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A pipeline to link meteorological information and TGFs detected by AGILE

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Key Points:
- The AGILE satellite has a TGF database linked to meteorological information
- Geostationary satellite data are processed to extract information on TGF-producing thunderstorms
- This pipeline allows for further meteorological studies about the physics of TGFs

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Abstract Terrestrial gamma ray flashes (TGFs) are brief (approximately hundreds of microseconds) intense gamma ray emissions coming from Earth's atmosphere (∼15 km above sea level), correlated with thunderstorms and atmospheric electric activity. Since their unexpected discovery in the early 1990s by the Burst And Transient Source Experiment/Compton Gamma Ray Observatory, TGFs have been further investigated by several satellites devoted to high-energy astrophysics. The Astrorivelatore Gamma ad Immagini LEggero (AGILE) mission turned out to be particularly suitable to detect these events, due to a very wide energy range (up to 100 MeV), an optimized triggering system, and a unique low-inclination near-equatorial orbit (2.5°). We describe a detection system, developed for the AGILE satellite, whose aim is to provide real-time meteorological information on each detected TGF. We take advantage of data acquired by geostationary satellites to promptly identify the associated storm and follow its evolution in space and time, in order to study its previous onset and development. Data from Low-Earth Orbit meteorological satellites, such as the Global Precipitation Mission, as well as ground measurements from lightning detection networks, can be integrated in the pipeline. This system allows us a prompt characterization of the ground meteorological conditions at TGF time which will provide instrument-independent trigger validation, fill in a database for subsequent statistical analysis, and eventually, on a longer term perspective, serve as a real-time alert service open to the community.

1. Introduction

In the early 1990s, the Burst And Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory detected gamma ray emissions coming from the Earth, a phenomenon later to be termed terrestrial gamma ray flashes (TGFs) [*Fishman et al.*, 1994]. These extremely brief (∼100 μs) and energetic (up to several tens of MeVs [*Tavani et al.*, 2011]) events are related to thunderstorm activity and are produced at the top of thunderclouds (∼15 km altitude) [*Dwyer and Smith*, 2005]. The most accepted model for TGF production is a bremsstrahlung emission by avalanches of electrons accelerated to relativistic energies within thunderstorm strong electric fields [*Gurevich et al.*, 1992; *Dwyer*, 2008].

At the moment, only a few missions devoted to high-energy astrophysics are detecting TGFs, such as the Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) [*Smith et al.*, 2005; *Grefenstette et al.*, 2008], the Astrorivelatore Gamma ad Immagini LEggero (AGILE) [*Marisaldi et al.*, 2010, 2014], and the Fermi Space Telescope [*Briggs et al.*, 2010].

A basic point in understanding the TGF physics is the study of the meteorology of the associated thunderstorms. So far, only few works have been carried out, addressing the phenomenology of the TGF-associated thunderstorms and trying to figure out the existence of particular features among these convective systems: such studies showed that TGFs follow the diurnal, seasonal, and geographic pattern of lightning activity on Earth and are associated with tall (13 – 17 km) tropical thunderstorms [*Splitt et al.*, 2010], with rare conditions of flash rate, convective available potential energy (CAPE) amount, and cloud extension [*Fabró et al.*, 2015]. However, radar observations pointed out no privileged thunderstorm conditions for TGF production [*Chronis et al.*, 2016], but every storm seems capable of producing TGFs. On the other hand, tropopause height plays an important but not dominant role in the TGF geographic occurrence [*Smith et al.*, 2010; *Nisi et al.*, 2014]: such a distribution can be affected by the higher altitude of convective systems at low latitudes that favors the detection of gamma rays up to the spacecraft. Also, by studying TGFs with an associated single storm within the uncertainty circle around the satellite point, *Smith et al.* [2010] find that TGFs tend to occur during the decreasing flash rate phase of a thunderstorm. By studying the correlation with sferics and lightning rate, the TGF sample cannot be fully considered a subset of the lightning sample: regional differences in the TGF/lightning ratio are observed by all satellites [*Smith et al.*, 2010; *Fuschino et al.*, 2011; *Briggs et al.*, 2013]. Investigations on the intrinsic brightness of TGFs also reveal that the source region should be placed in the interior of the thunderstorm, between the two main charge layers [*Cummer et al.*, 2014].

