CHAPTER III
CLIMATOLOGY OF TRANSIENT ELECTROMAGNETIC EVENTS

III.1. Climatology observations from Yucca Ridge. Since the discovery of tropospheric lightning-induced TREMEs in the middle atmosphere (Franz et al. 1990), 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, 2000; 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 (described in chapter II). A constant among these field programs has been the use of LLTV systems (primarily red sensitive Xybion ISS-255 units) which can continuously monitor the volume above convective storms at 100 to 1000 km distance when meteorological conditions appear favorable. While the summer observational periods, typically lasting 6 to 10 weeks were not identical from summer to summer; a general climatology has emerged. Figure 1 summarizes the observational periods at YRFS during the period 1993 through 1999. The number of nights on which TREMEs were detected are also shown. Two factors determine the success in sprite hunting on any given night. The first is the character of the meteorological systems present on the High Plains. The second is whether clouds and visibility allow for a clear line of sight from YRFS to the target. The peak period during which storms produce optically observable TREMEs from a High Plains ground station extends from July through mid-August.

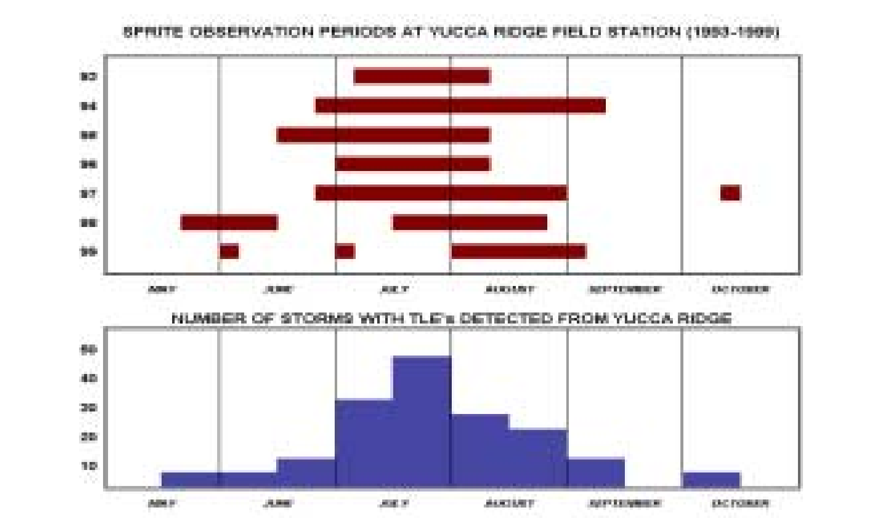

Figure 1. Summary of observational periods at Yucca Ridge Field Station.

Currently, the dates of TREMEs observations range from 19 May through 12 October. The ideal range from YRFS for sprite detection is between 200 and 500 km. The large majority of TREMEs are observed between 5 and 20 degrees elevation above the horizon.

Forecasting techniques continuously improved with each passing season. Based upon storm type, radar echo size, and the characteristics of the +CG lightning, we were able to issue short-term forecasts (approximately 2 hour lead times) of which cells would or would not produce TREMEs. Convective storms identified as TREME-capable actually were observed to produce events better than 90% of the time (visibility permitting).

Through 1999, some 147 storms have been documented to produce one or more TREMEs. While sprites can be imaged under ideal conditions for ranges up to 1000 km, most observation

