General Search Results--Full Record

Article 7 of 14

PREVIOUS

NEXT

SUMMARY

RELATED RECORDS

**A COORDINATED STUDY OF A STORM SYSTEM OVER THE SOUTH-AMERICAN
CONTINENT .2. LIGHTNING-RELATED DATA
PINTO IRCA, PINTO O, GIN RBB, DINIZ JH, DEARAUJO RL, CARVALHO AM
JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES
97: (D16) 18205-18213 NOV 20 1992**

Document type: Article **Language:** English **Cited References:** 26 **Times Cited:** 3

Abstract:

On December 13, 1989, a coordinated campaign was conducted in Brazil to study the electrical signatures associated with a large storm system over the **South American** continent. Balloon-borne VLF electric field data showed more than a hundred lightning-related stratospheric vertical electric field (sferics) signatures during approximately 6 hours. The sferic signatures were characterized by a rapid transient with peak amplitudes exceeding 7 V/m which would be expected by the removal of positive charge below followed by a slow recovery. This signature indicates that the lightning strokes experienced by the balloon were either cloud discharges or positive ground discharges. The peak amplitudes indicate that the positively charged region is of the order of tens of coulombs. The recovery curves are quite variable, reflecting the complex nature of the propagating phenomena in the atmosphere. A lightning position and tracking system (LPATS) network recorded 326 ground strokes at distances less than 100 km of the balloon. In contrast with previous observations during the summer in the northern hemisphere it was found that most lightning flashes (60%) were positive. In addition, only a small fraction of them occurred simultaneously with a balloon sferic signature, indicating that most balloon sferics were a result of cloud discharges. An analysis of wind and temperature data during the event showed that the predominance of positive ground flashes is apparently not supported by the tilted dipole hypothesis, being necessary to search for other mechanisms to explain it. Although this observation cannot be considered as usual in this region, it clearly indicates that the flash polarity should depend on many factors besides the season. These factors should be probably related to the geographical location and the meteorological environment.

KeyWords Plus:

WINTER THUNDERSTORMS, ELECTRIC-FIELDS, CONDUCTIVITY, IONOSPHERE, COAST

Addresses:

PINTO IRCA, INST NACL PESQUISAS ESPACIAIS, S JOSE CAMPO, SP, BRAZIL.
COMPANHIA ENERGET MINAS GERAIS, BELO HORIZON, MG, BRAZIL.

Publisher:

AMER GEOPHYSICAL UNION, WASHINGTON

IDS Number:

JZ602

ISSN:

0148-0227

Article 7 of 14

◀ PREVIOUS

NEXT ▶

▲ SUMMARY

Copyright © 2001 Institute for Scientific Information

A COORDINATED STUDY OF A STORM SYSTEM OVER THE SOUTH AMERICAN CONTINENT
2. LIGHTNING-RELATED DATA

I. R. C. A. Pinto, O. Pinto, Jr., and R. B. B. Gin

Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil

J. H. Diniz, R. L. de Araújo, and A. M. Carvalho

Companhia Energética de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil

Abstract. On December 13, 1989, a coordinated campaign was conducted in Brazil to study the electrical signatures associated with a large storm system over the South American continent. Balloon-borne VLF electric field data showed more than a hundred lightning-related stratospheric vertical electric field (sferics) signatures during approximately 6 hours. The sferic signatures were characterized by a rapid transient with peak amplitudes exceeding 7 V/m which would be expected by the removal of positive charge below followed by a slow recovery. This signature indicates that the lightning strokes experienced by the balloon were either cloud discharges or positive ground discharges. The peak amplitudes indicate that the positively charged region is of the order of tens of coulombs. The recovery curves are quite variable, reflecting the complex nature of the propagating phenomena in the atmosphere. A lightning position and tracking system (LPATS) network recorded 326 ground strokes at distances less than 100 km of the balloon. In contrast with previous observations during the summer in the northern hemisphere it was found that most lightning flashes (60%) were positive. In addition, only a small fraction of them occurred simultaneously with a balloon sferic signature, indicating that most balloon sferics were a result of cloud discharges. An analysis of wind and temperature data during the event showed that the predominance of positive ground flashes is apparently not supported by the tilted dipole hypothesis, being necessary to search for other mechanisms to explain it. Although this observation cannot be considered as usual in this region, it clearly indicates that the flash polarity should depend on many factors besides the season. These factors should be probably related to the geographical location and the meteorological environment.

