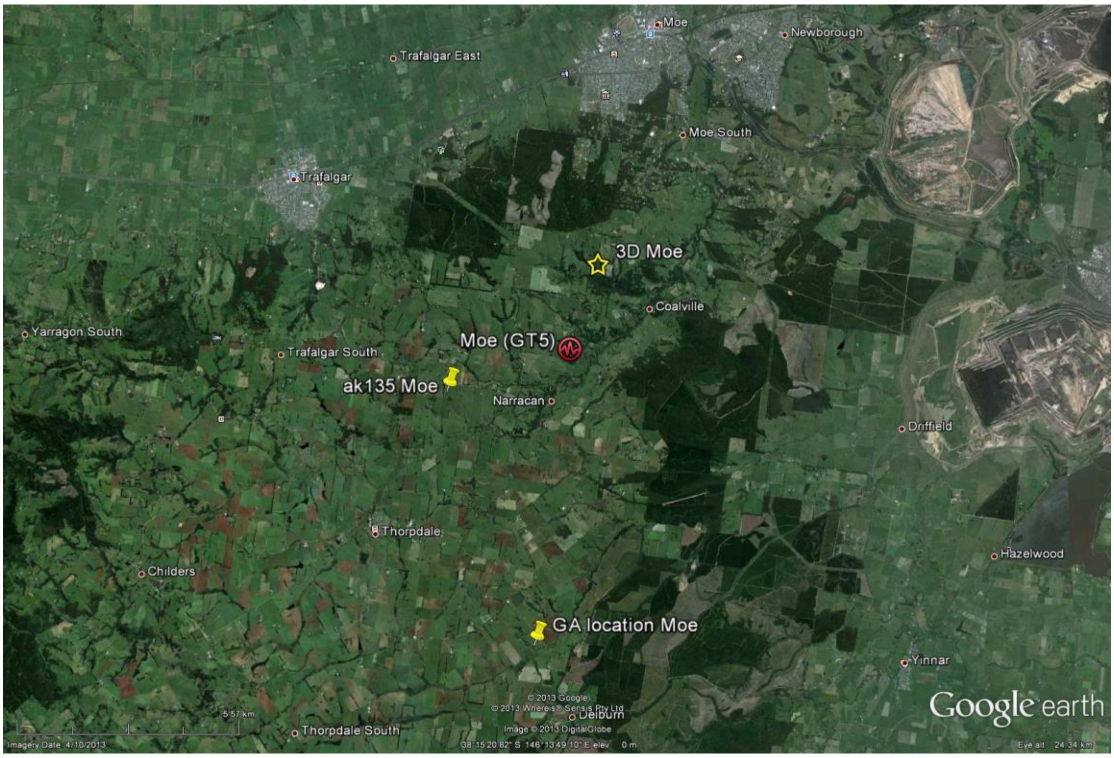

Figure 7. Moe. This Mw5.4 earthquake was well located using a regional network (Dan Sandiford, pers. comm.). Location errors are d(ak135)=3.3 km, d(3D)=2.3 km and d(GA)=7.5 km. S phases were difficult to pick for this event.

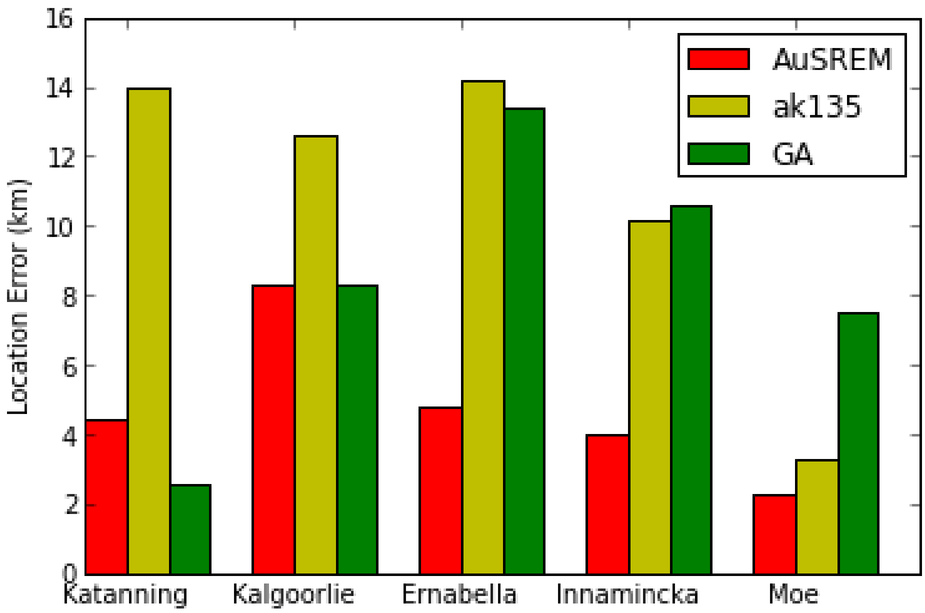

Figure 8. Location errors from 5 ground truth events calculated using the three velocity models.