In this perspective, a system producing and storing, in almost real time, meteorological information on each detected event represents a powerful tool to provide already processed data, suitable for prompt and further analysis. This pipeline system manages in the most efficient way data from AGILE and from five different meteorological satellites, and it is possibly improvable with products from other instruments, ground measurements, and network stations. The aim of this system is retrieving all the necessary information, in order to promptly characterize the meteorological scenario associated with each TGF detected by AGILE. Such information regard the amount of convectiveness, the number of single cell or multicell storms, the altitude and temperature of the cloud tops, and the lightning flash rate. In order to monitor how these quantities change in time and space and to investigate whether TGFs are mostly associated with particular types of thunderclouds or atmospheric conditions, data are stored and processed also for a large time interval around the TGF time.

2. The AGILE Satellite

The Astrorivelatore Gamma ad Immagini LEggero (AGILE) [*Tavani et al.*, 2009] is an Italian space mission, devoted to high-energy astrophysics, mainly aimed at studying pulsars, gamma ray bursts, Active Galactic Nuclei, supernova remnants, black holes, and other gamma ray and TeV sources. The AGILE satellite is a project of the Italian Space Agency (ASI), with collaboration of many other research institutes. AGILE was launched in 2007 and delivered in a low-inclination quasi-equatorial (2.5°) orbit at 540 km altitude.

The instrument includes three main detectors: a tungsten-Silicon Tracker (ST) gamma ray imager (30 MeV – 50 GeV), a silicon-based X-ray detector SuperAgile (SA) (18 – 60 keV), and a CsI(Tl) Mini-Calorimeter (MCAL) (300 keV – 100 MeV) [*Labanti et al.*, 2009]. The whole payload is surrounded by an AntiCoincidence (AC) system made of plastic scintillators, for the rejection of charged particles.

Being planned as an astrophysics mission, AGILE turned out also to be particularly suitable for TGF detection, for several reasons. First, MCAL is a sensitive detector with submillisecond trigger capability [*Argan et al.*, 2004; *Fuschino et al.*, 2008] that favors the detection of these rapid events. A second feature is the quasi-equatorial orbit that allows the study of the most stormy and electrically active regions in the world, where the TGF production is higher. Finally, a recently enhanced detection configuration of MCAL rose up the detection rate to ∼60 – 70 TGFs/month, increasing the total number of detected TGFs to more than a thousand TGFs in 8 years activity [*Marisaldi et al.*, 2015].

3. The Pipeline

Recently, we linked the AGILE continuously running TGF database to meteorological information. A real-time pipeline retrieves data acquired from meteorological satellites, regarding the geographic region of interest, in the shortest time possible. This is particularly useful to investigate the regions where the TGFs took place and to associate their occurrence with particular types of storm or atmospheric conditions.

3.1. Meteorological Satellites

Meteorological satellites provide useful data about precipitation, microphysical properties, electrical activity, and environmental conditions of convective systems, helping shedding light on the relationship between lightning production and high-energy radiation release inside thunderclouds.

GEOstationary satellites (GEO), endowed with IR and VIS sensors, are characterized by high spatial (1 – 3 km) and temporal (5 – 60 min) resolution. They offer a powerful tool to monitor the presence of convection and its evolution in space and time, occurring in conjunction with TGFs detected by AGILE: in particular, information on updraft strength, the presence of ice or liquid content, cloud depth, and cloud type can be obtained and related to lightning occurrence. This pipeline takes advantage of data acquired by the U.S. National Oceanic and Atmospheric Administration (NOAA) GOES satellites, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Meteosat satellites, the Chinese Meteorological Administration (CMA) FengYun-2 satellite, and the Japan Aerospace Exploration Agency (JAXA) Himawari-8.

