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SOLAR ACTIVITY INFLUENCES ON ATMOSPHERIC ELECTRICITY AND ON SOME STRUCTURES IN THE MIDDLE ATMOSPHERE

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INTRODUCTION

This paper is restricted on processes in the troposphere and the lower stratosphere (higher atmosph. see MATSUHITA, 1983). ***General aspects of global atmospheric electricity*** are summarized in Chapter III of NCR (1986), VOLLAND (1984) has outlined the overall problems of atmospheric electrodynamics, and ROBLE and HAYS (1982) published a summary of solar effects on the global circuit. The solar variability and its atmospheric effects (overview by DONELLY et al, 1987) and the solar-planetary relationships (survey by JAMES et al. 1983) are so extremely complex that only particular results and selected papers of direct relevance or historical importance can be compiled in this article.

A LOOK BACK AT THE HISTORY

BAUER (1925) first suggested a correlation between the electric field (E) recorded from 1902-1922 at 5 stations and the sun spot number. Also GISH and SHERMAN (1936) reported on solar effects in atmospheric electric data. However, ISRAEL (1961/1973) stated that solar influences on atmospheric electricity are unlikely. Of course, sunspot numbers are not the best for such an investigation and long term observations also raise problems. Hence Reiter used solar flares (SF) as ***well defined short term*** solar events. He showed that after flares E and the air earth current (I) increase significantly by 20-60% (REITER 1960, 1964/85, 1969, 1971) when they are recorded on mountain peaks during fair weather and above the mixing layer. These findings have been confirmed by COBB (1967) and SARTOR (1969). Then MARKSON (1971) considered in great detail solar and other extraterrestrial influences on atmospheric electricity and thunderstorms by including also Forbush decreases (FD) in the galactic cosmic rays (GCR) and the sector structure boundary passages (SBP) of the solar magnetic field (based on WILCOX 1965 et al.,1968). MÜHLEISEN (1974) executed an extensive work by applying radiosondes in order to study the long term variation of the electric ionospheric potential (EIP) which was shown to be correlated directly with the relative sunspot number 1963 - 1970.

In conclusion the following viewpoints particularly appeared as to be regarded in further investigations (of course, some more could be drawn):

a) For relevant studies the use of ***short term events*** being well defined by time and intensity and which are clearly linked with the solar activity seem to be most useful: e.g. SF, SBP of the interplanetary magnetic field, solar proton events, behavior of the solar wind and of the corona hole the importance of which has been recognized recently.

b) When studying short term events it is important to consider the respective ***phase of the solar cycle*** at the same time which can strongly modify the feature of the result (see REITER 1979).

c) For investigating solar-atmospheric electrical relations the parameters should be recorded or measured exclusively during ***fair weather*** conditions and ***above the mixing layer*** either on high mountain tops (REITER, COBB, see above) or at very remote islands or polar regions, or by airplane (MARKSON 1976), by balloons (MÜHLEISEN 1974, OGAWA et al. 1967, 1969) and other carriers.

SEVERE CRITIQUE

Critique has been claimed concerning the seriousness of sun-atmosphere investigations. And since atmospheric electricity cannot be separated from the behavior of specific parameters of aeronomy and meteorology all of those have been lumped together by this concern (e.g. see SHAPIRO 1979 who doubts the work of MARKSON 1971 and of WILCOX et al. 1974, 1976 on the SBP-vorticity index relation). A harsh refusal has been published by GREEN (1979) concerning misconceptions and misinterpretations in the investigations of sun-weather relationships. His reproach has been rather often repeated: lack of physical mechanisms connected with an overvalue of pure statistical associations. Another serious critique has been compiled recently in an extended article by TAYLOR (1986) who reviewed also some work in atmospheric electricity. He mainly points out the controversy and the lack in the work based on SBP and the suggestions of a link between cosmic ray induced changes in the stratospheric ionization rate and thunderstorm activity (MARKSON 1978a, LETHBRIDGE 1981). However, Taylor accepts the results on connections between FD (therefore also SF) and the behavior of atmospheric electrical parameters as well as trigger of stratospheric intrusions (REITER 1977b,1979). He points out that -if successively isolated and explained- external forcing *of short term variations in the dynamics* of the lower atmosphere would be of major accomplishment.

