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Analysis of the first gigantic jet recorded over continental North America

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[1] Two low-light cameras near Marfa, Texas, recorded a gigantic jet over northern Mexico on 13 May 2005 at approximately 0423:50 UTC. Assuming that the farthest of two candidate storm systems was its source, the bright lower channel ended in a fork at around 50–59 km height with the very dim upper branches extended to 69–80 km altitude. During the time window containing the jet, extremely low frequency magnetic field recordings show that there was no fast charge moment change larger than 50 coulomb times kilometers (C km) but there was a larger and slower charge moment change of 520 C km over 70 ms. The likely parent thunderstorm was a high-precipitation supercell cluster containing a persistent mesocyclone, with radar echo tops of at least 17 km. However, photogrammetric analysis suggests that the gigantic jet occurred over the forward flank downdraft region with echo tops of 14 km. This part of the supercell may have had an inverted-polarity charge configuration as evidenced by positive cloud-to-ground lightning flashes (+CG) dominating over negative flashes (−CG), while −CGs occurred under the downwind anvil. Four minutes before the gigantic jet, −CG activity practically ceased in this area, while +CG rates increased, culminating during the 20 s leading up to the gigantic jet with four National Lightning Detection Network–detected +CGs. A relative lull in lightning activity of both polarities was observed for up to 1.5 min after the gigantic jet. The maturing storm subsequently produced 30 sprites between 0454 and 0820 UTC, some associated with extremely large impulse charge moment change values.

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1. Introduction

[2] The discovery of gigantic jets by *Pasko et al.* [2002] from Puerto Rico and by *Su et al.* [2003] from Taiwan enlarged the family of documented types of middle atmospheric transient luminous events (TLEs). While red sprites and elves are common over large thunderstorm complexes [*Lyons et al.*, 2003a] and oceanic winter thunderstorms [*Takahashi et al.*, 2003], both ground-based and space-based observations of the jet-like phenomena in the TLE family have been comparatively sporadic.

[3] Jet-like TLEs (upward lightning, blue starters, blue jets, gigantic jets, and palm tree events) share the common characteristic that they emerge from the top of a thunderstorm [*Lyons et al.*, 2003b], as opposed to sprites and elves, which initiate in the mesosphere [*Sentman et al.*, 1995]. The few available observations have shown the stratospheric jets to be blue [*Wescott*, 1996; *Wescott et al.*, 1995, 1998, 2001], but palm tree events have been observed as red [*Heavner*, 2000]. The gigantic jets reported by *Pasko et al.* [2002] and *Su et al.* [2003] reached higher altitudes than blue jets, 70–90 km instead of 40 km, and did not exhibit a simple cone shape but exhibited one or more collimated rising channels, branching out into altitudes where sprites normally occur, at 50–90 km. The five events of *Su et al.* [2003] could be grouped in "tree" and "carrot" type jets and the upward speed (1000 km s^{-1}) was an order of magnitude faster than that of *Pasko et al.* [2002]. A characteristic found in both observations, as well as by *Tsai et al.* [2006], was a long-lasting afterglow of the transition zone and lower part of the gigantic jet. Note that palm tree or troll events (occurring during horizontally extensive sprites) bear considerable resemblance to gigantic jets by their appearance, with lower top altitudes ranging from 32 to 61 km. They can appear as grouped jets. *Marshall and Inan* [2007] recorded 12 palm tree events during two observing seasons in New Mexico. They proposed that these secondary TLEs develop in response to the enhanced vertical electric field when ionospheric potential is brought closer to the cloud top via the body of sprites. They also occur in Europe: Two such events

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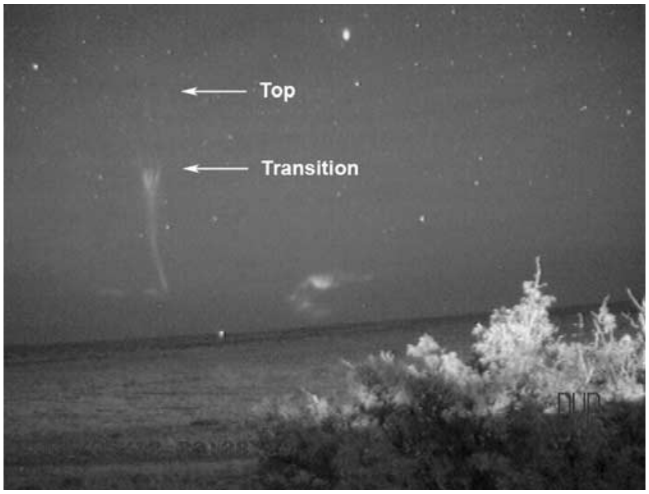

Figure 1. Low-light TV camera 4-s stacked image of the gigantic jet, seen in southeasterly direction from Marfa, Texas, 13 May 2005 at approximately 0423:50 UTC (corrected time). The horizontal field of view is 30°. Image is printed with permission (J. Bunnell).

were found by one of the authors (O. van der Velde) over the western Mediterranean Sea during Eurosprite 2005.

