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# Relocation of recent seismicity and seismotectonic properties in the Gulf of Corinth (Greece)

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#### SUMMARY

Recent seismicity (2008–2014) taking place in the Gulf of Corinth and recorded, since the establishment of the Hellenic Unified Seismological Network is relocated in this study. All the available P and S manually picked phases along with the waveforms of 55 broad-band, threecomponent seismological stations were used. The relocation is performed using the double difference method with differential times derived from phase-picked data and waveform crosscorrelation. The accuracy of the relocated catalogue, estimated using a bootstrap approach, is of the order of few hundred metres. In an attempt to define the stress regime in the area, we compute moment tensors of 72 earthquakes with  $M_{\rm L} \ge 3.0$  and use them to calculate the total seismic moment tensor. A dominant strike of 270° that found in the westernmost part, was changed to  $270^{\circ}$ –290° at the centre of the gulf, perpendicular to the almost N–S extension of the rift. Further to the east, a gradual change in fault orientation is observed. In the easternmost part, the strike becomes 240°, in agreement with the geometry of the rift. The highly accurate earthquake catalogue, consisting of  $\sim 26\ 000$  events, reveals two patterns of activity in the western Corinth Gulf, namely, strongly clustered seismicity in both space and time in shallow depths and below that activity a very narrow shallow north-dipping seismic zone. Earthquake clusters, mainly located in the western study area, are identified using CURATE algorithm and associated with different north or south-dipping fault segments. The seismicity in the shallow north-dipping seismic zone, defined in detail in this study, is continuous and free of earthquake clusters. This continuous activity most probably defines the boundaries between brittle and ductile layers. The central and eastern parts of the study area mainly accommodate spatiotemporal clusters.

**Key words:** Waveform inversion; Seismicity and tectonics; Continental tectonics: extensional; Dynamics: seismotectonics.

#### **1 INTRODUCTION**

The Corinth Gulf (Fig. 1), located in central Greece, is one of the most seismically active areas in Europe (Papazachos & Papazachou 2003; Ambraseys 2009). Its overall shape is an asymmetric half-graben, trending WNW–ESE with its width increasing from a minimum in westernmost part (Psathopyrgos fault, Fig. 1) to a maximum in the central part (Xylokastro fault, Fig. 1; Armijo *et al.* 1996). Geodetic measurements have shown that the extension rate is different in the two parts of the gulf (Billiris *et al.* 1991; Clarke *et al.* 1998; Briole *et al.* 2000; Avallone *et al.* 2004; Chousianitis *et al.* 2015). The western part extends at a rate of 13–14 mm yr<sup>-1</sup>, with the largest opening rate measured near Aigio fault (Fig. 1, Briole *et al.* 2000). The eastern part is deforming with lower extension rate of approximately 10–12 mm yr<sup>-1</sup>.

The Corinth Gulf is bounded to the south by a series of major north-dipping normal faults and a few south-dipping ones at its northern part (Fig. 1). The south faults are, from west to east, the Psathopyrgos, Aigion, Heliki and Xylokastro faults (Fig. 1), with lengths between 15 and 25 km, an average strike of  $270^{\circ}$ –285° and a northward dip of about 50° near surface (Armijo *et al.* 1996). At the eastern extremity of the gulf, the main fault segments (Offshore Perachora, Skinos and Alepochori, Fig. 1) strike at  $250^{\circ}$ –270°. Fault plane solutions presented by several researchers (Jackson *et al.* 1982; Taymaz *et al.* 1991; Baker *et al.* 1997; Papazachos *et al.* 1998) support the aforementioned strike and faulting type, in consistency with the rift structure. The west edge of the rift is connected with two major strike-slip faults, north and south of it (Fig. 1). The first one (12 in Fig. 1) is a left-lateral strike-slip fault located near Lake Trichonida, associated with the 1975 M = 6.0 earthquake

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**Figure 1.** Morphological map of the Corinth Gulf along with fault segments of: 01—Psathopyrgos, 02—Aigion, 03—Heliki, 04—Offshore Akrata, 05— Xylokastro, 06—Offshore Perachora, 07—Skinos, 08—Alepochori, 09—Kaparelli, 10—Lidoriki, 11—Delphi, 12—Trichonida and 13—Achaia (Armijo *et al.* 1996; Kiratzi *et al.* 2008; Console *et al.* 2013; Karakostas *et al.* 2017). Earthquakes that occurred since 1900 with  $M \ge 6.0$  and depth  $\le 50$  km are shown by stars (Papazachos & Papazachou 2003). Red circles show earthquakes that occurred between 2008 and 2014 and were relocated in this study, whereas green circles show the relocated catalogue of Karakostas *et al.* (2017). The stations of the Hellenic Unified Seismological Network (HUSN) are displayed by triangles. *Inset map:* the backarc Aegean sea and the surrounded area, with the dominant seismotectonic features, including the Hellenic trench along with the subduction of the East Mediterranean lithosphere under the Aegean, and the North Anatolian Fault (NAF) which accommodates the westward extrusion of the Anatolian plate into the Aegean. The tectonic setting is supplemented with the existence of the Cephalonia (CTF) and Rhodes (RTF) transform faults. The study area is enclosed in the rectangle.

(Kiratzi *et al.* 2008). The second one (13 in Fig. 1) is a right-lateral strike-slip fault related to the 2008 M = 6.4 Achaia earthquake south of Patraikos Gulf (e.g. Serpetsidaki *et al.* 2014; Karakostas *et al.* 2017).

Several destructive earthquakes struck the study area both in historical and instrumental eras (e.g. Papazachos & Papazachou 2003; Ambraseys 2009; Makropoulos et al. 2012), with 10 of them with M > 6.0 since 1900 (Fig. 1, Papazachos & Papazachou 2003). Several attempts to record the intense microseismicity in the study area were made in the past three decades. In 1991, a local network consisted of 51 seismological stations was installed in the western Corinth Gulf and operated for two months (Rigo et al. 1996; Latorre et al. 2004). During the summer of 1993, a temporary seismological network was installed over a period of seven weeks around the eastern Corinth Gulf (Hatzfeld et al. 2000). Since 2000, the Corinth Rift Laboratory (CRL) has been in operation in the western part of Corinth Gulf (Lyon-Caen et al. 2004; Bernard et al. 2006; Lambotte et al. 2014). Since 2008, permanent stations of the Hellenic Unified Seismological Network (HUSN) have been in continuous operation with adequate density for microseismicity monitoring and investigation (Fig. 1).

The adequate coverage of the seismological networks secures the record of the frequent seismic excitations since 2000. The 2001 Agios Ioannis earthquake swarm took place in the southern part of the study area and was attributed to fluid-driven seismicity (Pacchiani & Lyon-Caen 2010). The next two seismic crises were originated offshore in 2003–2004 and 2006–2007, and for the first one

evidence is provided that was related to fluid diffusion process (Bourouis & Cornet 2009; Duverger *et al.* 2015). On 2007 April 08, the Trichonida earthquake swarm initiated near the area where the 1975 M = 6.0 earthquake occurred (Evangelidis *et al.* 2008; Kiratzi *et al.* 2008; Kassaras *et al.* 2014). On 2010 January 18, an earthquake doublet occurred near Efpalio beneath the north coasts of the westernmost part of Corinth Gulf with two  $M_w = 5.5$  events (Karakostas *et al.* 2012; Sokos *et al.* 2012; Ganas *et al.* 2013). On 2013 May 22, an earthquake swarm that initiated near Aigio, with more than 1500 earthquakes detected in three months (Chouliaras *et al.* 2015; Kapetanidis *et al.* 2015; Mesimeri *et al.* 2016; Kaviris *et al.* 2017).

The underlying mechanism responsible for the high seismic activity is still under question even though several studies were conducted by different research groups (e.g. Rigo *et al.* 1996; Sorel 2000; Sachpazi *et al.* 2003; Bell *et al.* 2008, 2009; Taylor *et al.* 2011; Godano *et al.* 2014; Lambotte *et al.* 2014; Beckers *et al.* 2015). An outstanding feature revealed from the microseismicity in the area of western Corinth Gulf is the very shallow north-dipping seismic zone. Rigo *et al.* (1996) observed microseismicity defining the shallow northdipping seismic zone and interpreted it as a hypothetical detachment zone on which the mapped north-dipping normal faults are rooting. Similar observations have been made since the operation of the CRL network (Lyon-Caen *et al.* 2004; Bernard *et al.* 2006; Lambotte *et al.* 2014). Lambotte *et al.* (2014), in particular, identified several multiplets that match the geometry of the shallow north-dipping seismic zone. The fault plane solutions of these multiplets also advocate



Figure 2. Number of P and S phases against epicentral distance (a) for western and (b) eastern Corinth Rift, respectively.

this seismic zone (Godano *et al.* 2014). Lambotte *et al.* (2014) and Godano *et al.* (2014) relate the shallow north-dipping seismic zone with the existence of an immature detachment that is currently under development. On the contrary, Hatzfeld *et al.* (2000) proposed that the seismicity is probably related to the seismic–aseismic transition. A seismic reflection study conducted by Bell *et al.* (2008) suggests that the shallow geometry is more easily reconciled with a model in which faults are steep to a brittle–ductile transition, at 8–10 km, in agreement with the proposed model by Hatzfeld *et al.* (2000). Bell *et al.* (2008) found no evidence of fault listricity in shallower depths, and concluded that the existence of dominant south-dipping faults in their data is incompatible with a low angle north-dipping detachment.

In this study, we compiled, for the first time, a highly accurate earthquake catalogue for the entire area of the Corinth Gulf, aiming to contribute to the discussion on the structures governing the seismogenic process. The relocation was performed considering seven years of seismicity (2008-2014) and using differential times from waveform cross-correlation and phase-picked data. We further attempt to interpret the seismotectonic regime in the study area, by combining the relocated earthquake catalogue along with fault plane solutions computed in this study. The contribution to the seismic hazard assessment is the identification of the earthquake clusters and their association with certain fault patches. These fault patches are then compared to the geometry of the major faults for investigating a possible correlation between the occurrence of strong earthquakes and earthquake clusters. The earthquake clusters were also compared with the background seismicity looking for possible patterns in the spatial distribution of earthquakes.

