

COORDINATED OBSERVATIONS OF SPRITES AND OTHER TLE FROM THE SPACE SHUTTLE DURING THE MEIDEX

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This research was made possible by the devotion and enthusiasm of the seven astronauts of the space shuttle Columbia in mission STS-107, and is dedicated to their memory.

ABSTARCT: The Mediterranean Israeli Dust Experiment (MEIDEX) was performed on-board the space shuttle Columbia during its last mission in January 2003. During 25 orbits there were observations toward the Earth's limb above forecasted areas of active thunderstorms, in an effort to image Transient Luminous Events (TLEs) from space. The astronauts used a Xybion IMC-201 image-intensified camera and performed continuous recordings of the atmosphere from the direction of the night side toward the dusk terminator. Simultaneously with the optical observations from space, dedicated ground measurements in the ELF/VLF frequency range were conducted at several stations around the world. The obtained calibrated video data were analyzed during the mission and showed the occurrence of many TLEs over oceanic and continental storms.

INTRODUCTION

The first images of TLEs from space were obtained during the Mesoscale Lightning Experiment that was conducted in 1989-1991 [Boeck et al., 1998]. The space shuttle's cargo-bay cameras were used, which are standard low-light monochrome, un-calibrated video cameras that are often operated for monitoring activities within the shuttle cargo bay. The flight controllers at NASA Johnson Space Center (JSC) targeted the night limb and observed lightning activity over the eclipse side of the earth, without any crew involvement. An analysis of hundreds of hours of observations yielded 17 events of vertical flashes from cloud top toward the ionosphere [Boeck et al., 1994]. These events were approximately geo-located by using stars and ground lights, and were found to occur over Africa, South-America, USA, Australia, Borneo and the Pacific Ocean. The oblique view of the illumination inside the cloud (caused by a strong lightning flash) from the shuttle, provided the first unambiguous optical link between the parent stroke and the subsequent TLE.

While innovative and unique, these space-based observations were rather limited and lacked the accuracy needed to determine the optical energy, spectral properties or relation to the parent storm. The MEIDEX offered a significant improvement for space-based TLE observations, using an absolutely calibrated camera combined with ground ELF/VLF-based geo-locating systems. The experiment was designed so as to maximize observation opportunities, by guiding the astronauts to use visual observations of lightning activity in order to direct the gimbaled camera toward these regions. Contrary to remote-controlled or automatic robotic observations, the human factor played a significant and indispensable role in the real-time adjustment of target acquisition, greatly enhancing the success of MEIDEX.

EQUIPMENT AND CALIBRATION

The main science instrument in MEIDEX was a Xybion radiometric camera model IMC-201, equipped with a rotating filter wheel with six narrow-band filters [Yair et al., 2003]. The central wavelengths were 340nm, 380nm, 470nm, 555nm, 665nm and 860nm. The video format of the IMC-201 camera is NTSC which means that it produces its video output at 30Hz (33.3 msec/frame). Xybion cameras of other models were used for ground measurements of sprites by Lyons et al. [1995] and by other researchers. Spectral data from earlier studies showed that 5 out of 6 wavelengths chosen for the MEIDEX were good for TLE observations [Hampton et al., 1996]. The camera was equipped with a 50mm UV lens, adjusted with a special baffle to mitigate stray light from entering the optics. The FOV of the camera was rectangular, 10.76° vertical and 14.04° horizontal (diagonal 17.86°). The CCD had 486 x 704 pixels, where each pixel corresponds to $1.365 \cdot 10^{-7}$ steradian. When observing the limb 1900 km away, we covered 200 km above the ground, the expected altitude range for TLE occurrence. The camera was calibrated with a calibration sphere before the mission, and during flight by looking at the moon, ensuring a quantitative knowledge of its performance and the absolute translation of gray levels to energy units.

ON-ORBIT OPERATIONS

Sprite observations during the MEIDEX were conducted throughout the STS-107 mission, with little or no significant changes from the original plan and with an intensive crew involvement. The initial mission time-line contained 25 dedicated observation windows, each approximately 20-minute long, with an accumulated time of approximately 5 hours. This large volume was to be recorded on board the shuttle (Sony V10 and DSR20 digital recorders) or down-linked and recorded at the Payload Operations Control Center (POCC) in NASA/GSFC. No recording within the payload was planned for sprite observations.