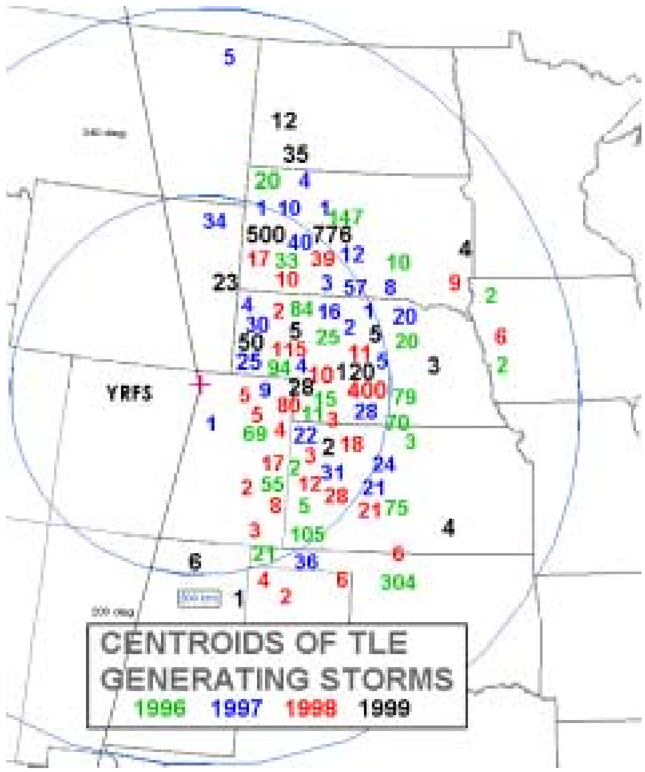

Figure 2. Centroids of TREME-producing storms in the region of Yucca Ridge Field Station.

periods were constrained to storms at 700 km or less. Figure 2 (left) is a plot of the centroids and the number of TREMEs for all monitored storms during the 1996–1999 period.

The climatology of large peak current (>75 kA) +CGs during summer months (discussed further below) shows a regional concentration of powerful +CG flashes in a broad belt ranging from New Mexico into Minnesota (Lyons et al. 1998). This is roughly coincident with the region of high sprite concentrations observed from YRFS. It is believed that the U.S. High Plains may represent one of the highest TREME-producing regions in the world. On the other hand, TREMEs undoubtedly occur, albeit probably at lower rates, in storms worldwide.

A database was prepared of the observations from 60 storms during the 1996-1998 seasons when viewing conditions were generally favorable throughout the storm's life cycle. The TREME 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, TREMEs tend not to commence 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 TREMEs 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 varied during these three years from a single sprite or elve to 400 (Figure 4). We discuss elsewhere in this report a single storm with 776 TREMEs with occurred during the 1999 season. The highest TREME 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 duration of TREME production ranges from a single event to almost six hours, with a mean of 143 minutes (Figure 5). The mean TREME count per storm is 45. TREME rates vary from a few per hour to over 2 per minute (in smoke influenced storms). A long-term mean is one TREME event every 3.2 minutes. Events often occur at rather fixed periodic intervals for an hour or more.

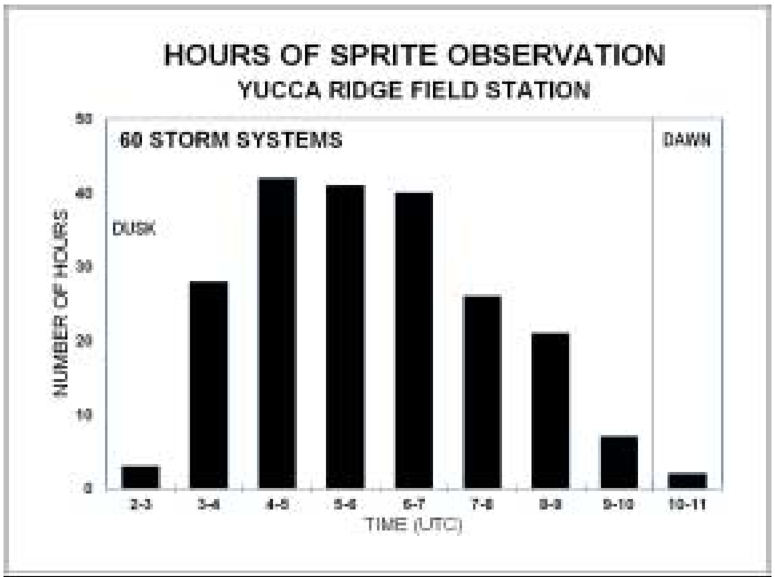

Figure 3. Temporal distribution of TREMEs observed from YRFS.