#### 2 EARTHQUAKE RELOCATION PROCEDURE

#### 2.1 Data

All the available data (i.e. P, S phases and waveforms) of seven years (2008-2014) seismic activity in the study area are selected. Phases are gathered from the Geophysics Department of the Aristotle University of Thessaloniki (GD-AUTh, http://geophysics.geo.auth.gr/ss/) and the Geodynamics Institute of the National Observatory of Athens (NOA, http://bbnet.gein.noa.gr/HL/). Due to technical reasons, phases from NOA were also collected from the Euro-Mediterranean Seismological Center (http://www.emsc-csem.org/) where they are available in the appropriate format (Godey et al. 2006). Then, we merged the bulletins and an initial earthquake catalogue was compiled, containing approximately 24 500 events for the western and 5300 events for the eastern part of the gulf. Regarding the waveforms, the recordings of the HUSN, which is in operation since 2008, are used. Particularly, we selected all the available recordings of 55 broad-band seismological stations with a sampling rate of 100 samples  $s^{-1}$ . These recordings were archived in calendar order (approximately 3 TB) and used for the waveform cross-correlation process.

Fig. 2 shows the distribution of the P and S phases with the epicentral distances in each subarea. For the western part, where the network is denser, 60 per cent and 93 per cent of the P, and 68 per cent and 96 per cent of the S phases are recorded in stations within distances of 50 and 100 km, respectively. In the eastern part, we observe that 66 per cent and 86 per cent of P, and 75 per cent

and 90 per cent of S phases are recorded in distances up to 75 and 100 km, respectively.

#### 2.2 Relocation process

Due to differences in spatial distribution of seismicity, earthquake relocation was performed for each data set separately (western and eastern parts of the study area). For the initial earthquake location, we used the HYPOINVERSE (Klein 2002) software and all the available manually picked P and S phases. The inputs required in this software are a Vp/Vs ratio and an appropriate local velocity model. For defining the Vp/Vs ratio, we applied the Wadati method to two data sets consisting of 411 and 136 earthquakes with more than 20 S phases for each subarea. The resulting Vp/Vs ratio equals to 1.79 and 1.76 for the western and eastern parts, respectively. The 1-D local velocity model used for both subareas (Rigo et al. 1996), after testing several crustal models, does not account for lateral variations in the velocity structure. Thus, an important factor in the location is the consideration of station corrections, which improve the performance of the velocity model. Station delays should be carefully calculated especially in large areas, where different type of phases are observed (Pg, Pb and Pn). In our case, it is not possible to calculate stations corrections for all the events simultaneously due to their relatively large interevent distance and the possible mix up of different P phases. For that reason, the two subareas are further divided into smaller parts, based on the spatial distribution of the seismicity. Stations residuals were calculated using HYPOIN-VERSE software and data sets consisting of the most recent events (2013-2014). After locating the earthquakes with HYPOINVERSE, we calculated a mean residual from all the available P phases and for each station. Then, we locate again the earthquakes taking into account the mean residual for each station and repeat the calculations until the changes in mean values in each station are negligible (Karakostas et al. 2012, 2014). The selected data sets include almost all the stations used in this study, as they were gradually added to the network over the years. For a few stations that were not in operation at that time, the corrections were separately calculated. The obtained delays were used for locating all the earthquakes and the resulting solutions are used as input in the double difference method.

In order to further improve the obtained locations, we relocate the earthquakes using the double difference package *hypoDD* (Waldhauser & Ellsworth 2000; Waldhauser 2001). Initially, we computed traveltime differences between the manually picked events in the catalogue, after choosing a maximum number of 10 neighbours per event within a 10 km distance. The event pairs with at least eight observations were kept, since the number of unknowns for one pair of events is eight and a maximum number of observations in each event pair was set equal to 40. This resulted to one million P phase pairs and 740 000 S phases pairs for the western part.

An important factor in the application of *hypoDD* is the determination of the maximum interevent distance between pairs of events. It has been shown that the traveltime error increases with increasing interevent distance (e.g. Waldhauser & Ellsworth 2000; Waldhauser & Schaff 2008). For the phase-picked data, this is mainly caused by heterogeneities in the velocity structure. Considering this effect, we tested several values for maximum separation distance for the two areas. In Fig. 3, the median traveltime residuals are plotted as a function of binned interevent distance for the western and eastern subareas, respectively. The residuals become unstable (i.e. deviation from zero) with increasing distance, which is illustrated in

distances greater than 5 km for the western and 6 km for the eastern subarea. These values are used as the maximum distance between linked events in the application of *hypoDD* for the phase-picked differential times.

The relocated earthquakes obtained from the hypoDD application, using phase-picked data, are considered for preparing the waveforms for the cross-correlation process. Waveforms with 60 s duration, starting from the origin time of each event, were selected and archived by station in calendar order. The resulting database consists of several millions of waveforms for each subarea (~65 GB). Then, the waveforms were bandpass filtered [2-10 Hz] and updated for P and S phase picks, when available. Cross-correlation measurements were performed in the time domain for all possible event pairs using 1 and 2 s window lengths for both P and S wave trains (Schaff et al. 2004; Schaff & Waldhauser 2005). A lag search over  $\pm 1$  s was set in order to find the highest value of the correlation coefficient (CC), even if the seismic phases are misidentified. All event pairs with CC above 0.7 (70 per cent) were saved separately for each component, window length and subarea, resulting to several millions of correlation measurements.

In order to prepare a robust data set of the acquired correlation measurements and reduce possible outliers, we applied the following restrictions. First, we considered only the event pairs with high similarity, namely  $CC \ge 0.8$  (80 per cent). Then, we looked for consistency of the measurements made in different window lengths (1 and 2 s). Therefore, we kept delay times based on the 1 s window length, if differences between same event pairs at the different windows are less than the sampling rate (0.01 s). Although all phases were manually picked and no theoretical times were calculated, we used this restriction to avoid bias from the routine analysis and possible misidentification of *P* and/or *S* phases. Finally, we selected event pairs with at least 4*P* or 4*S* delay time measurements.

For the sake of comparison, we used only the differential times derived from waveform cross-correlation and relocated the events with *hypoDD*. Figs 3(c) and (d) shows that the median of residuals increases with increasing interevent distance for both subareas. According to the residual distribution, we can consider a value for interevent distance of 2-4 km for the cross-correlated data.

At the final step of relocation, we exploit the ability of hypoDD to combine differential times derived from phase-picked data and waveform cross-correlation. We performed a joint inversion of all available differential times in order to obtain a highly accurate earthquake catalogue. A crucial part of the relocation process is the weighting and reweighting of the different kind of data (Waldhauser & Ellsworth 2000). For the current data sets, we used four sets with five iterations in each one and appropriate reweighting of the differential times. For the first 10 iterations, we downweight, by a factor of 100, the cross-correlation to allow location using only the catalogue data in larger interevent distances (5-6 km). Then, for the last 10 iterations we downweight, by a factor of 100, the pick data and let the cross-correlation differential times locate the earthquakes having shorter interevent distances ( $\sim 2 \text{ km}$ ). All the calculations were performed using the conjugate gradients method after appropriate damping of the data (LSQR, Paige & Saunders 1982).

The final catalogue contains 22 078 events in the western part, almost 90 per cent of the initial events, and 4323 events in the eastern part, almost 88 per cent of the initial catalogue. Events are rejected during the relocation process due to insufficient number of phases and number of links after the application of the weighting function. In the western part, 64 per cent of the earthquakes were located using both cross-correlation and phase-picked data, whereas a remaining



Figure 3. Median residuals against offset in 100 m bins for (a) and (b) phase-picked data and (c) and (d) cross-correlation data for the different parts of the Corinth Gulf.

36 per cent using only catalogue data, which mostly concerns earthquakes that occurred in the early period (before 2011) when the available stations were fewer. On the other hand, only 37 per cent of the earthquakes in the eastern part were relocated using both cross-correlation and phase-picked data and 63 per cent of them using only phase-picked data. The low percentage of cross-correlated events is most probably due to the large interevent distances, which results to few cross-correlation pairs.

Fig. 4 presents the effect of interevent distance and magnitude difference to the CC. In the western part, the CC decreases with increasing interevent distance (Fig. 4a). A similar pattern is observed in the eastern part (Fig. 4b), where higher CCs were found, and could be considered as the result of cross-correlations concerning seismic excitations very restricted spatially (e.g. Villia sequence, 2013). The CC decreases with increasing difference in magnitude between event pairs in both subareas (Figs 4c and d). In the western part, the CC has a median lower than 90 per cent for  $\Delta M \leq 1.5$ , whereas in the eastern part the median approaches 90 per cent for  $\Delta M \leq 1.5$ .

Fig. 5 shows the focal distribution obtained for each stage of the relocation process, along a vertical profile in an approximately N-S (195°) direction, almost normal to the dominant fault strike in both subareas. The initial locations derived from the routine analysis of different Institutes (GD-AUTh and NOA) exhibit an undefined cloud of seismicity, placed in depths between 0 and 20 km for both subareas (Figs 5a and b), mainly concentrated between 7 and 13 km for the western part. There are many alignments of the foci along horizontal lines at different depths, which more likely correspond to fixed depths or low resolution of the reported depths. After considering a local velocity model, a Vp/Vs ratio derived from the data and station corrections, the focal distribution is changed (Figs 5c and d). The foci of the western part are confined in a seismogenic zone 5 km thick (6-11 km depths, Fig. 5c) after the inclusion of stations corrections. In the eastern part, a change in focal depths distribution is also observed (Fig. 5d). The foci alignment is not observed in this stage. The relocation results after the application of hypoDD with the phase-picked data are shown in Figs 5(e) and (f). The seismogenic zone in the western region seems to be narrower



Figure 4. (a) and (b) Mean correlation coefficient against hypocentre separation in 100 m bins and (c) and (d) boxplots of correlation coefficient against difference in magnitude in bins of 0.5.

without any significant shift in the cluster centroid (Fig. 5e). The final locations are shown in Figs 5(g) and (h), where the improvement in the locations is clearly shown. The seismogenic zone in the western part is still confined in the depth range 6-11 km (Fig. 5g). In the eastern part, the interevent distances are reduced but the seismicity is not concentrated at certain depths, instead it is evenly distributed between 3 and 13 km.

#### 2.3 Error estimation

Errors in the final locations estimated by *hypoDD*, using the LSQR method, are not representative of the real location errors (Waldhauser 2001). Their values are of the order of few metres (3–5 m) and have no physical meaning. In order to estimate the accuracy of the final locations, we perform error analysis concerning the time delay uncertainties and the effect of the station distribution to the final locations.