Inputs to the daily Execute Package for the crew were derived from the sprite forecast for appropriate regions mostly in the SE Pacific (Australia and Fiji), Africa, the southern Indian Ocean and South America. Shuttle attitude and gimbal changes were deduced from the (almost) real-time IR satellite images that were on the Web (<http://www.bom.gov.au/weather/satellite/>) and from the VLF lightning location network (TOGA: http://ritz.otago.ac.nz/~sferix/TOGA_network.html) operated by the University of Otago in New-Zealand. This "now-casting" method allowed us to adjust the pointing and to increase the likelihood of the Xybion FOV to intercept the main lightning activity area, above which we could expect to find TLEs.

In general, tropical lightning activity was high during this period, with major storm centers found in northern Australia, Indonesia, Fiji and along the ITCZ over the Pacific ocean. Strong storms were also observed over the Amazon basin and central Africa. Most observations were conducted before local midnight, when convective activity had not yet subsided. The initial pointing was to an altitude of 40 km above the limb, and the filter used was #5, in 665 nm, where most of the radiation in red sprites is expected. Time stamping on the Xybion image was inserted from the ground as part of the camera setting and was corrected by the crew if the lag was greater than 2 seconds. Thus the accuracy of event timing may be considered to be ± 2 seconds (times on the images appear in MET, in the format 01/xx/03 where xx is the mission day).

Based on the crew's inputs, we concluded that there was little use for the Sekai Wide FOV camera as a target finder, since the view on the crew-cabin monitors were too dim. We therefore relied on the astronauts' visual observations and real-time gimbaling of the camera, a method that proved to be highly successful. With help from JSC-Pointing, we changed the attitude of the shuttle vertical axis pointing to 4 degrees below the horizon for several

orbits, and then modified it to point exactly at the limb. The camera settings were also modified to allow better sensitivity to dim events (gain increased to 90%, working in Average rather than Peak mode).

RESULTS

In the first MEIDEX sprite observation during orbit 44 (January 19th 09:05:23.94 UTC), Mission Specialist David Brown tracked a very active thunderstorm with continuous visible lightning activity located over the Pacific Ocean to the east of the Java-Fiji region. At the time of the event, the shuttle was pointing at 23°S 159°E and range of the storm center from the shuttle was 1635 km. When the video data was analyzed, the image in Figure 1 was retrieved, showing an Elve with the classical ring-like structure. The calculated altitude above the ground was 85 km. The unique doughnut shape with the



Figure 1. Enhanced image of an Elve captured in orbit 44.

distinct hole in the center above the location of the causative ground stroke is in accordance with the prediction of Inan et al. [1997], confirming the suggested mechanism of lightning induced EMP as the source for the Nitrogen first positive emissions at 662.4 nm. Subsequent observations (orbits 48, 76, 77, 87) were conducted with filters 5 and 6 (665 and 860 nm, accordingly) and at least those conducted in 665 nm were very successful in capturing sprites, elves and meteors, near or above the limb. The sequence shown in Figure 2 was photographed by Pilot William McCool, illustrating the raw data obtained from the Xybion camera. The triple sprite shown in the upper right appears in at least 2 consecutive frames, which means that the minimal duration was 33 msec. This event occurred on January 22nd 01:53:15.89 UTC and was located almost directly above the limb 1900 km away from the shuttle at 17°E 4°S, over continental south-western Africa. A subsequent observation a short time

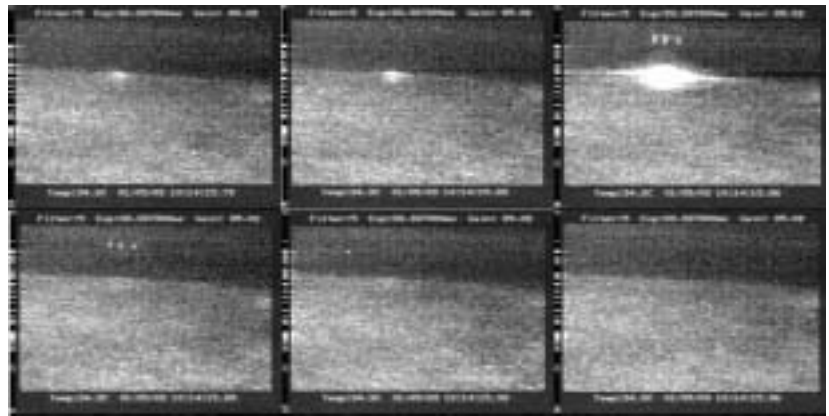


Figure 2: A sequence of Sprite images captured in orbit 87.

later (01:54:46.08 UTC) serendipitously caught a carrot-sprite in front of the planet Jupiter, a fact that enabled an accurate calibration of the relative emissions from the TLE and the planet (Figure 3). Sprite observations were concluded in orbit 239 (MET 14/21:20), in which we used the 380 nm filter and succeeded in imaging an active storm in northern Australia. These data will help calculating the emitted energy from lightning in the UV range. In the video from the 3 orbits analyzed thus far we have positively identified 15 TLEs in less than 1 hour of accumulated data (and additionally 20 suspected events), a significantly higher detection rate compared to the MLE observations.

