

**CHAPTER X.**  
**SATELLITE OBSERVATIONS OF UNUSUAL BEHAVIOUR ASSOCIATED WITH**  
**THUNDERSTORM LIGHTNING FLASHES**

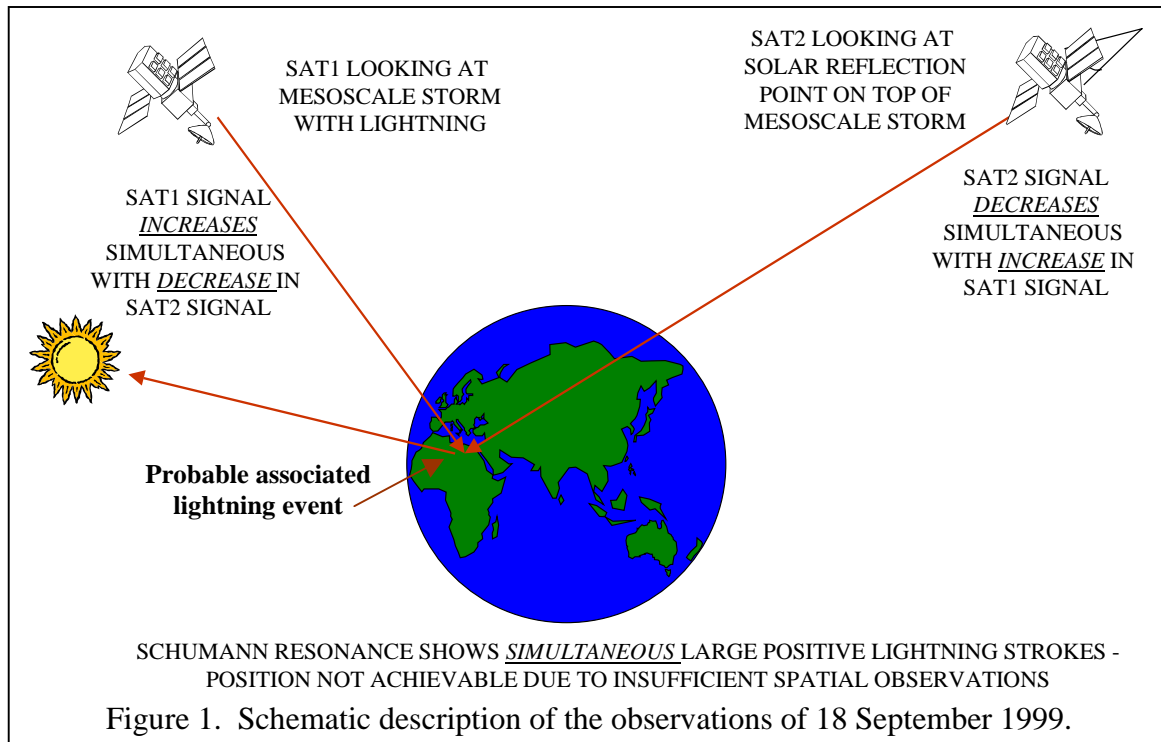
**(With contributions from Mr. Richard Spalding, Sandia Laboratories)**

**X.1. Introduction:** Some US satellites carry transient radiometric sensors capable of recording atmospheric visible-light flashes such as lightning and bright meteors (Tagliaferri, 1994). On 18 September, 1999, within a span of about 30 minutes, a sequence of seven visible-light flash events were detected by non-imaging transient radiometers aboard two geostationary satellites. Associated with three of these events were distinct shifts in the level of total background light from the earth received at each satellite. A consistent pattern, in which the satellite to the west of the event recorded an increase while the one to the east recorded a decrease, was observed. Changes in background level did not occur abruptly, but took place over a span of approximately one-half second, with onsets preceding the flashes by a quarter-second or less. Since these anomalous observations were not understood and were apparently associated with lightning from a mesoscale convective system (MCS), we held a DOE workshop on the topic in Albuquerque on 16 November 1999 to explore possible explanations. We considered a number of possible explanations but settled on a single viable explanation based on known physical properties of changes in solar reflectivity due to re-alignment of ice crystals as a result of the charge dynamics associated with large positive lightning events.

