ISUAL multi-band observations of elves

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Abstract

The Imager of Sprites and Upper Atmospheric Lightning (ISUAL) experiment on the FORMOSAT-2 satellite inferred the global occurrence rates of sprites, halos and elves to be ~1, ~1 and 35 events/min, respectively [1, 2]. Hence, elve is the most abundant type of transient luminous events (TLEs). From analyzing brightness observed by ISUAL Imager through different filters ($1PN_2$, 762, 630, 557.7, 427.8 nm), the relative intensity of the OH (9,3), O^1D, O^1S, $1NN_2^+$ and O_2 Atmosphere band (0,0) emissions in elves will be discussed.

1. Introduction

Recently, the global occurrence rates of sprites, halos and elves were inferred to be ~1, ~1 and 35 events/min based on the events recorded by ISUAL experiment onboard the FORMOSAT-2 satellite [1, 2]. Evidently, the occurrence of elves is the most frequent comparing with the other types of TLEs, including sprites, halos, gigantic jet, and blue jets. In this presentation, the images recorded by the ISUAL imager through several filters ($1PN_2$, 762, 630, 557.7, 427.8 nm filter) are analyzed with the aim to study the relative intensity of the OH (9,3), O^1D, O^1S, $1NN_2^+$ and O_2 Atmosphere band (0,0) emissions in elves.

2. ISUAL payload

ISUAL payload onboard the FORMOSAT-2 is first satellite payload dedicating for the long-term survey of upper atmospheric discharge phenomenon [3, 4]. The FORMOSAT-2 satellite has 14 sun-synchronized daily orbits with an altitude of 891 km. The mission was launched on 21 May 2004. ISUAL project is an international collaboration between the National Cheng Kung University-Taiwan, Tohoku University-Japan, and University of California, Berkeley-USA. ISUAL consists of three sensor packages including an intensified CCD imager, a six-channel spectrophotometer, and a dual-band array photometer. The imager is equipped with 5 selectable band-pass filters ($1PN_2$, 762, 630, 557.7, 427.8 nm filter) mounted on a rotatable wheel. The spectrophotometer contains six photometer channels, with the band-passes ranging from the far-ultraviolet to the near infrared. The dual-band ISUAL AP is respectively fitted with broadband blue and red filters. The mission objectives are to perform a global survey of lightning-induced TLEs, to determine the occurrence rate of TLEs above thunderstorms, to investigate their spatial, temporal and spectral properties, and to investigate of the global distribution of airglow intensity as a function of altitude. ISUAL have been successfully operated during its designed life (2004-2009). Due to the scientific achievements of the mission in the five years, the ISUAL mission has recently been granted an extension of 3 years (2010-2014) with funding support from National Space Organization and National Science Council in Taiwan.

3. ISUAL recorded elves

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In the past six years, five bandpass filters ($1PN_2$, 762, 630, 557.7, 427.8 nm filter) have been used for ISUAL TLE observations. The $1PN_2$ filter is a broadband filter with >50% responses in the wavelength range of 633.4-750.9 nm. The other narrowband filters are 759.4-767.1 nm (762-nm filter) at 50 % responses, 627.8-634.8 nm (630-nm filter), 555.7-561.7 nm (557.7-nm filter), and 426.4-431 nm (427.8-nm filter). With maim mission goal of performing global TLE survey through the broadband$1PN_2$ filter, only a small fraction of time was dedicated to the observations through the narrowband filters (762, 630, 557.7, 427.8 nm filter). Even so, weaker band emissions were successfully by the ISUAL Imager through these narrowband filters. However, due to the brief emission duration of elves (<1 ms), it is impossible to observe the same elve using different filters through operating the rotatable filter wheel of the ISUAL Imager. In this presentation, the relative intensity of the measured band emissions in elves and their comparison with the model will be discussed.

