ACATMOS Group in Brazil and LEONA Team in South America for Collaborative Research of TLEs and HEETs in South America

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Abstract: This paper will review the main results of the different Transient Luminous Event - TLE observations performed from Brazil up to date and the research on TLEs and High Energy Emissions from Thunderstorms - HEETs performed by the Atmospheric Electrodynamical Coupling - ACATMOS group at INPE. It will introduce the Transient Luminous Event and Thunderstorm High Energy Emission Collaborative Network in Latin America - LEONA. The team unites scientists of research institutions from several countries to investigate TLEs, HEETs and related phenomena. This project is not only a potential benchmark in TLE research by creating a collaborative network in Latin America and nucleating this research locally, it is also strategic since LEONA's camera network will be able to provide extremely valuable information to fill up this gap that most satellite measurements have in the South Atlantic Magnetic Anomaly - SAMA region.

Keywords: Sprites, Transient Luminous Events, TLEs, Thunderstorms, High Energy Emissions from Thunderstorms, HEETs, South America

1 Introduction

South America is one of the most active thunderstorm regions of the world. About 20 years ago, it was discovered that thunderstorm electrical activity, in the form of lightning discharges, can excite optical transients in the upper atmosphere directly above it. These transients are collectively named Transient Luminous Events - TLEs. Transient Luminous Event is the generic term attributed to upper atmospheric effects of thunderstorm electrical activity such as sprites, ELVEs, halos, blue jets, gigantic jets and others, associated with lightning discharges Figure 1. Their optical emissions are observed in the atmosphere directly above thunderstorms using low-light level video cameras located 150-1000 km from the producing thunderstorm, either on the ground or onboard airplanes, and onboard satellites. The observations are performed at night due to the low luminosity of the phenomena (a few hundred kR to a few MR). They were serendipitously discovered in 1989 when sprites were documented for the first time [4]. Their existence reveal the electrodynamical coupling of the several atmospheric layers, including the ionized regions, i.e. ionosphere and magnetosphere.

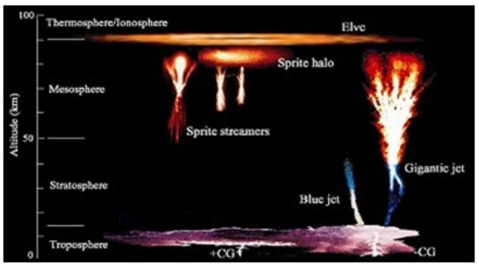

Figure 1: Illustration in scale with the main TLEs known up to date using false colors. [7]

More recently, it has been discovered that thunderstorms can also emit particles and photons with very high energy, High Energy Emissions from Thunderstorms - HEETs, adding a new component to the understanding of the atmospheric electrical coupling. Experiments onboard airplanes revealed the emission of X-rays by thunderstorms [8]. And about 10 years later, the Burst And Transient Source Experiment - BATSE, onboard the CGRO satellite, revealed the production of fast Gamma-Ray emissions, of the order of ms, with atmospheric origin [3], called Terrestrial Gamma-ray Flashes - TGFs. Current theories suggest that they originate inside thunderclouds, at 11-15 km, in association with positive intracloud (IC) discharges [15]. The TGF energy ranges is 20 keV - 100 Mev [14, 16].

Thunderstorm high energy emissions have also been detected with detectors on the ground. [9] reported X-ray emissions from negative stepped leaders, suggesting that the electrons were accelerated by Relativistic Runaway Electron Avalanche - RREA [5] and emit the X-rays by Bremsstrahlung process. [2] also detected Gamma and electrons emissions from thunderstorms with ground detectors. Their simulated energy spectra for the gamma rays reach 100 MeV, comparable to AGILE measurements [16]. Even harder to explain emissions are the neutron bursts from thunderstorm. First experimental observations of the neutrons during lightning activity were reported by [12], and lately also by [13], who proposed that they originate from fusion reactions of deuterium 2H(2H, n)3He with neutron energy E=2.45 MeV. But this source is not enough to provide the observed neutron flux [1]. They suggested that neutrons are produced in the atmosphere through photonuclear reaction when runaway electrons are observed. But [6] showed that this source is also not enough. Thus, the physical mechanism of the neutron fluxes production in the atmosphere during lightning is completely unknown, and is one of the "hot topics" in this research area.

2 Observations in Brazil

Up to date, six different field campaigns, between 2002 and 2012 have been successfully performed in Brazil to make TLE observations. More than 700 events, mainly sprites, have been recorded over thunderstorms in different places in South America during these campaigns. The first TLE observations from Brazil took place in 2002 [10]. We installed low-light level video cameras at INPE's facility in Cachoeira Paulista, São Paulo State, and onboard INPE's small Bandeirantes airplane. In the 2006 campaign, from INPE Southern Space Observatory (SSO), TLEs were observed above two very active TLE producing MCS over Argentina and Paraguay.

