Leader Studies with the Los Alamos Sferic Array

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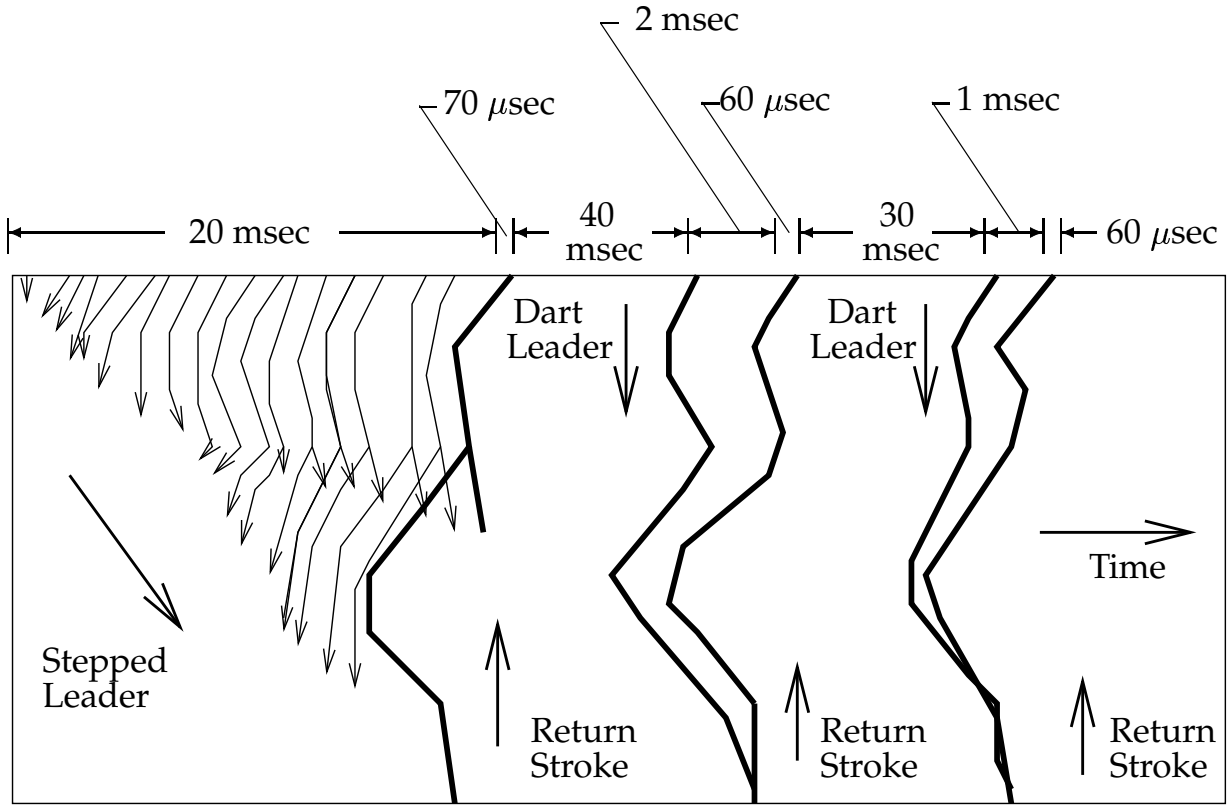
Abstract

The Los Alamos Sferic Array records the transient electrical activity associated with lightning discharges between 1 - 500 kHz. The multi-station array has been operated since 1998, routinely geolocating lightning based on the differential times of arrival at the stations. The fast electric field change records are predominantly 8 ms record lengths but are occasionally collected with longer record lengths (up to 1 s) to provide overall lightning discharge context (including leader activity). The stations are operated in a threshold-triggered mode and predominantly trigger on initial return stroke activity. However, individual stations may include leader radiation in the record or may even trigger on leader activity. The large number (> 2,000,000) of lightning events recorded provide a database for statistically significant studies of leader waveform parameters. We present initial results of studies of the leader activity in the sferic array database.

For a small number of leader events, the FORTE satellite recorded VHF emissions from individual leaders steps. The FORTE observations allowed source altitude determination for multiple steps and therefore vertical propagation velocity determination. One type of leader provides large amplitude signatures in both the LF/VLF of the sferic array and the VHF of FORTE. For this class of event, a velocity of 10^6 m/s has been determined. This speed is approximately an order of magnitude greater velocity than the typical stepped-leader associated with an intial return stroke.

