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METEOROLOGICAL CORRELATIONS WITH SOLAR-TERRESTRIAL PHENOMENA: A PROVISIONAL STUDY

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Abstract: A provisional data analysis to find the effect of solar-terrestrial events on the tropospheric and the lower stratospheric atmosphere has been made using radiosonde observations over Japan in 1988–1992. Although the lengths of analyzed intervals are short, significant changes of tropospheric and stratospheric temperatures of 2–3°C were observed over northern Japan after energetic solar proton events. A phase reversal of temperature changes took place when the phase of the Southern Oscillation Index (SOI) was reversed. A provisional analysis of radiosonde data at Syowa Station, Antarctica in 1990 is also given.

1. Introduction

The apparent correlation between short-term solar variability (solar flares, solar proton events, geomagnetic storms, sector-boundary passages, and Forbush decreases of cosmic rays) and meteorological changes has been a controversial subject for many years (see reviews given by HERMAN and GOLDBERG, 1978). Recently, a causal relationship between the cosmic ray flux and intensification of the vorticity area has been proposed by several authors (TINSLEY *et al.*, 1989; TINSLEY and DEEN, 1991). On the other hand, SCHUURMANS (1991) proposed that, using radiosonde data, temperatures increase in the troposphere and decrease in the lower stratosphere after solar proton events.

In many previous works, considerable efforts have been made to cover as long period as possible to obtain high reliability of the statistical analysis. However, this approach overlooks changes with a period shorter than the analyzed interval. We have a similar situation in the sense of the spatial scale when we average worldwide data without paying attention to local characteristics. It is still necessary to perform detailed data analysis taking temporal and spatial peculiarities into account to understand the causal relationship between solar and atmospheric phenomena. In this paper, we perform a provisional data analysis to see meteorological consequences of short-term solar-terrestrial phenomena using radiosonde data obtained in Japan and at Syowa Station, Antarctica. Since the coverage of data is not sufficient at this stage, it is not the purpose of this report to come to definite conclusions. We will give examples which show the SO (southern oscillation) is an important factor in the study of the solar connection of meteorological variability.

2. Data Sources

The principal data sources are radiosonde observations over Japan (18 stations) and Syowa Station, Antarctica. A list of the stations is given in Table 1. For radiosonde data in Japan, we used the data obtained in the interval from January 1988 to May 1992, which were available in a machine-readable format at the time of the present data analysis. Radiosonde observations in Japan have been conducted twice a day at 0830 JST (2330 UT) and at 2030 JST (1130 UT). For the data obtained at Syowa Station, we only used data in 1990. Observations at Syowa have been conducted also twice a day, at around 0230 UT and 1430 UT. These data sets were provided by Japan Meteorological Agency.

Table 1. A list of radiosonde stations.

Station	Latitude (deg.)	Longitude (deg.)	Station	Latitude (deg.)	Longitude (deg.)
Wakkanai	45.42 N	141.68 E	Fukuoka	33.58 N	130.38 E
Sapporo	43.05 N	141.33 E	Kagoshima	31.63 N	130.60 E
Nemuro	43.33 N	145.58 E	Naze	28.38 N	129.55 E
Akita	39.72 N	140.10 E	Ishigakijima	24.33 N	124.17 E
Sendai	38.27 N	140.90 E	Naha	26.20 N	127.68 E
Wajima	37.38 N	136.90 E	Minamidaitojima	25.83 N	131.23 E
Tateno	36.05 N	140.13 E	Chichijima	27.08 N	142.18 E
Hachijojima	33.12 N	139.78 E	Minamitorishima	24.30 N	153.97 E
Yonago	35.43 N	133.35 E			
Shionomisaki	33.45 N	135.77 E	Syowa	69.00 S	39.58 E

3. Method of Data Analysis

We performed a superposed-epoch analysis with respect to the occurrence time of solar-terrestrial events; major solar flares, energetic solar proton events at the Earth, sudden commencements of geomagnetic storms (SSCs). Since many Forbush decreases took place in association with SSCs with very short time delay, the analysis for the Forbush decreases is almost equivalent to that for the strong SSCs. We focused on major events selected by the following criteria for each solar-terrestrial phenomenon:

1) Solar flares of larger than 2B class.
2) Solar proton events with the flux of > 10 MeV protons exceeding 40 pfu at the geostationary orbit (GOES 6 and 7).
3) Geomagnetic storms having the main phase with depression (–dH) larger than 30 nT.

The data sources of solar-terrestrial activities are monthly and weekly issues of Solar-Geophysical Data (National Geophysical Data Center, Department of Commerce, U.S.A.). We extracted the data for 10 days centered on a "key day" which is