Another review of results of sun-atmosphere investigations has been given by EDDY (1983) which is still worth mentioning also today: no equivocal connection between solar variations and meteorological processes has yet been established. It must be made clear that studies of solar perturbations and their influences on the lower atmosphere are undeniably a proper part of *atmospheric physics in general*. Eddy concludes with three general ***recommendations*** the importance of which is still unchanged: (a shortened version)

a) The question of possible solar influence on special atmospheric phenomena must be treated within the general framework of solar-terrestrial physics and atmospheric science. Facts of adjoining disciplines must be fully regarded.

b) More effort should be devoted to the development of physical models and mechanisms.

c) The data base on which all the studies rest should be expanded and strengthned. This needs apart of an enhanced and improved monitoring of all important parameters describing the solar activity also measurements of solar-induced perturbations in the upper, middle and lower atmosphere. Electric and magnetic fields and their changes by the incidence of solar particles should be included.

Here, obviously, the overall criticism turns over in valuable recommendations which should be accepted and applied without reserve.

SOME OF THE RECENT INVESTIGATIONS OF IMPORTANCE

HOLZWORTH and MOZER (1979) found a direct evidence of solar flare modification of stratospheric electric fields. FISCHER and MÜHLEISEN (1980) reanalyzed their data on the EIP and found an influence of the SBP. TAKAGI et al. (1984) also found an effect of SBP (only for -/+) on the fair weather electric field on the earth's surface. He furthermore discussed the influence of cosmic ray variations on the EIP, the currents from thunderstorms and on I. However, he erroneously explained the SF effect by enhanced solar protons and attributed the variation of the GCR to the solar activity in general. It is a matter of fact that the SF effect is mainly based on the FD in the GCR and that energetic solar protons which reach the lower atmosphere are extremely rare and do normally not appear in connection with a flare except of very rare cases. Also OLSON (1983) tried to interpret the solar influence on the atmospheric electrical parameters. MEYEROTT et al. (1983) analyzed long term measurements (10 years) of the EIP but found no correlation with variations of the GCR intensity. However, the EIP seems to be better correlated with the stratospheric aerosol burden caused by volcanic eruptions (REITER 1986 et al., OLSEN 1983). This again is a hint showing that long term investigations are not a reasonable basis for solar-terrestrial studies.

Here some remarks on suggestions by MARKSON (1974, 1978b, 1981, 1983) are required. He claimed that a direct influence of solar events on the current between the ionosphere and the earths surface exists. Those, so MARKSON argues, liberate cosmic rays which reduce also the columnar resistance above each thunderstorm. By this way the upward electric current of positive charges being accumulated on top of the thundercloud by the charge separation processes is enhanced and the generators put more charge onto the ionosphere. However, only in very rare cases (f.e. see the event in August 1972) solar protons have such a high energy that they can penetrate down to the lower stratosphere. After SF normally the FD occurs and the ionization rate in the lower stratosphere and upper troposphere drops. But this is the inverse effect compared with MARKSON's model. Finally it may be pointed out that some competent ***reviews on solar-terrestrial relationships*** have been published recently: ROBLE and HAYS (1982), NEWELL (1984), and ROBLE and TZUR (1986). These reviewers agree with the claim of solar effects on E and I and on stratospheric intrusions published by the author.

THEORETICAL CALCULATIONS AND MODELING

A new era appeared with the theoretical treatment of atmospheric electrical data. ROBLE and HAYS (1979), TZUR et al. (1983), TZUR and ROBLE (1985), ROBLE (1985) and ROBLE and TZUR (1986) were successful in a mathematical modeling of the global atmospheric electric circuit and they could show that their results are in concordance with experimental results by REITER, COBB, and others. MAKINO and OGAWA (1983, 1984) also calculated the pattern of the global circuit based on assumptions of the global thunderstorm distribution. They confirmed the effect of solar flares on E and I (found by REITER 1960, 1964 and COBB 1967) quantitatively by incorporating the influence of the FD in 57.5°N on the stratospheric ionization rate (Fig.1d).