[4] Many jets appear to emanate from cores of thunderstorms with cloud tops reaching 16 km or more, unlike sprites, which typically occur over the stratiform region of thunderstorms. Previous studies have not found any triggering cloud-to-ground lightning activity, but the cases of *Pasko et al.* [2002] and *Su et al.* [2003] had associated large extremely low frequency (ELF) electromagnetic signals indicative of a large upward transfer of negative charge. In this paper we discuss a new observation of a gigantic jet, the first one to be recorded from the continental United States, with available meteorological data allowing the first in-depth analysis of a thunderstorm that produced cloud top TLEs since the analyses by *Wescott et al.* [1998] and *Lyons et al.* [2003b].

2. Observing Method

[5] Two Astrovid Stellacam II (Watec 120N) low-light monochrome surveillance cameras were installed by coauthor J. Bunnell near Marfa, in southwestern Texas. They were fitted with Cosmicar/Pentax 12 mm f/0.8 lenses, used at their widest aperture, that give a horizontal field of view of 30°. Both had a view to the southeast with a baseline of 2.35 km, oriented NNW-SSE, not perpendicular to the direction of the gigantic jet. To allow for longer unmanned operation, the cameras were set to frame integration mode, producing stacked images, each spanning 4.27 s. The images were each stored by a digital video recorder (DVR), which overlays a time stamp from its uncontrolled clock and varies according to where the DVR paused during the 4-s frame. For the camera that produced the image of Figure 1, gamma was set to "high" (0.35), and the manual gain dial was set to 3 ticks out of 15 (12 dB).

[6] Before local midnight on 13 May 2005, around 0423 UTC, both cameras imaged what appears to be a gigantic jet (Figure 1). The camera integration mode generated only a single image for each camera, not a video sequence, so that we cannot infer upward velocities or the total duration from the footage. The DVR time stamp could not resolve the gigantic jet time to within 4 s and had an unknown drift. However, the rich star field of the image, the presence of a distant mercury vapor light with known coordinates, and an astronomical program with the capability to overlay stars over an image made it possible to obtain a more precise estimate of the gigantic jet time and azimuth. Following the gigantic jet, 30 sprites were observed. Because sprites can be linked to a positive cloud-to-ground lightning strike [*Boccippio et al.*, 1995], a successful comparison of the drifting DVR time stamps with the times of positive cloud-to-ground lightning flashes (+CG) strikes resulted in a high confidence estimate that the gigantic jet occurred in the time window 0423:47–0423:52 UTC, 13 May 2005 (4 s of play in the time stamp and a rounding error of 1 s).

[7] The azimuth of the event was determined to be 122.25°. The great circle path crosses two thunderstorm cores at about 230 and 305 km distance, both over extreme northern Mexico. To ascertain which storm produced the gigantic jet, triangulation was attempted using the azimuths found by the star fixes of the two cameras. The parallax was only 15–20′, so the resulting intersection point was very sensitive to small errors. The errors of star fixing, pixel width, and cursor readout of the angles, as well as comparing distances of sprite +CGs with triangulated distances, made it clear that both storms remained potential gigantic jet-producing candidates. However, we postulate that the

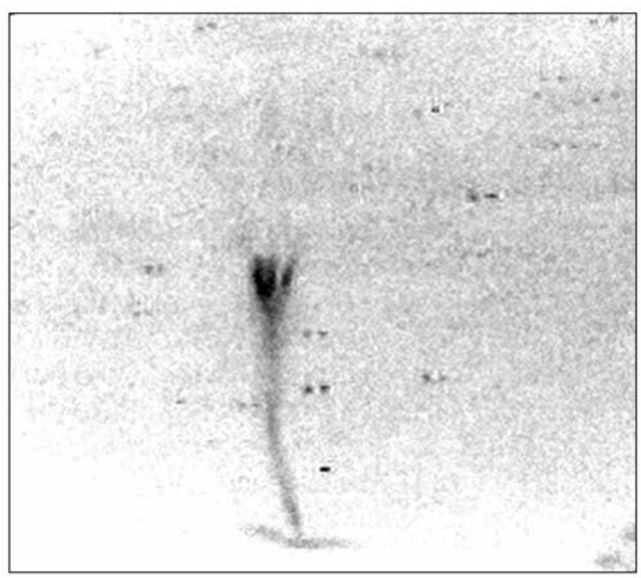

Figure 2. Contrast-enhanced inverted image of the gigantic jet, obtained by overlaying the jet in the images from the two cameras. The dots are stars displaying a parallax of 15–20 arc min. Discernable branches stretch upward from the bright transition zone.

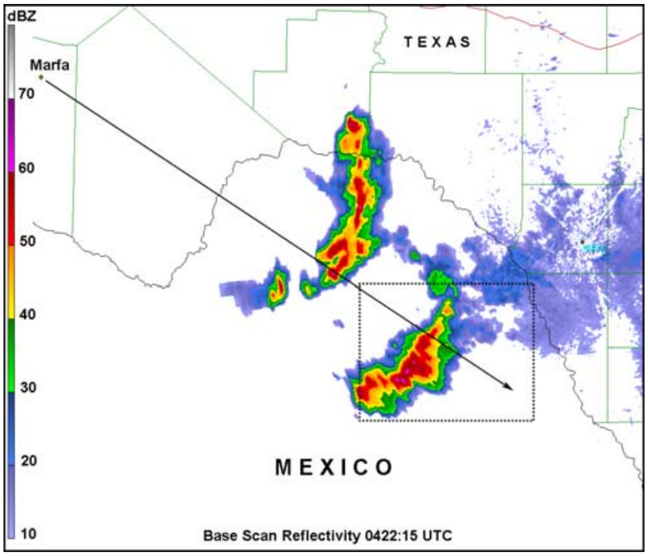

Figure 3. Base scan radar reflectivity at 0422 UTC from the Laughlin AFB, Texas, radar. The line of sight to the gigantic jet is indicated by an arrow. The box indicates the area of lightning activity plotted in Figure 6.

probability is greater that the more distant storm produced the gigantic jet, as also suggested by the storm top and altitude estimates shown in section 3.