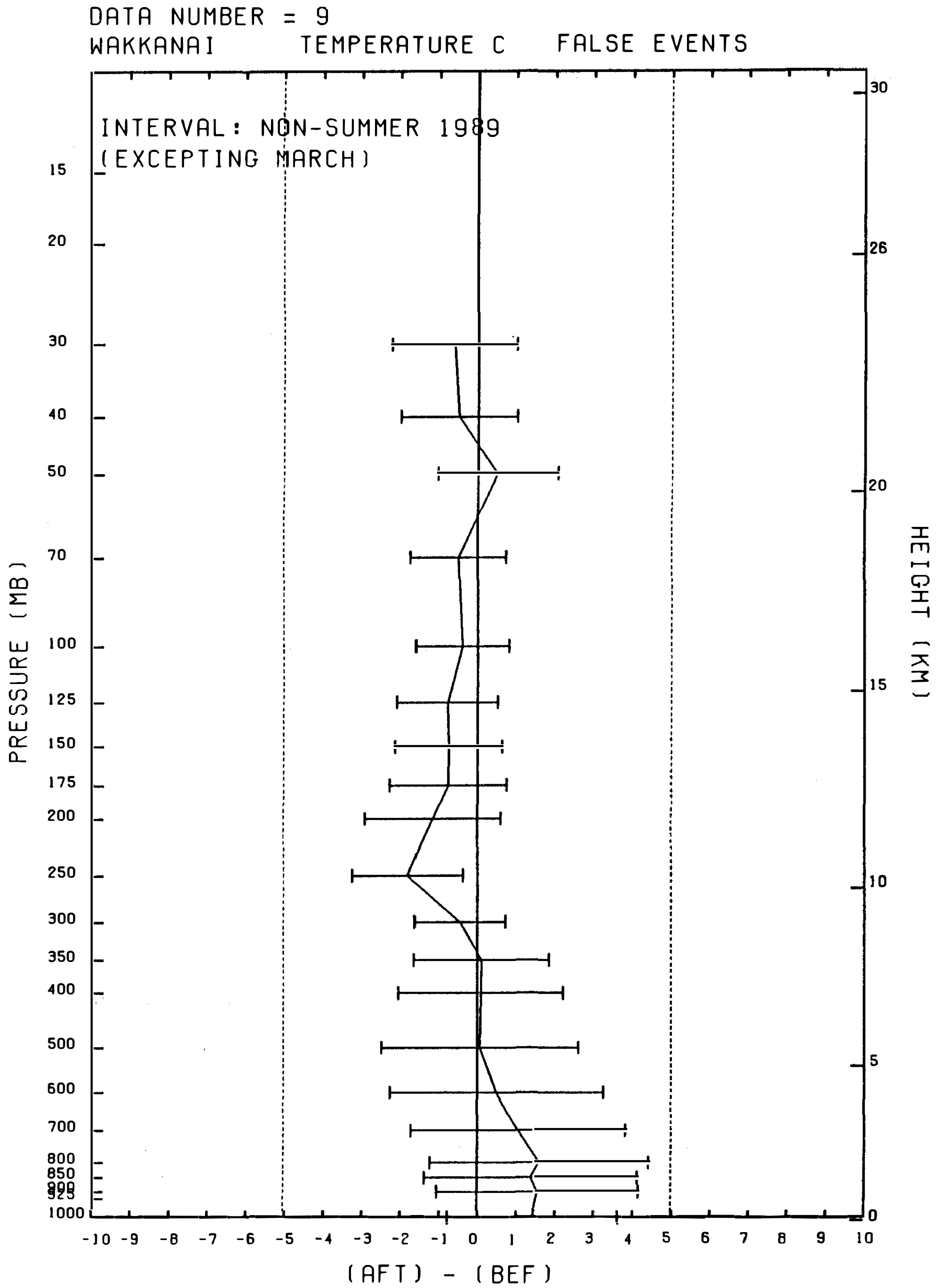

Fig. 1. Mean temperature difference over Wakkanai, Japan before and after randomly selected "false events" in winter (November–March) in 1989. The right-hand side vertical axis represents the geopotential height for each pressure level shown on the left-hand side axis.

the onset time of each event mentioned above, and superposed them to obtain mean levels of a selected parameter, *e.g.* temperature, before and after the key day. Then, the difference of the mean levels (after–before) at each pressure height is calculated. To check the possibility of accidental coincidence, we randomly selected nine key days in the winter of 1989 (in this paper, "winter" in the northern hemisphere means

