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Advances in Space Research 59 (2017) 1033–1040

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Persistent long-term (1944–2015) ionosphere-magnetosphere associations at the area of intense seismic activity and beyond

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Received 23 September 2016; received in revised form 5 November 2016; accepted 16 November 2016
Available online 24 November 2016

Abstract

Analysis of the earthquakes catalogues since 1944 reveals the area of the peak global earthquake occurrence in the Pacific Ocean southwards from the magnetic equator, in particular, at Australia. In the present study a long series of geomagnetic *aa* indices gathered from two antipodal magnetic observatories at Melbourne (Australia) and Greenwich (UK) are compared with the monthly-hourly critical frequency, *foF2*, from the nearby ionosonde measurements at Canberra and Slough (Chilton) and Moscow (control site) for 1944–2015. The annual percentage occurrence of the positive ionosphere storms W index (pW^+) and negative index (pW^-) is determined. It is found that the occurrence of the ionosphere plasma depletion pW^- of the instant *foF2* as compared to the monthly median is well correlated with the *aa* index at all three sites ($cc > 0.85$). The positive storm signatures of the plasma density enhancement pW^+ show high correlation with the geomagnetic activity *aa* index at Slough ($cc = 0.68$) and Moscow ($cc = 0.92$) but drastic difference of missing correlation at Canberra ($cc = 0.06$). It has been suggested that the frequent earthquake occurrence over Australia may produce the persistent significant ionosphere plasma enhancements at Canberra which disrupts balance between the ionosphere-magnetosphere activities.

Keywords: Ionosphere critical frequency; Ionospheric W index, geomagnetic *aa* index; Seismic activity

1. Introduction

The early magnetograph records from two nearly antipodal sites at Greenwich [51.5°N, 0°E] and Melbourne [−37.8°N, 145°E] corresponding to the activity level at the invariant magnetic latitude of 50° give a long series of geomagnetic *aa* indices since 1868. The *aa* index derived from magnetic perturbation values at only two observatories (as distinct from the planetary *ap* index) experiences larger extreme values if either input site is well situated to the overhead ionospheric and/or field aligned current systems producing the magnetic storm effects. The annual values of the geomagnetic index *aa* could be the resultant of two components: one originating from solar transient (or sporadic) activity which is in phase with the solar cycle; the other is related to recurrent solar drivers with peak in the declining phase (Feynman, 1982; Du, 2011a). The long-term trend of correlation of the annual *aa* index with sunspot number has changed in 1958 revealing a 2-cycle periodicity superimposed on secular trends (Du, 2011b). The earthquake related changes in surrounding geomagnetic field and ionosphere have been detected experimentally and justified with model simulations in (Liu et al., 2006; Kuo et al., 2011; Xu et al., 2013; Devi et al., 2014; Heki and Enomoto, 2015; and references therein) so the *aa* index along with the other geomagnetic indices can serve as a tool

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http://dx.doi.org/10.1016/j.asr.2016.11.022
0273-1177/

to discriminate impact of geomagnetic storms and/or earthquakes on the ionosphere (Gulyaeva and Arikan, 2016).

One of the major discriminants of earthquake, EQ, effects on the ionosphere is the spatial range of the disturbance. Typically, geomagnetic storms affect large portions of globe after the anomalous changes in IMF-B, global electric currents and have patterns that can be recognized in the geomagnetic field. The co-seismic and post-seismic disturbances in the ionosphere can be observed locally or regionally depending on the type, magnitude and depth of the earthquake as indicated in various studies (Rishbeth, 2006; Kuo et al., 2011). The positive ionosphere storm is a regional-scale condition of the ionosphere occurring either during the geomagnetic disturbances or the tectonic events during which plasma densities are driven above values normally observed during quiet periods (Buonsanto, 1999; Immel and Manucci, 2013). The seismic-ionospheric links may be a source of the double excess of number of positive ionospheric storms at Kokubunji located at the region of enhanced seismic activity as compared to that at Boulder during 1985–2005 (Vijaya Lekshmi et al., 2011). The positive ionosphere anomalies are more effective than the negative ones for both storm and non-storm earthquake subsets which indicate on the EQ aftereffects producing rather increased plasma variability in the ionosphere than its decreasing process (Gulyaeva and Arikan, 2016).