From a geographical point of view, these satellites provide a constant monitoring of the whole globe: in particular, GOES-N/O, Meteosat-10, and Himawari-7 satellites cover the main thunderstorm and TGF active regions, such as northern South America, central Africa, and the Maritime Continent, respectively. Moreover, the future Meteosat Third Generation (MTG) and Geostationary Operational Environmental Satellite R/S (GOES-R/S) will have higher spatial and temporal resolution, with respect to their predecessors: they will be endowed with more IR and VIS channels, offering better tools for convection monitoring and with a lightning sensor, providing a continuous detection of total intracloud and cloud-to-ground lightning discharges.

Data acquired by Low-Earth Orbit (LEO) satellites can also be used, whenever available. These satellites have a higher spatial resolution (down to 250 m), allowing for a fine reconstruction of the thundercloud structure, but are affected by a revisit time, limited to few overpasses a day. The Global Precipitation Mission (GPM) is an international network of satellites, aimed at providing accurate precipitation estimates and cloud structure retrieval at all latitudes, with a minimum of 3-hourly coverage (higher at high latitudes). The main satellite of this network is the successor of the Tropical Rainfall Measuring Mission (1997–2015), and it is equipped with a GPM Microwave Imager (GMI) and a Dual-frequency Precipitation Radar (DPR), which provide an accurate description of cloud microphysical properties, precipitation estimates, allowing the reconstruction of its 3-D structure. GPM overpasses will be exploited, whenever possible, with the combined use of GMI and DPR data, to get unique insights about the liquid and solid hydrometeor distribution within the cloud, together with its 3-D structure.

Passive microwave observations by LEO satellites may also provide information about surface precipitation and cloud properties, given by the interaction of MW radiation with cloud microphysical structure, as the presence of high-density hydrometeors, often associated to intense convective activity and lightning. Such measures are affected by coarse spatial (15 − 50 km) and temporal (1 − 2 overpasses a day) resolution.

Future implementations may include ground-based measurements and data from lightning location networks, such as the World Wide Lightning Location Network (WWLLN) and the Vaisala Global Lightning Dataset (GLD) 360; whenever available, also, spaceborne lightning sensor data can be successively implemented, providing more information for continuous follow-up of electrically active convective cloud systems.

3.2. The ISAC-CNR Receiving System

The Institute for Atmospheric Sciences and Climate (ISAC) at the National Research Council (CNR) in Rome manages a EUMETCast receiving system, archiving and processing data in real time from GEO and a suite of LEO satellites equipped with different sensors. EUMETCast is a primary dissemination mechanism of EUMETSAT, for the near-real-time delivery of satellite data and products. It is a multiservice dissemination system, based on standard Digital Video Broadcast (DVB-S2) technology. It uses commercial telecommunication geostationary satellites to multicast files (data and products) to a wide user community.

The ISAC-CNR receiving system supporting the DVB-S2 standard allows considerably high throughput on the transponders and is able to handle dissemination data rates beyond 40 Mbps. The system is based on three main blocks. A first block, composed of the antenna and the EUMETSAT streaming receiving system (Novra S300), is responsible for receiving the data stream using different channels depending on the product type and the timing of reception set by EUMETSAT. Then, a second block deals with the procedures of decoding and decompressing data; the decoding process is based on a hardware cryptographic key which uses the licenses previously activated by EUMETSAT to convert the data stream into an unprotected format that can be managed by the decompressing software (e.g., HRIT and HDF format for the GEO satellites and BUFR, NetCDF format for LEO satellites). Finally, a third block is dedicated to data processing (e.g., cropping and visualization of satellite data over specific geographical areas), to delivery of derived products (i.e., precipitation and cloud parameters, based on the application of specific algorithms developed at ISAC), and to the data storage. The data storage procedure allows access to two distinct areas: the first one called “direct access area” provides access to 1 week buffer data (for each satellite), while the second one called “database area” allows to work with large amounts of data arranged by a Structured Query Language database installed on a separate server in order to maintain the performance.

