Past and Future Challenges of Space Observations

Y. Yair[1]

[1]*The Open University of Israel, Ra'anana, Israel*

Space offers a unique vantage point for observing lightning and transient luminous events. Indeed, orbiting detectors on satellites such as the ISUAL on-board FORMOSAT were able to identify and map the global distributions of TLEs and their geographical and seasonal dependence. The RHESSI and AGILE satellites offer a similar, nearly global coverage for TGFs. During short duration, targeted campaign-mode observations, astronauts on board the Space Shuttle and the International Space Station were able to acquire excellent images of TLEs in nadir and limb viewing angles. This paper reviews results of past missions and on-going ones, and delineates the advantages and shortcomings of different observation modes. Future challenges for upcoming space missions are briefly described.

1. Introduction

Soon after their discovery in 1989, TLE observations were also attempted from space. The impetus was clear: a space-based platform overcomes many limitations of ground-based measurements, especially those arising from line-of-sight and cloud obscuration issues. Observations of the upper atmosphere from orbit enable the continuous monitoring and large scale coverage of these atmospheric phenomena [1]. Furthermore, top-side observations of TLEs can reveal details that may be partly or completely obscured in ground-based imaging, such as the 3D structure, the spectral features and the relations to other high-altitude phenomena such as meteors, gravity waves and airglow.

2.1. The Space Shuttle

Analog video footage taken by payload-bay cameras during the Mesoscale Lightning Experiment (1989-1991) yielded a harvest of 17 images identified as sprites and Elves [2]. Although of limited quality, these images became instrumental in identifying limb viewing as optimal for TLE imaging. Directed observations were also conducted in 2003 during the MEIDEX [3]. A calibrated multi-spectral camera (Xybion IMC-201) was commanded by the astronauts towards pre-determined regions where the likelihood of lightning activity was forecasted 24h in advance [4], maximizing the time allocated for TLE research. In 381 minutes of useful data from 21 orbits, a total of 18 events were found: 10 Elves, 7 sprites and one presumed conjugate event. The calibrated camera enabled computing absolute sprite radiance values of ~ few MR.

2.2. The International Space Station

Nadir observations were done during the LSO experiment by European astronauts in 2001-2002 [5]. The LSO used two cameras, one with a very narrow spectral filter, centered at 761±10 nm, which allowed the detection of intense sprite emission from the $N_2$1P (3-1) line at 767.2 nm. The filter was found to be useful in reducing the contamination of sprite observations by lightning light from IC and CG flashes, which are a major constraint for nadir observations. The results from 3.5 hours of data contained 10 sprites in 280 lightning flashes.

Targeted attempts were resumed in 2011 during the NHK "Cosmic Shore" campaign. An EMCCD TV camera was pointed manually by an astronaut in the Earth-pointing Copula module [6].

Fig. 1. A color image of a sprite halo in oblique view obtained from the ISS during the "Cosmic Shore" campaign in 2011 (red hazy oval). The computed volume occupied by the halo is $5.93 \cdot 10^5$ km^3 [6].

Results contained 8 sprites, 1 sprite halo (Fig.1) and 1 gigantic jet, in < 2 hours of video. A different usage of the ISS was reported [7], and during 20

hours of undirected observations 15 sprites were detected in still images taken by the crew at different viewing angles with a Nikon D3S camera (Fig. 2).

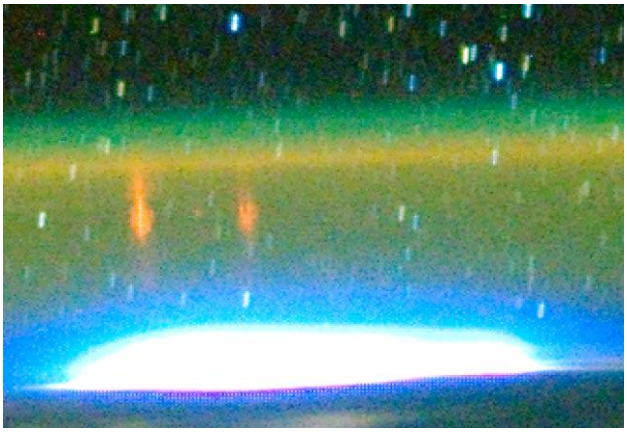

Fig. 2. Carrot sprites in limb view obtained from the ISS. The airglow layer is clearly visible (image courtesy T. Farges).

