Abstract

Mainland Portugal is located near the boundary of the Eurasian and African plates. The convergence between these plates is the main responsible of the seismicity of Portugal and offshore. The present work studies moment tensor solutions for 17 regional earthquakes with moment magnitudes ($M_w$) between 3.3 and 4.4. These events occurred between February 2007 and September 2009 in Southwest Iberia.

The KIWI (KInematic Waveform Inversion) tools is the method used, in this study, perform the moment tensor inversion [Cesca et al., 2010]. This method is a multi-step algorithm, allowing to perform inversions in the frequency and time domain. The solutions obtained use data from 2 to 9 stations. The number of stations used is a factor that is taken into account when assigning a quality factor to the results. The misfit between the recorded and the synthetic waveforms is also taken into account in the quality factor. The results are evaluated according to this quality factor, and compared with other moment tensor solutions obtained by other institutions, when they exist. A comparison is also made with results provided by the NEAREST working group using an OBS network [Geissler et al., in press]. These solutions present differences in depth and epicentre locations relative to the values provided by IM, which used a land network in the inversion. In order to evaluate the best result, several inversions are also performed using exclusively the IM parameters, exclusively the NEAREST parameters, and a combination of depth/epicentre location of both. Results reveal that the focal mechanism solutions have low sensitivity to variations in the epicentre location, whereas they are highly sensitive to variations in depth values.

Keywords: moment tensor inversion, regional earthquakes, Southwest Iberia
1 Introduction

The study of the seismic source is of great importance to Seismology, allowing us to understand the dynamics of earthquakes. The proper knowledge of the earthquake source is in turn key to study the Earth structure. The parameters that characterize the seismic source are calculated based on the ground motion recorded by the seismic stations and a propagation term, related to the medium through which the waves propagate.

This thesis focuses on the study of seventeen (17) regional earthquakes that occurred between 2007 and 2009 in Southwest Iberia. These earthquakes are studied using the KIWI tools (Kinematic Waveform Inversion), which is a moment tensor inversion algorithm. Most of the events occurred offshore (16) and with a moderate magnitude (3.3 to 4.4) preventing very good data records at the seismic stations located on land. Moreover, the station network has a reduced number of seismic stations, although some improvements have been done aiming at enlarging the seismic network. We perform the moment tensor inversions using the land stations available, testing the limits of applicability of this new method. This method is integrated in the Seiscomp 3, a software package for seismological data acquisition, quality control, archival and analysis in real time developed at GFZ, Potsdam. This integration allows an automatic retrieval of the moment tensor solution, which is a major improvement in the real-time seismology.

An opportunity to compare the results using OBS and land network (using starting epicentres provided by IM) arose when the NEAREST project published its first results. This comparison is only possible for 4 out of the 17 earthquakes, since the OBSs were only deployed for 11 months. The epicentres and depths retrieved using the land and the OBS data are notoriously different, which led us to study the influence of these two starting parameters.

This thesis is organized as follows. In Chapter 2, physical concepts are presented in order to understand the physics underlying this thesis. A background of the tectonics of Iberia and, in particular, of the Portuguese territory is given in Chapter 3. Chapter 4 concerns the data used to perform the inversion. The preprocessing of the recorded data and the generation of the Green’s functions are explained in detail. All the steps of the Kiwi tools are explained in Chapter 5, including output examples. The solutions of the moment tensor inversion using the Kiwi tools are presented in Chapter 6. These solutions are compared with solutions published by other European institutions. We also compare the results obtained with the OBS network with the solutions determined using land network by the Kiwi algorithm. We test the influence of using different initial parameters in the moment tensor inversion, comparing the results obtained using the OBS network and land network epicentres and depths. Finally, in Chapter 7 we present the conclusions of
our work.