**X.2. Observations:** The satellites whose data is discussed here carry transient radiometric sensors to record atmospheric visible-light flashes such as lightning and bright meteors. The general characteristics of the sensors involved are that they are non-imaging, view nearly a hemisphere with a single silicon photodiode (bandpass 0.4-1.0 microns), and that they record changes in the total light level received. The single output waveform from each sensor is digitized at approximately 300 samples per second.

Anomalous emission signals have been recorded on several occasions with these sensors wherein one sensor would record a signal increase while a second would record a simultaneous decrease. Such observations have generally been sporadic and were thought to be an instrumental artifact. However, on 18 September 1999, a series of seven well-defined events occurred each of which exhibited the “one up – one down” waveform from two satellites. Because of the geometrical alignment, only two satellites recorded the observation so the exact location of the source events could not be unambiguously determined. However, consistency arguments suggest that they were in the vicinity of the equator, between 20W and 30E (discussed below). This location puts them on or near the African continent, which turned out to be an important clue in suggesting a possible mechanism. The general description of the observations is shown in Figure 1. The event times were (UTC) 1458.36, 1521.00, 1528.49, 1536.07, 1541.44, 1545.43, 1549.56.

The time-intensity waveforms of the flashes that triggered these observations, an example of which is shown in Figure 2, were themselves not unusual, being typical of events routinely recorded by these sensors throughout the year, events presumed to be of thunderstorm origin. The presumption that events of this type are thunderstorm-related is based upon their temporal patterns of activity, which build up and decay over spans of tens of minutes to a few hours, and



the fact that when locations have been obtainable (three or more satellites observing same event) those locations fall in cloud-covered regions of probable thunderstorm activity.

It should be emphasized that the characteristics of the flash waveforms involved here are not those of typical cloud-to-ground discharge activity, which usually consists of a sequence of sub-millisecond light pulses. Limitations imposed by the 300 Hz sampling rate and the corresponding electronic bandpass serve to lessen sensor response to activity of that nature, although a substantial amount of that type of activity is recorded nevertheless. Light pulses with durations of a few milliseconds or more are better matched to bandpass constraints, and are thus detected more efficiently. The seven events that triggered these observations were of that variety. Recordings of these longer light pulses have been categorized within the satellite data set, for want of better specificity, as “long-duration lightning”.

What rendered the “long-duration lightning” events in this sequence remarkable were the apparent changes in the level of background light from the earth that occurred with each of them. With each event, there was a marked difference in the background level in the seconds following the event compared to that which had existed prior to it. The pattern of level shifts was consistently such that the satellite to the west recorded a distinct increase, while the satellite to the east recorded a decrease of even larger amplitude. Events exhibiting shift in background level had been recorded numerous times in the past, but, as isolated occurrences with normal background variations. The repetition in this sequence and the correlations between two satellites indicate with a fair degree of certainty that a real process at the earth is involved.

It is not known where on the earth these events occurred. Our first inquiry was of the MIT Schumann resonance facility operated by Dr. Earle Williams (described elsewhere in this report) since they have exhibited the ability to locate lightning events to within a few hundred

