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A COMPARATIVE ANALYSIS OF LIGHTNING DATA DURING THE EU-BRAZIL TROCCINOX / TroCCiBras CAMPAIGN

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Abstract - During the EU-Brazil TROCCINOX/TroCCiBras campaign (Tropical Convection, Cirrus and Nitrogen Oxides Experiment) in 2005 a particularly sensitive six-sensor lightning detection network with 3D capability (LINET) was set up in the State of Sao Paulo and operated from January 21 to February 27. Its main objective was to provide comprehensive VLF/LF lightning data on a continuous basis to complement radar observations and to allow a detailed comparison with data from the Brazilian Lightning Detection Network (RINDAT). In addition, results from the two networks were compared with space-borne observations from an optical lightning imaging sensor (LIS). LINET agrees reasonably with RINDAT as long as stroke amplitudes above ~12 kA are considered, whereas it reports an order of magnitude more events for weaker discharge amplitudes. Stroke multiplicities, occurrence of cloud-to-ground (CG) and intracloud (IC) events, and time dependence of various lightning parameters are presented. Finally, it is demonstrated that LINET detects the same discharge activities as LIS.

1 INTRODUCTION

One aim of the TROCCINOX campaign 2005 in Brazil was the investigation of NO_x production by tropical and subtropical thunderstorms. For this reason quantitative lightning detection was imperative. In order to optimise corresponding measurements a new network (LINET), designed by the University of Munich, was implemented by an IPMet/DLR team. It is efficient in an amplitude range down to some 2 kA current in lightning channels for both CG and IC discharges, and allows reliable distinction between CG and IC events. A local IPMet/DLR team pre-selected six sites in Bauru and vicinity so that an average sensor base-line of ~100 km was realized (Fig. 1). The entire set-up procedure took about a week and immediate operation was started, though for trivial reasons not all six stations worked all the time; the required minimum of four active sensors could be achieved during

the entire period. Four sensors were connected to internet so that online data collection, system control and immediate evaluation became feasible. Data from the two stand-alone sensors was picked up by mobile equipment. During eleven days strong lightning activity occurred in the covered area. On Feb. 4 the most intensive storms developed and massive amounts of data could be collected; we report mainly results from this day although only four sensors were active. Ten further storm days have been analysed as well, but except for stroke numbers and densities no other pronounced systematic differences were found. Evaluations comprising data from many other tools used in TROCCINOX will be presented elsewhere. This contribution is focused on both the presentation of typical lightning parameters obtained from LINET and a comparison with corresponding results extracted from RINDAT. Usefulness of LINET data is discussed not only for the purposes of the specialized TROCCINOX campaign, but also for meteorological applications such as recognition and nowcasting of severe thunderstorms.

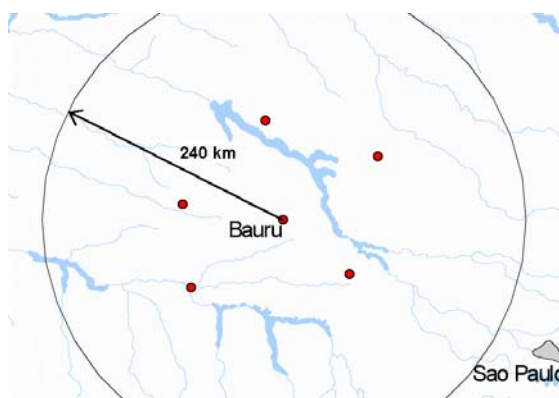


Fig. 1 – Location of the six LINET sensors (circles); the radar station is located at Bauru (-22.3578°/-49.0269°) and produces volume scans within a range of up to 240 km.

An additional comparison was made between RINDAT, LINET and the space-born lightning sensor LIS, which is important with respect to the contribution of intra-cloud activities to total lightning.

