CHARACTERISTICS OF THUNDERSTORMS AND LIGHTNING FLASHES WHICH PROODUCE MESOSPHERIC TRANSIENT LUMINOUS EVENTS

W.A. Lyons[1], T.E. Nelson[1], R.A. Armstrong[2], E.R. Williams[3], D.M. Suszcynsky[4], R. Strabley[4], M. Taylor[5] and L. Gardner[5]

[1]FMA Research, 46050 Weld County Road 13, Fort Collins, Colorado 80524 USA
[2]Mission Research Corp., 1 Tara Blvd, Nashua, New Hampshire 03062 USA
[3]MIT Parsons Laboratory, MIT 48-211, Cambridge, Massachusetts 02139 USA
[4]Los Alamos National Laboratory, MS D466, Los Alamos, New Mexico 87545 USA
[5]Space Dynamics Lab, EL241, Utah State University, Logan, Utah 84322 USA

ABSTRACT: A six year record of optical observations of lightning-induced mesospheric transient luminous events (TLEs) is available from the Yucca Ridge Field Station (YRFS) near Ft. Collins, CO. Climatological analyses reveal sprites and elves occur in a variety of convective storm types, but principally mesoscale convective systems (MCSs) and squall lines. Severe supercell storms rarely produce TLEs, except during their dissipating stage. Few TLEs are observed during storms with radar echo areas <7,500 km^2. Above this size there is a modest correlation with radar areal coverage. A typical High Plains storm produces 45 TLEs over a 143 interval. Sprites and most elves are associated with +CGs. The probability of a TLE increases with peak current. In six storms, 5.1% of +CGs produced TLEs, the number increasing to 32% of +CGs with >75 kA and 52% of +CGs with >100 kA peak current.

INTRODUCTION

Since the 1989 discovery of tropospheric lightning-induced TLEs in the middle atmosphere, sprites, elves and blue jets have been investigated using a variety of methods. These include RF signatures (*Boccippio et al.* 1995; *Huang et al*. 1999), broadband and multi-color photometry (*Armstrong et al*. 1998; *Suszcynsky et al*. 1998), and low-light television (LLTV) (*Lyons*, 1994). Each summer since 1993, investigators have gathered at YRFS for intensive periods of coordinated observations. A constant among these field programs has been the use of LLTV systems (primarily red sensitive Xybion ISS-255 units) which continuously image the volume above convective storms some at 100-800 km distance when conditions appeared favorable. While the summer observational periods, typically lasting 6 to 10 weeks, are not identical from summer to summer; a general climatology has begun to emerge. The peak period during which storms produce TLEs optically observable from a High Plains ground station extends from July through mid-August. Currently the dates of TLE observations range from 19 May through 12 October. To date some 132 storms have been documented to produce 1 or more TLEs. Figure 1 shows the locations of storms and the number of TLEs produced over the three most recent summers. While sprites can be imaged under ideal conditions for ranges up to 1000 km, most observation periods were constrained to storms at 700 km or less. Figure 2 shows the climatology of large peak current (>75 kA) +CGs occurring during summer months. It shows a regional concentration of powerful +CG flashes in a broad belt ranging from New Mexico into Minnesota (*Lyons et al.* 1998). It is believed that the U.S. High Plains may represent one of the highest TLE producing regions in the world. On the other hand, TLEs undoubtedly occur, albeit at lower rates, in storms worldwide.

