STRATOSPHERIC BALLOON MEASUREMENTS OF CONDUCTIVITY AND ELECTRIC FIELDS ASSOCIATED WITH SFERICS IN BRAZIL

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ABSTRACT: Measurements of stratospheric conductivity and of electric fields associated with sferics, were obtained during two balloon flights carrying double-probe electric field detectors launched from Cachoeira Paulista, Brazil (geographic coordinates 22°44'S, 44°56'W) on 26 January 1994 and 23 March 1995. From data obtained in 1994, a linear relationship between the vertical quasi-DC electric field peak amplitude and the decay time constant of sferics was found for negative flashes. The results are compared to similar data for intracloud flashes. The data were supported by radar and METEOSAT satellite images. For the first time, positive and negative conductivity vertical profiles were obtained in Brazil. During the flight, at an average altitude of 27.5 km, the balloon passed over two thunderclouds as identified, by on-board video images and photographs. The simultaneous conductivity measurements and thundercloud on-board observations allowed to determine that the presence of clouds affects the stratospheric negative conductivity, producing a extended and cumulative drop after the balloon passed over each cloud. Based on data obtained in 1995 and on the present knowledge about the differences between positive cloud-to-ground and intracloud flashes, two methods to distinguish between them in balloon electric field data are presented: the first is based on an estimation of the charge destroyed in the event; the second is based on the ratio between the vertical quasi-DC and the VLF electric field. The behavior of the vertical quasi-DC electric field before and after large cloud-to-ground lightning flashes is discussed and attributed to the existence a shielding layer around the thunderstorm caused by a factor decrease of three or more in the conductivity inside the cloud.

INTRODUCTION

It has been known for decades that understanding of the conductivity of the middle atmosphere is crucial for solving coupling problems between the lower atmosphere and the ionosphere [*Bering et al.*, 1980; *Hu et al.*, 1989]. This task has among others, two important aspects to be addressed: the determination of the atmospheric conductivity vertical profiles and the causes of conductivity variations in the stratosphere.

Two sorts of temporal variations in stratospheric conductivity have been observed at a constant altitude. First, temporal fluctuations of conductivity up to 30% of the mean value are commonly seen in fair weather [*Hu et al.*, 1989]. Second, some authors report that greater amplitude variations (up to 100% of the mean value) may occur during foul weather conditions.

To date very few *in situ* measurements of stratospheric vertical electric field associated with lightning flashes have been published [e.g. Burke, 1975; Holzworth and Chiu, 1982; Pinto et al., 1992]. The vertical electric field associated with lightning flashes have a typical signature of a sferic, that is, a rapid variation followed by a tail which lasts less than 10 seconds. The recovery curve (i.e. the return to the previous ambient field) depends on the local conductivity and, as it has a time constant different from the ambient relaxation time, it is probably influenced by electric charging processes inside the thundercloud.

CONDUCTIVITY RESULTS

On 26 January 1994, a stratospheric balloon was launched from Cachoeira Paulista, carrying a double probe electric field detector to measure the conductivity in the stratosphere.

Negative and positive conductivity were measured each 10 minutes during about 5 hours in daytime. The first negative and positive conductivity profiles were obtained in Brazil. At float altitudes, the positive conductivity was found to be contaminated by photoelectric emission and, consequently, were not used in this paper. The negative conductivity measurements obtained at the balloon float altitude are also presented and discussed in terms of thunderstorm related variations. These observations may add valuable contributions to the very limited amount of conductivity data obtained over thunderstorms. As far as we know, this is the first conductivity data in the stratosphere supported by video images. The support of video images leave no space for doubts commonly present in this kind of study such as if the balloon was actually over the thunderstorm. Hu et al. [1989] have pointed out that the horizontal distance between the thunderstorm and the balloon may be crucial in determining the effect of the storm on the conductivity.

The negative and positive conductivity values obtained during the ascension of the balloon launched on Jan 26, 1994, in Brazil, showed almost the same value. On the other hand, when the payload was at an altitude of 25.8 km, σ_+ was higher than σ_-, probably due to the influence of the photoelectric effect [*Chakrabarty et al.*, 1994].

The values of scale height, 5.2 km for negative and 5.8 km for positive conductivity, are in general agreement with other measurements made in different parts of the world. During its drift westward, at an average altitude of 27.5 km, the balloon passed over two thunderclouds as identified by video on-board images. The variation of the negative conductivity in Figure 1 shows a systematic decrease when the balloon approaches a thundercloud. The conductivity drops by a factor of about 2 in the vicinity of the first thundercloud and by a factor of about 1.5 after the second thundercloud. The same tendency seems to occur in the vicinity of the third thundercloud.

