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GROUND OBSERVATIONS OF SPRITES AND OTHER TLES IN TAIWAN

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ABSTRACT

Sprites, elves and blue jets are collectively denominated as the upper atmospheric transient luminous events (TLEs). They are recently discovered optical flashes between active thunderstorms and the ionosphere. In this report, a brief introduction to the most important characteristics of TLEs is given. Since 2001, scientists from the National Cheng Kung University have been performing yearly summer campaigns from various locations in Taiwan. The main achievements of their yearly campaign are presented.

Key words : Earth — terrestrial lightning, instrumentation: detectors — high-speed imaging , methods: statistical

I. INTRODUCTION

The region between thunderclouds and the ionosphere used to be viewed as an uninteresting place. The situation changed completely, after scientists recorded an optical flash (Franz et al., 1990) in this region now carries the name of sprites, in the summer of 1989. Through ground and aircraft campaigns in the following years, additional types of upper atmospheric flashes were discovered. These upper atmospheric transient flashes are collectively called the transient luminous events (TLEs). The current members of TLEs include sprites, blue jets, elves, and gigantic jets (Franz et al., 1990; Sentman, et al. 1995; Wescott et al., 1995; Fukunishi et al., 1996; Su et al., 2003). Brief introductions to sprites, elves and blue jets are presented here. Sprites (see Fig. 1) are lightning-induced luminous events with reddish structures that span the altitude range of 30-90 km and the lateral dimension of 5-30 km (Sentman, et al. 1995). Luminous duration of sprites typically lasts only for several milliseconds, but some exceptional ones could stay luminous for more than a hundred milliseconds. The sprite emissions are believed to come from the de-excitations of air molecules after they were impacted by energetic electrons. These electrons were accelerated by the quasi-static electric field establishing temporarily between thunderclouds and the ionosphere following a cloud-to-ground discharge that removed positive charge from the thundercloud. After the molecular N2 was excited by the field-driven energetic electrons, the most dominant de-excitation emission is the N2 first positive band, which gives sprites the characteristic reddish hue.

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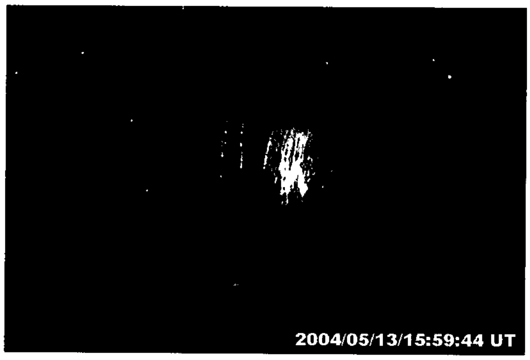

Fig. 1.— A cluster of sprites that appeared to dance over the Jade Mountain (false color). The bright star to the right of the sprites is Altair, and bright stars to the left are members of the constellation Cygnus. Under careful inspections, one can also find the constellation Delphinus to the right of sprites.

Morphologically, most sprites have a so-called lassical carrot form,which consists of a luminous center body, a lower filamentary tendril and a diffusive hair region above the body. Columniform sprites are also often observed, but not as frequently as the carrot sprites. Sometimes, sprites could occur along with a donut-shape elves and/or a dish-like halo over their top.

As the lower ionosphere is constantly heated by electromagnetic pulses emitted by cloud-to-ground lightning strokes. Under favorable but not yet fully understood circumstances, extended optical emissions, called elves, can be resulted (Fukunishi et al. 1996; Inan et al., 1996). The occurrence elevation of elves is around 90km. Elves usually are donut-shape, with a luminous duration of less than 1 ms and a horizontal scale of hundreds of kilometers, see Fig. 2.