First, a bootstrap resampling method (Efron 1982) is applied by creating 200 samples, with replacement, of the final residual vector derived from the double difference joint inversion. The residuals are then added to all differential traveltimes with unit weights and the relocation is repeated for each sample. The distribution of the

differences between the final locations and the 200 samples is used to compute the 95 per cent confidence error ellipse per event. Table 1 summarizes the uncertainty estimates for each direction, type of data and subarea. It is observed that median errors are larger in the eastern part, whereas in the western part they are of the order of few hundred metres. In addition, it is shown that for both areas the phase-picked data have larger uncertainties than events located using both cross-correlation and phase-picked data.

Taking into account that the most recent earthquakes are located using cross-correlation differential times, we looked for any significant temporal variations in the errors. Fig. 6 shows the median errors in the three directions as a function of time for the two types of data (phase-picked and cross-correlation) in each subarea separately. The median errors are calculated within a moving window of 300 events and step of five events. For the western part (Fig. 6, upper panel), the errors for the cross-correlated data are decreasing with time. On the other hand, the phase-picked data have larger errors for the entire period with an increasing trend in the late years. This is due to the lower accuracy of the few remaining events relocated with phase data compared to cross-correlated ones. For the eastern part of the gulf (Fig. 6, lower panel), we do not observe a decreasing trend of error uncertainties with time. However, in two cases, which are associated with certain seismic excitations occurred in 2011 and



Figure 5. Different stages of relocation process for the two areas of Corinth Gulf. (a) and (b) Initial location obtained from routine analysis, (c) and (d) application of single-event location with station corrections, (e) and (f) application of *hypoDD* with phase-picked data and (g) and (h) final locations after joint inversion of cross-correlation measurements and phase-picked data.

 Table 1. Median errors of the relocated catalogue in the three directions for

 the different parts of Corinth Gulf and the different type of data (phase-pick and cross-correlation). All errors are in metres.

| Direction | All | Western part<br>Phase pick | CC  | All | Eastern part<br>Phase pick | CC  |
|-----------|-----|----------------------------|-----|-----|----------------------------|-----|
| X         | 380 | 660                        | 282 | 856 | 1230                       | 617 |
| Y         | 260 | 439                        | 190 | 629 | 864                        | 441 |
| Ζ         | 300 | 513                        | 221 | 655 | 933                        | 436 |

2013, respectively, a decrease in error is illustrated. This is mainly due to the high density of seismic activity in both excitations. The spatial distribution of the errors in three directions evidences that errors are smaller in areas where seismic activity is denser (Fig. C1).

The effect of station distribution in the final locations is tested by applying a jackknife method (Efron 1982). Particularly, we repeat the relocation process of the initial data set by omitting one station at a time (Waldhauser & Ellsworth 2000). Then, we calculate the

Downloaded from https://academic.oup.com/gji/article-abstract/212/2/1123/4554391 by Biblio Planets user on 06 January 2018 standard deviation of the differences between the initial locations and the ones obtained from the jackknife method for each event in the three spatial directions. The median errors for the western part are 101, 68 and 79 m for the two horizontal and the vertical directions, respectively. These values are significantly smaller than the ones introduced by noise in the data in bootstrapping method. The median errors in the eastern part are 123, 132 and 446 m for the three directions, respectively, implying that the network geometry affects the final locations.

#### **3 MOMENT TENSORS**

Focal mechanisms are computed on a routine basis, for events with  $M_{\rm L} \ge 4.0$  occurring in the broader area of Greece, using regional or local data and different algorithms for waveform inversion (Konstantinou *et al.* 2010; Roumelioti *et al.* 2011; Serpetsidaki *et al.* 2016). For the area of Corinth Gulf, several studies with fault plane solutions were performed, using *P*-wave onsets from a local network



Figure 6. Median error in the three directions as a function of time for the phase-picked data (red lines) and the cross-correlated one (black lines) for the western (upper panel) and eastern Corinth Gulf (lower panel), respectively.

(e.g. Rigo *et al.* 1996; Hatzfeld *et al.* 2000; Godano *et al.* 2014) or after studying a certain seismic excitation (e.g. Hatzfeld *et al.* 1996; Karakostas *et al.* 2012; Kapetanidis *et al.* 2015; Mesimeri *et al.* 2016). Waveform inversion techniques were also applied in the study area in order to compute fault plane solutions for moderate to strong events in several cases (e.g. Baker *et al.* 1997; Evangelidis *et al.* 2008; Zahradnik *et al.* 2008; Sokos *et al.* 2012).

Aiming to obtain a reliable and homogeneous data set of fault plane solutions for the study area, we used the ISOLA software (Sokos & Zahradnik 2008, 2013) to compute centroid moment tensors for  $M_{\rm L} > 3.0$  events that occurred between 2011 and 2014. ISOLA uses the iterative deconvolution method of Kikuchi & Kanamori (1991) modified for regional distances. The set of stations used for relocation purposes is considered here along with the velocity model proposed by Rigo et al. (1996). The inversion was performed for a deviatoric moment tensor and the waveforms are filtered to a frequency range of 0.03-0.09 Hz. From the 58 events of the relocated catalogue with  $M_{\rm L} \ge 3.5$ , we computed 50 moment tensors (86 per cent). Due to the density of the network, we were able to look for possible moment tensors for events within the magnitude range  $3.0 \le M_{\rm L} \le 3.5$ . Even though it is difficult to determine fault plane solutions for smaller magnitude earthquakes, we computed 22 focal mechanisms out of 116 events with  $3.0 \le M_L < 3.5$ ( $\sim$ 18 per cent). The spatial distribution of the 72 focal mechanisms is shown in Fig. 7 and relevant information is provided in Appendix A.

At the latest version of *ISOLA* package, the user has the ability to estimate the quality and the uncertainties of the computed moment tensors using several quantitative criteria (Sokos & Zahradnik 2013). The first two estimated factors after the waveform inversion are the variance reduction (VR), which reflects the similarity between the synthetic and the observed waveforms, and the condition number (CN), which measures the stability of the inversion. Two additional indicators of solution quality regarding the spacetime variability of the solution could be obtained. Focal-Mechanism Variability Index (FMVAR), which compares the obtained solutions with the optimal solution using the Kagan angle (Kagan 1991), and Space-Time Variability Index (STVAR), which measures the size of the space-time area corresponding to the given correlation threshold. The solutions with low values of FMVAR (<30) and STVAR (<0.30) are considered more stable.

The aforementioned quantitative criteria are estimated for the 72 moment tensors computed in this study, which have CN < 7 with a mean value of 2.74 and mean VR equal to 0.5. The mean values of the FMVAR and STVAR parameters are 9.0 and 0.19, respectively, supporting solutions stability. For the 82 per cent of the solutions six or more stations are taken, a number which is considered quite satisfactory for the waveform inversion. The mean percentage participation of the double-couple component in the moment tensor is 85 per cent for the 72 moment tensors.

In order to quantify the stress regime in the study area, we calculated the total seismic moment tensor (TSMT), which is the sum of the moment tensors calculated from the individual solutions

$$M_{ij}^{\text{total}} = \sum_{k=1}^{N} M_0^k m_{ij}^k$$
(1)

3.7

where k is the number of earthquakes,  $M_0$  the scalar seismic moment of each event and  $m_{ij}$  the seismic moment tensor components (Buforn *et al.* 2004). TSMT, compared to other approaches (e.g. Frohlich & Apperson 1992), has the advantage of taking into consideration the magnitude of each earthquake and using it as a weighting factor. As a result, the earthquakes with high  $M_0$  values have the largest contribution in the estimation of TSMT.

The study area is now divided into eight subregions based on the spatial extent of the major faults in the area and the spatial



Figure 7. Fault plane solutions obtained in this study. The boxes define the different subregions used for the estimation of the TSMT. Inset panel: TSMT solutions for the different subregions.

Table 2. Total Seismic Moment Tensor solutions (TSMT) for each subregion along with the number of fault plane solutions (FPS) used and the CLVD percentage.

|           | NT 1   | CLUD       |            | Plane 1 |          |            | Plane 2 |          | Т         | axis         | Р         | -axis        |
|-----------|--------|------------|------------|---------|----------|------------|---------|----------|-----------|--------------|-----------|--------------|
| Subregion | of FPS | (per cent) | Strike (°) | Dip (°) | Rake (°) | Strike (°) | Dip (°) | Rake (°) | Trend (°) | Coplunge (°) | Trend (°) | Coplunge (°) |
| 01        | 3      | 16         | 63         | 66      | 174      | 155        | 85      | 25       | 21        | 69           | 286       | 77           |
| 02        | 23     | 15         | 263        | 43      | -84      | 76         | 48      | -95      | 169       | 87           | 292       | 5            |
| 03        | 24     | 3          | 277        | 27      | -86      | 93         | 63      | -92      | 185       | 72           | 359       | 18           |
| 04        | 5      | 1.5        | 271        | 36      | -86      | 87         | 54      | -92      | 179       | 81           | 347       | 9            |
| 05        | 5      | 2          | 289        | 71      | -49      | 40         | 44      | -152     | 351       | 74           | 242       | 43           |
| 06        | 6      | 1          | 298        | 22      | -70      | 96         | 70      | -98      | 193       | 66           | 354       | 25           |
| 07        | 4      | 5          | 273        | 31      | -95      | 98         | 59      | -87      | 186       | 76           | 16        | 14           |
| 08        | 2      | 2          | 240        | 42      | -87      | 56         | 48      | -93      | 148       | 87           | 297       | 4            |

distribution of the focal mechanisms (Fig. 7). For each subregion, we estimate the TSMT using only the focal mechanisms computed in this study (Fig. 7 inset panel and Table 2). Starting with the westernmost part north of the Patraikos Gulf (subregion 01), where the dominant structure is a left-lateral strike-slip fault (Evangelidis et al. 2008; Kiratzi et al. 2008; Kassaras et al. 2014), we observe a right-lateral strike-slip motion near the Lake Trichonida, which is orthogonal to the left-lateral structure. Normal faults are prevalent in Corinth Gulf striking from 260° and gradually reaching 290° at the eastern edge. The mean strike in subregion 02 is  $260^{\circ}$ , where the Psathopyrgos fault is located, equal to 277° in subregion 03 (Aigion fault). In subregions 05, 06 and 07 the mean strikes are equal to 298°, 298° and 273°, respectively, showing a change in faulting orientation from north to south. The major faults in the area (Offshore Akrata, Xylokastro and Offshore Perachora) have a strike of 280°-290°, similar with that obtained from TSMT analysis in the southern part of the area. In 2013 May, an earthquake swarm took place in subregion 04 with more than 1500 earthquakes occurring in only months, revealing microstructures striking almost E-W. The focal mechanisms obtained here, using the ISOLA package and the waveform inversion method, are in accordance with those computed using P-wave onsets (Kapetanidis et al. 2015; Mesimeri et al. 2016) for events with smaller magnitudes ( $M_L > 2.0$ ). At the easternmost part (subregion 08), the TSMT reveals normal faulting striking SW-NE (240°).

