Comparison of VHF-DITF lightning observations with RINDAT CG strokes during the TroCCiBras 2004 experiment: A case study

COMPARISON OF VHF-DITF LIGHTNING OBSERVATIONS WITH RINDAT CG STROKES DURING THE TroCCiBras 2004 EXPERIMENT: A CASE STUDY

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Abstract - During the international TroCCiBras (Tropical Convection and Cirrus experiment Brasil) campaign in January to March 2004, 3-D lightning observations were provided by an experimental network of VHF Broadband Digital Interferometers, which was operated near Bauru by the Lightning Research Group of Osaka University. This paper focuses on the importance of observing Intra-Cloud (IC) and Cloud-to-Cloud (CC) lightning activity in addition to Cloud-to-Ground strokes provided by the conventional Lightning Observation Networks, which is highlighted in the presentation of a case study (20 February 2004), with IC, CC and CG lightning being superposed on a variety of radar images. For operational purposes, radar and lightning observations can be integrated by the Software TITAN, installed at IPMet.

1 - INTRODUCTION

The Meteorological Research Institute (IPMet) of the São Paulo State University has been monitoring the three-dimensional structure of severe thunderstorms, including the radial velocities inside and near these storms since 1992 and 1994, respectively, using two S-band Doppler radars in the central and western part of the State of São Paulo. Since one of IPMet´s main objectives is the dissemination of nowcasting bulletins for the public, and especially emergency services, criteria for the early detection of severe wind and hailstorms have been sought and are already, at least in part, incorporated in the real-time monitoring and alert system. However, research into the relationship between radar echoes and lightning discharges only commenced in 2004, when Cloud-to-Ground (CG) lightning strokes became available from the RINDAT Lightning Detection Network (now called BrasilDat, [1]), through the cooperation with the Lightning Research Group (ELAT) of the National Space Research Institute (INPE).

During an intensive international field campaign, TroCCiBras (Tropical Convection and Cirrus experiment Brasil, [2, 3]), which was conducted jointly with the European HIBISCUS and TROCCINOX projects from January to March 2004, 2-D and 3-D lightning observations were provided by an experimental network of VHF Broadband Digital Interferometers (DITF), which was operated near Bauru by the Lightning Research Group of Osaka University (LRGOU, Japan).

2 – OBJECTIVE

Severe storms have a significant impact on power electric systems. Their strong winds, intense lightning activity and, occasionally, the formation of tornadoes, might cause outages in transmission and distribution lines, leading to a significant impact on the quality average indices FEC ("Yearly Interruption Frequency Index") and DEC ("Yearly Interruption Duration Index"). Thus, the timely issue of alerts is of extreme importance not only to the electric power industry, but also to Civil Defense Organizations, Traffic Police and the productive sector in general.

Lightning activity and radar observations were analyzed for three days, viz., 20-22 February 2004. Based on these results, this paper focuses on the importance of observing Intra-Cloud (IC) and Cloud-to-Cloud (CC) lightning activity, in addition to the conventional Cloud-to-Ground (CG) strokes / flashes, which is highlighted in the presentation of a case study (20 February 2004), with IC, CC and CG lightning being superposed on radar images.

With this in mind, this paper highlights the need for the availability of real-time IC observations, together with the conventional BrasilDat lightning data and high-resolution radar observations. One of the tools used to visualize integrated lightning and radar data is the latest version of NCAR's (National Center for Atmospheric Research) TITAN Software (Thunderstorm Identification, Tracking, Analysis and Nowcasting, [4]), which had been implemented at IPMet in collaboration with NCAR and adapted for local requirements in 2006. Lightning and radar observations, integrated by TITAN, could significantly improve IPMet's nowcasting capability and also extend the time range of the nowcast, thus allowing a longer lead time after an alert had been issued.

3 – DATA

3.1 - RADAR OBSERVATIONS

IPMet's S-band Doppler radars are located in the central and western State of São Paulo, viz. in Bauru and Presidente Prudente (Figure 1). Both have a 2° beam width and a range of 450 km for surveillance (0° PPI every 30 or 15 min), but when operated in volume-scan mode every 7,5 minutes, it is limited to 240 km, with a resolution of 1 km radially and 1° in azimuth, recording reflectivities and radial velocities. A reflectivity value of 10 dBZ corresponds to a rainfall rate of 0,15 $mm.h^{-1}$, but for the comparison with the 2-D and 3-D lightning images a reflectivity threshold of 5 dBZ and –15 dBZ, respectively, was selected.

