LA-UR-00-4956

Approved for public release; distribution is unlimited.

Title: SATELLITE-BASED GLOBAL LIGHTNING AND SEVERE STORM MONITORING USING VHF RECEIVERS

Author(s): David M. Suszcynsky, NIS-1
Abram Jacobson, NIS-1
Joseph Fitzgerald, NIS-1
Charley Rhodes, NIS-1
Earl Tech, NIS-1

Submitted to: International Lightning Detection Conference
Tucson, Arizona
November 7-9, 2000

DISCLAIMER

DISCLAIMER

Satellite-based Global Lightning and Severe Storm Monitoring Using VHF Receivers

D. M. Suszcynsky, A. Jacobson, J. Fitzgerald, C. Rhodes, and E. Tech
Los Alamos National Laboratory, Space & Atmospheric Sciences Group, MS D466
Los Alamos, New Mexico 87545

ABSTRACT

This paper outlines an effort to develop and promote a concept definition for a satellite-based global lightning detection system called V-GLASS (VHF Global Lightning and Severe Storm monitor). The proposed system would be an outgrowth of an already-funded constellation of broadband VHF receivers (V-Sensors) to be flown on the Block IIF Global Positioning System (GPS) satellite constellation for the purpose of monitoring nuclear detonations for treaty verification. The use of an existing VHF sensor constellation would greatly reduce system cost and would allow the lightning detection community to capitalize on the specific benefits of VHF lightning detection, namely the transparency of clouds to VHF emissions and the ability to both geolocate and identify lightning types (cloud-to-ground versus intra-cloud) based on VHF power profiles. A conceptual system design is presented along with a discussion of expected system performance and capabilities.

1. INTRODUCTION

Over the last few decades, there has been a growing interest within various scientific, military, and civilian communities to develop and deploy an automated and continuously operating satellite-based global lightning monitor [see e.g. *Goodman et al.*, 1993].

For the aviation community, a global lighting/thunderstorm monitor would provide valuable regional and global information that would aid in the assessment of flight conditions for both military and civilian purposes. Such a system would provide global, real-time severe weather information, in standardized form, that could be used to support military operations, suggest optimal flight paths, and considerably increase the safety and efficiency of commercial air travel. A satellite-based system would be particularly useful over oceanic regions that are not sufficiently covered by ground radar.

For the meteorology community, a satellite-based global lightning monitor would provide an enhanced severe storm monitoring and early warning capability, particularly over regions of the world that are not sufficiently monitored by ground facilities. For example, lightning rates have been shown to be related to cloud-top height and consequently, updraft velocity [e.g *Williams*, 1989] which is a direct indication of storm severity. If the sensor can distinguish between cloud-to-ground (CG) and intra-cloud (IC) lightning, even more functionality may be available. The ratio of IC to CG lightning flashes in storms has been shown to be a sensitive indicator of storm evolution [e.g. *Williams*, 1989] and the IC/CG ratio and total flash rate has been correlated to the onset of severe weather conditions including tornadoes [*Williams et al.*, 1999; *Buechler et al.*, 2000]. Thus the ratio could provide valuable early warning information of impending tornadic activity.

For the scientific community, the resulting data set would be unprecedented. There are a growing number of scientific investigations that show relationships between regional/global lightning activity and rainfall [e.g. *Petersen et al.*, 1998], the evolution and structure of deep convective processes [e.g. *Williams et al.*, 1989], and regional climatic variations such as the El Nino Southern Oscillation (ENSO) [e.g. *Goodman et al.*, 2000]. While these relationships have yet to be fully explored and quantified, the potential impact that they could have on global and regional climatology/meteorology studies and as input into General Circulation Models (GCMs) is considerable. For example, a satellite-based global monitoring of lightning activity as a reliable proxy for deep convective activity would represent a dramatic improvement over current methods of global convection estimation that are limited in accuracy and geographic extent. Additionally, the distribution, dynamics and variability of lightning and thunderstorms are driven in part by global and regional climatic variations such as El Nino and La Nina. These climatic variations can influence the dynamics of storm tracks, precipitation patterns, and cloud cover.

Recent efforts to develop a satellite-based global lightning monitor have relied upon the use of optical detectors (CCD arrays), primarily because of their ability to provide single-platform geolocation and the prohibitively expensive alternative of using multi-platform radio frequency (RF) sensors. However, aside from the added cost of additional satellites, RF sensor technology provides a practical alternative to traditional optical detection. Table 1 summarizes the strengths and weaknesses of optical versus VHF detection of lightning from space.

