Earthquake Location Study

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ABSTRACT: In 2014 a new digital station was installed near Cleve, South Australia. Activity about 15 km south of Cleve allowed for a study of different location programs and methods. These revealed a variety of locations, and considerable variation in error estimates. Given the poor network distribution, the one station location method gave the best location results, if the seismometer was properly aligned. One location program gave error ellipses, but these were unrealisticly small. Another location program gave easting and northing errors consistent with the observed location scatter in most cases, but tended to be unstable when computed depths became negative.

1 INTRODUCTION

1.1 New seismograph and nearby earthquake activity

A new digital station with three axis seismometer was installed near Cleve in August, 2014, with station code CLV2. It replaced the old station CLV which had been running since 1964 with a Benioff vertical seismometer, alongside a now noisy road. With the new station, some local activity soon became apparent. In particular, a number of events were located about 15 km south of Cleve. They occurred in a few bursts, and appeared to be coming from the same place. For the purposes of this study, it is assumed that they are coming from the same location. Most events were located separately, i.e. phase picks from each event were used in a location program. This meant independent solutions could be compared.

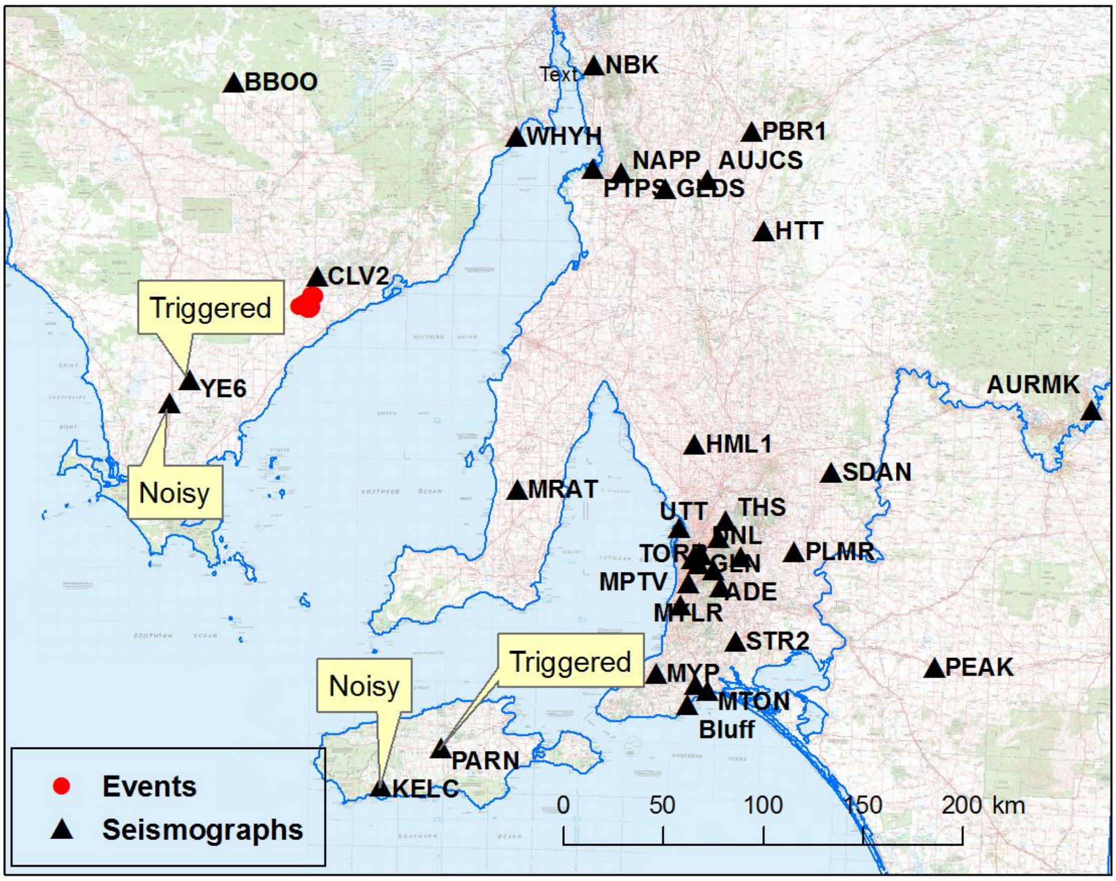

Figure 1 showing area of activity, and recording network.

1.2 Network distribution and reliability

Apart from the nearby CLV2 station the network distribution was far from ideal (figure 1). Two other stations to the south-west (YE6 and AUCAS), less than 100km away were not reliable, one being triggered, the other being in a noisy environment. To the far south, PARN is triggered and KELC is near the ocean. This meant epicentre calculations sometimes had a large gap angle. Occasionally the solutions gave negative depths. The study that follows focusses mainly on epicentres, not including depth, except to check that depths were realistic.