Currently, the system receives, processes, and stores data from the following GEO and LEO satellites, as shown in Figure 1: Meteosat Second Generation, Himawari-7, GOES-N, GOES-O, and FengYun Meteorological Satellites with a timeliness of 15 min (for MSG) and 30 min (for the other satellites). In the near future, MTG and Himawari-8 will be also added.

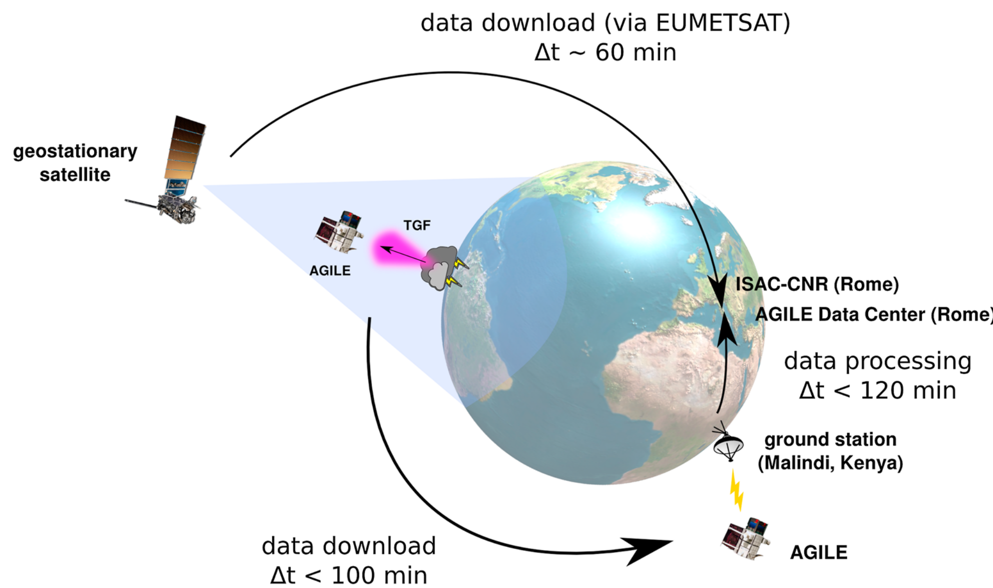

Figure 1. GEO satellites included in the pipeline and related area coverages. The U.S. NOAA GOES-O (−135°) and GOES-N (−75°), the European EUMETSAT Meteosat-10 (0°), the Chinese CMA FengYun-2, and the Japanese JAXA Himawari-8 (145°) provide a global coverage of the whole world surface.

The LEO satellites currently received are Defense Meteorological Satellite Program (DMSP-16, DMSP-17, and DMSP-18), National Oceanic and Atmospheric Administration (NOAA 16, NOAA 18, and NOAA 19), European Space Agency (MetOp-A and MetOp-B), and Suomi National Polar-orbiting Partnership (NPP) satellite. The timeliness for LEO satellites ranges from 30 min (for near-real-time dissemination) to a few hours.

3.3. Working Principle

Our pipeline associates meteorological information to the TGFs detected by AGILE, with a fast processing and the possibility of alert. Meteorological products from every geostationary satellite are continuously downloaded by the ISAC-CNR EUMETCast receiving system and stored into a 1 week data buffer, providing a continuous monitoring of the TGF zone. Whenever AGILE detects a TGF, our algorithm selects the most suitable GEO satellite, which would have been observing the region of interest, and processes the related meteorological data. In order to collect information about the onset, the development, and the evolution of the thunderstorm system, previous and successive hours of data are also processed, providing a complete picture of the evolution of the thunderstorm system in space and time.

