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Strong earthquakes and geomagnetic jerks: a cause-effect relationship?

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Abstract
Secular variation of the geomagnetic field observed at the Earth's surface has been found to undergo impulsive accelerations (jerks) lasting less than a few years. In this paper the relations between jerks and the occurrence of strong earthquakes ($M_s \geq 7.0$) is analysed for this century, disclosing a positive correlation between the maximum number of recorded strong earthquakes and jerk occurrence. Analysing only very strong earthquakes ($M_s \geq 8.0$) the jerks seem to take place with a time delay of about 2-5 years with respect to earthquake occurrence. Reliable processes that could justify this intriguing correspondence are suggested.

Key words *secular variation – jerk – earthquake*

The annual mean values of any magnetic element (northern (X), eastern (Y) and vertical component (Z)) as recorded at a particular geomagnetic observatory, generally undergo a steady decrease or increase in time. This change is called the «geomagnetic secular variation» and is linked to the cause of the main field itself (Parkinson, 1983).

A jerk is defined as a sudden change in secular variation taking place in a year or two and is visible as a step function in the secular acceleration; fig. 1, shows a geomagnetic jerk (indicated by the arrow) as recorded at the L'Aquila observatory (AQU, Lat. 42.383°N, Long. 13.317°E).

A first report on the existence of geomagnetic jerks observed in Europe, was published in 1978 (Courtillot *et al.*, 1978), reporting on a sudden acceleration of the eastward component of the geomagnetic field around 1970 (fig. 1). A subsequent inspection showed that the occurrence of the phenomenon took place over much of the northern hemisphere (Courtillot *et al.*, 1978; Ducruix *et al.*, 1980; Le Mouël *et al.*, 1982). Another occurrence was found later around 1910 pointing out a similar geographic extent (Vestine, 1952; Courtillot and Le Mouël, 1984). Recently, by means of the wavelet analysis method, some authors were able to isolate five singularities during the last century: 1913, 1925, 1969 and 1978 (Alexandrescu *et al.*, 1995).

Golovkov *et al.* (1989, 1995) indicated the existence of an impulsive change also in 1947 and 1958. Other evidences of such impulses before 1900 have been reported (*e.g.* Le Mouël and Courtillot, 1981; Nevanlinna, 1995) but the small number of observatories available at that time does not permit to investigate in detail their spatial and geographical extent.

After the first report of a jerk, there was a fast growing debate on this phenomenology mainly focused on its sources (external or internal) (*e.g.* Nevanlinna and Sucksdorff, 1981; Alldredge, 1985; Nevanlinna, 1985; Backus *et al.*, 1987; Stewart and Whaler, 1992) and on their world-wide extent (*e.g.* Chau *et al.*, 1981; Le Mouël *et al.*, 1982; McLeod, 1992). Among the external origin supporters, Alldredge

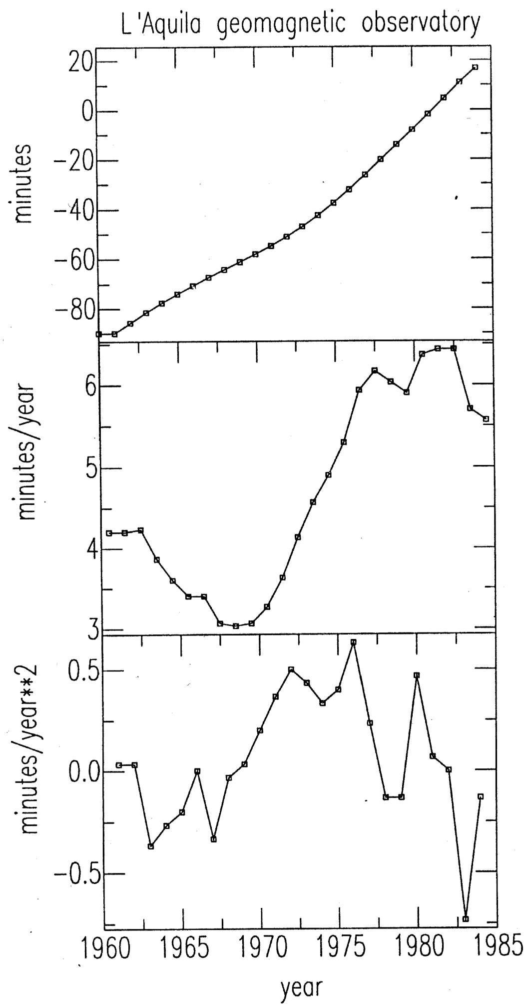

Fig. 1. Magnetic declination, secular variation and its secular acceleration observed at the L'Aquila observatory (AQU, Lat. 42.383°N, Long. 13.317°E) for the period 1960-1985.

