

## INTISARI

### **Sintilasi Ionosfer di Indonesia Selama Badai Geomagnetik: Studi Kasus di Pontianak dan Analisis Statistik 2003–2024**

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Sistem navigasi satelit seperti *Global Navigation Satellite System* (GNSS) digunakan secara luas untuk keperluan transportasi, komunikasi, dan pemetaan. Kinerjanya sangat bergantung pada propagasi sinyal yang stabil saat melewati ionosfer. Namun, akurasi GNSS dapat terganggu oleh sintilasi ionosfer, yaitu fluktuasi cepat amplitudo dan fase sinyal akibat irregularitas ionosfer. Di Indonesia, sintilasi sering dikaitkan dengan *Equatorial Plasma Bubbles* (EPBs) saat senja. Namun, peristiwa badai geomagnetik dapat menimbulkan gangguan medan listrik yang memperkuat atau menekan pembentukan sintilasi.

Penelitian ini menganalisis pola sintilasi amplitudo (indeks S4) selama badai geomagnetik periode 2003–2024. Data yang digunakan meliputi indeks geomagnetik (Dst, SYM-H, AE), komponen angin surya (IMF Bz, Vsw, IEF Ey), hpF2 dan indeks S4. Dua pendekatan diterapkan, yaitu studi kasus empat badai geomagnetik di Pontianak dan analisis statistik menggunakan metode *Superposed Epoch Analysis* (SEA) terhadap 419 kejadian badai. Titik epoch 0 ditetapkan berdasarkan waktu minimum indeks SYM-H, sedangkan klasifikasi badai dibagi menjadi *weak–moderate* ( $-100 \text{ nT} < \text{Dst} \leq -30 \text{ nT}$ ) dan *strong* ( $\text{Dst} \leq -100 \text{ nT}$ ).

Hasil studi kasus menunjukkan bahwa sintilasi tidak selalu muncul selama fase utama karena *Prompt Penetration Electric Field* (PPEF) dan proses alami *pre-reversal enhancement* (PRE) yang lemah. Pada fase pemulihan, medan listrik *Disturbance Dynamo Electric Field* (DDEF) dapat memperkuat atau menunda sintilasi ionosfer tergantung waktu lokal puncak badai. Analisis statistik menunjukkan sintilasi kuat muncul sekitar 6 jam setelah minimum SYM-H untuk badai *weak–moderate*, dan 12 jam untuk badai *strong*. Sintilasi hampir tidak muncul saat puncak badai bertepatan dengan waktu senja akibat dominasi DDEF yang menekan pertumbuhan EPBs.

Kata kunci: Sintilasi ionosfer, GNSS, Badai geomagnetik, Indeks S4, *Superposed Epoch Analysis* (SEA)

## ABSTRACT

### **Ionospheric Scintillation in Indonesia During Geomagnetic Storms: A Case Study in Pontianak and Statistical Analysis 2003–2024**

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Satellite navigation systems such as the Global Navigation Satellite System (GNSS) are widely used for transportation, communication, and mapping purposes. Their performance strongly depends on the stable propagation of signals as they pass through the ionosphere. However, GNSS accuracy can be degraded by ionospheric scintillation, which refers to rapid fluctuations in signal amplitude and phase caused by plasma irregularities. In the Indonesian region, scintillation is often associated with the occurrence of Equatorial Plasma Bubbles (EPBs) that develop after sunset. Meanwhile, geomagnetic storms can induce electric field disturbances that either enhance or suppress scintillation formation.

This study analyzes the characteristics of ionospheric amplitude scintillation (S4 index) during geomagnetic storms over the period 2003–2024. The dataset includes geomagnetic indices (Dst, SYM-H, AE), solar wind parameters (IMF Bz, Vsw, IEF Ey), hpF2, and S4 measurements. Two approaches are employed: (1) case studies of four geomagnetic storms observed in Pontianak, and (2) a statistical analysis using the Superposed Epoch Analysis (SEA) method applied to 419 storm events. The epoch 0 is defined based on the time of minimum SYM-H, while storm intensities are classified into weak–moderate ( $-100 \text{ nT} < \text{Dst} \leq -30 \text{ nT}$ ) and strong ( $\text{Dst} \leq -100 \text{ nT}$ ).

The case study results show that scintillation does not always occur during the main phase due to weak Prompt Penetration Electric Field (PPEF) and natural pre-reversal enhancement (PRE) processes. During the recovery phase, the Disturbance Dynamo Electric Field (DDEF) can either strengthen or delay scintillation depending on the local time of the storm peak. Statistical analysis indicates that strong scintillation tends to appear approximately six hours after the minimum SYM-H for weak–moderate storms and twelve hours for strong storms. Scintillation is rarely observed when the storm peak coincides with local sunset, owing to the dominance of DDEF that suppresses EPB development.

**Keywords:** Ionospheric scintillation, GNSS, Geomagnetic storm, S4 index, Superposed Epoch Analysis (SEA)