In addition to the LLTV images, YRFS archives GOES satellite imagery, NEXRAD regional radar reflectivity mosaics, and other supporting meteorological data. TREMEs 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 TREMEs, with the exception of brief bursts of sprites during their dissipating phase when a sufficiently large stratiform precipitation area develops.

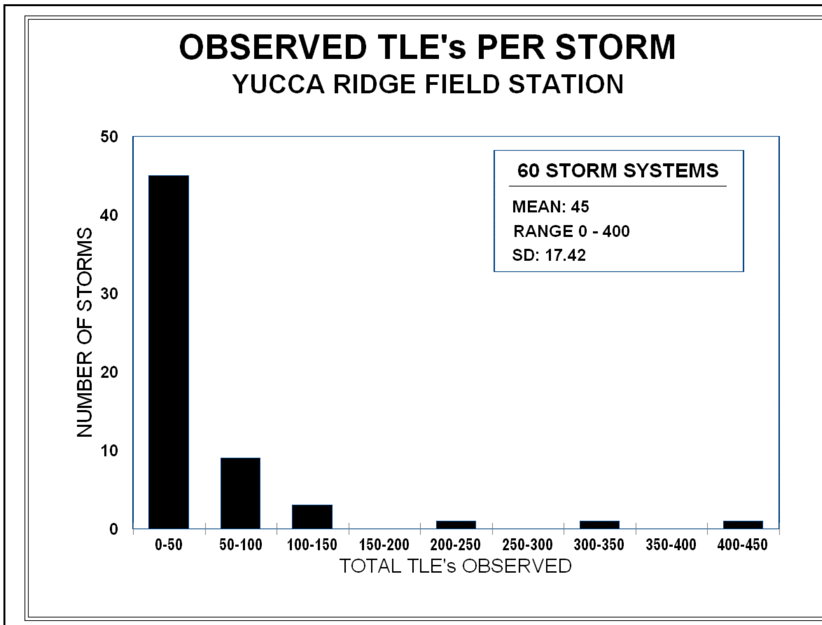

Figure 4. Histogram of the number of storms producing a range of TREMEs.

During the 1998 campaign, 21 storms were tracked throughout most of their TREME production phase. Hourly TREME rates ranged from 1 to 168. By far the two highest hourly TREME rates were associated with storms ingesting smoke from Mexican wildfires. The areal coverage of base reflectivity (generally >15 dBZ) during the hour of peak TREME 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 TREMEs 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 TREMEs is modestly correlated with echo size (Figure 6). However, the two high