Figure 1 - IPMet's Radar Network (BRU = Bauru; PPR = Presidente Prudente), showing 240 and 450km range rings. The positions of the lightning sensors are indicated by ∗ (RINDAT in red; Broadband DITF in blue).

3.2 - LIGHTNING OBSERVATIONS FROM RINDAT

In 2004, the RINDAT Lightning Detection Network derived its data from LPATS and IMPACT sensors [1]. For the purpose of this study, information on CG strokes was extracted from the RINDAT Data Base, using a geo-referenced system to directly correlate the lightning observations with the radar echoes. The flashes were grouped into 7,5 min intervals, corresponding to the radar volume scans, but flash frequencies, as well as other stroke properties, were also analyzed.

3.3 - BROADBAND DITF LIGHTNING OBSERVATIONS

Already in 1970, Proctor [5] used five VHF receivers in the Pretoria–Johannesburg region, in South Africa, to record and plot time-resolved three-dimensional pictures of lightning from VHF sferics by accurately measuring their time of arrival at the various receivers. This method enables flashes and all their branches to be tracked from their origins throughout their entire lifetime. Using latest advancements in computer and electronics technology, the LRGOU has been developing a VHF Broadband Digital Interferometer (DITF) to image precise lightning channels and to monitor lightning activity widely [6]. The main feature of broadband DITF is its bandwidth (from 20 MHz to 100 MHz) and implicit redundancy for estimating VHF source locations. Based on phase differences for all Fourier components of broadband EM signals, captured by two properly separated antennas, the incident angle of EM signals against the baseline can be estimated. In other words, to obtain one VHF source location, a few tens Fourier components contribute, and this "*implicit redundancy*" is the noticeable superiority to any other source location technique. According to initial observations and numerical calculations, the accuracy of 0.01 radians may be feasible. Since it is known that VHF impulses are mainly radiated from the tip of the breakdown-like stepped leader, the VHF impulse source location is equivalent to imaging the lightning channel development, even within a thunderstorm.

The LRGOU DITF system comprises 3 sensors with 5-10 m separation. A single system can detect EM waves radiated from lightning discharges at few kilometers distant from the station. The exact distance is unknown, because it depends on the environment, influence from radio noises, etc. Thus, only azimuth and elevation mapping of lightning channels can be derived (2-D images), which then can be related to radar echoes. However, if an area is covered by two or more systems, preferably separated by 20 – 30 km, the records can be used for 3-D imaging.

During the TroCCiBras experiment, the LRGOU operated two DITF systems, one near the BRU radar (UNIP) and the other one along a 28,6 km base line to the south-east (USJ), as indicated in Figures 1 and 6.

3.4 – SYNOPTIC SITUATION AND CONVECTIVE ACTIVITY

The large-scale synoptic situation, affecting the convective activity during the study period, was a Cyclonic Vortex at High Altitude (VCAN), positioned just off the coast of Northeast Brazil, while at the same time, a typical South Atlantic Convergence Zone (SACZ, [7]) occurred over the State of São Paulo, remaining semi-stationary and being responsible for the advection of moist oceanic air at low levels. Since the divergence at 200 hPa, above the SACZ, resulted in strong vertical motion above the State of São Paulo and the VCAN bringing in tropical moist air at high levels, conditions were extremely favorable for convective storms in the State of São Paulo. The Bauru radar records show an increase of the storm intensity in the afternoon, with some echo tops penetrating through the tropopause (tops >18 km at times), especially in the central region of the State during late afternoon.

