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 was launched successfully in July, 2012 as part of the multi-mission consolidated equipment on Japanese Exposure Module (JEM). Our mission goals are to identify temporal and spatial evolutions of lightning and TLEs and to clarify the occurrence conditions of TLEs and global occurrence locations and rates of TLEs from the nadir observation. 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.

JEM-GIMS was successfully launched and transported to the ISS by the H-II Transfer Vehicle (HTV) No.3 cargo transporter at the end of July 2012, and started its operation from December 2012. So far, more than one thousand events were recorded. In this paper, we present on the mission overview, examples of the observation results, and several initial analysis for the observed events such as on the identification of the intra-cloud and ground flashes from optical measurements and lightning location from the broad band interferometry at VHF band.

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INTRODUCTION

First satellite sensors 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). They successfully locate both the cloud and ground flashes with high detection efficiency and accuracy, and reveal time-varying global distribution of lightning. 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, 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). 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. The mission was successfully launched on July in 2012, and has been operated since then. In this paper, mission overview, instrumentation and a few examples of the initial results are described.

MISSION AND INSTRUMENTS

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 (Ushio et al., 2011). The primary lightning and TLEs instruments on GLIMS are the Lightning and Sprite Imager (LSI) (Sato et al., 2011), Photometers (PH) (Sato et al., 20111), a VLF Receiver (VLFR), and a VHF Interferometer (VITF) (Morimoto et al, 2011) as shown in Figure 1. 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 with a 50 degree inclination angle. The combination of space-borne LSI at two different wavelengths and PHs at six channels, which is deployed in the 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. These information is also used to discriminate the ground discharge process from intra cloud discharge process based on the attenuation difference at two different wavelength. 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–can be detected by the VITF sensor on GLIMS. 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 for the stepped leader and NBP events. Maybe this is the first time to locate the source of VHF radiation events from space.

INITIAL RESULTS

Since the launching of the GLIMS mission on July in 2012, the mission sensors detected total more than 3000 lightning and TLE events. In figure 2, one typical example of the detected event is shown. This event was recorded at 19:50:40 UTC on Sep. 28 in 2013 over central Africa. The LSI 1 CMOS camera observation at 765-830 nm wavelength in the left panel of Figure 2 clearly shows the illuminated cloud by lightning. On the other hand, the LSI 2 observation in the left panel in Figure 2 shows a slightly different illuminated pattern from the LSI 1 observation although the band width of the LSI 2 filter may cause some leakage problem from lightning, suggesting the occurrence of TLE event. The photometer observation in the right panels of Figure 2 particularly at 600 – 700 nm shows the time sequence of lightning process and the abrupt change at the triggering point suggest the occurrence of return stroke. And at 150 – 280 nm wavelength which is the attenuation band, a few ms after the abrupt change of PH4, weak signal is recorded at PH1, indicating the occurrence of TLE. In order to make sure the occurrence of TLE event, the charge moment estimation from the ELF ground observation network was conducted and the estimated results shows more than 1500 ckm which is enough to excite the TLE.

In Figure 3, one example of the VHF waveform data of A and B system recorded by the VITF on February 11, 2013 at 02:45: 03.01514 UTC is shown. Top panel shows the broad band VHF waveform recorded by antenna A, and the bottom panel shows the one by antenna B. The recorded waveforms from antenna A and antenna B are quite similar each other and indicate that the sensor system recorded the VHF emission from the same source. The broad band interferometric location method was applied to these waveforms and the located results are shown in Figure 4. The triangle indicates the position of the maximum emission captured with the LSI-1 camera, and the yellow line is the location of the VHF source, which was 88°. In this sensor configuration, because we have only one pair of antenna system, we can determine only the incidence angle to the baseline of the two antennas, which means the VHF source are somewhere along the hyperbolic curve on the earth. Nevertheless, the lightning detected by the CMOS camera (LSI 1) is located just above the curve, which shows the recorded VHF emission are from the lightning and successfully located from the space platform for the first time.

CONCLUSIONS

The GLIMS mission was successfully launched in 2012, and continuously recorded more than 3000 events since then. Examples of the detected events were shown here for the LSI (CMOS Camera), PH (Photometer), and VITF (broadband VHF Interferometer) instruments. From the analysis of the attenuated band, the recorded events for LSI and PH were identified as TLE and its parent lightning from the nadir observation on ISS. The broad band VHF emission from lightning was also recorded simultaneously at two antennas separated about 1.5 meter on the ISS module, and from the interferometric analysis the sources of the emission were located along with the LSI camera observation, showing the location from VITF is coincident with the location from the LSI observation.

