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ポーラーレインオーロラの発生周期性と太陽活動との関係

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Retitive occurence of Polar Rain Aurora Across the Solar Cycle

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Auroras are luminous phenomena that occur when charged particles precipitate into the upper atmosphere (altitude ˜100 – 300 km) along the magnetic field lines, where they excite and subsequently de-excite atmospheric oxygen atoms and nitrogen molecules, emitting light. The electrons responsible for auroras do not always come directly from the Sun but are often accelerated in the Earth's magnetotail (plasma sheet). These electrons precipitate into the polar region along closed magnetic field lines, forming a ring-shaped auroral oval centered on the magnetic pole. As a result, during moderately disturbed conditions(i.e., during southward IMF conditions), auroras are absent in the polar cap region. However, on December 25, 2022, during an interval of exceptionally low solar wind density (˜0.5 cm^{-3} or lower), a large auroral structure covering the entire polar region was observed (Hosokawa et al., 2024). The unique physical mechanism responsible for this phenomenon was suggested to be polar rain precipitation, generated by a direct influx of solar wind electrons into the polar ionosphere. This type of aurora is observed near the geomagnetic poles and is called polar rain aurora (PRA; Zhang et al., 2007). High-energy (˜keV) electrons in the solar wind, known as "Strahl," directly precipitate along open magnetic field lines, producing spatially uniform emissions in the polar cap. Under typical solar wind conditions, for example southward IMF conditions, auroras do not appear in the polar cap. PRA becomes evident only when the solar wind density is exceptionally low and the Interplanetary Magnetic Field (IMF) is directly connected to the Earth's magnetic field. Because PRA is an extremely rare phenomenon, with fewer than ten reported cases, it has not been widely recognized as a major auroral category.

To investigate the characteristics and origin of this unique aurora, we conducted a long-term statistical analysis using SSUSI data from the DMSP F16, F17, and F18 satellites. The study covers the period from 2005 to 2023. We analyzed trans-polar auroral images obtained in the Lyman-Birge-Hopfield short-wavelength channel (140 – 150 nm) through line-scanning observations in imaging mode. The DMSP satellites operate in a Sun-synchronous polar orbit at an altitude of ˜850 km, completing a full orbit in ˜97 minutes. During the analysis period, at least two of the three DMSP satellites were operational simultaneously, allowing us to obtain large-scale images of auroras in the polar cap at ˜50-minute intervals. From the dataset, we identified PRA events and then examined their occurrence frequency, hemispheric distribution, and corresponding solar wind plasma and IMF conditions using NASA's OMNIWeb database. As a result, we detected 14 PRA events over the past two decades, ranging from weak, localized occurrences to strong events covering the entire polar cap. Furthermore, for the first time, we identified a repetitive occurrence of PRA with a cycle of ˜25 – 30 days. PRA events were particularly concentrated during periods of significantly reduced solar wind density, and their ˜27-day recurrence pattern suggests a potential relationship with Corotating Interaction Regions (CIR). When categorized by solar cycle, we found that during the solar maximum transition of Cycle 25, intense PRA events occurred frequently, whereas only two weak events were detected in Cycle 24. This suggests that PRA occurrence frequency is influenced by the overall strength of solar activity. For Cycle 23, we did not check day-by-day coverage for the entire period; however, previous studies have reported PRA cases within this cycle that also exhibited similar periodicity (e.g., two cases reported by Foster et al. (1976) showed the same ˜27-day periodicity). Nevertheless, not every ˜27-day recurrence was accompanied by a PRA event; in some cases, it appeared only after skipping one or two ˜27-day cycles. This suggests that, even under similar solar wind conditions, additional factors beyond low-density conditions are required for PRA to occur. Future work will include a full day-by-day survey of Cycle 23 to clarify its relationship with solar activity.