Transient Luminous Event & Radio Emission Correlator

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Introduction

Globally up to ∼2000 thunderstorms are active at all times, with 40 to 100 lightning discharges occuring every second [1]. These numbers are testament to the influence thunderstorms have on the global electric circuit. Within the last two decades intensive studies of thunderstorms have revealed several previously undetected phenomena, seemingly associated with certain types of lightning strikes found in large nocturnal Mesoscale Convective Systems (MCS) over the continental plains of North America, Africa, Central Europe and Asia. Commonly designated as Transient Luminous Events or TLE's, some of these phenomena partly manifest themselves as extremely fast and highly dynamic optical emissions between the top of the thunderclouds and the ionosphere - some reaching the very edge of space.
The scientific community has taken great strides towards improving our understanding of the complex physics behind these phenomena, and assess their influence on the global climate.
To date all but two observation campaigns have been conducted as ground or plane/ballon based surveys. Space shuttle mission STS-107 (2003) and the 700kg ROCSAT-2 satellite (2004)[2] are the only Earth orbiting missions so far which have flown instrumentation dedicated to studying these phenomena. For both missions the scientific focus has been on characterizing TLE optical properties and mapping their spatial distribution. Several TLE spectra have been obtained by ROCSAT-2 after comissioning its ISUAL instrument in June 2004, and the data acquired provides the scientific basis for the proposal at hand.

This proposal covers the Transient luminous event & Radio Emission Correlator (TREC) instrument package, which will facilitate the first ever satellite based study of electromagnetic coupling mechanisms between high altitude TLE's and the ionosphere. TREC combines three optical sensors into an automated payload capable of detecting and imaging TLE's, whilst simultaneously recording Extremely Low Frequency/Very Low Frequency (ELF/VLF) E-field variations - all within the constraints of the CubeSat platform [3].

Transient Luminous Events

Research into Transient Luminous Events is a relatively new field in atmospheric science with many - as of yet - unanswered questions remaining. Traditionally the TLE's have been subdivided into three categories - Sprites, Elves and Blue Jets. Recent observations do however, suggest that several more categories are needed to distinguish between the different event types. **Sprites** refer to brief optical emissions originating in the mesosphere ($\sim$50 to 80km altitude) extending upwards towards the lower edge of the ionosphere and sometimes downwards into the stratosphere below. Sprites predominantly appear following a particularly intense type of lightning discharge, denoted positive cloud-to-ground (+CG) or precursor lightning. Recent studies have found Sprites to accompany roughly 0.2-1% of all lightning strikes [4]. Perhaps the most widely recognized of the TLE's, Sprites are mostly reddish in color and can be detected with the naked eye under favorable viewing conditions.

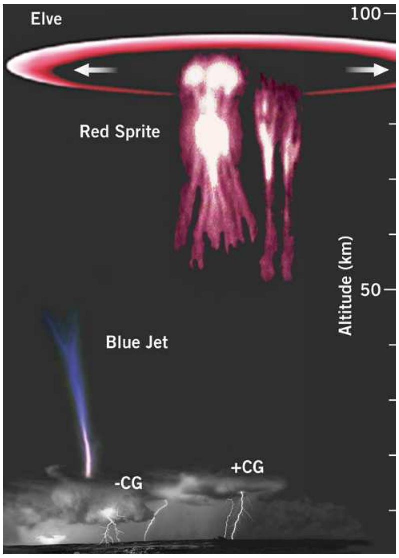

Figure 1: TLE Types

	Sprite	Elve	Blue Jet
Altitude [km]	40-90	80-100	20-40
Width [km]	25-50	100-300	3-5
Duration [ms]	5-500	$<$1	$\sim$250
Intensity [kR]	100-1000	$>$1000	10-500

Table 1: TLE Characteristics [5][7]

Elves appear as an extremely fast lateral expansion of optical luminosity situated at and altitude of 85-95km. Often reaching diameters of 300km, the "doughnut" shaped Elve is believed to be generated by an ElectroMagnetic Pulse (EMP) inducing a shortlived transient glow in the ionosphere. The source of the EMP seems to be +CG lightning of very high peak currents ($>$150kA). **Blue Jets** are the most elusive of the three phenomena, partly due to atmospheric scattering of the shorter wavelengths making ground observations difficult. Seemingly lacking a direct link to any precursor event such as observed for Sprites and Elves, the Blue Jets are usually found propagating at high speeds ($\sim$100km/s) from the top of the thunderclouds into the lower mesosphere.
General characteristics of the three main phenomena are provided in Table 1, which clearly indicate how event duration and intensity will be the main constraints on any optical system designed to observe TLE's. The sprite phenomena provides the best optical, spatial, temporal characteristica and will be the main focus of the TREC instrumentation package, eventhough it may be possible to study other TLE types with the same instrumentation.

