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RESULTS FROM THE SPRITES'99 AND STEPS 2000 FIELD PROGRAMS

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1. INTRODUCTION

It was once a widespread misperception that the middle atmosphere above thunderstorms was quiescent and "uninteresting." However, on 0414 UTC, 6 July 1989, a low-light television (LLTV) system being tested at the University of Minnesota for a rocket flight accidentally captured two fields of video showing brilliant pillars of light extending tens of kilometers above distant thunderstorm tops (Franz et al., 1990). This confirmation of what are now called red sprites launched a period of intensive theoretical and observational investigations of the linkages between tropospheric lightning and electrical processes in the stratosphere and mesosphere. In 1993, an LLTV system at Yucca Ridge (near Ft,. Collins, CO) obtained the first intentional sprite images above a large MCS in Kansas. The sprites were almost exclusively generated by positive cloud-to-ground (+CG) lightning flashes (Lyons, 1994). Each year since, annual SPRITES campaigns have been conducted to further investigate the relationships between tropospheric lightning and the several classes Transient Luminous Events (TLEs) that have since been identified (sprites, elves, blue jets). A preferential region of sprite generation is the trailing stratiform region of large nocturnal MCS over the U.S. High Plains (Lyons, 1996; Williams, 1998). In general sprites are associated with high peak current +CGs, which are abundant during the night in this region (Lyons et al., 1998). Recent investigations using ELF signatures in the Schumann resonance band (3-120 Hz) called Q-bursts, suggest that charge monument (the product of the total charge transferred and the altitude from which it is removed) is the more pertinent metric (Huang et al., 1999). The SPRITES'99 campaign identified two additional classes of TLEs. STEPS 2000 obtained the first coordinated measurements of sprites with the first full-scale deployment of the 3-D New Mexico Tech Lightning Mapping Array and its electric field sensors (www.lightning.nmt.edu/nmt_lms).

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2. SPRITES'99

The 1999 campaign was conducted primarily in support of the NASA Office of Space Science Stratospheric Balloon Missions (Gar Bering, University of Houston, PI). During August, numerous storms over the High Plains were monitored using photometers, RF sensors (ELF, VLF) and high speed image-intensified cameras. The latter device, configured at 1000 fps rates, obtained evidence of an additional TLE type. A massive MCC over Nebraska on 18 August 1000 produced an impressive series of over 100 sprites, many of which were very bright (even visible to the naked eye at 500+ km. Some sprites were preceded by a diffuse, disk-shaped glow that superficially resembled elves. These were initially interpreted as elves followed by sprites ("sprelves"). However, these structures, now called "sprite halos," are usually less than 100 km wide, and propagate downward from about 85 to 70 km altitude. They last 1-3 ms (far longer than elves). Columnar sprite elements sometimes emerge from the lower portion of the sprite halo's concave disk as shown in Figure 1. Halos appear to be a response to the quasi-electrostatic field induced during large CG discharges (Barrington-Leigh and Inan, 2000). Initial inspection of the 1999 balloon data suggests that halos may also occur without sprites and perhaps may be induced by –CGs as well.

During the same 18 August storm, video confirmation was obtained of another TLE, the troll. In conventional LLTV videos, trolls superficially resemble blue jets (Wescott et al., 1998), yet they are clearly dominated by red emissions. Moreover, they occur after an especially vigorous sprite in which tendrils have extended downward to near cloud tops. The trolls exhibit a luminous head leading a faint trail and move upwards initially around 150 km/sec, gradually decelerating and disappearing by 50 km. It is still not known whether the preceding sprite tendrils actually extend to the physical cloud tops or if the trolls emerge from the storm cloud per se. Figure 2 portrays the final series of sprite illuminations and the subsequent troll.

3. STEPS 2000

The Severe Storm Electrification and Precipitation Study (STEPS) was conducted on the High Plains of eastern Colorado, western Kansas and southwest Nebraska from 22 May through 16 July 2000. The observational program was designed for coordinated measurements of the dynamical, microphysical and electrical processes within several classes of severe storms, especially those producing positive CGs (http://www.mmm.ucar.edu/community/steps.html). TLEs are preferentially associated with +CG events, often with large peak currents, yet not all large peak current +CGs generate optically detectable responses in the mesosphere. The Yucca Ridge Field Station monitored TLEs in the stratosphere and mesosphere above storms in or near the 400 km coverage area of the LMA, centered near Goodland, KS. STEPS provided the first opportunity to coordinate LLTV and photometric detection of TLEs with the NLDN, ELF and VLF signatures, lightning video and 3-D LMA. The goal was to comprehensively characterize those CGs which do, and do not, produce TLEs. Numerous observations of single and multiple (dancing) sprites above the trailing stratiform precipitation region of MCS were obtained (Fig. 3). Sprites (and most elves) were usually far removed from the high reflectivity convective cores Rather they tended to concentrate near the secondary reflectivity maximum of the trailing stratiform, where vales typically were 30-35 dBZ. TLEs are most commonly found above MCS with radar echoes (>20 dBZ) showing contiguous coverage of $>10^4$ km^2.