#### 4 DETERMINATION OF ACTIVE SEGMENTS AND SEISMOTECTONIC PROPERTIES

In an attempt to identify the active fault segments in the study area by exploiting the high accuracy of the relocated seismicity, we looked for seismic excitations that took place in the Corinth Gulf during the time span of the relocated catalogue. The identification of seismic excitations, known as earthquake clusters, is performed using the CURATE algorithm (Jacobs et al. 2013) on the relocated earthquake catalogue. CURATE focuses on periods when the seismicity rate is increased above the background rate in a given area, and identifies earthquake clusters by applying an interevent distance and day rule for each earthquake in the catalogue. Taking into consideration, the errors in hypocentre locations, calculated using the bootstrap method, we set a distance rule for the CURATE algorithm equal to 2 km for the western subarea. We chose a low value due to the high location accuracy and spatial density of the earthquakes, which are mainly associated with small fault segments. For the eastern part, the distance rule was set to 4 km due to the larger location errors. The day rule was set to two days for both subareas.

The identified spatiotemporal clusters are initially filtered based on the number of events ( $N \ge 10$ ). Then, it was attempted to relate them to fault segments by constructing several cross-sections normal to a wide range of strikes for each identified cluster. The



Figure 8. Spatial distribution of the relocated catalogue occurred since 2011 in the western Corinth Gulf along with the major faults in the area (see Fig. 1). White circles show seismicity that is not part of a cluster, green circles show events that are members of a cluster with  $N \ge 10$ , whereas red circles show the clusters that are associated with a fault segment. The epicentres of the Aigio 2013 earthquake swarm obtained from Mesimeri *et al.* (2016) are depicted with magenta. The traces of the fault segments at the mean depth of each cluster are shown with thick black lines and thin black lines correspond to the vertical cross-sections shown in Fig. 9.

cross-section in which the foci delineate a seismogenic zone is selected as the most appropriate one in each case and the dip for each selected cross-section was measured. The search for earthquake clusters is performed for each subarea separately and a correlation between their spatial distribution and seismicity in the area is attempted.

#### 4.1 Western Corinth Gulf

In the western Corinth Gulf 185 clusters with 10 or more earthquakes are identified by *CURATE* algorithm, with 47 of them being related to fault segments dipping north (37) and south (10) with angles ranging from 30° to 65° and striking in the range  $220^{\circ}-300^{\circ}$ and  $90^{\circ}-110^{\circ}$ , respectively. The differences between the strikes and dips of the identified segments, and the TSMT solutions are shown in Table B1. The deviations indicate that seismic excitations take place not in patches of the major faults which are locked but in patches of buried/blind secondary faults in the area.

In Fig. 8, the identified clusters with  $N \ge 10$  which occurred since 2011 are plotted (green circles) along with the clusters that are associated with a fault segment (red circles) and the background activity (white circles). The majority of the clusters are located offshore with only few onshore exceptions. It is notable that several clusters are located north of the fault associated with the 1995 Aigion  $M_w$  6.5 earthquake (Bernard *et al.* 1997), whereas a lack of earthquake clusters is observed north of the westernmost edge of Psathopyrgos fault. Forty two (42) of the 47 identified segments are associated with seismic excitations that occurred after 2011, indicating that the earlier locations or the network detectability were not adequate for defining fault segments.

We constructed a set of 20 cross-sections (Fig. 9) normal to the main strike of the rift, taking into account the major north-dipping faults, the fault plane solutions and the TSMTs computed in this study, in order to correlate the earthquake clusters with the spatial

distribution of seismicity. Considering the time dependency of the errors, we plot the events which occurred between 2008 and 2010 in the background (grey circles) in order to compare them with the ones that occurred later (2011–2014, black circles). Earthquakes belonging to clusters were plotted as in the map of Fig. 9.

The earthquakes of the first two cross-sections (W01 and W02) are located in the Patraikos Gulf, where the seismicity is sparse and the dominant strike differs from the rest of the study area. The foci distribution is comprised into almost vertical groups of seismicity, which have been identified as spatiotemporal clusters but are not associated with a fault segment, and clusters (red circles) defining segments striking at  $250^{\circ}$ - $260^{\circ}$ .

The W03-W20 cross-sections are normal to a mean strike of 285°N, even though the segments defined by the earthquake clusters have variable strikes. In cross-sections W03-W05, earthquake clusters and background activity occur at focal depths of 7-12 km. A different pattern is illustrated in the next four cross-sections (W06-W09), where the most recent events (black circles) form a very narrow, shallow north-dipping zone, which initially has a shorter length but becomes longer as we move to the east. The earthquake clusters that are associated with fault segments (red circles) or they do not define any structure (green circles) occur at shallower depths. Few events belonging to spatiotemporal clusters that are found very close to the narrow zone are located with larger errors (>300 m), whereas their cluster centroid is shallower. It is also noteworthy that the earthquakes in this cross-section are located in the area between the two major faults Aigion and Psathopyrgos (Fig. 8). Comparison between the two data sets, namely, the 2008-2010 (grey dots in Fig. 9) and 2011-2014 (black dots in Fig. 9), shows that the earlier ones form a cloud around the later ones, revealing the location improvement with time.

Moving further to the east (W10–W14) across the Aigion fault, we observe that the defined clusters and the background activity are located at the same depths. A different pattern is observed



Figure 9. Set of 20, normal to the main trend of the gulf, cross-sections as denoted in Fig. 8. Black dots show the earthquakes that occurred since 2011, whereas grey dots show the seismicity from 2008 to 2010. Green dots show the clusters with  $N \ge 10$ , red dots show the clusters related to a fault segment and magenta dots show the Aigio 2013 earthquake swarm (Mesimeri *et al.* 2016). Black lines indicate the major faults. The width of each cross-sections is 3 km.



Figure 9. (Continued.)

during the 2013 Aigion swarm (magenta circles), illustrated in cross-sections W12–W14 (Fig. 9). This cross-section contains the well-studied earthquake swarm, which was initiated in 2013 May and lasted almost three months (Chouliaras *et al.* 2015; Kapetanidis *et al.* 2015; Mesimeri *et al.* 2016; Kaviris *et al.* 2017). It reveals a north-dipping structure at the southern part of the western Corinth Gulf. This activity is located south of the shallow northdipping seismic zone and could not be associated with the offshore activity.

Finally, east of W14 cross-section, the last six cross-sections (W15–W20) were constructed in an area with sparse seismicity where the association of clusters with active fault segments is not feasible. As we reach the eastern part of Corinth Gulf, the seis-

micity is reduced and this pattern continues to the eastern Corinth Gulf.

#### 4.2 Eastern Corinth Gulf

After applying the *CURATE* algorithm 35, spatiotemporal clusters with at least 10 events are identified and two of them are related to a certain fault segment. The first cluster that is related to a fault segment occurred in 2009 May following an  $M_{\rm L} = 4.4$  earthquake. The second one refers to the Villia sequence that occurred in 2013 June near Kaparelli fault and lasted approximately one month (Kaviris *et al.* 2014, Appendix B). In Fig. 10, we show the spatial distribution of the background activity (white circles) along with the identified spatiotemporal clusters with  $N \ge 10$  (green circles) and those that are related to fault segments (red circles). As in the western part, we consider only events since 2011 due to the improvement in the location accuracy.

A set of 18 cross-sections (Fig. 10) are constructed normal to the main orientation of the eastern part keeping the same notation as in Fig. 9. A clear difference in the seismicity distribution is observed, compared to the western part. In the first 15 cross-sections (Fig. 11), we could not define any structure, but a pattern of vertical distributions of foci, which in several cases are identified as spatiotemporal clusters (green circles), is depicted. An example of this pattern is the E06 cross-section, which shows two vertical groups of foci in different depths (green circles). Most of these events occurred in 2012 September following an  $M_{\rm w} = 5.1$  earthquake. Due to the vertical distribution of the foci, we looked for a possible relation to fluid intrusion by applying distance-time plots. These plots, in cases of fluid intrusion, describe the migration of seismicity, which is evident by a characteristic triggering front (Shapiro 2015). However, for this particular sequence, we did not find evidence for fluid migration, whereas a further examination of fluid intrusion in the eastern Corinth Gulf is beyond the scope of this study.

At the easternmost part of the study area, the dominant fault strike is again changing, also shown by the TSMTs. The final three cross-sections (E16–E18) include the 2013 Villia sequence (E17 red circles) and two sequences that occurred in 2009 (E18 grey circles) and 2013 (E16 green circles), respectively. A south-dipping structure related to the Villia sequence (2013 June) is shown in cross-section E17, located at focal depths of 7–9 km.



Figure 10. Spatial distribution of the relocated catalogue for the eastern Corinth Gulf along with the major faults in the area. The notation is the same as in Fig. 8.



Figure 11. Set of 18, normal to the main trend of the gulf, cross-sections as denoted in Fig. 10. The notation is the same as in Fig. 9.

The 2009 sequence located south of the Villia sequence forms an almost vertical structure confined in shallower depths, very close to the surface. Due to the sparse seismicity in the area, with only two exceptions, the location accuracy is not adequate for making strong conclusions about the active structures in the area.

#### **5 DISCUSSION**

A highly accurate earthquake catalogue for the area of Corinth Gulf is compiled for the first time, using the data of the HUSN from 2008 to 2014. Approximately 22 000 events are located in the western study area, which is twice the number of events in the relocated catalogue of Lambotte *et al.* (2014) which however covers a different

time period (2000–2007). Additionally, for the first time a massive relocation of recent seismicity has been performed for the eastern Corinth Gulf (~4000 events). The catalogue is considered highly accurate, especially in the western Corinth Gulf, with the uncertainty in horizontal and vertical directions of the order of few hundred metres. The major finding of this study is that the spatial distribution of the relocated seismicity revealed two patterns of activity in the western subarea, namely, strongly clustered seismicity in both space and time in depths shallower than 10 km and below that activity a very narrow shallow north-dipping zone void of spatiotemporal clusters.

The earthquake clusters identified in the western subarea, after applying certain space-time criteria, were examined and related to 47 fault segments having variable strikes and dipping either to the north or to the south. The majority of the clusters are located offshore between 22.00° and 22.20°E with high dip angles [40°- $60^{\circ}$ ], strikes of 270°-290° and their depths in the range 6–10 km. In the westernmost part of the study area, few clusters are aligned at slightly different strikes [250°-270°].

