Confirming terrestrial ice-core and tree-ring records as solar proxies through pink noise analysis†

M. Morikawa*1,*2 and Y. Motizuki*1

Interaction between solar activity and the atmospheric and geological systems of the Earth has been a subject of interest. This study delves into the long-term influence of solar pink noise on terrestrial systems, focusing on nitrate ion (NO_3^-) and ^{10}Be concentration variations stored in ice cores, as well as on the ^{14}C content in tree rings.

Pink noise, characterized by a power spectral density (PSD) inversely proportional to frequency, is commonly found in vacuum tube currents, semiconductors, thin metals, bio-membranes, crystal oscillators, *etc.* Although the origin and robustness of pink noise have remained unidentified for a century, we recently proposed a mechanism attributing pink noise to amplitude modulation.[1] The solar-terrestrial connection, particularly the detection of solar pink noise in relics on Earth, is relevant to verify this proposal.

Pink noise represents a hallmark of solar activity and manifests in various phenomena;[2] it has been identified in solar five-minute oscillations (SFO), which have eigenmodes with infinitely accumulating eigenfrequencies. Many waves with these eigenfrequencies beat and exhibit systematic signals in the low-frequency domain. This is the pink noise associated with SFO. This pink noise has been observed in the SOHO-GOLF measurement 16.5 years data, exhibiting power-law PSD with a modest slope of -0.82 over six orders of magnitude. The PSD peak associated with the SFO modes manifests at around 5 minutes. Furthermore, the long-time series of sunspot numbers have shown a PSD consistent with pink noise.[3] This pink noise is considered to be inherited from the SFO pink noise through dynamo activity in the sun.

Solar pink noise propagates through space, influencing Earth's systems. Solar ultraviolet radiation, which exhibits 11-year oscillations, affects the chemical composition of the stratosphere and surface snow, resulting in NO_3^- concentration variations in ice cores.[4] Solar magnetic fields modulate the cosmic ray flux, which affects the production of cosmogenic nuclides such as ^{10}Be and ^{14}C; they are preserved in polar ice and tree rings, respectively.

Figure 1 shows the result of the PSD analysis using our NO_3^- concentration data for a Dome Fuji shallow ice core (DF01) covering the period from 1610 to 1904 CE (overlapping sunspot observations after the invention of the telescope), where 11-, 22-, and ∼90-year solar periods were discovered for the first time.[4] Although the specific frequencies are invisible in the present log-log diagram, Fig. 1 shows a clear pink noise signature with a power index of -1.06 in the frequency domain from 2×10^{-10} Hz to 10^{-8} Hz, *i.e.*, 3–160 years in the time domain. This finding suggests a direct connection between solar pink noise and the NO_3^- data from Dome Fuji, strengthening the case for using it as a novel solar activity proxy.

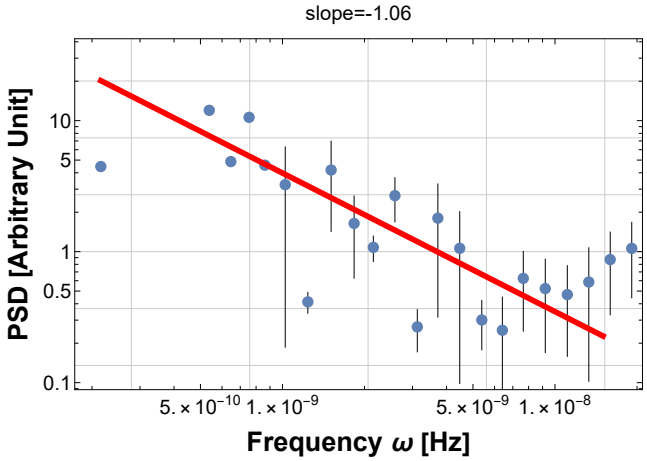

Fig. 1. Power spectral density (PSD) of NO_3^- concentration time-series data from the Dome Fuji ice core (Antarctica) over three centuries,[4] exhibiting clear pink noise with a power index of -1.06.

Cosmogenic nuclides ^{10}Be and ^{14}C are traditionally known solar proxies. In addition to NO_3^-, we confirmed pink noise signatures in the time-series records of both ^{10}Be[5] and ^{14}C.[6]

In conclusion, we confirmed the existence of pink noise in all solar activity proxies suggested so far: ^{14}C, ^{10}Be, and the Dome Fuji NO_3^- concentration variations. These distinctive noise patterns may have originated from the SFO pink noise. There is evidence showing that the Dome Fuji area catches the solar-influenced stratospheric components better than any other areas in Antarctica.[4] We plan to analyze the Dome Fuji deep ice core data of a thousand to a million years beyond the presently analyzed data of ∼300 years. Should further evidence of pink noise be found in deeper cores, it may unveil the complete narrative of solar-terrestrial interactions.

References
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*1 RIKEN Nishina Center
*2 Ochanomizu University

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