Mission Perspective

The data obtained by TREC will be the first of its kind, essentially opening up a new field in atmospheric science. It will aid future space based investigations in devising effective algorithms for TLE discrimination and improve our common understanding of how TLE's interact with the charged particles of the ionosphere, thought to potentially change the wave propagation charactaristics relied upon for long range radio communication. Furthermore, TREC will bolster the knowledge database initiated by ROCSAT-2 with respect to TLE temporal and spatial properties as well as global occurance rates and distribution. TREC will also fulfill the obligation of DTUsat to provide a service to the amateur radio community, by investigating the long standing hypothesis of TLE's as initiators of radio ”sferics” and ”whistlers”. Finally, it should be noted that successfully operating TREC will irrefutably prove the viability of the CubeSat platform as a facilitator of pioneering scientific investigations.

Observation Prerequisites

As shown in Table 1 the luminous intensity of TLE's is limited. Figure 2 depicts the incident photon flux versus distance between the observer and the TLE for different event intensities. Clearly, these illumination levels do not suffice for imaging with miniature optics - and as such - initial design considerations call for the implementation of a Charge Coupled Device (CCD) imager fitted with an intensifier unit in order to achieve a sufficient Signal to Noise Ratio (SNR).

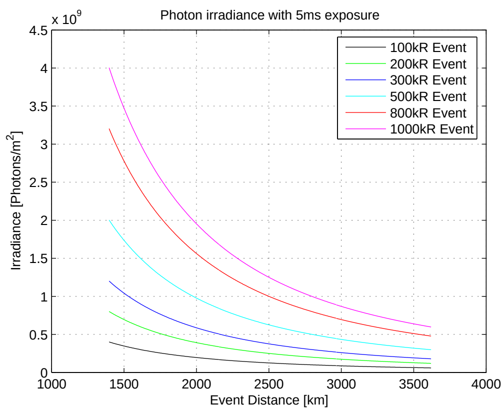

Figure 2: Sprite irradiation intensities for 5ms exposure

The intensity of a Sprite precursor lightning can be so high that the intensified imager will be blinded making positive Sprite identification impossible. As such, TREC will utilize several different techniques to improve Sprite to precursor lightning intensity ratios. Firstly, a limb viewing approach illustrated in Figure 3 is used to induce spatial separation between the Sprite and the precursor lightning. Secondly, the CCD sensor of the imager is equipped with an anti-blooming system, minimizing pixel to pixel contamination. Finally, TREC employs a monochromatic near Ultra Violet (UV) sensor (330nm) to ensure image exposure activation occurs at the appropriate time, minimizing precursor lightning influence.

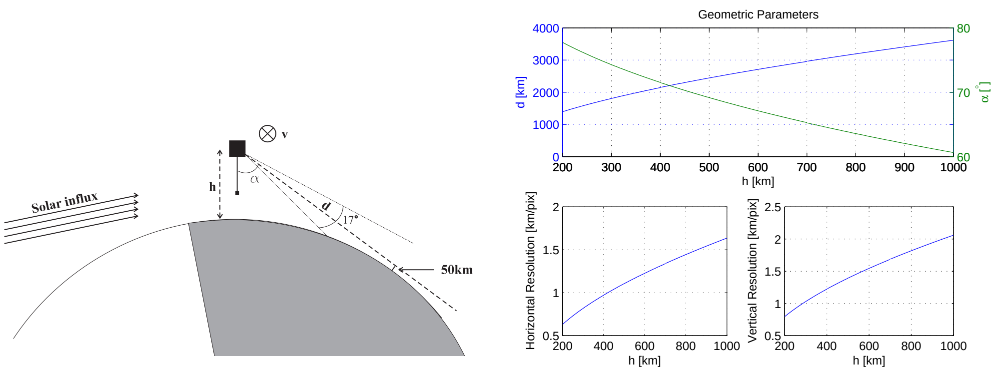

Figure 3: TLE observation geometry

For illustrative purposes Figure 3 depicts the satellite observing an area perpendicular to the direction of motion. In reality observations will be made in the ram direction, surveying an area with local time around 1-1$\frac{1}{2}$ hours after sunset or before dawn. This situation is ideal for Sprite observations as the nocturnal MCS usually experience peak activity around these times. The surveying configuration is adopted to ensure coherence between optical observations and the ELF/VLF emissions conforming to the Earths magnetic field lines due to refraction in the ionosphere. Figure 4 illustrates the envisioned ELF/VLF radio wave reception concept.