3. Gigantic Jet Features

[8] The event appears as a collimated, slightly bent jet with a forked top. However, in both images, there are discernable dim branches extending upward half the height of the main channel (Figure 2). The branches look similar in the images from both cameras so that image noise patterns can be ruled out. The bright forked transition zone makes for a different appearance than that of blue jets, which have been observed as diverging cone shapes with gradually decreasing brightness. The gigantic jets of *Pasko et al.* [2002] and *Su et al.* [2003] show a long-lasting, relatively bright transition zone from which upward branches emerge. This similarity is the reason we believe this jet is a gigantic jet instead of a large blue jet as in the work of *Wescott et al.* [2001].

[9] No lower side streamers as in the work of *Pasko et al.* [2002] or *Wescott et al.* [2001] are visible. The lower tendrils of the recorded sprites (known to appear typically in only a few normal video frames) provided a reference in the assessment of brightness of the features in the 4-s accumulated frames. While the bottom gigantic jet channel appeared of similar brightness as the brightest of tendrils of the subsequent sprites, the wispy top part appears much less luminous. Even if we assume a duration for the upper branched part of one normal video frame ($\sim$20 ms) with a longer-lasting lower channel, we must conclude that the brightness of the upper branches must have been less than most sprites. This marks a difference with the gigantic jets studied by *Pasko et al.* [2002] and *Su et al.* [2003], where the top parts appear as bright as sprites.

[10] The estimated gigantic jet altitudes depend on the choice of distance (Figures 3 and 4 and Table 1). The triangulation showed that the gigantic jet somewhat more likely occurred over the far storm. The great circle path runs over both the secondary storm top and part of the downwind anvil that produced National Lightning Detection Network (NLDN) detected lightning discharges within the time interval of the gigantic jet video image, at approximately 305 and 348 km from the camera baseline. Heights calculated using these distances mark lower and upper bounds for the gigantic jet features. Also listed in Table 1 are the heights if the close storm at 233 km had produced the gigantic jet. These are considerably lower than previously documented cases [*Pasko et al.*, 2002; *Su et al.*, 2003; *Hsu et al.*, 2004], so assuming that the present gigantic jet reached similar altitudes of 70–90 km, the far storm must have been the more likely producer of the event. The channel width calculated from these distances cannot be reliably calculated since it barely exceeds the pixel width of stars, which have an infinitely small angular size in reality. The wider fork feature varies from 3 to 5 km according to the choice of near or far storm, respectively.

4. Electromagnetic Signals

[11] The NLDN detected the storm's cloud-to-ground discharges. During the 0423:47–0423:52 UTC time period bounding the gigantic jet image, only a few flashes were reported close to the direction of the gigantic jet. We also use the Duke University extremely low/ultralow frequency (ELF/ULF, 3–3000 Hz) radio sensor in North Carolina [*Cummer and Lyons*, 2004] to detect any lightning sferics from the direction of the jet. Figure 5 shows the continuously

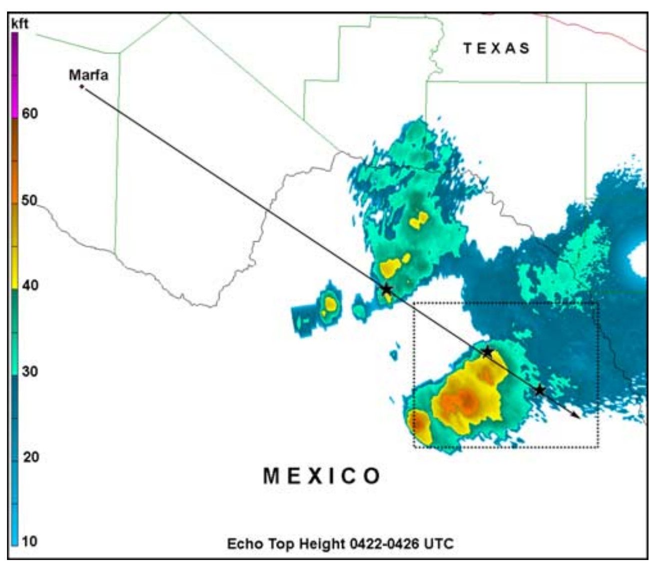

Figure 4. Radar echo top heights at 0422–0426 UTC (smoothed). Box and arrow are as in Figure 3. Stars indicate areas along the gigantic jet line of sight with lightning flashes during the gigantic jet time frame. The maximum top reaches about 17 km, while the highest tops under the gigantic jet azimuth are around 14 km.

