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# Electrical conductivity of air in thunderstorm environment at a mountain station

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ABSTRACT. Measurements of electrical conductivity of air have been made under the conditions of negative potential gradient resulting from thunder clouds at Gulmarg (2700 m). Seven thundery situations have been discussed. Abormal conductivities have been recorded especially after the field changes sign from a large negative to either a positive or a small negative value. Positive polar conductivity showed increase whenever wind appeared to come from the direction of the thunder cloud. On a number of occasions the general level of conductivity was found to be higher in the morning which was followed by a thunderstorm occurring in the evening and atleast on one occasion large negative ions were recorded about 12 hours before the occurrence of the thunderstorm. Positive polar conductivity invariably dropped to zero value under negative potential gradient much greater than 100 V $m^{-1}$. The results seem to be in general agreement with the theoretical observations of Amiram (1972) and are relevant to the observations made by Chalmers (1967) on abnormal conductivity.

## 1. Introduction

Chalmers (1967) suggested that abnormal conductivities of air below thunder clouds should be investigated in aircraft and on high ground as the evidence on this problem was conflicting. It was pointed out by him that in negative potential gradient a point discharge would take negative charge down to earth and positive ions would be liberated in the atmosphere which may be observed as enhanced conductivity. There should be corresponding increase in potential gradient with height which could not be actually observed. To explain this Chalmers considered various possibilities like the effect of negative ions coming from the cloud to remove the positive space charge and also the capture of ions by falling drops or their removal by upward air currents but none of these was found sufficient to account for the absence of the expected increase of potential gradient with height. However, if enhance positive polar conductivity is actually observed it would mean confirmation of the space charge expected from point discharge otherwise a new effort would be required to explain the absence of positive space charge.

Gockel (1917) observed that on days with afternoon thunderstorms the conductivity in the morning was already significantly higher but other observers found no such effect and Starr (quoted by Whipple and Scrase 1936) found no abnormality of conductivity due to thunderstorms except for slight changes associated with lightning flashes and lasting for a few seconds only.

Krasnogroskaya (1965) observed drastic reduction in polar conductivities measured at two mountain altitudes 2140 m and 3100 m in negative potential gradient. Since then no further experimental data bearing on the problem have come to out knowledge. Wilkening (1964) studied the influence of the electric field such as those existing under thunderstorms upon the concentration of the radioactive ions. Recently more complete theoretical investigation of radon 222 daughter ions in fair weather and thunderstorm environments has been made by Amiram (1972).

Khera and Raina (1973) reported some results on the conductivity of air pertaining to a single thunderstorm. Taking advantage of the favourable location of our atmospheric electricity station at Gulmarg (2700 m) conductivity measurements were carried out under thunderstorm conditions. Since each thunderstorm is unique in some way we report here our observations on seven thundery situations. The results obtained appear to be interesting especially in the light of Amiram's work and the observations made by Chalmers on abnormal conductivities.

## 2. Experimental arrangement and equipment

The measurements were made at the Gulmarg

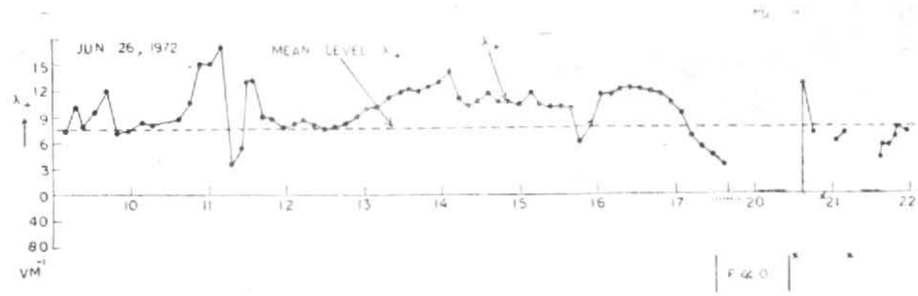


Fig. 1. Variation of positive polar conductivity (plotted in arbitrary units) and the potential gradient (for a short period only) with local time