The north-dipping seismic zone observed in several previous seismicity studies (Rietbrock et al. 1996; Rigo et al. 1996; Hatzfeld et al. 2000; Lyon-Caen et al. 2004; Bernard et al. 2006; Lambotte et al. 2014) is also identified in this study, particularly in the W06-W09 (Figs 8 and 9) cross-sections. However, the underlying mechanism that triggers the seismicity in this seismic zone has been questioned for over three decades. We found here that the observed shallow north-dipping seismic zone is free of spatiotemporal earthquake clusters and the activity is continuous throughout the study period. The space-time-clustered events (earthquake clusters) are located in different parts of the rift, whereas only a few of them are located above the shallow north-dipping seismic zone in shallower depths. Assuming that the multiplets defined by Lambotte et al. (2014) are comprised in the same shallow north-dipping seismic zone that is found in this study, we observe that these multiplets last several years, and in a few cases, span the entire period of the CRL operation (table A1 in Lambotte et al. 2014). Additionally, there is no seismic activity below the shallow north-dipping seismic zone, as it is illustrated in the cross-sections (Fig. 9). Thus, the continuous microseismic activity, observed only in the western part of Corinth Gulf, most probably defines the seismic-aseismic transition (Hatzfeld et al. 2000).

The seismicity in the eastern subarea is relatively low and highly sparse compared to the western Corinth Gulf. Two out of the 35 spatiotemporal clusters identified in the study period are related to a certain fault segment. The most recent cluster related to a fault segment occurred in 2013 June, lasted almost one month and comprised some hundreds events with magnitudes  $0.5 < M_{\rm L} < 3.5$ (cluster E01, Table B1). This activity forms a south-dipping structure (E17 in Fig. 11) and exhibits similar characteristics as the Kaparelli fault, which was activated during the 1981 Alkyonides sequence (Papazachos et al. 1984; King et al. 1985). In a few cases (E06 and E18 in Fig. 11), it appeared that seismic activity is clustered in shallow depths and forms almost vertical lines, which could not be attributed to any known fault segment. However, the location uncertainty, the limited data, as well as the local network geometry are not favourable for making strong conclusions.

The moment tensors computed for 72 earthquakes using waveform inversion techniques and the fault plane solutions are in accordance with the N–S extension of the rift. We followed a different approach from Godano *et al.* (2014) as we considered events with  $M \ge 3.0$  for the entire Corinth Gulf regardless of their correlation with earthquake clusters. However, the results of both studies are quite similar for the central part of the western subarea. The computation of total moment seismic tensor for eight different subregions revealed gradual strike changes from west to east. The seismic activity is still on near Trichonida Lake with few strike-slip fault plane solutions, which exhibit SW–NE orientation, perpendicular to the spatial alignment of the 1975 aftershock sequence and the 2007 swarm (Kiratzi *et al.* 2008; Kassaras *et al.* 2014). The faults of the westernmost and the easternmost extremities are striking almost at  $250^{\circ}$ .

#### 6 CONCLUSIONS

A firm conclusion traced in this study is that the difference in seismicity between the two parts of the Corinth Gulf is clearly depicted and can be attributed to the different extension rates estimated from geodetic data. The highly accurate catalogue defines in great detail the existence of a shallow north-dipping seismic zone which lacks of spatiotemporal earthquake clusters and is characterized by continuous seismic activity. It is evident that the seismic activity ceases below this structure and the lower depth can be interpreted as the boundary between the seismic and aseismic layers. The absence of recent strong earthquakes (M > 6.0) in the dominant faults (Psathopyrgos and Aigion) along with spatially clustered continuing activity raises questions about the possibility of creeping faults in that area. Thus, the full exploitation of the recorded seismic activity, the catalogue compilation and its future updates will be a valuable tool in the direction of understanding the underlying mechanism of earthquake process in the Corinth Gulf and constitutes an indispensable component for any seismic hazard assessment study.

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#### APPENDIX A: FAULT PLANE SOLUTIONS

