Global Lightning and Sprite Measurements from International Space Station

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ABSTRACT: The Global Lightning and sprIte MeasurementS (GLIMS) on the International Space Station (ISS) is a mission to detect and locate optical transient luminous events (TLEs) and its associated lightning simultaneously from the non-sun synchronous orbit, and is scheduled to be launch from Japan in January, 2012 as part of the multi-mission consolidated equipment on Japanese Exposure Module (JEM). Our mission goals are (1) to detect and locate lightning and sprite within storm scale resolution over a large region of the Earth's surface along the orbital track of the ISS without any bias, (2) to clarify the generation mechanism of sprite, and (3) to identify the occurrence conditions of TLEs. To achieve these goals, two CMOS cameras, six Photometers, VLF receiver, and VHF interferometer with two antennas, are installed at the bottom of the module to observe the TLEs as well as causative lighting discharges at nadir direction during day and night time. Though the luminous events so-called sprite, elves and jets have been investigated by numerous researchers all over the world based mainly on the ground observations, some important problems have not been fully understood yet such as generation mechanisms of columniform fine structure and horizontal offset of some sprites from the parent lightning discharges. In the JEM-GLIMS mission, observations from our synchronized sensors are going to shed light on above-mentioned unsolved problems regarding TLEs as well as causative lighting discharges. In this presentation, the scientific background, instrumentation, project summaries and initial observation results are given.

1. INTRODUCTION

The first observation of lightning from space was enabled by the Japanese ISS-b satellite, and was a byproduct of the satellite's original purpose. Nevertheless, this mission firstly showed the possibility of lightning observations from space. After that, the first satellites specifically designed for observing lightning are the OTD (Optical Transient Detector)(Christian et al. 2003) and LIS (Lightning Imaging Sensor) aboard the Tropical Rainfall Measuring Mission (TRMM)(Christian et al. 1999), which clearly show the global distribution of lightning, a global lightning rate of about 50 flashes/s and so on. These optical sensors have a successful detection efficiency of more than 90 percent. They reveal not only time-varying global distribution of lightning, but also that the data on lightning can be assimilated into weather prediction models. Based on these results, lightning measurements from geo-stationary orbit have been planned and will be launched in the near future from the United States.

While the distribution and variability of lightning discharges can be obtained by optical observations, identification of the discharge process is made possible by VHF observations. The Los Alamos National Laboratory's FORTE (Fast On-orbit Recording of Transient Events) satellite is the first satellite to observe the broadband VHF radiation from lightning. a) Narrow Bipolar Events (NBEs) and b) Cloud-to-Ground events (CG) have been reported (Suszcynsky et al. 2004) using VHF observations. NBE is a discharge process on the order of 100 m in length and about 1 microsecond in duration, with the radiated energy in terms of EIRP 100 kW or more and highly intense VHF emission with weak light intensity. On the other hand, the CG event is emitted mainly by the return stroke process or the negative stepped leader process with a current of tens of kA. Although the VHF observation can identify the lightning process, the FORTE satellite is equipped with only one VHF antenna, and hence is not able to locate the sources of the VHF radiation.

Transient Luminous Events (TLEs) occurring just above thunderstorms were first reported by US researchers in 1989 (Franz et al. 1990). In the early 1990s, radio and optical observations of TLEs were actively made by numerous researchers, mainly those in the United States. TLEs are reported to be associated with the cloud-to-ground discharges with large amount of positive charge (Lyons et al. 1996, Sentman et al. 1995). In addition, the TLEs have been classified into a few categories and named sprites, blue jets, and elves according to their morphology.

The mechanism by which TLEs are generated is not yet fully understood. The most promising explanation so far is the quasi-static electric field model (Pasko et al. 1997). However, this model also has several problems such as the fact that (1) real sprites can be generated by positive lightning with small charge moments on the scale of 100Ckm[8], while the model assumes the large charge moment of more than 1000Ckm, (2) sprites do not necessarily take place just above the parent thunderstorm, and (3) the model cannot explain the mechanisms by which columniform fine structure are generated.

In order to shed light on the unsolved problems regarding TLEs and causative lightning discharges that were mentioned above, the GLIMS (Global Lightning and sprIte MeasurementS) mission was proposed as one of the experimental facilities of the JEM (Japan Exposure Module) on the ISS (International Space Station). It is scheduled to be launched in 2012. The mission goals are (1) to detect and locate lightning and sprites within storm scale resolution over a large region of the Earth’s surface along the orbital track of the ISS without any bias, (2) to clarify the mechanisms by which sprites are generated, and (3) to identify the conditions under which TLEs occur.

2. GLIMS OVERVIEW

GLIMS is a mission to observe lightning and TLEs at the Exposure Facility (EF) of the Japanese Experiment Module (JEM) on the International Space Station as shown in Figure 1, and the mission success criteria are shown in Table 1. The objectives of GLIMS are to clarify the conditions under which TLEs occur, the global occurrence rates and distributions of TLEs, the mechanism by which terrestrial gamma-ray flashes (TGFs) occur and their relation to lightning discharges, as well as to locate the sources of VHF radiation emitted by lightning. The primary lightning and TLEs instruments on GLIMS are the Lightning and Sprite Imager (LSI), Photometers (PH), a VLF Receiver (VLFR), and a VHF Interferometer (VITF) as shown in Figure 2. Additionally, the GLIMS mission will carry two related processing instruments in the Signal Handling Unit (SHU) and the GPS receiver. The space segment of GLIMS is the ISS in about 400 km circular orbit