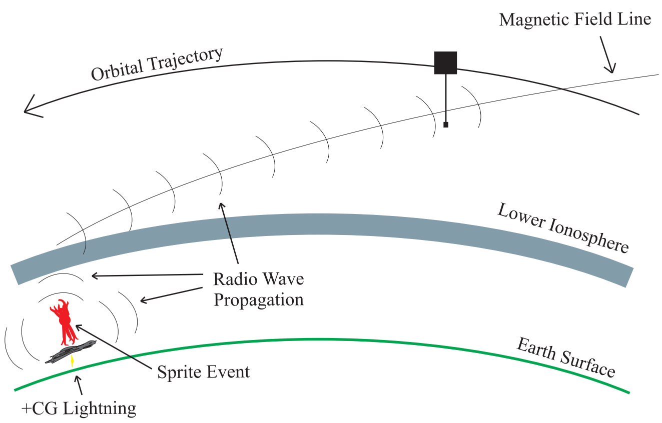

Figure 4: TREC ELF/VLF radio wave reception concept

So far, all CubeSat satellites launched or slated for launch are employing retrograde, low eccentricity, sun-synchronous orbits with similar LTAN to the described situation. Hence, considering the likelihood of DTUsat2 obtaining similar orbital parameters, the platform provides TREC with global coverage and near optimal viewing conditions.

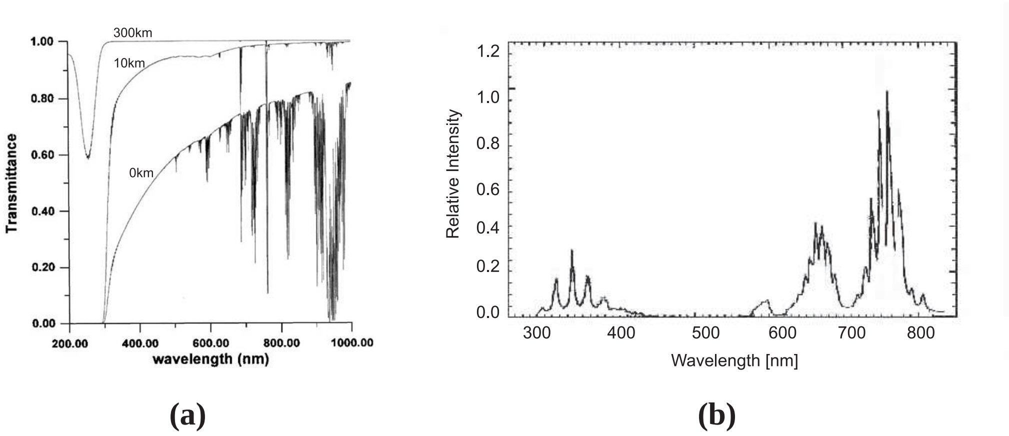

Figure 5: Atmospheric transmission profile (a), Sprite emission spectrum (b)

Utilizing the atmospheric attenuation at near UV wavelengths ensures effective discrimination of Sprites over their precursor lightning. Figure 5.a shows the atmospheric transmittance for different observer altitudes with the luminous source at an altitude of 50km versus 5.b depicting a normalized Sprite emission spectrum [6][7]. Clearly, observing the source from LEO allows transmission in the 330nm band, while any emission from 10km and below (eg. precursor lightning) will be severely attenuated. Adjusting the threshold of the UV sensor should allow for dynamic event discrimination [2].

Instrument Package Description

The TREC instrumentation package is comprised of four separate sensors fused functionally to perform efficient observations of Sprite events:

- An image intensified CCD imager based upon the PICOCAM camera developed at DTU - FOV(H,V)= $20°, 17°$.
- A 2m monopole antenna and ELF/VLF bandpass receiver, with the antenna doubling as a Gravity Gradient stabilizer for the CubeSat platform.
- A high sensitivity boresighted monochromatic 330nm near UV sensor acting as event detection trigger for the imager and ELF/VLF receiver.
- A high sensitivity boresighted wideband photosensor for lightning activity detection.

The Field Of View (FOV) of the UV and Wideband sensors mimic that of the CCD imager through their boresighted mounting interface. The relatively large FOV is chosen to allow for some discrepancy in the pointing accuracy of the platform, and to ensure coverage of a large atmospheric volume. As such, Sprite rates in the FOV can be estimated at 20-50 events/month for an optimal orbit [7]. Figure 6 depicts the preliminary Functional Block Diagram for the instrument package.

