STATISTICAL ANALYSES OF AFTERSHOCKS AND SWARMS ASSOCIATED WITH ACTIVE FAULTS IN CENTRAL GREECE: INTER-EVENT SEPARATION AS AN INDICATOR OF SEISMO-TECTONIC SETTING?

S.R. Curd[(1)], P.W. Burton[(1)], C.A. Davenport[(1)], E. Sokos[(2)] and G.-A. Tselentis[(2)]
[(1)]School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, United Kingdom, s.curd@uea.ac.uk
[(2)]Seismological Laboratory, University of Patras, Rio 261 10 Greece, thimios@geology.upatras.gr

ABSTRACT

Microearthquake data from local networks in central Greece, e.g. the network of the University of Patras (PATNET) and an earlier network associated with Volos (VOLNET), are analysed in an attempt to discern patterns indicative of their seismo-tectonic setting.

PATNET is located around the tectonically complex western end of the Gulf of Corinth and the Gulf of Patras, within an area exhibiting active transtensional and extensional fault zones. The area has a history of large earthquakes, notably Egion (6.2 Ms in 1995) and Patras (5.3 Ms in 1993). Similarly large events occur in adjacent areas, e.g. the Ionian Islands immediately to the west. The 1995 Egion earthquake seems to have occurred on a major east-west trending normal fault whilst the 1993 Patras earthquake appears to be associated with sinistral strike-slip movement on a north-south trending fault zone. The seismicity recorded by VOLNET includes swarm activity associated with the Nea Ankhialos fault, a relatively clearly identified seismo-tectonic feature associated with major earthquakes e.g. the 1980 July sequence of 5.6, 6.5 and 6.0 Ms. Aftershock and swarm sequences associated with these regions are evaluated using spatial and temporal criteria. The time interval (*time jump*) and the spatial separation (*space jump*) between successive earthquakes in the sequence are used to form frequency distributions of the time and space jump data. The different time jump data sets show fairly similar frequency distributions and are fitted by lognormal distributions. The corresponding space jump data, however, are fitted with either gamma or Weibull distributions. The space jump distributions are significantly different from one another. It is suggested that the differences in the gamma or Weibull distributions of the space jump data from these different sequences arise from their respective seismo-tectonic settings.

INTRODUCTION

Inter-event statistics have been shown to hold potential as important indicators of the seismo-tectonic setting within which microearthquake swarms occur (Burton & Curd 2000). This paper reports on the results of the analysis of the spatial and temporal jumps between consecutive earthquakes in the Patras area of west-central Greece and the Volos area of east-central Greece.

The local seismic network of the University of Patras (PATNET) is currently operating around the town of Patras in west-central Greece. Data for the period 1991-97 has been made available and is analysed in this paper. Additional data from a regional seismic network around the town of Volos (VOLNET) is also incorporated (Melis *et al.* 1995).

The Patras area is seismically active and tectonically complex with a history of damaging earthquakes, notably Egion (6.2 Ms in 1995) and Patras (5.3 Ms in 1993). The 1995 Egion earthquake appears to have occurred on a major east-west trending normal fault that throws down to the north and that forms the southern margin of the Gulf of Corinth half-graben in this region. Although only ca 40 kilometres to the west of the Egion event, the Patras 1993 earthquake appears to have occurred on a northwest trending sinistral strike-slip fault. It is postulated that the Patras strike-slip fault marks the tectonic boundary between the dip-slip regime to the east exemplified by the Gulf of Corinth and a strike-slip regime to the west caused by the southwards extrusion of a structurally complex "Ionian Block".

The seismicity of east-central Greece is variable. VOLNET recorded swarm activity associated with the Nea Ankhialos fault. This fault has a history of large dip-slip earthquakes e.g. the July 1980 sequence of 5.6, 6.5 and 6.0 Ms. To the southwest, Pavliani is an area of only low to moderate historical seismicity. Here, VOLNET recorded two microearthquake swarms; Pavliani A and B (Burton *et al.* 1995). Finally, a microearthquake swarm in the vicinity of Egion was also recorded by VOLNET in 1983.

SWARM IDENTIFICATION AND INTER-EVENT STATISTICS

Events were classified as belonging to a microearthquake swarm or aftershock sequence if they clustered in space and in time (Gardener & Knopoff 1974). These criteria allowed easy separation of the microearthquake swarms and aftershock sequences from each other and background seismicity. The microearthquake swarms and aftershock sequences analysed are tabulated below.

Swarm / Aftershock	No. Events	Mag. Range Ms	Network
Egion 1995 Aftershocks	568	6.2 - 2.2	Patnet
Patras 1993 Aftershocks	329	5.4 - 1.0	Patnet
Egion 1983 Swarm	288	3.4 - 1.9	Volnet
Pavliani 1983-84 Swarm A	261	3.2 - 1.0	Volnet
Pavliani 1983-84 Swarm B	95	4.6 - 1.9	Volnet

The temporal separation between consecutive events is simply calculated as the difference in origin times between consecutive events. Two spatial separations are calculated (in km) and statistically analysed. The 2D epicentral separation is calculated from application of Pythagorus theorem to converted latitude and longitude co-ordinates. The 3D separation includes the focal depth to give the hypocentral separation.

FREQUENCY DISTRIBUTIONS

Various equal class intervals for both time, 2D and 3D jumps were tested for preservation of distribution shape versus noise reduction and to result in 10 - 20 classes for the distribution (e.g. Harper 1991). Optimal class intervals were found of 1,000 seconds for the time jumps and 2.0 km for the space jumps. The time jump data and the 2D and 3D space jump data are classified accordingly and frequency distributions plotted.