ANALYSES

A database was prepared of the observations from 60 storms during the 1996-1998 seasons with viewing conditions generally favorable throughout the storm's life cycle. The TLE event times were obtained from the nightly observer logs made directly from the LLTV monitors. These storm logs capture about 80% of the total events. Thus, the following statistics slightly underreport the true values. Sprites have been observed by LLTV at all times when ambient light conditions permitted their detection (about 45 minutes after sunset and before sunrise). In general, however, TLEs tend not to occur until at least an hour after darkness, perhaps in response to changes in the ionosphere after the passage of the terminator. Developing nocturnal storms also are increasing in size during this period. Figure 3 shows the temporal distribution of TLEs observed from YRFS. There is a broad maximum between 0400 and 0700 UTC (local sunset is typically around 0230 UTC). The fall off towards dawn represents the weakening of some storm systems and/or their passage beyond LLTV detection range. The number of events from storms varies from a single sprite or elve to 400 (Figure 4). The highest counts occurred during an intrusion of Mexican smoke into the central U.S. during the spring of 1998, which resulted in dramatic increases in +CG percentages and peak currents (*Lyons et al.* 1998). The mean TLE count per storm is 45. The duration of TLE production ranges from a single event to almost six hours, with a mean of 143 minutes. TLE rates vary from a few per hour to over 2 per minute (in smoke influenced storms). A long-term mean is one TLE event every 3.2 minutes. Events often occur at rather fixed periodic intervals for an hour of more.

In addition to the LLTV images, GOES satellite imagery, NEXRAD regional radar reflectivity mosaics, and the supporting meteorological data were archived. TLEs have been observed above a variety of convective storm types. In the High Plains, years of forecasting experience have shown they are most likely above large mesoscale convective systems (MCS) exhibiting horizontally extensive stratiform precipitation regions. The greatest number of sprites and elves has been associated with the largest mesoscale convective complexes (MCCs). Linearly extensive squall lines also produce sprites. Intense, compact supercell storms, though often extremely electrically active, rarely produce many TLEs, with the exception of brief bursts of sprites during their dissipating phase when a sufficiently large stratiform convective area develops. During the 1998 campaign, 21 storms were tracked throughout most of their TLE production phase. Hourly TLE rates ranged from 1 to 168. By far the two highest hourly TLE rates were associated with storms ingesting smoke from Mexican wildfires. The areal coverage of base reflectivity (generally >15 dBZ) during the hour of peak TLE activity ranged from 10,200 km^2 to 140,000 km^2, with a mean of about 50,000 km^2. Only isolated instances of TLEs have been noted from storms with <10,000 km^2 radar area. Above a threshold value of around 7,500 km^2 for sprite production, the peak number of hourly TLEs is modestly correlated with echo size (Figure 5). Using data from the 1998 storms, a curve can was fit (dashed line) showing this relationship. However, the two high TLE rate outliers (associated with smoke-ingesting storms) may represent a different regime of TLE-echo size relationship. During 1998, the correlation between the peak hourly TLE rate and radar echo cover has an R^2 value of 0.60. The peak TLE rate was uncorrelated to the total CG flashing rate (R^2 = 0.12), but showed a stronger linkage to the percentage of CG flashes with positive polarity (R^2 = 0.39) and the total number of +CGs (R^2 = 0.52). The 1998 storms producing TLEs had average –CG peak currents of 21 kA and +CG peak currents of 40 kA, the latter being somewhat higher than the annual U.S. mean of 27 kA. The percent positive rates during the peak TLE hour for 1998 storms ranged form 6% to 89% with a mean of 30% during the hour of peak TLE. However, in this sample the 8 potentially smoke influenced storms averaged 63% positive polarity, versus 13% for the other storms.

Detailed analyses were conducted for six storms in which all TLEs were precisely time-tagged and correlated to their parent +CG lightning (*Lyons* 1996). The storms includes smaller MCS systems, two large MCCs and a squall line. A total of 370 TLEs were detected. During the TLE producing intervals, the NLDN recorded 67,212 –CGs and 7,242 +CGs. Thus the percent positive for active TLE producing storms (9.7%) is only marginally higher than for most (non-smoke influenced) summer convective systems in the central U.S. The rate of TLEs (roughly 90% of which are sprites) is approximately 1 event for every 200 CGs reported by the NLDN for active storms. One of every 20 +CGs produced a sprite. Sprites typically are associated with +CGs with somewhat higher (order 50%) peak currents than others in the storm. We do note several apparent sub-10 kA +CGs triggering sprites (assuming the correct attribution was made between the sprite and parent +CG). Elves are associated with the largest peak current CGs (mostly +CGs but a few –CG have been recently documented). What is clear is the percentage of +CGs producing TLEs rises monotonically with peak current (Figure 6). Only 2.5% of +CGs with peak currents <49 kA produced observable TLEs. By contrast 32% of +CGs >75 kA and 52% >100 kA had TLEs, approaching 100% above 200 kA. If this sample is representative, then Figure 2 may represent a density map of TLEs (with the contour values divided by 3).