Supercells were a major focus of STEPS. It has been our experience over many years of LLTV monitoring that supercells, in spite of their extremely high intracloud (IC) flash rates and numerous +CGs, rarely produce many TLEs. The one exception appears to be during their decaying stage when significant stratiform debris clouds develop. On 25 June 2000, a supercell with nearly continuous IC discharges passed through the LMA. It was monitored by several LLTV cameras and produced no sprites – until the very last +CG of the storm (0529.05 Z). The sprite occurred over the low reflectivity portion of the decaying storm which had reached a size of ~7500 km2 (but which did have an extremely large anvil many times this size). Initial ELF observations in California (Martin Fuellekrug, personal communication) showed the parent +CG produced a classic Q-burst. Charge moments computed by Steve Cummer (Duke) found 1000 C-km in the first 2 ms and 1800 C-km after 6 ms, well above the 300 C-km threshold suggested by Huang et al. (1999). Initial inspection of the LMA return finds a complex discharge which initiates near 12 km and descends rapidly to 4-7 km while travelling several tens of kilometers horizontally (Mark Stanley, personal communication). STEPS data appear capable of testing the hypothesis that the prime generators of sprites are +CGs with large charge moments (>300 C-km) and unusual continuing current characteristics associated with horizontally extensive "spider" lightning discharges.

Cooperating with the Yucca Ridge program are onsite investigators from Stanford University (telescopic and photometric measurements), and the Space Dynamics Lab of Utah State University (OH imaging of storm-generated gravity waves). Offsite collaborators monitored ELF emissions associated with TLEs are Tel Aviv University (Colin Price), the Massachusetts Institute of Technology (Earle Williams), the University of Frankfurt (Martin Fuellekrug) and Duke University (Steve Cummer). Summaries of STEPS 2000 operations at FMA can be found at www.FMA-Research.com. Operations were coordinated with the University of Oklahoma balloon missions and the New Mexico Tech LMA and interferometer (Mark Stanley, Paul Krehbiel).

4. ACKNOWLEDGEMENTS
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Figure 1. High speed (1000 fps) image intensified camera showing the descending disk of a sprite halo (first two 2 ms) followed by the emergence of sprites from the halo's bottom ledge.

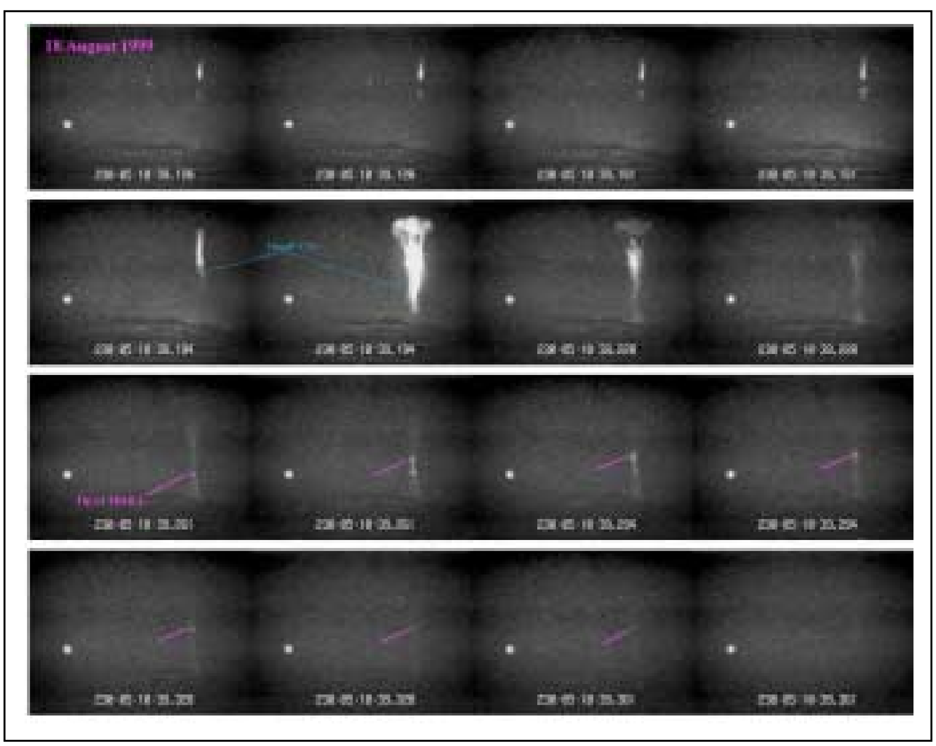

Figure 2. Portion of a Xybion red-sensitive LLTV sequence (17 ms fields) showing a sprite with downward extending tendrils followed by the upward growth of a troll into the decayed tendril channel.