During this campaign from the SSO we recorded more than 400 TLEs above the Argentine convective system, which was considered to be the third most prolific in the world [17]. The majority of the observed events (86%) was sprites. [11] studied in detail the characteristics of this system, which lasted for at least 20 h. The convective analysis indicated a moderate convection, with cloud top temperatures 10-20^{o} C higher that regular MCS's producing TLEs, which in principle would not be sufficient to produce the necessary amount of charge to originate the observed sprite production, two times of an average sprite producing MCS. However, this system ingested a large PM2.5 aerosol content that could have been a source of ice nuclei, important for the strong documented thunderstorm electrification. [11] suggested that the aerosols could have affected the positively charged ice particle production being responsible for the charge transfer needed to originate the observed TLE production.

Given the high thunderstorm electrical activity in our region, it is expected to have an extremely high TLE occurrence rate as well as intense emission of TGFs, high energy electron beams, neutron beam, X-Rays, i.e. HEET in general.

3 LEONA's Goal and Objectives

The project has the goal of establishing the Collaborative Network LEONA to study the electrodynamical coupling of the atmospheric layers signaled by TLEs and HEETs. We will develop and install a remotely controlled network of cameras with 21 ground stations to perform TLE observations in different locations in South America, and one neutron detector in southern Brazil. The camera network will allow building a continuous data set of the phenomena studied in this continent. There will be two observation sites in Argentina, one at the Pierre Auger Observatory and another at the Bosque Alegre Astronomical Observatory of the National University of Cordoba - NUC. They will provide a privileged view of the upper atmosphere above thunderstorms in the Pampas region, northwest of the site, where the most several thunderstorms in South America occur. The NUC site will provide unobstructed viewing of the upper atmosphere above thunderstorms over the Pierre Auger Observatory, allowing for combined collaborative studies of TLEs and HEET produced by thunderstorms above Auger and other locations in South America. LEONA will also provide ground support to several upcoming satellite and stratospheric balloon missions to perform TLE and HEET measurements, such as the TARANIS French Microsatellite and the ASIM mission onboard the International Space Station (ISS), scheduled to be launched in 2017, and the COBRAT mission, to fly long and short duration balloons performing these measurements in South America, starting in 2017.

We expect to determine the TLE geographic distribution, occurrence rate, morphology, and possible coupling with other geophysical phenomena in South America, such as the South Atlantic Magnetic Anomaly - SAMA. We also expect to study thunderstorm neutron emissions in a region of intense electrical activity, measuring neutron fluxes with high time resolution simultaneously with TLEs and lightning for the first time in South America. Using an intensified high-speed camera for TLE observation during 2 campaigns we expect to be able to determine the duration and spatial-temporal development of the TLEs observed, to study the structure and initiation of sprites and to measure the velocity of development of sprite structures and the sprite delay. The camera was acquired via the FAPESP project DEELUMINOS (2005-2010), which also nucleated our research group Atmospheric Electrodynamical Coupling - ACATMOS at INPE. LEONA will nucleate this research in other institutions in Brazil and other countries in South America, providing continuity for this important research in our region. The camera network will be an unique tool to perform consistent long term TLE observation, and in fact is the only way to accumulate a data set for a climatological study of South America, since satellite instrumentation turns off in this region to avoid damages due to the energetic particle precipitation due to the SAMA.

Figure 2: Map of South America showing LEONA initial configuration, the regions of COBRAT balloon flights (white lines), and supporting instrumentation sites. Green circles represent the 800-1000 km radius of coverage of each installed camera, and the yellow are the coverage of the planned sites for 2012. The smaller colored circles show the 240 km coverage of the meteorological radars. The dotted black and blue lines represent the current coverage of RINDAT, and UNC lightning detection networks, respectively.

References

[1] Babich, L. P., and R. A. Roussel-Dupre´ (2007), Origin of neutron flux increases observed in correlation with lightning, J. Geophys. Res., 112, D13303, doi:10.1029/2006JD008340 Chilingarian A., Mailyan