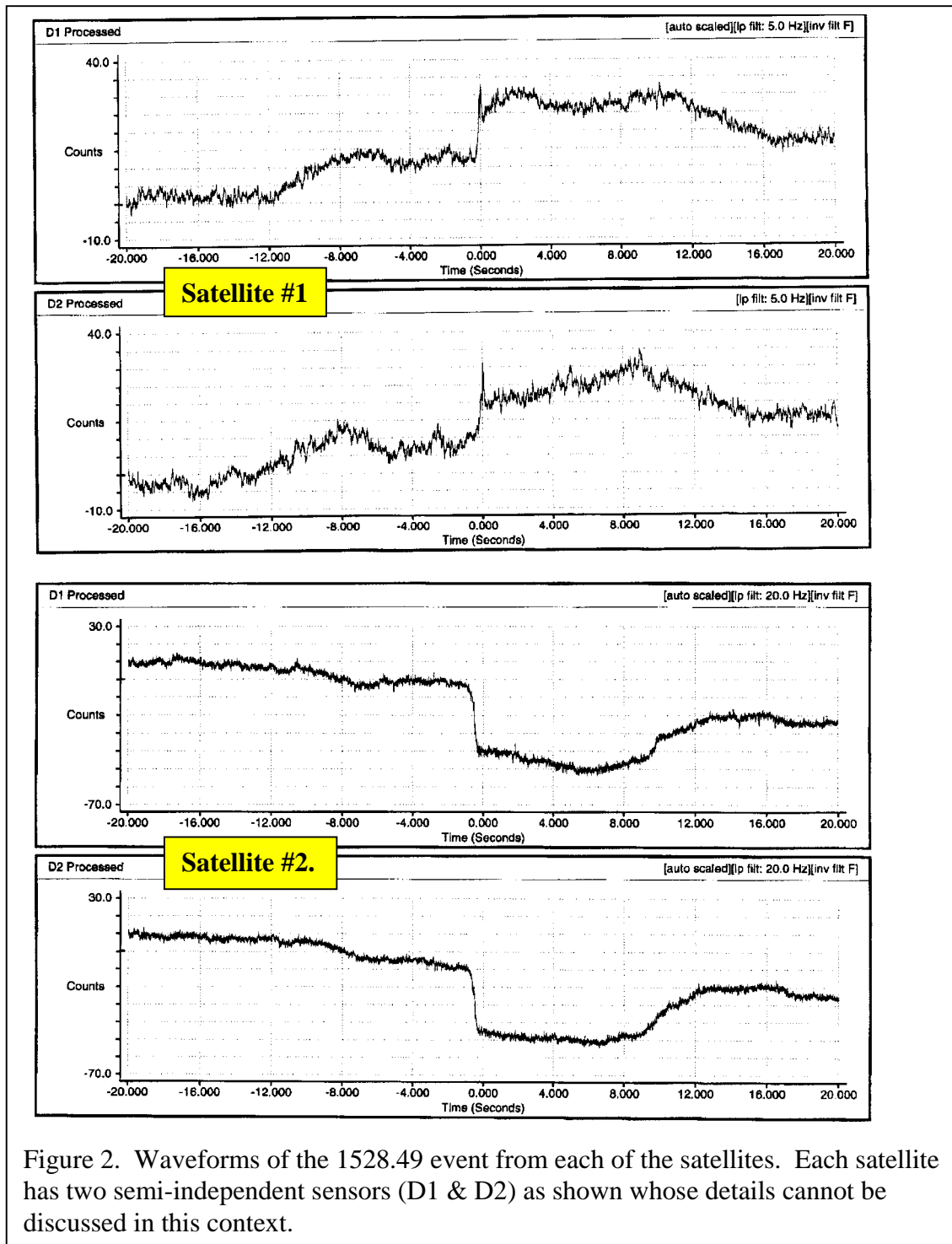
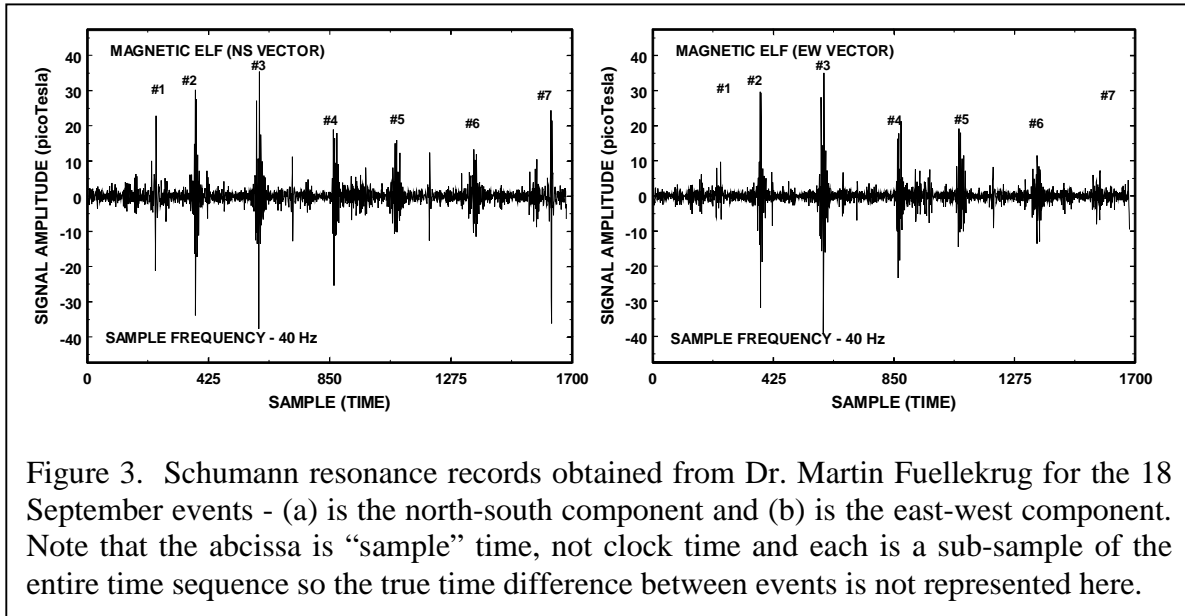