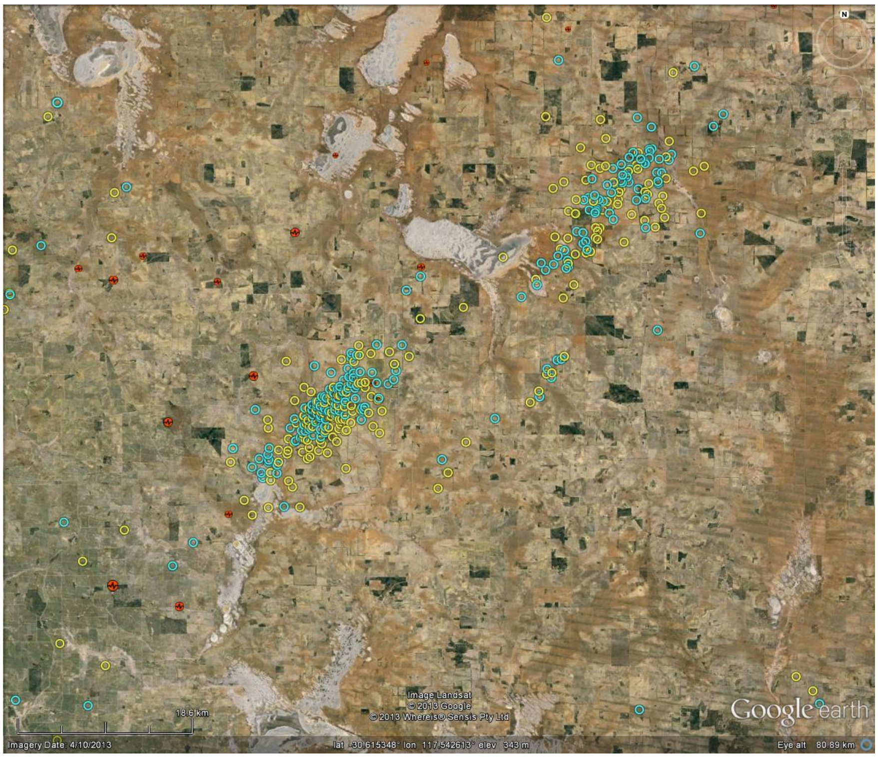

Figure 9. Locations of events near Koorda in the period 2012 to 2013 calculated using travel-times from the AuSREM model with the neighbourhood algorithm (blue circles) compared to locations taken from the GA catalogue (yellow circles).

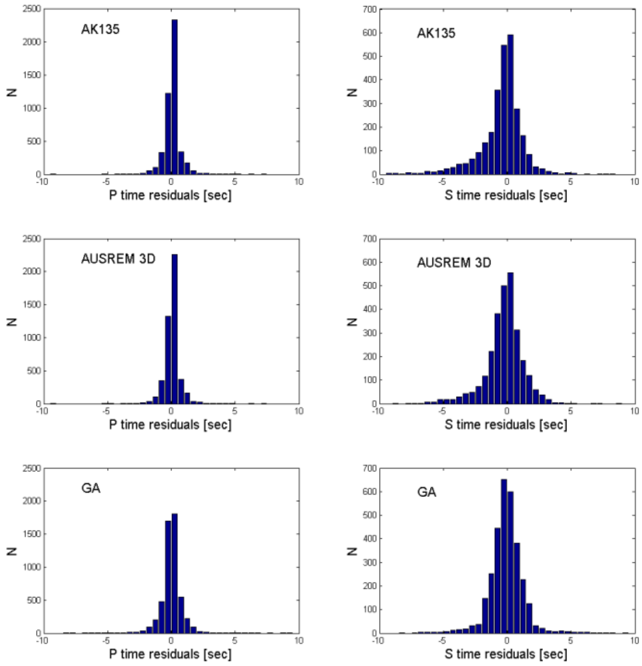

Figure 10. Travel time residuals for the events located in figure 9 for the three models.

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