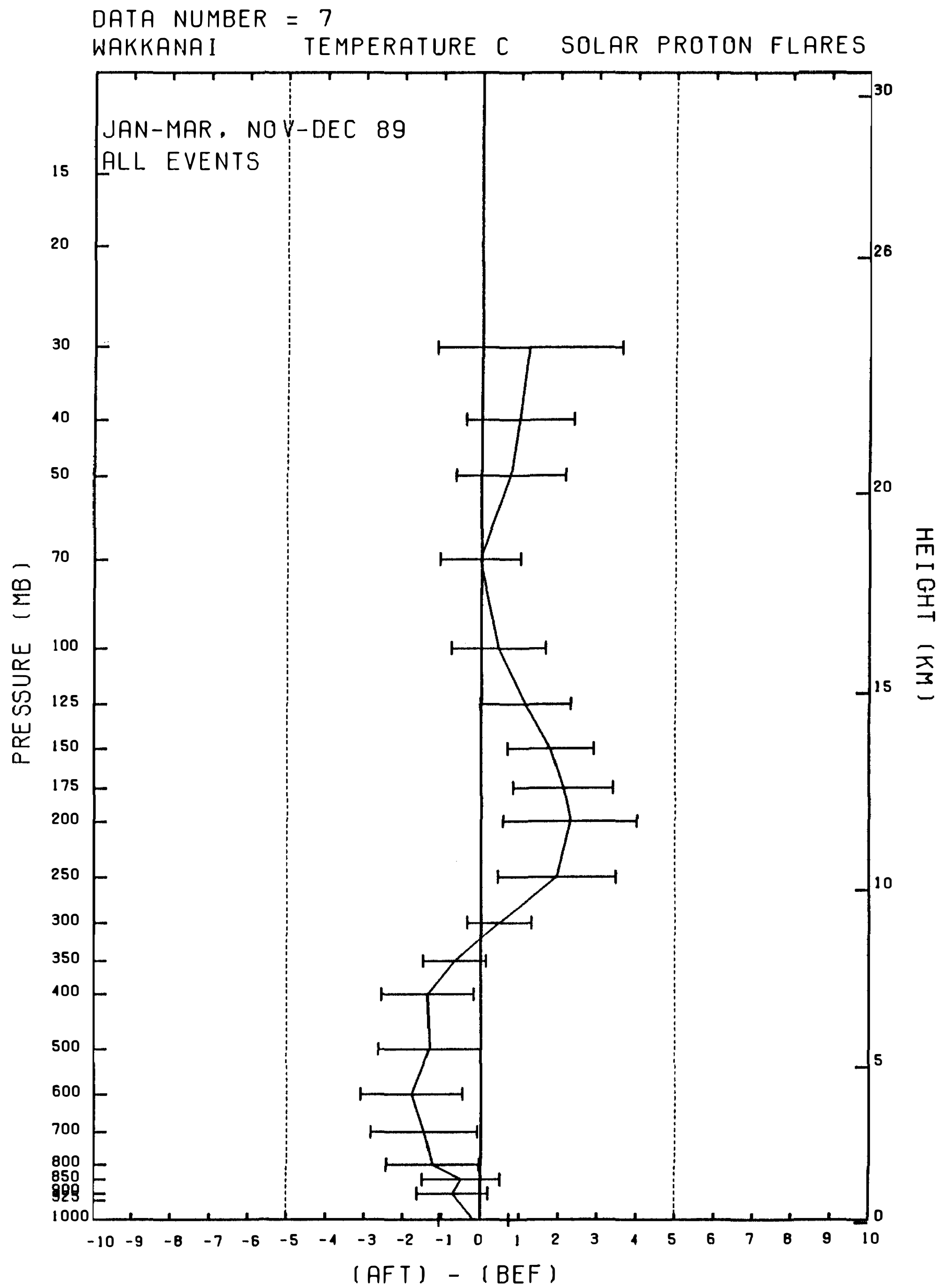

Fig. 2. Same as Fig. 1 but for solar flares of larger than 2B class taking place in winter (November–March) in 1989.

the months of November–March). The result for the data taken over Wakkanai (the northernmost station in Japan) is shown in Fig. 1 as a function of the geopotential height (gpkm) estimated from the Standard Atmospheric Model 1972. The error