Figure 2. Waveforms of the 1528.49 event from each of the satellites. Each satellite has two semi-independent sensors (D1 & D2) as shown whose details cannot be discussed in this context.

kilometers. Unfortunately, at the time of these observations, a hurricane had traversed the east coast and knocked out the power to the station. We also inquired of the status of the Israeli Schumann resonance system (Dr. Colin Price) but they were not operational during this period. Searching further we discovered that Dr. Martin Fuellekrug of the Institute for Meteorology and Geophysics at the University of Frankfurt was operational with his Schumann resonance station. Dr. Fuellekrug's system obtains the magnetic component of the Schumann resonance (shown in

Figure 3) but not the electric component. Therefore while he can characterize the events, he cannot locate them with any certainty. He was able to identify the events as being associated large positive lightning strikes, offering another clue as to the explanation of the observations.



Unfortunately, we could not demonstrate an unambiguous location of the source events. However, the range of locations can be constrained to the mutual fields seen by the two satellites. In addition, based upon the relative flash signal amplitudes at the two satellites, it appears likely that the events were situated much nearer to the longitude of the western satellite. That would place them in the sunlit portion of the earth in the sub-tropical convergence zone. That determination must be regarded as tentative, however, since it is not possible to separate the effect of obscuration by weather clouds from the attenuation due to atmospheric path length and distance.

It is appropriate to remark upon the relative amplitudes of the background level shifts so as to convey their apparent scale. On the light curves examples of which are shown in Figure 2, above, one digitizer count corresponds to a source power at earth distance of about  $2.4E8 \text{ W sr}^{-1}$  of  $6000^\circ\text{K}$  blackbody radiation (solar). A negative shift in background of about 40 counts thus corresponds to a decrease of  $6E10 \text{ W}$  of scattered sunlight. Solar radiation onto clouds is about  $1.3 \text{ kW m}^{-2}$ , so the decrease in equivalent area amounts to about  $4.6E7 \text{ m}^2$  ( $46 \text{ km}^2$ ). This is consistent with the physical size of the top of a MCS, offering another possible clue as to the source of the anomalous readings.

**X.3. Possible explanations:** At the workshop, we discussed a range of possible explanations for the satellite observations.

1. Instrumental or processing artifacts
2. Airglow enhancements/diminishments
3. Rapid cloud formation
4. Combination of optical processes

Each possibility is addressed in the paragraphs that follow.