2 LIGHTNING NETWORKS

RINDAT has been described by Saba et al. [1] and Pinto [2]. This VLF/LF-network employs common sensors (Vaisala Inc.) and has a base-line of about 300 km; it is claimed that the detection efficiency amounts to ~50% for strokes above 5 kA, while the corresponding flash detection efficiency reaches ~90%. According to its designation only CG strokes should be reported. The LINET technology [3-5] also utilizes the VLF/LF range and employs both time-of-arrival and bearing angles. Due to various measures the efficiency becomes greatly enhanced, resulting in unprecedented low-amplitude detection power; below ~10 kA an order of magnitude more signals are identified compared to conventional networks, even for equal baseline. Since abundant IC events are located an effective discrimination against CG is required: the chosen solution consists in the employment of a new 3D-technique [5] which is independent of any adjustable parameters. Since 2003 LINET has been tested in Germany mainly by thorough comparisons with European networks combined in EUCLID [3]. For the present campaign in Brazil, six sensor sites have been selected at Bauru, Araraquara, Botucatu, Ourinhos, Marilia, and Novo Horizonte. Because LINET arrays in Germany and Brazil are identical in its basic features, an excellent opportunity arises for intercontinental comparisons of thunderstorms and network parameters. Due to space limitations this report concentrates on data from Brazil.

3 LIGHTNING MAPS

Figures 2-4 present the lightning events located by the two networks on Feb. 4, 2005. It becomes obvious that all storm cells are identified by both networks, though LINET resolves the activities in much more detail and allows easier cell definition. Incidentally, in Figs. 2-4 all individual events are plotted with the same dot size.

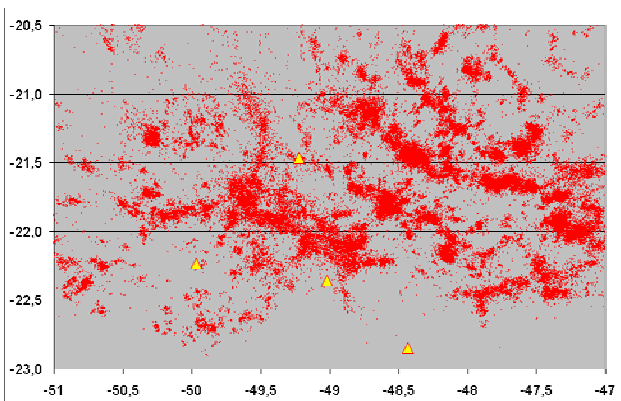


Fig. 2 – 81.500 LINET CG strokes on Feb. 4, 2005.

A similar though not identical cell structure is produced by the LINET IC discharges. In the centre area IC identification is quite reliable while the border areas outside the network may contain some events which could not reliably identified because the requirement of ~100 km maximum distance between lightning event and closest sensor was not fulfilled. Due to the circumstances that LINET operated only with four sensors, an additional group of mostly weaker discharges has been detected by three sensors only; this group comprises some 60.000 locations mainly inside the network area and yields the same cell structure. Since site-error corrections have not yet been carried out, 3-sensor solutions did not allow an IC-CG discrimination and the data is not displayed here. We expect that it comprises dominantly - but not exclusively - IC discharges, so that a significant amount of mostly weak CG strokes must be added to the CG data from Fig. 2. Comparison between the CG and IC location patterns reveals a varying contribution of IC discharges, indicative of different storm cell qualities. These findings will be illustrated in more detail below.

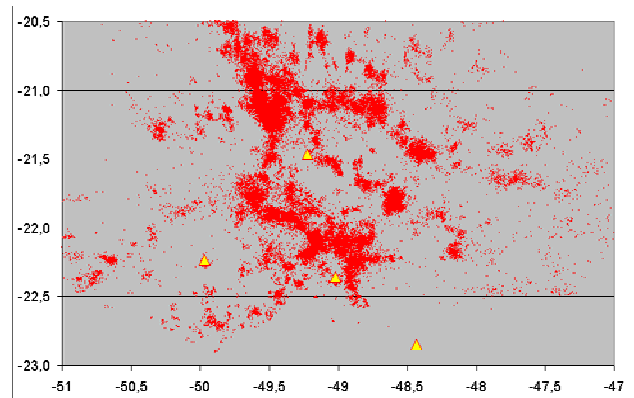


Fig.3 – 52.900 LINET IC discharges on Feb. 4, 2005.