Table 1. Altitudes Over the Spherical Surface of the Globe Corresponding to Possible Positions of the Gigantic Jet[a]

Elevation	Altitude, km at Distance of 233 km	at Distance of 305 km	at Distance of 348 km
Top of branches ∼11°	51	69	80
Top of fork 7.75°	37	51	59
Width of fork ∼46′	3.1	4.1	4.7

[a]Not corrected for atmospheric refraction of light.

measured azimuthal magnetic field at Duke University during the 5-s jet window. The system detected three clear sferics (shown as A, B, and C in Figure 3) that originated in the direction of the jet, all of which are positive polarity. Signal C is from a flash classified as two simultaneous −CG strokes by the NLDN that occurred at 0423:50.945 UTC in the anvil east of the far storm core. This waveform is unambiguously positive, which suggests that the NLDN must have had difficulty classifying this unusual discharge signal. The other two were not detected by NLDN. All three of these pulses were produced by impulsive charge moment changes between 40 and 50 coulomb times kilometers (C km). Signal B also contains a larger but slower charge moment change of an additional 450 C km over 70-ms duration. This waveform is not unlike a sprite-producing +CG, which can contain a modest return stroke and significant continuing current. These magnetic field recordings are continuous, not triggered, and therefore signals from all lightning and related processes are part of this analysis. Whether any of these signals were produced by or in association with the gigantic jet cannot be determined, given the uncertainty of the image time. However, even the largest total charge moment change (520 C km) is less than the charge moment changes possibly associated with jets reported by *Su et al.* [2003] (1000–2000 C km).

5. Thunderstorm Analysis

[12] Next Generation Weather Radar (NEXRAD) radar data from Laughlin Air Force Base in Texas were examined to understand the characteristics and organization of convection which occurred in the Big Bend region of Texas and the Serranías del Burro region of northeastern Mexico. GOES geostationary satellite and radar imagery initially revealed two distinct areas of convection (see Figure 3) that shared one large anvil canopy downstream at their northeast side. The western storm was a linearly organized multicell. The southern end of this line was composed of rapidly evolving multicellular convective elements. No cells within the line showed any supercellular characteristics. The cells over which the great circle path passes developed at the southern end of the line about 30 min before the gigantic jet and were decreasing in intensity shortly after the event. These cells reached echo tops of approximately 14 km (Figure 4), while values of 40 *dBZ* (decibels *Z*) (moderate precipitation intensity) in the reflectivity column were estimated to reach 10–12 km.

[13] The storm more likely associated with the gigantic jet was a "high-precipitation" (HP) supercell [*Moller et al.*, 1994]. This cell was part of a NNE-SSW oriented broken line of storms. Although we have no reports of severe weather from this sparsely populated area, large hail is common to this type of storm, and even a tornado could have occurred [*Edwards*, 2006]. The NEXRAD Level III hail indicator marked both this storm and the closer storm as hail producers.

[14] The embryonic cell that eventually developed into the storm of interest formed at about 0157 UTC and split

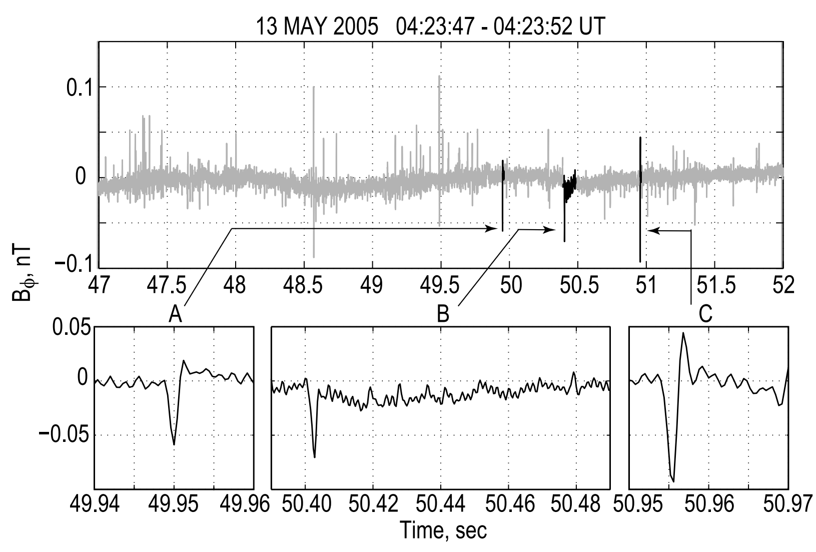

Figure 5. (top) Measured ELF/ULF magnetic field during the 5-s jet window. The three biggest sferics (A, B, and C) from the geographic direction of the gigantic jet are highlighted as dark. All other significant signals in the gray background are from other geographic directions. (bottom) Waveform of these three pulses, all of which are produced by impulsive charge moment changes between 40 and 50 C km. Signal B is also followed by a slow current containing an additional charge moment change of 450 C km over 70 ms.