RESULTS RECENTLY OBTAINED

Fig.1 shows the departures of E and I from the mean fair weather values (in %) some days before, during and after SF events. Fig.1a recalls the finding by COBB (1967). Figs.1b, 1c show the result by Reiter as it appears when a new series of data (1977-1981) is added to the former (REITER 1971) of 1967-1971. There is no doubt that this extension over now 2 solar cycles (No.20, 21) sufficiently confirms the previous results. The departures of E and I from the mean fair weather values during solar quiet are more than 3σ and consequently significant. Fig.1d shows the theoretical result by MAKINO and OGAWA (1984) for 3 km altitude (=Zugspitze station). They calculated the departures of E and I after SF based on the FD in the GCR for 57.5°N as expected in the mean. MAKINO and OGAWA state: *these results are consistent with the features of Reiter's observation.* By this way the recommendations b) and c) by EDDY (1983) are realized: the amount of data was increased and the primary result could be confirmed. A reasonable physical mechanism has been established by independent investigators.

Although the applicability of SBP in solar-terrestrial investigations has yet not been finally accepted, the results of two independent studies based on SBP dates (by SVALGAARD 1976) are shown in Fig.2a. In the case of a passage of the typ -/+, E and I measured on Zugspitze Peak in 3 km a.s.l. significantly depart (REITER 1976, 1977a) from the fair weather mean by +15 to +20% showing a maximum in the +2 day. In the same figure the E and I values are overlaid by the daily mean concentration of the isotope Be7 (halflife time 53 days) in the air at the same station. Be7 is constantly produced in the lower stratosphere in 20-27 km by nuclear reaction of cosmic rays with air molecules and its concentration in the upper troposphere is normally rather low. However, by each intrusions of stratospheric air through the tropopause near a folding, Be7 significantly increases also in 3 km altitude and indicates an intrusion confidently (REITER et al. 1971, REITER 1977b, 1979). Fig.2a consequently shows that the increase in E and I after SBP is coupled with an enhancement of stratospheric intrusions. Fig. 2b confirms that this is significantly linked with the solar activity: at the same time when the FD is initiated (drop in the neutron density, upper panel of 2b) the concentrations of Be7 strongly increa-

ses (the weak drop of the GCR intensity during a FD has no direct influence on the Be7 generation). This coupling of E,I effects with stratospheric dynamics is in accordance with recommendation a) by EDDY (1983). The trigger by solar events of dynamic processes in the lower stratosphere also appears by considering the day by day variations of the stratospheric O_3 pattern. Fig.3 shows one example (for more see REITER 1983). From March 10 to March 19 (Fig. 3b) a FD lasted and during the same sequence the initially normal and rather smoothed stratospheric O_3 profile became totally scattered (3a): a complex overlay of stratospheric and tropospheric air strata above the tropopause occurred (for more details see REITER 1983).
Using the values of 480 O_3 radiosonde flights during 37 sequences with 8 - 30 day by day ascents along the solar cycle No. 21 and the 35 cases of well established FD, the scatter (σ^2) of the stratospheric O_3 values before, during and after the FD has been calculated (Fig. 4a). From the -2 day to the key day the value of scatter increases significantly and then it consistently drops.
The increase of the O_3 scatter on the key day amounts more then 2 times of its standard deviation (sigma in Fig. 4a).
By using the same key days, also a significant (compare sigma values) change in the tropopause height on and after the FD is shown (4b): it drops in the average by 40 hPa. Also these results confirm the importance of the GCR for solar-terrestrial studies of the stratospheric dynamics in accordance with TAYLOR (1986). In this case the GCR may have the character of an indicator of important short term solar events. Here also the work of NEUBAUER (1983) should be mentioned. He demonstrated solar impacts on dynamic processes in the lower stratosphere which corroborate the findings shown in Figs. 3 and 4.
Last but not least a recent result of recordings (E, I, air conductivity, all meteorological parameters) executed at a new private mountain station in 1780 m a.s.l. should be mentioned (Fig. 5). During an exceptional and long lasting fine weather period in January 1989 three strong and one heavy solar flares (imp.3b) occurred during which the station was constantly above the mixing layer. Fig. 5b shows the behavior of the 10 cm flux, of the GCR intensity and the flare calendar. A FD occurred on 16 January and the 10 cm flux showed a peak at the same day. A magnetic storm was reported for January 20. From January 17 to 18, E and I increased remarkably and remained until 21 January by 30 - 70 % higher than the fair weather mean. This is a single event being consistent with the results obtained statistically and demonstrated in Fig.1.