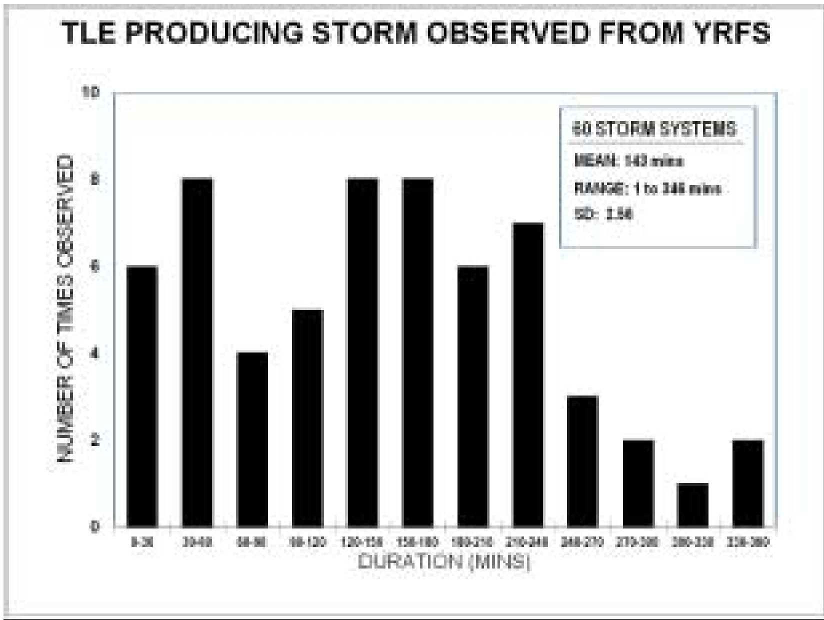

Figure 5. Duration of TREMEs in sampled storm systems.

TREME rate outliers (associated with smoke-ingesting storms) may represent a different regime of TREME-echo size relationship. During 1998, the correlation between the peak hourly TREME rate and radar echo cover has an R^2 value of 0.60. The peak TREME rate was uncorrelated to the total CG flash 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 TREMEs had average –CG peak currents of 21 kA and +CG peak currents of 40 kA, the latter being 48% larger than the annual U.S. mean of 27 kA. The percent positive rates during the peak TREME hour for 1998 storms ranged from 6% to 89% with a mean of 30% during the hour of peak TREME. However, in this sample the 8 potentially smoke influenced storms averaged 63% positive polarity, versus 13% for the uninfluenced storms.

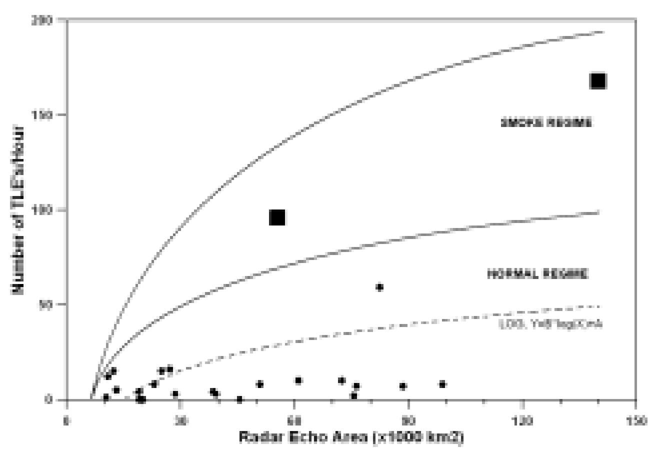

Figure 6. Correlation of the TLE production rate as a function of the radar echo area.

Detailed analyses were conducted for six storms in which all TREMEs were precisely time-tagged and correlated to their parent +CG lightning (Lyons, 1996). These storms included three smaller MCSs, two large MCCs and a squall line. A total of 370 TREMEs were detected. During the TREME-producing intervals, the NLDN recorded 67,212 negative CGs and 7,242 +CGs. Thus the percent positive for active TREME-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 TREMEs (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 (during TREME-generating storms only). Sprites typically are associated with +CGs with distinctly higher (order 50%) peak currents than others in the storm. We have noted several apparent sub-10 kA +CGs triggering sprites (although this assumes the correct attribution was made between the sprite and parent +CG). Elves are