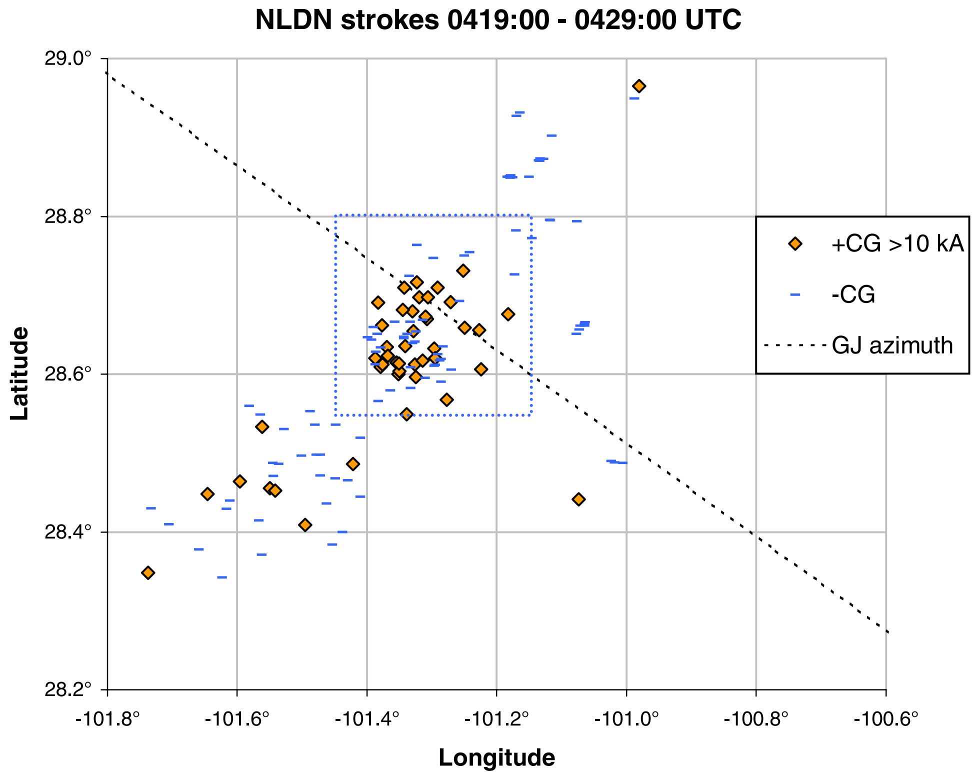

Figure 6. Plot of +CG and −CG strokes between 0419 and 0429 UTC. This domain is shown as a box in Figures 3 and 4. The portion over which the gigantic jet has occurred was dominated by +CGs, with −CGs occurring in the downwind anvil, suggesting a possible inverted polarity charge structure. The box marks the region used for the cumulative flash rate graph of Figure 7.

into left and right members at 0241 UTC. The right member became dominant and evolved into a HP supercell that displayed an inflow notch or hook echo radar reflectivity structure from 0325 to 0450 UTC. This notch was widest around the time of the gigantic jet and started to occlude 7 min later. Analysis of Level II reflectivity data using three-dimensional display software revealed that the maximum supercell echo top at the time of the gigantic jet was at least 17 km and possibly up to 20 km (uncertainty caused by the radar beam width), with a well-defined overshooting top penetrating the local tropopause of 12.7 km. However, the great circle path from the cameras near Marfa to the gigantic jet did not pass over the highest top and mesocyclone (rotating updraft) of the supercell but rather over the forward flank downdraft region [*Lemon and Doswell*, 1979] about 30 km to the northeast. This part of the storm also displayed very strong precipitation (>55 *dBZ* echoes) but had lower echo top heights of around 14 km. It may have been a separate convective cell, as there is a distinct separation in high reflectivities between the supercell main core and this area, and the echo tops indicate two maxima. In this supercell cluster, reflectivities of 40 *dBZ* were found at very high levels of 12–15 km.

[15] Infrared satellite images indicated the vigor of the supercell complex as the anvil of this storm was rapidly expanding against the direction of the upper winds. This may have caused convergence of the upper charge which may have been an additional factor in the initiation of the gigantic jet, although there is no certainty as to where exactly over the forward flank downdraft region the gigantic jet occurred. The largest possible distance of the gigantic jet (Figure 4) is associated with a part of the anvil away from precipitation at the surface, with radar echo tops of 10–12 km and reflectivities aloft of less than 25 *dBZ*. Almost no lightning activity was present in this part of the storm, except a sequence of a few NLDN-detected strokes occurring during the time window of the event, seen in Figure 6 near −101°, as described earlier.

[16] The storms formed in an environment sampled at 0000 UTC by the Del Rio, Texas, sounding, believed to be still roughly representative of the conditions near 0400 UTC on 13 May. Strong conditional instability with convective available potential energy values about 3000 J kg^{-1} and a lifted index of −9 may have actually been enhanced by higher dew point temperatures advecting into the Rio Grande Valley after 0000 UTC as indicated by the NOAA/National Centers for Environmental Prediction Rapid Update Cycle (version II) mesoscale model analysis for 0400 UTC. The HP supercell's overshooting top penetrating the tropopause by more than 4 km suggests very intense updrafts. The vertical wind profile was marginally favorable for supercell storms. Winds between 800 and 700 hPa levels displayed veering with height from southeast to southwest, while vertical wind shear and storm-relative flow were just at the lower margins common for supercells. The nearly stationary movement of the line of cells at the east side of the Serranías del Burro mountain range seems to indicate