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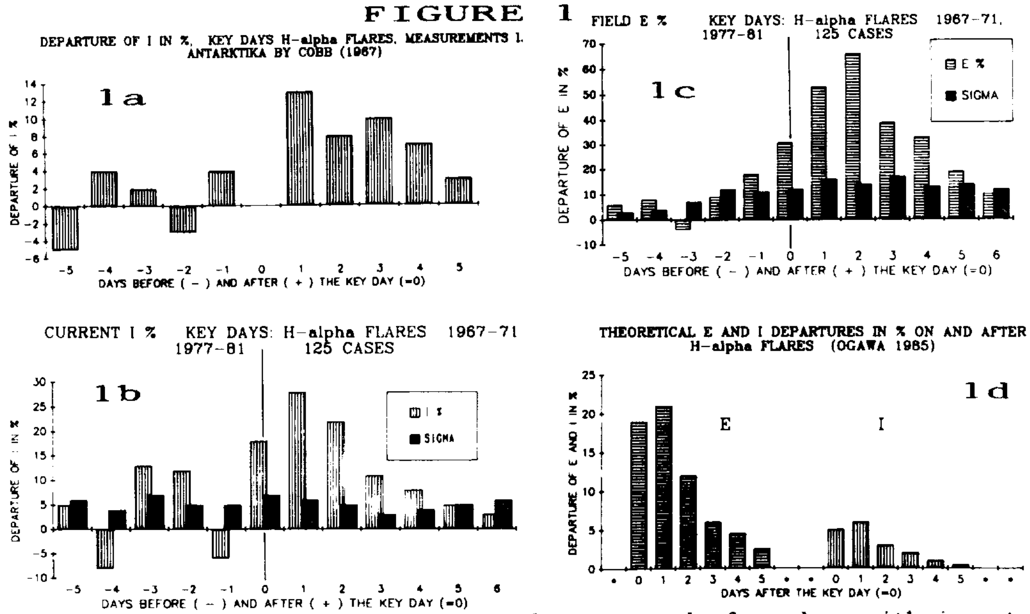
FIGURE 1

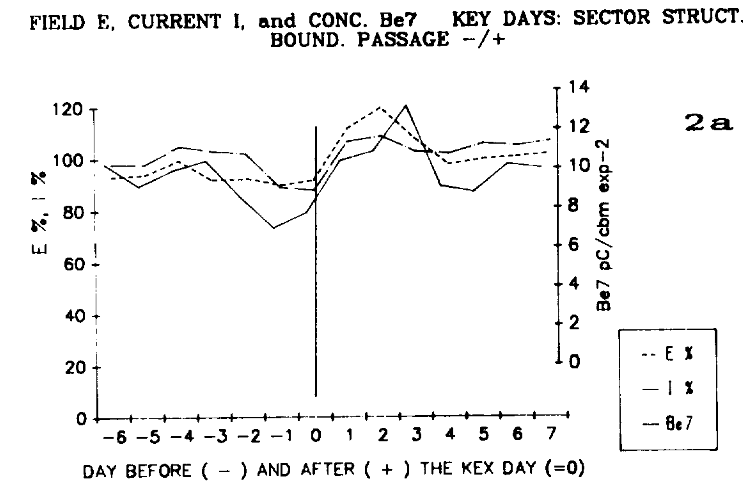


Variation of field E and current I before, on and after days with important and isolated solar flares (= key day 0).

a) The result by COBB (1967) based on I measurements at Mt. Mauna Loa.

b) and c) Recordings by REITER on Zugspitze Peak (2964 m a.s.l.) during fair weather. Data of 1967-1971 (REITER 1971) have been updated by new ones of 1977-1981. Departure of E and I in % from mean fair weather level = 0%. Number of key days = 125. Sigma = standard deviation.

d) Theoretical result by MAKINO and OGAWA (1984) confirming a), b) and c).