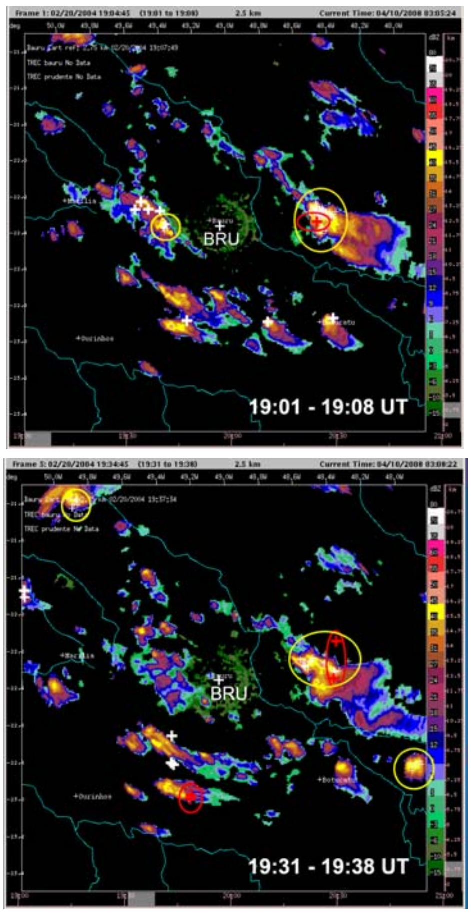

Figure 2a – Thunderstorms around Bauru with lightning strokes from RINDAT (+, neg. in white, pos. in red) on 20 February 2004; CAPPIs (2,5 km amsl) at 16:01-16:08 LT and 16:31-16:38 LT. Envelopes indicate cells with a large number of strokes per 7,5 min volume scan.

The TITAN radar images (CAPPIs) shown in Figures 2a,b represent the maximum reflectivities detected during the 7,5 min volume scans, together with lightning strokes observed by RINDAT during the same period. Cells with high stroke frequencies are highlighted in yellow, while regions of positive strokes are outlined in red.

Storms detected by IPMet's radars in the Bauru region (about 150 km radius) during the afternoon of 20 February 2004 are depicted at 16:08 and 16:38 LT (Figure 2a) for the earlier storm situation, indicating no storms in the near range of the BRU radar. However, intense lightning activity already occurred at 16:08 LT about 40 km west and about 70 km east of BRU. At 16:38 LT, only the cell some 60 km east-north-east of BRU was still active. Relatively little activity was recorded at ranges further out.

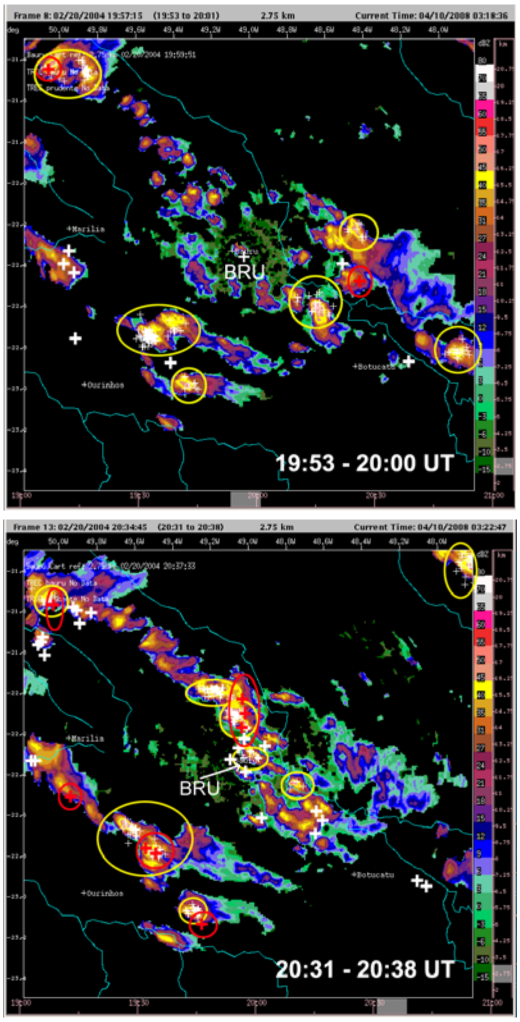

Figure 2b – Same as Figure 2a, but CAPPIs (2,75 km amsl) at 16:53-17:00 LT and 17:31-17:38 LT.

Figure 2b shows storms in their early stage of development around Bauru at 17:00 LT with no strokes being detected by RINDAT, but several storm cells further away are very active with high stroke frequencies. Only 40 min later (at 17:38 LT), these weak cells around Bauru have developed rapidly and now produce a high frequency of strokes, as can be seen in the lower figure.

Very few positive CG strokes were recorded.