**X.3.1. Possible instrument or processing artifact:** Is it conceivable that the measured increases/decreases are not real but rather an instrumental or processing artifact? Considering how the information is derived, this is not likely. A substantial amount of signal processing is involved in extracting these background shifts, which are on the order of one-millionth of the total background. Consequently, small offsets or drifts induced by algorithm errors or imprecision cannot be ruled out. However, event detection is accomplished in ground data processing by creating and continually adjusting a prediction (template) of background behavior, then comparing current behavior to the existing template. Departure from predicted behavior exceeding a dynamic (noise-riding) threshold, results in capture of approximately one minute of data centered on the thresholding. The scene viewed by each satellite is not static, but continually changes due to satellite motion, earth rotation, and the evolution of clouds, so the prediction algorithm is necessarily designed to accommodate such changes. Thus, event detection (and data interpretation) amounts to determining a band of “normal” change behavior, then thresholding whenever change exceeds the normal.

In the thousands of thresholdings recorded each month, apparent background level shifts are seldom observed. Thus, there seems to be no inherent mechanism within the processing responsible for the effect. There are things that can occur on the satellite that could affect the apparent background, things like switching of power on other subsystems. However, power switchings would not explain coincident responses on two satellites, or moreover, a whole sequence of them that are time-correlated with Schumann resonance signals. The observations reported here were derived within a single computer. And, although data from each satellite is intended to be processed independently, it is not beyond imagination that an unintended coupling between satellite data sets could somehow occur within it. Such coupling could explain how a change on one satellite might produce a coincident change on the other. However, one would still need to explain how the initiating increase or decrease occurred in the first place. Therefore, for these observations the probability of the shifts being bogus seems so small that it is certainly prudent to believe them real and to look for explanation elsewhere.

**X.3.2. Airglow enhancements or diminishment:** We reviewed the possibility that a possible explanation for the unusual background behavior might lie in airglow or auroral phenomena. A fraction of the light background seen by the satellite arises from luminosity due to energy from the ionosphere/magnetosphere depositing into the atmosphere. If that rate of deposition can be modulated by electric/magnetic field disturbances, then the mechanism might constitute a means for producing rapid changes in the level of earthlight similar to those observed. Conceivably, extremely large areas of the atmosphere could be involved, so that only very small changes in the intrinsic brightness of the glow regions would be needed to generate the observed effects. In addition, it is quite imaginable that a widespread field disturbance could be oriented or polarized such as to create an enhancement in one area of the atmosphere and a diminishment in another. This would permit one satellite to see primarily the enhanced area while the other sees mostly the area containing diminishment.

Whether or not the total airglow contribution to earthlight is large enough to accommodate the observed changes might be questioned. If only nighttime airglow was involved, that would

certainly be the case. But, it would appear quite possible that our knowledge of airglow occurring in the areas under direct solar illumination may not be complete, since most observation of airglow is accomplished under twilight/nighttime conditions, and the extreme brightness of the daylight scene may have obscured some airglow processes. The preceding paragraph envisions airglow due to charged-particle deposition, but it seems quite possible that the efficiency of airglow production due to UV excitation could also be modulated by electric or magnetic field changes.

Such characteristic behavior of the atmosphere has not heretofore been documented and is very difficult to justify on any physical grounds that we could substantiate, especially at low latitudes. We are also faced with the relatively rapid and simultaneous changes in signal and the likelihood that the observations occurred during daytime events. It is also again true that the events correspond to the times of Schumann resonance signatures (described above), thus it is likely that some other phenomenon is responsible.

**X.3.3. A “new-cloud” hypothesis:** Another possibility considered for explaining the simultaneous effects on background levels at the two satellites is to invoke a rapid formation of a new cloud at high altitude in the sunlit region. While it may not be immediately obvious how introduction of a single cloud could produce an increase on one satellite and a decrease on another, that actually can happen in at least a small fraction of geometric scenarios. Primarily, it requires that the new cloud be situated well above existing weather clouds and that its albedo be higher than that of nearby unclouded areas. Such clouds are known to occur and are called “noctiluscent clouds”.