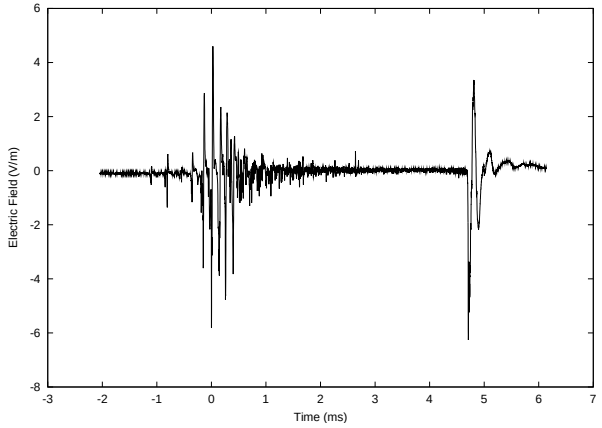
Leader Observations

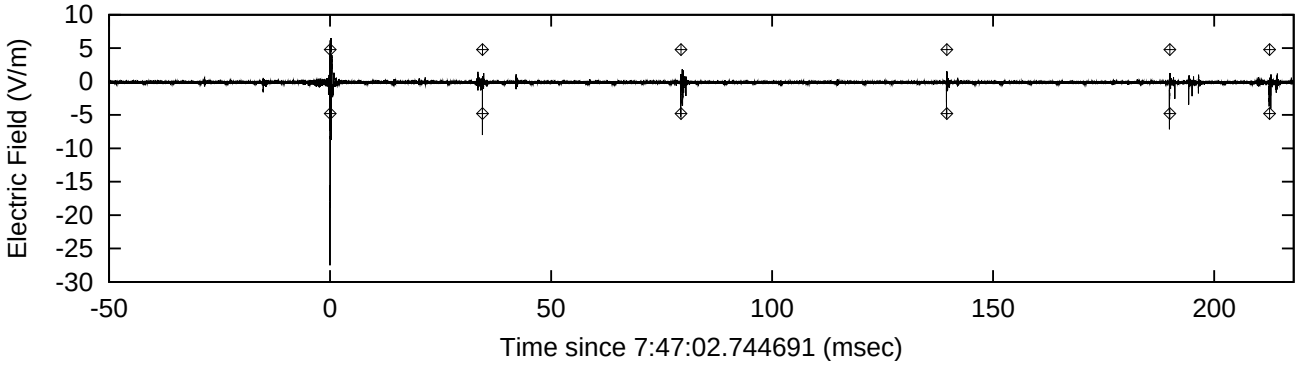


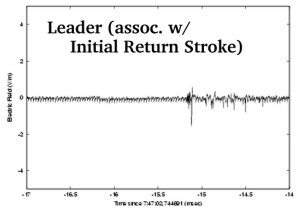
A negative cloud to ground (-CG) lightning flash often has multiple strokes. The figure above (after [4]) illustrates the typical timing of the processes of a multi-stroke -CG. A typical stepped leader has velocity $\sim 10^5$ m/s while dart leaders have velocity $\sim 10^6$ m/s.

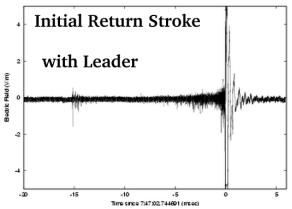
Leader Observations (cont'd)

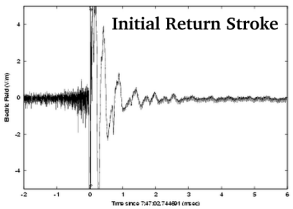
Predominantly, LASA [3] collected 8 ms of threshold triggered data, so the stepped leader 20 ms before the return stroke is not observed. The electric field change waveform at right presents a 8 ms LASA record with leader (which is extra-ordinary because of the fast/intense stepped leader).