4 - LIGHTNING OBSERVATIONS

In this Section, seven one-second observations from the VHF Broadband Digital Interferometer (DITF) will be compared to CG records from RINDAT and correlated to three volume scans of radar data from 19:53-20:15 UT. The DITF records were collected at 19:56:16, 19:57:52, 20:03:39, 20:04:23, 20:05:44, 20:05:45 and 20:09:42 UT.

4.1 - 2-D DITF NETWORK

Figure 3 shows three single-station observations from site USJ, viz. Cloud-to-Ground (CG; a and c), as well as Intra-Cloud (IC) and Cloud-to-Cloud (CC) flashes, which were recorded on 20 February 2004 during the volume scan 17:00-17:08, when scattered storms occurred (Figure 4, top). Since a radar volume scan takes about 7.5 min to be completed between 0° and 35° elevation, it is impossible to match the lightning records instantaneously with the radar observations. Unfortunately, the electric field changes have not been recorded during the observation period, which would have allowed a differentiation between CG and CC flashes. However, based on the radar observations, one could infer CG, CC and IC flashes, as indicated in the figures, by matching the lightning channels to specific cells (designated #n) in the storms. In order to achieve this, at first the lightning records were analyzed to identify significant features at specific azimuths and then collocated with radar cross-sections along the same bearings (azimuth) originating at the recording site. To illustrate these results, some of the lightning activity during the first three events shown in Figure 3a-c has been placed inside the radar volume scan 17:01-17:08.

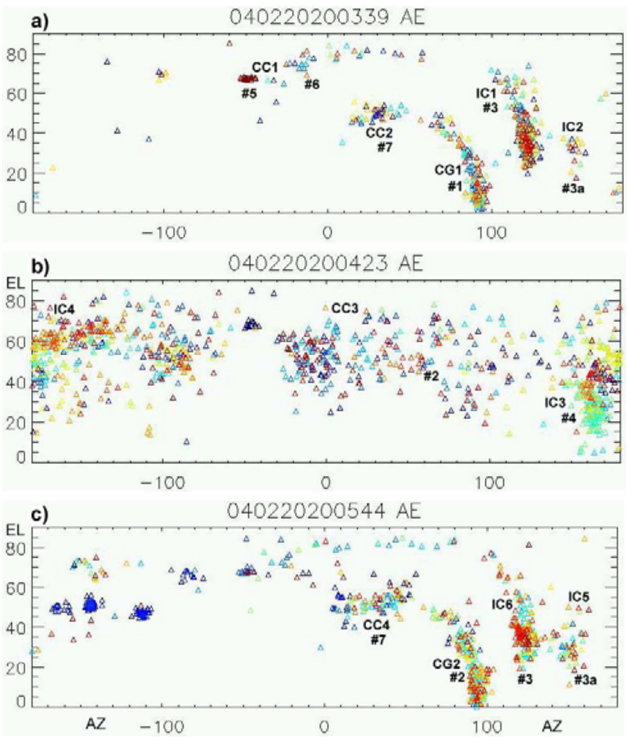

Figure 3 – Electrical discharges observed by the sensors at site USJ on 20 February 2004:
a) 20:03; b) 20:04; c) 20:05 UT. EL = elevation, AZ = azimuth (0° = north, -90° = east, +90° = west, ±180° = south) relative to USJ. Labels refer to flash types and cells (#n) as in Figure 4.

Figure 4 shows the interpolated positions of discharges relative to the storm echoes in a CAPPI (3km above mean sea level, amsl, 17:01 LT) and in various cross-sections through the volume scan 17:00-17:07 (the base lines are indicated in the CAPPI).

