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Gamma Ray Storms: preliminary meteorological analysis of AGILE TGFs

Meteorology of AGILE TGF observations

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Abstract Despite the recognition from their discovery that Terrestrial Gamma Ray Flashes (TGFs) originate from thunderstorms, little is known about the characteristics of TGF-producing storms. The characteristics of thunderstorms that produce TGFs are here investigated using meteorological data, with the aim to set up a framework of analysis to be propagated to more complete TGFs archives. In this work we present the preliminary results. As first analysis, we considered 72 events detected by the Astrorivelatore Gamma ad Immagini Leggero (AGILE) from March 2015 to June 2015, estimating their electric activity in terms of flash production. To this end, we examined World Wide Lightning Location Network (WWLLN) lightning data in the spatial and temporal proximity of each AGILE TGFs, searching for relationship between flash rate peak and distribution and the TGF occurrence. Moreover, we analyzed the low-Earth orbiting (LEO) satellite observation of theTGF producing storms to define, through the capabilities of microwave sensors (both active and passive), the structure of the convective storms correlated with TGF events. In particular, we focused on the Global Precipitation Measurement (GPM) observations and show here a case study observed by the dual-frequency precipitation radar (DPR). Preliminary results indicate that the TGF often occur during the most active lightning phase of the storm, while the intensity of the storm is not a key ingredient for the production of a TGF. The multisensory capability of LEO satellites provide a picture of the storm structure, that, despite the poor coverage of such sensors, is an unprecedented tool to study such cloud system over remote areas and open ocean. This study framework is meant to be applied to other TGF database, such as the ones collected by other space missions (e.g. FERMI, RHESSI).

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1 Introduction

Satellite observed Terrestrial Gamma ray Flashes (TGFs) from the Burst and Transient Source Experiment (BATSE) and the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) are well documented (e.g. [1], [2]). Using Monte Carlo simulations of runaway breakdown, Dwyer and Smith [3] estimated that the source altitude of these TGFs were between 15 and 21 km, and thus suggested that thunderstorm tops might be the source regions. Observed TGFs have been directly associated with specific lightning events [4], [5] and have been related to large convective systems (e.g., [1], [6]). There are further evidence that TGFs emanate from source regions near and above thunderstorm top [7], [8] and that they are associated with positive intracloud discharges [9], [7]. Splitt et al. [10] performed the first meteorological comparison of TGFs and associated thunderstorms and reported that TGFs follow diurnal, seasonal and geographic patterns similar to thunderstorms. Utilizing infrared (IR) data, they found that TGF storm systems are closely associated with tall (13.6 17.3 km) tropical thunderstorm systems. They identified a specific storm/TGF event that occurred in Mozambique. The storm was analyzed using Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) hydrometeor 2A12 data product. The TGF storm was found to have relatively high concentrations of hydrometeors near 6 km, which is within the mixed phase region, but not atypical for tropical convection. This study develops along two main lines: a case study of a TGF observed by a near coincident GPM-CO overpass is presented to highlight the role of satellite view in such studies, and 2) a statistical analysis of the distribution of flashes in the TGF producing storms.

2 Supporting data and Instrumentation

2.1 AGILE

AGILE [13] is a mission of the Italian Space Agency (ASI) dedicated to astrophysics in the gamma-ray energy range 30 MeV 30 GeV, operating since April 2007 in a low inclination (2.5 degrees) low-Earth orbit at 540 km altitude. The AGILE Gamma-Ray Imaging Detector (GRID) is a pair-tracking telescope based on a tungsten-silicon tracker. A mini calorimeter (MCAL) [14], based on scintillating bars for the detection of gamma rays in the range 300 keV100 MeV, and a plastic anticoincidence detector complete the high-energy instrument. Thanks to its timing accuracy, energy range extended up to 100 MeV and orbit inclination (optimal for mapping the equatorial region, where most the events take place), AGILE is proved to be a very efficient instrument for TGF detection [15], [16]. Here we used the AGILE TGF database from

March 2015 to June 2015 (time and location of 72 events). These events have been selected only based on a simulataneous (within 500 microsec) WWLLN detections and not all of them are included in the catalog described in [17].

2.2 Lightning data

The very low frequency (VLF) based World Wide Lightning Location Network (WWLLN) [11], [12] data were used to help identify single storm cases in which a specific thunderstorm can be associated with an AGILE identified TGF event. The selection criteria for these cases include the following: (1) at least four WWLLN strokes occur within 25 min of the AGILE TGF observation time, and (2) the distance from the TGF WWLLN stroke position is less than 25 km. The WWLLN absolute location accuracy is roughly 20 km [11].