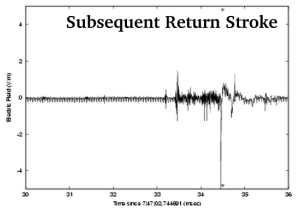








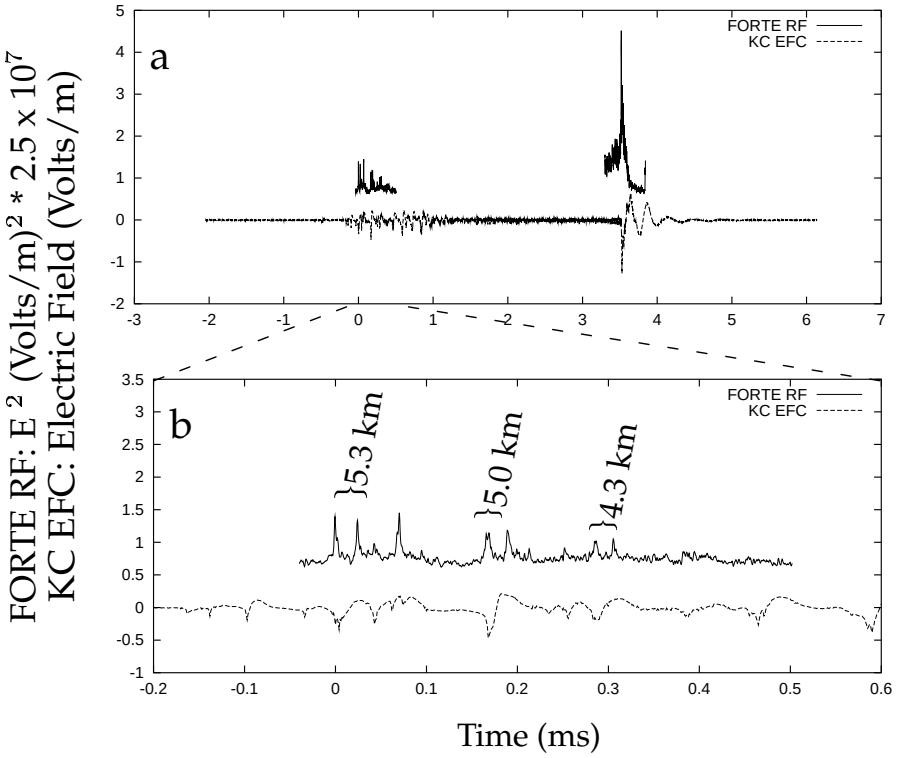




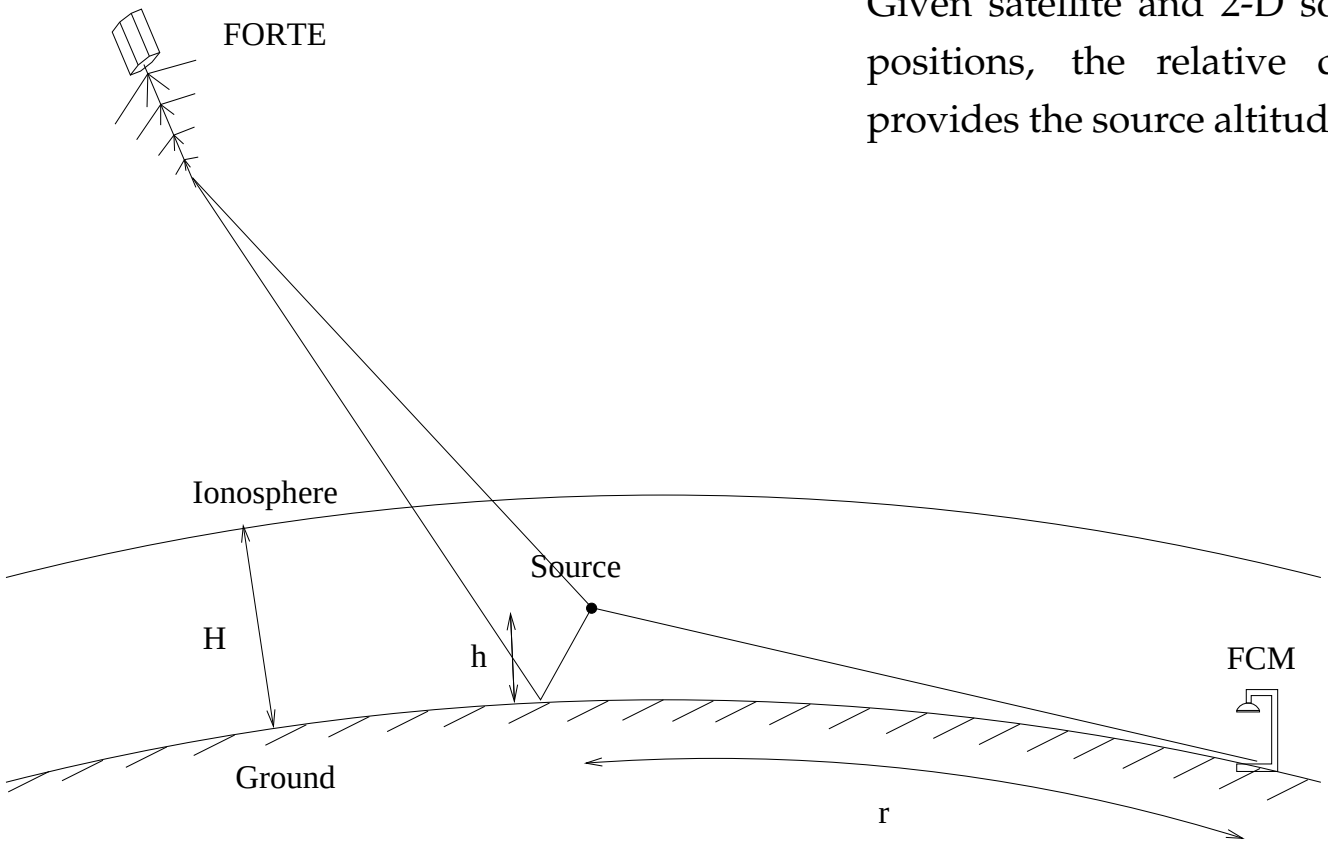
A longer (>250 ms) LASA record, presented above, has good agreement with the 'typical' time line presented on the previous page. The smaller panels are the same record with expanded time axes to illustrate the leader activity and a subsequent return stroke.