|                    |          |               |                |                   |                |  |            | -       |          |            | 1        |           | 4         |            | E         |            |      |     |      |       |
|--------------------|----------|---------------|----------------|-------------------|----------------|--|------------|---------|----------|------------|----------|-----------|-----------|------------|-----------|------------|------|-----|------|-------|
|                    |          |               |                |                   |                |  |            | Plane 1 |          |            | Plane 2  |           | Ļ,        | axis       | I         | -axis      |      |     |      |       |
| titude (°          | N) Longi | tude (°E) L   | )epth (km)     | $M_{\rm L}$ $M$   | M <sub>w</sub> | (M (N m)                                       | Strike (°) | Dip (°) | Rake (°) | Strike (°) | Dip (°)  | Rake (°)  | Trend (°) | Plunge (°) | Trend (°) | Plunge (°) | VR   | S   | N FM | VAR S |
| 38.4179            | ) 22     | .0244         | 7.79           | 3.5 3             | 3.6 3.6        | $562 \times 10^{14}$                           | 307        | 70      | -79      | 67         | 22       | -118      | 234       | 63         | 28        | 25         | 0.18 | 3.4 | 7    | ~     |
| 38.3932            | 2 21     | .7899         | 10.12          | 4.2 4             | 4.0 1.4        | $407 \times 10^{15}$                           | 129        | 90      | -25      | 219        | 65       | -180      | 81        | 17         | 176       | 17         | 0.70 | 2.1 | 10   | ~     |
| 38.3897<br>38.4991 | 21       | .7895<br>6624 | 10.99<br>14 46 | 3.0<br>3.0<br>3.0 | 3.7 3.5        | $999 \times 10^{14}$<br>842 × 10 <sup>14</sup> | 224<br>75  | 12      | -168     | 319<br>344 | 78<br>89 | 20<br>-18 | 91<br>298 | v <u>1</u> | 31        | 22         | 0.32 | 1.9 | б «  | 0~    |
| 38.5002            | 212      | .6627         | 14.36          | 3.7 3             | 3.7 3.5        | $958 \times 10^{14}$                           | 341        | 85      | -31      | 74         | 59       | -174      | 293       | 25         | 31        | 1 81       | 0.54 | 2.3 | 6    |       |
| 38.3904            | 1 21     | .8013         | 10.71          | 3.7 3             | 3.6 3.5        | $390 \times 10^{14}$                           | 126        | 59      | -22      | 228        | 71       | -147      | 91        | 36         | 355       | 7          | 0.27 | 3.0 | 7    | 1     |
| 38.2667            | 7 22     | .1924         | 9.68           | 3.4 3             | 3.4 1.5        | $394 \times 10^{14}$                           | 269        | 19      | 84       | 83         | 71       | -92       | 349       | 64         | 174       | 26         | 0.27 | 2.6 | 5    | 2     |
| 38.2867            | 7 22     | .3976         | 13.27          | 4.0 3             | 3.8 6.1        | $153 \times 10^{14}$                           | 89         | 60      | -88      | 264        | 31       | -94       | 5         | 75         | 177       | 15         | 0.62 | 1.9 | 7    |       |
| 38.3457            | 7 21     | .8141         | 9.90           | 3.6 3             | 3.4 1.5        | $881 \times 10^{14}$                           | 242        | 23      | -140     | 114        | 75       | -72       | 48        | 56         | 190       | 28         | 0.42 | 4.0 | 7    | ~     |
| 38.4366            | 5 21     | .8307         | 13.09          | 3.4 3             | 3.4 1.6        | $672 \times 10^{14}$                           | 257        | 26      | -106     | 94         | 65       | -83       | 19        | 69         | 178       | 20         | 0.54 | 2.6 | 5    |       |
| 38.4318            | 3 22     | .0633         | 6.55           | 3.3 3             | 3.2 7.5        | $355 	imes 10^{13}$                            | 256        | 28      | -83      | 68         | 63       | -94       | 330       | 72         | 161       | 18         | 0.62 | 5.4 | 5    | ~     |
| 38.2368            | 3 22     | .5373         | 19.19          | 3.3 3             | 3.3 9.8        | $813 \times 10^{13}$                           | 305        | 34      | -54      | 83         | 63       | -111      | 316       | 65         | 189       | 16         | 0.43 | 1.9 | 9    | 9     |
| 38.3947            | 7 22     | .0013         | 9.64           | 3.1 3             | 3.3 1.1        | $161 \times 10^{14}$                           | 291        | 28      | -79      | 66         | 63       | -96       | 356       | 72         | 193       | 18         | 0.57 | 2.1 | 9    |       |
| 38.2661            | 1 22     | .5302         | 14.40          | 3.5 3             | 3.7 4.1        | $153 \times 10^{14}$                           | 234        | 57      | -131     | 111        | 50       | -45       | 87        | 57         | 351       | 4          | 0.36 | 1.7 | 6    | 2     |
| 38.3757            | 7 22     | 0631          | 10.59          | 3.7 3             | 3.5 2.4        | $456 \times 10^{14}$                           | 322        | 30      | -56      | 104        | 99       | -108      | 343       | 65         | 207       | 19         | 0.28 | 1.8 | 8    | ~     |
| 38.351             | 22       | .3146         | 15.51          | 3.1 3             | 3.3 1.2        | $239 \times 10^{14}$                           | 299        | 31      | -64      | 89         | 63       | -105      | 330       | 69         | 190       | 17         | 0.53 | 1.9 | 4    | ~     |
| 38.3534            | 4 22     | 0147          | 8.41           | 3.9 3             | 3.9 8.2        | $287 \times 10^{14}$                           | 292        | 23      | -75      | 95         | 67       | -96       | 354       | 67         | 190       | 22         | 0.59 | 1.9 | 10   |       |
| 38.0740            | ) 22     | .7446         | 15.99          | 5.1 4             | 1.9 2.6        | $560 \times 10^{16}$                           | 300        | 21      | -68      | 96         | 71       | -98       | 353       | 63         | 193       | 25         | 0.60 | 1.7 | 12   | ~     |
| 38.5509            | ) 21     | .9171         | 18.69          | 3.1 3             | 3.3 1.5        | $319 \times 10^{14}$                           | 238        | 48      | -131     | 110        | 56       | -54       | LL        | 61         | 175       | 4          | 0.44 | 1.9 | 5    | _     |
| 37.9479            | ) 22     | 6038          | 10.28          | 4.1 4             | 4.0 1.5        | $313 \times 10^{15}$                           | 271        | 30      | -97      | 66         | 60       | -86       | 19        | 75         | 186       | 15         | 0.46 | 1.8 | 6    |       |
| 38.2181            | 1 21     | .8490         | 9.06           | 3.8 3             | 3.9 9.6        | $652 \times 10^{14}$                           | 255        | 35      | -138     | 128        | 68       | -63       | 76        | 58         | 198       | 18         | 0.80 | 2.0 | 10   |       |
| 38.3250            | ) 22     | .1627         | 9.52           | 3.6 3             | 3.7 4.5        | $707 \times 10^{14}$                           | 277        | 27      | -83      | 89         | 63       | -94       | 351       | 72         | 182       | 18         | 0.54 | 2.1 | 12   | 1     |
| 38.3916            | 5 21     | .7607         | 13.88          | 3.1 3             | 3.3 1.(        | $013 \times 10^{14}$                           | 203        | 46      | -135     | 78         | 60       | -54       | 40        | 58         | 143       | 8          | 0.27 | 2.4 | 8    | 1     |
| 38.2261            | 1 22     | .1059         | 9.85           | 3.6 3             | 3.6 3.1        | $109 \times 10^{14}$                           | 287        | 42      | -67      | 78         | 52       | -109      | 290       | 74         | 181       | 5          | 0.44 | 2.7 | 6    | ~     |
| 38.2293            | 3 22     | .1097         | 10.14          | 4.0 3             | 3.7 3.8        | $856 \times 10^{14}$                           | 226        | 26      | -112     | 71         | 99       | -79       | 0         | 67         | 153       | 20         | 0.44 | 2.2 | 10   |       |
| 38.1590            | ) 23     | .1956         | 10.00          | 3.5 3             | 3.6 3.1        | $128 \times 10^{14}$                           | 252        | 26      | -73      | 54         | 65       | -98       | 307       | 69         | 150       | 20         | 0.36 | 1.8 | 8    | 0     |
| 38.2169            | ) 22     | .1197         | 9.18           | 3.8 3             | 3.8 5.4        | $454 \times 10^{14}$                           | 103        | 48      | -91      | 285        | 42       | -89       | 358       | 87         | 194       | 9          | 0.53 | 2.0 | 7    | ~     |
| 38.4156            | 5 21     | .9633         | 9.80           | 3.1 3             | 3.2 8.5        | $332 \times 10^{13}$                           | 282        | 26      | -75      | 85         | 65       | -97       | 340       | 70         | 181       | 19         | 0.44 | 3.0 | 9    | 6     |
| 38.2298            | 3 22     | .0917         | 10.95          | 3.3 3             | 3.5 2.(        | $006 \times 10^{14}$                           | 256        | 40      | -105     | 95         | 51       | -78       | 57        | 62         | 176       | 5          | 0.85 | 3.2 | 5    | 4     |
| 38.2298            | 3 22     | .0986         | 10.98          | 3.5 3             | 3.7 4.5        | $312 \times 10^{14}$                           | 263        | 39      | -98      | 94         | 51       | -83       | 41        | 82         | 179       | 9          | 0.70 | 2.1 | 6    |       |
| 38.1670            | ) 23     | .1052         | 13.42          | 4.4               | 4.4 4.5        | $304 \times 10^{15}$                           | 56         | 47      | -92      | 238        | 43       | -88       | 301       | 87         | 147       | 2          | 0.34 | 2.0 | 11   |       |
| 38.3019            | ) 22     | .1353         | 8.39           | 3.7 3             | 3.8 7.2        | $233 \times 10^{14}$                           | 261        | 25      | -103     | 95         | 65       | -84       | 17        | 69         | 181       | 20         | 0.81 | 2.5 | 9    |       |
| 38.2999            | ) 22     | .1292         | 8.85           | 3.1 3             | 3.1 6.(        | $028 \times 10^{13}$                           | 246        | 21      | -121     | 66         | 73       | -79       | 26        | 61         | 180       | 27         | 0.40 | 2.5 | 5    | 2     |
| 38.3669            | 9 21     | .8797         | 8.19           | 3.1 3             | 3.1 9.8        | $891 \times 10^{13}$                           | 131        | 59      | -13      | 227        | 79       | -148      | 93        | 30         | 355       | 13         | 0.76 | 2.7 | 9    |       |
| 38.3807            | 7 21     | .7454         | 14.54          | 3.7 3             | 3.6 3.2        | $308 \times 10^{14}$                           | 64         | 47      | -74      | 221        | 45       | -106      | 47        | 78         | 143       | 1          | 0.54 | 1.7 | 7    |       |
| 37.8548            | 3 22     | .7335         | 13.74          | 3.5 3             | 3.6 3.(        | $080 \times 10^{14}$                           | 293        | 36      | -82      | 103        | 54       | -96       | 349       | 80         | 197       | 6          | 0.23 | 1.4 | 9    |       |
| 38.3374            | 4 21     | .9980         | 7.91           | 3.8 3             | 3.8 6.2        | $244 \times 10^{14}$                           | 311        | 49      | -65      | 96         | 47       | -115      | 291       | 72         | 24        | 1          | 0.48 | 3.6 | 6    | ~     |
| 38.3411            | 1 21     | .9822         | 8.48           | 3.9 4             | 4.1 1.6        | $637 \times 10^{15}$                           | 306        | 52      | -72      | 98         | 41       | -112      | 273       | 75         | 24        | 5          | 0.72 | 5.6 | 7    | ~     |
| 38.342             | 21       | .9804         | 8.47           | 3.1 3             | 3.3 1.         | $.31 \times 10^{14}$                           | 310        | 60      | -66      | 88         | 38       | -125      | 264       | 66         | 23        | 12         | 0.53 | 6.3 | 9    | 5     |
| 38.3857            | 7 21     | .8672         | 9.04           | 3.7 3             | 3.7 4.5        | $311 \times 10^{14}$                           | 231        | 26      | -132     | 96         | 71       | -72       | 31        | 60         | 172       | 24         | 0.57 | 2.9 | 7    | 1     |
| 38.3397            | 7 21     | .9749         | 8.94           | 3.4 3             | 3.5 2.5        | $501 	imes 10^{14}$                            | 311        | 58      | -57      | 81         | 45       | -131      | 275       | 62         | 18        | 7          | 0.63 | 6.8 | 9    | ~     |
| 38.3339            | ) 21     | .9769         | 8.67           | 3.9 3             | 3.9 7.8        | $897 \times 10^{14}$                           | 111        | 45      | -93      | 296        | 45       | -87       | 282       | 88         | 23        | 0          | 0.73 | 5.1 | 7    | ~     |
| 38.3144            | 4 21     | .7066         | 16.29          | 4.3 4             | 4.2 2.2        | $221 \times 10^{15}$                           | 303        | LL      | -41      | 4          | 51       | -163      | 255       | 37         | 359       | 17         | 0.65 | 2.1 | 6    | 2     |
| 37.9327            | 7 22     | .5926         | 11.70          | 3.5 3             | 15 23          | 215 ~ 1014                                     | 150        | 00      |          |            |          | 0         |           | C          |           | 0          |      | ,   |      |       |
|                    |          |               |                |                   | 0.7            | 01 X CTC                                       | 707        | 67      | - 109    | 105        | 63       | -80       | 36        | 70         | 188       | 18         | 0.13 | 2.1 | 2    | _     |

