RELATIVE EPICENTRAL LOCATION WITH CROSS-CORRELATION OF SURFACE WAVES: APPLICATION TO STUDIES OF FAULTING EVOLUTION IN FOUR BRAZILIAN EARTHQUAKE SEQUENCES.

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Introduction

Accuracy in hypocentral location is very important in many studies such as: determination of seismogenic fault orientation, detection of epicentral migration in long-time sequences, development of best regional velocity models using well-known epicenters, among others. Nevertheless, epicentral location using regional stations typically can have uncertainties up to 20 km; errors less than 5 km require more than 10 stations closer than 200 km (Bondár et al., 2004), which is usually not possible in Brazil. Epicentral uncertainties are due to low signal-to-noise ratio, which causes errors in identifying P- and S-waves arrivals, but also to lateral velocity variations, which go unnoticed in 1D velocity models. Cross-correlation techniques can retrieve relative arrival times between different events recorded at the same station, even for low signal-to-noise ratio events. On the other hand, Lg waves, a superposition of S waves trapped within a stable continental crust, are regarded as the most efficient way of seismic energy transport trough large distances (Campillo, 1990), what make then the clearest arrival at regional stations in most of the cases.

A combination of cross-correlation and the larger signal-to-noise ratio of Lg waves can be used for accurately locating epicenters relative to one another, in the case of a swarm activity or an aftershock sequence. We used this method with four sequences of earthquakes in Brazil: Montes Claros 2012-2013 sequence (Agurto et al., 2014), Mara Rosa 2010 sequence (Barros et al., 2014), Porto dos Gaúchos 2005 sequence (Barros et al., 2009) and Água Limpa 2014 sequence (Assumpção et al., 2014).

Methodology

For this technique to work, it is necessary that at least one epicenter to be used as reference, usually, one well-determined by local stations. In addition, it must have a magnitude large enough to be recorded by regional stations as well.
Let the distance \( d \) (see Fig. 1) between the target and the reference event be much smaller than the distance to the station. In this case, the angle \( \beta \) is very small and we can assume that the ray paths of the two events are parallel. Thus, the difference in travel time between the target and the reference event can be given by:

\[
T_t - T_r = A_0 - \frac{d \cdot \cos(A_s - A_t)}{V_{ap}}
\]

(1)

Where \( T_t \) is the travel time of the Lg wave released by the target event, \( T_r \) is the Lg-wave travel time of the reference event, \( A_0 \) a correction for the target event origin time, \( A_s \) the station azimuth, \( A_t \) the target azimuth in relation to the reference and \( V_{ap} \) the apparent velocity of the Lg wave.

Equation 1 enables us to calculate a theoretical curve of time difference \( (T_t - T_r) \) versus station azimuth \( (A_s) \). On the other hand, if we know the origin time (even approximate) for each event and since we also know the surface-wave arrival times, we can calculate the observed delays for each station. Thereby, it is possible to build an iterative algorithm that finds the unknown parameters \( (A_0, d, A_s) \) which best fit the curve to the observed points, both improving the target’s origin time and locating it.

**Results and Discussions**

The location found for the mainshock of Montes Claros (Fig. 2a) perfectly agrees with the expected rupture geometry based on a previous study using the locally determined aftershocks. In addition, the relative locations of the 2011 and 2014 events show that the Montes Claros activity has
remained in the same fault zone. Looking only at the reference and relocated events we could be lead to believe that there is some migration occurring southward but, when the event of 2013 and the two events of early 2014 are also considered, we see that no clear migration has occurred since then. However, considering that the three events in 2014 occurred at the NW and SE extremes of the aftershock zone, we suggest that a possible slight increase of the rupture area has occurred since the mainshock of May 2012.

Figure 2a: Final location of all events in Montes Claros. Stars are the references and circles the located events accompanied by their respective error bars. Brown square is a magnitude 3.4 event occurred in April 18, 2013; crimson square and royal blue square are two events that occurred in April 06, 2014, both with magnitude 3.3. All these last events were located using the remaining local stations and the closest regional stations.

Figure 2b: Final location of all events in Mara Rosa. Blue star is the reference event and circles the located targets events. Beach ball represents the focal mechanism calculated by Barros et al. 2014.

A previous study in Mara Rosa (Barros et al., 2014) showed that the fault is NNE-SSW oriented. The epicenters found here (Fig. 2b) are somewhat close to this orientation. This result exceeded our expectations: as we do not know the depth of the events, there was no need that they were aligned in this position. Besides, the three epicenters span a distance of approximately 0.6 km, which is consistent with a nucleation that started in a small area and expanded up to 1 or 2 km in the following months (Barros et al., 2014).

The relative location found for the Água Limpa epicenters (Fig. 3a) perfectly agrees with the fault plane orientation determined by Assumpção et al. 2014 using the aftershocks hypocenters and it is also supported by the focal mechanism orientation calculated in this same study by Moment Tensor Inversion. The epicenters show a rupture area of approximately 1 km, what is consistent with a magnitude ~4 $m_b$ earthquake.
The epicenters determined for the two events in Porto dos Gaúchos (Fig. 3b) show an SW-NE orientation, very close to the WSW–ENE and focal mechanism found by Barros et al. 2009.

Figure 3a: Final location of all events in Água Limpa. Yellow star is the reference event and circles the located targets events. Red circles represent the precursor events; blue circles the aftershocks that occurred a short time the main event; magenta circles the latter aftershocks. Beach ball represents the focal mechanism calculated by Assumpção et al. 2014. Figure 3b: Two events belonging to the Porto dos Gaúchos 2005 sequence. Yellow star is the reference event and red circle the relocated target. Beach ball represents the focal mechanism calculated by Barros et al. 2009.

Conclusion

Accurate locations of foreshocks and aftershocks in the four earthquakes sequences (Montes Claros, Mara Rosa, Água Limpa and Porto dos Gaúchos) show that use of Lg-correlation and relative location is a powerful and easy-to-use technique to study source geometry in regions of sparse station distribution, even when the event depth cannot be determined.

References