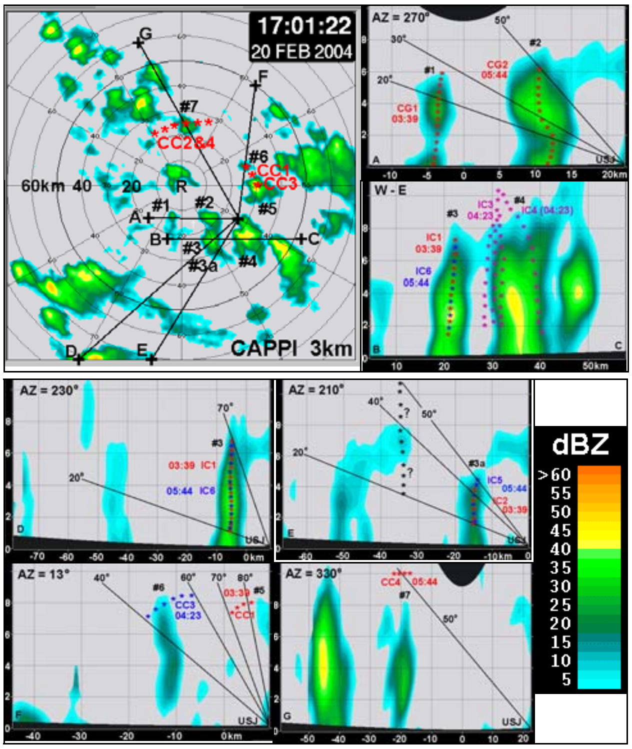

Figure 4 – Lightning activity recorded by the sensors at site USJ on 20 February 2004 (Figure 3) in relation to storm cells observed by Bauru radar 17:00-17:08 LT. The reflectivity threshold is 5 dBZ.

Figure 5 shows the TITAN image of the volume scan depicted as CAPPI in Figure 4, but now with strokes from RINDAT. The 60 km range ring can be used for aligning the CAPPI. The strokes in the two cells south-west and south-east of USJ compare well with the activity in the cross-section B-C (cells #3 and #4). The single stroke in #3 also shows up as activity in the cross-section D-USJ (AZ=230°), but the DITF also recorded IC activities in the southern tip of this cell (E-USJ, AZ=210°). Also interesting is the situation in cells #5 and #6 (cross-section USJ-F, AZ=13°) - obviously, the strokes seen in #5 did not occur during the 3 records analyzed from the DITF, while no CG strokes were recorded near #6, but the DITF recorded CC activity. Similar results are found for #7 (USJ-G, AZ=330°). However, cells #1 and #2 (A-USJ, AZ=270°) indicate CGs in the DITF observations, but no strokes were recorded by RINDAT.

4.2 - 3-D DITF NETWORK

In this Section, 3-D analysis of lightning discharges observed from the same storm cells as shown above, had been derived by matching the simultaneous observations from both receptors. Figure 6 shows the area for which 3-D lightning discharges have been calculated, based on two sets of the DITF, viz. UNIP and USJ. It also shows the various cells (3,5 km amsl CAPPI, volume scan 16:53-17:00), from which the discharges possibly originated, while Figure 6 (bottom) represents the tops of the –15 dBZ echo contour. However, it should be borne in mind, that the radar sensitivity drops off rapidly with distance from the radar, viz. –15 to –10 dBZ is visible up to a maximum of 25 km only.

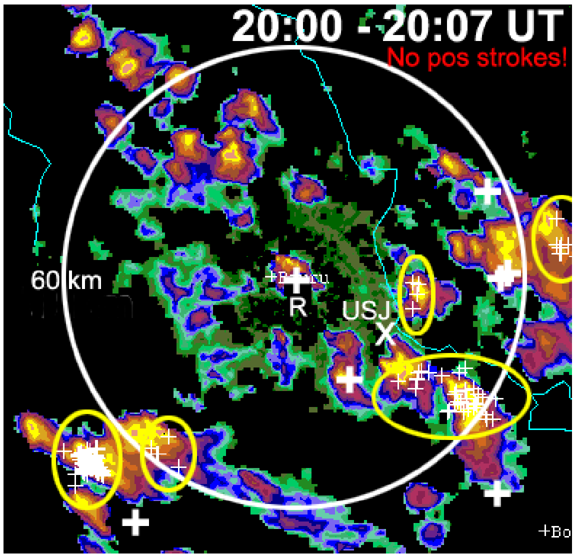

Figure 5 – Lightning strokes recorded by RINDAT during the volume scan of 17:00-17:07 LT. Envelopes indicate cells with a large number of strokes per 7,5 min volume scan.

