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Detailed study of Pi2 damped oscillations from low latitude magnetic observatory

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ABSTRACT

The study of low latitude damped Pi2 oscillations (40–150 s) are investigated using archived data from Choutuppal (CPL), geomagnetic observatory, operated by CSIR-NGRI, Hyderabad, India. The period of investigation is during solar cycle 21 (1975–1983). All the Pi2 events identified during this period are subjected to detailed analysis for their association with substorm and non-substorm events. It is interesting to note that there is equal probability of occurrence of Pi2s with or without a substorm. The Pi2 frequencies associated with substorms showed an increased value in the post-midnight sector than compared to the Pre-midnight sectors. The non-substorm Pi2s are seen to be associated with lower levels of geomagnetic activity. The corresponding period of Pi2s decreases with increasing level of activity. While the generation of Pi2s are generally attributed to substorm onset, it is seen that the quiet time non-substorm events are related to plasmaspheric cavity mode resonances at low latitudes.

1. Introduction

Pi2 pulsations are damped irregular oscillations in Ultra-low-frequency (ULF) range with periods between 40 and 150 s (6–25 mHz). These are magnetohydrodynamic (MHD) waves released when the near-Earth magnetotail has a rapid configurational change (e.g., (Osaki et al., 1998; Kepko et al., 2001)).

Observations from ground and satellite studies show that Pi2s cover a large spatial extent from low to high and even polar latitudes (Saito, 1969; Olson, 1999). The amplitudes, periods and number of wave cycles of observed Pi2s vary with respect to latitudes. The typical amplitude at low latitude is around 0.25–2.5 nT (Sutcliffe, 2010), below 10 nT at mid latitudes (Cao et al., 2008) and as large as 15 nT or higher at high latitudes (Rostoker and Samson, 1981). Periods of Pi2s vary from 50 s at low latitude to 120 s at high latitudes. The local time distribution covers all local time sectors at low latitudes which is limited to only the night time sectors at high latitudes (Keiling and Takahashi, 2011). Recently, there have been observations of substorms at very high latitudes (at Indian Antarctic station Bharati (corrected geomagnetic (CGM) coordinates 74.7S, 97.2E, and IMAGE chain observatories in Northern hemisphere, localized poleward of the standard auroral oval) (Singh et al., 2012; Zelinsky et al., 2014).

Different generation mechanisms have been proposed depending on the location of observation and geomagnetic activity. At high latitudes, Pi2 pulsations are mainly observed in the region of substorm-enhanced ionospheric electrojet which is tied to the evolution of the substorm current system e.g. (Olson and Rostoker, 1975). This type of Pi2s are associated with oscillations of the substorm current wedge (SCW). The low/middle latitude Pi2s are explained on the basis of inner magnetospheric models. According to this model, three main mechanisms are proposed viz: (1) Plasmaspheric Cavity Resonances (PCR), (2) Plasmapheric Virtual Resonances (PVR) and (3) Plasmaspheric Surface Resonances (PSM) [see reviews by (Keiling and Takahashi, 2011)]. These generation mechanisms and propagation has been studied extensively in the inner magnetosphere (Yeoman and Orr, 1989; Sutcliffe, 1975; Sutcliffe and Yumoto, 1989, 1991; Yumoto et al., 1989, 1990; Takahashi et al., 1995; Osaki et al., 1998; Fujita and Itonaga, 2003; Kwon et al., 2013; Luo et al., 2014). In response to these observations, theoretical/numerical studies on the behavior of low-latitude MHD waves have been carried out (Allan et al., 1986; Lee, 1996, 1998; Lee and Kim, 1999; Pekrides et al., 1997; Itonaga et al., 1997). Recently, the cavity resonances has been debated against the Bursty Bulk Flow (BBF) as a generation mechanism of low and middle latitude Pi2 pulsations. In BBF-driven process, periodical BBFs travel from the magnetotail and generate pressure pulses in the inner magnetosphere, which manifest as Pi2 pulsations at low/middle latitudes (Nosé, 2010; Cao et al., 2008). It should be noted that oscillation periods associated with SCW are typically longer than those of the PCR/PVR-Pi2s [e.g., (Yumoto et al., 1990)], and their largest amplitudes lie in the auroral zone, typically at high latitudes. The above discussed mechanisms relate to Pi2s that are associated with substorms.

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There is evidence that Pi2s can also occur during pseudo-breakups, which have other signatures similar to substorm expansion phases, such as auroral arc brightening and enhancement of the westward electrojet. These pseudo-breakups have shorter lifetime, and are extremely localized as compared to substorms (McPherron, 1991). In general, there are a number of processes that can result in Pi2 pulsations which depend on the latitude and geomagnetic activity. However, most of the studies discussed above relate to observations of Pi2s associated with substorms.

In recent years, investigation of Pi2s that occur during quiet geomagnetic conditions without the association of substorms has gained a lot of importance (Sutcliffe and Lyons, 2002; Kosaka et al., 2002; Kwon et al., 2013). Different mechanism have been proposed for the observed Pi2s during quiet geomagnetic conditions. Poleward Boundary intensifications (PBIs), is one such mechanism that explains the Pi2s observed at low latitudes (Lyons et al., 1999; Sutcliffe and Lyons, 2002; Kim et al., 2005). The associated Pi2s have the similar period and wave form as that in case of substorm. These studies discussed the mechanism of PBIs and showed that PBIs are associated with enhanced Pi2 activity that occur nearly simultaneously at high and low latitudes. The investigation of Pi2 pulsations observed from low latitude ground magnetic station during extremely quiet solar wind and geomagnetic conditions (3-hourly ap index close to zero) showed that Pi2 pulsations at low latitudes were extremely sensitive ground-based signatures of small scale magnetotail flux reconfigurations and plasma flows (Sutcliffe, 1998). There have been two more such studies that investigate Pi2s at extremely low geomagnetic conditions representing the near ground state of magnetosphere. Troitskaya (1967) examined the K_p dependence of Pi2 period during minimum, intermediate, and maximum solar activity levels and detected many Pi2 events for $k_P < 1$. Some of the Pi2 events had longer period than the classical upper limit of Pi2 band (150 s, after (Jacobs et al., 1964)). Similar study of Pi2s during super quiet geomagnetic ($k_p = 0 - 1$) showed that about 80% of the Pi2 pulsations had a period between 110 and 300 s, much larger than classical band of Pi2s (Kwon et al., 2013).