(1979, 1985) interpreted the rapid secular change as part of the solar cycle effect and attributed it to polar electrojets and magnetospheric ring-current. However, the jerk occurrence did not follow the 11 year cycle of the sunspots; in particular, during the 1969 jerk, the input energy of the solar wind to the Earth's magnetosphere was roughly 30% lower than during the adjacent sunspot cycles (Nevanlinna, 1985), where no jerks were clearly identified.

Spherical harmonic analyses (*e.g.* Malin and Hodder, 1982; Gubbins, 1984; McLeod, 1985, 1992) are instead in favour of an internal origin of the jerk, even if this approach does not provide a separation of the main field from those induced in the conducting mantle by external sources.

The detection of magnetic signals generated in the Earth's core and diffused through the electrically conducting mantle, provide a valid constrain to the mantle electrical conductivity estimates (Runcorn, 1955; McDonald, 1957; Courtillot and Le Mouël, 1984).

Several authors also tried to correlate these impulsive variations to other geophysical phenomena; among others, Le Mouël and Courtillot (1981) correlated these secular acceleration impulses with minima in the Earth's rotation rate suggesting some kind of core-mantle coupling. In this paper the effects of strong earthquakes on the dynamic of the outer fluid core are considered.

We analysed the earthquakes around the world starting from year 1900 up to date. The data came from different catalogue sources (Abe, 1981; Bath, 1979; Duda, 1965; Pacheco and Sykes, 1992; NEIS, 1995; Kanamori, 1988) and regarded earthquakes with $M_s \geq 7.0$. The data were smoothed using a four year running average; the resulting annual number of large earthquakes around the world are shown in fig. 2a. In the figure four main peaks, coinciding with the years 1910, 1925, 1947, 1969, are clearly evident pointing out a striking correspondence between the occurrence of strong earthquakes and the magnetic field singularities.

We also extracted from the database earthquakes with $M_s \geq 8.0$. The resulting annual number of these events and the occurrence of impulsive variations of the magnetic field are shown in fig. 2b. The figure indicates out that the jerk occurrences follow by a time delay of about 2-5 years, the maximum earthquake peaks. In particular, a maximum peak for the year 1985 anticipates the 1990 jerk recently observed (Cafarella and Meloni, 1995).

