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THE DETECTION OF VHF LIGHTNING FROM GPS ORBIT

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ABSTRACT: Satellite-based VHF lightning detection is characterized at GPS orbit by using a VHF receiver system recently launched on the GPS SVN 54 satellite. Collected lightning triggers consist of Narrow Bipolar Events (80%) and strong negative return strokes (20%). The results are used to evaluate the performance of a future GPS-satellite-based VHF global lightning monitor.

INTRODUCTION

Over the last few decades, there has been a growing interest to develop and deploy an automated and continuously operating satellite-based global lightning monitor. To date, efforts to acquire such a capability have focused on the deployment of optical sensors that can provide cost-effective single-platform geolocation of lightning flashes [e.g. *Christian et al.*, 1989]. As an alternative and/or complementary approach to the problem, we have recently proposed the development of a satellite-based Very High Frequency (VHF) Global Lightning And Severe Storm monitor (V-GLASS) [e.g. *Suszcynsky et al.*, 2001]. This system would be an outgrowth of an already-funded constellation of broadband VHF receivers to be flown on the upcoming Block IIF Global Positioning System (GPS) satellite constellation and would likely be accompanied by an array of optical photodiode detectors.

Table 1 lists the performance parameters for satellite-based optical versus VHF lightning detection. Optical lightning detection offers the highest overall detection efficiency and two-dimensional geolocation (latitude/longitude) of generic lightning activity and can be deployed as a single-platform system. VHF lightning detection offers geolocation into the third dimension (altitude), can discriminate between cloud-to-ground (CG) and intra-cloud (IC) activity, and is particularly sensitive to a strong and meteorologically important type of lightning known as a Narrow Bipolar Event (NBE).

NBEs are the very low frequency (VLF) manifestions of impulsive (< 20 μs duration) in-cloud lightning discharges that are commonly observed by both ground-based electric-field-change sensors [e.g. *Smith et al.*, 1999] and ground and satellite-based VHF receivers [e.g. *Jacobson and Light*, 2002]. They are the most intense forms of radio frequency lightning observed, are spatially compact, optically weak, and can occur as temporally isolated impulses or as precursors to more generic forms of in-cloud lightning activity. Meteorologically speaking, NBEs have been observed to occur near and within regions of high radar reflectivity (> 40 dBZ) associated with the convective cores of thunderstorms [*Smith et al.*,1999]. NBE flash rates have also been statistically correlated to the convective strength of thunderstorms [*Suszcynsky and Heavner*, 2003]. Since the basic premise of satellite-based global lightning monitoring is to detect lightning as proxy for mapping out and quantifying global convective activity, NBEs thus provide an excellent target of opportunity for a future VGLASS system.

	OPTICAL	VHF
Detects:	Light (current)	VHF (changes in current)
Geolocation Technique (Min. # of sats):	CCD/photodiode array, Single-platform, (lat/lon)	Time-of-arrival (TOA), Multi-platform, (lat/lon/alt)
Atmospheric Effects:	Scattering/ Attenuation of signal	none
Ionospheric Effects:	none	Frequency-dependent Dispersion (can be mitigated)
Lightning Taxonomy:	Cannot reliably distinguish	Can distinguish CG vs. IC, return strokes, leaders, TIPPs/NBEs, etc.
Most Sensitive to:	CGs, Non-impulsive ICs	Strong CGs, Impulsive (~ 1 μs) ICs
Secondary Missions:	Bolide Detection	Total Electron Content (TEC) Monitoring

Table 1. Comparison of techniques for satellite-based optical versus VHF lightning detection.

Extensive studies with the low-earth-orbiting Fast On-Orbit Recording of Transient Events (FORTE) satellite [e.g. *Jacobson and Light*, 2002] have demonstrated that the majority of VHF lightning detected from space is associated with NBE-like activity. With the recent launch on Jan. 30, 2001 of a suite of VHF sensors aboard the GPS/SVN 54 satellite, we now have a unique opportunity to characterize VHF lightning detection from a high-altitude orbit (~ 20,000 km) appropriate for satellite-based VHF global lightning monitoring.