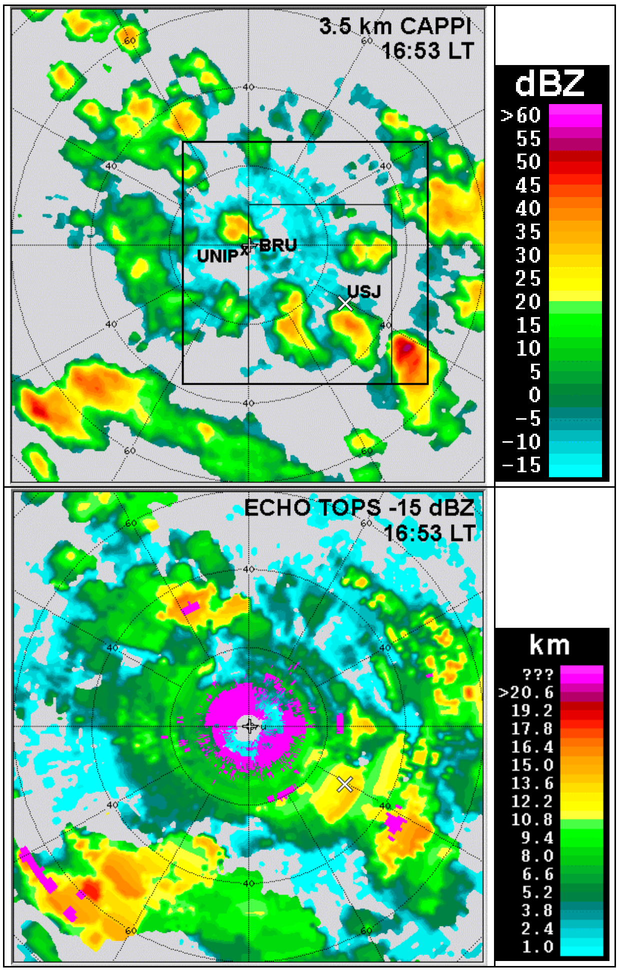

Figure 6 – *Top:* CAPPI 20 Feb 2004, 16:53 LT, showing the two DITF sites, as well as the frames of 3-D lightning analysis (bold) and the 3-D radar image (thin).
Bottom: Tops of the –15 dBZ echo contour at 16:53 LT.

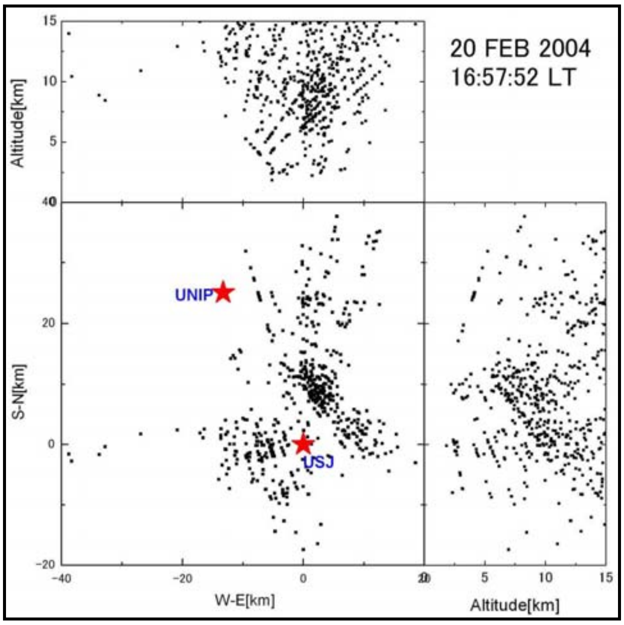

Figure 7 – X-Y-Z representation of a typical lightning discharge (19:57 UT).

Figure 7 shows one event of <1s duration in an X-Y-Z presentation, while the 3-D representation of the discharges is shown in Figure 8. The main activity (CG stroke) seems to originate from the cell to the north-east of USJ, but no stroke was recorded by RINDAT (Figure 9) at this exact time, but also not at any other time during the volume scan 19:52-19:59 UT. The other two 3-D events analyzed (19:56:16 and 20:05:45) were weaker stepped leaders and possibly therefore also not being captured by RINDAT.