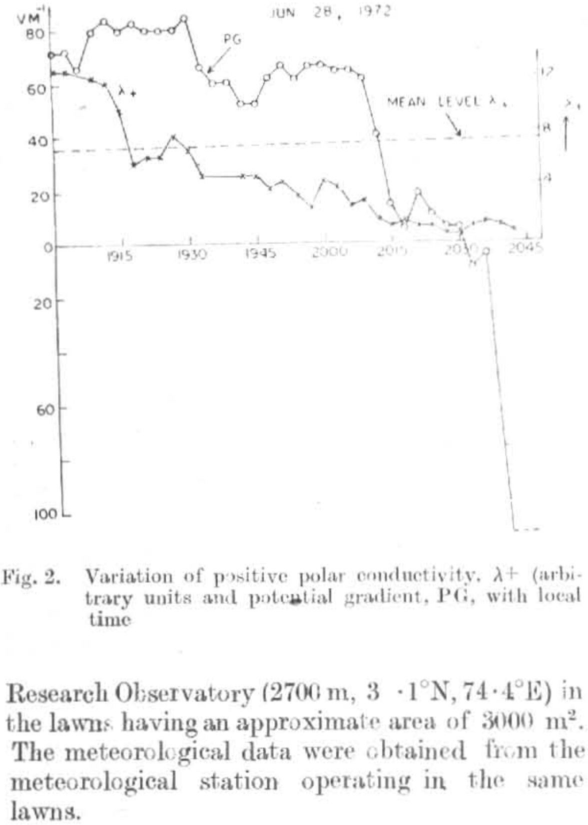


Fig. 2. Variation of positive polar conductivity, λ+ (arbitrary units and potential gradient, PG, with local time

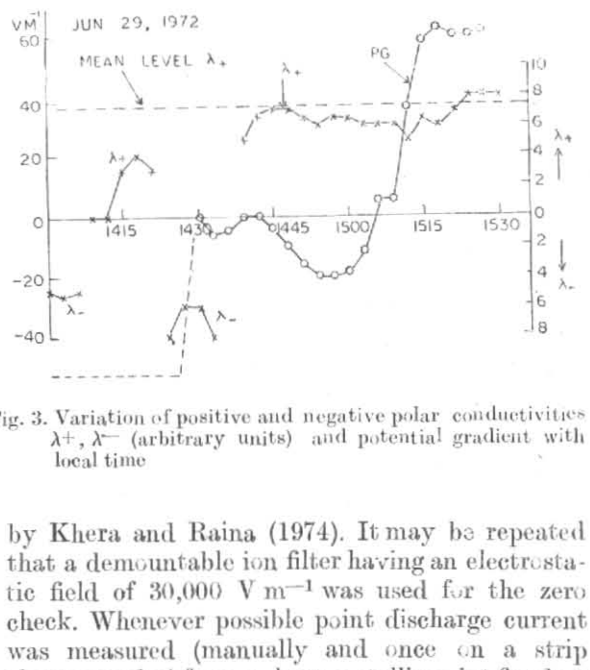


Fig. 3. Variation of positive and negative polar conductivities λ+, λ− (arbitrary units) and potential gradient with local time

Research Observatory (2700 m, 3 ·1°N, 74·4°E) in the lawns having an approximate area of 3000 m². The meteorological data were obtained from the meteorological station operating in the same lawns.

Potential gradient was measured by using Crozier's (1963) antenna system discussed by Khera and Raina (1972) earlier. This type of sensor being suitable for fair-weather work had an operating range of —100 V to 250 V. Therefore the dotted lines drawn in various figures imply that the actual values of negative potential gradient are not known but these should be greater than —100 V m⁻¹.

Positive and negative ion conductivity was measured at the height of 1 m above the ground by an improved version of Gerdien's aspirated cylindrical condensor and has been described by Khera and Raina (1974). It may be repeated that a demountable ion filter having an electrostatic field of 30,000 V m⁻¹ was used for the zero check. Whenever possible point discharge current was measured (manually and once on a strip chart recorder) from a sharp metallic point fixed on a nearby tree top. Since the occurrence of point discharge at an artificial point was no guarantee that point discharge was taking place naturally on the tree tops an effort was made on one occasion to record the point discharge from a nearby living tree by inserting two electrodes at a distance of 2 metres in the tree trunk. The current was indicated by a low resistence galvanometer.