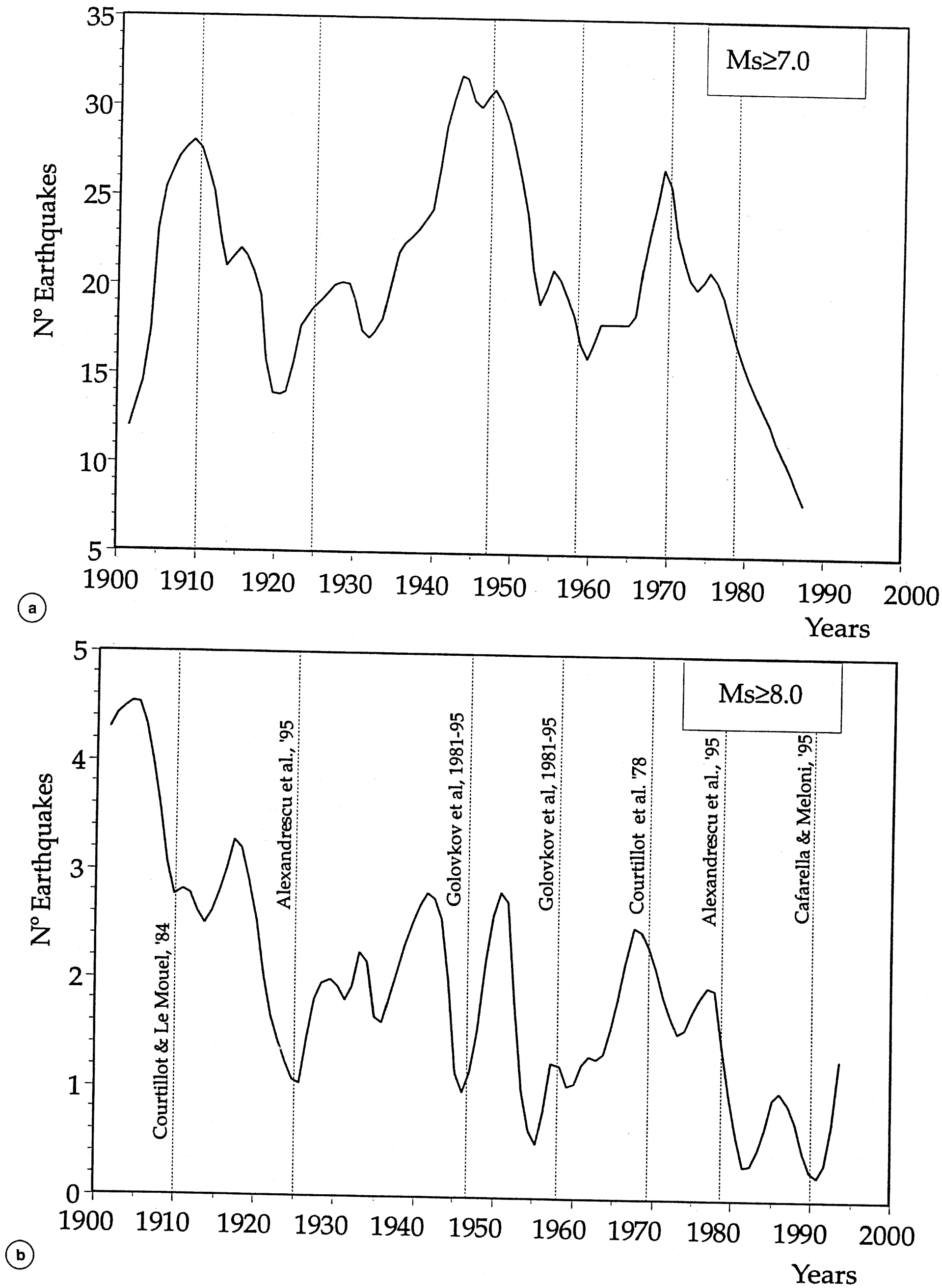

Fig. 2a,b. a) Annual number of large ($M_s \geq 7.0$) earthquakes around the world, for the period 1900-1990; b) annual number of very large $M_s \geq 8.0$ earthquakes around the world, for the period 1900-1995, and the occurrence of geomagnetic jerks, reported with dashed lines; principal source references for the geomagnetic jerks are reported.

The intriguing correspondence stresses out that strong earthquakes could excite processes affecting the geodynamo and, in particular, the vectorial configuration of the velocity field of the outer fluid core layers. Four reliable processes can be invoked to generate these effects:

1) a deformation of the Core Mantle Boundary (CMB) topography due to strong earthquakes, which can be predicted on the basis of global viscoelastic Earth models (Piersanti *et al.*, 1995). The consequent outer core fluid motion response would involve a portion of the core having a wavelength comparable with the distance between the seismic source and the CMB;

2) deep earthquakes characterised by low frequencies and large amplitude could excite the Earth's normal modes, causing instabilities in the outer core convection cells where the magnetic field generates;

3) the momentum of inertia of the Earth will change as a consequence of mass redistribution within it, caused by strong earthquakes. To conserve angular momentum, the Earth's rotation rate must also change causing a differential rotation between the outer core and the lower mantle. The changing conditions at the CMB may affect the generation mechanism of the Earth's magnetic field. Within the framework of viscoelastic Earth models, the impact of viscoelastic deformation of the CMB and differential rotation between the mantle and the core on time variations of the magnetic field has already been analyzed for postglacial rebound, which occurs on time scales of 10^3 yrs (Lefftz *et al.*, 1994);

4) the solid inner core of the Earth may be excited to a state of oscillation by an external agent such as an earthquake (Won and Kuo, 1973) inducing complications in the flow pattern of the outer fluid core.

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