A comparative analysis of lightning data from lightning networks and LIS sensor in the North and Southeast of Brazil

O. Pinto Jr., I. R. C. A. Pinto, and H. H. de Faria

Atmospheric Electricity Group - Brazilian Institute of Space Research (INPE), Brazil

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[1] Intracloud and cloud-to-ground (CG) lightning data in the North and Southeast regions of Brazil are compared based on observations from 01 October 1999 to 13 April 2000. The observations were made by ground networks and the Lightning Imaging Sensor (LIS) on board the TRMM satellite. For the whole period of observation, a detailed comparative analysis indicates that the cloud-to-ground lightning activity in the North region is about 20% higher than that in the Southeast for a similar size area, while the percentage of intracloud flashes is almost the same in both regions (~60–65%). On a 49-day basis (to avoid the local time bias in the LIS data), the same analysis indicates that the lightning activity recorded by LIS is representative of the CG lightning activity detected by the lightning networks, either in the same time and space seen by the satellite sensor, or in the area of the study. It was also found that the percentage of positive CG flashes in the North region is correlated to the percentage of intracloud flashes. *INDEX TERMS:* 3324 Meteorology and Atmospheric Dynamics: Lightning; 3314 Meteorology and Atmospheric Dynamics: Convective processes. **Citation:** Pinto, O., Jr., I. R. C. A. Pinto, and H. H. de Faria, A comparative analysis of lightning data from lightning networks and LIS sensor in the North and Southeast of Brazil, *Geophys. Res. Lett.*, *30*(2), 1073, doi:10.1029/2002GL016009, 2003.

1. Introduction

[2] Brazil is the largest tropical country of the world and, in consequence, has a great amount of lightning activity. Based on meteorological satellite data, it is known that two of the main regions of occurrence of thunderstorms are the North and the Southeast regions. However, unlike in the United States [*Orville and Silver*, 1997; *Orville and Huffines*, 1999], long-term lightning network information about the cloud-to-ground (CG) lightning distribution has been obtained only in the Southeast region [*Pinto et al.*, 1992, 1999; *Pinto and Pinto Jr.*, 2002; *Pinto Jr. et al.*, 1992, 1996, 1999, 2002; *Pinto Jr. and Pinto*, 2000]. In 1999, an independent lightning network was installed in the North region through a collaboration program between the Brazilian Institute of Space Research (INPE) and the NASA Marshall Space Flight Center (MSFC) [*Blakeslee et al.*, 1999]. The information in the North region is the first to characterize the lightning activity in the Amazon base.

[3] In this paper, the results obtained by these two networks are compared with the information obtained by the Lightning Imaging Sensor (LIS). The period of analysis is from 01 October 1999 to 13 April 2000, the first warm season after the installation of the network in the North region of the country. Such a period was chosen to avoid gaps associated with technical problems and/or configuration changes in the network data.

2. Lightning Data

[4] The first observations related to the lightning activity in Brazil were performed in the beginning of the 1960s, when the keraunic level, that is, the number of days per year on which thunder is heard at a given location, began to be reported at different parts of the country. These observations covered three decades and provided the earliest information for the whole country. Based on these observations, it was concluded that in most parts of Brazil thunderstorms occur in more than 50 days per year, with a large fraction of the country experiencing thunderstorms in more than 100 days per year. The maximum value of 140 thunderstorm days per year apparently occurs in the Amazon region.

[5] At the end of the 1980s, the first lightning observations in Brazil using a ground network were made in the Southeast region. During this study, the lightning network in the Southeast was composed of 14 sensors (4 Impact T-141, 4 LPATS-III and 6 LPATS-IV sensors). The location of these sensors and the region of study (from 14°S to 24°S of latitude and from 42°W to 52°W of longitude) are shown in Figure 1. The estimated detection efficiency of the network in the region of study was assumed to be 80%. Only positive flashes with peak current above 15 kA were considered in this study to avoid a possible contamination by intracloud flashes.

[6] In 1999, a four T-141 ES Impact-sensor lightning network was installed in the North region of the country through a collaboration program between INPE and NASA [*Blakeslee et al.*, 1999]. The location of these sensors and the region of study (from 6°S to 16°S of latitude and from 57°W to 67°W of longitude) are also shown in Figure 1. Although there are fewer sensors in the North region, their higher sensitivity allow us to consider the same estimated detection efficiency (80%) for a region with similar area. It is also assumed the threshold of 15 kA for positive flashes as above.