LF/VLF & VHF Lightning Fast Stepped Leaders

The July 11, 2000 16:20:39.615019 UT event is presented below. FORTE's 100 MHz receiver triggered twice during the 8 ms LASA record, collecting two 546 μs records. Panel a is the 8 ms Kennedy Space Center (KC) waveform overlaid with the two 546 μs FORTE RF records. (scaled by 2.5 x 10^7). The sferic array located the event ~200 km east of the Florida coast, 309 km from the KC station. Panel b is an expanded view of the 546 μs plot of FORTE power associated with the leader activity. Three pulse pairs are identified. Based on the delay between the direct and reflected pulses, the source heights are 5.3 km, 5.0 km, and 4.3 km as indicated. For time delays of 166.4 μs and 119.3 μs between the pairs of pulses, vertical velocities of 1.7 x 10^6 m/s and 5.4 x 10^6 m/s are determined. For the 285.7 μs duration across all three pulse pairs, the average vertical velocity is 3.2 x 10^6 m/s.



LF/VLF & VHF Lightning Fast Stepped Leaders(cont'd)



Given satellite and 2-D source positions, the relative delay provides the source altitude [2].

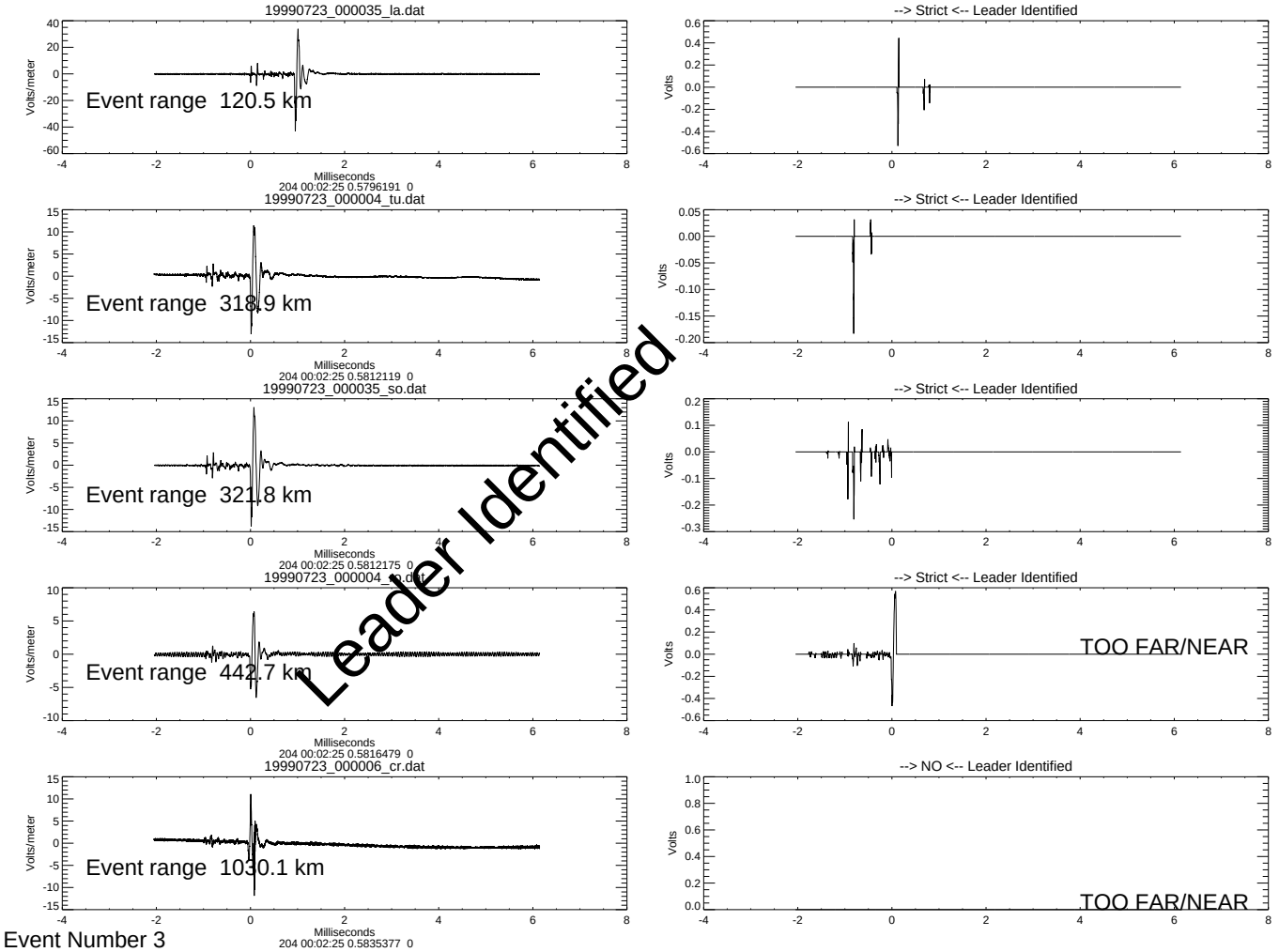
LF/VLF & VHF Lightning Fast Stepped Leaders(cont'd)

We have identified a total of four intense/fast leader events for which heights and velocities may be determined. These leaders associated with inital return strokes have average vertical velocity 2.1 x 10^6 m/s, with a range in velocities of 0.88 - 5.4 x 10^6 m/s. The leader step altitudes are between 4.0-5.5 km. The multiple-step velocity determination is consistent with the velocity required for the leader propagation from the initial height to the ground in the time between the initial leader and the return stroke. One important issue regarding these observations is whether the observed leader is from an initial or subsequent return stroke (to understand if the leader is a stepped leader or dart leader), based on evidence discussed by [1], the events are initial return strokes.