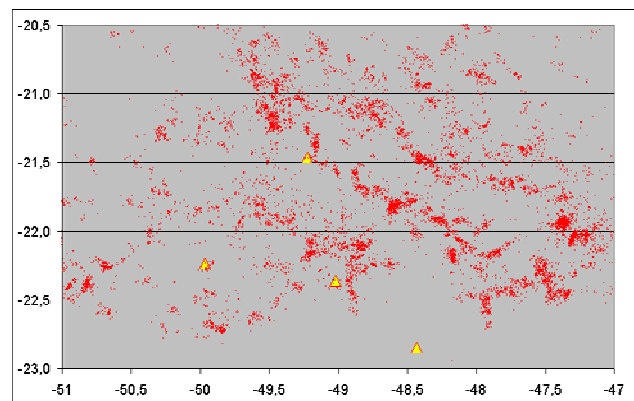


Fig. 4 – 12.700 RINDAT strokes on Feb. 4, 2005.

On Feb. 4 scattered storms began to develop within the range of the Bauru radar around noon, local time (LT), initially in the north-eastern sector, but rapidly spreading across the northern half of the radar coverage and merging into large complexes with very intense echo cores. Fig. 5 shows the radar scans at 14:00, 16:00, 18:00 and

20:00 LT. When the lightning data is compiled for appropriate time intervals excellent agreement is obtained with radar reflectivity. Later on we discuss some of the time-dependent observations (see Figs. 15-16). A more detailed analysis of life cycles and correlations with radar observations is under way and will be presented separately.

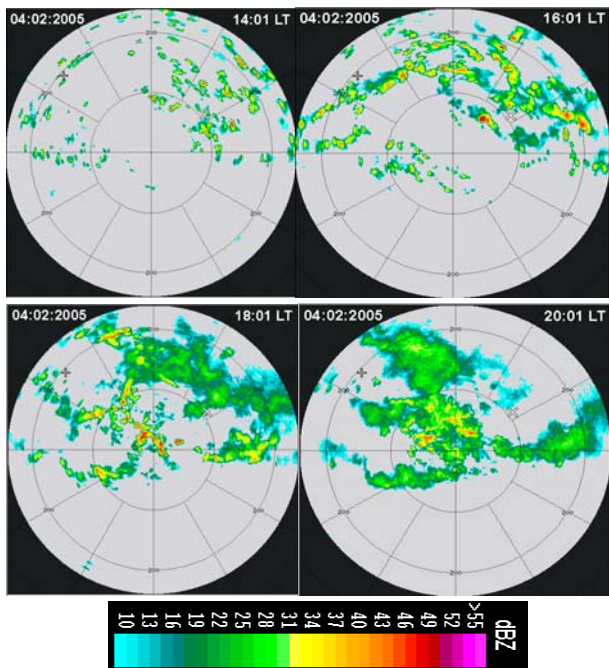


Fig. 5 – thunderstorm activity as observed by the Bauru radar on Feb. 4, 2005 (3,2 km CAPPIs, 240 km range. See Fig. 1 for radar and lightning sensor locations.

4 AMPLITUDE DISTRIBUTIONS

Figs. 6-7 show the distribution of event amplitudes normalized by means of an 1/distance-law, and calibrated by a procedure verified for LINET in Germany. Still, a statistical comparison of some 10.000 time-coincident events revealed that LINET amplitudes were almost 20% larger than RINDAT listings. Signal signs agreed well.