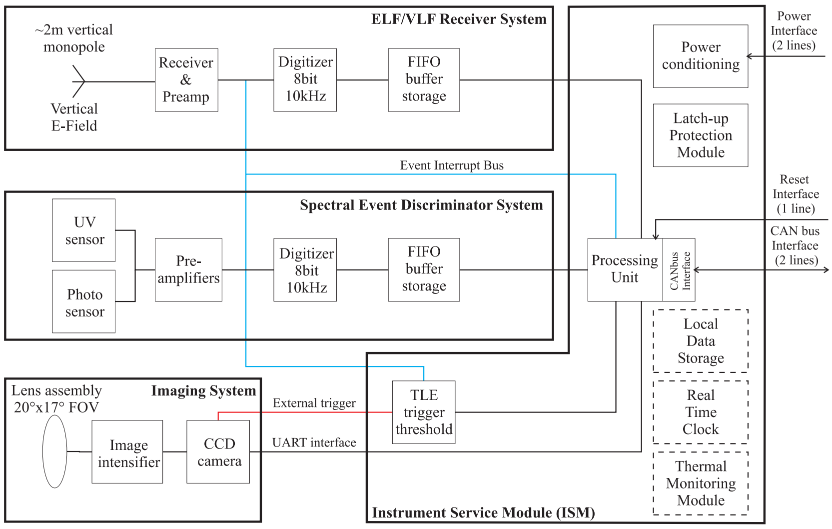

Figure 6: TREC functional block diagram

Figure 7 shows an example of how TREC could be physically implemented on the CubeSat platform. With the ELF/VLF antenna mounted in the center of the satellite, the CCD imager and the Spectral Event Discriminator must be oriented to support limb viewing operations. All TREC elements are attatched to the nadir pointing panel of the satellite, easing integration.

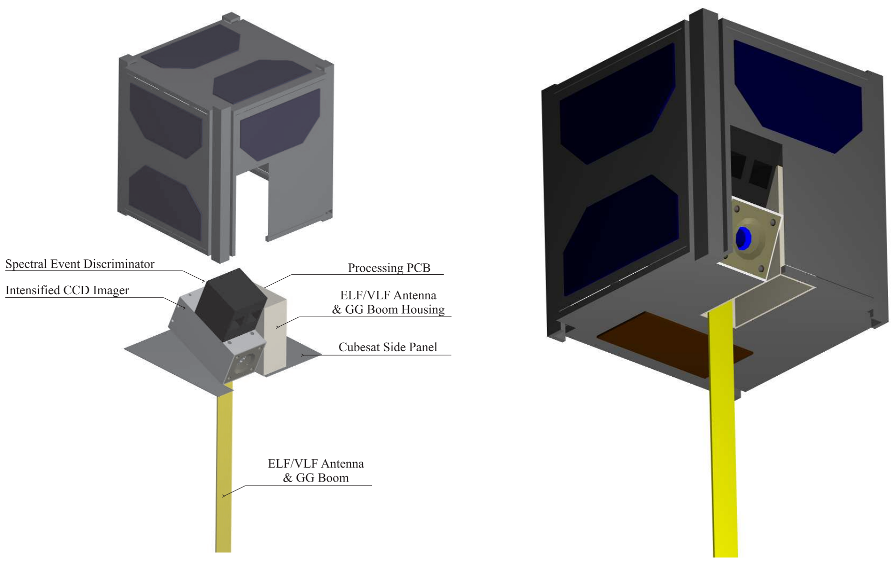

Figure 7: CAD rendering of TREC implemented on CubeSat platform

While it will be possible to operate each sensor individually, the main string of operations will be based upon the TLE data acquisition sequence, depicted in its envisioned form in Figure 8.

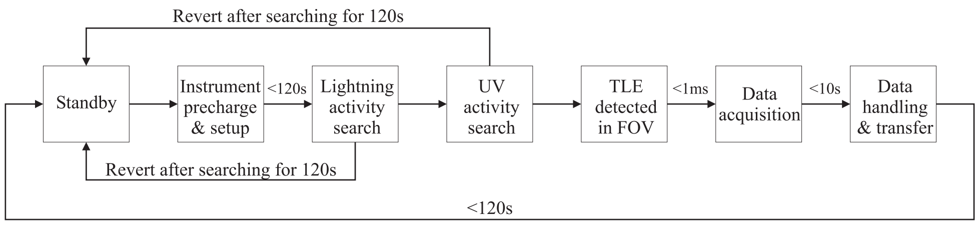

Figure 8: TREC operating sequence

Following this operating sequence the instrument primarily runs in the low consumption lightning activity search mode, thus making it possible for the CubeSat platform to sustain instrument operations for extended periodes of time. If sufficient lightning activity is detected the payload enters the high consumption UV activity search, which terminates either after 120s if no activity has been detected or by data aquisition if a TLE occurs in the FOV. The CCD imager runs continuously throughout the UV activity search mode, but only stores an image after being interrupted by the UV sensor. Preliminary assesments suggest a full data package return will encompass a ∼30kb JPEG image, ∼40kb (60% compression) ELF/VLF data covering 5 seconds before and after the event, and ∼40kb (60% compression) data from the spectral discriminator. In all, roughly 110kb/event. Reduced package sizes will also be supported.