	OPTICAL	VHF
Detects:	Light (current)	VHF (changes in current)
Geolocation technique/ Required no. of satellites:	CCD array/ 1 satellite minimum	Time-of-arrival (TOA)/ 3 satellite minimum
Atmospheric effects:	Scattering/attenuation	None
Ionospheric effects:	None	Frequency-dependent dispersion of signal (can be mitigated)
Lightning taxonomy:	Cannot distinguish	Can distinguish CG vs IC, return strokes, leaders, TIPPs, etc.

Table 1. Summary of strengths and weaknesses of optical and VHF lightning detection from space.

This paper outlines an effort to develop and promote a concept definition for a satellite-based global lightning detection system called V-GLASS (VHF Global Lightning and Severe Storm monitor). The proposed system would be an outgrowth of an already-funded constellation of broadband VHF receivers (V-Sensors) to be flown on the Block IIF Global Positioning System (GPS) satellite constellation. The utilization of existing hardware on an established satellite constellation significantly reduces development costs, thereby providing a global VHF lightning monitoring system for a fraction of the cost of an independently designed and implemented system. A brief overview of the V-sensor system is presented in section 2 and the conceptual design for the V-GLASS implementation of V-Sensor is presented in section 3. Section 3 also addresses expected system performance and capabilities in terms of VHF data analysis results from a similar experimental system currently being operated aboard the FORTE satellite.

2. V-SENSOR DESCRIPTION

V-Sensor is a next-generation broadband VHF receiver system designed to detect and geolocate the electromagnetic pulse (EMP) from nuclear detonations on a worldwide continuous basis. The system is currently in the design phase and is scheduled for deployment as part of the Nuclear Detonation System (NDS) package aboard the upcoming Block IIF Global Positioning Satellite (GPS) System. Current plans call for an eventual constellation of 24 V-Sensors to be distributed at GPS orbit (~20,000 km altitude) with launches beginning in 2005. Event geolocation is accomplished by way of a time-of-arrival technique that uses event waveforms collected by three or more satellites.

The V-sensor consists of broadband VHF receivers operating in the low- to mid-VHF frequency range. Data collection for a given receiver is triggered when the amplitude of a detected signal exceeds a preset amplitude threshold in a pre-set number of sub-bands distributed within the receiver bandwidth. This triggering technique along with an associated digital signal analysis algorithm allows the instrument to (a) trigger on and detect weak signals of interest in the presence of strong interfering manmade carriers and (b) distinguish and discriminate between nuclear EMP and other man-made and naturally occurring events. Downlinked data records include timing information and waveforms with FORTE-like time resolution. When a non-nuclear event (e.g. lightning) is detected by an individual V-sensor, a waveform and supplemental information about the triggered event will be stored in an on-board buffer. The contents of each satellite's buffer will be downloaded to the ground at least once per day. Once on the ground, the data will be further processed to extract timing and geolocation information for each event.

3. CONCEPT DEFINITION FOR V-GLASS

3a. System Architecture

The VHF Global Lightning and Severe Storm Monitor (V-GLASS) is a proposed implementation of the existing V-Sensor system for the purpose of monitoring and reporting lightning and severe storm activity on a global and continual basis. Because of programmatic considerations, V-GLASS is for the most part, being developed within the constraints of existing V-sensor hardware, software, and ground station design as described in section 2. The main development effort for a V-GLASS mission would involve (1) an effort to increase the number of ground stations in order to maximize the number of detected events, (2) software development for the creation, analysis and archiving of data products, and, (3) development of an unclassified data transport and distribution network.

One of the primary challenges of implementing V-GLASS will be to maximize the number of downloaded lightning events such that a global and continuous lightning database can be realized. At this point, it is difficult to accurately estimate the lightning detection efficiency and hence, the detected lightning event rate for the proposed V-GLASS system since the V-sensor signal processing algorithms, specifically the discriminaton criteria and threshold levels, are still under development. However, these issues are actively being addressed, in particular by applying scaling laws and candidate V-sensor discrimination algorithms to the data from the Fast On-Orbit Recording of Transient Events (FORTE) satellite. The FORTE satellite is currently flying a VHF receiver that is similar in functionality to the V-sensor design and provides operational data that can be used to gauge the performance of the proposed V-sensor as a lightning detector.

Preliminary results indicate that we might expect to collect about 1000 lightning events/day/satellite given the current baseline system design limitation of 4 MB of on-board memory and only one ground station. This event rate would provide a marginal global monitoring capability. However, there is an on-going effort to increase the number of ground stations and a prototype design for the additional ground stations has already been developed. If the effort to actually deploy these additional ground stations is successful, the number of events that can be detected and downloaded would increase substantially since each instrument's buffer could be downloaded and refilled more often. In fact, preliminary studies show that the addition of only two more ground stations would provide a real-time downloading capability, thus completely eliminating the dependence on on-board memory and subsequently providing a truly global continuous coverage.