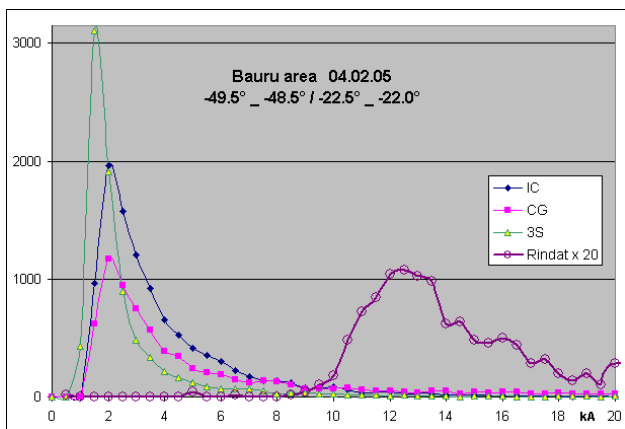


Fig. 6 – Lightning amplitude distribution in the Bauru area: RINDAT scaled up by a factor of 20; LINET is divided into CG, IC and unspecified (3S = 3-sensor) data; in steps of 0,5 kA.

For the considered storm cells, Fig. 6 reveals that below ~10 kA the IC-fraction surpasses 50% (see also Fig. 12). Still, the majority of CG strokes is found in the range below ~10 kA where RINDAT, like most other operational networks, exhibits decreasing efficiency.

Due to the large count rate differences for various amplitudes it becomes helpful to present a semi-logarithmic plot. Fig. 7 demonstrates that in the range of stroke amplitudes above ~12 kA the lightning distributions of LINET and RINDAT agree relatively well, but for weaker strokes LINET reports distinctly more signals, even if only CG strokes are considered. For other storm days similar relations were found. In part, the additional LINET strokes can be attributed to higher detection efficiency which results automatically from the use of a smaller base-line; a major portion of the difference, though, originates from refined signal treatment by hard- and software features.

A systematic investigation of the many additional LINET events leads to the conclusion that these are neither exclusively IC discharges nor stroke-associated events such as M-components or special stepped-leader radiation. The dominant quality is merely a somewhat smaller amplitude, smoothly connecting to results from established networks. In the following section we reinforce this view.

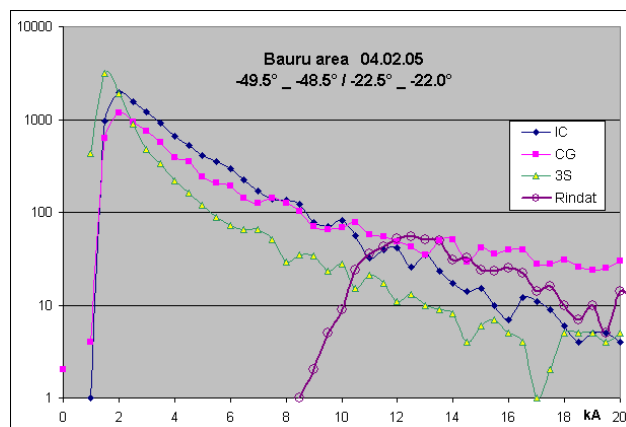


Fig. 7 – Amplitude distribution as in Fig. 6, in a semi-log scale.

5 MULTIPLICITY

For many purposes it is meaningful to group strokes into flashes. Usually one defines that strokes belong to a flash when they occur within a time span of 1 sec and within locations of ~10 km. The single event data from Figs. 2-4 has been treated correspondingly and yields the results shown in Figs. 8-9. The high LINET multiplicities arise from the sensitivity of the network to low-amplitude signals. When the 3-sensor data is ignored, LINET detects 36.000 flashes; when only CG strokes are considered the flash number becomes 27.500. RINDAT, by comparison, counts 4.370 flashes. Nevertheless, for large amplitudes RINDAT and LINET CG strokes are highly compatible; the distributions would agree even better when the ~20% difference in amplitude scaling were corrected.

It is interesting to note that the average stroke amplitude does not depend too much on the stroke order. Both RINDAT and LINET produce this somewhat surprising result (Fig. 10), whereby the averaged amplitudes from LINET are smaller because of the increased low-amplitude detection efficiency. In the literature it is usually asserted that higher stroke orders produce distinctly lower currents. The present finding is relevant for estimates of quantitative NO_x production.