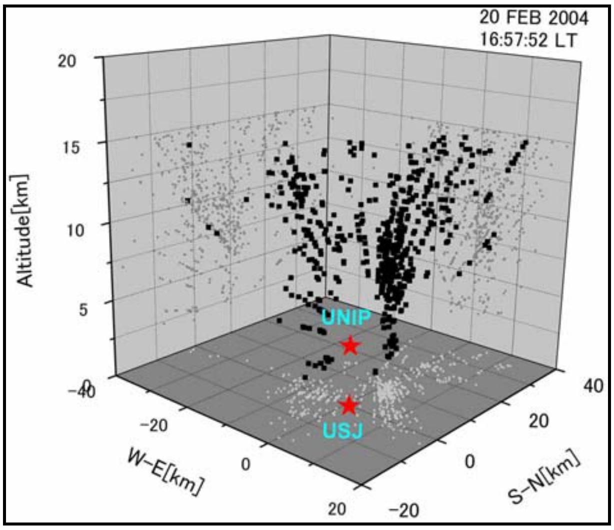

Figure 8 – 3-D representation of the lightning discharges recorded at 19:57:52 UT.

The storm cells producing the lightning discharges recorded by the DITF system were small and in their early life-cycle, but intensified and grew in height as they moved south-eastwards during the subsequent 45 min (Figure 2b). It can be concluded from this analysis, that the top of lightning discharges originates between 10-15 km height, a region of small ice crystals (probably cirrus capping the storm cells; also confirmed in vertical cross-sections), which is well above the normally detectable radar echoes (the 10 dBZ contour reached only up to 9,5 km). A 3-D image of these storm cells had been presented in [8] for the 10 dBZ radar echo contour. Similar heights for the lightning initiation were also found by LINET (German VLF/LF lightning detection system) deployed during February 2005 in the Bauru region [9].

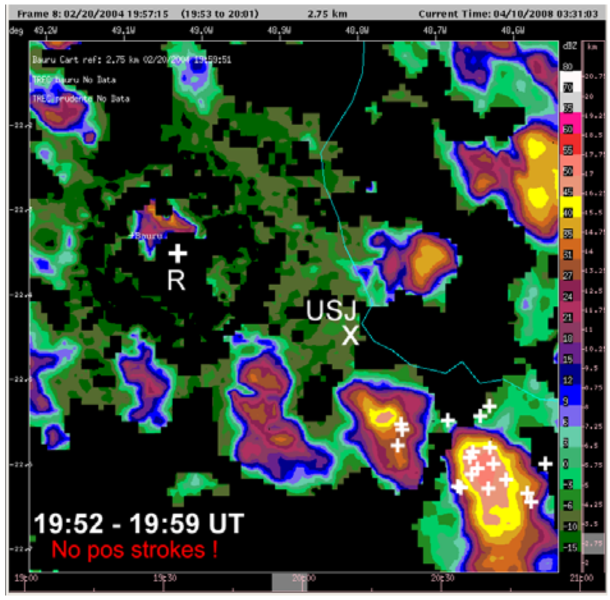

Figure 9 – Lightning strokes recorded by RINDAT during the volume scan of 16:52-16:59 LT. The zoomed area shown here coincides with the bold frame in Figure 6 and the graphic representations of the DITF records in Figures 7 and 8.

5 – CONCLUSIONS

Lightning observations within the ca 100 km range of the Bauru radar were conducted during the second half of the summer season in 2004 and 2005, deploying a variety of sensors. From these lightning records it is concluded, that during the early stages of cell development, lightning discharges commence up to 5 km above the 10 dBZ radar reflectivity contour, within a layer of small ice crystals, high-lighting the importance of detecting intra-cloud lightning discharges, pointing towards regions of strong development not yet visible on radar images. However, the very detailed results from the VHF Broadband Digital Interferometer (DITF) System, deployed during the TroCCiBras Campaign in 2004, are rather time consuming to analyze and therefore more suitable for a small research area, while for operational applications commercially manufactured systems, such as the VLF/LF and VHF sensors of LINET or the Vaisala LS8000 can be directly integrated into conventional Lightning Detection Networks, yielding CG, IC and CC flashes.

The detection of Intra-Cloud lightning activity during the early stages of cell development, indicating a very likely intensification of that cell into a severe storm some 15-30 minutes before the detection of CG strokes by a conventional network, and well before the radar would initiate an alert, would greatly enhance the Nowcasting capability. Once integrated into the TITAN Nowcasting programs, an early storm alert system could be offered to the electric power industry.

6 - ACKNOWLEDGEMENTS

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