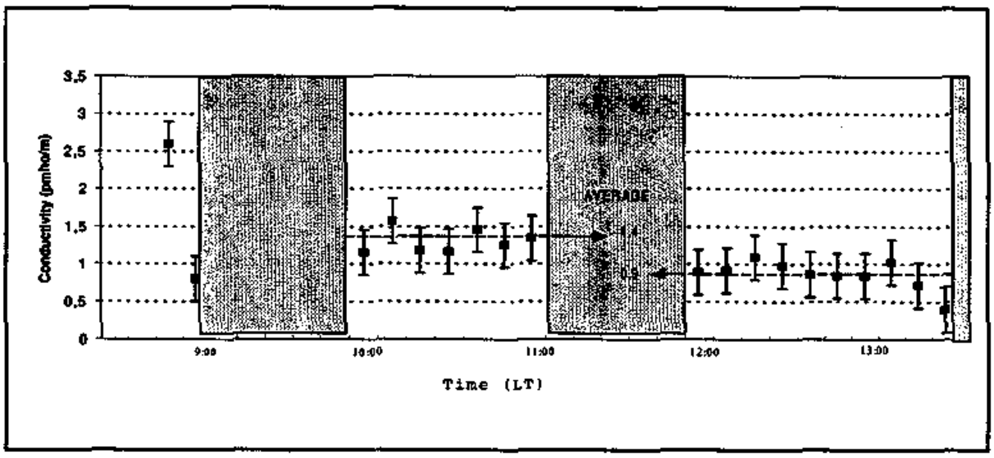

Figure 1. Negative conductivity measurements obtained on 26 January 1994.

Variations of this order in the stratospheric conductivity values have already been reported in some papers [*Bering et al.*, 1980; *Holzworth et al.*, 1986; *Pinto et al.*, 1988; *Hu et al.*, 1989]. The present measurements not only confirm the influence of thunderstorms on stratospheric conductivity, but also seem to reveal a sort of an extended and cumulative drop of σ_- values after each thunderstorm. It seems that this influence is not limited to the space right above the thundercloud, but is prolonged along the direction of the stratospheric winds that conduct the balloon. In case of more than one thunderstorm, the drop on the σ_- values would sum up. The same behavior in the conductivity was apparently seen by *Pinto et al.* [1988], although no images were available at that time.

It is known that penetrative cumulus convection is an effective source of atmospheric gravity. These waves are considered to be important for transport of momentum and substances across the tropopause because they are associated with strong vertical motions [*Sato et al*, 1995]. Considering that in our case the thunderclouds were in the mature stage, when updrafts dominate, it is very plausible to suppose that gravity waves were the responsible for the conductivity variations observed.

Even though the variations in conductivity values involved both space and time changes, which can no be easily separated, we suggest that the systematic decrease of the stratospheric conductivity may be explained by injection in the stratosphere of air parcels containing low concentration of small ions from the top of the thunderstorms, reducing the total concentration of small ions. Such parcels are known to be found in the interior of thunderstorms [*Makino and Ogawa*, 1985]. The mechanism above, however, could not explain the increase in the conductivity observed by other authors. This fact suggests that different mechanisms can be acting at different situations. It is also possible that the location of the balloon with respect to the storm may be fundamental to determine what kind of variation will occur.

ELECTRIC FIELDS ASSOCIATED WITH SFERICS

On 23 March 1995, a 54000-m^3 balloon was launched at 1335 LT and drifted westward, as usual in this period of the year. During the flight, it passed over a thundercloud at an altitude of 32 km and registered a few but intense sferics. The flight on 26 January 1994, registered also several sferics when balloon passed over the thunderclouds. The payload in both flights was equipped with a double probe electric field detector to measure the vertical quasi-DC electric field and an antenna to measure the VLF electric field. The data were sampled every 50 milliseconds using two different gains [Saba et al., 1998].

Based on electric field data and on the present knowledge about the differences between positive cloud-to-ground and intracloud flashes, two methods to distinguish them are presented: the first is based on an estimate of the destroyed charge in the event (smaller destroyed charges for intracloud flashes); the second is based on the peak amplitude ratio between the vertical quasi-DC and the VLF electric field (smaller ratios for intracloud flashes).

Relationship between the Amplitude and Decay Time Constant of Sferics

Figure 2 shows the relationship between the amplitude of the sferics associated with negative cloud-to-ground flashes and their decay time constants (Jan. 1994) Decay time constants were obtained from exponential curve fits for the first 60 data points after the electric field peak amplitude. As there is no other published relationship for negative flashes our results are shown with those obtained by Burke [1975] for intracloud flashes. The best fit lines, equations and correlation coefficients are also presented. In both cases the correlation coefficients are high, although the slope of the linear equations are very different. Such a different behavior cannot be explained by different ambient conductivity only; it must be associated with the different types of lightning considered in each case, indicating that the temporal variation of the charging process inside the cloud in each case may be quite different. At present, this process is not well known. It is also worth noting that for large sferics the decay time constant can be higher than the ambient relaxation time.

