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RELATION WITH AI OF MAGNETIC MICROPULSATIONS AT LOW LATITUDE IN INDIA

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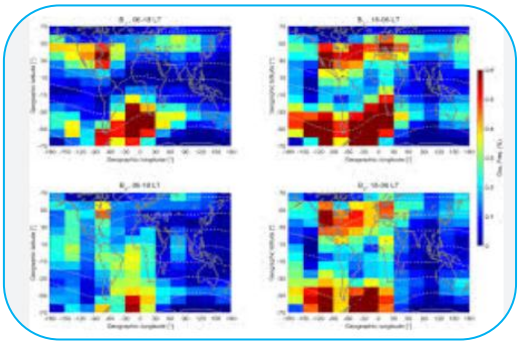


ABSTRACT :

Pc4 geomagnetic pulsations are quasi-sinusoidal variations in the earth's magnetic eld in the period range 45-150 seconds. These pulsations can be observed in a number of ways. However, the application of ground-based magnetometer arrays has proven to be one of the most successful methods of studying the spatial structure of hydromagnetic waves in the earth's magnetosphere. The solar wind provides the energy for the earths magnetospheric processes. Pc3-5 geomagnetic pulsations can be generated either externally or internally with respect to the magnetosphere. The spatial and temporal variations observed in Pc4 occurrence are of vital importance because they provide evidence which can be directly related to wave generation mechanisms both inside and external to the magnetosphere. At low latitudes (L < 3) wave energy predominates in the Pc4 band and the spatial characteristics of these pulsations have received little attention in the past. An array of four low latitude induction coil magnetometers was established in south-east India over a longitudinal range of 17 degrees at L=1.8 to 2.7 for carrying out the study of the effect of the solar wind velocity on these pulsations. Digital dynamic spectra showing Pc4 pulsation activity over a period of about 12 months have been used to evaluate Pc4 pulsation occurrence. Pc4 occurrence probability at low latitudes has been found to be dominant for the solar wind velocity in the range 320- 700 Km/s. This paper reviews current methodologies that integrate AI in the analysis of magnetic micropulsations, highlighting their advantages, limitations, and potential future directions.

KEYWORDS *: Pc4 magnetic pulsations, Pc4 occurrence, solar wind velocity, magnetospheric physics.*

1. INTRODUCTION

Observations of geomagnetic pulsations at low latitudes (L<3) indicate that significant hydromagnetic wave energy penetrates deep into the magnetosphere and the plasmas sphere. Statistical studies carried out in the past show that wave energy at low latitudes is primarily in the Pc4 frequency band [1]. However, the origin of these waves has not been fully established and it is important to determine whether they are generated within or external to the magnetosphere and to identify their generation mechanism.

It is generally accepted that some of the dayside Pc4 pulsation energy is associated with sources external to the magnetosphere. Statistical studies show that the Pc4 wave period is strongly correlated with the magnitude of the interplanetary magnetic eld while the pulsation occurrence rate is dependent on the orientation of the interplanetary magnetic field [2]. The first direct evidence for the propagation of external Pc3-4 wave energy into the magnetosphere had been presented by Greenstadt. They had shown that similar wave frequencies were observed simultaneously by ISEE-1 and ISEE-2 spacecrafts in the magnetosheath and the outer magnetosphere respectively while lower power was seen within the magnetosphere. In contrast to the external source, waves generated within the magnetosphere must originate from instabilities or free energy sources. Using the data of ISEE1, Cao et al. have reported that Pc3 waves most frequently occur just outside synchronous orbit and are approximately centered on local noon's [3]. Furthermore, using the data from GOES-2 satellite, Yumoto et al. have proposed that Pc3-4 wave energy is convected through the magnetosheath to the magnetopause [4], transmitted deep into the magnetosphere without significant changes in spectra, and then couple with various hydromagnetic wave modes in the magnetosphere.

There is ample evidence that the solar wind velocity controls some of the properties of Pc3-4 pulsations [5]. In addition, the direction of IMF also plays an important role in controlling these pulsations [6]. Studies of the joint e ect of the solar wind velocity (Vsw) and the angle of the interplanetary magnetic eld from the sun-earth line have shown that the amplitude (occurrence) and energy of Pc3-4 pulsations are positively and negatively correlated with Vsw and XB respectively [7]. The present study describes the dependence of low latitude Pc4 occurrence on Vsw over the period range of January 01 to Dec 31, 2005.