Leader Identification

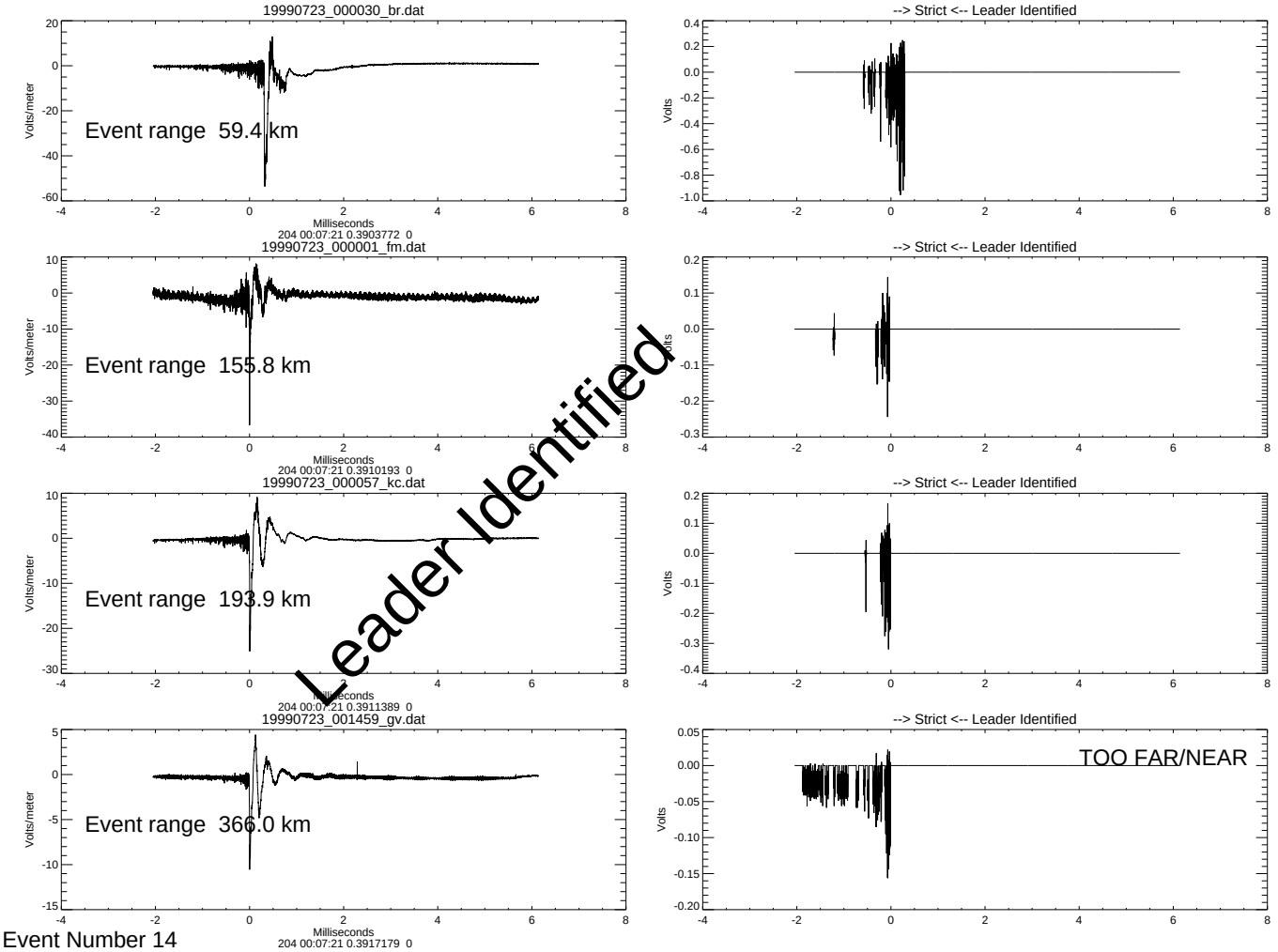
The routine identification of LASA records with leader signature is nearing completion. Only stations within 50-350 km to the event are considered. The method used is wavelet analysis using a Coiflet basis function. A specific scaling which emphasizes the leader, while retaining the return stroke and attenuating most local noise sources is used. If the leader to return stroke relative amplitude is $> .25$ for any station, then station pairs are cross-correlated. If the cross-correlation is $> .8$ then the event is determined to have leader signature within the record. Three examples of multi-station observations of return strokes with intense/fast leaders are presented in the next pages. The waveforms are plotted on the left column, while the identification of leader is shown in the right column.

Leader Identification (cont'd)