The total recorded time of sprite observations that was downlinked to the ground and saved at NASA/GSFC exceeds 7 hours. Future analysis is needed in order to evaluate what fraction of this volume contains useful scientific

information. During the periods of sprite observations, electromagnetic data in the ELF/VLF range were collected at many ground sites around the world, for coordination with the sprite/elve observations from the shuttle. The very low frequency (VLF) data were sampled from Sde-Boker, Israel, continuously at 100 kHz sampling rate during the sprite observation windows, each approximately 30 minutes in length. During the same period the extremely low frequency (ELF) data were sampled at a Mitzpe Ramon, at a sampling rate of 250Hz. Teams around the world also measuring ELF/VLF signals related to sprites and elves were located in Japan, Antarctica, Hungary, New Zealand, USA, and Brazil. Analysis of the common events will enable a geo-locating of the lightning according the method developed by Price et al. [2001]. This work is presently in progress.

In conclusion, the MEIDEX Sprite campaign proved highly successful and obtained a considerable amount of new observations. The data are yet to be calibrated, analyzed and synched with the ground measurements. The mission proved the flexibility and global coverage of sprite observations from space and set a benchmark for future satellite and ISS-based TLE observations.

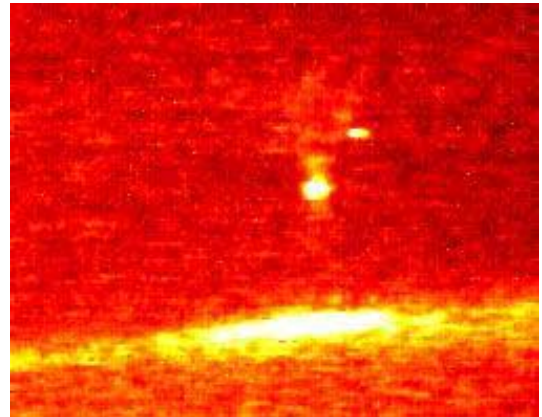


Figure 3. An enhanced color image of a "carrot" sprite and the planet Jupiter.

REFERENCES

- Boeck, W. L., O. H. Vaughan, R. J. Blakeslee, B. Vonnegut, M. Brook and J. McKune, 1994: Observations of lightning in the stratosphere. *J. Geophys. Res.*, **100**, D1, 1465-1475.
- Boeck, W. L., O. H. Vaughan Jr., R. J. Blakeslee, B. Vonnegut and M. Brook, 1998: The role of the space shuttle videotapes in the discovery of sprites, jets and elves. *Jour. Atmos. Sol. Terr. Phys.*, 60, 669-677.
- Hampton, D.L., M. J. Heavner, E. M. Wescott and D. D. Sentman, 1996: Optical spectral characteristics of sprites. *Geophys. Res. Lett.*, **23**, 1, 82-92.
- Inan, U. S., C. Barrington-Leigh, S. Hansen, V. S. Glukov, T. F. Bell and R. Rairden, 1997: Rapid lateral expansion of optical luminosity in lightning-induced ionospheric flashes referred to as "Elves". *Geophys. Res. Lett.*, 24, 5.
- Lyons, W. A., 1995: Characteristics of luminous structures in the stratosphere above thunderstorms as imaged by low-light video. *Geophys. Res. Lett.*, **21**, 875.
- Price, C., M. Asfur, W. A. Lyons and T. Nelson, 2001: An improved ELF/VLF method for globally geolocating sprite-producing lightning. *Geophys. Res. Lett.*, 29 (3), 11-14.
- Yair, Y., C. Price, Z. Levin, J. Joseph, P. Israelevitch, A. Devir, M. Moalem, B. Ziv and M. Asfur. 2003: Sprite observations from the space shuttle during the Mediterranean Israeli Dust Experiment (MEIDEX). *J. Atmos. Sol. Terr. Phys.*, in press.

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