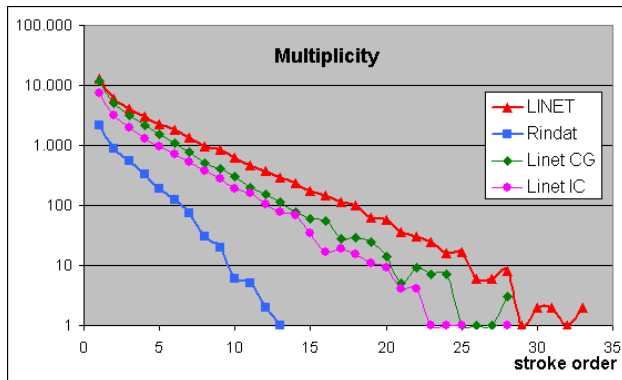


Fig. 8 – Multiplicity of the lightning events from Figs. 2-4, in a semi-log scale (Feb. 4, 2005). The probability to find an increasing number of strokes per flash decreases exponentially as a function of stroke order; the decay constant reflects the stroke detection efficiency of the network.

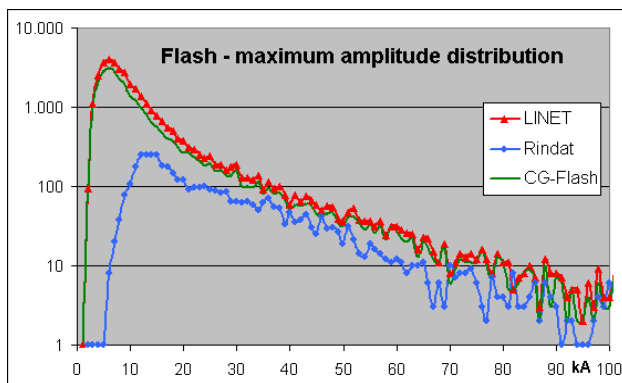


Fig. 9 – Distribution of flash-maximum amplitudes (Feb. 4, 2005). The data combines negative and positive signals.

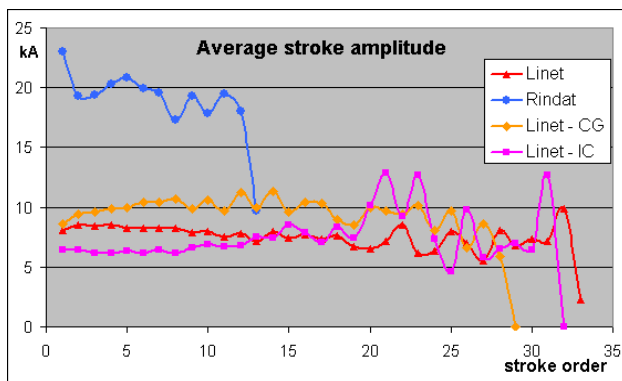


Fig. 10 – Lightning amplitudes averaged in each stroke order, as a function of stroke order (Feb. 4, 2005). The fluctuation for higher stroke orders is due to small event numbers.

6 LOCATION ACCURACY

Almost all of the RINDAT strokes in the area have also been reported by LINET; when time-coincidence is required a set of 10.900 cases can be used for comparison.

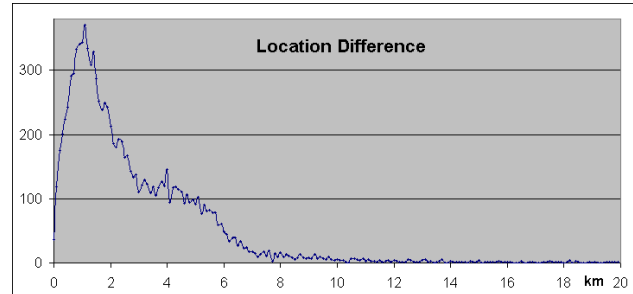


Fig. 11 – Location difference of 10.900 time-coincident RINDAT and LINET events on Feb. 4, 2005 (increments 0.1 km).