Suppose that from the viewing aspect of the westernmost satellite, a portion of the new cloud obscures regions that were not previously cloud-covered. Because sunlit cloud background is brighter than land or water scenes, the newly-clouded area will add to total background earthlight. Any previously-clouded areas obscured by the new cloud will make essentially no net change, so the composite would still be an increase. For the satellite to the east, suppose that from its viewing aspect the new cloud forms entirely over areas previously cloud-covered. Again, assuming similar albedos, where the new cloud obscures previous clouds, there would be little net change. However, the new cloud will cast a shadow, and within that shadowed region, the intensity of scattered sunlight will be reduced. Thus, for this geometry, the eastern satellite would record a decrease in background. For this shadowing scenario to be viable, the elevation of the new cloud would need to be tens of kilometers above existing weather cloud-tops.

An obvious question concerning the above is; what about the shadowed area for the westernmost satellite? Most likely, some of the shadowed area is in view of it. However, because that satellite is closer to the sun direction, it would observe less of it. All that is necessary for that satellite to register an increase is for the newly-clouded area to be greater than the newly-shadowed area visible to it.

In further speculation about these observations, it is natural to make a possible connection to the sprites phenomenon. The properties of sprites that invite such association are:

1. Altitude regime - sprites extend up to the lower ionosphere, thus can potentially affect the atmosphere at altitudes necessary to create elevated clouds. For the new cloud explanation to work as described, those clouds would need to be considerably elevated above the weather clouds.
2. Expanse - sprites can encompass 50 km or more in diameter. Thus, even if only a tenuous cloud were formed within the volume, it could still produce the effects noted.
3. Sprites are observed to occur in conjunction with positive cloud-ground strokes, which in turn occur in the phase of thunderstorm development where long-duration, horizontal, in-cloud flash processes are common.
4. Low visibility - sprites eluded detection for many years owing to their relative dimness compared to the attendant lightning. In daytime, the same may be said in comparison to the light from sunlit clouds. If a sprite also produces a tenuous cloud, an observer's vantage point may have to be just right to permit the cloud to be seen. At night, the cloud would almost naturally escape detection unless experimenters were pointed to its possible existence.
5. Onset time - Rapid development of a cloud of such large implied dimensions is virtually impossible via convective or shock-propagated processes. An electrical or electromagnetic propagation process, such as occurs in a sprite, is inferred.

Search for sprites-related diminution of background stars would constitute a good test of this hypothesis. We have performed a cursory search for such diminution with a null result. However, the instruments used for sprite observations are not well suited for this application.

A significant variation on the new cloud hypothesis adds the condition of sunglint to the scenario. Sunglint is near-specular reflection at the earth. The presence of sunglint can greatly reduce the degree of atmospheric transmission reduction necessary to create the observed effect. That is due to the intrinsic brightness of the glint region. Glint brightness varies immensely, and is greatest for near-grazing incidence on calm water. Swampy areas and slow-moving rivers are the most consistent bright-glint producers, because their water surfaces are generally protected from the wind. Wave action, nearly always present on larger bodies of water, usually reduces glint intensity, although on occasion seas and oceans can become quite calm. An additional property of grazing-angle sunglint that may be important here is that it is strongly polarized. That may permit an obscuration mechanism that is polarization-sensitive (such as aligned ice crystals, for example) to have a particularly large effect. Moreover, if an electric field change were capable of flipping the orientation of the obscuring/scattering particles, it could create an effect over a very large area.

While this mechanism cannot be ruled out on the basis of current knowledge, it is again difficult, on physical grounds, to justify. Although sprites are generated on very short time scales, we have never observed a "cloud" associated with them. The altitude of sprites extends across several scale heights and over a large variation in temperature. We know of no mechanism which could cause such a sudden cloud formation across such a wide altitude range. However, the possibility of a cloud suddenly changing scattering characteristics due to ice crystal alignment is a potential key to understanding the phenomenon (see below).