2.3 Satellite-Based Remote Sensing System

GPM is a science mission with integrated applications goals for advancing the knowledge of the global water/energy cycle variability as well as improving hydrological prediction capabilities through more accurate and frequent measurements of global precipitation [18].The GPM core satellite is equipped with a microwave radiometer called GMI (GPM Microwave Imager) and a Dual-frequency precipitation radar (DPR) operating at Ku (13.6 GHz) and Ka (35.5 GHz) band. GMI instrument is a multi-channel, conical- scanning, radiometer characterized by thirteen microwave channels ranging in frequency from 10 GHz to 183 GHz. Microwave techniques provide the most direct observation of precipitation as microwave radiation is less affected by cloud droplets and interacts with precipitation-sized hydrometeors. DPR is designed to improve our knowledge of precipitation processes relative to the single-frequency (Ku-band) radar used in TRMM, by providing greater dynamic range, more detailed information on microphysics, and better accuracies in rainfall retrievals [19].

3 Polar observations on AGILE dataset: GPM case study.

A case study from the single storm data set was selected given the near simultaneous overpass of the GPM-CO satellite over Indonesia. The TGF was observed by AGILE on 08:18 UTC 18 April 2015, while DPR passed over this storm approximately 30 seconds after the TGF event. The WWLLN identified TGFs location on the coast (black dot, range of uncertainty 25 km) in Fig. 1, left panel. To understand the nature of precipitation event we first consider DPR reflectivity data in Ku band: in the left panel of Figure 1 is shown the vertical cross section of the atmosphere up to the elevation of 22 km a.s.l. where the columnar cloud structure is rendered in color shades. The cloud stretches from the ocean surface, where moderate to intense precipitation is

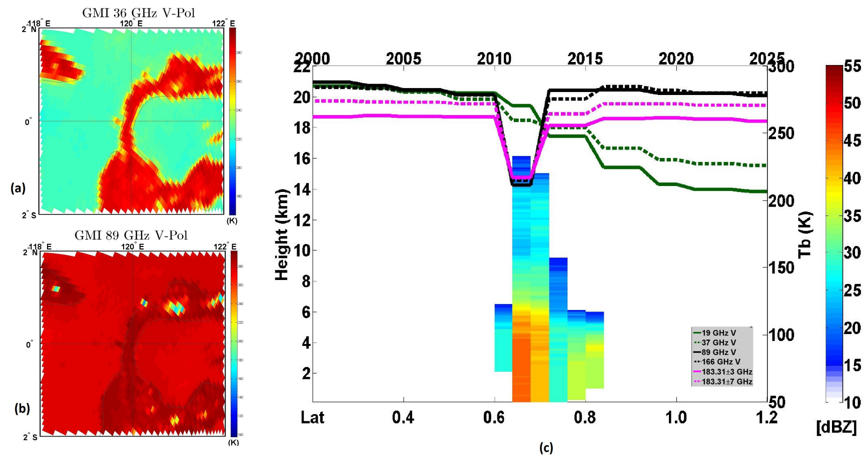

Fig. 1 GPM-DPR images for the 08:18 UTC 18 April 2015 overpass : (a,b) GPM brightness temperature at 36 GHz V and 89 GHz V Channel images (TGF location 0.2 N 120.25 E). (c) Vertical DPR sections for the TGF producing thunderstorm over Indonesia with correponding brightness temperature profiles.

detected, to the tropopause (around 15 km a.s.l.). However, the upper cloud layers (above 7 km a.s.l.) have a modest hydrometeor content, as can be inferred by reflectivity values below 30 dBz, while the highest reflectivity (above 40 dBz) is measured around 4-5 km a.s.l.. The profiles of the corresponding Tb (V-pol) are plotted in the upper part of the panel (scale on the right axis): only the 89 GHz Tb shows sensitivity to the cloud, dropping to 210 K in correspondence, indicating a significant ice content, even if with limited horizontal extension. The lack of signal in the lower frequencies is very likely due to the size of the cloud well below the GMI footprint at frequencies below 37 GHz (15 to 32 km). The black vertical line in figure 1b indicates the position where the TGF and the corresponding WWLLN flash are detected. In figure 2 a deeper analysis is shown.