It can be seen from Fig. 11 that the majority of events is located with differences around 1 km. Some very large as well as small systematic deviations were also found but not investigated further. Similar comparisons at other days where LINET operated with 6 sensors and, thus, with higher reliability, revealed the same differences.

7 IC DISCHARGES

A new discrimination method to identify IC discharges has been presented in [5]. It relies on delayed arrival times and works well as long as at least one sensor is within ~100 km from the lightning. This condition is fulfilled for the network area except in the border regions. For example, an analysis of storm cells in the centre of the network (Bauru area) should provide reliable IC information. Fig. 12 shows the relative contribution of IC discharges as a function of event amplitudes. As expected, the IC fraction increases towards small amplitudes. Interestingly, there are storm cells which produce significant IC fractions even for higher amplitudes.

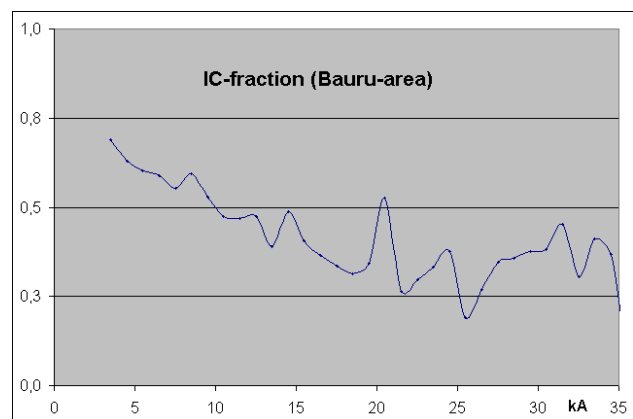


Fig. 12 – Fraction of well identified LINET IC discharges in the Bauru area ($-49,5^{\circ}$ to $-48,5^{\circ}$ / $-22,5^{\circ}$ to -22° ; Feb. 27, 2005), as a function of discharge amplitude. IC events dominate below ~10 kA, but are still present at higher amplitudes. The data contains both positive and negative signals.

We point out that there is very little published information on IC discharges in the VLF/LF regime which originates dominantly from charge acceleration in very long channels (e.g. recoil streamers); in contrast, abundant VHF measurements exist which refer mainly to short discharge channels (e.g. stepped leaders).

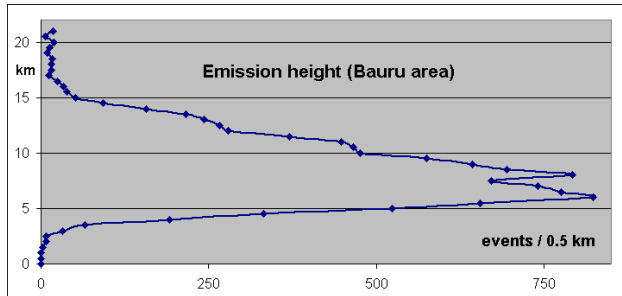


Fig. 13 – Distribution of emission heights for IC discharges detected in the Bauru area on Feb. 4, 2005 (resolution 0.5 km).

When the identified IC discharges are analysed with respect to their emission height [5] one obtains distributions such as the one shown in Fig. 13. The dominant heights are compatible with the cloud extensions, verified by simultaneous radar observations. A separation of positive and negative IC signals did not yield a systematic height difference as observed by Smith et al. [6] for specially selected very strong events.

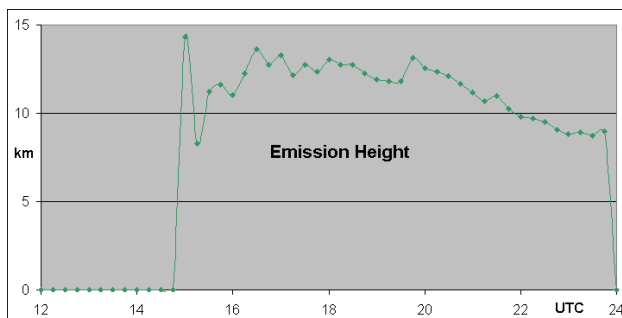


Fig. 14 – Time variation of the emission height within a particular storm cell on Feb. 4, 2005.