2. RESEARCH TECHNIQUE AND DATAANALYSIS

Geomagnetic micropulsations are used in a wide range of studies. The following are some of the most commonly utilized techniques [163, 164].

1. Flux Gate and Rb-vapour magnetometers are used to measure magnetic component fluctuations.
2. Time derivative of magnetic fluctuation components is determined using induction coils.
3. The magnetic field pulsation is employed to trigger the potential difference between the earth-wrapped electrodes.

The deployment of magnetometer array on the ground has been shown to be most successful techniques for determining the earth's magnetosphere's spatial structure of HM waves. Except in a few unusual circumstances, previously acknowledged Pc4 factors were limited to high and low latitudes. The spatial and temporal fluctuations in wave occurrence and recurrence circulation are important because they provide confirmation that may be closely linked to the technique used to create waves both inside and outside of the magnetosphere, as well as generating modes within the magnetosphere. Prior research on the spatial characteristics of Pc4 pulsations has been modest, and must be thoroughly analyzed in order to comprehend how these waves are generated and propagated.

Fluxgate Magnetometer

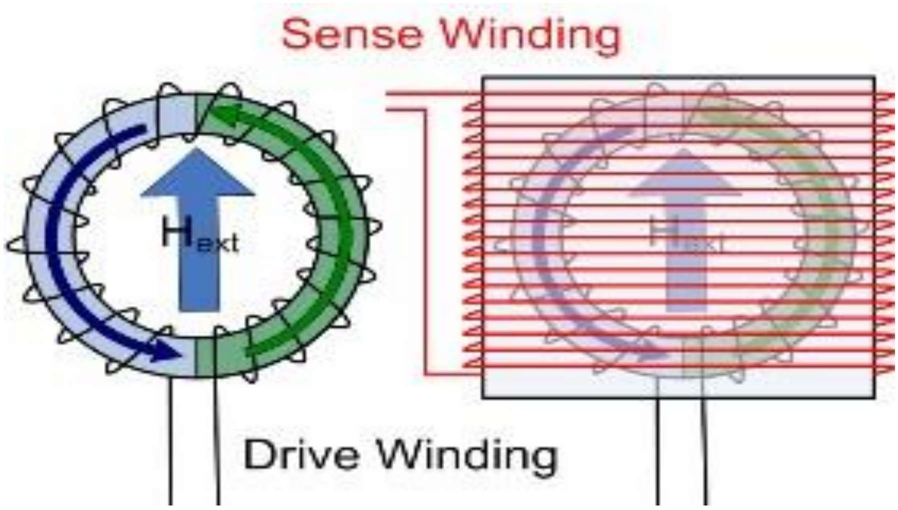
For vector magnetic fields, the fluxgate magnetometer is a magnetic field sensor. Its resolution is well below one 10,000th of that of the earth, and its normal range makes it useful for measuring the earth's field. It has historically been used for prospecting, metal detecting, and navigational tasks involving compass work. Despite being simple to build, it is frequently overlooked in the world of silicon and MEMS sensing technology today.

There are two main types of fluxgate magnetometer designs: those that use ring cores and those that use rod cores. The first type of core designs were rod cores, which were developed starting around 1930 and the more practical twin core designs in this category is divided into two styles: the Forsteri and Vaquera based designs. The Forster variant and the latter, which is the older design, are both still in demand in contemporary designs that make use of the newest materials and electronics. Despite first appearing in the 1930s, the ring core models were not fully developed until 1962, when they were quickly acknowledged as an effective substitute to the rod core. Although there are numerous other designs, most of which are based on rod cores, none of them have come close to the level of performance and development attributable to the above-mentioned designs. This document is therefore limited to the twin rod and ring core fluxgate variants.

Working

Typically, fluxgate sensors consist of two coil windings wound around an alloy ring core that is highly magnetically permeable: the drive winding and the sense and drive winding. There will be a third feedback winding on some sensors as well. If the purpose of the sensor is to operate as a closed cycle, it can be useful to consider two separate half cores make up the ring core, represented in the figure by the colors green and blue. This ring core's objective is to measure the field in the direction of Hext.

A field with a component pointing in the same direction as Hext will be produced by one half core as long as the current passes through the drive winding, and a field with a component pointing in the other direction will be produced by the other half core.



Driven Waveform

Figure 2a displays an example of a driving waveform. In reality, the transitions are “squarer” than what is depicted in the figure; they are emphasized here to highlight what is happening in the two half cores.