The time needed to link meteorological information to every detected TGF depends on the time required by both AGILE and the ISAC-CNR EUMETCast receiving system to process all data. AGILE data are routinely downloaded every ∼100 min at each passage over the Luigi Broglio Space Centre (BSC) ground station in Malindi (Kenya) and then quickly sent to the Telespazio Mission Operation Center (TPZ-MOC) in Fucino (L'Aquila, Italy): here data are preprocessed, analyzed, and stored at the AGILE Data Center at the ASI Science Data Center (ASDC), to be available to the AGILE team, guest observers, and public domain. The whole process takes about 2 h [*Pittori*, 2014]. As the satellite orbits from west to east, the time needed to process TGF data and to retrieve the related meteorological information strongly depends on the location where the event is detected: all TGFs taking place over the African continent, just before the passage over Malindi, represent the best case, in terms of time delay, while all TGFs detected just after having overpassed Malindi represent the worst case, as it takes a whole orbit for the telemetry data to be downloaded. Meteorological products from GEO satellites are available on our server about 1 h after their acquisition. Meteosat-10 data are generated every 15 min, whereas GOES-N/O and Himawari-7/8 data are generated every 30 − 60 min. The elaboration of meteorological products related to the TGF events by the pipeline requires only few minutes. In Figure 2, a schematic view of the pipeline is shown, including the time delays needed for the transmission and the processing of all data.

All the different channels available for each GEO satellite can be displayed, providing different information about the observed clouds. The ∼10.8 μm brightness temperature refers to the cloud top temperature of clouds in the atmosphere. Moreover, several meteorological products, either processed by the pipeline or

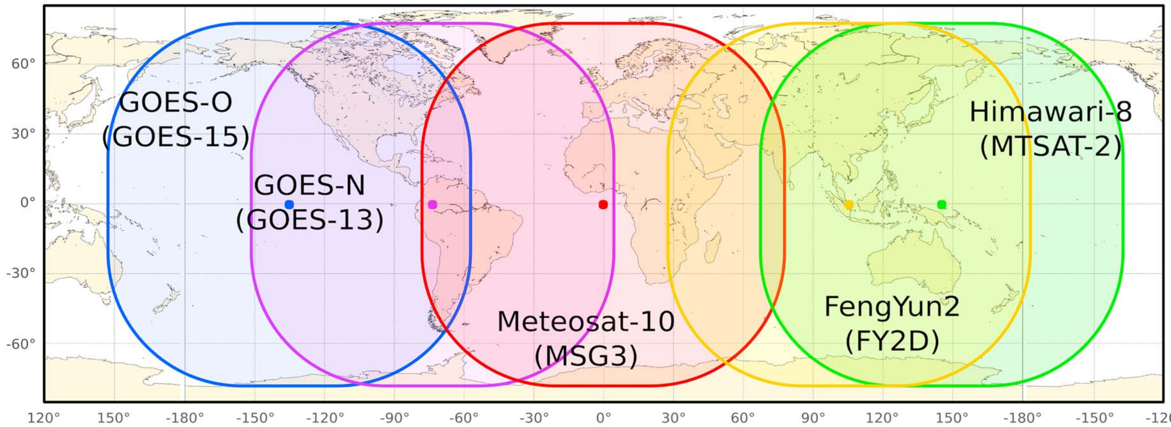

Figure 2. Schematic view of the AGILE meteorological pipeline. AGILE detects a TGF and downloads data to the BSC ground station in Malindi (Kenya), within a time delay of <100 min; these data are then preprocessed and sent to the AGILE Data Center in Rome, a process that takes about 120 min. On the other hand, the data by the GEO satellite that was observing the TGF region are downloaded at the ISAC-CNR institute, via the EUMETCast streaming receiving system, with a time delay of about 60 min.