Wescott, et al. (1995) described blue jets to be

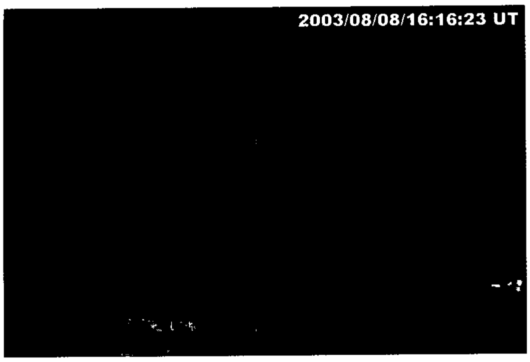

Fig. 2.— A donut-shape optical emission is the hallmark of elves (false color). The black patch on the elves is a frontal cloud. This image was recorded at Kenting National Park, Taiwan at sea level.

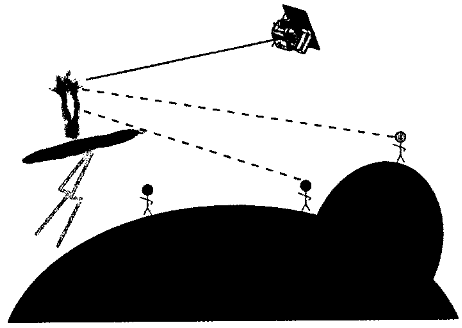

Fig. 3.— A cartoon illustration of the TLE observation strategies that the NCKU team involved in. Observing from a sea level site, one has easy transportation and good logistic supports but pays the penalty in severe atmospheric absorption. With a mountain-top site, the frontal cloud obstruction is less but harder to get to. Space observation can avoid most of the pitfalls that ground observations may face, but is very costly.

narrowly-collimated beams of blue light that appeared to propagate upward from tops of thunderstorms, with speed approximately at 100 km/s and reached terminal altitudes of 40-50 km. The beam of light seemed diverge at top with a luminous duration of ~200 ms. An airborne color intensified CCD imager revealed that the blue jet is mostly blue with some green emissions. Blue jets are hard to observe on the ground, due to severe atmospheric absorption of blue emission and the obstruction of clouds, such that there is little progress in elucidating their characteristics except for their color. Next milestone occurred at September of 2001, when a giant blue jet was observed by Pasko, et al. (2001) to reach an altitude of 70km and to last for ~800ms. In the summer of 2001, scientists from the National Cheng Kung University (NCKU), Taiwan, started to perform summer TLE campaigns from several locations. The main purpose was to gain hand-on experience of TLE observation and therefore to be ready to carry out the ISUAL experiment on the FORMOSAT-2 satellite (formerly ROCSAT-2). In this report, the instruments and observation scenario is introduced first. Then, the key and exciting results from Taiwan TLE campaigns are presented.

II. INSTRUMENT AND OBSERVATION

Taiwan TLE campaigns deploy several sets of NTSC ICCD cameras, which are equipped with different optical filters to form a multi-band observation system. A typical camera contains a Watec N100 ICCD, SONY DCR-PC5 DV recorder, and Sigma 20mm/f1.8 lens with FOV 18.5 H ×13.8 V degrees. The R, G, B KENKO filters are lab-calibrated. The TLE activity around Taiwan usually starts to rise near late spring and tapers off near late summer. Therefore, we stage our yearly campaign between April and September. Over the years, four different observation sites had been tested: (1) Lulin Observatory on the central ridge of Taiwan, (2) Ali Mountain Weather Station, (3) Kenting National Park at the southern tip of Taiwan, and (4) the NCKU campus – at the center of Tainan City. A clear night sky over the campaign site, an active thunderstorm at 200-800km away, and good seeing condition along the line of sight are crucial and preferred for the nightly observation. After four years, we have concluded that both Lulin Observatory and Kenting National Park are good sites for hunting TLEs near Taiwan. A cartoon illustration can be found in Fig. 3 that nicely sums up the observation advantage with each site. The brightness of TLEs often exceeds the bright star Vega. However, even at this brightness level, the occurrence of TLEs are unpredictable and their luminous duration is short. These two factors often substantially increase the difficulty level in observing TLEs. Our nightly observation procedures are:

1. Using GOES9 IR cloud map to choose the target thunderstorm.
2. Monitoring the thunderstorm activity all night.
3. Staring at the monitor of camcorders and waiting for the occurrence of TLEs.
4. Keeping an event log for all the flashes.
5. Checking the recorded tapes and download images later.