**X.3.4. Combination of optical processes:** The above scenarios are certainly not the only viable explanations. And, it is not necessary that a single mechanism be involved. It seems quite possible, for example, that the increase seen by one satellite and the decreases seen by the other are due to two different mechanisms, both triggered by an initiating event. Also, since the satellites can see widely separated regions of the earth, it is conceivable that the phenomena observed are not constrained to a single region.

During the discussion of these possibilities, it was suggested (by Mark Stanley, NMT), as mentioned in V.3.3 above, that the nature of the reflectivity of clouds can change as a result of the alignment of ice crystals. The alignment (or randomization) of the crystals is easily influenced by changes in electric and magnetic fields. In fact, this observation has been demonstrated many times under laboratory conditions. We coupled this information with the following observations to arrive at what we believe to be the most probable explanation of the satellite observations.

- (1) We know from the Schumann resonance data in figure 3, above, that the satellite observations were time-coincident with large positive lightning events.
- (2) Although the location of the lightning events could not be unambiguously determined, it is highly likely from the satellite geometry that the events were located near Africa in daytime, under which conditions large sub-tropical thunderstorms are known to occur (see discussion on Schumann resonance elsewhere in this report).
- (3) Assuming (2) is true, then the solar reflection point for the east satellite would have been in the region near equatorial Africa.
- (4) The intensity of the reflected solar energy at the specular reflection point is significantly greater than the intensity of any other natural event, including lightning.
- (5) There was another set of similar observations on 07 October 1999 under similar conditions in the same region. Further review indicated that all satellite observations identified to-date showing this “anomalous” behavior occurred in either spring or fall under conditions which would suggest that they all had the appropriate geometry for observations near the same location (Africa).
- (6) The discharges in MCS clouds are known to be quite complex, involving regions near the tops of the clouds which correlate especially well with large positive cloud-to-ground discharges. In revolutionary work by Krehbiel, et al (2000), detailed information on discharge channels has been obtained within large MCSs in Oklahoma. An example of this is shown in Figure 4, demonstrating time-and-space correlated interconnected channels which exhibit significant presence near the top of the cloud.
- (7) The location of discharge channels near the top of the thunderstorm cloud over large areal extents suggests that the field in the vicinity of the ice crystals that make up the cloud top suddenly changes, affecting the alignment of the ice crystals. Under these conditions, if the storm were near the solar reflection point, then the solar reflectivity of

the cloud as seen by the east satellite would significantly change. Such changes would not be as obvious at angles away from the solar reflection point.

The working group critically discussed these combined observations (1-7) and suggested what we consider to be the most likely explanation for the apparently anomalous satellite recordings. The east satellite, at the time of the observations, would have been observing the vicinity of the solar reflection point at the appropriate geographic location. If one assumes that the east satellite was observing the solar reflection from the top of the MCS associated with the lightning events as recorded by Martin Fuellekrug's Schumann resonance station, the field change associated with the discharges similar to those shown in Figure 4 (below) would have re-aligned the ice crystals for time scales similar to those observed resulting in a dramatic change in the solar reflectivity. This would, in turn, have significantly *decreased* the apparent signal intensity as observed by the east satellite. The west satellite, however, being distant from the solar reflection point, would have observed the lightning and seen an apparent *increase* in signal of duration determined by the discharge channel time (and the satellite reset cycle time).

It is our conclusion that this combination of events appears to be both very possible and the most likely explanation. It avoids invoking explanations which cannot be defended on physical grounds. It is suggested that weather satellite data be obtained to confirm the presence of thunderstorms in the region under question. This might be obtainable from Dennis Boccippio, using the NASA/TRMM/LIS data set. It may also be possible that the English lightning detection system may have records for this time and location. Exploring these suggested activities under this DOE contract effort was not performed.