2 Theoretical Framework

In this Chapter we discuss the necessary theoretical background to understand the work underlying this thesis. We derive the expression for the displacement on the Earth’s surface occurred due to an earthquake:

\[ U_n(x, t) = M_{ij} * G_{ni,j} \]  

(1)

This expression relates the Moment tensor and the derivatives of the Green’s functions through a convolution. The concepts of moment tensor and Green’s function are explained. The moment tensor describes the source, the faulting style and magnitude of the earthquake, while the Green’s functions represent the wave propagation through the medium from the source to the receiver.

3 Tectonic Background

Mainland Portugal is located near the boundary of the Eurasian and African plates. The tectonic activity of these plates is the main cause of seismicity in Portugal. Devastating historical earthquakes, such as the earthquake of 1755 and of 1969, which affected Lisbon and the southern part of Portugal. The seismicity in the Iberian Peninsula is affected by different tectonic structures with different regimes (strike-slip, extensional and compressional). The Portuguese territory and near region of the Atlantic Ocean experience frequent small earthquakes \((M \leq 5.0)\) and occasional moderate to large earthquakes \((5.0 \leq M \leq 7.5)\).

The seismic network that covers Mainland Portugal, has difficulty in accurately locating offshore earthquakes. The events occurred far from the land are the most difficult to constrain due to the absence of inadequate station coverage. The results retrieved by different institutions do not agree, specially with respect to the depth. This is a consequence of the geographic location of Portugal, which creates an azimuthal gap. One of the solutions for this problem would be to install a permanent network of OBS in that region.

4 Data

Most of the seventeen (17) events are studied in this thesis occurred offshore, southwest of the Saint Vincent Cape, within the geographical limits 35–38° Lat N and 7–13° Lon W. In total, we have access data recorded at twenty-one stations spread between Mainland Portugal (18), Madeira (2) and in Rabat, in the Morocco coast (1). The data preprocessing is an important step before the actual moment tensor inversion. All the data processing is done automatically through SAC a script. During the preprocessing the data is subjected to different procedures: demean, detrend, removal of the instrument response, bandpass filtering and resampling.

The velocity structure model chosen is a re-
gional layered model proposed by Stich et al. [2003]. The generation of the Green’s Functions (GFs) is made automatically running QSEIS [Wang, 1999], which allows the generation of GFs for a given number of epicentral distances and source depths. A tree structure is used in this work to allocate the GFs.

After all these steps the data is ready to be used in the moment tensor inversion algorithm.

5 Kiwi: The Inversion Method

In this chapter we explain in detail all the steps of the inversion. The method is composed of 3 steps in total. In our study we only use the first and the second step, since the third step performs a kinematic inversion. The kinematic inversion cannot be performed in this study due to the low magnitudes of the earthquakes.

The Kiwi tools are a flexible method that allows the treatment of different types of data (time traces, amplitude spectra, body waves, surfaces waves, full waveforms, etc.). This method also has many options to operate the data (tapering, weighting, filtering, etc.), as well as different inversion schemes (Levenberg-Marquardt, grid walk, L1 norm, L2 norm, etc.).

The fact that Green’s functions databases can be run in advance renders the method fast, allowing the easy use of different Earth models. The computational time of the inversion is very important, since the goal is to implement the method in real-time. In each step of the method, the most adequate dataset is chosen to retrieve a group of parameters.

Another difference from other methods is that, in the Kiwi algorithm, the depth is computed using the Levenberg-Marquardt algorithm along with the other parameters at once, instead of running the inversion for different depths till find the best solution.

6 Results and Discussion

We computed moment tensor for 17 events located offshore in the Atlantic area, southwest of St Vincent Cape (16) and onshore in Mainland Portugal (1). We obtained reliable results for 15 of the 17 earthquakes. Due to the quality of the recorded waveform data and to the large distance of the events from the portuguese coast, a low number of stations recorded good quality data of the events. A quality criteria is assigned to the results based on the misfits obtained in the first and second step of the inversion method. The inferred moment tensor solutions are presented in Figure 1.