B., Vanyan L., 2012. Recovering of the energy spectra of electrons and gamma rays coming from the thunderclouds. Atm. Res. 114-115, 1-16.
[2] Chilingarian A., Mailyan B., Vanyan L., 2012. Recovering of the energy spectra of electrons and gamma rays coming from the thunderclouds. Atm. Res. 114-115, 1-16.
[3] Fishman, G. J., et al., Discovery of intense gamma-ray flashes of atmospheric origin, Science, 264, 1313-1316, 1994.
[4] Franz, R. C., R. J. Nemzek, and J. R. Winckler. ”Television image of a large upward electrical discharge above a thunderstorm system.” Science 249.4964 (1990): 48-51.
[5] Gurevich, A.V., Milikh, G.M., Roussel-Dupre, R., 1992. Runaway electron mechanism of air breakdown and preconditioning during a thunderstorm. Phys. Lett. A 165, 463-468.
[6] Gurevich A.V., Antonova V. P., Chubenko A. P., et al., Phys. Rev. Lett., 108, 125001-4 (2012). Hampton, D. L.; Heavner, M. J.; Wescott, E. M.; Sentman, D. D. Optical spectral characteristics of sprites. Geophysical Research Letters, v. 23, n. 1, p. PP. 89-92, 1996. 8, 9.
[7] Hampton, D. L.; Heavner, M. J.; Wescott, E. M.; Sentman, D. D. Optical spectral characteristics of sprites. Geophysical Research Letters, v. 23, n. 1, p. PP. 89-92, 1996. 8, 9
[8] M. McCarthy and G. K. Parks. Further observations of x-rays inside Thunderstorms. Geophysical Research Letters, 12(6):PP. 393-396, 1985
[9] Moore C. B., Eack K. B., Aulich G. D., and Rison W.. Energetic radiation associated with lightning stepped-leaders. Geophysical Research Letters, 28(11):PP. 2141-2144, 2001
[10] Pinto Jr., O., M. M. F. Saba, I. R. C. A. Pinto, F. T. São Sabbas, K. P. Naccarato, M. J. Taylor, P. D. Pautet, and R. H. Holzworth (2004), Thunderstorm and lightning characteristics associated with sprites in Brazil. , Geophys. Res. Lett., doi:10.1029/2004GL020264, v. 31, n. L13103, p. 1-4.
[11] São Sabbas, F. T., M. J. Taylor, P.D. Pautet, M. Bailey, S. Cummer, R. R. Azambuja, J. P. C. Santiago, J. N. Thomas, O. Pinto, N. N. Solorzano, N. J. Schuch, S. R. Freitas, N. J. Ferreira and J. C. Conforte, Observations of prolific transient luminous event production above a mesoscale convective system in Argentina during the Sprite2006 Campaign in Brazil, J. Geophys. Res., 115, A00E58, doi:10.1029/2009JA014857, 2010.
[12] Shah, G. N., Razdan, H., Bhat, C. L., Ali, Q. M., 1985. Neutron generation in lightning bolts. Nature 313, 773-775; doi: 10.1038/313773a0.
[13] Shyam, A., Kaushik, T. C., 1999. Observation of neutron bursts associated with atmospheric lightning discharge. J. Geophys. Res., Vol. 104, NO. A4, PP. 6867-6869; doi:10.1029/98JA02683.
[14] Smith, D. M., L. I. Lopez, R. P. Lin, and C. P. Barrington-Leigh (2005), Terrestrial gamma-ray flashes observed up to 20 MeV, Science, 307, 1085-1088.
[15] Stanley, M. A., X.-M. Shao, D. M. Smith, L. I. Lopez, M. B. Pongratz, J. D. Harlin, M. Stock, and A. Regan (2006), A link between terrestrial gamma-ray flashes and intracloud lightning discharges, Geophys. Res. Lett., 33, L06803, doi:10.1029/2005GL025537.
[16] Tavani M., Marisaldi M., Labanti C., Fuschino F., Argan A., Trois A., Giommi P., Colafrancesco S., Pittori C., Palma F., Trifoglio M., Gianotti F., Bulgarelli A., Vittorini V., Verrecchia F., Salotti L., Barbiellini G., Caraveo P., Cattaneo P. W., Chen A., Contessi T., Costa E., D'Ammando F., Del Monte E., De Paris G., Di Cocco G., Di Persio G., Donnarumma I., Evangelista Y., Feroci M., Ferrari A., Galli M., Giuliani A., Giusti M., Lapshov I., Lazzarotto F., Lipari P., Longo F., Mereghetti S., Morelli E., Moretti E., Morselli A., Pacciani L., Pellizzoni A., Perotti F., Piano G., Picozza P., Pilia M., Pucella G., Prest M., Rapisarda M., Rappoldi A., Rossi E., Rubini A., Sabatini S., Scalise E., Sotta P., Striani E., Vallazza E., Vercellone S., Zambra A., and Zanello D.. Terrestrial Gamma-Ray Flashes as powerful particle accelerators. Physical Review Letters, 106(1):018501, January 2011.
[17] Thomas, J. N.; Taylor, M. J.; Pautet, D.; Bailey, M.; Solorzano, N. N.; Holzworth, R. H.; McCarthy, M. P.; Kokorowsky, M.; Sabbas, F. S.; JR, O. P.; Cummer, S. A.; Jaugey, N.; Li, J.; Schuch, N. J. A very active sprite-producing storm observed over argentina. Eos, v. 88, n. 10, p. PAGE 117, 2007.