Introduction

In general, the beginning of strong electrification in thunderstorms is associated with a rapid vertical and horizontal development of the cloud. When the electrical stresses within

the cloud become sufficiently large, dielectric breakdown and lightning occur. The study of lightning is an important part of thunderstorm investigations. Besides being an indicator (or even modifier) of the storm's electrification, lightning is of interest as a phenomenon in itself. The rapid electric field changes associated with the phenomenon can provide information on the magnitude of the electrical charges deposited by the lightning and, if measurements are made at several places, on the location of these charges. Measurements of the amount of charge transferred per lightning are quite variable, depending on many factors such as geographical location and meteorological and seasonal circumstances. Values ranging from 0.3 C to 100 C for intracloud discharges, or simply cloud discharges [see Orville, 1982], and from 1 C to 400 C for cloud-to-ground discharges, or simply ground discharges [see Ogawa, 1982], have been reported.

Besides the charge transferred, there are many other parameters which characterize the properties of lightning discharges. Such parameters vary over a wide range, depending on several factors such as season, latitude, and so on. Although often more common the cloud discharges have been studied much less than the ground discharges, being difficult to describe a common knowledge of them. In turn, there is very extensive information about ground discharges. Typically, the ground discharge is made up of one or more intermittent partial discharges. A total lightning discharge whose time duration is about 0.5 s is called a flash, and each component whose luminous time duration is measured in tenths of milliseconds is called a stroke. Usually the first stroke, called return stroke, has a typical peak current of 20-30 kA, lowering to the ground a negative charge. This type of stroke is called a negative stroke and the corresponding flash a negative flash. There is another type of flash, lowering a positive charge to the ground, called positive flash. Due to the availability of large-scale networks for ground lightning location [Orville et al., 1983], positive flashes have received particular attention in the last decade, being recorded in several places around the world [Beasley, 1985]. They are mostly single-stroke flashes [Uman, 1985; Beasley, 1985; Orville et al., 1987] with electric field waveforms very similar to those of negative flashes [Beasley, 1985]. In general, positive flashes are less common. However, there have been some

Copyright 1992 by the American Geophysical Union.

Paper number 92JD01486.
0148-0227/92/92JD-01486\$05.00

observations of winter thunderstorms in Japan [Takeuti et al., 1978; Brook et al., 1982] and in the eastern United States [Orville et al., 1987] reporting a predominance of positive flashes. Such observations have been satisfactorily explained by the tilted dipole hypothesis suggested first by Brook et al. [1982]. This hypothesis assumes that the cloud charge distribution is largely shifted from the vertical. The horizontal displacement of the upper positive charge is attributed to vertical wind shear. Recently, Takagi et al. [1986] and Engholm et al. [1990] showed that the percentage of positive flashes, in addition to be strongly correlated with the vertical wind shear (that is, the vertical shear in the horizontal wind), is also well correlated with the height of the positive and negative charges. On the other hand, Williams [1989] has discussed in some detail the possible role played by the positive charge beneath the negative charge on the occurrence of positive flashes. This is frequently referred to as the inverted dipole hypothesis. In spite of the process responsible for the predominance of positive flashes in the observations cited above, they give support to the idea that the charge distribution in different meteorological environments may favor one polarity over the other.