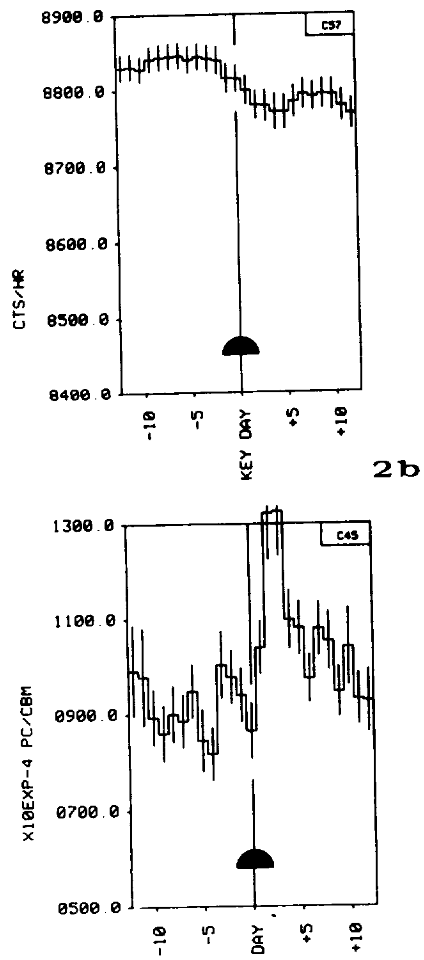


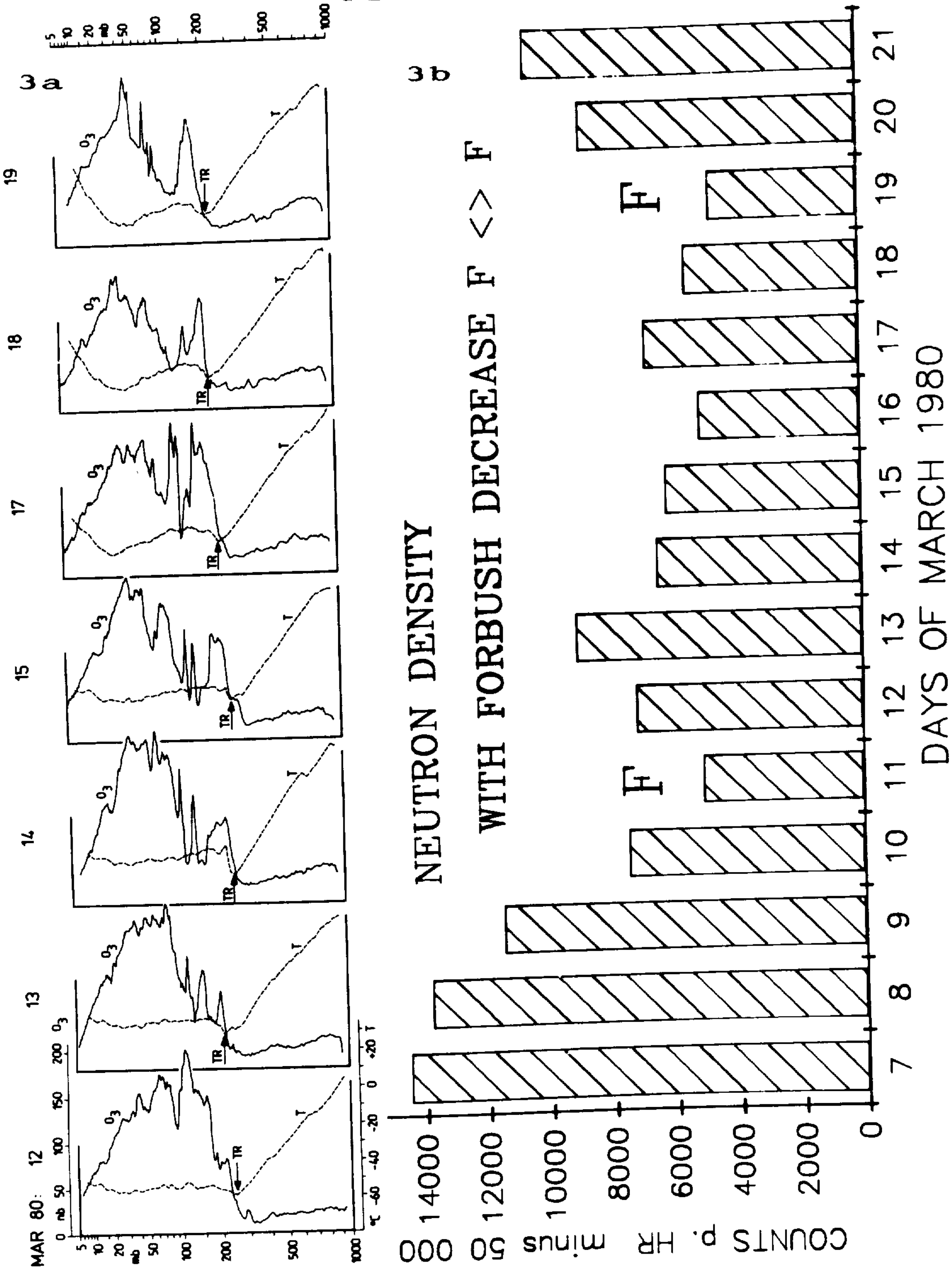
FIGURE 2

a) Behavior of E, I, and Be7 concentration (all measured on Zugspitze in 2964 m a.s.l.) before and after days (in total 80) with sector structure boundary passages of type: > −/+ >

b) Variation of the galactic cosmic ray intensity (counts/hr) and of the Be7 concentration before, during and after solar flares (total: 60 key days)