2 LOCATION METHODS

2.1 Location programs

Three location programs were used. Firstly the Eqlocl program, a command line program by the Seismology Reseach Centre, (version 4.0.5f, 1998). The main algorithm is a non-linear least squares inversion using a variation of the Levenberg-Marquardt method. Secondly the Eqfocus 4.1 program, by Seismology Research Centre in 2014, and thirdly, the EqFocus 4.3.5 program in 2015. The first two programs had errors listed as km in easting and northing directions; the last had error ellipses (semi-major and semi-minor axes, and azimuth). It is understood that these were all intended to be two standard deviations.

2.2 Locations by different people on the same data set

A set of events were located from separately picked phases by the two authors. The first locations by Wallace using the Eqlocl program used all phases from all stations that could be read. The second locations by Love using EqFocus 4.1 did not use more distant stations, and removed some stations where a number were near the same azimuth. The velocity model SA1A was used throughout the study. The results are shown in figure 2. Clearly both epicentre sets have a good deal of scatter, and the same events by different authors may be close or considerably apart (shown by black arrows for most events). This was a little surprising, but is mostly the result of different phase picks. The events were mostly quite small (half being under magnitude 1.7), with low signal to noise ratios on most stations. Also for occasional clear signals, digital filtering artifacts made a difference.

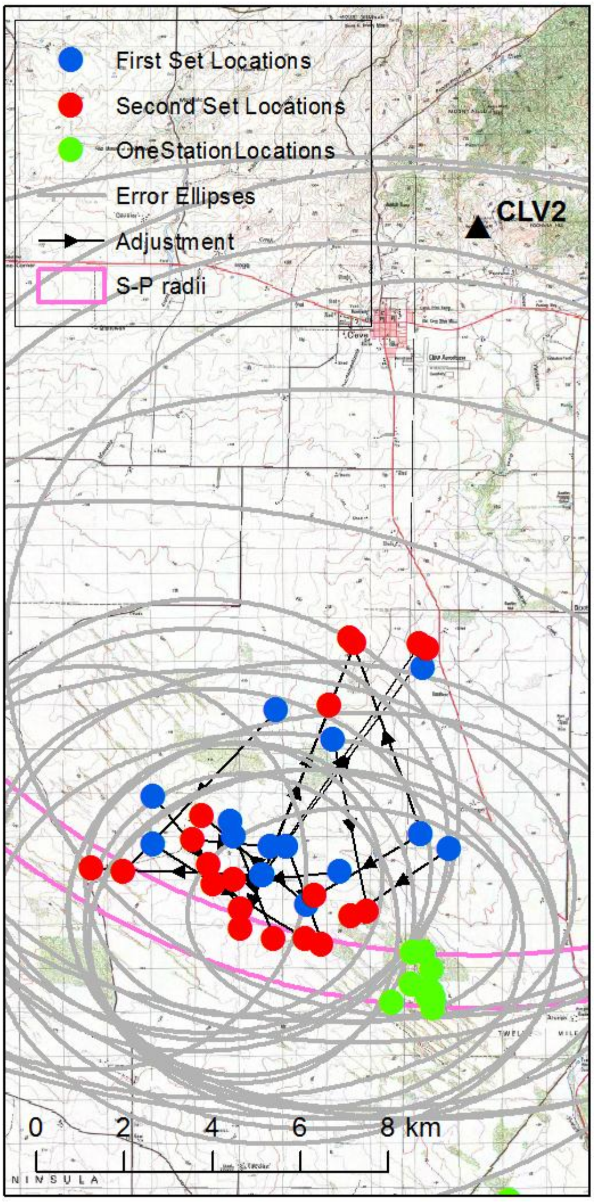

Figure 2 showing initial (Eqlocl - blue) and revised (eqFocus 4.1- red) solutions and movements, error ellipses from eqFocus 4.1, one station locations (green) and expected variation from S-P times (pink arcs).

2.3 **S minus P measurement**

At first, only vertical waveforms were recorded by CLV2. Later, when 3 component ones were available (example figure 3), a number of these from events in the area of interest were examined in detail. There was considerable similarity between many, as would be expected, and S arrivals were usually clear. S minus P times were picked, comparing waveforms to see that the same relative waveform points were being picked. This resulted in only small time variations of 0.11 seconds in a set of 20 events, or 0.08 seconds with three outliers ignored. The velocity model SA1A uses velocities of 6.23 km/sec for P waves, and 3.58 for S waves in the top 38 km. While the model was developed around the Flinders Ranges, it has been used in most areas of the state. This produces a multiplier of 8.4 to convert S-P times to distance. Using 0.11 seconds, and allowing for some downward angle, limiting circles are displayed in figure 2. Clearly, the independently located events scatter much more widely than the arcs defined by the S minus P times. Using 0.08 seconds, we get a variation of only 670 m.