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| Table | A1. (     | (Continued.) |               |                |            |             |             |                        |            |         |          |            |         |          |           |            |           |            |        |          |       |       |
|-------|-----------|--------------|---------------|----------------|------------|-------------|-------------|------------------------|------------|---------|----------|------------|---------|----------|-----------|------------|-----------|------------|--------|----------|-------|-------|
|       |           |              |               |                |            |             |             |                        |            | Plane 1 |          |            | Plane 2 |          | P-6       | txis       | T.        | axis       |        |          |       |       |
| Year  | Date      | Origin time  | Latitude (°N) | Longitude (°E) | Depth (km) | $M_{\rm L}$ | $M_{\rm w}$ | (U U) W                | Strike (°) | Dip (°) | Rake (°) | Strike (°) | Dip (°) | Rake (°) | Trend (°) | Plunge (°) | Trend (°) | Plunge (°) | VR 0   | N N      | FMVAI | STVAR |
| 2014  | 03 21     | 18:35:49.92  | 38.4122       | 22.4547        | 10.21      | 4.0         | 3.9         | $7.537 \times 10^{14}$ | 25         | 41      | -171     | 288        | 84      | -49      | 234       | 37         | 347       | 27         | 0.51 2 | 0.10     | 11    | 0.27  |
| 2014  | 04 07     | 20:15:11.86  | 38.3348       | 21.8022        | 9.29       | 3.2         | 3.3         | $1.01 \times 10^{14}$  | 232        | 25      | -140     | 105        | 74      | -70      | 41        | 57         | 179       | 26         | 0.74 3 | 5.4      | 11    | 0.14  |
| 2014  | $04 \ 10$ | 17:40:45.16  | 37.9305       | 22.5980        | 10.47      | 3.5         | 3.5         | $2.577 \times 10^{14}$ | 110        | 48      | -78      | 273        | 43      | -103     | 84        | 81         | 192       | 3          | 0.12 1 | .7 5     | 8     | 0.25  |
| 2014  | $04 \ 17$ | 07:04:04.56  | 38.4092       | 22.4625        | 9.57       | 3.7         | 3.8         | $5.569\times10^{14}$   | 281        | 64      | -56      | 4          | 42      | -138     | 237       | 57         | 347       | 12         | 0.20 1 | .9       | 20    | 0.28  |
| 2014  | $04 \ 18$ | 05:07:36.93  | 38.4223       | 21.8443        | 11.25      | 4.2         | 3.9         | $7.888 \times 10^{14}$ | 102        | 86      | -72      | 204        | 18      | -168     | 30        | 46         | 176       | 39         | 0.63 3 | 0.       | 13    | 0.33  |
| 2014  | 05 10     | 03:04:50.13  | 38.4164       | 22.4471        | 9.99       | 4.2         | 4.1         | $1.889 \times 10^{15}$ | 286        | 69      | -64      | 53         | 33      | -138     | 232       | 58         | 357       | 19         | 0.31 2 | 2 9      | 11    | 0.35  |
| 2014  | 05 11     | 17:34:06.24  | 38.4361       | 21.6997        | 15.02      | 3.6         | 3.6         | $2.879 \times 10^{14}$ | 38         | 78      | 173      | 130        | 83      | 12       | 264       | 3          | 354       | 13         | 0.73 2 | 28       | 8     | 0.27  |
| 2014  | 06 08     | 15:10:51.81  | 38.3260       | 22.0525        | 4.30       | 4.3         | 4.2         | $2.506\times10^{15}$   | 105        | 46      | -84      | 276        | 45      | -97      | 95        | 85         | 191       | 0          | 0.53 2 | T        | 4     | 0.09  |
| 2014  | $06 \ 10$ | 02:14:30.72  | 38.3332       | 22.062         | 8.76       | 3.3         | 3.5         | $1.96 \times 10^{14}$  | 95         | 46      | -91      | 277        | 44      | -89      | 328       | 89         | 186       | 1          | 0.30 2 | 5        | 7     | 0.14  |
| 2014  | $06 \ 10$ | 22:52:42.08  | 38.3315       | 22.0668        | 8.15       | 3.6         | 3.5         | $2.196 \times 10^{14}$ | 272        | 57      | -100     | 110        | 34      | -75      | 154       | 76         | 6         | 12         | 0.51 2 | 2.5      | 12    | 0.18  |
| 2014  | 06 20     | 01:53:28.78  | 38.323        | 22.0492        | 8.32       | 3.3         | 3.4         | $1.754 \times 10^{14}$ | 112        | 41      | -90      | 291        | 49      | -90      | 200       | 86         | 22        | 4          | 0.39 4 | 8        | 5     | 0.07  |
| 2014  | 06 25     | 09:21:41.85  | 38.3597       | 21.7543        | 17.93      | 4.2         | 4.1         | $1.605\times10^{15}$   | 197        | 69      | -136     | 88         | 50      | -28      | 09        | 45         | 318       | 12         | 0.40 2 | .1       | 14    | 0.29  |
| 2014  | 06 27     | 00:47:23.63  | 38.3852       | 21.9995        | 9.44       | 3.0         | 3.2         | $8.258 \times 10^{13}$ | 325        | 31      | -53      | 104        | 99      | -110     | 341       | 64         | 209       | 19         | 0.49 2 | .6 7     | 6     | 0.35  |
| 2014  | $07 \ 30$ | 07:56:35.32  | 38.3487       | 21.8156        | 9.74       | 3.4         | 3.4         | $1.877 	imes 10^{14}$  | 239        | 24      | -125     | 76         | 70      | -76      | 29        | 62         | 176       | 24         | 0.40 2 | 5 10     | 6 (   | 0.16  |
| 2014  | 08 09     | 22:22:24.28  | 38.3603       | 21.8744        | 8.51       | 3.0         | 3.0         | $4.529 \times 10^{13}$ | 236        | 39      | -120     | 93         | 57      | -67      | 53        | 69         | 167       | 6          | 0.56 2 | 9        | 15    | 0.17  |
| 2014  | 08 12     | 04:06:16.20  | 38.3992       | 22.5064        | 10.05      | 3.4         | 3.4         | $1.462 \times 10^{14}$ | 255        | 30      | -101     | 87         | 60      | -84      | 14        | 74         | 173       | 15         | 0.56 1 | 9 6.     | 2     | 0.24  |
| 2014  | 08 28     | 04:11:12.25  | 38.4129       | 22.4655        | 10.62      | 3.3         | 3.4         | $1.451 \times 10^{14}$ | 302        | 65      | -61      | 69         | 38      | -136     | 254       | 59         | =         | 15         | 0.70 3 | .1       | 21    | 0.10  |
| 2014  | 09 03     | 00:58:47.98  | 38.3379       | 21.9031        | 6.85       | 3.5         | 3.8         | $5.454 \times 10^{14}$ | 78         | 18      | -91      | 259        | 72      | -90      | 169       | 63         | 348       | 27         | 0.36 4 | 5        | 6     | 0.08  |
| 2014  | 09 19     | 09:33:24.85  | 38.3620       | 21.8255        | 8.76       | 3.5         | 3.7         | $4.038 \times 10^{14}$ | 274        | 53      | -65      | 56         | 44      | -119     | 243       | 69         | 346       | 5          | 0.41 3 | 1        | 9     | 0.12  |
| 2014  | 09 19     | 15:35:08.84  | 38.3687       | 21.8372        | 10.27      | 4.1         | 4.1         | $1.619 \times 10^{15}$ | 86         | 54      | -88      | 262        | 37      | -93      | 7         | 81         | 174       | 6          | 0.60 2 | <u>%</u> | 4     | 0.11  |
| 2014  | 09 21     | 00:43:39.42  | 38.3477       | 21.8381        | 9.50       | 4.6         | 4.8         | $1.780 \times 10^{16}$ | 70         | 47      | -102     | 268        | 44      | LL -     | 269       | 81         | 169       | 2          | 0.74 4 | .9 1(    | ) 3   | 0.04  |
| 2014  | 09 21     | 01:13:26.45  | 38.3637       | 21.8235        | 9.25       | 4.0         | 4.3         | $3.008\times10^{15}$   | 271        | 42      | -78      | 74         | 49      | -101     | 283       | 81         | 172       | ę          | 0.70 2 | 9        | 5     | 0.08  |
| 2014  | 09 25     | 02:04:24.34  | 38.3511       | 21.8079        | 10.52      | 3.7         | 3.9         | $9.637 \times 10^{14}$ | 269        | 55      | -82      | 26         | 35      | -101     | 206       | 78         | 354       | 10         | 0.39 4 | .6       | -     | 0.03  |
| 2014  | 09 26     | 04:33:32.17  | 38.3447       | 21.9647        | 9.38       | 3.8         | 3.9         | $8.386 \times 10^{14}$ | 293        | 51      | -73      | 88         | 41      | -110     | 260       | 76         | 11        | 5          | 0.56 2 | 4        | 7     | 0.03  |
| 2014  | $10 \ 30$ | 06:09:09.20  | 38.1461       | 22.6267        | 9.18       | 3.7         | 3.9         | $8.056\times10^{14}$   | 293        | 42      | -70      | 87         | 51      | -107     | 298       | 76         | 189       | 5          | 0.19 2 | .6       | 2     | 0.09  |
| 2014  | 11 07     | 17:12:59.68  | 38.2890       | 22.1226        | 8.51       | 4.8         | 4.9         | $3.261\times10^{16}$   | 270        | 23      | -96      | 96         | 67      | -88      | 10        | 67         | 184       | 22         | 0.75 3 | 0        | 3     | 0.07  |
| 2014  | 12 09     | 17:08:29.00  | 38.4047       | 22.2319        | 14.68      | 3.6         | 3.5         | $1.890\times10^{14}$   | 122        | 23      | -94      | 307        | 67      | -88      | 220       | 68         | 36        | 22         | 0.48 2 | 8        | ŝ     | 0.30  |
|       |           |              |               |                |            |             |             |                        |            |         |          |            |         |          |           |            |           |            |        |          |       |       |

#### APPENDIX B: CHARACTERISTICS OF EARTHQUAKES CLUSTERS

**Table B1.** Characteristics of earthquakes clusters: serial number (ID), where W is for clusters that occurred on the western part of Corinth Gulf and E for those on the eastern part, start and end time, number of events (*N*), maximum magnitude in each cluster ( $M_{max}$ ), mean epicentral coordinates (Longitude and Latitude), mean depth of the segment, strike, dip, fault trace at the given depth, the subregion (see Table 2) and the absolute difference in strike ( $\Delta S$ ) and dip ( $\Delta D$ ) from the corresponding TSMT solution.