Once on the ground, the downlinked raw data would be processed into various data products to be made available to collaborators/users. Table 2 contains a list of candidate primary and secondary data products. The list of secondary products depends on user needs, the final form of the V-sensor discrimination algorithm, and our ability to further develop a VHF lightning classifier (see section 3b).

PRIMARY DATA PRODUCT	DESCRIPTION
Event time	UT trigger time of event
Event geolocation	Lat./Lon. location of event

SECONDARY DATA PRODUCT	DESCRIPTION
Event type, IC/CG ratio for individual storms	Description of event based on figure 1 taxonomy
Flash information	Events grouped into flashes based on temporal/spatial relationships
Real-time/archived rate maps	Real-time, diurnal, seasonal, etc rate maps

Table 2. List of some candidate data products

3b. Anticipated System Performance and Capabilities

The space-based detection of VHF emissions from lightning processes is currently being demonstrated with a suite of instrumentation aboard the FORTE satellite [e.g. Jacobson et al., 1999]. The FORTE results have shown that there is a robust phenomenology of lightning VHF emissions that can be used to both geolocate [*Jacobson et al.*, 2000] and type [*Suszcynsky et al*, 2000a] lightning events.

As a single-platform experiment, FORTE receivers do not explicitly demonstrate VHF event geolocation (geolocation is instead provided by an on-board CCD imaging array [*Suszcynsky et al*, 2000b]). However, the current generation of treaty-monitoring VHF sensors aboard the Block IIA and IIR GPS constellation provide excellent location accuracies.

One of the potential advantages of a VHF-based detection system is the ability to identify lightning types based on the VHF power versus time profile of the event [*Suszcynsky et al*, 2000a, *Jacobson et al.*, 2000]. If further developed, this capability might allow for an on-orbit determination of the IC to CG flash ratio and could serve as an important diagnostic in assessing the evolution and severity of

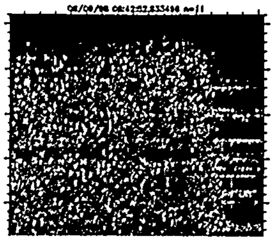
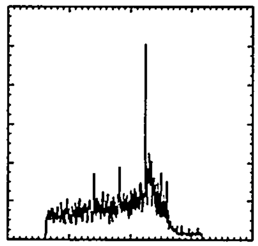
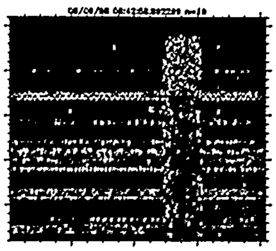
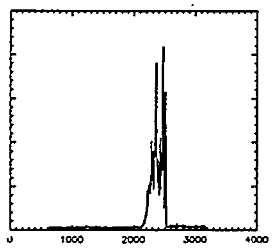
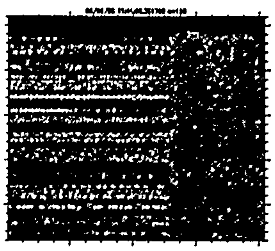
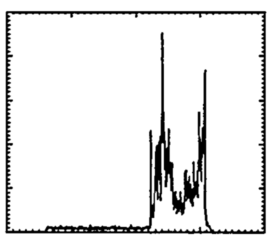
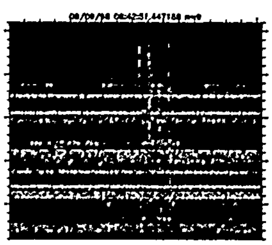
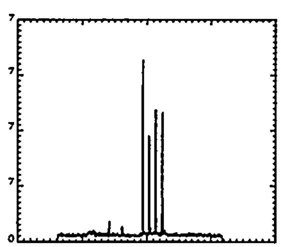
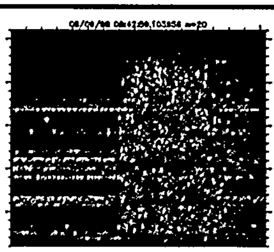
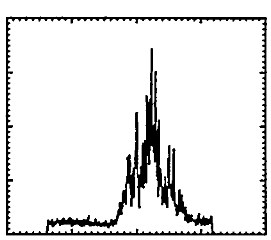
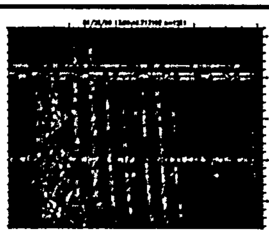
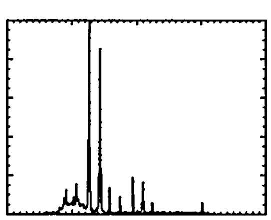
Spectrogram	Power profile	Taxonomy	Features
		1st -RS w/ stepped leader	width > 400 μS, steady increase, impulse at attachment
		Subseq. -RS w/ dart leader	10μS < wid. < 500 μS sharp fall, impulse at attachment
		1st +RS	10μS < wid. < 500 μS sharp rise, impulse at attachment
		Impulsive in-cloud events, including TIPPS	1 μS < width < 10 μS strong
		Non-impulsive in-cloud events including K-events	10 μS < wid. < 500 μS slow rise/fall
		Mixed impulsive and non-impulsive in-cloud events	Mixed of impulsive and non-impulsive features