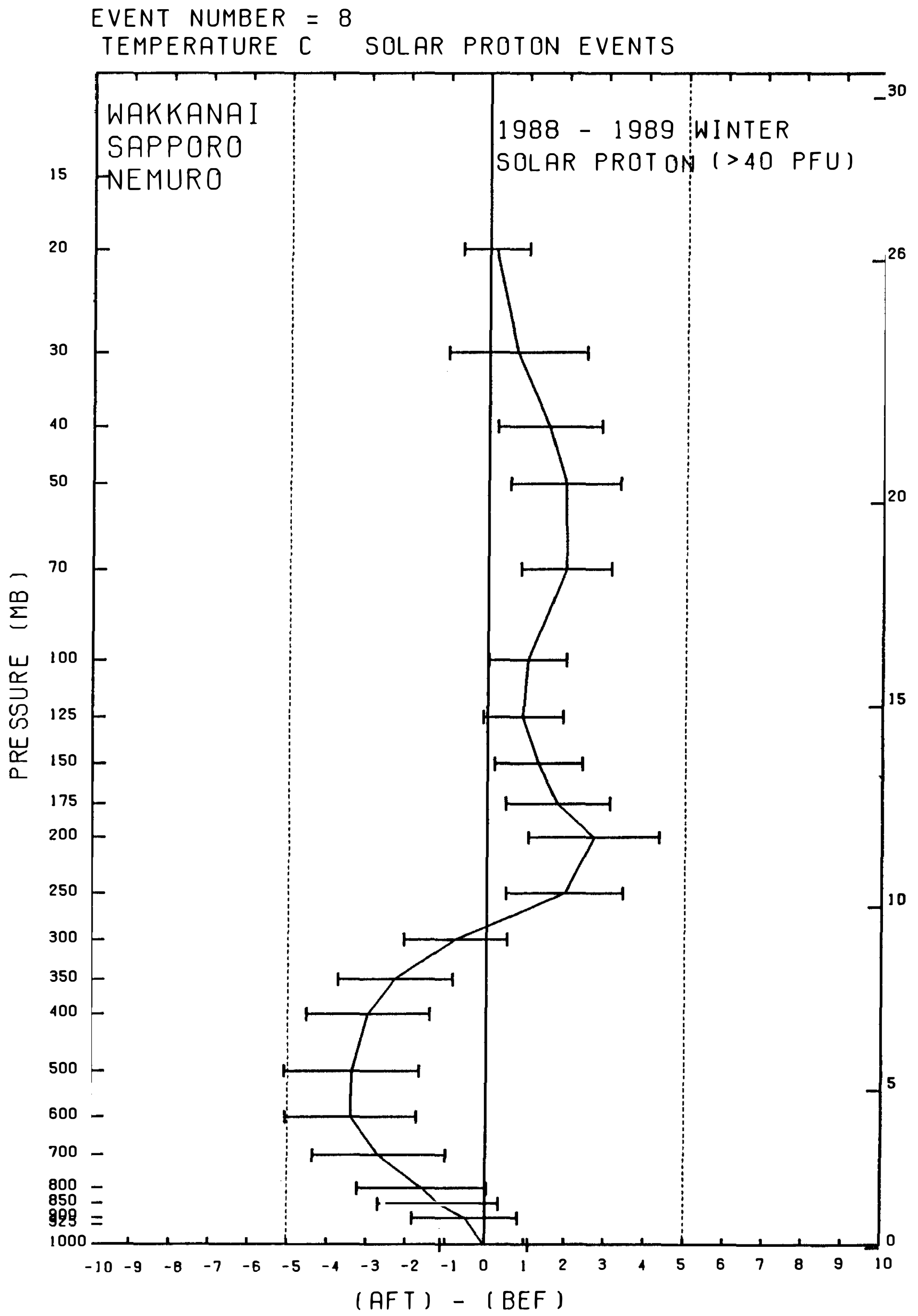

Fig. 3. Same as Fig. 1 but for solar proton events (> 10 MeV) at the geostationary orbit (GOES 6&7) of larger than 40 pfu taking place in winter (November–March) in 1988–1989. The results for three stations in Hokkaido (Wakkanai, Sapporo, and Nemuro) are averaged.

bar at each reference level represents the standard deviations of the data. It is seen that no significant change in the temperature is seen before and after the "false" events.

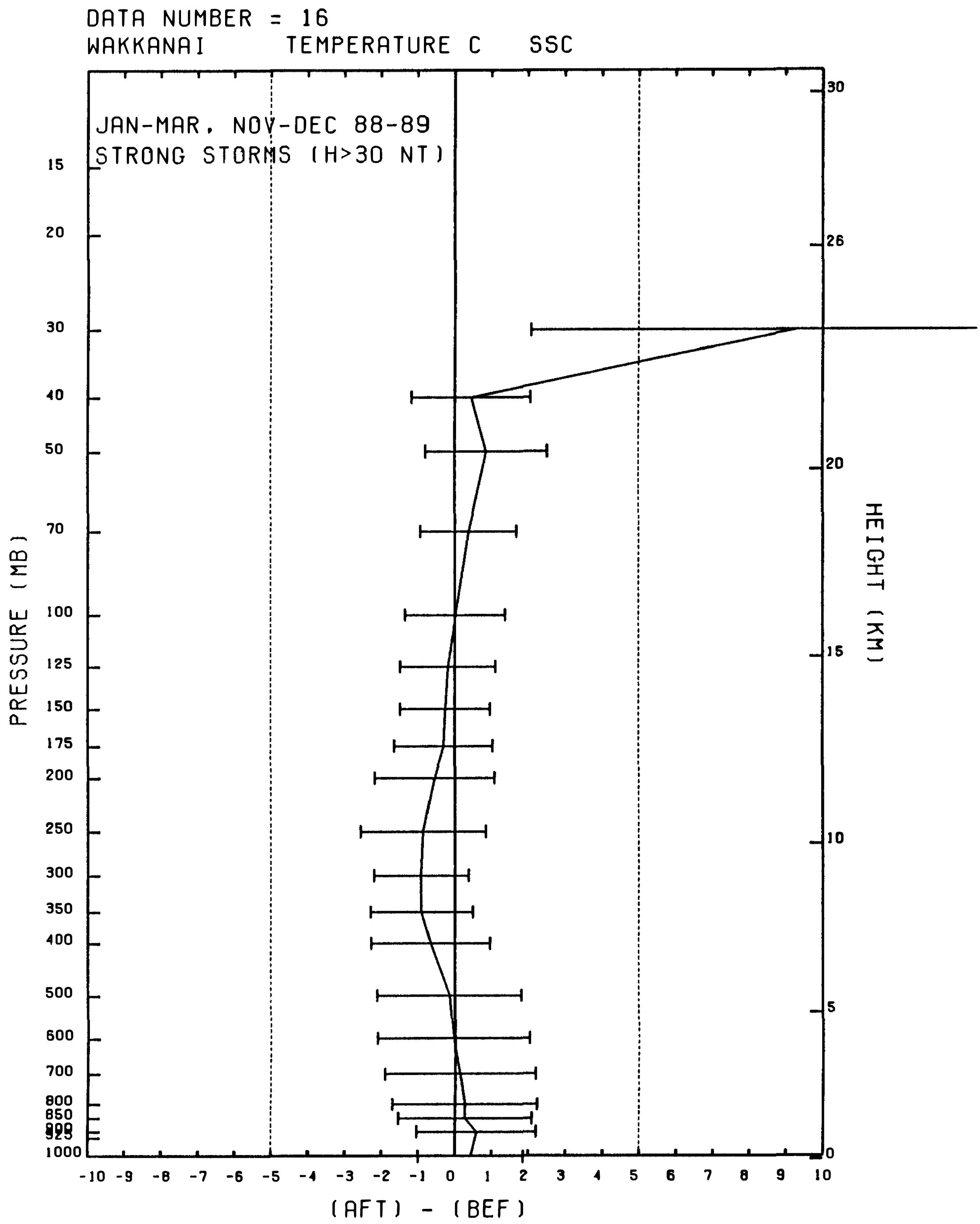

Fig. 4. Same as Fig. 1 (Wakkanai) but for SSCs of strong geomagnetic storms (−dH > 30 nT) taking place in winter (November–March) in 1988–1989.