directly downloaded by the EUMETSAT server, can be quickly obtained after the retrieval. In order to identify convection in the atmosphere, crucial for what concerns TGF production, the Global Convective Diagnostics (GCD) algorithm [*Mosher*, 2001; , 2002; *Martin et al.*, 2008] and the Severe Storm (SS) RGB composite [*Lensky and Rosenfeld*, 2008] can be used. The first consists of the simple difference between the brightness temperatures in the 10.8 μm Infrared (IR) channel and the 6.2 μs Water Vapor (WV) channel, present on every meteorological geostationary satellite: all regions where this parameter is GCD $\leq$ 0 K are regions where convection is present. On the other hand, the SS RGB composite exploits more energy channels, to enhance the presence of convection and to discriminate between old and young convective regions: differently from the GCD, this algorithm is available only during the daytime. For what concerns Meteosat data, the already processed EUMETSAT Cloud Top Height (CTH) product (EUMETSAT CTH product guide EUM/TSS/MAN/14/786420 available at https://www.eumetsat.int) provides useful information on the altitude of the cloud, with a vertical resolution of 1500 m. Visible image reconstructions are possible, though available only during the daytime. Convection and convective features, such as overshooting tops, can be observed and discriminated in GCD, SS RGB, and visible images.

Other information can be implemented in a second moment, such as the convective available potential energy (CAPE) or the cloud top altitude for the non-Meteosat geostationary satellites, depending on the availability of the products. Such further information takes advantage of data by models, such as the European Centre for Medium-Range Weather Forecast. Moreover, other Low-Earth Orbit (LEO) satellites, such as the Global Precipitation Measurement (GPM) mission, as well as by lightning networks and microwave (MW) sensors, can be added to the pipeline or successively processed offline.

4. Pipeline Application Example

It is interesting to address a case study, in order to evaluate the effective power of this pipeline system and to see the relevance of the processed products. We take into consideration TGF150408.30022, detected by AGILE over Africa, on 8 April 2015, at 07:12:19.336 (UTC): the event exhibits a time duration of about 33 μs, triggering the onboard submillisecond (0.293 ms) trigger logic. This TGF was detected after the onset of the enhanced MCAL configuration [*Marisaldi et al.*, 2015] and a WWLLN-associated sferic was found, at ~290 km distance from the satellite footprint. This TGF is not reported in the previous work (enhanced data set available at the ASDC website: https://www.asdc.asi.it/mcaletgfcat/), because the maximum energy is 36 MeV, exceeding the 30 MeV limit imposed by the adopted selection criteria [*Marisaldi et al.*, 2014], but arises from a new selection strategy based solely on match with WWLLN-detected lightning. Taking into consideration a TGF source altitude of 15 km, the delay experienced by the photons, due to the propagation to the spacecraft, is about 1.86 ms and the resulting time difference between the TGF peak and the sferic is −7 μs, which makes the lightning sferic basically simultaneous with the TGF, within the WWLLN timing accuracy. The existence of