On a global scale, we note that the regions over which TLEs have been documented from ground observatories, aircraft and the Space Shuttle very roughly correspond to the regions of high lightning frequency. Figure 7 includes recent reports of sprites above Hurricane Georges (R. Hood, G. Heymsfield, personal communication) and over the Sea of Japan snow squalls long known for producing extremely powerful +CG events (Y. Takahashi, personal communication). It is unlikely, however, given the regional variability of characteristic storm type and size and frequency of +CG flashes, that a TLE density map would correspond closely to the total lightning density maps generated from orbiting sensors (the OTD and TRMM missions). Storm types similar to TLE-bearing U.S. High Plains systems are found in limited regions, including the South American pampas, southern Africa, the Indian subcontinent, and Australia. (Tropical cyclones and winter storms represent special cases). Many tropical convective systems are not necessarily TLE producers even given very high lightning rates, due to characteristically smaller areal coverage and lower numbers of +CGs than mid-latitude MCSs. However, the recent linkage between regional biomass smoke plumes and increased +CG percentages and peak currents compounds the difficulty in ascertaining global TLE distributions and frequency. Since massive biomass smoke palls are occurring with increasing frequency in tropical regions where deep convection is most common, it is conceivable that TLEs could episodically become very widespread throughout tropcial regions. Global-scale ELF transient monitoring may help reduce some of the uncertainties involved in developing a worldwide TLE climatology (*Huang et al*. 1999).

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REFERENCES

Armstrong, R.A., J.A. Shorter, M.J. Taylor, D.M. Suszcynsky, W.A. Lyons, and L.S. Jeong, Photometric measurements in the SPRITES'95 & '96 campaigns: Nitrogen second positive and first negative emission, *J. Atmos. Terr. Phys.*, 60, 787--799, 1998.

Boccippio, D. J, E.R. Williams, S.J. Heckman, W.A. Lyons, I.T. Baker and R. Boldi, Sprites, ELF transients, and positive ground strokes, *Science*, 269, 1088--1091, 1995.

Huang, E., E. Williams, R. Boldi, S. Heckman, W.A. Lyons, M. Taylor, T. E. Nelson and C. Wong, Criteria for sprites and elves based on Schumann resonance observations. *J. Geophys. Res*. (in press).

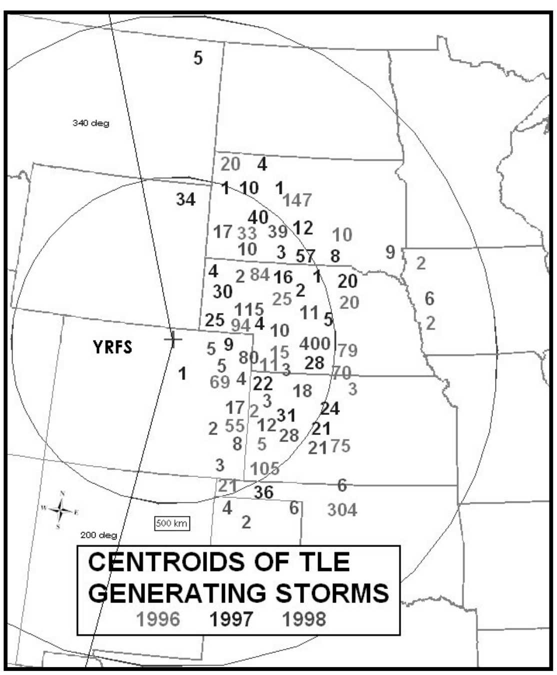
Lyons, W.A., Characteristics of luminous structures in the stratosphere above thunderstorms as imaged by low-light video, *Geophys. Res. Lett.* 21, 875--878, 1994.