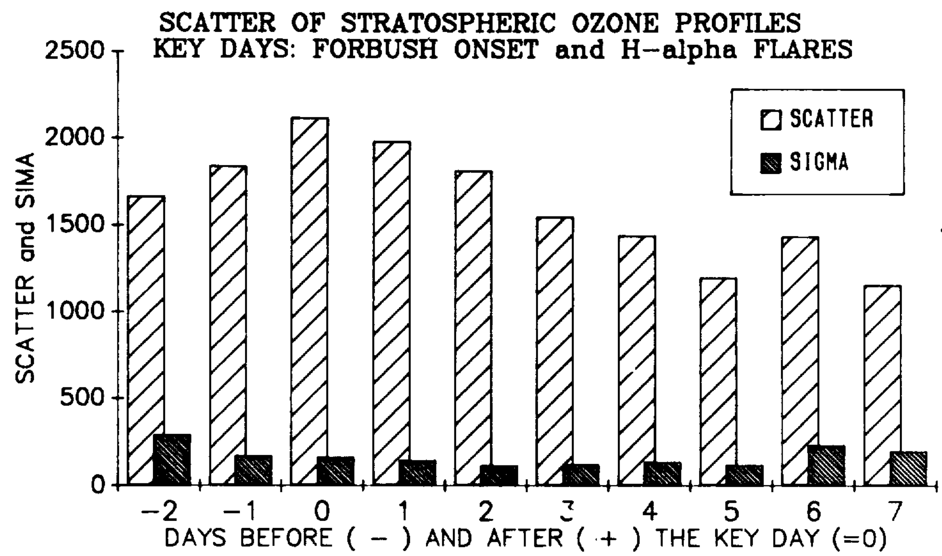
KEY DAY: ▲ H_α FLARES

FIGURE 3



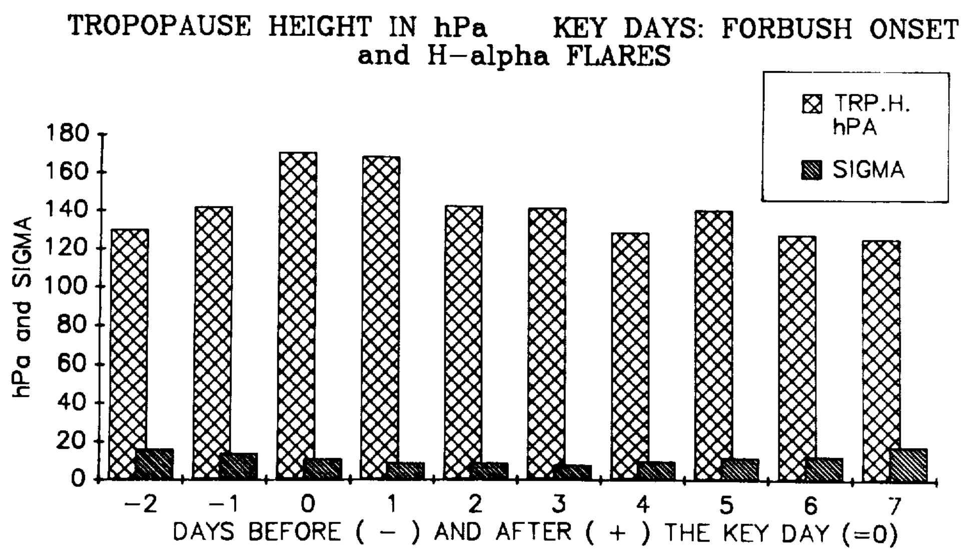
a) Daily stratospheric O_3 and temperature (T) profiles obtained by radiosonde during a sequence of 7 days.
b) mean daily neutron densities from March 7 until March 21, 1980. A strong Forbush decrease was reported from March 10 to March 19.