4. Interval 1988–1989 (SOI>0); Observations in Japan

First, we examined observations in 1988–1989 because a reversal of the SOI phase took place between 1989 and 1990. The result for the solar flares observed in the winter of 1989 over Wakkanai is shown in Fig. 2. It is seen that the temperatures in the troposphere and the stratosphere showed slight fall and rise respectively, although the correlation is not very significant. For the solar proton events (Fig. 3), the temperature in the troposphere significantly dropped by an amount of 3℃ after the onset of proton events. In the stratosphere, the temperature increased with a similar magnitude to that in the troposphere. In this case, we averaged the results for three stations in Hokkaido (Wakkanai, Sapporo, and Nemuro) to increase the statistical reliability. The magnitude of the temperature change decreased monotonously with decrease in latitude, and no appreciable change was seen over Chichijima (latitude = 27.08°N). For geomagnetic SSCs, no appreciable change is seen either in the troposphere or the stratosphere, as shown in Fig. 4. The large deviation seen at the 30 mb level is probably caused by small sampling number because this altitude is near the limit of radiosonde observations.

We have seen that the most significant correlation was obtained when we selected the onsets of solar proton events as key days. It is suggested that the most important solar-terrestrial phenomena which cause the transient changes in tropospheric and stratospheric conditions are the energetic solar proton events. Since some of the proton events were observed immediately after the related solar flares, it is understandable to obtain weak correlation to the occurrences of solar flares, as shown in Fig. 2. Since we have not obtained a significant correlation for geomagnetic storms, it is also suggested that Forbush decreases of galactic cosmic rays are not important in this particular interval. In the present analysis, we neglected the effect of the day-night temperature change because very similar results were obtained for cases in which only the daytime or nighttime data are included. We also checked the seasonal dependence of the correlation. When we selected the summer season (April–October), no apparent correlation was found.

5. Interval 1990–1992 (SOI<0); Observations in Japan

In this period, the SOI of the negative phase was observed. We only show the result for the proton events because the same tendency to that seen in the previous section was recognized also in the present case. As seen in Fig. 5, the temperature variations in the opposite sense to that seen in 1988–1989 (SOI>0) took place after proton events in 1990–1992; rising temperature in the troposphere, and the dropping temperature in the stratosphere. It is suggested that the response of stratospheric/tropospheric characteristics depends on the phase of SOI.

6. Latitudinal Movement of the Jet Stream Associated with Solar Proton Events

The apparent correlation between the transient temperature variations and solar proton events suggests the presence of stratospheric/tropospheric response to the incidence of energetic solar particles in the high-latitude region where solar protons can reach lower atmospheric levels (TINSLEY and DEEN, 1991). If this is the case, the atmospheric response will appear as the change in the characteristics of the jet