Electric field signatures of lightning in the stratosphere (sferics) at middle and high latitudes have been reported by several authors [Benbrook et al., 1974; Burke, 1975; Holzworth, 1981; Holzworth and Chiu, 1982; Holzworth et al., 1985; Hu et al., 1989]. Based on these works, it is found that the electrostatic part of most sferics, as seen from the stratosphere, lasts for a few seconds and has the sense which would appear from the rapid removal of positive charge below followed by slower recovery to prestroke values following a quasi-exponential curve. This sense indicates that the sferics are due to either cloud discharges or positive ground discharges. Considering that cloud discharges are much more common than positive ground discharges, it is probably that these signatures should be due to cloud discharges. No conclusive evidence of a balloon signature due to a positive ground discharge has been reported yet. Signatures having the sense which we would expect for negative ground discharges have been rarely recorded. This relative rare occurrence perhaps can be explained invoking different propagation conditions to stratosphere associated with these discharges. In turn, the time constant of recovery and the amplitude of the balloon signatures are quite variable, depending on source location, propagation characteristics, and altitude. Holzworth and Chiu [1982] have shown that in one case, the sferic time constants were shorter by about a factor of 2 than the ambient time response, attributing such a factor to propagation effects. Holzworth et al. [1985] measured amplitudes of a few tens of millivolts per meter at a distance of 96 km of a thunderstorm. Burke [1975] and Hu et al. [1989] measured 500 mV/m at distances of 22 km and 50 km, respectively. Benbrook et al. [1974] and Holzworth and Chiu [1982] measured amplitudes larger than 1 V/m at distances less than 20 km (in the second case, the distance was estimated

from the ratio between the vertical and the horizontal electric field; see Pinto et al. [1988] for details about this procedure). Although the amplitude of the balloon signature also depends on the storm intensity, the results above can give some indication about the expected values at different distances to the storm. At the same time, they indicate that most balloon signatures come from discharges at distances less than 150 km of the balloon.

This paper reports a detailed presentation of the lightning-related stratospheric electric field data (sferics) obtained in a coordinated campaign conducted in Brazil on December 13, 1989, to study the electrical signatures associated with a large storm system. Simultaneous lightning-related ground-based data are also presented. An overview of the campaign, including quasi-DC stratospheric electric field data, has been addressed by Pinto et al. [this issue], hereinafter referred to as part 1.

Balloon Data

More than a hundred lightning-related stratospheric vertical electric field (sferics) signatures were recorded during approximately 6 hours of a balloon flight launched from Cachoeira Paulista at 0920 UT on December 13, 1989, to study the electrical signatures associated with a large storm system over Brazil. Figure 1 is a semiquantitative cartoon showing balloon track versus storm position. During the flight the balloon moved westward approaching to a storm front and a thunderstorm line. Around 1600 UT the balloon was at a distance less than 25 km of the thunderstorm line. At that time, the thunderstorm line already had cells with tops above 7 km. In the next hours the tops increased up to 14 km. Near the end of the flight the balloon encountered a storm front containing clouds with tops at the tropopause. An overview of the campaign, including a discussion about the instrumentation, has been addressed in part 1. Figures 2 to 4 show examples of sferic signatures at two different altitudes (approximately 30 km at Figure 2 and 27 km at Figures 3 and 4). The signatures were characterized by a rapid transient with peak amplitudes from a few

Fig. 1. Semi quantitative plot showing balloon location versus storm location on December 13, 1989.

Fig. 2a. Balloon sferic signatures recorded around 30 km on December 13, 1989, at 1720 UT.

Fig. 2b. Same as in Figure 2a, at 1722 UT.