[7] After 1995, with the new technology of optical sensors on board orbiting satellites, other methods to detect the lightning activity in Brazil became available [*Christian et al.*, 1999]. In 1997, the Lightning Imaging Sensor (LIS), the second sensor of this new generation of sensors, was launched on board the TRMM satellite in a lower altitude orbit than the previous sensor (the Optical Transient Detector – OTD). When the satellite sensors pass over Brazil, however, they are subjected to the influence of the South

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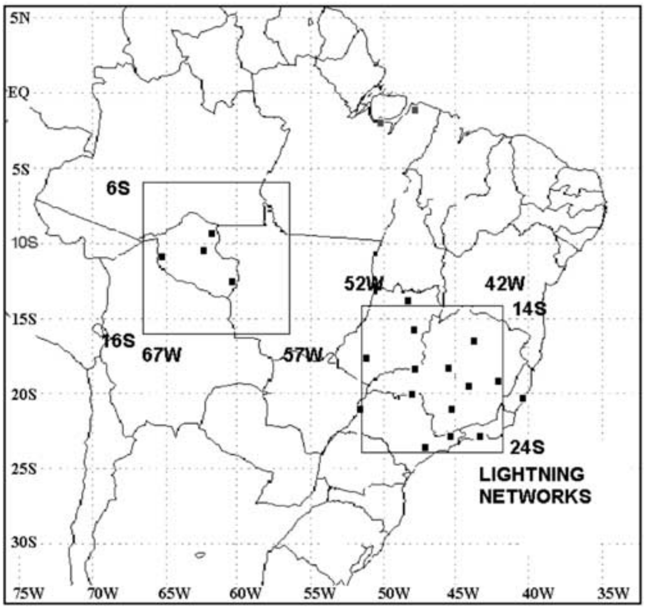

Figure 1. Map of Brazil, indicating the location of the lightning sensors of the two networks and the regions considered in this study.

Atlantic magnetic anomaly (SAMA), a large region covering part of South America and Atlantic ocean, where the Earth's magnetic field has its lowest intensity [for a review, see *Pinto Jr.*, 1993 and references therein]. The energetic charged particles from the inner radiation belt in the SAMA may produce pulses in the sensor output, which may be confused with lightning events. Considering that the core of the SAMA is presently in the South region of Brazil and, in consequence, closer to the Southeast region than the North region, some difference in the influence of the SAMA on the LIS data in both regions may be expected. The effect of the SAMA on the LIS results, however, is expected to be small and it will be neglected in this study. A more detailed study of the influence of the SAMA on the LIS data is currently being made by the MSFC group. In addition, due to the lack of discrimination between cloud-to-ground and cloud flashes, the LIS observations should be seen as representing the total lightning activity. Another aspect in the LIS data that should be considered is its diurnal bias. In order to avoid this sampling limitation, the comparative analysis presented in this paper is based on data blocks (or windows) of 49 days that match the natural precession cycle of the satellite. Four windows were considered: 01 Oct. 1999 to 18 Nov. 1999 (W1), 19 Nov. 1999 to 06 Jan. 2000 (W2), 07 Jan. 2000 to 24 Feb. 2000 (W3), and 25 Feb. 2000 to 13 Apr. 2000 (W4). In each window the entire local time cycle is sampled evenly. A comparison between the LIS data with the network data gives an opportunity to estimate the intracloud lightning activity in the North and Southeast regions. In this study, the detection efficiency of the LIS sensor was assumed to be 90% in both regions (R. Blakeslee, private communication). We assume that a possible geographic variability in the LIS detection efficiency in both regions (if any) is small, so that we can neglect its effect on the results. Such variability might occur in association with a difference in the storm optical depth in the two regions [*Boccippio et al.*, 2001]. Nevertheless, there is no reason to believe that a significant difference exists. We also assume that any differences from the intracloud and CG LIS detection efficiency can be neglected [*Goodman et al.*, 1988]. Recent results based on a limited case study [*Thomas et al.*, 2000], however, have indicated that the CG detection efficiency may be lower than the intracloud efficiency. The influence of a possible difference in the intracloud and CG detection efficiency on our results will be discussed later.