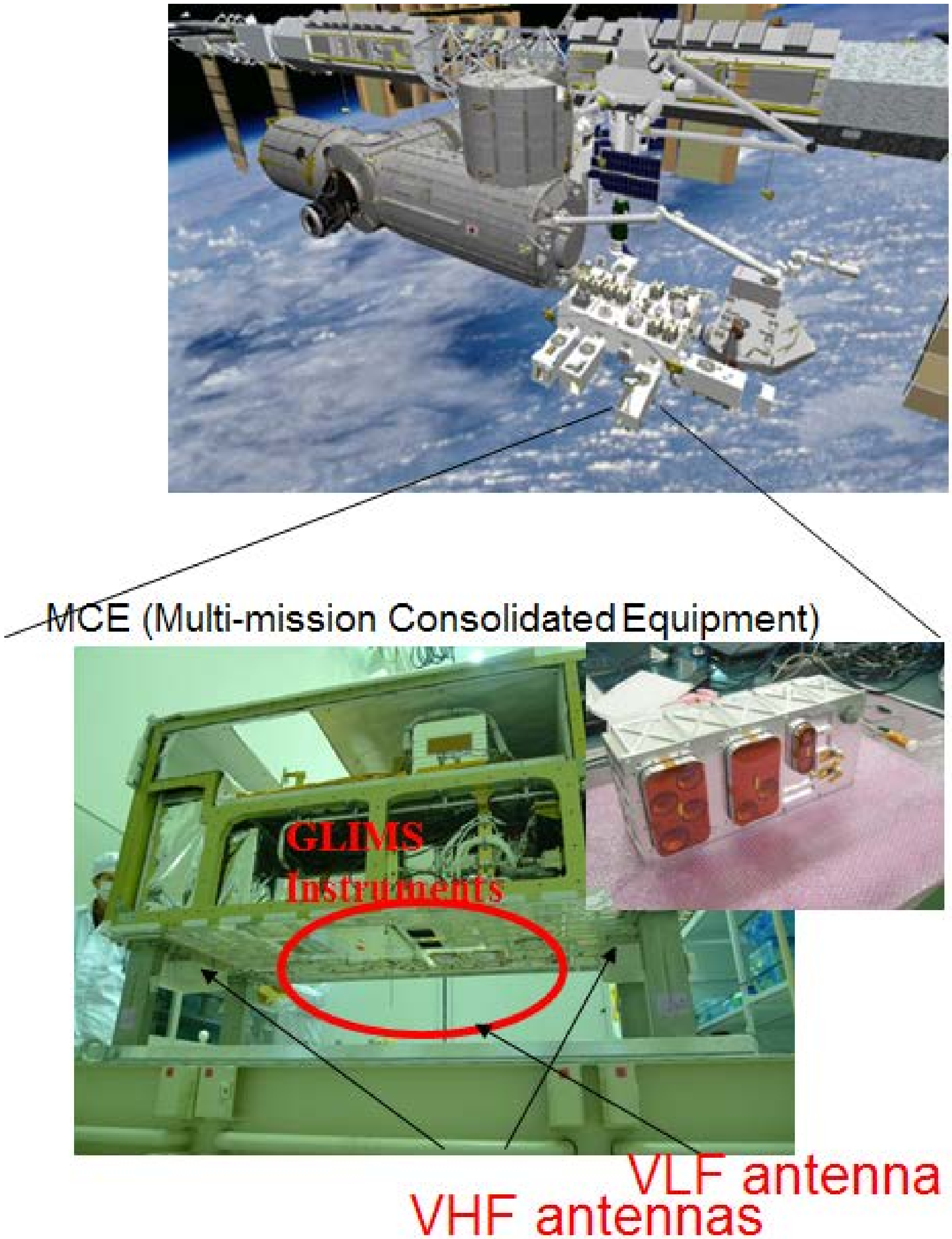

Figure 1 GLIMS mission on the International Space Station.