Fig. 3a. Balloon sferic signature recorded around 27 km on December 13, 1989, at 2015 UT.

hundreds of millivolts per meter to more than 7 V/m, followed by a slower return to prestroke values lasting for about 2 to 4 s around 27 km and for about 20 to 30 s around 30 km. The signatures had also the sense which would appear from the removal of positive charge below, indicating that the lightning flashes experienced by the balloon were either cloud discharges or positive ground discharges. Signatures related to negative ground discharges were not observed. The peak amplitudes of the sferics were in general in excess of 2 V/m. The variation in the vertical electric field associated with the complex structure and dynamics of the storm did not allow one to identify low-amplitude sferics due to distant flashes. In general, the characteristics described above are quite similar to data obtained near thunderstorms at middle and high latitudes [Holzworth, 1981; Holzworth and Chiu, 1982; Holzworth et al., 1985]. Figures 2a, 3a, and 4a also show exponential fits to the data. In the case of Figure 2a (at 30.6 km) we found that the curve can be reasonably fit by two different exponentials, with recovery time constants of 0.60 and 6.30 s (the same behaviour is also the case for Figure 2b). In the case of Figure 3a (at 27.3 km) the curve is tentatively fitted (although not very well) by just one exponential with a time constant of 0.36 s. Finally, in the case of Figure 4a (also at 27.3 km) the curve is well fitted by an exponential with a time constant of 0.10 s. Basically, all balloon

lightning signatures followed one of these three different behaviours.

Lightning Position and Tracking System Data

The lightning position and tracking system (LPATS) is a computer-based system for locating lightning strokes, operating at several different countries. In Brazil the Companhia Energética de Minas Gerais (CEMIG) has operated, since the end of 1988, a 4-station network that uses the BRASILSAT satellite TV signal for network receiver time synchronization. Each station measures the electric field radiated from the discharge in a broadband spectrum of bandwidth 2 kHz to 500 kHz. The stations are located at Volta Grande (21°46'S, 42°32'W), Hydroelectric of Tres Marias (19°00'S, 45°20'W), Lavras (21°20'S, 45°00'W), and Ipatinga (19°30'S, 42°32'W), covering a large area (about 800.00 km²), which included that covered by the balloon flight. The use of a BRASILSAT signal for time synchronization gives a few hundred nanoseconds time accuracy allowing one to obtain very good accuracy in the stroke location. In the region of the balloon flight the strokes were located with an accuracy of about 2 km and an efficiency estimated to be near 80%. For practical and technical reasons the computer system is set up

Fig. 3b. Same as in Figure 3a, at 2024 UT.

so that only ground strokes are recorded. Further details about the LPATS can be found in the work of Bent and Lyons [1984] and Araujo et al. [1990].

Figure 5 shows a map with the location of 326 ground strokes recorded by the LPATS network between 0900 UT and 2030 UT on December 13, 1989, at distances less than approximately 100 km of the balloon position relative to the balloon trajectory. In the same period, 731 strokes were recorded within about 300 km of the balloon position.

Discussion

Balloon Data

We have conducted a detailed analysis of more than a hundred balloon sferic signatures. Most of them have amplitudes less than 7 V/m and the sense which corresponds to either cloud discharges or positive ground discharges. This fact is in agreement with past observations [Holzworth and Chiu, 1982] which describe this sense as the most common one. On the other hand, we did not observe sferic signatures with precursors, such as those observed by Holzworth and Chiu [1982] and Holzworth et al. [1985].

Figure 4 shows two examples of unusual large sferic signatures with amplitudes estimated (by

Fig. 4a. Example of large sferic signature measured at balloon altitudes on December 13, 1989.

Fig. 4b. Same as in Figure 4a.

Fig. 5. Map showing the location of 326 ground strokes recorded by the lightning position and tracking system (LPATS) network between 0900 UT and 2030 UT on December 13, 1989, which occurred at distances less than approximately 100 km of the balloon position. Also shown is the approximate balloon trajectory.

simple extrapolation) around 14–15 V/m. Figure 6 shows the storm location (based on radar data) near the balloon position at 2000 UT, just a few minutes before the large signatures recorded in Figure 4. From this figure we can assume that the large signatures came from an active region approximately 15 km from the balloon. Considering that in the atmosphere within a range of around 30 km from a lightning source the dominating field is electrostatic [Burke, 1975], it is possible to estimate the approximate charge destroyed in these flashes by the same calculation used in part 1 to determine the main static charge concentrations inside the cloud. It was found that the amount of discharge is of the order of tens of coulombs (the exact value depends on the altitudes of the charge centers and the conductivity profile). It indicates that very large thunderstorms were present in the storm system.