It will be shown below that the earthquakes catalogues since 1944 reveal the area of the peak global earthquake occurrence in the Pacific Ocean southwards from the magnetic equator, and, in particular, at Australia. Accordingly, in the present study the ionosphere critical frequency, *foF2*, is analyzed from the ionosonde measurements at two antipodal observatories, Canberra and Slough (Chilton), located nearby the sites providing the magnetograph measurements for the *aa* index, and one extra ionosonde at Moscow (control site) for 1944–2015. The daily-hourly-annual percentage occurrence of the positive ionospheric W index (pW^+) and negative index (pW^-) is determined. Magnitude of W index at each location varies from the quiet state, $W = \pm 1$, to intense storm, $W = \pm 4$ (Gulyaeva et al., 2008, 2011, 2013). Probability of occurrence, pW^+, of the positive phase of ionosphere storm with *foF2* enhancement ($W = 3$ and $W = 4$) and the negative phase, pW^- ($W = -3$ and $W = -4$) is calculated in hourly-daily regime for the period of ionosonde observations from 1944 to 2015.

The global distribution of earthquakes and the data analysis method are provided in Sections 2 and 3, respectively. The paper ends with Conclusions section.

2. Global distribution of earthquakes

Two Catalogues for more than 70 recent years of tectonic observations are used to produce estimates of the spatial distribution of earthquakes for the epoch of ionosonde service. First, we use earthquake events from the ISS.CAT for a period from 1944 to 1963 (Villasenor et al., 1997). This Catalogue contains hypocenters of earthquakes listed in the bulletins of the International Seismological Summary (ISS) from 1918 to 1963. In addition, the hypocenters listed in the bulletins of the British Association for the Advancement of Science (BAAS) Seismological Committee (the predecessor of the ISS) for 1914–1917 have also been included. The magnitude of earthquakes, M, is introduced by Gutenberg and Richter (1956) at the second half of 20th century so the file ISS.CAT contains only hypocenters of earthquakes that have available phase arrival time data listed in tabular form in the ISS bulletins. Undetermined shocks and earthquakes reported by other agencies without arrival time data are not included in this file. When more than one hypocentral solution was produced for the same event (this practice was only used in the early years of the ISS) only the first solution has been listed, in order to avoid duplicate entries.

Second, the earthquake data from the global Catalogue of the Advanced National Seismic System (ANSS) provided by the Northern California Earthquake Data Center (NCEDS, 2014) are used for a period from 1964 to 2015. The composite Catalogue of earthquakes created by ANSS is a world-wide earthquakes catalog which is generated by merging the master earthquake catalogs from contributing ANSS member institutions and removing duplicate events, or non-unique solutions for the same event.

The global spatial distribution of earthquakes is irregular tending to denser earthquake occurrence in the Pacific region (Levin and Sasorova, 2012; Gulyaeva, 2014; Gulyaeva and Arikan, 2016). The circum-Pacific “Ring of Fire” belt is generally accepted as the world’s greatest earthquake zone, where about 90 percent of the world’s largest earthquakes occur (Williams, 2016). The belt extends from the southern tip of South America, up along the coast of North America, across the Bering Strait, down through Japan, and into New Zealand. The actual pattern of the relative density of the spatial percentage distribution of 93,591 earthquakes during 72 recent years (from 1944 to 2015) is demonstrated in Fig. 1.

The regions of enhanced seismic activity (Fig. 1) are observed along the tectonic plates boundaries (designated with the black points) at geographic longitudes from 90° to 190°E and magnetic latitudes from 40°S to 40°N, with dominant earthquake occurrence in the sub-equatorial region of the South magnetic hemisphere. The next appreciable zones of enhanced tectonic activity are revealed around the Far East Asia, the West coast of South America and the south part of Eurasian plate which also correspond to the tectonic plate boundaries. We note that most of the earthquakes are located within the limits of the closed magnetic field lines (±60° of magnetic latitudes). Some uncertainty in the EQs distribution in Fig. 1 may be attributed to possible inclusion of earthquakes of arbitrary magnitudes in ISS.CAT (11,857 events for 1944–1963) while those from NCEDS catalogue with magnitudes equal to