Despite several studies mentioned above, investigation of Pi2s from low latitude ground stations with emphasis on their association with substorm and non-susbtorm periods have not been investigated so far. The generation of Pi2s during substorm and non-substorm might differ and needs to be studied. Pi2 dependence on geomagnetic activity indices, auroral activity indices gives information about the generation of Pi2s at low latitudes. Some of the important issues that need to be addressed are as follows: (1) How does the occurrence of Pi2s (during substrom and non-substorm events) vary with different phases of a solar cycle? (2) How often the Pi2s are observed during substorm and non-substorm events? (3) How does the period of Pi2 vary with respect to the magnitude of susbstorms? (4) What information about the intensification of substorm can we get from the low latitude observation of Pi2s? (5) How does the period of Pi2s vary with non-substorm events for different levels of geomagnetic activity? (6) What is the source of Pi2 that is associated with non-substorm events? (7) How often the bursts of Pi2s are observed and are there any relation in the period of different bursts of Pi2?

In order to answer these questions, it is necessary to conduct a comprehensive statistical analysis of Pi2 pulsations associated with both substorm and non-substorm events. In the present study, we attempt to discuss all these questions. For this purpose, we use archived data of Pi2 pulsations from Choutuppal magnetic observatory (CPL: Gm. Lat.: 7.50 N), operated by CSIR-NGRI, India.

The paper is organized as follows. A brief description regarding the Choutuppal observatory and data sets is included in Section 2. Section 3 discusses the data sets used and data selection procedure. In Section 4, we present the results and discussion. In Section 5, we compare our results with results from middle and high latitude studies. We conclude our findings in Section 6.

2. Choutuppal (CPL) Observatory

The CSIR-NGRI operated the three component induction coil magnetometer at Chouttuppal (Gm. Lat.: 7.50 N), about 60 km due east of Hyderabad during 1969–1990 covering almost two solar cycles (Sarma et al., 1969). The magnetic pulsation recording system were of induction type having high permeability core-coil sensor, with a feedback arrangement to facilitate recording of actual variation in the field rather than the rate of change. The magnetic fields are recorded at two chart speeds viz. 30 mm/min (Ultra-quick-Run, UQR) and 90 mm/h (Quick-Run, QR). These two are recorded for measuring different kinds of pulsations. Pulsations with periods less than 20 s i.e. continuous pulsations Pc1 (0.2–5 s), Pc2(5–10 s) and irregular pulsation Pi1 (1–40 s) pulsations (as defined by (Jacobs et al., 1964)), are recorded on the UQR setup while pulsations with periods greater than 20 s are, recorded on the QR setup (Sastry et al., 1983).

A visual inspection of pulsation records of the Choutuppal observatory suggests that the Pc class of pulsations are the most dominant type of activity at this station appearing from early morning to late evening hours while the Pi type of pulsations are mainly present on the night time charts. The Pi pulsations, which occur mainly on the nighttime records, are often seen as irregular damped wave trains occurring sometimes in groups.

It must be noted that data from photographic charts were manually recorded using a graph that could provide the period of pulsations in different frequency range. Metadata of CPL from record books, can be directly used to study the pulsation effects during quiet and disturbed periods. Volume of metadata archived was spread over 14 years (1971–1984) for CPL observatory. Thus, metadata for all pulsations from Pc1-Pc5 and Pi-1 and Pi2 is available in tabulated form during 1975–1983 in different volumes of Observatories Data, published quarterly by the CSIR-NGRI.

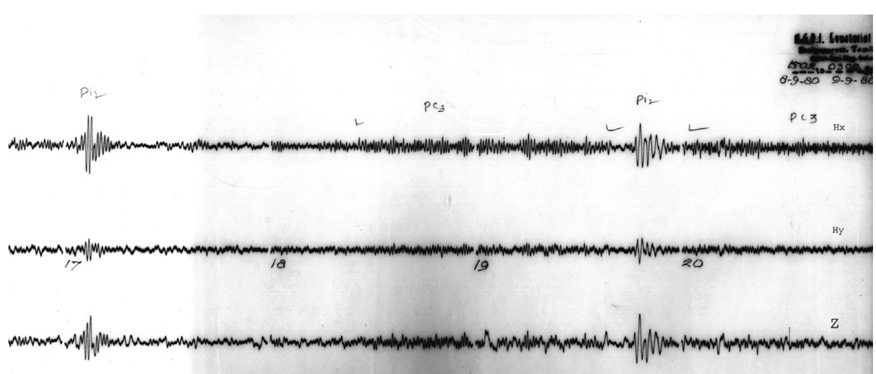

Fig. 1. A typical signature of Pi2 pulsation as obtained form the QR set up at Chouttuppal observatory during 08 September 1980-09 September 1980. Different types of pulsations like Pi2 and Pc3 observed between 1700 and 2100 UT.