Fig. 6. Storm location near the balloon position at 2000 UT.

We have analyzed the occurrence time of the discharges as measured at balloon altitude and on the ground. We found that only a small fraction occurred simultaneously. In order to explain this fact we tried to search for a possible time lag between the on-board balloon time and the CEMIG time. Figure 7 shows a comparison between the occurrence time of lightning signatures recorded at balloon altitude and on the ground between 2009 UT and 2021 UT. Also indicated in Figure 7 is the balloon distance at the time of each ground event and the occurrence time of the large sferic signatures shown in Figure 4. From the detailed analysis of this figure we found that if a time lag exists, it is less than 1 s, and it could not explain the time difference between the events recorded at balloon altitude and on the ground. On the other hand, the amplitudes of the sferics indicate (see discussion in the introduction) that they probably came from thunderstorms close to the balloon (distances less than 50 km, or less). Considering only the flashes which occurred at distances less than 50 km of the balloon, we have found that the number of balloon signatures (174) is about 6 times larger than the number of positive ground flashes (27) and about 4 times larger than the total number of ground flashes. The first result led us to conclude that most balloon sferics were a result of cloud discharges. The second result indicates that the cloud flashes were about 80% of the total flashes measured in agreement with what is expected at low latitudes [Ogawa, 1982]. We have investigated the form of the sferics for the events measured simultaneously (within 1 s) at balloon altitude and on the ground, in order to identify a signature related to a positive ground flash. However, no differences were found. So, it is possible that such events had been due to simultaneous cloud discharges. Figure 8 shows a comparison between the VLF electric field background at 2 kHz measured at balloon altitude (with a time resolution of 0.25 s) and the percent number (in 10-min steps) of strokes recorded by the LPATS network with respect to the

the altitude or with the position relative to the storm in association with the storm system. Evidence on the influence of thunderstorms on the conductivity in the stratosphere have been reported by several authors [Holzworth et al., 1986; Pinto et al., 1988; Hu et al., 1989].

LPATS Data

The main characteristics of the flashes recorded by the LPATS network during the balloon flight on December 13, 1989 at distances less than 300 km of the balloon position are shown in Figures 10 and 11. Figure 10 shows that most of the flashes (60%) were positive. Also, it shows that a very low percent (~1%) of flashes were of (possible) dual (bipolar) polarity. Figure 11 shows the distribution of positive and negative flashes as a function of the number of strokes. We found that 56% of negative and 93% of positive flashes were single-stroke flashes. While the multiplicity of positive flashes is in agreement with other observations in the northern hemisphere, the multiplicity of negative flashes was less than the average value (three) generally reported by observations in the northern hemisphere.

The predominance of positive flashes in the summer is in contrast with most of previous observations in the northern hemisphere, where it occurs in the winter. In order to explain our observations in terms of the tilted dipole hypothesis we have determined the altitude of the -10°C isotherm from a number of weather stations and computed the average vertical wind shear between the cloud top and this altitude. We found an average value of about $2 \text{ ms}^{-1} \text{ km}^{-1}$ for the vertical shear in the horizontal wind and an altitude of about 6.5 km to the -10°C isotherm. The comparison of these values with the results obtained by Takagi et al. [1986] shows that our observations cannot be supported by the

Fig. 10. Percentage of positive, negative, and bipolar flashes recorded during the balloon flight on December 13, 1989, at distances less than 300 km of the balloon position.

Fig. 11a. Distribution of positive flashes as a function of the number of strokes.