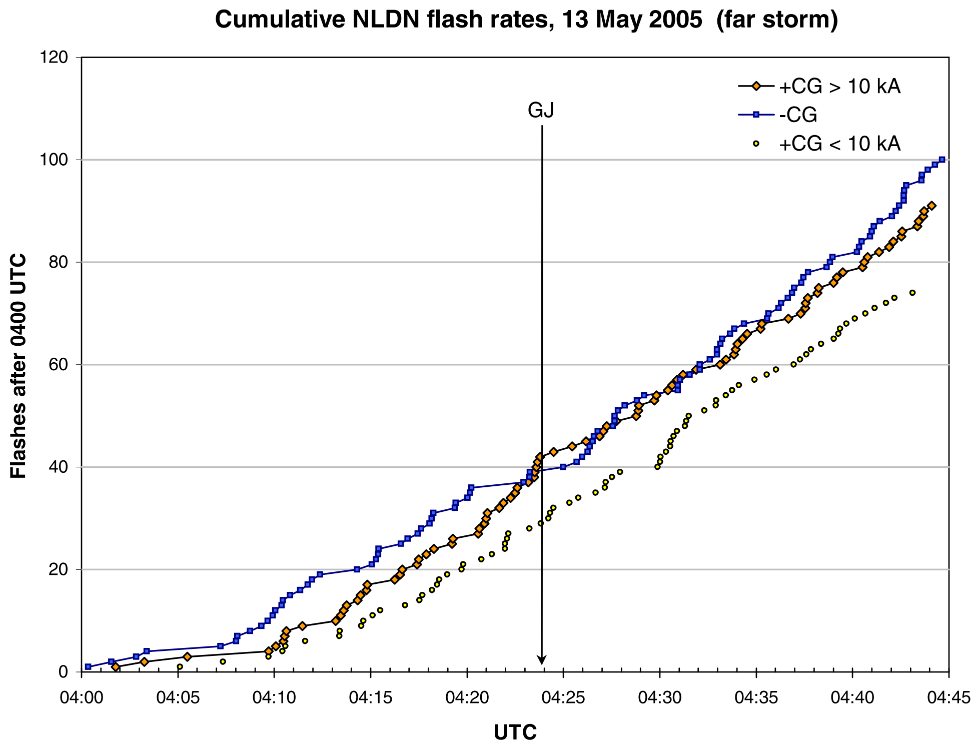

Figure 7. Cumulative flash rates (by NLDN) for the portion of the far storm near the direction of the gigantic jet, indicated by a box in Figure 4. A rapid rise of +CG flash rates occurs before the gigantic jet, during a 5-min period of almost absent −CG flashes, followed by a relative pause in +CG rates. NLDN +CG flashes <10 kA are considered a subset of intracloud flashes.

that orographic lift associated with southeasterly low-level flow was triggering the convection.

6. Lightning Activity

[17] We segregated +CG strokes with peak currents less than 10 kA, which are likely to be intracloud flashes falsely identified by the NLDN system [*Cummins et al.*, 1998]. Series of strokes occurring within 10 km and 1 s from each other were grouped as flashes.

[18] The HP supercell did not exhibit the highest cloud-to-ground flash rates of the storm cells in the region on this night. At the time of the gigantic jet, the HP supercell exhibited a low density of negative and positive CG flashes throughout the main core/mesocyclone region near 28.4°N and 101.45°W: only 26 −CGs and 8 +CGs during the period of 0419–0429 UTC (see lightning plots, Figure 6). Just 5 min prior to this period, −CG flash rates increased temporarily together with the intensification of rear flank downdraft reflectivites and widening of the inflow notch. The highest −CG flash rates occurred around 0433 and 0441 UTC.

[19] A separate more concentrated cluster of CG flashes occurred northeast of the main core/mesocyclone region in the forward flank downdraft over which the gigantic jet azimuth passes. This portion of the storm was dominated by positive CGs: 28 +CG flashes and 22 −CG flashes occurred during the above 10-min period (19 excluded +CGs had peak currents less than 10 kA), and only 11% of the peak currents of both polarities were over 20 kA. Farther north-east, around an extension of weaker precipitation, −CG strokes occurred in similar densities as in the main core region.

[20] In the part of the far storm over which the gigantic jet direction ran (depicted by a box in Figure 6), positive flash rates increased to a small "jump" of one flash every 5 s during the 20-s period before the gigantic jet (see the cumulative flash rate graph in Figure 7). A relative lull of more than 1.5 min followed, with only +CGs at 0424:30 and 0425:27 UTC, after which previous flash rates (2–3 min^{-1}) were regained. Negative CG flashes almost ceased during a long period (0420:13–0425:00 UTC), while positive flashes occurred frequently: 4 −CG flashes to 17 +CG flashes. Such a sequence appeared only once to this extent.

[21] Note that the chance of NLDN falsely categorizing intracloud (IC) flashes as CGs decreases gradually with increasing peak current, especially for +CG flashes. Several flashes that made up the jump were classified by NLDN as +CG of 12–16 kA and might have been IC. For >15 kA +CGs, rates did not change around the time of the gigantic jet (1 min^{-1}), while for weak +CGs <10 kA (most likely intracloud flashes), a small activity jump occurred 2 min before the gigantic jet.