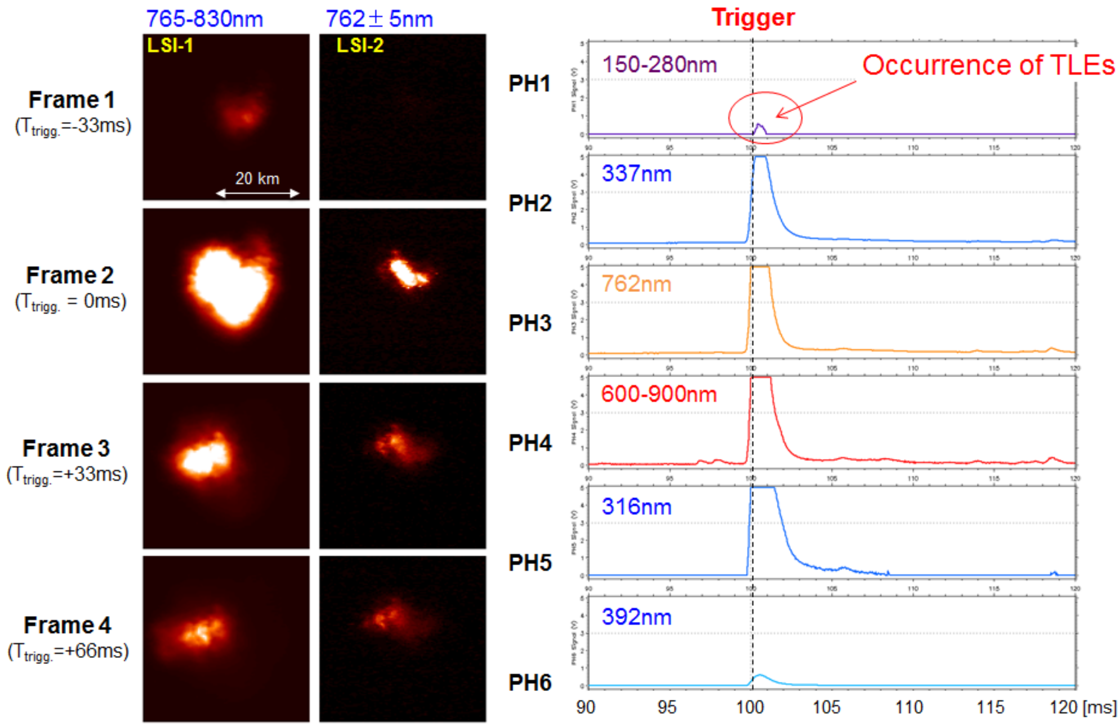

Figure 2 One typical example of the TLE event and its associated parent lightning detected by LSI and PH sensors. Left panels shows a time series of the images detected by LSI 1(765-830 nm) and LSI 2 (762+-5 nm), and right panel shows the photometers recordings at six channels.