Fig. 11b. Same as in Figure 11a, for negative flashes.

hypothesis above, being necessary to invoke other mechanisms in order to explain them. Although the predominance of positive flashes may be unusual in Brazil, it clearly indicates that the flash polarity should depend on many factors besides the season. These factors should probably be related to the geographical location and the meteorological environment. Considering the scarcity of data in the southern hemisphere, the data presented in this work can even suggest a possible annual (no seasonal) variation in the global percentage of positive flashes with a maximum in January, though no explanation for this is known.

The results about the flash polarity show a general agreement with other observations [e.g., Orville et al., 1987]. The positive flashes were mostly single-stroke flashes, while the percentage of one-stroke negative flashes was similar to that observed in the summer in the northern hemisphere. The maximum number of strokes for a negative flash was six.

Finally, from the analysis of the relative position of positive and negative flashes with respect to the storm no evidence of a bipole pattern, such as that suggested by Orville et al. [1988], was observed.

Conclusions

In this paper we have analyzed the lightning-related data in association with a mesoscale convective system over the South American continent. The main conclusions of the study were:

1. A calculation based on a simple electrostatic model estimated that charges of the order of tens of coulombs were destroyed in some flashes during this event.

2. Most flashes measured at the balloon altitude were cloud flashes.

3. Balloon signatures showed different decay curves, sometimes fitted by one exponential curve, sometimes by two. This fact seems to be related to different propagation conditions between lightning and balloon position. To our knowledge this is the first time that stratospheric electric field data show such behaviour.

4. We have measured a predominance of positive flashes (about 60%) in association with a mesoscale convective system in the South American continent. From the analysis of the wind and temperature data and assuming that the results of Takagi et al. [1986] are valid in our case, we found that such predominance cannot be supported by the tilted dipole hypothesis, being necessary to invoke other unknown mechanisms to do that.

As a final remark we would like to suggest that the electrical structure of thunderstorms in the South American continent may have some peculiarities. This assumption is based on the absence of intensification of the stratospheric electric field in the fair weather orientation (shown in part 1) and on the predominance of positive flashes (shown in this paper).

Acknowledgments. This work was partially supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo-FAPESP. The authors would like to pay homage to Maria Auxiliadora M.A. Bonafé (in memoriam).