3. Results

[8] Figure 2 shows the CG lightning activity in the North and Southeast regions during the period of study sorted in four 49-day windows. They show different variations during the period of study. The activity in the North region is great in the first two windows, while in the Southeast region it is great in the last two windows, probably indicating that they are related to different meteorological phenomena. The average 49-day window activity for the whole period of observation in the North region (~386,000 flashes) is about 20% higher than that in the Southeast (~328,000) for approximately the same area. This difference is apparently significant, although it could be explained assuming that the estimated detection efficiency in the North region would be larger than that in the southeast by 10%. Such a possibility, however, seems not reasonable considering the network characteristics in both regions.

[9] Figure 3 shows the 49-day window distribution of the number of flashes recorded by LIS in the North and Southeast regions. Despite of the large variations, the average 49-day window activity for the whole period of observation in both regions is amost the same (~2200 flashes).

[10] Figure 4 shows a comparison between the number of flashes recorded by LIS and the lightning networks in each 49-day window for the same time intervals and locations of the TRMM orbits in the (a) North region and (b) Southeast region. The network data were subsetted to include only CG flashes occurring within the LIS overpasses. The variations in both regions follow the same pattern, indicating that the LIS observations are representative of the CG lightning activity in both regions on a 49-day basis.

[11] Figure 5 shows a comparison between the number of flashes in each 49-day window recorded by LIS and by the

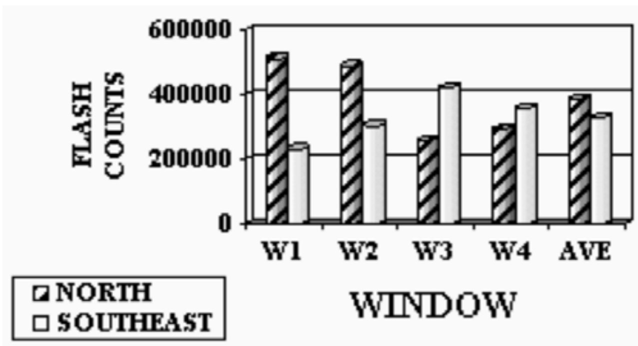

Figure 2. The CG lightning activity in each of 49-day window in the North and Southeast regions. The last column corresponds to the average activitiy for the whole period of observation in both regions.

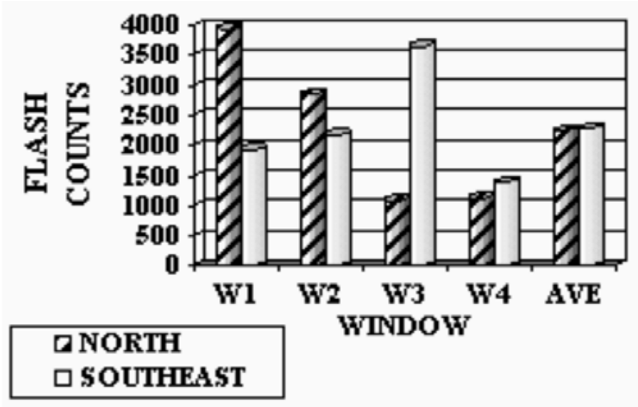

Figure 3. The lightning activity recorded by LIS in each of 49-day window in the North and Southeast regions. The last column corresponds to the average activitiy for the whole period of observation in both regions.

lightning networks for the whole area studied in the (a) North region and (b) Southeast region. Again, a significant agreement between the LIS and network data is evident.

[12] Figure 6 shows the percentage of intracloud flashes in the North and Southeast regions computed by comparing the CG ground lightning data recorded during the LIS pass over the regions with LIS data. The average percentage of intracloud flashes for the whole period of observation is 56% in the North region and 61% in the Southeast region. They correspond to intracloud/CG flash ratios of 1.3 and 1.6, respectively. These ratios are in reasonable agreement with the values reported for this range of latitude [*Mackerras et al.*, 1998]. This percentage, however, is dependent on the assumed detection efficiency of the networks, as well as on the assumption that the LIS detection efficiency for intracloud and CG flashes are equal. For instance, if we

