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Dynamical characterization of the 1982–2015 seismicity of Aswan region (Egypt)

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ABSTRACT

In this study, the seismicity that occurred in Aswan region from 1982 to 2015 is investigated using robust statistical methodologies. The completeness magnitude, estimated by using two different methods (MAXC and GFT) is 2.5 for the whole catalog with $b \sim 1.07$. By using the expectation maximization algorithm, two depth classes of events were identified with a threshold at about 12 km. The events deeper and shallower than the threshold could be likely generated by the same mechanism: the loading/unloading operation of the Lake Nasser reservoir. We suggest that the shallow seismicity occurs on shallow small fractures in correspondence of the intersection of N-S faults with E-W faults, which may form a minor pull-apart basin. The deep events mainly occur along the right-lateral, strike-slip, E–W Kalabsha fault and the seismicity is characterized by mainshock-aftershocks sequences that mask the annual periodicity if not properly aftershock-depleted. Indeed, before applying the declustering on the seismic catalog, the analysis of the time-clustering properties of the shallow earthquakes reveals already the presence of annual modulation that is not evident in the time dynamics of the deep earthquakes. Furthermore, the shallow events are featured by the Allan Factor scaling exponent (measuring the strength of the time-clustering in an earthquake sequence) lower than that of the deep events, indicating a tendency of the time dynamics of the shallow earthquakes to behave more regularly than the deep ones. The detrended fluctuation analysis of the magnitude series suggests that the earthquake series are weakly persistent, characterized by the tendency of events of similar value of magnitude to follow each other.

1. Introduction

River Nile, the longest river in the world, is a common basin between 11 countries, traveling over 2700 km through Sahara Desert without any significant perennial tributary inputs (Woodward et al., 2007). Throughout time the river has gone through natural and anthropological changes, being a structurally controlled stream since its early stages. Several studies (i.e. Adamson and Williams, 1980; Said, 1981, 1993) have proposed that the river Nile is in continuous evolving process by major tectonic phenomena and climatic changes including the Rifting of East African that could be the shaping factor for the location of sedimentary basin and the drainage pattern.

The river has gone through many water resources management mega projects; the largest till now is the Aswan High Dam constructed between 1960 and 1971, which is 111 m high, a crest length of 3830 m, and impounds the second largest reservoir in the world, the Lake Nasser, that has a gross capacity of 169 billion cubic meters. On November 14, 1981, an Ms 5.3 earthquake took place south of the dam. This earthquake has raised the concerns about the dam stability from one side and its relation to seismicity from the other side. A network of 13 stations was established (Simpson et al., 1987) to monitor seismicity around the lake since 1982, and intense seismic activity has been recorded since then (Simpson et al., 1990; Gahalaut et al., 2016, and references therein).

Several researchers explored the relationship between the Aswan reservoir water level and the observed seismicity in the region (e.g., Kebeasy et al., 1981; Simpson et al., 1990; Hassoup, 1994; Selim et al., 2002; Mekkawi et al., 2004; Haggag et al., 2008; Telesca et al., 2012a, b, c; Gahalaut et al., 2016) and, even if in some periods there were found no or weaker reservoir influence (Hassoup, 1994; Selim et al., 2002; Mekkawi et al., 2004; Telesca et al., 2012a, b, c), it has been commonly accepted that the Aswan seismicity is a case of continuous reservoir triggered seismicity (RTS). Therefore, Aswan area belongs to the reservoir sites that exhibit triggered seismicity every year or after a gap of a few years, such as Lake Mead in the USA (Carder, 1945), Koyna-Warna reservoir in India (Gupta, 2002; Durá-Gómez and Talwani, 2010), Nurek Dam in Tajikistan (Simpson and Negmatullaev,

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1981), Açu reservoir in Brazil (El Hariri et al., 2010), and Pertusillo reservoir in Italy (Stabile et al., 2014; Telesca et al., 2015). In all the cases mentioned above delayed seismic response to water fluctuations of reservoirs was observed suggesting that the dominant mechanism of the observed continued RTS is the diffusion of pore fluid pressures. Particularly for the Aswan area, Gahalaut and Hassoup (2012) demonstrated from an analytical simulation that although the stress due to the reservoir load stabilizes seimogenic faults of the area, the effect of pore fluid pressure leads the faults to go beyond the critical stress for failure.

Due to the presence of the High Dam and the seismic risk that it could raise, a deep dynamical characterization of the seismic process governing Aswan area is challenging and, at same time, crucial to best understand the mechanisms related to the generation of local earthquakes.

In fact, it is widely recognized that investigating with detail the structure of magnitude, space and time distribution of earthquakes is fundamental for earthquake hazard assessment as well as for the comprehension of properties of seismic processes (see e.g. Goltz, 1997; Kagan, 1997; Matcharashvili et al., 2009). In particular, the investigation of the characteristics of time distribution of earthquake occurrences on various temporal scales has been the focus of very intense research. Several studies based on different conceptual frameworks approached the analysis of earthquake time patterns by means of both field and laboratory data as well as numerical simulations (e.g. Issac et al., 2004; Lyakhovsky et al., 2001; Matcharashvili et al., 2000; Telesca et al., 2004). Most of such studies highlight that seismic processes are characterized by intermittent time behavior with phases of intense seismic activity interspersed with those of low seismicity (Ben-Zion and Lyakhovsky, 2002; Kiyashchenko et al., 2004; Pliakis et al., 2012; Vallianatos et al., 2012); thus, evidencing the presence of nonrandom components in earthquake generation in energy, space and time domains (Iliopoulos and Pavlos, 2010).