References

- Araújo, R. L. de, J. H. Diniz, L. C. Cherchiglia, A. J. Ericsson, and H. J. Geldenhuys, Applied Research in an intertropical mountainous Area, paper presented at the First International Conference on Power Distribution, The Institute of Electrical and Electronics Engineers, Inc., Belo Horizonte, Minas Gerais, Brazil, 1990.
- Baginski, M. E., L. C. Hale, and J. J. Olivero, Lightning-related fields in the ionosphere, *Geophys. Res. Lett.*, **15**, 764-767, 1988.
- Beasley, W., Positive cloud-to-ground lightning observations, *J. Geophys. Res.*, **90**, 6131-6138, 1985.
- Benbrook, J. R., J. W. Kern, and W. R. Sheldon, Measured electric field in the vicinity of a thunderstorm system at an altitude of 37 km, *J. Geophys. Res.*, **79**, 5289-5294, 1974.
- Bent, R. B., and W. A. Lyons, Theoretical evaluations and initial operational experiences of LPATS to monitor lightning ground strikes using a time-of-arrival technique, paper presented at the Second International Conference on Atmospheric Electricity, American Meteorological Society, Boston, Mass., 1984.
- Brook, M., M. Nakano, P. Krehbiel, and T. Takeuti, The electrical structure of the Hokuriku winter thunderstorms, *J. Geophys. Res.*, **87**, 1207-1215, 1982.
- Burke, H. K., Large scale atmospheric electric fields: Comparisons with balloon data, Ph.D. thesis, Rice Univ., Houston, Tex., 1975.
- Dejnakarintra, M., and C. G. Park, Lightning-induced electric fields in the ionosphere, *J. Geophys. Res.*, **79**, 1903-1910, 1974.
- Engholm, C. D., E. R. Williams, and R. M. Dole, Meteorological and electrical conditions associated with positive cloud-to-ground lightning, *Mon. Weather Rev.*, **118**, 470-487, 1990.
- Hale, L. C., Experimentally determined factors influencing electrical coupling mechanisms, in *Weather and Climate Responses to Solar Variations*, edited by B. M. McCormac, Colorado Associated University Press, 1983.
- Holzworth, R. H., High latitude stratospheric electrical measurements in fair and foul weather under various solar conditions, *J. Atmos. Terr. Phys.*, **43**, 1115-1125, 1981.
- Holzworth, R. H., and Y. T. Chiu, Sferics in the stratosphere, in *Handbook of Atmospheric*, vol. 2, CRC Press, Boca Raton, Fla., 1982.
- Holzworth, R. H., M. C. Kelley, C. L. Siefring, L. C. Hale, and J. D. Mitchell, Electrical measurements in the atmosphere and the ionosphere over an active thunderstorm, 2, Direct current electric field and conductivity, *J. Geophys. Res.*, **90**, 9824-9830, 1985.
- Holzworth, R. H., K. W. Norville, P. M. Kintner, and S. P. Fowl, Stratospheric conductivity variations over thunderstorms, *J. Geophys. Res.*, **91**, 13,257-13,263, 1986.
- Hu, Hua, R. H. Holzworth, and Y. Q. Li, Thunderstorm-related variations in stratospheric conductivity measurements, *J. Geophys. Res.*, **94**, 16,429-16,435, 1989.
- Ogawa, T., The lightning current, in *Handbook of Atmospheric*, vol. 1, CRC Press, Boca Raton, Fla., 1982.
- Orville, R. E., Lightning detection from space, in *Handbook of Atmospheric*, vol. 2, CRC Press, Boca Raton, Fla., 1982.
- Orville, R. E., R. W. Henderson, and L. F. Bosart, An east coast lightning detection network, *Bull. Am. Meteorol. Soc.*, **64**, 1029-1037, 1983.
- Orville, R. E., R. A. Weisman, R. B. Pyle, R. W. Henderson, and R. E. Orville, Jr., Cloud-to-

- ground lightning flash characteristics from June 1984 through May 1985, J. Geophys. Res., 92, 5640-5644, 1987.
- Orville, R. E., R. W. Henderson, and L. F. Bosart, Bipole patterns revealed by lightning locations in mesoscale storm systems, Geophys. Res. Lett., 15, 129-132, 1988.
- Pinto, I. R. C. A., O. Pinto, Jr., W. D. Gonzalez, S. L. G. Dutra, J. Wygant, and F. S. Mozer, Stratospheric electric field and conductivity measurements over electrified convective clouds in the South American region, J. Geophys. Res., 93, 709-715, 1988.
- Pinto O., Jr. I. R. C. A. Pinto, R. B. B. Gin, O. Mendes Jr., and W. D. Gonzalez, A coordinated study of a storm system over the South American continent, 1, Weather information and quasi-DC stratospheric electric field data, J. Geophys. Res., this issue.
- Takagi, N., T. Takeuti, and T. Nakai, On the occurrence of positive ground flashes, J. Geophys. Res., 91, 9905-9909, 1986.
- Takeuti, T., M. Nakano, M. Brook, D. J. Raymond, and P. Krehbiel, The anomalous winter thunderstorms of the Hokuriku coast, J. Geophys. Res., 83, 2385-2394, 1978.
- Uman, M. A., Lightning return stroke electric and magnetic fields, J. Geophys. Res., 90, 6121-6130, 1985.
- Williams, E. R., The tripole structure of thunderstorms, J. Geophys. Res., 94, 13,151-13,167, 1989.
-
- R. L. de Araújo, A. M. Carvalho, and J. M. Diniz, Companhia Energética de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.
- R. B. B. Gin, I. R. C. A. Pinto, and O. Pinto, Jr., Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil.

(Received September 12, 1991;
 revised June 14, 1992;
 accepted June 22, 1992.)