[22] Following the method used by *Wescott at al.* [1998], an energy estimation can be obtained. While four +CG flashes are normally expected to occur during the 1.5-min lull, on the basis of previous average rates of 2.5 flashes per minute, only two occurred. The two missing +CG flashes would have had relatively low peak currents and a single stroke, so we assume that the ones in this storm are comparable in energy to normal −CG first strokes [*Cooray*,

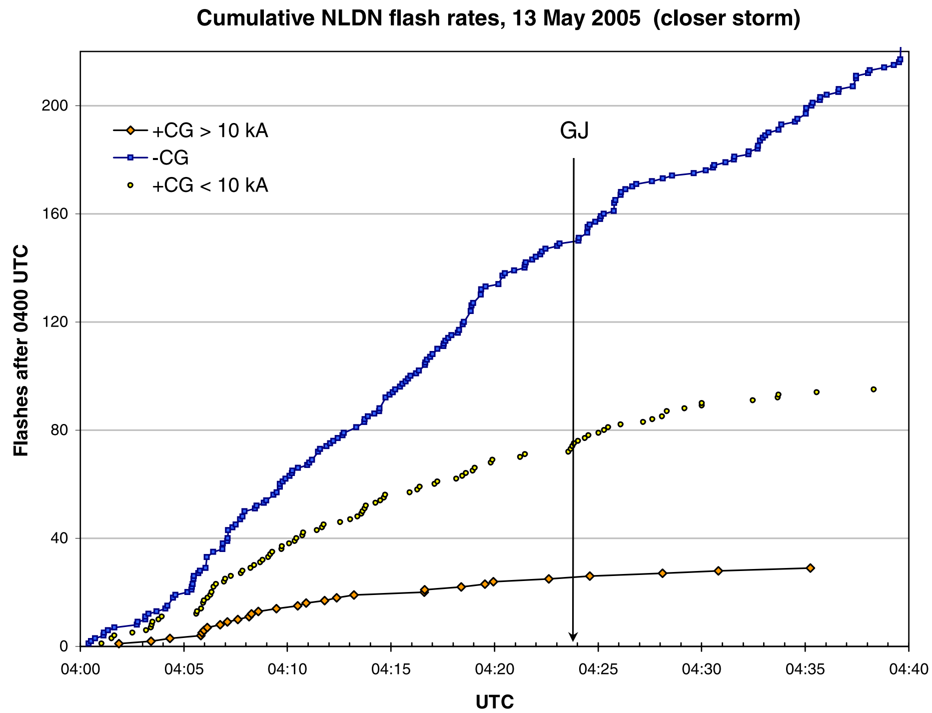

Figure 8. Cumulative flash rates (by NLDN) for the portion of the close storm near the direction of the gigantic jet. This storm produced about six −CG flashes per minute, with low +CG flash rates. Just before the time of the gigantic jet, a lull of −CG flashes occurred, with NLDN +CG <10 kA (intracloud flashes) starting to become active just before the time of occurrence of the gigantic jet (GJ), after an absence of 2 min.

1997]. This equates to an energy deficit of about 1.25×10^9 J that we suggest could be attributed to the gigantic jet. If we consider instead the four flashes per minute occurring during the few minutes before the gigantic jet, we arrive at twice the amount of energy, although the storm did not regain such flash rates.

[23] The same flash rate analysis was performed for the closer candidate storm, which was dominated by −CG activity. Figure 8 shows the cumulative flash rates for the southern cells of the linear multicell storm over which the gigantic jet path ran. It shows −CG flash rates of on average 6 min^{-1}. A short lull of about 45 s in −CG rates occurs before the time of the gigantic jet. Shortly before the gigantic jet, four weak NLDN +CGs, likely intracloud flashes, started occurring with a rate of one every 5 s, after a lull of 2 min. These rates slowed gradually after the event.

7. Sprites

[24] Thirty sprites were recorded from this storm, the first (0454 UTC) occurring 28 min after the gigantic jet with the last at 0820 UTC. The more frequent sprite rates were recorded after the two convective regions of the storm system coagulated, (forming a mostly parallel stratiform multichannel seismic profile [*Parker and Johnson*, 2000]) and developed a substantial stratiform precipitation region such as described by *Lyons et al.* [2003a]. Many sprites were quite bright and were associated with large impulse charge moment change values [*Cummer and Lyons*, 2004]. The 0606 UTC sprite parent +CG produced an exceptionally large value of 1908 C km. Imagery showed a group of bright columniform elements with long tendrils. Most sprites occurred a few tens of kilometers northeast of the cross section of the earlier gigantic jet azimuth and the far storm.

8. Discussion and Conclusions

[25] A gigantic jet occurred just east of the Serranías del Burro mountain range in northern Mexico. It is the first recorded over continental North America. At 28.7°N, this gigantic jet is the most distant from the equator documented so far. The event did not occur over sea (it occurred 440 km inland), which *Su et al.* [2003] previously speculated to be an important factor. One other gigantic jet [*Hsu et al.*, 2004] also occurred over land (but perhaps it also occurred in a maritime tropical air mass).