3.1 $1PN_2$ emission

The $1PN_2$ band emission (478-2531 nm) is a dominant source of optical emissions in elves. A typical elve has average $1PN_2$ brightness between tens of kilo Rayleigh (kR) to hundreds of kR inferred from ISUAL images taken with 29 milliseond exposure time. Considering 1) the detected percentage of $1PN_2$ emission in $1PN_2$-filtered Imager (14%) and 2) the temporal resolution (0.1 ms) in the brightness measurement, the peak intensity of the total $1PN_2$ band emission in an ISUAL recorded elves was reported to be as bright as 44 mega Rayleigh (MR) [5]. This result is consistent with the theoretical prediction (> 10 MR) by Inan et al. [6] and has been observed in ground-based photometer measurements [7].

3.2 630-nm emission

Huang et al. [8] investigate the lightning-induced sudden brightening in the OH airglow layer using ISUAL 630-nm-filtered Imager. They also proposed the conceptual mechanism responsible for the induced OH nightglow enhancement. Huang et al. [9] further analyzed 630-nm-filtered Imager recorded elves, and found that there is a considerable intensity enhancement (~1.25 kR) unaccounted for after the N_21P contribution has been removed. Huang et al. [9] suggests that there might be OH emissions in elves and that OH species might also be involved in the lightning-induced process and contribute to the intensity enhancements that was observed.

3.3 $O(^1S)$ 557.7 nm emission

The 557.7 nm optical emission of the atomic transition of $O(^1S\text{-}^1D)$ is a spin-forbidden process with the radiative lifetime of 0.71 second. The major/dominant process in producing metastable atomic oxygen $O(^1S)$ is the electron-impact process, $e+O_2 \rightarrow e+O(^3P)+O(^1S)$; the other two $O(^1S\text{-}^1D)$ contributor processes that have the second and the third highest reaction rates are $N_2(A)+O(^3P) \rightarrow N_2+O(^1S)$ and $N_2(C)+O_2 \rightarrow N_2+O(^1S)+O(^3P)$. Due to the long radiative lifetime of $O(^1S\text{-}^1D)$ and the slow radiative deactivation processes associated with $O(^1S)$, $O(^1S)$ emission at 557.7 nm is too weak (<1 kR) to be detectable using the ISUAL Imager with 557.7-nm filter. However, the optical signature of $1PN_2$ emissions in an elve can clearly be discerned from the ISUAL AP data.

3.4 $1NN_2^+$ emission from 427.8-nm filter

Only one elve event that has extremely bright $1NN_2^+$ emissions was recorded during the four month ISUAL 427.8 nm campaign (December 2008 to March 2009). If one considers the high ISUAL detection rate of elves, this implies that the typical brightness of $1NN_2^+$ emissions is well below the detection threshold (about 5 kR) of the 427.8-nm-filtered ISUAL Imager. Due to the low sensitivity and low S/N ratios for ISUAL Imager observed through the narrowband 427.8 nm-filter, only the diffuse emissions from the ionized structure in this elve was recorded. The ionized patch appears as a large luminous horizontal patch (lateral length of ~200 km and vertical span of ~15 km) in the airglow layer (80-95 km) and is the only evident structure in this elve. However, the observation of the $1NN_2^+$ emissions does provide the evidence that supports the existence of direct electron-impact ionizations of N_2 in elves.

4. Discussion and Conclusion

We analyzed the band emissions in elves and estimated their brightness using ISUAL images taken through different narrowband filters (762, 630, 557.7, 427.8 nm filter). A typical elve is found to have average $1PN_2$ brightness

between tens of kilo Rayleigh (kR) to hundreds of kR. Estimation of the OH intensity enhancement (~1.25 kR) in an elve event was obtained after subtracting the $N_2$1P contribution in the 630-nm-filtered ISUAL Images. For elves, the intensity of the O(^{1}S) emissions at 557.7 nm is below 1 kR and the intensity of the 1NN2+ emission is below 5 kR. Furthermore in this talk, the ISUAL detected emissions (OH (9,3), O^{1}D, O^{1}S, 1NN$_2^+$ and O_2 Atmosphere band (0,0)) will be compared with the numerical modelings.

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