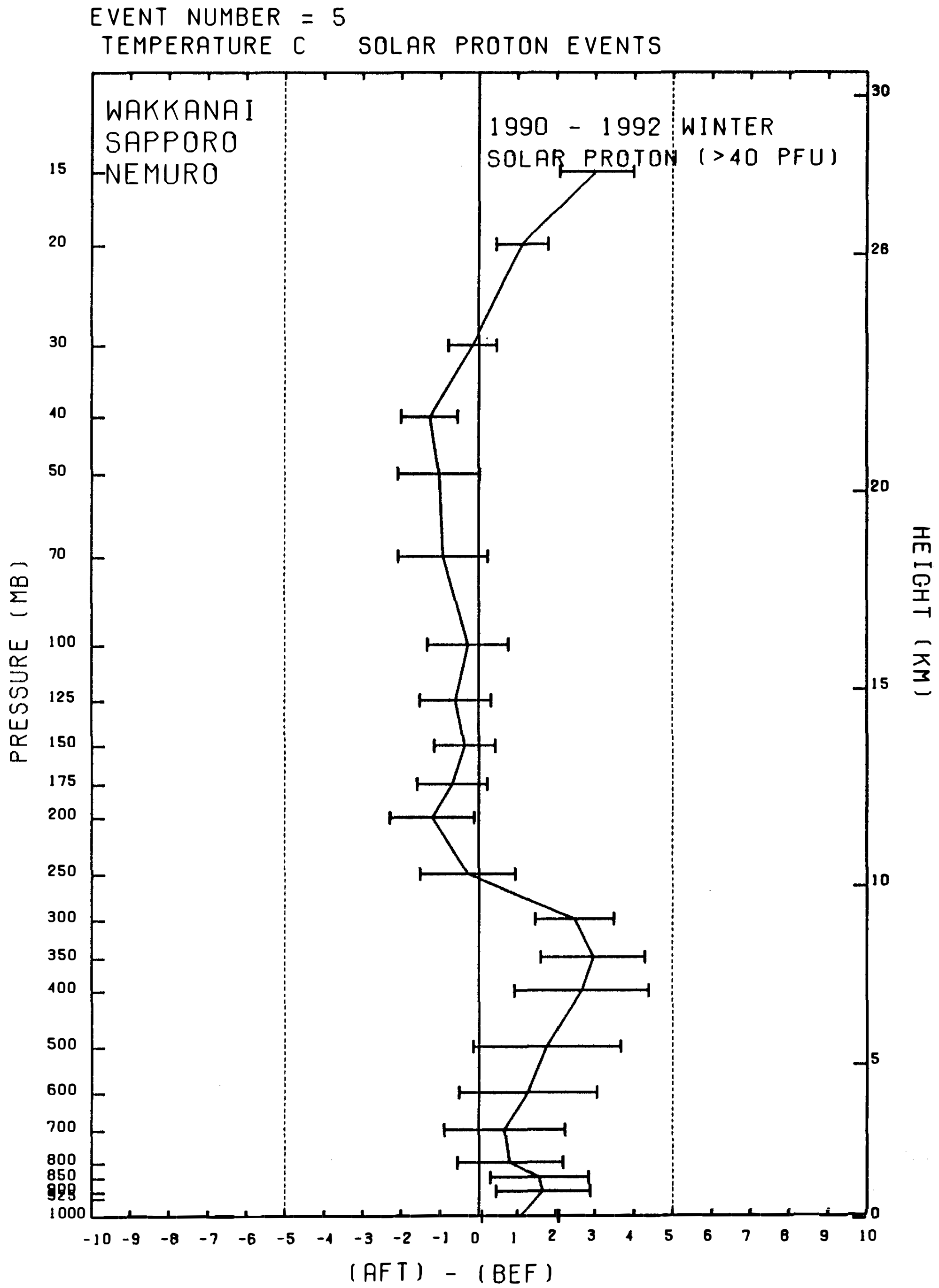

Fig. 5. Same as Fig. 1 but for solar proton events (> 10 MeV) at the geostationary orbit (GOES 6&7) of larger than 40 pfu taking place in winter (November–March) in 1990–1992. The results for three stations in Hokkaido (Wakkanai, Sapporo, and Nemuro) are averaged.