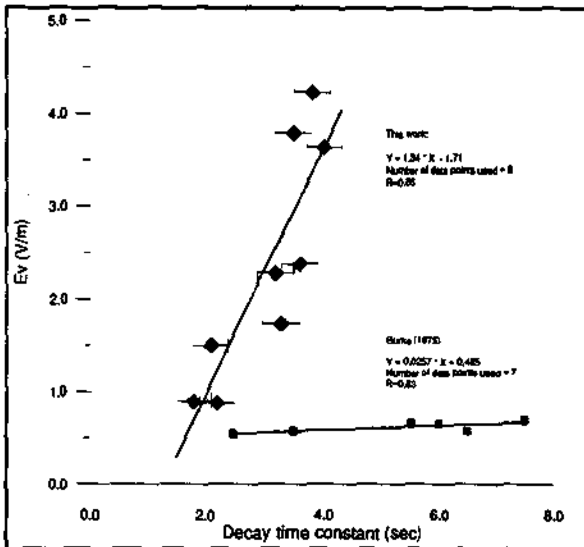

Figure 2. Sferic peak amplitude versus decay time constant

The Behavior of the Vertical Electric Field during the Occurrence Sferics

Figure 3 shows an 8-min. interval of continuous stratospheric vertical electric field data obtained at an altitude of 32.2 km on 23 March 1995. The two positive cloud-to-ground flashes, P1 and P2 and a third flash (cloud-to-ground or intracloud flash), originated in the same isolated thunderstorm, can be seen in the figure.

There are two points worth mentioning about Figure 3. First, the average value of the vertical electric field just before and just after the occurrence of P1 and P2 is not altered. This is in agreement with most balloon-borne electric field measurements recorded in literature. Second, the electric field shows an abrupt increase about 15 sec before the first flash (P1).

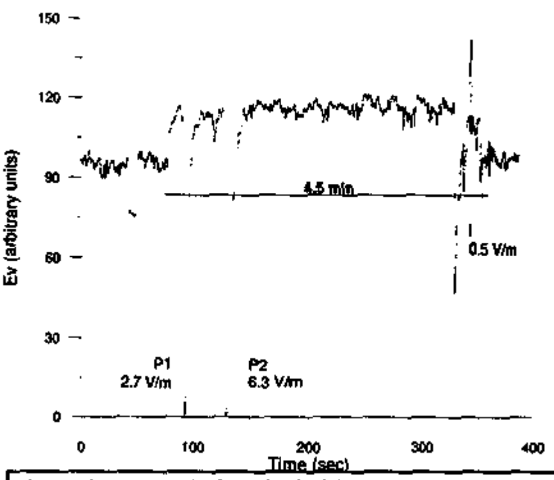

Figure 3. Vertical electric field obtained on March 23, 1995, showing three sferics and an abrupt increase around 70 s.

With respect to the first point, charges destroyed by P1 and P2 should have produced a decrease of at least 0.43 V/m in the vertical field, considering the measured conductivity scale height of 5.2 km [Saba et al., 1998]. Since this decrease was not observed, and considering that the vertical electric field resolution of our measurements was 0.15 V/m, we suppose that a screening layer around the thunderstorm should have reduced the variation of the electric field seen by an external observer. The estimated shielding factor associated with the screening layer would be equal or greater than 3. Considering that this factor is also related to the ratio between the conductivity inside and outside the thunderstorm [Volland, 1984], we found that the conductivity inside the cloud is lower than that outside by a factor of three or more.

The second point related to Figure 3 is the occurrence of an abrupt increase in the electric field about 15 sec prior to the first positive flash. It was of about 0.28 V/m and remained for about 4.5 minutes. Although the actual process behind this phenomenon may be very complex, we suggest that this increase be related to a transient shielding layer just above the cloud. It could have been produced in consequence of the large breakdown field. The necessary time to a transient shielding layer to be completely shielded (99%) was estimated by Brown et al. [1971] as approximately equal to five times the relaxation time constant at the shielding layer altitude. Considering the altitude of the top of the cloud (8 km), a complete shielding would occur at about 5 minutes. This value is of the same order of the 4.5 minutes interval indicated in Figure 3. A similar case (with an increase of about 0.3 V/m) seems to have been observed by Holzworth and Chiu [1982].

CONCLUSIONS

The first negative and positive stratospheric conductivity profiles in Brazil were obtained. The scale heights are found to be in reasonable agreement with measurements in other parts of the world. We suggest that the extended and cumulative drop of σ_- values after each thunderstorm is caused by the injection of air parcels in the stratosphere. We suppose that the persistence of this decrease along the trajectory of the balloon is due to the fact that the balloon passed exactly over the thunderclouds, and moved with these air parcels.

The criteria for identification of two lightning sferic signatures as being due to positive flashes were presented. A linear relationship between the amplitude and the decay time constant for negative lightning sferics was found to be different from the same relationship for intracloud sferics. The reason for such a difference is probably related to charging processes inside the thundercloud and remains to be investigated in more details.

The existence of a screening layer around the thundercloud could be the explanation sought for the fact that even after the occurrence of strong flashes the vertical electric field remains unaltered.

An intensification of the electric field inside the thundercloud could be a possible reason for the observed abrupt increase of vertical electric field about 15 sec prior the occurrence of a positive flash. This high intensity field may be responsible, or related to some of the emissions recently reported to occur over the top of thunderstorms. If so, the abrupt increase of the vertical electric field reported here and that reported by Holzworth and Chiu [1982] may be considered as one of the few electric field signatures associated with such emissions.

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