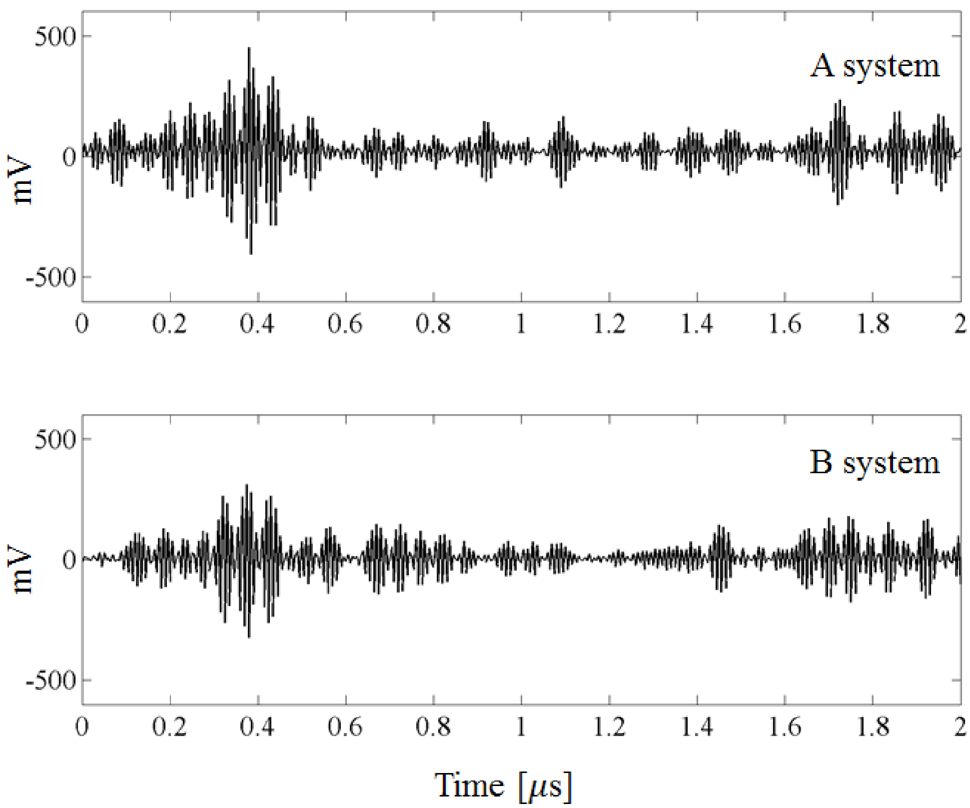

Figure 3 One example of the VHF waveform data of A and B system recorded by the VITF on February 11, 2013 at 02:45: 03.01514 UTC

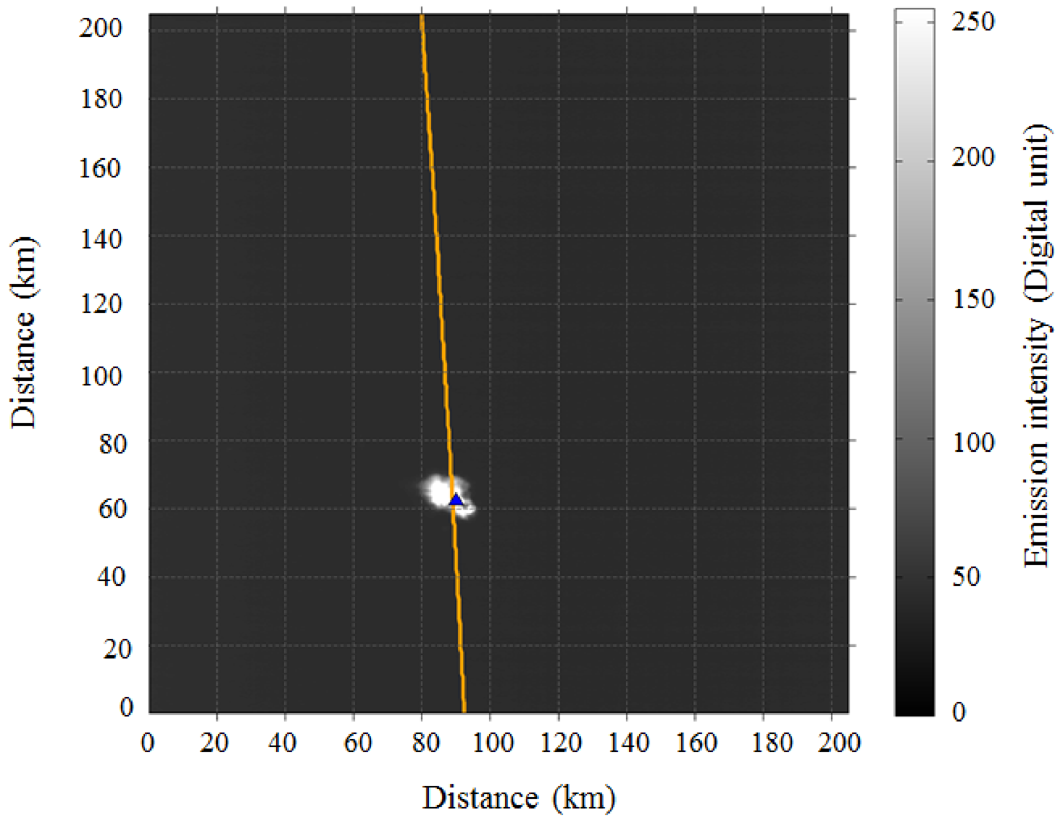

Figure 4 Estimation result using the interferometric method. The triangle indicates the position of the maximum emission captured with the LSI-1. The yellow line is the result of the estimation, which was 88°.

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