**3. Observations, results and discussion**

(*a*) Figs. 1 and 2 give the variation in the positive polar conductivity on 26 and 28 June 1972. Fig. 2 shows also the variation of potential gradient. During both these days the conductivity (positive) was found to be higher by about 35-40 per cent from its normal fair-weather value much before the development of thunderstorm. The general higher level of positive conductivity was also found on 16 and 27 September (Figs. 5 and 7) which was followed by a thunderstorm in the evening. These observations are in general agreement with those of Gockel (1915) and Rossman (1950) who used glider to circle a large cumulus in the ascending air current. Since visibility on these days appeared to be the same as on other days under discussion the above increase in conductivity may be due to the enrichment of ambient air by radioactive emanation brought up by the ascending thermals (below our level) which precede a thunderstorm. As our station overlooks a valley 500-700 m below it is quite possible for us to detect this effect.

About 45 minutes before the field reversed its polarity the conductivity showed decrease. This may be due either to the gradual increase in the concentration of condensation nuclei prior to the occurrence of the thunderstorm or to the injection of negative space charge. The first possibility appears more probable. According to Amiram (1972) an increase in the concentration of condensation nuclei from $10^4$ to $10^5$ nuclei $cm^{-3}$ causes a reduction by a factor of 7 or more in the radioactive ion concentration relative to the ambient concentration of radon-222.

On 28 June, point discharge current from the artificial metallic point fixed on a tree top was observed soon after the field reversed its polarity but no corresponding change in the positive conductivity was measured.

(*b*) Fig. 3 shows measurements when the thunder cloud was in its last stage of dissipation. Observations could not be taken earlier because of some precipitation. It is seen that under small negative values of potential gradient the positive ion conductivity is still considerable (85-90 per cent of its usual fair-weather value).

(*c*) Fig. 4 represents the case when the station was completely shadowed by cumulus and stratocumulus clouds and cloud development was actively taking place. The observations, therefore, cannot be ascribed to a particular single cloud. It was calm from 1522-1524 hr. This was followed by gusts of wind ($\sim 2$ m $s^{-1}$) coming from the direction of the cloud. It was observed (similar observations were also made in other cases reported below, *e.g.*, Figs. 3, 1 etc) that when the potential gradient changed from positive to negative value the positive conductivity decreased from its

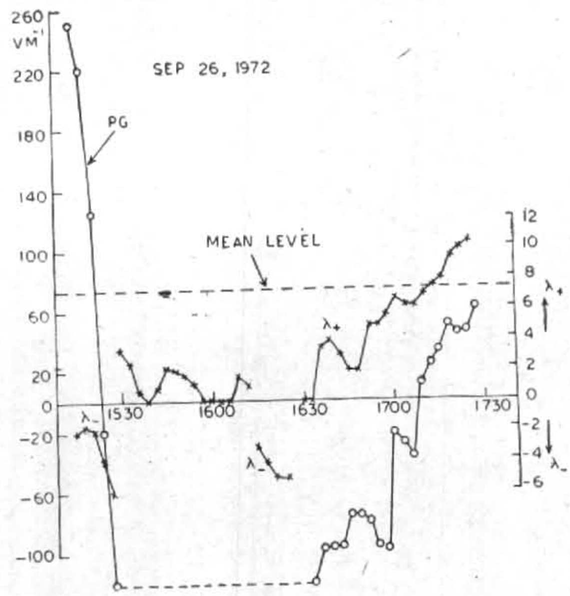


Fig. 4. Variation of positive and negative polar conductivities, $\lambda+$, $\lambda-$ (arbitrary units) and potential gradient with local time

initial value to practically zero within the accuracy of our measurements. When the negative potential gradient was much higher than $-100$ V $m^{-1}$. These observations seem to be in general agreement with those of Krasnogorskaya (1965). The negative polar conductivity also seems to decrease under the action of relatively stronger positive potential gradient and shows some increase when potential gradient is negative. This is also in agreement with our earlier observations (Khera and Raina 1973). Wilkening (1964) studied the influence of the electric field due to thunderstorm upon the concentration of the radioactive ions. Amiram (1972) has given a one-dimensional numerical model which predicts the behaviour of radon-222 and its daughter products considering factors like attachment, recombination, electric field and eddy diffusion. The study shows that electric fields such as those existing under thunderstorm environment are dominant cause of high depletion of the radioactive ions due to their migration in the first 30 m thick surface layer, beyond which no major changes in ion concentration due to the electric field are observed. The migration of ions is governed by drift velocity, $wF$, where $w$ is the mobility of ions and $F$ is the potential gradient. Negative potential gradient of the order 6-10 kV $m^{-1}$ was shown to cause a reduction by a factor of 8 or more in the ion concentration relative to the ambient radon-222 concentration close to the ground. These observations are relevant to the present investigation as the radionuclides have essentially the same characteristics as small ions in the atmosphere