[26] A bright transition zone and dim upward branches correspond with the previously observed morphology of gigantic jets rather than blue jets, although we could not confirm upward propagation speed, color, and an accurate location of the event. We made the assumption that this gigantic jet reached similar altitudes as previously observed, thus placing it above the far storm with a top height of 69–80 km, consistent with those of *Pasko et al.* [2002] and *Su et al.* [2003]. The dimness of the upper part leads us speculate that this jet did not complete the electrical pathway to the ionosphere, lacking a return current as indicated by *Pasko et al.* [2002] and *Su et al.* [2003] as a rebrightening after the full height has been reached. This

may perhaps explain the weaker or absent ULF/ELF signal compared to the positive findings of *Pasko et al.* [2002] and *Su et al.* [2003], whose images also showed much brighter top parts.

[27] Our case shows that an exceptionally high thunderstorm cloud top directly beneath the gigantic jet is not the only determining factor for producing this phenomenon nor is the presence of a mesocyclonic updraft. Assuming the far storm system as the producing system, the gigantic jet occurred 30 km downwind (northeast) of a supercell core, from lower tops, where NLDN-detected lightning activity was predominantly positive at rates of 4 min^{-1} during the minutes before the gigantic jet. Although supercell charge configurations can be complex and are currently subject to intense study [e.g., *Stolzenburg et al.*, 1998; *Wiens et al.*, 2005; *Rust et al.*, 2005], the observed pattern of lightning may be indicative of an inverted polarity tripole charge configuration [*Rust and MacGorman*, 2002] with a main positive charge in the midlevel mixed-phase temperature region and significant negative charge in the anvil, away from the main core. Predominantly positive lightning activity is rare for normal thunderstorms but fairly common to supercells over the Great Plains of the United States [*Carey et al.*, 2003]. Despite having a view covering this area, more than 10 years of TLE observations from Colorado have not yielded any video observations of blue jets and gigantic jets.

[28] The vigor of convection in the far storm system can also be illustrated by comparing observed vertical reflectivity profiles to the climatology of *Zipser and Lutz* [1994]. With our storm displaying 40 *dBZ* echoes reaching into altitudes of 12–15 km, this reflectivity column is 3–6 km higher than the average for midlatitude continental thunderstorms. The anvil containing the farthest candidate position displays only reflectivities below 25 *dBZ*. Interestingly, in tropical continental and oceanic storms the 40 *dBZ* reflectivity column typically does not reach higher than 6 km, with oceanic storms exhibiting the weakest storm tops of less than 15 *dBZ* at altitudes beyond 9 km, due to weaker updrafts.

[29] If the closer linear multicell storm system with echo tops of about 14 km produced the event, the branches would extend to 51 km and the fork-shaped end of the bright channel to 37 km altitude. Predominantly negative flash rates of 6 min^{-1} were present (total rates more frequent than in the other candidate storm), and the cells were only 30 min old at the time of the event. The 40 *dBZ* column is less tall than that of the other candidate storm, 10–12 km, but is still much taller than for the average tropical storm of *Zipser and Lutz* [1994]. It is slightly above the average for midlatitude continental storms. Contrary to *Wescott et al.*'s [1998] observations, negative flash rates showed a lull before and during the event, while only NLDN-detected intracloud discharge rates showed a short increase just before the event.

[30] The far storm, however, displayed a rapid rise in cloud-to-ground lightning activity, followed by a lull that occurred around the time of the event, similar to the blue jet and starter events described by *Wescott* [1996] and *Wescott et al.* [1998]. In our case, this concerned positive flash rates (in the temporary absence of negative flashes), compared to the *Wescott et al.* [1998] case's negative flash rates. This is consistent with the different CG polarity dominance in the storms. There is a remarkable difference in the timescale, partly caused by the much lower flash rates in our storm (2.5–4 min^{-1}) compared to their storm (30 min^{-1}): about 1.5 min from start of the increase to the end of the lull, compared to a few seconds in the analysis of *Wescott et al.* [1998]. From our calculation we find a 2–4 times larger energy deficit than for *Wescott*'s *et al.* [1998] blue jets, or about $1.25–2.5 \times 10^9$ J using CG flash energy estimates by *Cooray* [1997]. Note that it is currently unknown how common such "rise-and-lull" flash rate features are and how often they are accompanied by jet-like TLE.

[31] If the association of the gigantic jet with the far storm is correct, it, together with *Wescott*'s *et al.* [1998] results, supports the thinking that (relative) removal of lower charge by numerous CG flashes may trigger jet events from the upper charge reservoir if a sufficiently high amount of charge has accumulated there. Besides this, *Tong et al.* [2005] found that their model preferred to initiate an upward discharge if a large vertical charge separation (one at 7 km and the other at 15 km) was used, which may also fit with our flash rate observations and the elevated charge hypothesis of *MacGorman et al.* [1989].

[32] *Pasko et al.* [1996] and *Pasko and George* [2002] simulated jets using the classic positive over negative charge dipole configuration from which they removed the lower negative charge. Extremely low frequency (ELF) signals in the work of *Pasko et al.* [2002] and *Su et al.* [2003], however, have suggested upward motion of negative charge. Our lightning observations also hint at an inverted-polarity charge configuration with an upper negative charge center. We therefore suggest reconsidering the negative streamer option for some of the jet phenomena (as modeled by *Sukhorukov et al.* [1996]) growing out of inverted polarity storms. The observed transition zone and the occurrence or absence of a return current appear equally worthy of modeling efforts.

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