Due to the high IC-sensitivity it is possible for LINET to trace the height evolution in specific storm cells as a function of time. Fig. 14 shows an example where emission heights first increase from ~10 km to 12 km and then decrease to 9 km (the first peak at 14 kA results from only a few events). Future evaluations will focus on possible correlations with life cycles of the cells. In particular, this kind of data enables investigations of the connection between severe weather conditions and increased IC activity in the VLF/LF range.

In Fig. 15 we examine the time evolution of lightning amplitudes from a storm cell near Bauru, averaged over 15-min intervals and separated into CG and IC signals. Obviously, the CG fraction dominates around 18:00 UTC. By contrast, Fig. 16 presents an example for dominating IC discharges around 20:00; for some time almost no CG stroke is observed. Moreover, the discharge density raises

sharply and reaches relatively high values. The radar images in Fig. 5 support the quoted trend, though a more refined data comparison should be carried out in order to establish suspected correlations between radar and lightning for the detection of severe weather conditions.

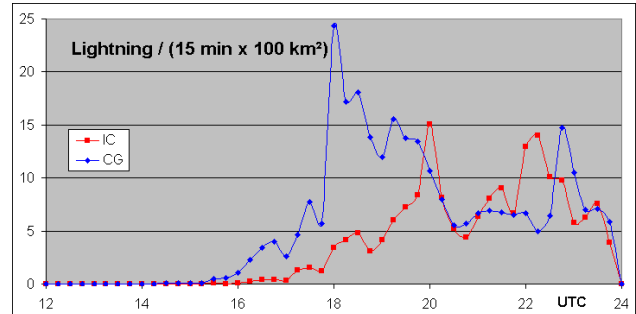


Fig. 15 – Storm cell with dominant number of CG strokes (Feb. 4, 2005); the two curves show the density (lightning/ 15 min x 100 qkm) of CG and IC events, respectively, as a function of time.

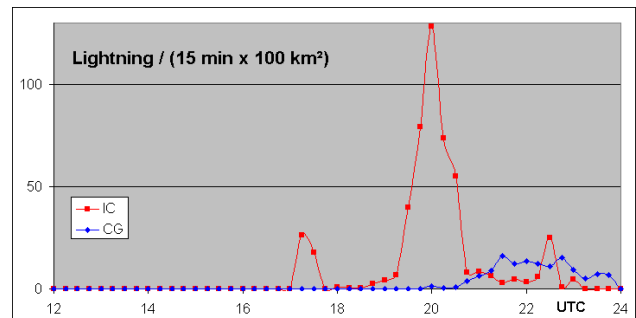


Fig. 16 – Example for a storm cell with dominant IC discharges (for explanation see Fig. 15).

When one displays the amplitudes of CG and IC events as a function of time, irrespective of sign, distinct variations can be found. Fig. 17 gives an example for pronounced time changes of both CG and IC amplitudes. Here, CG strokes precede IC discharges, for other cells the opposite trend may occur.

We emphasize that the systematic difference between CG and IC amplitudes reflects not only an expected trend, but also verifies the applicability of our discrimination scheme, because a random type-classification would mix the CG and IC amplitudes in a statistical manner.

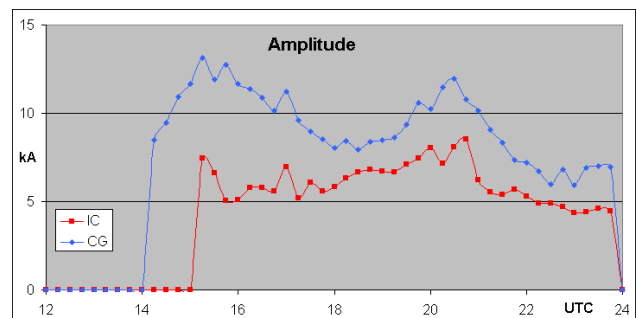


Fig. 17 – Average lightning amplitude for a storm cell, separated into CG and IC events, as a function of time.