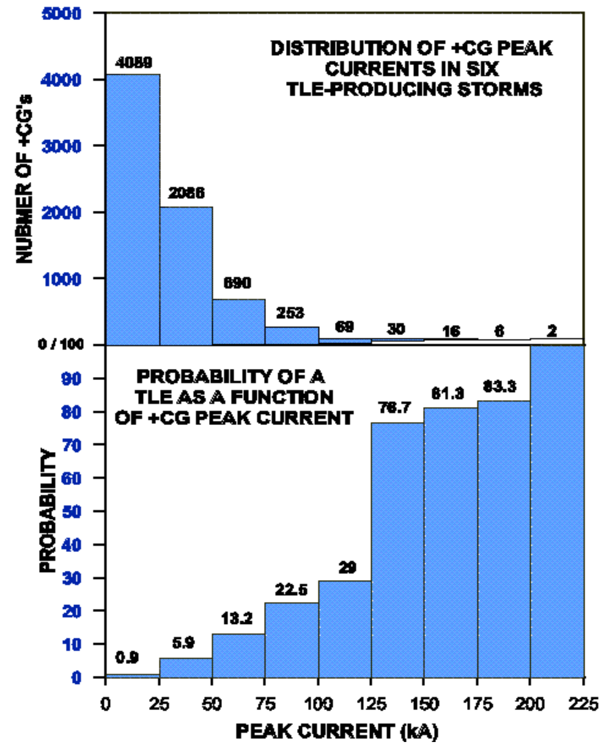

Figure 7. Distribution of peak current and probability of TREME with peak current.

associated with the largest peak current CGs (mostly +CGs but a few –CG have been recently documented). It is interesting to note that the largest peak current lightning events are do not usually exhibit the largest charge moments. What is clear is the percentage of +CGs producing TREMEs rises monotonically with peak current (Figure 7, left). Only 2.5% of +CGs with peak currents <49 kA produced observable TREMEs. By contrast 32% of +CGs >75 kA and 52% >100 kA had TREMEs, approaching 100% above 200 kA. It must be remembered, however, that Figure 7 is only valid during the limited period in which given storms are producing sprites and elves.

III.2.Global Climatology: Given the broad distribution of eyewitness reports available even before video confirmation of the existence of TREMEs, it seems fair to presume that sprites, elves, blue jets and related phenomena occur worldwide. In the United States, TREMEs are most likely to occur with massive MCC storms. Convective storms resembling these U.S. High Plains systems are found in other selected regions around the world (Laing & Fritsch, 1997), including the South American pampas, southern Africa, the Indian subcontinent, and Australia (Figure 8 - right). Many other tropical deep convective systems are not necessarily TREME producers, even given their very high lightning rates, due to characteristically smaller areal coverage and lower numbers of +CGs than mid-latitude MCSs. However, the possible linkage between regional biomass smoke plumes and increased +CG percentages and peak currents compounds the task of ascertaining global TREME distributions and frequencies. Since massive biomass smoke palls are occurring more often in the tropical regions where deep convection is most common, it is conceivable that TREMEs could episodically become more widespread throughout tropical regions.

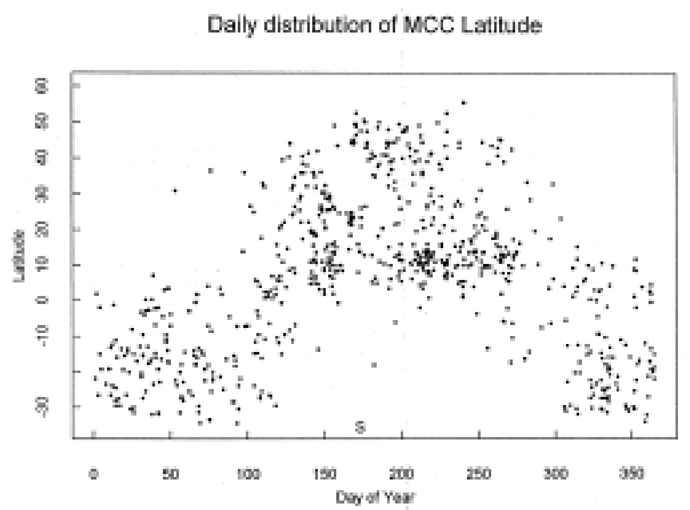

Figure 8. Global distribution of MCCs (Courtesy, Laing & Fritsch, 1997).