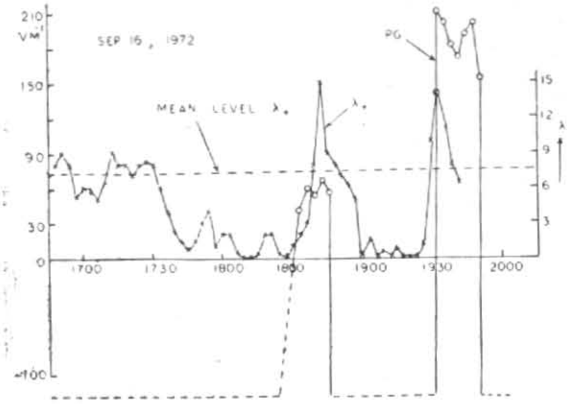


Fig. 5. Variation of positive polar conductivity (arbitrary units) and potential gradient with local time

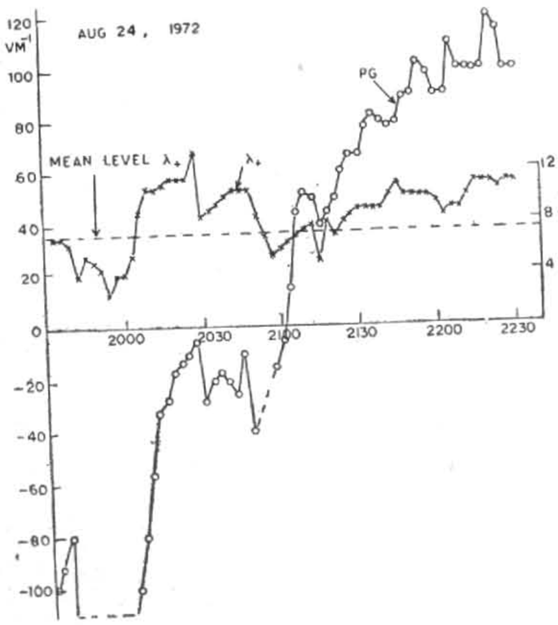


Fig. 6. Variation of positive polar conductivity (arbitrary units) and potential gradient with local time

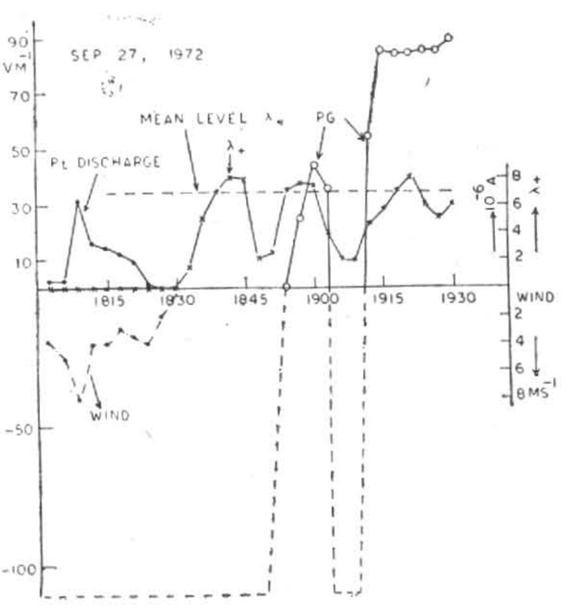


Fig. 7. Variation of positive polar conductivity (arbitrary units), potential gradient, point discharge current and wind speed with local time

and further the main contribution to the ionisation near the ground (under fair-weather conditions) is made by the ground radioactivity, radon and thoron gases and their daughter products. The *reduction* of positive ion conductivity under strong negative potential gradient is therefore explained in terms of the migration of small ions—the greater the vertical field component the greater is the migration or drift velocity of ions.