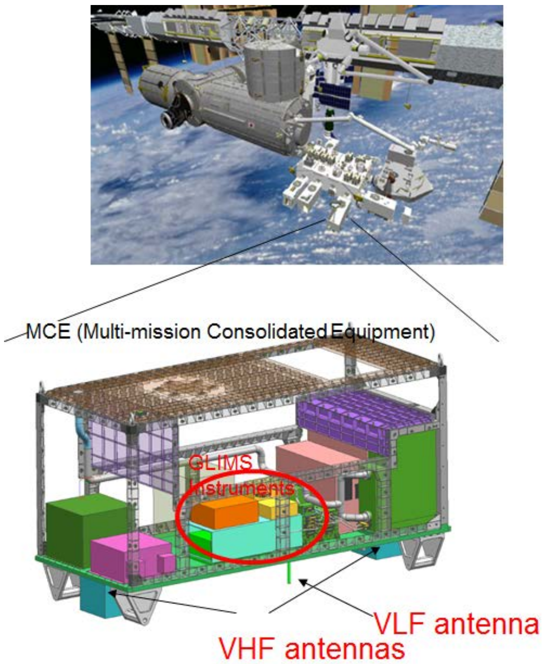

Figure 1 The GLIMS mission on the MCE/ISS.

with a 50 degree inclination angle. It is scheduled to be launched in January, 2012 with a mission life of at least 3 years.

The combination of space-borne LSI at two wavelengths and PHs at six channels, which is to be deployed in the upcoming GLIMS, promises to provide critical information on the global distribution of TLEs and the generation mechanism of TLEs. Coincident measurements from LSI and PH are complementary. CMOS cameras measure the optical emissions from TLEs and lightning, which cannot be identified separately because the TLEs and lightning both occur simultaneously with less than the temporal resolution of the cameras. Due to this, GLIMS takes the dual frequency (740-830nm and 762 nm) approach to discriminate lightning and TLEs. At 762 nm, the optical emission from lightning occurring at low altitude is generally absorbed and attenuated by the atmospheric air, while the optical emission from TLEs at this wavelength that occurs at high altitudes is most intense. At 740-830 nm, the CMOS cameras measure the optical emission from lightning. In this way, the two CMOS cameras distinguish, detect and locate the TLEs and associated lightning. At the same time, photometers at six channels (150-280 nm , 337+/-5 nm, 762+/-5 nm, 600-900 nm, 316+/-5 nm, 392+/-5 nm) provide information on electron energy based on the absolute light intensity emitted by TLEs and lightning. However, the six-channel photometers can only measure the intensity in light wavelength and cannot identify which lightning and TLEs emit the signal. To specify the location of TLEs and parent lightning measured by PHs, spatial location information provided by the LSI is needed.

The VLFR on GLIMS adds information on the charge moment of the parent lightning based on the whistler wave of the VLF waves that the lightning generates. While VLF observation does not locate the sources of the radiation, VLFR serves an important role as a bridge in coupling the occurrence of TLEs to lightning. The VITF plays an important role in pursuing the scientific objectives of the GLIMS mission. It is widely known that lightning discharge emits broadband electromagnetic radiation ranging from DC to gamma ray. Among them, the VHF band signal is intense and is believed to be radiated by the negative breakdown process such as negative stepped leader. Additionally, the strong VHF radiation events–so called NBP events–will be detected in the GLIMS mission. By installing the two antennas at the bottom of the platform in ISS, the direction of the electromagnetic wave at VHF band can be determined using the interferometric technique[9] for the stepped

Table 1. Success criteria of the GLIMS mission

	Minimum Success	Full Success	Extra Success
Global Distribution	Continuously observe TLEs and lightning for more than 1 year with CMOS camera or VHF interferometer. Obtain data on the seasonal variation of the TLEs and lightning.	Observe TLEs and lightning within the 80% of the area from -50 to 50 in latitude with 1 km and 200 us resolution for more than 2 years. Obtain data for estimating the effects on atmospheric composition due to the occurrence of TLEs and for assimilating the lightning data into meteorological models.	Discover a new type of TLE.
Spatial Structure	Obtain at least one set of TLE data by using LSI or VITF. Determine the spatial and temporal difference between the horizontal progression of lightning and TLEs.	Detect the TLEs with 1 km and 10 us resolution and lightning with 10 km and 10 us resolution. Clarify the mechanism by which TLEs are generated.	Clarify the generation mechanism of the new type of the TLEs due to the EMP from horizontal progression of lightning
Spectrum Observation	-	Detect at least one TLE by using the photometer at near-ultraviolet. Determine the electron temperature and existence or non-existence of the N_2 ion.	Obtain the spectrum data for all the TLEs observed, and understand the mechanism of the electron acceleration
Gamma ray observation	-	-	Detect lightning which is correlated with a gamma ray emission with 1 km and 10 us resolution. Specify the lightning process producing gamma rays. Understand the sources of the gamma ray emission from statistical data sets
VLF	-	-	Detect at least one VLF signal from lightning

leader and NBP events. This information will bring new insights into not only the generation of the TLEs, but also high energy, gamma ray phenomena.

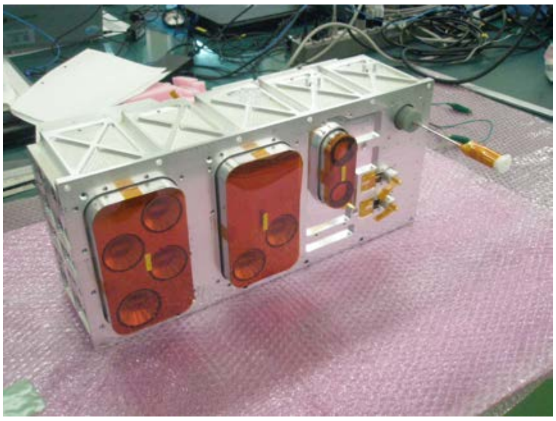

Figure 2 Picture of the GLIMS instruments

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