The comparison of the focal mechanisms with those obtained by other institutions is only possible for 4 earthquakes. Since we are studying regional earthquakes, only Spanish institutions have calculated the moment tensor for a few of the studied earthquakes (4).

The three focal mechanisms (ours, IAG’s and IGN’s) available for the 11/01/08 earthquake are
all strike-slip. Apart from some minor differences, the IAG results agree best with our work. The IAG focal mechanism is in agreement with our result also for the 10/05/2008 event. The results of the 17/07/08 and 18/08/09 events obtained with the Kiwi tools are different from the IAG and IGN focal mechanisms, although both present strike-slip regimes.

Geissler et al. [in press], retrieved the focal mechanisms of 36 offshore earthquakes recorded by a temporally OBS network (NEAREST experiment). Four of these 36 events are also studied in the present thesis using the Kiwi tools.

We compare the NEAREST results with those obtained in this thesis using the Kiwi tools and a land-recorded data. There are 4 earthquakes studied both in this thesis and by the NEAREST project. The results of the comparison are presented in Figure 2. The results determined by the NEAREST project and those obtained in this thesis, are dissimilar for 2 of the 4 events. This may be due to two reasons: 1) the correct epicentre and depth location is extremely important for these two earthquakes in particular; or 2) the quality of the results is not good enough to provide a good agreement with the OBS solutions.

In order to verify the robustness of the previous results we perform inversions with the exclusive use of the IM parameters, the NEAREST parameters, or a combination of depth/epicentre of both.

The results reveal almost no change in the focal mechanisms for the 11/01/08 and 14/04/08 earthquakes, which have very good quality (A and B). However, the other two events (06/11/07 and 10/05/08 earthquakes) present some changes. In the case of the first event the differences are minor. In the case of the 10/05/08 earthquake we obtain very different focal mechanisms. The solutions for these two earthquakes have average quality factors of C and D. The poor quality factor may be an explanation for the large discrepancies specially in the 10/05/08 event. The depth is the parameter which most affects the inversion.

7 Conclusions

In this thesis we use the Kiwi tools in order to study 17 regional earthquakes that occurred in southwest Iberia. In general, the obtained results are of good quality, being some of them in agreement with the solutions published by other European institutions as IAG and IGN. Within all the focal mechanism we have 5 pure strike-slips, 4 strike-slips with a minor reverse component and 2 strike-slips with a minor normal component. We also obtained 4 focal mechanisms with normal faulting style and 1 with a reverse regime. The comparison with the results provided by the NEAREST project indicate that the depth is a difficult parameter to retrieve. In general, the Kiwi tools obtained results closer to the NEAREST values, which we think to be more accurate than those obtained by IM.

The influence of the starting epicentral location and depth were tested. The results reveal that be-
tween the two, the depth is the parameter which has more influence in the focal mechanism solution. This last study proved that quality factors are well-calibrated given that the poor quality assigned to the results (C and D) provide unstable solutions. This work provides an extension of the moment tensor catalogue in southwest Iberia contributing not only with other solutions for earthquakes previously studied but also with eleven new moment tensor solutions of unexplored seismic events.

References


Figure 1: Map showing the results obtained using the Kiwi tools. The results obtained by IGN and IAG are also shown. The focal mechanisms in red are the results obtained using the Kiwi tools. The focal mechanisms in grey show the results provided by other agencies, as IGN and IAG. Each solution has the quality factor assigned as well as the moment magnitude ($M_w$) retrieved by our method. The focal mechanism is identified by the date that the earthquake occurred followed by the ID of the event.

Figure 2: Focal mechanisms comparison between NEAREST and Kiwi tools results. The determined results using the Kiwi tools are presented as "present work", and the results provided by the NEAREST working group which have used the OBS network are presented as "NEAREST". The letter in the bottom-right corner is the given quality factor. [Courtesy of NEAREST WP3 Working Group]