8 LIGHTNING IMAGING SENSOR (LIS)

Finally, we compare LIS observations with lightning data from RINDAT and LINET. As an example, an overpass on Feb. 4, 2005 is presented which lasted 90 sec and yielded marked activity in the area of interest. The corresponding optical signals are grouped in Fig. 18. A search for corresponding VLF/LF-activity reveals that LINET reproduces the LIS-groups very well (Fig. 19). Most, but not all of the coincident LINET signals were of the IC-type and exhibited small amplitudes; this is why RINDAT did not allow to reproduce the LIS pattern.

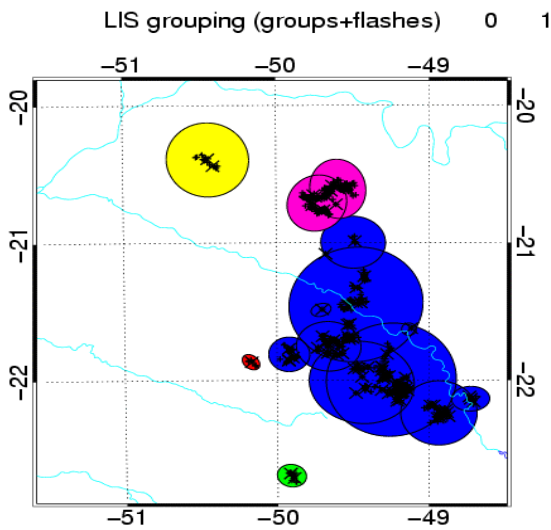


Fig. 18 – LIS observations on Feb. 4, 2005.

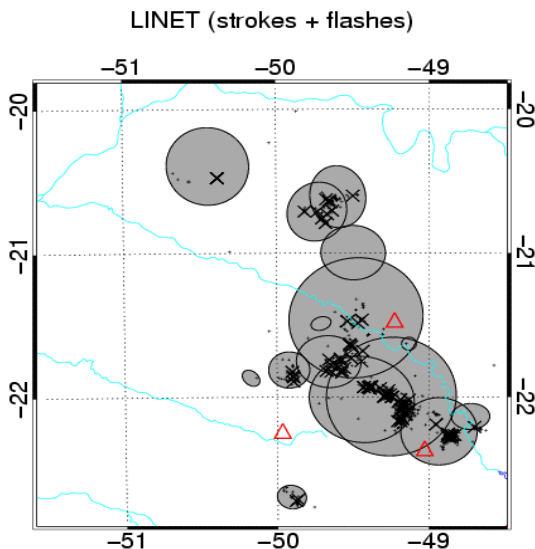


Fig. 19 – LINET data corresponding to LIS in Fig. 18.

To our knowledge, such a strong correlation between LIS groups and VLF data has not been presented before; in the past similar coincidences have been reported only on the basis of VHF data. It must be kept in mind that the two

sets of data come from very different physical processes; LIS refers to optical transitions in excited single atoms, while the detected VLF signals, IC or CG, originate from complex discharges in very long channels.

9 CONCLUSIONS

The TROCCINOX/TroCCiBras campaign succeeded in massive data collection which needs further evaluation. Lightning data was obtained from two networks and compared to mutual benefit. Since many new observations are presented, intensive further discussions are necessary, especially with respect to the large fraction of alleged low-amplitude CG strokes and the utilization of efficient IC measurements in the VLF regime. In any case, we suspect that properly measured lightning parameters will be useful for many purposes, such as studies of basic discharge processes and several meteorological applications including simple and helpful contributions to nowcasting and recognition of severe weather conditions.

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