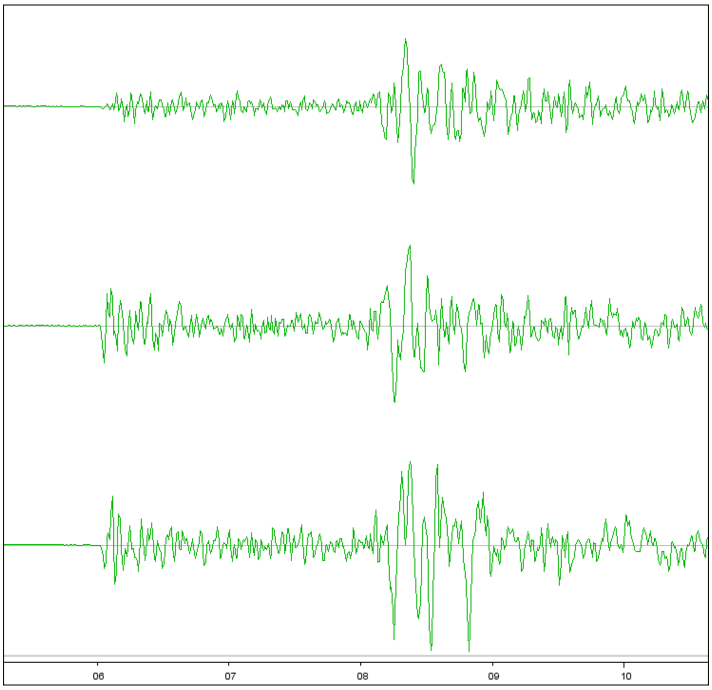

Figure 3 Example 3 axis seismogram from CLV2.

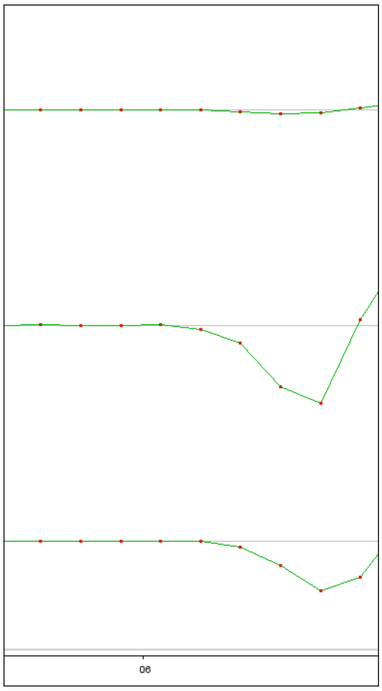

Figure 4 showing first quarter wavelength.

2.4 **One station locations**

The amplitudes from the first quarter wavelength of the P arrival were tabulated from the three components (example figure 4). This was done moderately quickly by eye, taking into account the original background noise level. Assuming a direct compressional arrival, vectors were computed from these values. The lowest angle to the surface (emergence angle) was 25 degrees. This included a number of events in other directions from CLV2. Assuming that there is a shallow layer of lower velocity, 15 degrees was subtracted from all the emergence angles, and the resulting epicentres plotted, using azimuth, adjusted emergence and S-P distance. These are shown in green in figure 2. The scatter is surprisingly small by comparison with the traditional location methods! However the points do not fall in the same region as the previously located ones. This is possibly due to seismometer orientation, which has not yet been carefully checked. It is possible that the seismometer is pointing magnetic north, which is 7 degrees east of true north. This would result in the points moving close to the first and second sets of locations.

The largest events in the sequence were two of magnitude 3.3. If the rupture occurred on a single square fault plane, the size would be approximately 600 by 600 m. Most aftershocks would be expected to occur within, or on the edges of this plane. This is consisent with the S minus P times discussed above (particularly 0.08 seconds variation), allowing for the signal to noise levels.