#### **X.4. References:**

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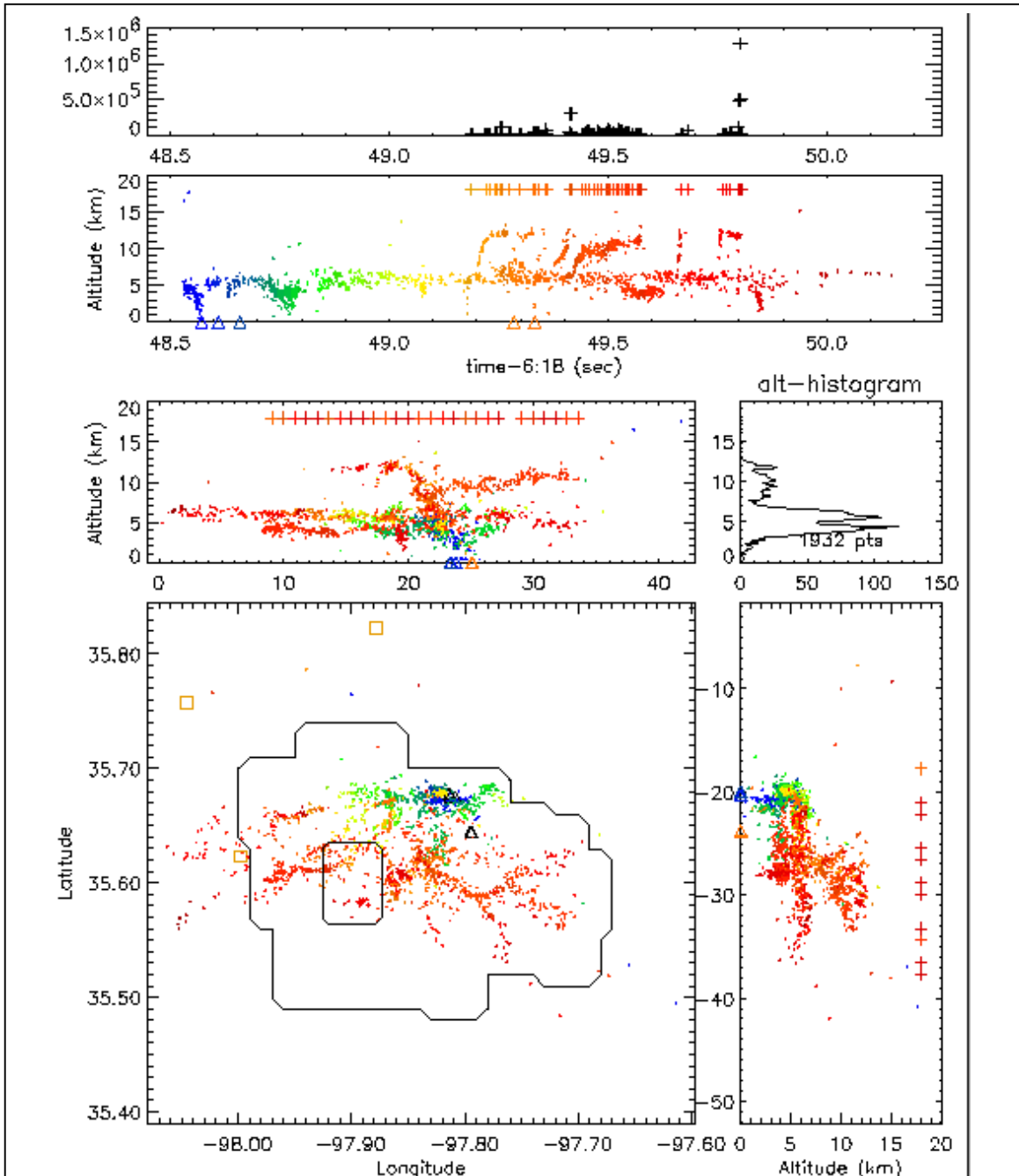


Figure 4. Lightning discharge event mapping using the lightning mapping array (LMA) (Courtesy, Paul Krehbiel & Ron Thomas, New Mexico Tech.). The top three panels show the time-altitude behavior along with the altitude histogram. The bottom two panels show the spatial correlations. The “+” signs show the correlations with large positive lightning events, color-coded by event.