III. KEY RESULTS FROM TAIWAN TLE CAMPAIGNS: 2001-2004

In 2001, we successfully confirmed the existence sprites and elves over the Asian continent for the first time. We also discovered a characteristic difference between land and ocean sprites (Su et al., 2002). Among the recorded oceanic sprites, 78% of them contained only a single column (see Fig. 4) and 22% of them consisted of clusters of sprite columns (Fig. 5). In contrast, 36% of land sprites was single column and 64% of the land events was multi-column clusters. Since most of the TLE studies concentrated on events observed

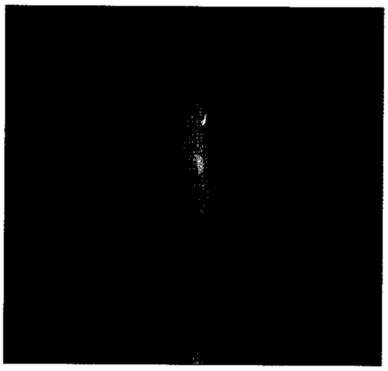

Fig. 4.— A true color single column sprite that was recorded at Kenting National Park (02:19:36 UT, 12 July 2003). The dark area below the sprite is the sea surface and the bright stripe is the reflection of this sprite.

Fig. 5.— A cluster of sprites that was recorded at NCKU campus (false color). Besides the sprite red glows, other light emissions were from the NCKU campus buildings and the highly light-polluted Tainan City.

over the U.S. High Plains, this intriguing characteristic difference was never noticed before.

As it can be seen in table 1, the morphological disparity between land and oceanic sprites remains true over the years, except for the year 2002 when there were too few recorded sprite events to be statistically meaningful. If we exclude the under sampling data from 2002, on average 65% of land sprites is a multi-column sprite, whereas only 35% of oceanic sprites is a clustering event.

In the past four years, many TLE events were registered by our multi-band observation system. However, the blue- and the green-band images contained little emission. This means that all the observed sprites and elves are predominately red at ground level. The event shown in Fig 4 is a typical true color sprite image from our data set. It is very likely that the shorter wavelength emissions are highly attenuated due to the absorption or scattering of Earth atmosphere. More sensitive ICCD cameras probably are needed to detect TLE short wavelength emissions, especially for the emissions induced by energetic electrons in the streamer regions of sprites.

The optical-band brightness for some of the more luminous sprites was estimated to exceed 5 MR. Figs. 4 & 5 show two extremely bright and interesting sprites were able to cast reflection on the ocean surface or shone through the highly light-polluted sky of Tainan City. These two events are clearly out-shine most of the stars in our night sky.

The most remarkable TLE events, that were ever recorded in our yearly campaigns, occurred on the night of 22 July 2002. In that eventful night, five gigantic jets (GJs) were discovered above a oceanic thunderstorm near the Philippines (Su et al. 2003). Figure 6 shows a few selected frames from one of the recorded gigantic jets. The temporal evolution of these jets can been divided into three stages: the leading jet, the fully-developed jet and the trailing jet. The whole luminous period of GJs lasted from 300 ms to 500 ms. At the fully-developed stage, the most luminous structure extends from cloud top at 15 km to the E-layer ionosphere at 95 km. From the available lightning data, no cloud-to-ground strokes were found to be associated with these GJs. Therefore, it is probable that GJs were not CG-induced events, and very likely they are discharges between thunderclouds and the ionosphere. Since no similar event was ever observed over the U.S. High Plains in the past decade of continuing observation, we initially suspect that GJs might only occur above local convection systems over the oceans.

However, after nearly two years of hunting, another GJ was captured from Lulin observatory on 18 June 2004. This event occurred above a frontal system which was stationing at Anhui province of China about 700km away. This fact indicated that GJs could also occur over land. Unfortunately, this gigantic jet was not in the FOV of our multi-band system, thus the color characteristic of gigantic jets is still unknown.