(*d*) The data in Fig. 5 (16 September 1972) pertain to a thunder cloud which started developing around 1500 hr just behind the southern peak (4300 m) and the distance between the thunder cloud and our station was estimated to be 1·5-2 km. Throughout the period of thunderstorm the weather remained dry and calm. Considering the prevailing negative potential gradient (>100 V $m^{-1}$) the general level of positive polar conductivity between 1648-1730 hr was much higher than expected. Around 1827 hr when the potential gradient reversed its polarity due to electric discharge (probably within the cloud) abnormally high values of positive polar conductivity was recorded. The peak value was about 100 per cent greater than the usual fair-weather positive conductivity, although the magnitude of positive potential gradient was smaller than its fair-weather value. The conductivity decreased to zero value with the field becoming negative and once again when the field reversed its polarity unusually high value of conductivity was recorded (1930 hr). The enhanced conductivity was invariably observed whenever field changed from strong negative to either positive or small negative value (*see* also Fig. 1 around 2040 hr).

These results can be accounted for if there is a space charge resulting from widespread point discharge and residing in the air below the cloud. When the cloud is neutralised by the electric discharge the resulting positive potential gradient may be considered as due to the presence of positive space charge below the cloud. Further as the field changes sign from negative to postitive the migration of positive ions and nuclides existing in fair weather field along with those freshly created by point discharge phenomenon in the atmosphere takes place with the drift velocity $wF$. If the wind velocity is also considered the velocity of migration could be the vector sum of the two velocities.

The fact that abnormally high conductivity was recorded implies that the excess small positive ions from the point discharge must have come from a region extending roughly to the tree-top level around the measuring site. Around 1950 hr wind started blowing and it came from the direction of the thunderstorm region. At the same time large positive ions were also recorded (This could be ascertained by using ion filter having an electrostatic field of 30 kV $m^{-1}$ at the entrance of the Gerdien chamber). The detection of large ions showed that small ions coming from the region of cloud could become large by attachment. The relatively high value of potential gradient at around 1930 hr shows the extent and magnitude of positive space charge.

Fig. 6 also shows enhanced positive polar conductivity immediately after a field reversal around 2006 hr. The thunder cloud started developing around 1930 hr and was accompanied by very light drizzle. The observations were commenced soon after the drizzle stopped. For most of the period of the observations wind appeared to come from the direction of the cloud and lightning flashes were observed very frequently behind the mountain range in SE, S and SW. Between 1930 & 2000 hr wind gusts (2-6 m $s^{-1}$) were observed. The positive conductivity did not drop to zero value which may be due to the widespread point discharge occurring and carried to the station by wind gusts. This is quite possible especially when wind came from the direction of the cloud most of the time. As a matter of fact it was observed (not shown in the figure) that positive ions conductivity showed increase whenever wind seemed to be coming from the direction of cloud and it decreased when the direction was reversed. The step-like increase in potential gradient appeared to be due to flashes within distant clouds.

(*e*) Measurements shown in Fig. 7 represent a severe thunderstorm. Point discharge from artificial point fixed at a tree-top together with wind speed measured are shown in the figure. Point discharge from a living tree was also observed manually on a low resistence galvanometer which indicated current varying upto about 6 $\mu$ a. No precipitation occurred at the station and wind appeared to be a sweeping away from the station toward the cloud indicating possibly an updraft. The distance from the station to the thunderstorm was estimated to be 3-5 km. The following observations not shown in the figure were specially noted :

(*i*) the general level of positive ion conductivity was much higher in the morning around 0800 hr;

(*ii*) large negative ions (as indicated by the electrostatic ion filter) were observed from about 0500 to 0645 hr especially under calm conditions or with low wind speed $\approx$ 1 m $s^{-1}$.

Lightning activity was observed around 1800 hr and positive ion conductivity remained zero from 1800 to 1830 hr. During this period large positive ions were also absent as ascertained with the help of ion filter. The point discharge current showed virtual mirror relation to the wind speed. As soon as the wind sweeping away from the station stopped or decreased considerably fairly high values or positive conductivity were recorded even when the negative potential gradient was higher than 100 V $m^{-1}$. This together with the observed absence of the point discharge indicate that negative field was not strong. This may also be the reason for the absence of the expected abnormal conductivity soon after the field reversal around 1852 hr.

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