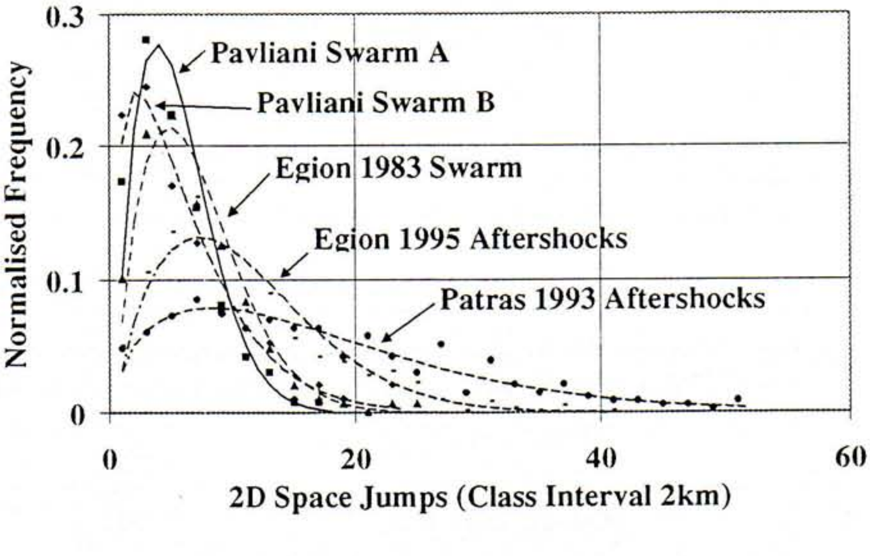

Figure 1. Comparison of 2D space jump distributions with best fit Weibull probability distribution.

The frequency distributions are quantified by fitting known probability distributions to the data; the goodness of fit being assessed by Chi^2

analysis. For the 2D and 3D space jump data, gamma and Weibull distributions were the only distributions to give a consistently good fit.

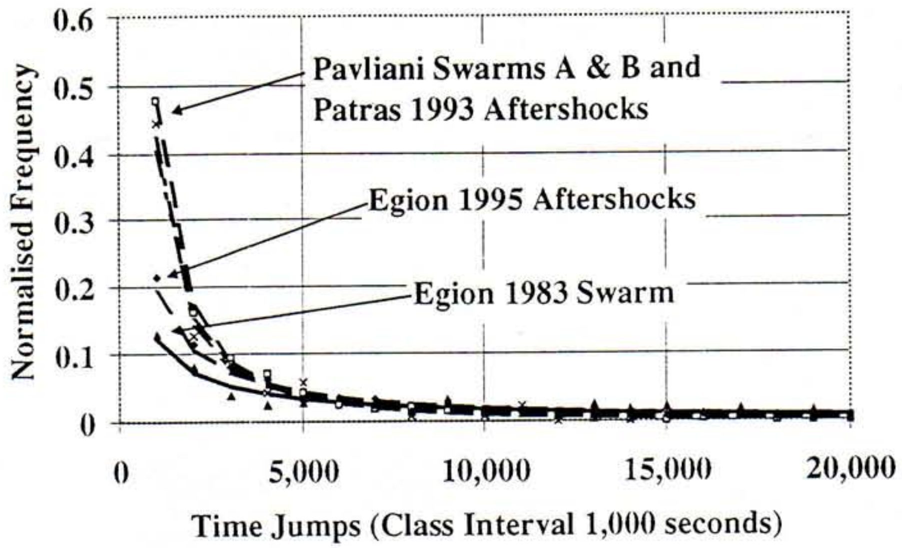

Figure 2. Comparison of the time jump distributions.

The time jump data are exclusively fitted well by the lognormal distribution. The frequency distributions of the data can, therefore, be quantified by the parameters of the appropriate probability distributions.

DISCUSSION

That the time jump data are well fitted by lognormal and the space jump data are well fitted by either gamma or Weibull distributions indicate that the data are non-independent. The only continuous distribution to indicate independence of the data is the exponential distribution. Udias and Rice (1975) found that the exponential distribution fitted their time jump data from the San Andreas fault, indicating independence of the data, whereas the exponential distribution produced an inferior fit to that of the lognormal distribution with the swarm and aftershock data analysed here.

The comparison of 2D and 3D space jump distributions for any given swarm or aftershock sequence show very similar distributions but with slightly inferior Chi^2 values for the 3D distributions as expected due to uncertainty in the focal depth estimates. Comparison of the space jump distributions for different swarms, however, show interesting differences. The two Pavliani swarms, A and B, are very similar whereas the Egion and Patras aftershocks show two different distributions to each other and to the Pavliani swarms. The 1983 swarm in the Egion area shows a distribution similar to that of the Pavliani swarms.

The time jump distributions in lognormal form show more subtle variation; the Egion 1983 microearthquake swarm and Patras 1993 aftershock sequence distributions show the largest differences.

The Pavliani swarms A and B show no significant difference in either their space or time jump distributions. The space jump distributions indicate that the Patras 1993 aftershocks and the Egion 1995 aftershocks are significantly different from each other and the other data sets. The time jump distributions highlight differences between the Egion 1983 microearthquake swarm and the Patras 1993 aftershock sequence. These differences are thought to be indicative of the different seismo-tectonic settings of the swarms or aftershock sequences.

CONCLUSIONS

- The 2D and 3D spatial jumps are characterised by the parameters of gamma or Weibull distributions.
- The temporal jumps are characterised by the parameters of lognormal distributions.
- Inter-event data for the microearthquake swarms and aftershock sequences are non-independent.
- The shapes of the distributions appear promising as indicators of the seismo-tectonic setting and may be indicative of a tendency of an area to suffer damaging earthquakes.

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