INSTRUMENTATION

The SVN 54 instrumentation was not specifically designed for lightning detection and cannot be reconfigured or optimized for formal lightning detection campaigns. However, the hardware and software configurations are similar enough to the proposed VGLASS design to allow us to use the resulting data to evaluate and predict the expected performance of an operational VGLASS system. The SVN 54 VHF receivers used for this study [*Suszcynsky et al.*, 2001] cover the lower VHF frequency range and operate with a multi-channel amplitude-threshold triggering scheme similar to that used by the FORTE VHF instruments [*Jacobson et al.*, 1999]. Lightning triggers were collected from May 1 – Sept. 30, 2001 and April 1 – September 30, 2002 for an approximately 5-hour period each day during which a ground-based array of electric-field-change sensors was within the field-of-view of the SVN 54 antenna pattern. This ground-truthing array is known as the Los Alamos National Laboratory (LANL) Sferic Array (LASA).

The LASA array [*Smith et al.*, 2002] consists of eight capacitively coupled electric-field change sensors in central Florida, is sensitive to both IC and CG lightning activity, and provides excellent ground-truthing for both the FORTE and SVN 54 sensors. When a lightning event produces a signal that exceeds a preset threshold amplitude, an 8.192 ms duration waveform is collected at a 1 Megasample/s sampling rate at each station that is threshold triggered. The collected waveforms are GPS-time-stamped and used to determine event type and event locations with a time-difference-of-arrival technique.

RESULTS AND DISCUSSION

Correlated observations of lightning events by both the LASA array and the SVN 54 VHF receivers were identified by comparing the LASA trigger times to the VHF receiver trigger times, corrected for time-of-flight to the satellite. The detection of the LASA VLF signals typically preceded SVN 54 VHF detection by up to 300 μs. Once temporal correlations were identified, the LASA waveforms were analyzed to deduce lightning type. Figure 1 shows the fractional percent occurrences of positive, negative and unknown polarity NBEs, and positive, negative and unknown polarity CGs. Correlated events are seen to consist of ~ 75 % NBEs (mostly positive) and ~ 25 % CGs (mostly negative).

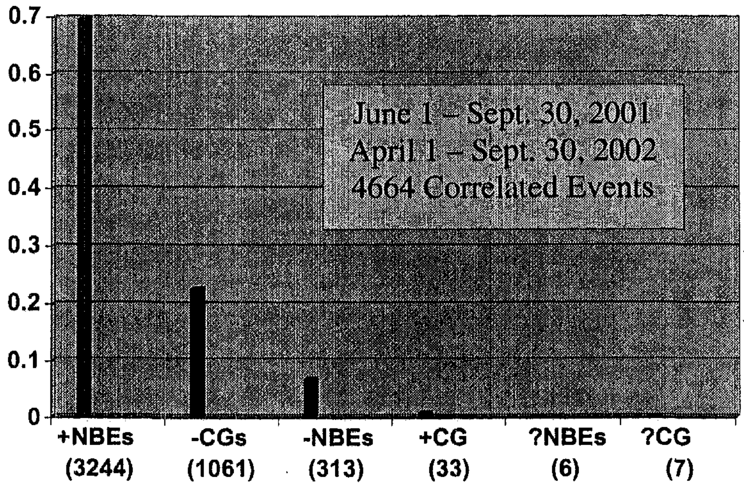

Figure 1. Fractional percent composition of lightning types for the 4664 LASA/SVN 54 correlated lightning events collected from June 1, 2001 to September 30, 2001 and from April 1, 2002 to September 30, 2002.

Figure 2 compares the relative peak amplitudes of the correlated events to those of the generic LASA data set collected over the same time period. The LASA amplitudes for both CG (figure 2a) and NBE (figure 2b) correlated events tend to lie in the high amplitude tail of the generic distribution of LASA NBE and CG events. In addition, analysis of the SVN 54 on-orbit waveforms indicates that (1) NBEs are readily distinguishable from CG emissions based on the shape of the emission profile and (2) the satellite receivers trigger on and collect data from the impulsive burst of VHF power associated with the "attachment" phase of the CG, rather than emission from the leader or return stroke

Based on the observed GPS/SVN 54 event rate implied in figure 1, an extrapolation of FORTE performance and sensitivity to VGLASS design parameters, and anticipated VGLASS bandwidth and processing time constraints, we estimate a VGLASS maximum detectable event rate on the order of 1 event per second per satellite (in the proportions shown in figure 1). This number, although too small to provide a high detection efficiency approach to generic lightning detection, is consistent with the VGLASS strategy of only detecting the strongest VHF lightning events. It is fortuitous, yet not unanticipated, that the strongest VHF lightning events at GPS orbit are NBEs and that they are robust statistical indicators of thunderstorm convective activity and strength [*Suszcynsky and Heavner*, 2003].