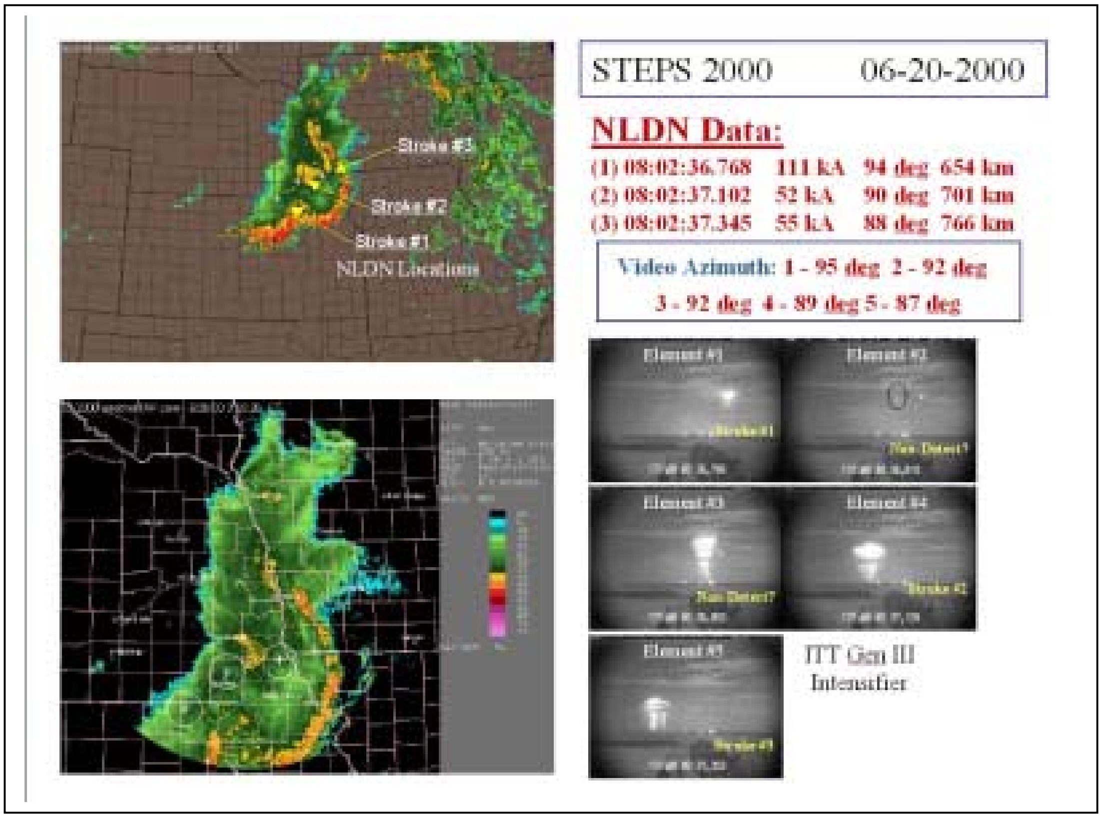

Figure 3.A "dancing" sprite in which five discrete elements propagated across the trailing stratiform region. Three of the sprites had associated +CGs in the NLDN, probably connected by a spider lightning discharge.

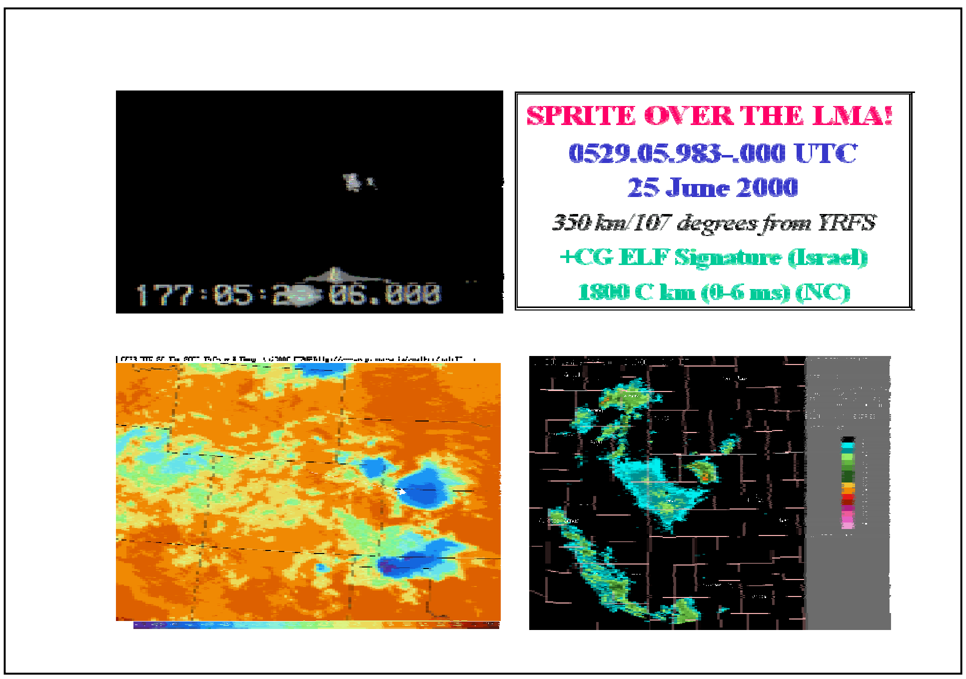

Figure 4. A sprite detected near the heart of the LMA at 0529 UTC during the decay stages of a supercell In spite of extremely high IC rates, no other TLE was observed. It occurred with the last +CG of the storm.