2.3 Satellite Observations

By far, the most successful TLE satellite mission to date is the ISUAL on-board the FORMOSAT-2 satellite (launched 2004) in a polar, sun-synchronized orbit at 891 km. It carries a CCD imager, a 6-channel spectrophotometer and a 2-channel array photometer. The satellite operates in trigger-mode and is able to detect over-the-limb events from ranges > 3000 km. After a decade of successful observations, by May 2013 sprite climatology was obtained from a total of 31,361 TLEs, with a deduced global rate of 24 min^{-1} [8].

For TGF research, there are presently 3 active satellites: RHESSI (since 2002), AGILE (2007; ~10 TGFs per month) and Fermi-GBM (2008; 2 TGFs per week, 415 as of 1/2014). The different sensors and energy level detection thresholds of these platforms do not readily produce a global distribution of these elusive events, yet the clear connection to thunderstorms is a well accepted fact, while the mechanism is still being debated [9].

3. Future Challenges

The challenges facing new space missions are many. A desired high frame-rate camera necessitates large memory and fast downlink capability of detected events. Getting the finer details of sprite structure or of Gigantic-Jet propagation requires telescopic lenses, because of the huge range to the limb. Fixed or moveable detectors limit the coverage or require commanding, and pointing accuracy is essential. To maximize the yield, coordination with ground-based optical observations is needed in various geographic locations, preferably those with a dense lightning detection network. The next decade of research from space will undoubtedly bring new and exciting discoveries and increase our understanding of these beautiful phenomena.

4. References

[1] Yair, Y.: Observations of Transient Luminous Events from Earth Orbit. *IEEJ Transaction, Special Issue on Physics of Lightning and Related Phenomena*, 126, 4, 244-249 (2006).

[2] Boeck, W. L., O. H. Vaughan Jr., R. J. Blakeslee, B. Vonnegut and M. Brook: The role of the space shuttle videotapes in the discovery of sprites, jets and elves. *J. Atmos. Sol.-Terr. Phys.*, 60, 669-677 (1998).

[3] Yair, Y., P. Israelevich, A. Devir, M. Moalem, C. Price, J. Joseph, Z. Levin, B. Ziv and A. Teller: New sprites observations from the space shuttle. *J. Geophys. Res*., 109, D15 (2004).

[4] Ziv, B., Y. Yair, K. Pressman and M. Fullekrug: Verification of the Aviation Center global forecasts of Mesoscale Convective Systems. *Jour. App. Meteor*., 43, 720-726, (2004).

[5] Blanc, E., T. Farges, R. Roche, D. Brebion, T. Hua, A. Labarthe and V. Melnikov: Nadir observations of sprites from the international space station, *J. Geophys. Res*., 109, A02306, doi:10.1029/2003JA009972 (2004).

[6] Yair, Y., L. Rubanenko, K. Mezuman, G. Elhalel, M. Pariente, M. Glickman-Pariente, B. Ziv, Y. Takahashi and T. Inoue: New color images of transient luminous events from the International Space Station. *Jour. Atmos. Sol. Terr. Phys.*, 102, 140-147 (2013).

[7] Jehl, A., T. Farges, and E. Blanc: Color pictures of sprites from non-dedicated observation on board the International Space Station, *J. Geophys. Res. Space Physics*, 118, doi:10.1029/2012JA018144 (2013).

[8] Chern, J-S, A-M. Wu and S-F Lin: Globalization extension of transient luminous events from FORMOSAT-2 observation. *Acta Astronautica*, 98, 64-70 (2014).

[9] Østgaard, N., T. Gjesteland, B. E. Carlson, A. B. Collier, S. A. Cummer, G. Lu, and H. J. Christian: Simultaneous observations of optical lightning and terrestrial gamma ray flash from space, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50466 (2013).