Lyons, W.A., Sprite observations above the U.S. High Plains in relation to their parent thunderstorm systems, *J. Geophys. Res.*, 101 (D23), 29641-- 29652, 1996.

Lyons, W.A., T.E. Nelson, E.R. Williams, J.A. Cramer and T.T. Turner, Enhanced positive cloud-to-ground lightning in thunderstorms ingesting smoke from fires, *Science,* 282, 77—80, 1998.

Lyons, W.A., M. Uliasz and T.E. Nelson, Large peak current cloud-to-ground lightning flashes during the summer months in the contiguous United States, *Monthly Weather Rev*., 126, 2217--2233, 1998.

Suszcynsky, D.M., R.A. Roussel-Dupré, W.A. Lyons, R.A. Armstrong, Blue light imagery and photometry of sprites, *J. Atmos. Terr. Phys.,* 60, 801-809,1998.



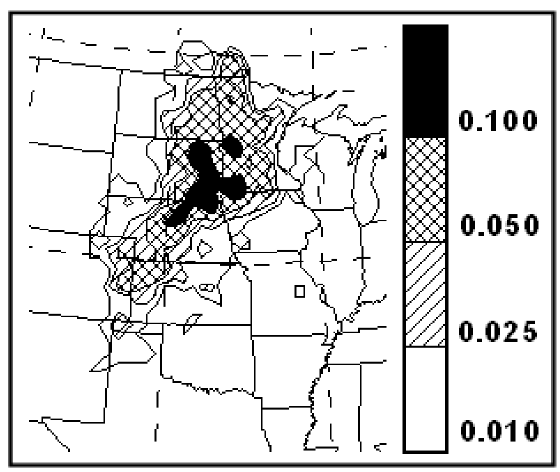
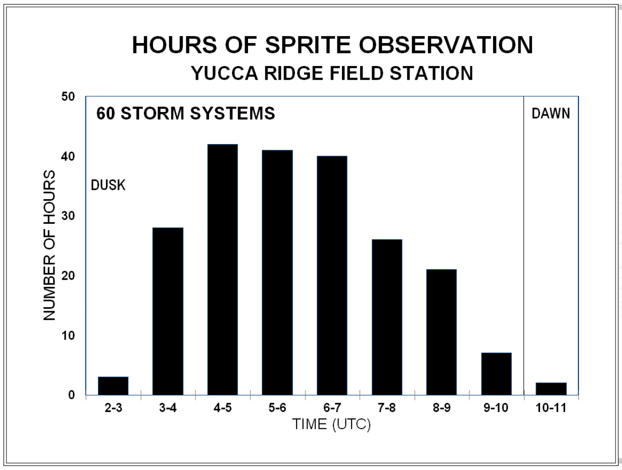


Figure 1. Locations of storms producing TLEs observed optically from the Yucca Ridge Field Station during the SPRITES'96, '97 and '98 campaigns. Figure 2. Density of +CG flashes with peak currents >75 kA, summed over 14 summer months, in flashe/ km2 (Lyons, Uliasz and Nelson, 1998).



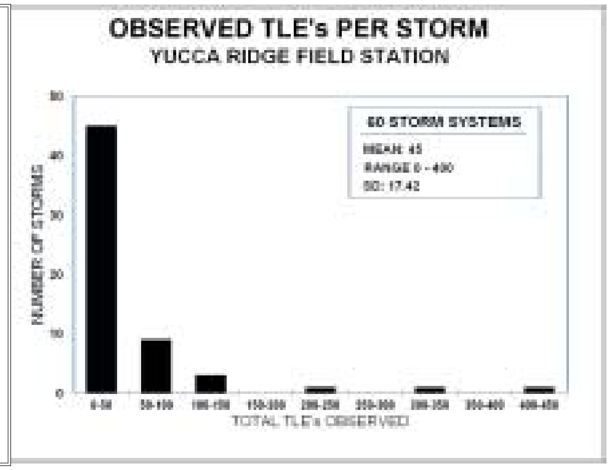
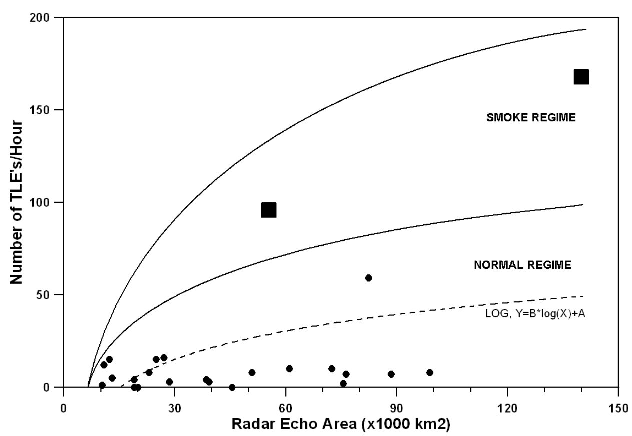