SOI>0

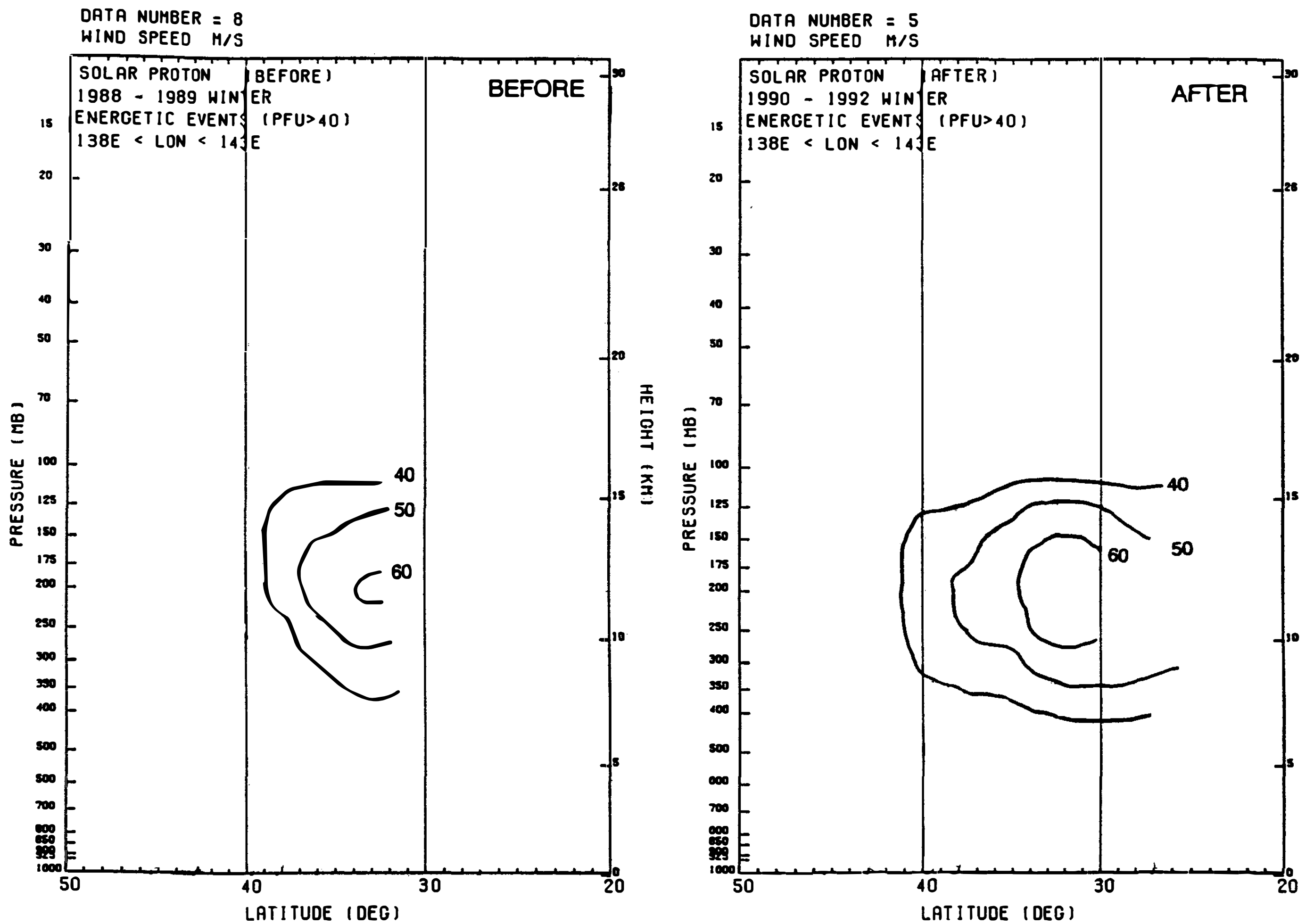

Fig. 6. The latitude-height distribution of the wind speed around the 140°E meridian, before and after the proton events in winter of 1988–1989 (SOI>0).

SOI<0

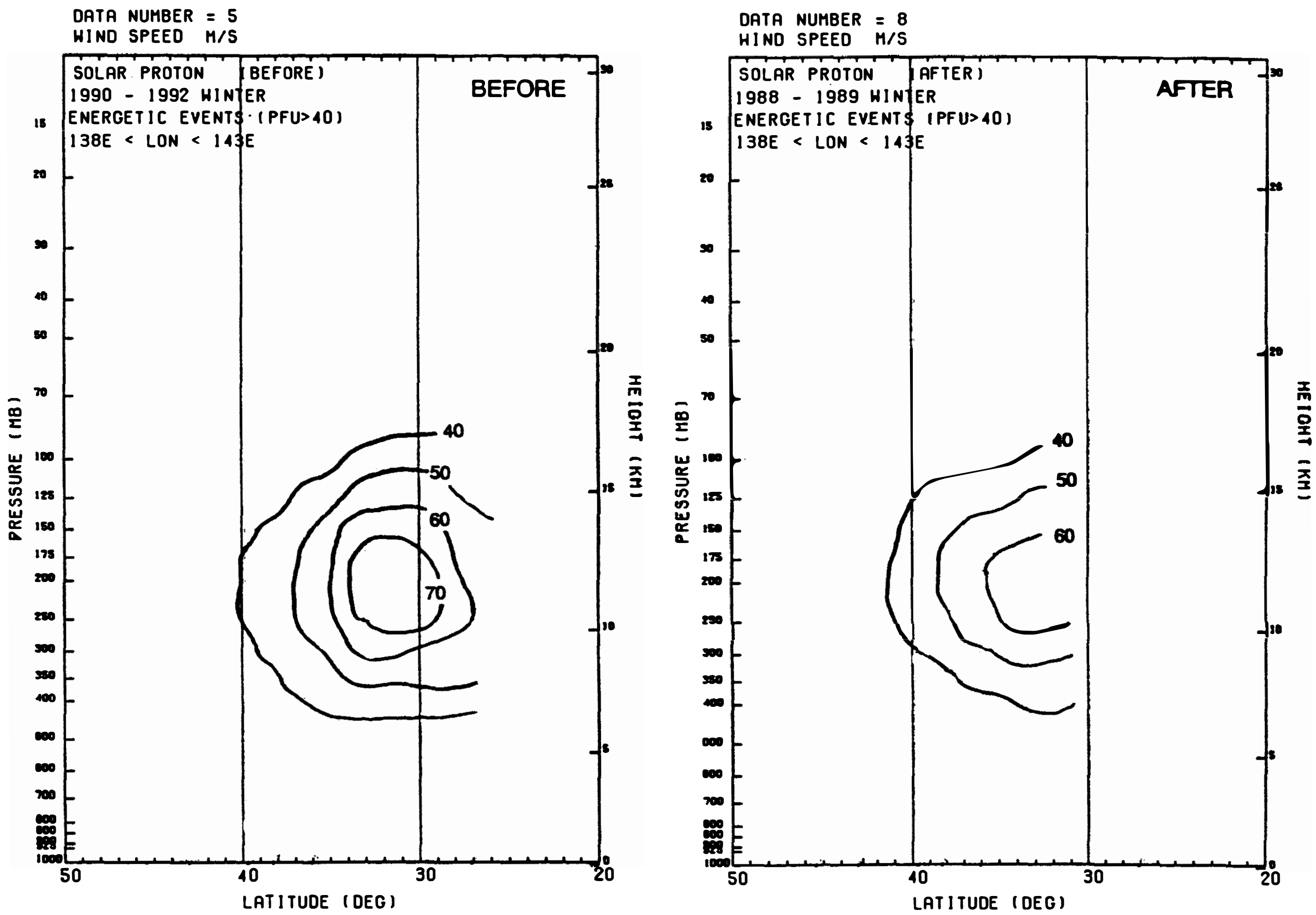

Fig. 7. Same as Fig. 6 but for winter of 1988–1989 (SOI<0).

stream flowing over Japan, and observed temperature variations will take place. To see the temporary variations of the jet-stream characteristics, we examined wind-speed data obtained at stations which are distributed near the meridian of 140°E (Wakkanai, Nemuro, Sapporo, Sendai, Tateno, Hachijojima, Chichijima). Figure 6 shows the latitude-height distributions of the wind speed before and after the proton events which were observed in the winter season of 1988–1989 (SOI>0). An intensification of the wind speeds up to 10 m/s and general southward displacement of the axis of the jet stream was seen after proton events. This change will produce the drop in the tropospheric temperature and associated rise in the stratospheric temperature. The same diagrams but for the winter of 1990–1992 (SOI<0) are shown in Fig. 7. Decrease in the wind speed of about 10 m/s and the northward displacement of the stream axis is seen. In this case, transient rise in the tropospheric temperature (and associated drop in the stratospheric temperature) is expected.