Event Number 3

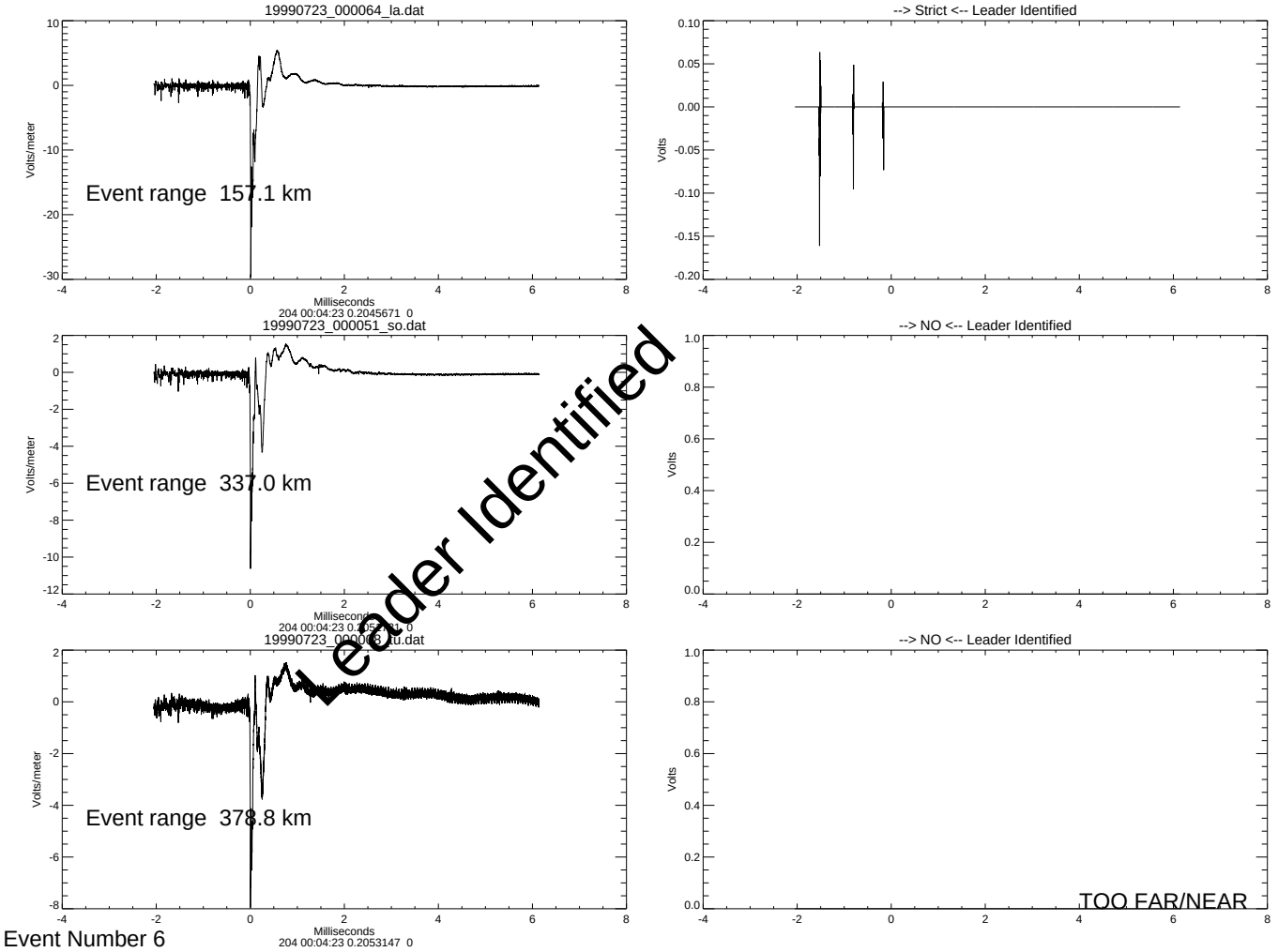
Leader Identification (cont'd)



Leader Identified

Event Number 14

Leader Identification (cont'd)



Event Number 6

Conclusions

The electric field waveforms recorded by the Los Alamos Sferic Array are dominated by return stroke signatures. However, intense/fast step leader activity is observed in many records. Combined with FORTE observations heights of 4-5.5 km and velocities of 10^6 m/s are determined for these intense/fast step leader events. LASA is occasionally operated with longer records lengths (80 ms and 1 sec) for short periods of time. One of these long records has been presented and agrees with the traditional view of electrical activity associated with a multiple-stroke -CG. LASA has recorded millions of lightning electric field change waveforms, which include several different types of leader signatures. We are finalizing the automatic recognition of leader activity.

References

[1] M. J. Heavner, D. A. Smith, A. R. Jacobson, and R. J. Sheldon. LF/VLF and VHF lightning fast stepped leader observations. *J. Geophys. Res.*, 2002. submitted.

[2] A. R. Jacobson, S. O. Knox, R. Franz, and D. C. Enemark. FORTE observations of lightning radio-frequency signatures: Capabilities and basic results. *Radio Sci.*, 34(2):337–354, 1999.

[3] D. A. Smith, K. B. Eack, J. Harlin, M. J. Heavner, A. R. Jacobson, R. S. Massey, X. M. Shao, and K. C. Wiens. The Los Alamos Sferic Array: Ground truth for the FORTE satellite. *J. Geophys. Res.*, 2001. submitted.

[4] Martin A. Uman. *The Lightning Discharge*, volume 39 of *International Geophysics Series*. Academic Press, Inc., Orlando, Florida, 1987.