Within this context, in this study we aim at investigating the dynamical properties of the most updated seismic catalog of Aswan applying several robust statistical methodologies to the magnitude and time distribution of seismicity that occurred nearby Lake Nasser from 1982 to 2015 in order to better characterize its time dynamics.

2. Seismo-tectonic settings and data description

Aswan (or Syene as its Greek name, which is named after the type locality for the igneous rock syenite) is located in the southern part of Egypt at the interface between the stable Archean craton of the Nubian Shield and the less stable Pan-African orogeny of the southern most of the Egyptian Eastern Desert. Aswan exhibits a complex geological situation with a number of different rock types, ranging from quaternary deposits to cretaceous sedimentary rocks of Nubian sandstone, to igneous and metamorphic rocks of the deep-lying basement complex, which have been uplifted and exposed to surface. In many areas in and around Aswan the river has eroded the overlying Nubian sandstone and carved deep channels into the igneous rocks (Greiling et al., 1994).

From early satellite imagery, El Shazly et al. (1973) has described the structural trends in Aswan area to be mainly NNW-SSE fractures making notable horizontal separation and NW-SE fractures showing horizontal and vertical separation along geological and relief boundaries. Furthermore, the NNE-SSW fault west to Kurkur shows horizontal left-lateral trend. In addition, two major fracture trends are present in NE-SW and the ENE-WSW. According to El Shazly et al. (1973) the NE-SW fractures do not show separation, and they may be major tension fractures perpendicular to the principal force creating the previously mentioned two major fault trends. Fractures seem to represent tension zones along the hinges of major folds, which may have been faulted along the same zones.

These trends have been reactivated as both strike-slip E-W dextral and N-S sinistral faults (WCC, 1985; Abdeen et al., 2000), and dip-slip faults (Issawi, 1978) and propagated up through the sedimentary cover. The seismic activity is concentrated along N-S and E-W fault intersections. The N-S faults have less activity than that of E-W faults. Recent stress regime deduced from Earthquake focal mechanism (Hussein et al., 2013) is in good agreement with that of geological studies and borehole breakout data (Bosworth and Strecker, 1997) with Shmax E-W and Shmin NNE-SSW. Under this stress regime, the province is found to be consistent with both right lateral faults (E–W striking) and left lateral faults (N–S striking).

The largest of the Aswan earthquakes was of magnitude Ms 5.3, and occurred on 14 November 1981. From the intensity data, the well-determined locations of numerous aftershocks recorded using portable stations and a telemetered network, the event appears located on the Kalabsha fault beneath Gebel Marawa (Kebeasy et al., 1987). The depths of the aftershocks and the special study of teleseismic records of the mainshock (WCC, 1985) indicate that the mainshock was at a depth from 18 to 20 km. Prior November 14, 1981, no earthquakes had been reported in the Aswan area in the catalog of the International Seismological Center (ISC) since the ISC's inception in 1920. Because of the lack of continuous and reliable data during the early stages of the filling of the Aswan reservoir, it is not possible to determine exactly when low-magnitude activity may have started. The first seismographs installed in the Aswan area that were capable of recording small local earthquakes were Soviet short-period (SMK) instruments installed at Aswan and Abu Simble in 1975. Although the operation of the stations was irregular prior to 1981, 20 events of magnitude > 2.5 have been identified by Helwan Institute located in the Wadi Kalabsha area. Thirteen of these took place during approximately 200 days of station operation between August 1980 and August 1981. A long sequence of aftershocks followed the 14 November 1981 earthquake, including the immediate aftershocks and the continuation of Aswan activity until the present both in the area of the mainshock and around the northern part of the Aswan reservoir.

Following the mainshock, portable microearthquake recorders were installed in the northern part of reservoir area by Egyptian Geological survey from December to June 1982. In late June 1982, the portable seismic field stations were replaced by a telemetry network erected by Helwan Observatory and Lamont-Doherty Geological Observatory (USA). The purpose of the telemetry network is to monitor the induced/triggered seismicity along the Kalabsha fault (Fig. 1), which continues to occur in the area of the November 14, 1981 earthquake (Kebeasy et al., 1987; Fat-Helbary and Tealb, 2002). Data were transmitted to a data center to record the output signals coming from the field stations. Five monitors with pen recorder were used for the visual record and all the data were recorded in the FM magnetic tape as analog data and in the 9-track tape as digital data. A playback unit and computer facilities had been installed at the center to allow earthquakes to be quickly analyzed and located. Since 2009, the Aswan seismic network has been updated and replaced by new digital broad band network. The transmission system is changed from telemetry to satellite and in addition some stations in field were moved to near better sites. As well as the data from field stations is sent to the main center for the necessary analysis using the recent software programs such as Atlas and Earlybird.

The output data include latitude, longitude, focal depth, origin time, epicenter distance and azimuth for each station. Various measures of location accuracy are also given. The output data are used for constructing the seismicity map of the Kalabsha area (Fig. 2a).

3. Methods and results

In this study we investigate the seismicity that occurred from January, 1, 1982 to December 31, 2015 in the area of Aswan (Fig. 2). We employed several independent statistical methods to obtain the most complete picture of the dynamical properties of the seismic process in the area.