In the past several years, confirmed reports of TREMEs have been received from several regions outside the U.S. In 1998, Japanese & New Zealand researchers imaged bright sprites above deep convective storms in northwest Australia (Hardman, et al., 1998). During ER2 overflights of Hurricane Georges during NASA's 1998 CAMEX experiments, pilots reported visual observations of vivid sprites and/or blue jets (R. Hood, G. Heymsfield, personal communication, 1998). LLTV systems positioned at Langmuir Laboratory (New Mexico) and in southern Arizona have routinely observed very bright sprite events above the massive nocturnal thunderstorms that are common along the western Mexican coastline from Acapulco northwards Stanley et al, 1999). The University of Alaska researchers have recorded sprites over small storms in Central and South America (Heavner et al., 1995). Blue jet images have been obtained by amateur photographers in northwest Australia and over Madagascar in recent years.

During the cold winter monsoon season, the Sea of Japan has long been known as a breeding ground for an unusual class of convective storms. The Hokuriku Coast thunderstorms have been studied for two decades because of their production of powerful positive CG flashes associated with winter snow squalls. (Similar storms occur elsewhere, such as in the Great Lakes region). Unusually bright optical flashes ("superbolts") have been recorded in the area from spaceborne sensors (Turman, 1977). Thus given the known propensity of large peak current +CG flashes to create sprites and elves (Boccippio et al., 1995; Lyons, 1996), it was postulated by Lyons and Williams (1993) that this region should also produce wintertime sprites.

Our colleagues from Tohoku University (participants in the Yucca Ridge SPRITE campaigns since 1995) monitored this region during the 1998-1999 winter from a mountaintop using low-light television cameras. Sprites and elves were indeed recorded on two dates (Figure 9). On 19

Figure 9. Representative image of sprites occurring off the Hokuriku Coast in the Sea of Japan during winter (Courtesy, Y. Takahashi, Tohoku University).

December 1998, some 13 TREMEs were recorded followed by 16 more on 27 January 1999 (Fukunishi et al., 1999). It should be noted that the parent storms were very shallow, often less than 3 km in depth. What these storms do have in common with the High Plains cousins appears to be very powerful +CG flashes associated with vast horizontally extensive dendritic lightning channels.

We have summarized the regions over which TREMEs have been documented from ground observatories, aircraft and the Space Shuttle (Figure 10). At first glance there exists an approximate correspondence between the TREME reports and those regions of high lightning frequency as determined by orbiting lightning mappers (Figure 11).

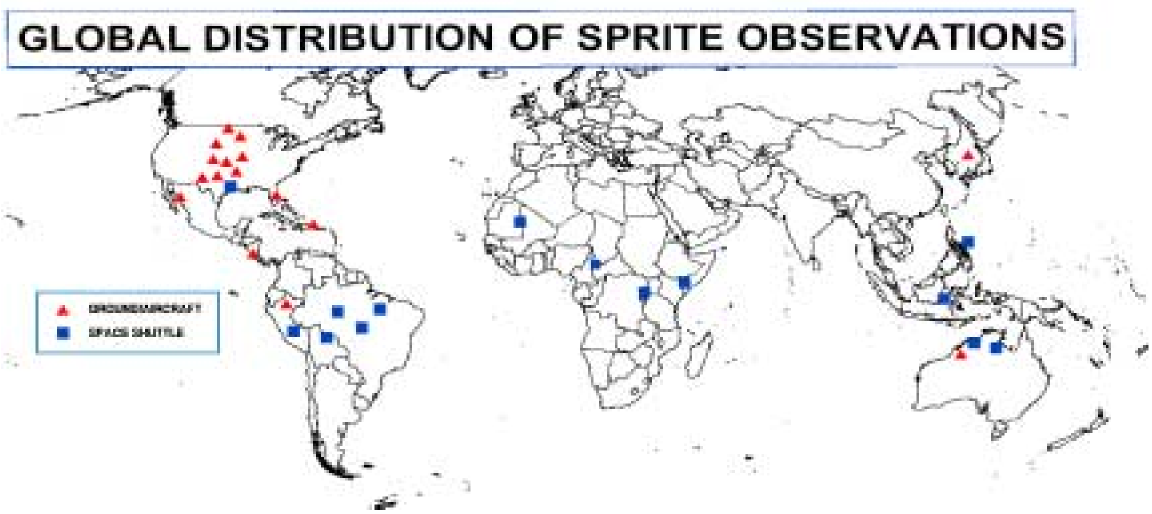

Figure 10. Global distribution of confirmed observations of TREMEs.