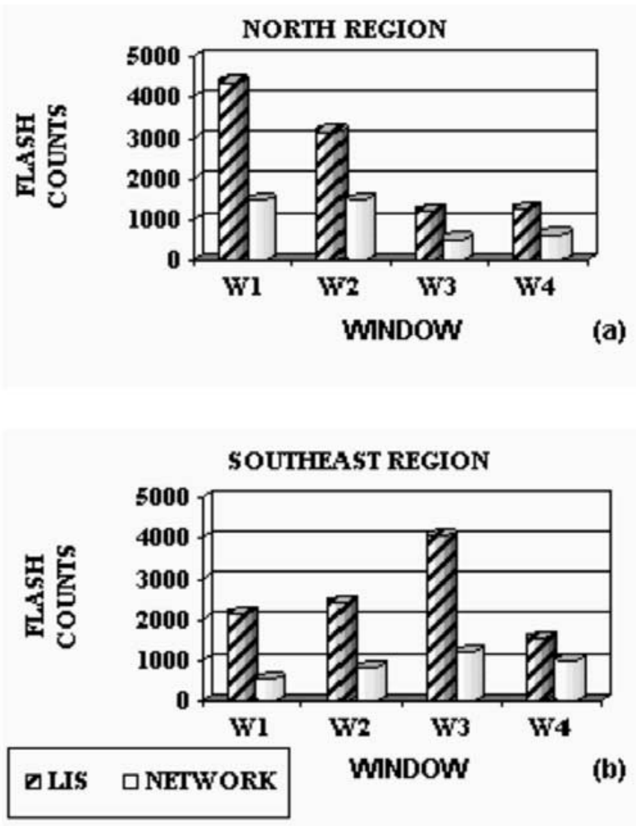

Figure 4. Comparison between the number of flashes recorded by LIS and by the lightning networks in each 49-day window for the same period and location of the TRMM orbits: (a) North region and (b) Southeast region.

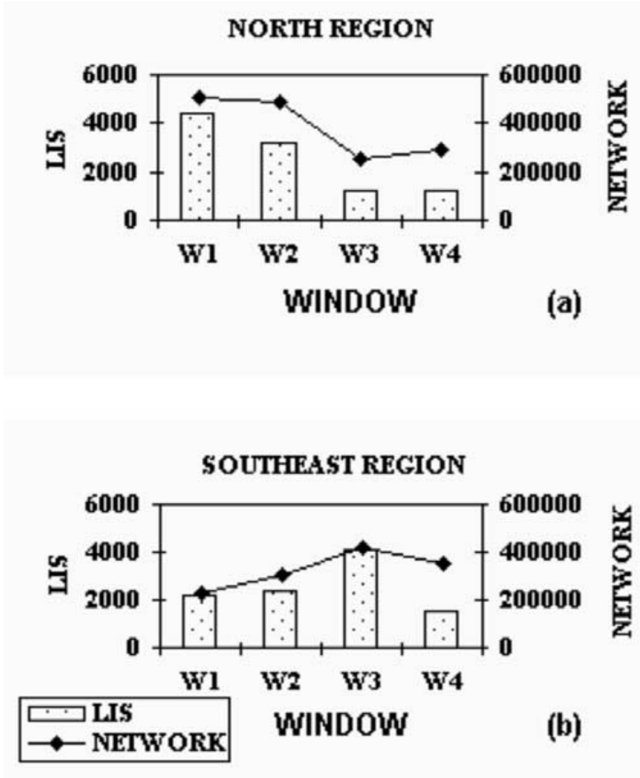

Figure 5. Comparison between the number of flashes recorded by LIS and the number of flashes recorded by the lightning networks in each 49-day window for the whole area of study: (a) North region and (b) Southeast region.