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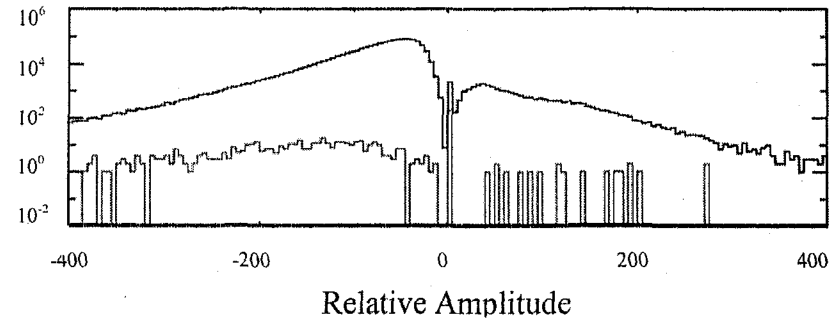

(b.)

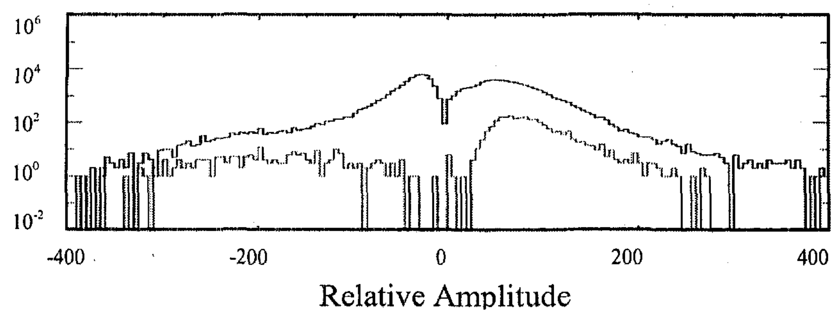

Figure 2. Histograms showing (a) the distribution of estimated peak amplitudes of the generic population of LASA-detected CG events (black) versus that of the LASA/SVN 54 correlated CG events (red), and (b) the distribution of estimated peak amplitudes of the generic population of LASA-detected NBE events (black) versus that of the LASA/SVN 54 correlated NBE events (red).

REFERENCES

Christian, H. J., R. J. Blakeslee, and S. J. Goodman, The detection of lightning from geostationary orbit, *J. Geophys. Res., 91*, 13329-13337, 1989.

Jacobson, A. R., S. O. Knox, R. Franz, D. C. Enemark, FORTE observations of lightning radio-frequency signatures: capabilities and basic results, *Radio Sci., 34*, 337-354, 1999.

Jacobson, A. R. and T. E. Light, Bimodal Radiofrequency pulse distribution of intracloud-lightning signals recorded by the FORTE satellite, submitted, *J. Geophys. Res. – Atmos.* 2002.

Smith, D. A., X. M. Shao, D. N. Holden, C. T. Rhodes, M. Brook, P. R. Krehbiel, M. Stanley, W. Rison, and R. J. Thomas, A distinct class of isolated intracloud lightning discharges and their associated radio emissions, *J. Geophys. Res.*, 104, 4189-4212, 1999.

Smith, D. A., 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, in press, *J. Geophys. Res. – Atmos, 2002.*

Suszcynsky, D. M., S. Davis, A. Jacobson, M. Heavner, and M. Pongratz, VHF Global Lightning and Severe Storm Monitoring from Space: Storm-level Characterization of VHF Lightning Emissions, *EOS Trans. AGU 2001 Fall Mt. Prog. And Abstr.* 82, No. 47, F143, 2001.

Suszcynsky, D. M. and M. J. Heavner, "Narrow Bipolar Events as indicators of thunderstorm convective strength," submitted to *Geophys. Res. Lett.*, 2003.