Quantitative Analysis of Solar Activity and Terrestrial Weather Using Open Data Focusing on Temporal Lag and Regional Differences

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In this study, the possible relationship between solar activity and terrestrial weather was investigated using publicly available data. Solar activity is known to affect social infrastructure such as communication systems and power grids, but its relationship with everyday meteorological variables on the Earth's surface has not yet been fully clarified. In particular, variations in the space environment may influence cloud formation and atmospheric processes, which could affect solar radiation and sunshine duration, although their temporal response and regional variability remain unclear.
We hypothesized that changes in the cosmic-ray environment influence cloud formation and appear as changes in solar radiation and sunshine duration at the ground level. Based on this hypothesis, we focused on the large solar flare events in May 2024 and conducted a time-series analysis of the relationship between solar activity and terrestrial weather. The datasets used include solar X-ray flux from NASA, the Kp index from NOAA, and meteorological data from the Japan Meteorological Agency, including sunshine duration, global solar radiation, and cloud cover. These datasets from different scientific fields were integrated on a common time axis.
The results show that increases in the Kp index followed solar flare events, and a subsequent decrease in sunshine duration was observed at the ground level. A regional comparison revealed that the decrease in sunshine duration occurred on May 11 in Abashiri and on May 12 in Tokyo, indicating the presence of temporal lag and regional differences.
Lag correlation analysis between the Kp index and both sunshine duration and solar radiation revealed that, in Tokyo, the strongest negative correlation was observed at a lag of two days ($r = -0.61$ for sunshine duration and $r = -0.63$ for solar radiation). In contrast, in Abashiri, the strongest negative correlation was observed at a lag of one day for both variables (r about -0.34). These results indicate that delayed responses exist in both regions, but the timescale differs depending on location.
This regional difference may be related to the structure of the Earth's magnetic field. At high latitudes, energetic particles and cosmic rays can more easily enter the atmosphere, which may lead to a more direct response. At mid-latitudes, the effects may be mediated by atmospheric processes such as cloud formation and advection, resulting in delayed responses. Synoptic weather analysis also suggests that conventional meteorological factors contributed to the observed changes.
These findings suggest that solar activity and terrestrial weather are related with a temporal lag, and that the impact is not uniform but depends on geographic and meteorological conditions. This study provides quantitative insight into the interaction between the space environment and the Earth's surface environment.

Keywords: Solar activity, Terrestrial weather, Temporal lag, Regional differences

結果

太陽フレア、Kp指数、地上日照時間の時系列と時間差

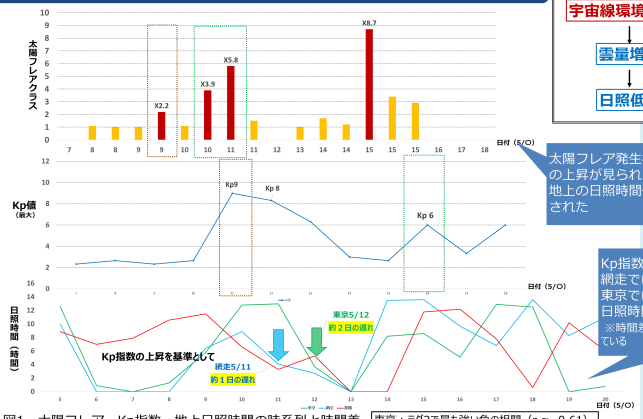
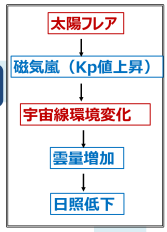


図1　太陽フレア、Kp指数、地上日照時間の時系列と時間差

東京：ラグ2で最も強い負の相関（r ≈ -0.61）
網走：ラグ1で最も強い負の相関（r ≈ -0.34）



太陽フレア発生後にKp指数の上昇が見られ、その後に地上の日照時間低下が観測された

Kp指数の上昇を基準として
網走では、約１日、
東京では、約２日遅れで
日照時間低下が見られた
※時間差はKp指数のピークを基準としている

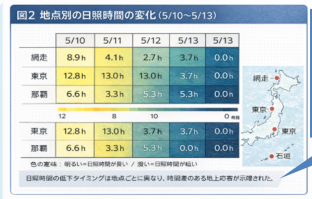
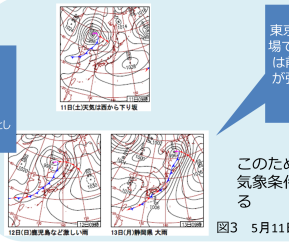


図2　地点別の日照時間の変化（5/10～5/13）

網走では5/11、東京では5/12に日照時間の大きな低下がみられ、地点ごとに低下タイミングの違いが確認された

日照時間の低下タイミングは地点ごとに異なり、時間差のある地上応答が示唆された



東京では5/11は比較的晴天場であったが、5/12～13には前線や湿った空気の影響が強まり、雷雨場へ移行した

このため、日照低下には通常の気象条件も関与した可能性がある

図3　5月11日～13日の総観気象場の変化