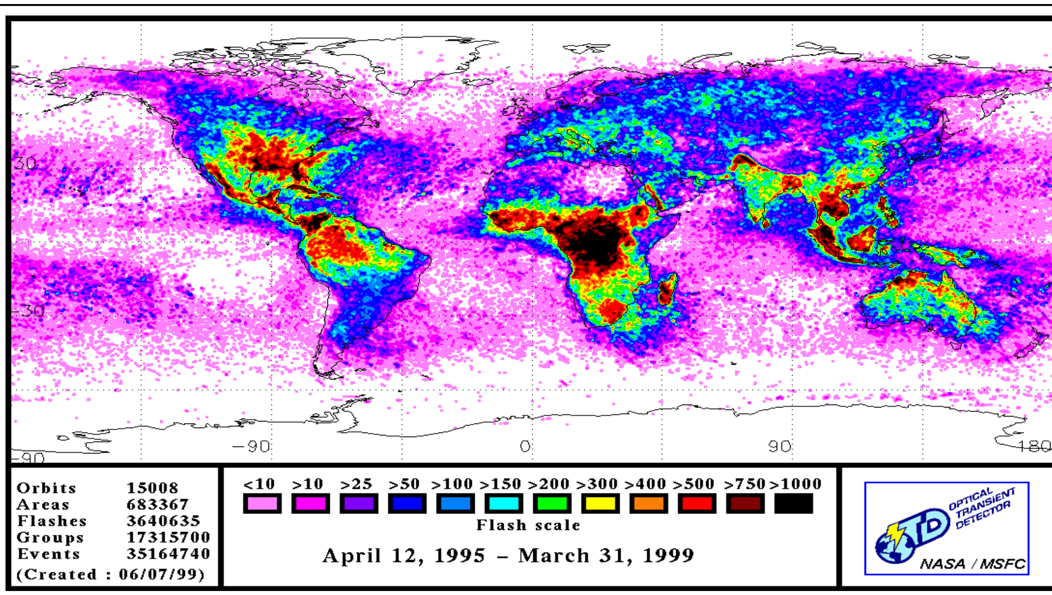

Figure 11. Global distribution of lightning events collected by the NASA/OTD satellite.

However, given the regional variability of characteristic storm types, sizes and frequencies of +CG flashes, a TREME density map may not closely correspond to the satellite based total lightning density maps (from orbiting sensors such as OTD and the TRMM mission). Global-scale ELF transient monitoring represents a much more direct technique to reduce the uncertainties involved in developing a worldwide TREME distribution (Huang et al. 1999) as discussed elsewhere in this report.

We can, however, use the new TREME climatological statistics to perform a rough "back of the envelope" calculation of the likely upper bound for global TREME rates. As indicated above, in those six U.S. storms with an accurate TREME and lightning census, we found one TREME per every 200 CGs (this is likely to be the highest possible rate that could be globally applied). It is estimated that for every CG there are roughly 5 intracloud (IC) discharges. Thus for the U.S. storms, there was one TREME per 1000 cloud flashes (CGs + ICs). Recent satellite estimates of global total flash rates suggest a mean value on the order of 50 flashes/second. Thus, if the U.S. TREME statistics are applied globally, we could expect a TREME rate at about once every 20 seconds. More detailed analyses of ELF transients (Q-bursts) might help determine how far below the postulated upper limit lies the actual global TREME rate. Initial impressions suggest that these estimates agree within an order of magnitude.

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