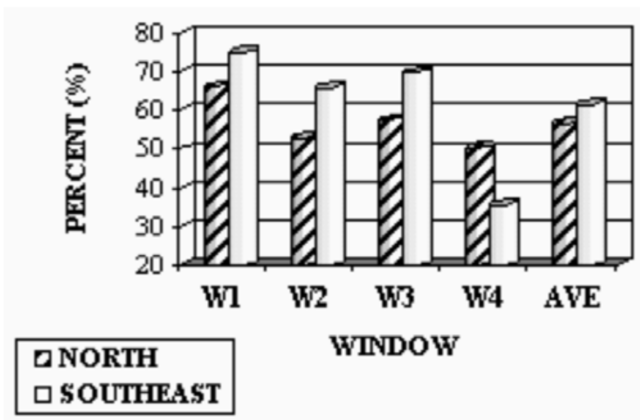

Figure 6. Percentage of intracloud flashes in each 49-day window for the North and Southeast regions. The last column corresponds to the average percentage for the whole period of observation in both regions.

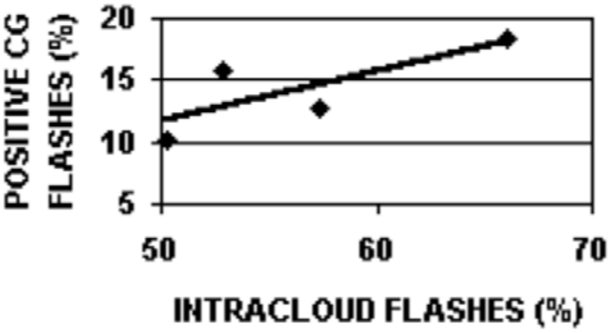

Figure 7. Percentage of intracloud flashes versus the percentage of CG positive flashes for the whole area of study in the North region.

assume the LIS detection efficiency of CG flashes inferred by *Thomas et al.* [2000] (60%), maintaining the intracloud detection efficiency equal to 90%, the average percentage of intracloud flashes would be 62% and 67%, respectively.

[13] Finally, Figure 7 shows the percentage of intracloud flashes versus the percentage of positive CG flashes for the North region. It indicates that they are correlated, with a correlation coefficient of 0.79. This coefficient is not affected significantly by changing the LIS detection efficiency of CG flashes from 90% to 60%. No such correlation was found for the Southeast region. The correlation in the North region and the lack of correlation in the Southeast may result from two hypotheses: the intracloud flashes in the North region are more intense than those in the Southeast region, contaminating the positive flashes even above 15 kA, and the electrical structure of the thunderstorms in the North region is different from that in the Southeast. The second hypothesis is supported by recent results obtained by *Boccippio et al.* [2001] who have found a correlation between intracloud and positive CG flashes. They suggested that the correlation may be explained by the elevated dipole model of charge structure [*MacGorman and Nielsen*, 1991]. Assuming their suggestion is correct, we can speculate that this model occur in the North and not in the Southeast. However, it is possible that a correlation in the Southeast does exist when considering a longer time period. Clearly, more data are necessary to clarify this point.

4. Conclusions

[14] Intracloud and cloud-to-ground (CG) lightning data in the North and Southeast regions of Brazil were compared based on data obtained by lightning networks and the LIS sensor from 01 October 1999 to 13 April 2000. The observations in the North region are the first of this type obtained in the Amazon region. For the whole period of observation, a detailed comparative analysis indicates that the cloud-to-ground lightning activity in the North region is about 20% higher than that in the Southeast for a similar size area during the whole period, while the percentage of intracloud flashes is approximately the same for both regions (~60–65%). On a 49-day basis, the same analysis indicates that the lightning activity recorded by LIS is representative of the CG lightning activity detected by the lightning networks, either in the area of the study or in the same time and space seen by the satellite sensor. Finally, it was found that the percentage of positive flashes in the North region is correlated to the percentage of intracloud flashes. No such relationship was found in the Southeast.

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References

Blakeslee, R. J., J. C. Bailey, W. J. Koshak, and O. Pinto Jr., The Rondonia lightning detection network: Network description, data analysis, science objectives, and first results, Proceedings of Fall Meeting, AGU, San Francisco, Dec. 1999.

Boccippio, D. J., K. L. Cummins, H. J. Christian, and S. J. Goodman, Combined satellite-and surface-based estimation of the intracloud-cloud-to-ground lightning ratio over the continental United States, *Mon. Wea. Rev.*, *129*, 108–122, 2001.

Christian, H. J., R. J. Blakeslee, S. J. Goodman, D. A. Mach, M. F. Stewart, D. E. Buechler, W. J. Koshak, J. M. Hall, W. L. Boeck, K. T. Driscoll, and D. J. Bocippio, "The Lightning Imaging Sensor", Proceedings of the 11th International Conference on Atmospheric Electricity, pp. 746–749, Guntersville, Alabama, June 1999.