In the absence of external field

The two half cores enter and exit saturation simultaneously, when there is no external field present (Hext= 0). As seen in Figure 2b, the fields produced exactly cancel out, causing neither an induced voltage nor a net change in flux in the sensing winding.

In the Presence of external magnetic field

In the presence of an external field, the half core that is creating the field that is directed against the external field (represent green-color for first transition in Figure 2c) emerges from contrast earlier; in contrast, the half core arises later in the same direction as the external field. The sense winding has a net change in flux (colored black) during this period and the fields do not cancel out. A voltage is produced by this net change in flux, and figure 2d illustrates it in black, in accordance with Faraday's law. Similarly, as Hext reaches saturation earlier toward the end of the transition, a field is now being produced by half core in the same direction. As a result, the drive frequency is doubled by the induced voltage, and there are two voltage spikes for every drive transition.

Measuring the field

The direction and strength of the external field are indicated by the generated spikes' dimensions and phase. Imperial College's fluxgate magnetometers to assist enhance this signal and make it easier to determine, adjust the sensing winding with a capacitor. In Figure 2d, the tuned sensor waveform is displayed in red.

3. DATA ANALYSIS

The research work is supported by digital 1s geomagnetic sampling data from three Indian stations located in a latitudinal array. From 01 January 2005 to 31 December 2005, the Earth's magnetic field's X (north–south), Y (east–west), and Z (vertical) components were measured using three pivotal flux-gate magnetometer clusters at the station: Hanle, Nagpur, and Pondicherry with 1s sampling data. In India, locations of the stations were at very low latitudes. The IIG, Navi Mumbai, set up and operated the magnetometer cluster. The exact locations for these stations, as well as the schematic depiction of their location are represented individually in Table 1 and Figure 1. Time is constantly taken to in Universal Time (UT), i.e. IST= UT + 5:30 hr [8].

The data from a large number of stations was evaluated in a single second. The digital dynamic spectra of 24-hour time interval were built for all three sites in 2005 via MATLAB programming. We were able to identify the pulsation events to these dynamic spectra. On various days, we detected micropulsation occurrences at all sites. Generally, pulsation events occurred at frequencies ranging from 10 to 30 mHz.

Table 1: Coordination of recording station details

Recording stations	Geographic co-ordinates		Geomagnetic co-rdinates	
	Longitude °E	Latitude °N	Longitude °E	Latitude°N
Pondicherry (PON)	80.92	12.93	153.00	02.55
Nagpur (NAG)	80.01	22.11	153.83	11.72
Hanle (HAN)	80.07	34.01	153.09	23.23