Platform Requirements

TREC imposes a number of performance requirements on the carrier satellite, with platform stability being the most critical. Fortunately, the TREC instrument package includes the 2m ELF/VLF monopole, which - when augmented with a tip mass of 30g - induces pitch and roll stability with a liberation frequency $\omega_{lib} = 0.00173 rad/s \simeq 0.104°/s$, and an amplitude $< 5°$ in a 600km circular orbit. The Gravity Gradient boom thus ensures conformation to the limb viewing concept, and provides fairly accurate nadir pointing alignment for the satellite communication subsystem. Yaw stability is not included however. With [5] indicating 5ms as being a suitable threshold for the minimum duration of Sprites, the ACDS system of the platform must support 5ms exposures without inducing motion smear into the images. As such, a maximum yaw rate requirement of ∼0.1°/s is imposed upon the ACDS subsystem. The TREC instrument package would benefit from the yaw axis being subject to active control. Mass and power requirements are given in Tables 2 and 3, respectively:

Component	Mass [g]	Tolerance [g]	Estimate Basis
CCD Imager	70	±5	Prototype
Image Intensifier	40	±10	Estimate
VLF Antenna/GG Boom 2m	25	±5	Prototype
VLF Antenna/GG Boom Housing	25	±10	Estimate
GG Boom Tip Mass	30	-	Design Spec.
UV/Photo Sensors & Mount	25	±5	Estimate
Processing PCB	10	±5	Estimate
Electrical Components	15	±5	Estimate
Harness	10	±5	Estimate
Total	250	±50	

Table 2: TREC Instrument Package Preliminary Mass Budget

	Power Loads [mW]				Operational Modes				
Component	**Standby**	**Active**	**Peak**	**Estimate Basis**	**Standby**	**Lightning Search**	**UV Search**	**Event Data Recording**	**Data Transfer**
CCD Imager	15	30	1200	Prototype	15	15	1200	1200	15
Image Intensifier	0	50	50	Estimate	0	0	50	50	0
ELF/VLF Receiver	0	30	30	Estimate	0	0	30	30	0
UV Sensor	0	70	70	Estimate	0	0	70	70	0
Lightning Detector	0	30	30	Estimate	0	30	30	30	0
ISM Processing	15	30	100	Estimate	15	30	30	100	100
Mode Totals [mW]					30	75	1410	1480	115
Mode Totals with 15% Margin [mW]					**35**	**87**	**1622**	**1702**	**133**

Table 3: TREC Instrument Package Preliminary Power Budget @3.6V supply

The combined volume of the instrument parts is estimated at 140cm^3. Utilizing the data in Table 3, the operating sequence of Figure 8 can be found to consume a maximum of ∼250J or rougly 1.3% of the capacity offered by a standard 3.6V 1500mAh Li-Ion battery.

Concluding Comments

The considerations of this proposal have unequivocally shown that a dedicated CubeSat platform will support the TREC instrumentation package. Moreover, they have illustrated that the main performance restrictions of the system are found in the source illumination limitations. Further studies will most likely confirm the necessity of photon multiplicator devices for both the UV sensor and the CCD imager. The estimated mass, volume and power consumption of such devices has been accounted for in the applicable preliminary budgets.

TLE and ionospheric interaction research is a relatively new field of atmospheric science, where even small amounts of data can further the combined knowledge of the scientific community significantly. Demonstrating that the familiar ELF/VLF waveforms of Sprites can be detected from Low Earth Orbit will be a major step towards developing better event discrimination algorithms for future missions, and improve our understanding of how Sprites interact with the ionosphere.

Building upon simple measurement concepts, the ambition of the TREC payload is not only to investigate the correlation between low frequency radio emissions and Sprites, but also to provide the DTUsat project with a great source of outreach and Public Relations material. As such, a single Sprite observed by TREC will - besides setting new standards for what capabilities can be attributed to the CubeSat platform - serve to stimulate public awareness of Danish space activities.

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