3 ERROR ESTIMATES

Firstly the phase uncertainty in Eqfocus 4.1 was varied from the default value of 0.01 seconds to 0.3 seconds which is normally used in Eqlocl. This resulted in larger errors, approximately double in most cases. Error ellipses were calculated for all three programs using the arrival times from the Eqlocl program, and 0.3 seconds uncertainty throughout. It is clear that the ellipses from Eqfocus 4.3.5 are too small and not realistic. The ellipses for program EqFocus 4.1 are also shown in figure 2, where they have a common intersection area. This suggests that the ellipse sizes are reasonable. The Eqlocl error ellipses are slightly smaller, but are still considered to be a reasonable size, given that the Eqlocl epicentres in figure 2 have slightly less scatter. However the Eqlocl program errors gave higher values when computed depths approached negative values. This was outstandingly so for one solution. It is clear that phase uncertainties need to be included if we are to have believable error ellipses. Picking phase uncertainties can take significant extra time, however reasonable automatic values may be possible from the signal ratio before and after the phase pick.

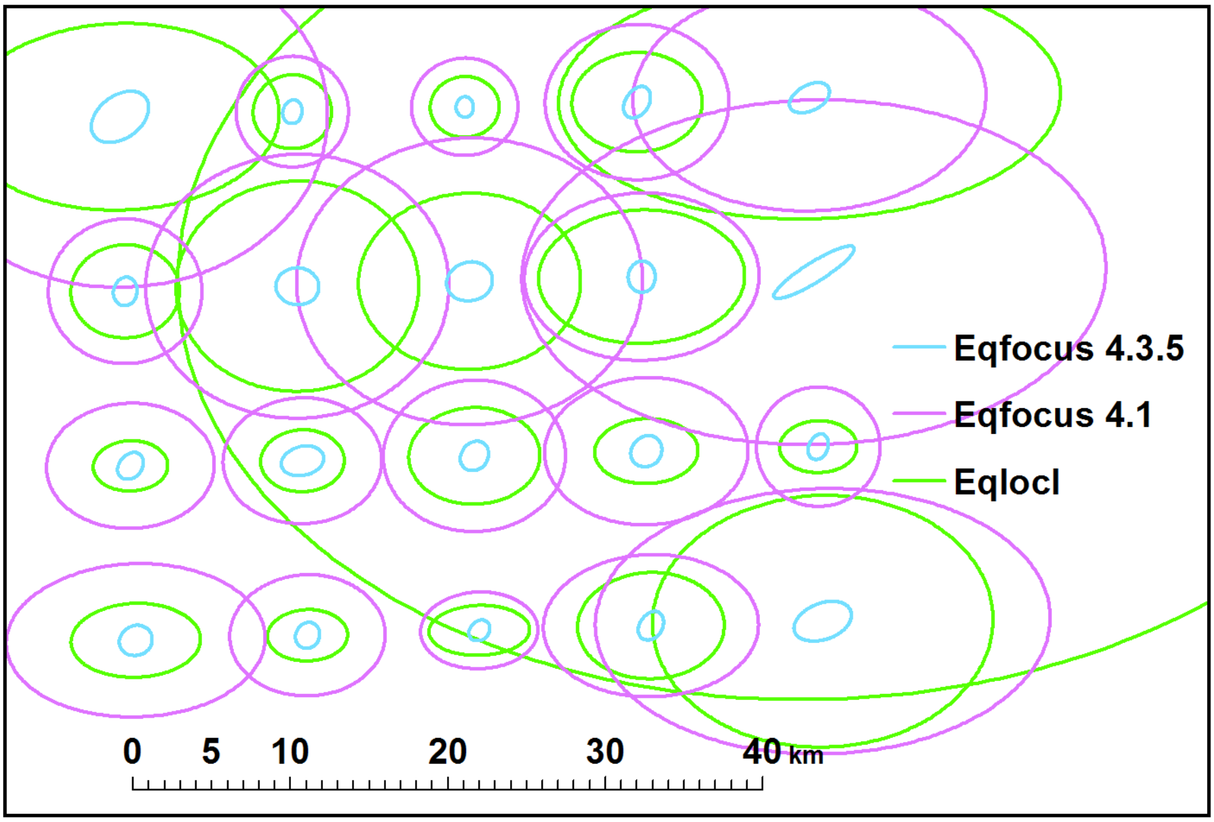

Figure 5 showing error ellipses for Eqfocus 4.3.5 in blue, Eqfocus 4.1in mauve and eqlocl in green. Eqfocus 4.3.5 includes azimuth in the ellipse definition. Eqfocus 4.1 ellipses are shown in figure 2. Note the larger Eqlocl errors on 2 solutions when depths became unstable.

4 CONCLUSIONS

When network configuration is poor, and one station with a 3 axis seismometer is near the epicentre, one station locations may be the best solution, even for relatively large events. The alignment of seismometers should be carefully checked where possible, as this directly affects one station solutions. Phase uncertainty estimates are important when estimating error ellipses. These ellipses should be checked against reality where possible. These ellipses become important when trying to evaluate if an event has occurred on a structure such as a fault, mine or fracking site, or when looking for lineations.