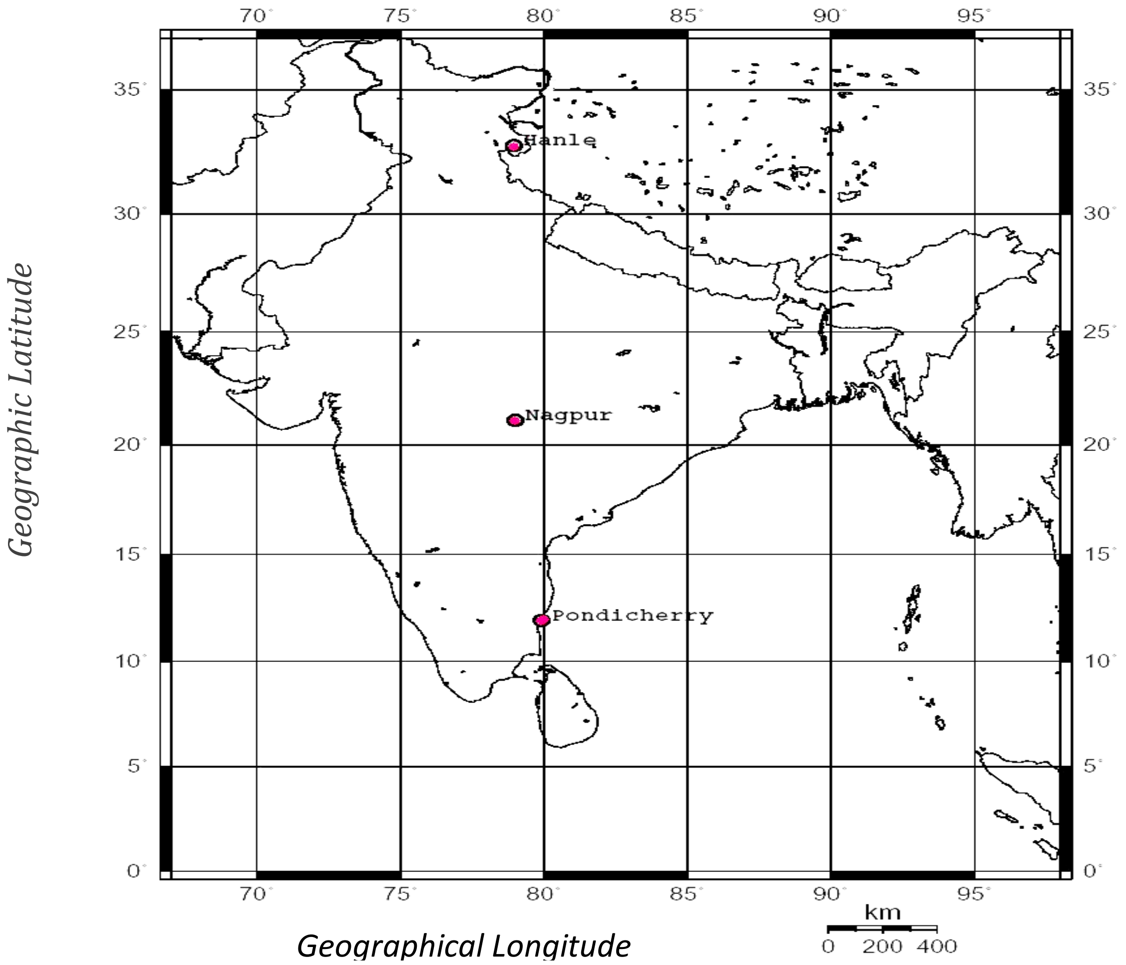


Figure 1: Graphical Map of location of the three recording stations

4. AI TECHNIQUES IN MAGNETIC MICROPULSATIONS ANALYSIS

4.1. Discrete Wavelet Transform (DWT) Combined with Artificial Neural Networks (ANN)

A study by Omondi et al. introduced a method combining DWT with ANN to detect Pc4 pulsations in auroral zones. The DWT was used to preprocess geomagnetic data, enhancing signal features relevant to Pc5 pulsations. Subsequently, an ANN was trained to classify these features, achieving an average correlation of 98% across different solar cycle phases [9].

4.2. Convolutional Neural Networks (CNN) Guided by Multi-Resolution Analysis (MRA)

Another approach utilized CNNs guided by MRA of DWT to detect ULF signals. By decomposing geomagnetic records into multiple resolution levels, the CNN could focus on specific frequency bands associated with micropulsations. This method achieved an accuracy of approximately 91.11%, outperforming traditional DWT-based algorithms.

4.3. Physics-Enhanced Tiny Machine Learning (Tiny ML)

Siddique and Mahmud developed a physics-guided Tiny ML framework for real-time detection of ground magnetic anomalies. By integrating physics-based regularization during model training and compression, the framework improved prediction reliability while maintaining computational efficiency, making it suitable for deployment on resource-constrained devices [10].

5. Applications and Implications

The integration of AI in magnetic micropulsation analysis has several significant applications:

- **Space Weather Monitoring**: Enhanced detection of geomagnetic pulsations aids in forecasting space weather events, which can impact satellite operations and communication systems.
- **Fusion Plasma Diagnostics**: In fusion research, AI techniques assist in identifying magnetohydrodynamic (MHD) oscillation modes, contributing to plasma stability analysis.
- **Biomedical Signal Processing**: AI methods have been applied to detect weak biomagnetic signals from induced pluripotent stem cell-derived cardiomyocytes, demonstrating potential in non-invasive medical diagnostics.

6. Challenges and Future Directions

While AI techniques have shown promise, several challenges remain:

- **Data Quality and Availability**: High-quality, labeled datasets are essential for training effective AI models.
- **Model Interpretability**: Understanding the decision-making process of complex AI models is crucial for scientific validation.
- **Integration with Physical Models**: Combining AI with traditional physics-based models can enhance prediction accuracy and reliability.

Future research should focus on developing hybrid models that integrate AI with domain-specific knowledge, improving model transparency, and expanding applications to other areas such as environmental monitoring and geophysical exploration.

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