| ID  | Start               | End                 | N   | $M_{\text{max}}$ | Longitude (°N) | Latitude (°E) | Depth (km) | Strike (°) | Dip (°) | Fault trace (°N, °E)             | Subregion | $\Delta S(^{\circ})$ | $\Delta D(^{\circ})$ |
|-----|---------------------|---------------------|-----|------------------|----------------|---------------|------------|------------|---------|----------------------------------|-----------|----------------------|----------------------|
| W01 | 2008/07/19 00:21:22 | 2008/07/30 10:54:24 | 113 | 3.7              | 21.9046        | 38.2919       | 7          | 100        | 40      | 21.8887-21.9171, 38.2935-38.2874 | 02        | 24                   | 8                    |
| W02 | 2009/01/10 13:31:41 | 2009/01/13 05:05:03 | 27  | 3.1              | 22.0364        | 38.3089       | 8          | 280        | 50      | 22.0235-22.0493, 38.3108-38.3067 | 03        | 3                    | 23                   |
| W03 | 2009/03/10 00:18:42 | 2009/03/16 20:46:13 | 56  | 3.9              | 21.8442        | 38.3513       | 8.5        | 255        | 45      | 21.8301-21.8537, 38.3544-38.3590 | 02        | 8                    | 5                    |
| W04 | 2009/06/23 10:11:21 | 2009/07/10 03:45:52 | 72  | 3.7              | 22.0621        | 38.3064       | 8          | 290        | 45      | 22.0390-22.0801, 38.3149-38.3006 | 03        | 13                   | 18                   |
| W05 | 2010/05/06 10:08:17 | 2010/05/27 03:11:32 | 229 | 3.8              | 21.8318        | 38.4289       | 10         | 270        | 55      | 21.8178-21.8556, 38.4278         | 02        | 7                    | 15                   |
| W06 | 2011/02/01 19:52:23 | 2011/02/03 17:58:56 | 19  | 3.5              | 21.7981        | 38.3903       | 10.5       | 270        | 50      | 21.7908-21.8037, 38.3920         | 02        | 7                    | 10                   |
| W07 | 2011/02/04 11:05:46 | 2011/02/07 15:27:39 | 109 | 3.5              | 22.0236        | 38.4158       | 8.5        | 290        | 65      | 22.0127-22.0337, 38.4208-38.4140 | 03        | 13                   | 38                   |
| W08 | 2011/02/19 19:04:32 | 2011/02/25 19:26:46 | 103 | 3.7              | 21.6590        | 38.4988       | 14.5       | 75         | 84      | 21.6513-21.6715, 38.4951-38.5024 | 01        | 12                   | 8                    |
| W09 | 2011/03/19 03:33:33 | 2011/03/24 06:33:46 | 25  | 2.9              | 21.8636        | 38.3933       | 8.5        | 255        | 60      | 21.8487-21.8791, 38.392-38.398   | 02        | 8                    | 17                   |
| W10 | 2011/07/23 10:20:18 | 2011/08/11 04:15:37 | 279 | 4.3              | 21.7514        | 38.3149       | 9          | 240        | 60      | 21.7371-21.7828, 38.3033-38.3249 | 02        | 23                   | 17                   |
| W11 | 2011/08/30 05:09:32 | 2011/09/21 03:40:04 | 56  | 3.4              | 21.7599        | 38.3157       | 9.5        | 290        | 55      | 21.7452-21.7726, 38.3163-38.3098 | 02        | 17                   | 12                   |
| W12 | 2011/09/18 05:43:49 | 2011/09/21 01:29:14 | 91  | 3.3              | 21.8316        | 38.2193       | 7.5        | 220        | 50      | 21.8252-21.8403, 38.2101-38.2253 | 02        | 43                   | 7                    |
| W13 | 2011/10/01 21:06:19 | 2011/10/03 03:02:14 | 10  | 2.4              | 21.7653        | 38.3245       | 8.5        | 110        | 45      | 21.7589-21.7698, 38.3270-38.3227 | 02        | 34                   | 3                    |
| W14 | 2011/10/04 18:28:25 | 2011/10/05 05:26:43 | 10  | 2.3              | 21.8300        | 38.2168       | 8          | 270        | 40      | 21.8259-21.8346, 38.2171         | 02        | 7                    | 3                    |
| W15 | 2011/11/16 09:04:18 | 2011/11/20 00:15:24 | 40  | 2.2              | 21.8452        | 38.4131       | 10.5       | 270        | 50      | 21.8422-21.8551, 38.4140         | 02        | 7                    | 7                    |
| W16 | 2011/11/30 03:16:36 | 2011/12/01 07:34:25 | 20  | 1.7              | 21.8826        | 38.2647       | 7.5        | 270        | 30      | 21.8775-21.8860, 38.2616         | 02        | 7                    | 13                   |
| W17 | 2011/12/19 23:41:38 | 2011/12/22 12:22:22 | 25  | 2.3              | 22.0413        | 38.3417       | 8.5        | 280        | 65      | 22.0324-22.0454, 38.3422-38.3405 | 03        | 3                    | 38                   |
| W18 | 2012/01/17 17:13:01 | 2012/01/21 22:15:16 | 62  | 3.1              | 21.8365        | 38.3795       | 9          | 270        | 65      | 21.8294-21.8474, 38.378          | 02        | 7                    | 22                   |
| W19 | 2012/02/25 11:01:13 | 2012/02/27 00:53:16 | 11  | 2.3              | 22.0812        | 38.3126       | 8.5        | 290        | 60      | 22.0762-22.0804, 38.3126-38.3093 | 03        | 13                   | 33                   |
| W20 | 2012/03/11 23:49:25 | 2012/03/24 05:44:52 | 37  | 2.8              | 21.6914        | 38,5893       | 10         | 110        | 30      | 21.690-21.7008, 38.5903-38.585   | 02        | 34                   | 18                   |
| W21 | 2012/04/15 21:03:53 | 2012/04/24 17:07:35 | 91  | 3.8              | 22,1226        | 38.2934       | 8.0        | 280        | 60      | 22.1059-22.1318.38.296-38.2908   | 03        | 3                    | 33                   |
| W22 | 2012/06/12 08:34:06 | 2012/06/14 03:08:59 | 23  | 2.1              | 22.0666        | 38.2721       | 10.5       | 110        | 55      | 22.0596-22.0705, 38.2720-38.2685 | 03        | 17                   | 8                    |
| W23 | 2012/06/21 15:37:15 | 2012/06/28 22:24:51 | 18  | 2.9              | 22.0951        | 38.3029       | 8.0        | 290        | 55      | 22.0822-22.0992, 38.3123-38.3005 | 03        | 13                   | 28                   |
| W24 | 2012/06/24 02:14:30 | 2012/06/27 20:42:11 | 15  | 1.7              | 21.8633        | 38,4957       | 15         | 90         | 40      | 21.8614-21.8700, 38.4933         | 02        | 14                   | 8                    |
| W25 | 2012/08/12 08:07:46 | 2012/08/23 18:40:45 | 64  | 3.1              | 22.1127        | 38.2953       | 8.25       | 280        | 60      | 22,1004-22,1356, 38,2977-38,290  | 03        | 3                    | 33                   |
| W26 | 2012/09/06 01:43:47 | 2012/09/18 02:03:35 | 32  | 3.1              | 21.8616        | 38.3603       | 8.7        | 290        | 50      | 21.8577-21.8757, 38.362-38.358   | 02        | 27                   | 7                    |
| W27 | 2013/01/27 15:47:35 | 2013/01/30 11:44:12 | 30  | 3.2              | 38.3017        | 23.1105       | 8.5        | 290        | 60      | 22.1363-22.1563, 38.3239-38.3160 | 03        | 13                   | 33                   |
| W28 | 2013/01/28 08:43:15 | 2013/02/14 13:09:31 | 44  | 3.6              | 22,1469        | 38.3173       | 8.5        | 290        | 60      | 22.1018-22.1200, 38.3066-38.2988 | 03        | 13                   | 33                   |
| W29 | 2013/03/20 22:41:31 | 2013/03/24 18:27:53 | 23  | 3.3              | 22.0391        | 38.3229       | 8.0        | 280        | 40      | 22.0302-22.0448, 38.3217-38.3200 | 03        | 3                    | 13                   |
| W30 | 2013/06/14 21:09:36 | 2013/06/19 05:52:13 | 71  | 1.9              | 22.1730        | 38.2420       | 8.5        | 260        | 45      | 22.1594-22.1913, 38.2382-38.2441 | 04        | 11                   | 9                    |
| W31 | 2013/07/05 17:23:49 | 2013/07/07 10:15:56 | 53  | 2.7              | 22.0629        | 38.3277       | 8.5        | 90         | 50      | 22.0497-22.0686, 38.3268         | 03        | 3                    | 13                   |
| W32 | 2013/09/09 16:26:48 | 2013/09/14 00:00:09 | 131 | 2.8              | 22.0326        | 38,3984       | 8          | 110        | 50      | 22.0215-22.0395, 38.4011-38.3952 | 03        | 17                   | 13                   |
| W33 | 2013/10/22 03:38:57 | 2013/10/29 23:06:54 | 29  | 3.1              | 21.8812        | 38,3682       | 7.5        | 110        | 30      | 21.8909-21.9045, 38.3753-38.3710 | 02        | 34                   | 18                   |
| W34 | 2013/10/26 09:26:47 | 2013/11/12 12:25:18 | 249 | 3.1              | 22.1119        | 38.2331       | 10.5       | 280        | 45      | 22.1036-22.1209, 38.2328-38.2307 | 04        | 9                    | 9                    |
| W35 | 2013/10/26 09:33:11 | 2013/10/28 11:27:31 | 22  | 3.1              | 21.8983        | 38.3753       | 8          | 110        | 40      | 21.8718-21.8854, 38.3689-38.3641 | 02        | 34                   | 8                    |
| W36 | 2013/12/02 21:02:46 | 2013/12/15 18:27:06 | 79  | 2.8              | 21.8422        | 38.3267       | 8          | 270        | 60      | 21.820-21.860, 38.328            | 02        | 7                    | 17                   |
| W37 | 2014/01/07 23:41:30 | 2014/01/22 06:09:05 | 53  | 2.9              | 22.0175        | 38.3872       | 7.5        | 280        | 60      | 22.0133-22.0251, 38.3885-38.3862 | 03        | 3                    | 33                   |
| W38 | 2014/01/16 22:53:58 | 2014/01/26 07:49:42 | 37  | 2.6              | 21.9802        | 38.3465       | 8.25       | 280        | 40      | 21.9653-21.9880, 38.3495-38.3459 | 03        | 3                    | 13                   |
| W39 | 2014/06/08 00:32:41 | 2014/06/24 19:34:06 | 132 | 4.3              | 22.0545        | 38.3221       | 8.5        | 280        | 50      | 22.0441-22.0627, 38.3248-38.3216 | 03        | 3                    | 23                   |
| W40 | 2014/06/08 16:49:41 | 2014/06/17 13:30:32 | 67  | 3.6              | 22.0645        | 38.3328       | 8.5        | 270        | 50      | 22.0524-22.0731. 38.3313         | 03        | 7                    | 23                   |
| W41 | 2014/07/25 09:56:50 | 2014/07/29 06:08:57 | 13  | 2.2              | 22.0862        | 38.3013       | 8.5        | 280        | 50      | 22.0808-22.0931. 38.3021-38.3005 | 03        | 3                    | 23                   |
| W42 | 2014/08/23 21:00:15 | 2014/08/27 21:47:26 | 18  | 2.4              | 22.0749        | 38,3079       | 8.5        | 280        | 45      | 22.0683-22.0791. 38.3107-38.3090 | 03        | 3                    | 18                   |
| W43 | 2014/09/18 05:43:21 | 2014/09/28 23:34:54 | 170 | 4.6              | 21.8181        | 38,3573       | 10         | 250        | 55      | 21.796-21.8551. 38.349-38.36     | 02        | 13                   | 12                   |
| W44 | 2014/11/07 17:12:59 | 2014/12/02 00:33:13 | 270 | 4.8              | 22.1380        | 38.2745       | 7.5        | 270        | 35      | 22.12-22.16.38.275               | 03        | 7                    | 8                    |
| W45 | 2014/11/24 12:32:39 | 2014/11/27 04:52:27 | 14  | 2.5              | 22.0902        | 38,3046       | 8.5        | 270        | 45      | 22.0765-22.0960, 38.3039-38.3005 | 03        | 7                    | 18                   |
| W46 | 2014/12/09 14:06:05 | 2014/12/15 02:27:30 | 22  | 2.2              | 22.0705        | 38,3035       | 8.0        | 290        | 40      | 22.052-22.0762, 38.3052-38.2930  | 03        | 13                   | 13                   |
| W47 | 2014/12/17 18:20:15 | 2014/12/24 22:09:10 | 28  | 2.1              | 22.0817        | 38,2991       | 8.25       | 280        | 50      | 22.0770-22.0967, 38.3005-38.2971 | 03        | 3                    | 23                   |
| E01 | 2009/05/16 12:56:19 | 2009/05/22 17:13:19 | 43  | 4.4              | 22.6764        | 38,1230       | 9.0        | 280        | 50      | 22.6542-22.7014, 38.1245-38.1143 | 06        | 18                   | 23                   |
| E02 | 2013/06/10 04:53:57 | 2013/06/29 02:55:05 | 332 | 3.5              | 23.1999        | 38.1615       | 8.0        | 60         | 55      | 23.1896-23.2193, 38.1484-38.1606 | 08        | 4                    | 7                    |

#### APPENDIX C: SPATIAL DISTRIBUTION OF ERRORS



Figure C1. Spatial distribution of errors in (a) and (b) X, (c) and (d) Y and (e) and (f) Z-direction for the different parts of Corinth Gulf. Errors are in metres.