FIGURE 4



4a

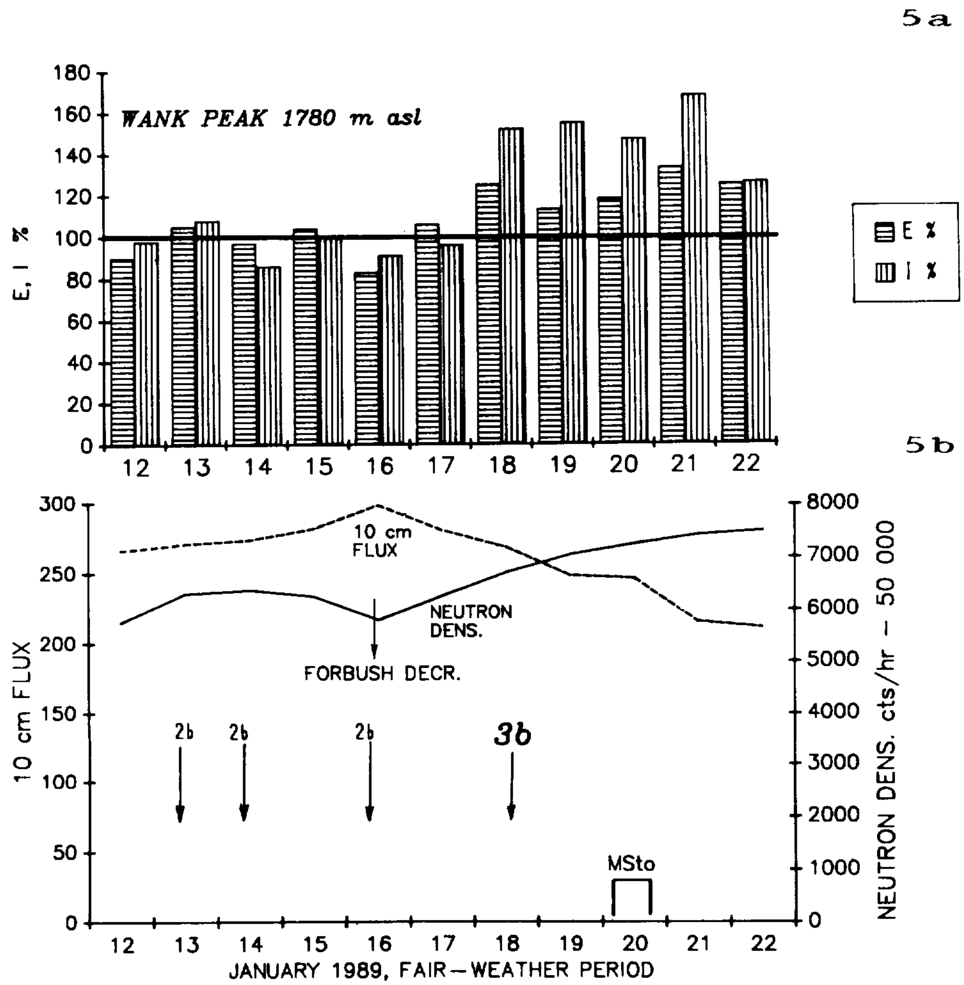
4b



a) The scatter (σ^2) in the stratospheric O_3 profiles of 35 sequences of day by day radiosonde ascents superimposed before, on, and after key days with a significant Forbush decrease. Sigma is the standard deviation of the scatter value.
b) Departure of the tropopause height expressed in hPa, data based on the same radiosonde ascents and key days as in a).

FIGURE 5

FIELD AND AIR EARTH CURRENT, 100 % = FAIRE WEATHER MEAN



a) Daily mean values of E and I recorded on a mountain top in 1780 m a.s.l. in January 1989. The values are expressed in % of the mean fine weather data without solar events (set = 100%, heavy line).
b) Daily mean values of the 10 cm flux and the galactic cosmic ray intensity on the same days. Solar flares of importance 2b and 3b are inserted.
MSto = magnetic storm.

MEASUREMENTS OF MESOSPHERIC ELECTRIC FIELD UNDER VARIOUS GEOMAGNETIC CONDITIONS

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The results of measurements of electric field strength in the mesosphere are given for high and middle latitudes. At high latitudes, there is observed a distinct dependence of the height profile of electric field on the geomagnetic disturbance level.