7. Interval 1990; Observations at Syowa Station, Antarctica

Since the direct response of the atmosphere to solar proton events will be seen in the high-latitude region, we examine radiosonde data obtained at Syowa, Antarctica. KODAMA *et al.* (1992) proposed the presence of stratospheric cooling after solar proton events observed in 1956–1990. We also apply our method of analysis to radiosonde data in 1990. Since the analyzed interval is short, we only show very provisional results. In Antarctic winter season (April–September), solar proton events produced no appreciable effect in the tropospheric/stratospheric temperatures although the events analyzed in the present paper were not included in the analysis performed by KODAMA *et al.* (1992). The tropospheric cooling and stratospheric heating is seen in the cases of geomagnetic storms (14 events). It is necessary to perform further data analysis using a comprehensive database covering many years.

8. Concluding Remarks

According to radiosonde observations over Japan, we have seen that the most important solar-terrestrial phenomena which affect the tropospheric and stratospheric condition are energetic solar proton events. It is also shown that the phases of the temperature changes taking place after solar proton events reversed when the phase reversal of the SOI took place, although the present analysis covered only one cycle of the Southern Oscillation. The phase of temperature change did not show apparent correlation with the phase of QBO. On the other hand, SCHUURMANS (1991) concluded that, using radiosonde data obtained at De, Bilt, Netherlands in 1955–1984, temperatures increase in the troposphere and decrease in the lower stratosphere after solar proton events. He also showed that this tendency is strengthened in the East phase of the QBO. The reason we did not obtain apparent correlation to the QBO phase is unknown. To find the reason for this discrepancy, it is necessary to perform further detailed analysis for long intervals taking both the QBO and the SOI phases into account.

Several authors have proposed mechanisms to produce temperature variations associated with incidence of high-energy particles, galactic cosmic rays and solar protons, into the terrestrial atmosphere (*e.g.*, Tinsley, 1991). Tinsley *et al.* (1989) and Tinsley and Deen (1991) proposed a process involving the electro-freezing of supercooled water droplets in high clouds of cyclones, their growth by the Wegener-Bergeron instability, and sedimentation to lower level supercooled clouds where they enhance freezing and latent heat release. The latent heat released by the above-mentioned mechanism will produce intensification of convection, and in warm core winter cyclones the extraction of energy from the barometric instability to further intensify cyclones, leading to changes in the general circulation. Winter cyclones east of the North American and Asian continents will be intensified by this process (Tinsley and Deen, 1991). This will cause intensification of the jet stream, and will result cooling of the troposphere, as observed in 1988–1989, during the period of SOI>0.

The next question is why the phase of the temperature change was reversed in the years of SOI<0. According to van Loon *et al.* (1982), the temperature of the Arctic atmosphere depends on the phase of SOI. When the trade winds are weak in the South Pacific Ocean (SOI<0), the temperature tends to be higher over the Arctic than that in the opposite extreme. This means that the strength of the winter Arctic vortex in the phase of SOI<0 will be weaker than that in the opposite phase. Incidence of high-energy solar protons in the phase of SOI<0 will result in the further weakening of the strength of the warm Arctic vortex. This produces weakening and northward shift of the jet stream, then the temperature increase in the troposphere in the SOI<0 phase is expected. In conclusion, although it is still necessary to perform further detailed data analysis, energetic solar protons are suggested to be the most important agent to produce atmospheric variation induced by solar-terrestrial activity.

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References

Herman, J. R. and Goldberg, R. A. (1978): Sun, Weather, and Climate. NASA SP-426. 360 p.

Kodama, M., Kohno, T. and Kanzawa, H. (1992): Stratospheric sudden cooling after solar proton event over Syowa Station, Antarctica. J. Geomagn. Geoelectr., **44**, 361–366.

Schuurmans, C. J. E. (1991): Changes of the coupled troposphere and lower stratosphere after solar activity events. J. Geomagn. Geoelectr., **43**, Suppl., 767–773.

TINSLEY, B. A. (1991): Interpretation of short-term solar variability effects in the troposphere. J. Geomagn. Geoelectr., **43**, Suppl., 775–783.

TINSLEY, B. A., and DEEN, G. W. (1991): Apparent tropospheric response to MeV-GeV particle flux variations: A connection via electrofreezing of supercooled water in high-level clouds? J. Geophys. Res., **96**, 22283–22296.

TINSLEY, B. A., BROWN, G. M. and SCHRRER, P. H. (1989): Solar variability influences on weather and climate: Possible connections through cosmic ray fluxes and storm intensification. J. Geophys. Res., **94**, 14783–14792.

VAN LOON, H., ZEREFOS, C. Z. and REPAPIS, C. C. (1982): The Southern oscillation in the stratosphere. Mon. Weather Rev., **109**, 225–229.

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