Figure 3. Hours (UTC) during which TLEs were optically observed from YRFS during the SPRITES'96,'97 and '98 campaigns. Figure 4. Distribution of the total number of TLEs optically observed from YRFS above 60 storms during the SPRITES'96, '97 and '98 campaigns.



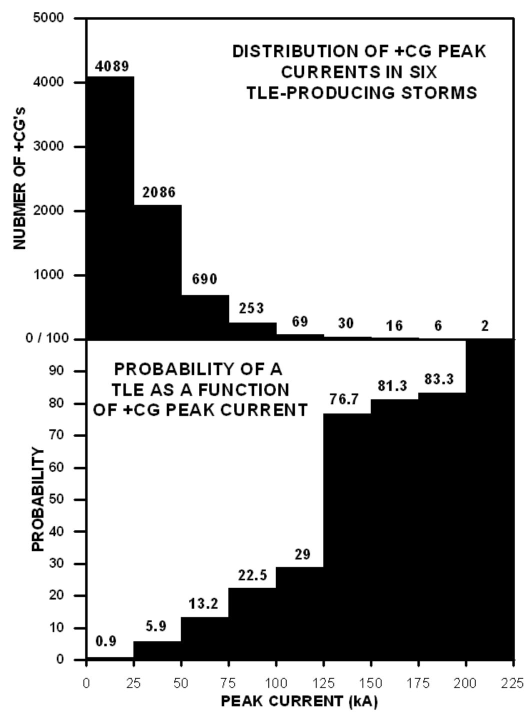


Figure 5. Distribution of radar echo area versus the highest hourly rate of TLEs for 21 storms during SPIRTES'98. The two apparent outliers are associated with storms ingesting smoke form Mexican biomass fires. Figure 6. Distribution of peak currents of all +CGs during TLE producing period in six storm systems (top) and the percentage of +CGs producing TLEs as a function of peak current (bottom).

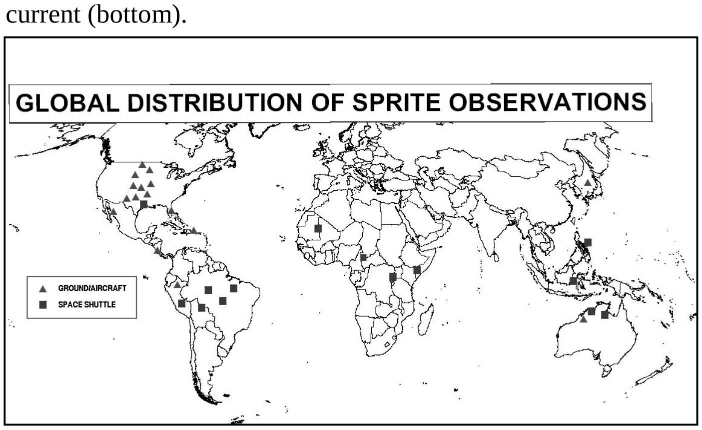


Figure 7. Global distribution of sprites confirmed by ground, aircraft and Space Shuttle observations. The distribution in the central U.S. represents a very small sample of the total events.