IV. CONCLUSION AND PERSPECTIVES

Taiwan is at a good location to study TLEs for it situates at the boundary of Asian Continent and the Pacific Ocean. From this location, both TLE events occur over land and over oceans can be studied. The data recorded over the regions surrounding Taiwan could facilitate a better understanding of these mysterious transient flashes. Through years of observations, we found that both Lulin Observatory and Kenting National Park are good sites for TLE studies.

Existing data indicate that land sprites tend to cluster and oceanic sprites prefer to appear in single column. The cause(s) of this morphological difference are unknown as of this writing. To construct color TLE images using our present multi-band imaging system has proven to be harder than expected. The main difficulty is in the severe atmospheric absorption or scattering of the TLE short wavelength emissions. We hope that the newest generation of ICCD cameras could improve the situation.

TABLE 1.
STATISTICS OF LAND AND OCEANIC SPRITES FROM THE TAIWAN TLE CAMPAIGNS

YEAR	2001		2002		2003		2004	
EVENT # (%)	SINGLE COLUMN	GROUP	SINGLE COLUMN	GROUP	SINGLE COLUMN	GROUP	SINGLE COLUMN	GROUP
OCEAN	14(78%)	4(22%)	3(60%)	2(40%)	35(53%)	31(47%)	11(65%)	6(35%)
LAND	15(36%)	27(64%)	2(67%)	1(33%)	28(42%)	38(58%)	29(24%)	93(76%)

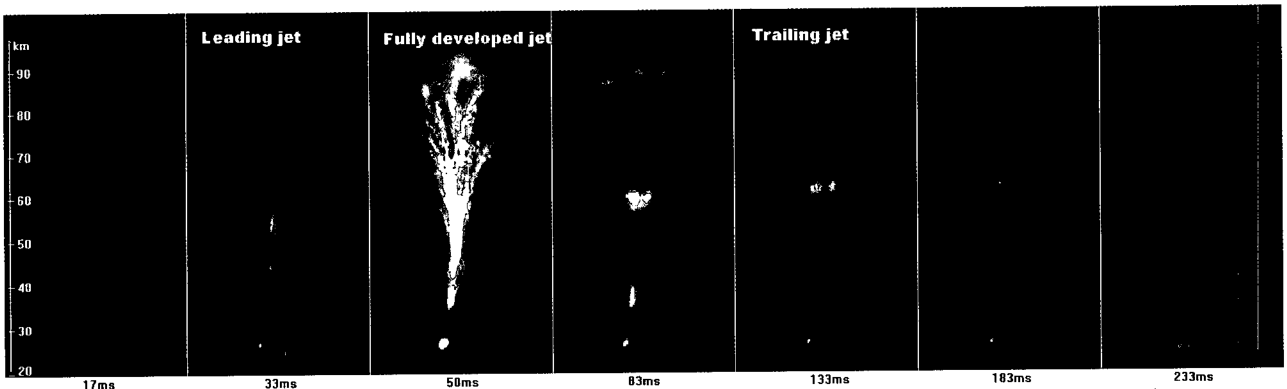

Fig. 6.— Selected image fields of a gigantic jet that was recorded on 22 July 2002 from Kenting (false color).

Gigantic jet, which is a new type of TLEs, was first discovered in 2002, and another GJ was recorded in 2004. All of them were from localized convection systems over ocean or frontal system over continent. We hope that as more gigantic jets are documented, the relationship between GJs and their meteorological occurrence conditions could be clarified. Furthermore, in order to investigate the physical and chemical processes of GJs, a spectrograph and a high speed camera clearly are needed to obtain the spectroscopic information and to explore the dynamical evolution of GJs.

In the near future, an automatic TLE observation system will be deployed at Lulin Observatory to lessen the demand on human resource and to improve the efficiency in capturing TLE events. In the mean time, the ISUAL experiment, which is a scientific payload on Taiwan's FORMOSAT-2 satellite, had been launched on 20 May 2004. Besides performing global observations of TLEs from space, we will also strive to achieve coordinated ground-space observations with ISUAL. With the multi-platform data, TLEs and the region between thunderstorms and the ionosphere may be better understood.

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