Figure 1. FORTE lightning taxonomy. RS = Return Stroke.

storms. Figure 1 illustrates a VHF lightning taxonomy that is currently being developed under the FORTE program. The first column illustrates the six basic types of detected events as frequency versus time spectrograms. Each spectrogram spans 800 μs of time and covers the 26 – 48 MHz frequency range. The second column shows a power versus time plot where the spectrogram has been dechirped (dispersive effects of ionosphere removed), pre-whitened (man-made carriers removed) and where the power has been integrated (collapsed) over all frequencies. The third column indicates the deduced lightning type (based on similarities between the spectrograms and previous ground-based VHF data and also on National Lightning Detection Network ground truth [*Suszcynsky et al.*, 2000a]), and the fourth column contains the key temporal features upon which the identification is based. As can be seen, initial and subsequent return strokes, stepped and dart leaders, and in-cloud activity all have unique power versus time characteristics that can be used to provide on-orbit identification of lightning types.

Eventually, a full system model will address the issue of V-GLASS lightning detection efficiency as a function of lightning type. However, based on our experience with FORTE, and an extrapolation of those results out to GPS orbit, V-GLASS-detected lightning events will likely be dominated by in-cloud impulsive events. Impulsive events, including TIPPS [e.g. *Jacobson et al.*, 1999], are ubiquitous during severe storm activity and provide an excellent means by which to identify and locate active lightning storms.

4. V-GLASS PROGRAM STATUS

The V-Sensor program is currently in the design and prototyping stage. The V-GLASS effort up to this point has primarily been focused on developing a conceptual definition of how the mission can be accomplished within the framework of the existing V-Sensor hardware, software, and ground station baselines. Future effort will include the development of community advocacy and identification of a program sponsor so that data product and distribution plans can be developed. A primary emphasis will be to increase the number of available ground stations.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of Paul Argo, Sean Davis, Tess Light, Dave Simons and the FORTE Science and Operations Teams of Los Alamos National Laboratory. This work was sponsored by the United States Department of Energy.

6. REFERENCES

Buechler, D. E., K. T. Driscoll, S. J. Goodman, and H. J. Christian, Lightning activity within a tornadic thunderstorm observed by the optical transient detector (OTD), *Geophys. Res. Lett., 27*, 2253-2256, 2000.

Goodman, S. J., and H. J. Christian, Global observations of lightning, in "Atlas of Satellite Observations Related to Global Change", edited by R. J. Gurney, J. L, Foster, and C. L. Parkinson, pp. 191-219, Cambridge Univ. Press, New York, 1993.

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., K. L. Cummins, M. Carter, P. Klingner, D. Roussel-Dupre, S. O. Knox, FORTE radio-frequency observations of lightning strokes detected by the National Lightning Detection Network, *J. Geophys. Res.*, *105*, 15653-15662, 2000.

Petersen, W. A., and S. A. Rutledge, On the relationship between cloud-to-ground lightning and convective rainfall, *J. Geophys. Res., 103*, 14025-14040, 1998.

Suszcynsky, D. M., M. W. Kirkland, A. Jacobson, R. Franz, S. Knox, J. L. Guillen, J. Green, FORTE Observations of Simultaneous RF and Optical Emissions from Lightning: Basic Phenomenology, *J. Geophys. Res. - Atmos.*, *105*, 2191-2201, 2000a.

Suszcynsky, D. M., T. E. Light, S. Davis, M. W. Kirkland, J. L. Green, J. L. L. Guillen, W. Myre, Coordinated Observations of Optical Lightning from Space using the FORTE Photodiode Detector and CCD Imager, submitted, *J. Geophys. Res. – Atmos.*, 2000b.

Williams, E. R., M. E. Weber, and R. E. Orville, The relationship between lightning type and convective state of thunderclouds, *J. Geophys. Res., 94*, 13213-13220, 1989.

Williams, E. R., B. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan, and D. Buechler, The behavior of total lightning activity in severe Florida thunderstorms, *Atmos. Res.*, 51, 245-265, 1999.