Goodman, S. J., H. J. Christian, and W. D. Rust, A comparison of the optical pulse characteristics of intracloud and cloud-to-ground lightning as observed above clouds, *J. Appl.*, 1369–1381, 1988.

MacGorman, D., and K. E. Nielsen, Cloud-to-ground lightning in a tornadic storm on 8 May 1986, *Mon. Wea. Rev.*, *119*, 1557–1574, 1991.

Mackerras, D., M. Darveniza, R. E. Orville, E. R. Williams, and S. J. Goodman, Global lightning: total, cloud and ground flash estimates, *J. Geophys. Res.*, *103*, 19,791–19,809, 1998.

Orville, R. E., and A. C. Silver, Lightning ground flash density in the contiguous United States: 1992–95, *Mon. Wea. Rev.*, *125*, 631–638, 1997.

Orville, R. E., and G. R. Huffines, Lightning ground flash measurements over the contiguous United States: 1995–97, *Mon. Wea. Rev.*, *127*, 2693–2703, 1999.

Pinto, I. R. C. A., O. Pinto Jr., R. B. B. Gin, J. H. Diniz, R. L. de Araujo, and A. M. Carvalho, A coordinated study of a storm system over the South American continent 2. Lightning-related data, *J. Geophys. Res.*, *97*(D16), 18,205–18,213, 1992.

Pinto, I. R. C. A., O. Pinto Jr., R. M. L. Rocha, J. H. Diniz, A. M. Carvalho, and A. Cazetta Filho, Cloud-to-ground lightning flashes in the southeastern Brazil in 1993, 2, Time variations and flash characteristics, *J. Geophys. Res.*, *104*(D24), 31,381–31,387, 1999.

Pinto, I. R. C. A., and O. Pinto Jr., Lightning distribution in Brazil, *J. Atmos. Solar-Terr. Phys.*, submitted, 2002.

Pinto, O., Jr., I. R. C. A. Pinto, R. B. B. Gin, and O. Mendes Jr., 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.*, *97*(D16), 18,195–18,204, 1992.

Pinto, O., Jr., "Recent research on South Atlantic Magnetic Anomaly", in *Trends in Geophysical Research*, *Research Trends*, (2), 45–54, 1993.

Pinto, O., Jr., R. B. B. Gin, I. R. C. A. Pinto, O. Mendes Jr., J. H. Diniz, and A. M. Carvalho, "Cloud-to-ground lightning flash characteristics in the southeastern Brazil for the 1992–1993 summer season", *J. Geophys. Res.*, *101*(D23), 29,627–29,635, 1996.

Pinto, O., Jr., I. R. C. A. Pinto, M. A. S. S. Gomes, A. L. Padilha, I. Vitorello, J. H. Diniz, A. M. Carvalho, and A. Cazetta Filho, Cloud-to-ground lightning in the southeastern Brazil in 1993, 1, Geographical distribution, *J. Geophys. Res.*, *104*(D24), 31,369–31,379, 1999.

Pinto, O., Jr., and I. R. C. A. Pinto, "Thunderstorms and lightning in Brazil", pp. 200, INPE Press, 2000 (in Portuguese).

Pinto, O., Jr., I. R. C. A. Pinto, J. H. Diniz, A. Cazetta Filho, A. M. Carvalho, and L. C. L. Cherchiglia, A long-term study of the lightning flash characteristics in the southeastern Brazil, *J. Atmos. Solar-Terr. Phys.*, in press, 2002.

Thomas, R. J., P. R. Krehbiel, W. Rison, T. Hamlin, D. J. Boccippio, S. J. Goodman, and H. J. Christian, Comparison of ground-based 3-dimensional lightning mapping observations with satellite-based LIS observations in Oklahoma, *Geophys. Res. Lett.*, *27*(12), 1703–1706, 2000.

H. H. de Faria, I. R. C. A. Pinto, and O. Pinto Jr., Atmospheric Electricity Group (ELAT), Brazilian Institute of Space Research, São José dos Campos, São Paulo, Brazil. (osmar@dge.inpe.br)