In figure 2 a description of the lightning activity of the storm is presented: the number of lightning measured by WWLLN in four circular areas of decreasing radius (100, 50, 25 and 10 km) in intervals of 10 minutes centred on the TGF time. The analysis confirms that the storm was not very intense, with a limited lightning activity (NN lightning in the 40 minutes of storm life). Moreover, the temporal distribution of lightning shows that the TGF occurs after the peak of flash rate

4 Storm-phase analysis

Given the difficulties to find GPM-CO overpass in coincidence with TGF detection in the small AGILE database, a statistical analysis is conducted to better understand the characteristics of TGF producing thunderstorm systems. The subset of single storm events described above is analyzed to provide

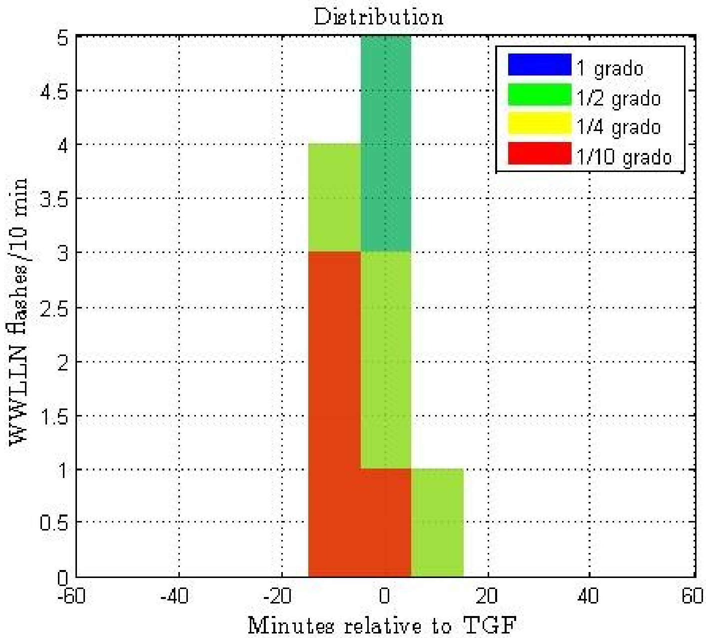

Fig. 2 08:18 UTC 18 April 2015 - Flash rate histogram in time for 4 different square areas for three TGFs. All the ashes have been related to the TGF-producing storm within 60 min of zero (TGF in 0, count step 10 min).

Table 1 TGF related to flash rate peak

Before	Peak	After
17 %	60 %	23 %

estimates of storm-phase evolution. To determine in what phase of the storm evolution TGFs most commonly appear, we considered the distribution of ash rate as function of time for each TGF- related storm. Since it is difficult to follow the motion and evolution of the active part of a convective system, we considered 4 different square areas (L=100, 50, 25 and 10 km) centered to the event, with the aim to assign to the TGF producing storm only the ashes produced by the storm. Figure 3 shows histograms, aligned so that each TGF occurs at t=0 for three representative TGFs. Tab 1 shows the correlation in time between the ash rate peak (for each event) and the TGF time.

5 Discussion and conclusions

Global distribution of the Terrestrial Gamma-ray Flashes (TGFs) detected by AGILE for the period from March 2015 to June 2015 has been analysed, with

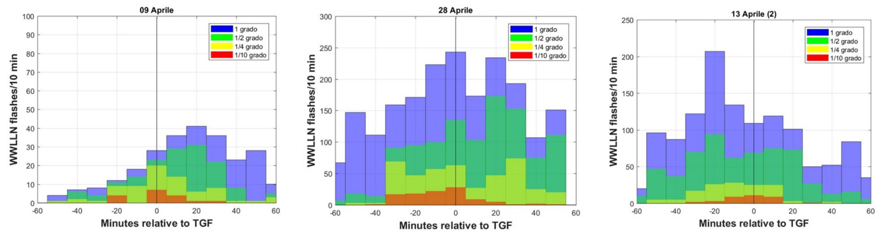

Fig. 3 Flash rate histogram in time for 4 different square areas for three TGFs. Our criterion to define the related single storm is to have almost 4 flashes in the smallest area considered. All the flashes have been related to the TGF-producing storm within 60 min of zero (TGF in 0, count step 10 min).

the aid of GPM-CO observation and WWLLN lightning data. A case study analysis shows that the considered TGF was produced by a storm of average intensity and very limited extension and lightning activity.The TGF occurred on the edge of the cloud more intense structure and relatively closer to the cloud final stage. Satellite observation, especially in the microwave (active and passive), provide a valuable tool to study such cloud systems producing TGF over the ocean. For the TGfs population (72) the ”single storm” criterion required at least 4 fashes within 25 km and 25 min before and after the event. We considered 4 different square areas centered to the event. To analyze characteristics of TGF producing storms two primary questions were pursued with this investi-gation: is TGF production merely a function of lightning fash count and does hydrometeor content within the TGF-related storms contains higher concen- trations of cloud water, cloud ice, precipitation water, and precipitation ice? Two investigative methods were employed to answer these questions: 1- Storm-phase Analysis: to determine in what phase of the storm evolution TGFs most commonly appear we made a histogram of ash rate as a function of time for each related storm. Statistical analysis shows that there is a clear peak of fash rate suggesting that TGF occur preferentially during the peak of flash production Tab 1.

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