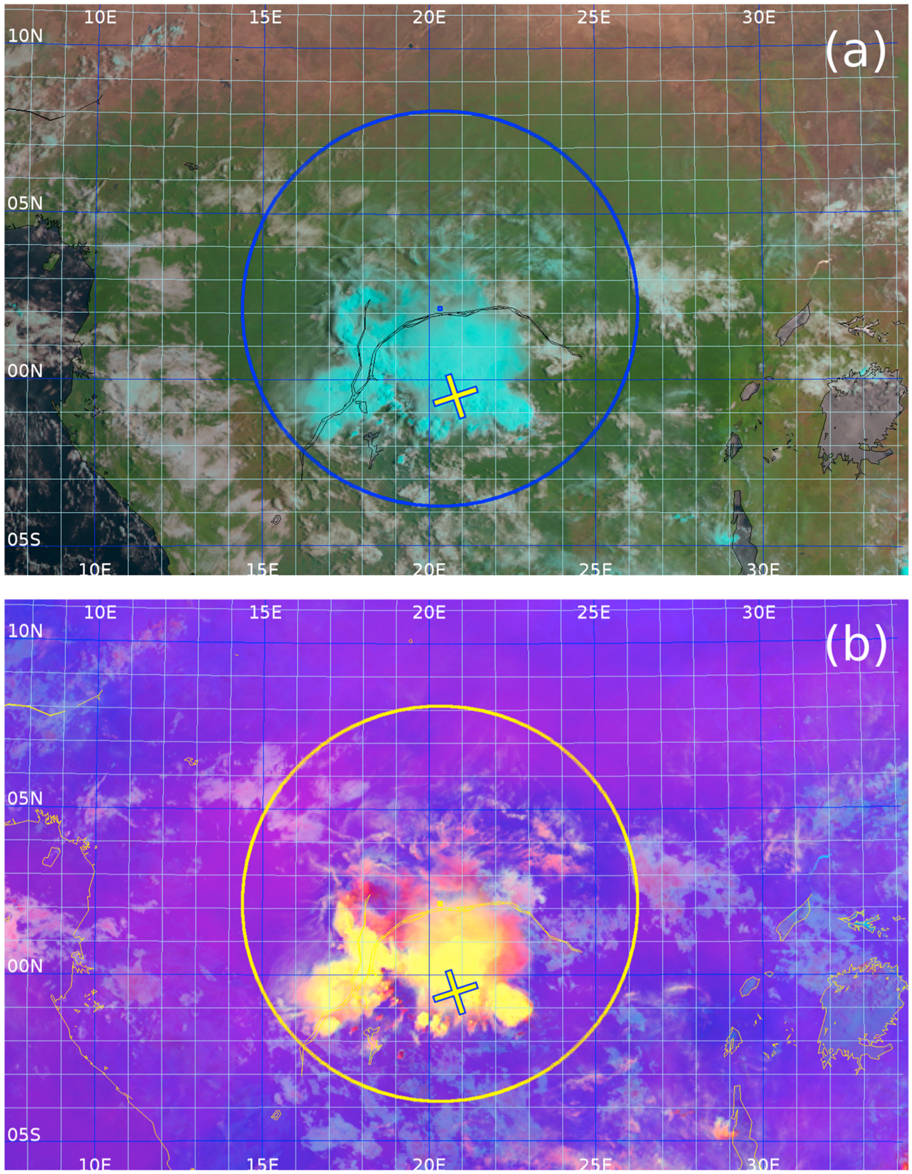

Figure 3. Example of TGF150408.30022, as processed with the AGILE meteorological pipeline system, exploiting data from Meteosat-10. As the event occurred in the morning, both (a) visible reconstruction and the (b) Severe Storm RGB were applied, showing a large single convective system, developed within the 6° radius uncertainty circle around the footprint. In each image, the cross corresponds to the location of the associated WWLLN sferic.

a correlated sferic is a crucial point in studying the associated thunderstorm, as it allows the localization of TGFs, otherwise difficult to achieve: once the TGF is localized, it is possible to identify the storm source that produced the detected event.

As the region where the event takes place lies within the [−60° − + 60°] longitude range, the data on the associated meteorology are retrieved from the Meteosat-10 satellite. In Figure 3, reconstructed meteorological images of the region of interest are shown, with a 6° (∼670 km) radius circle around the satellite footprint, indicating the most probable region for the TGF source, in case location is not known (termed uncertainty region in the following). It is worth noting that in this case, such a region can be highly reduced, given the existence of an associated sferic that allows a precise localization of the TGF source region: however, we preferred to perform the analysis adopting the standard uncertainty region, in order to better show the development and path of the correlated convective activity. Data refer to the time 07:15:00 (UTC), after less 3 min from the detected event. As the TGF occurred in the morning, an overview by means of the visible channels is possible,

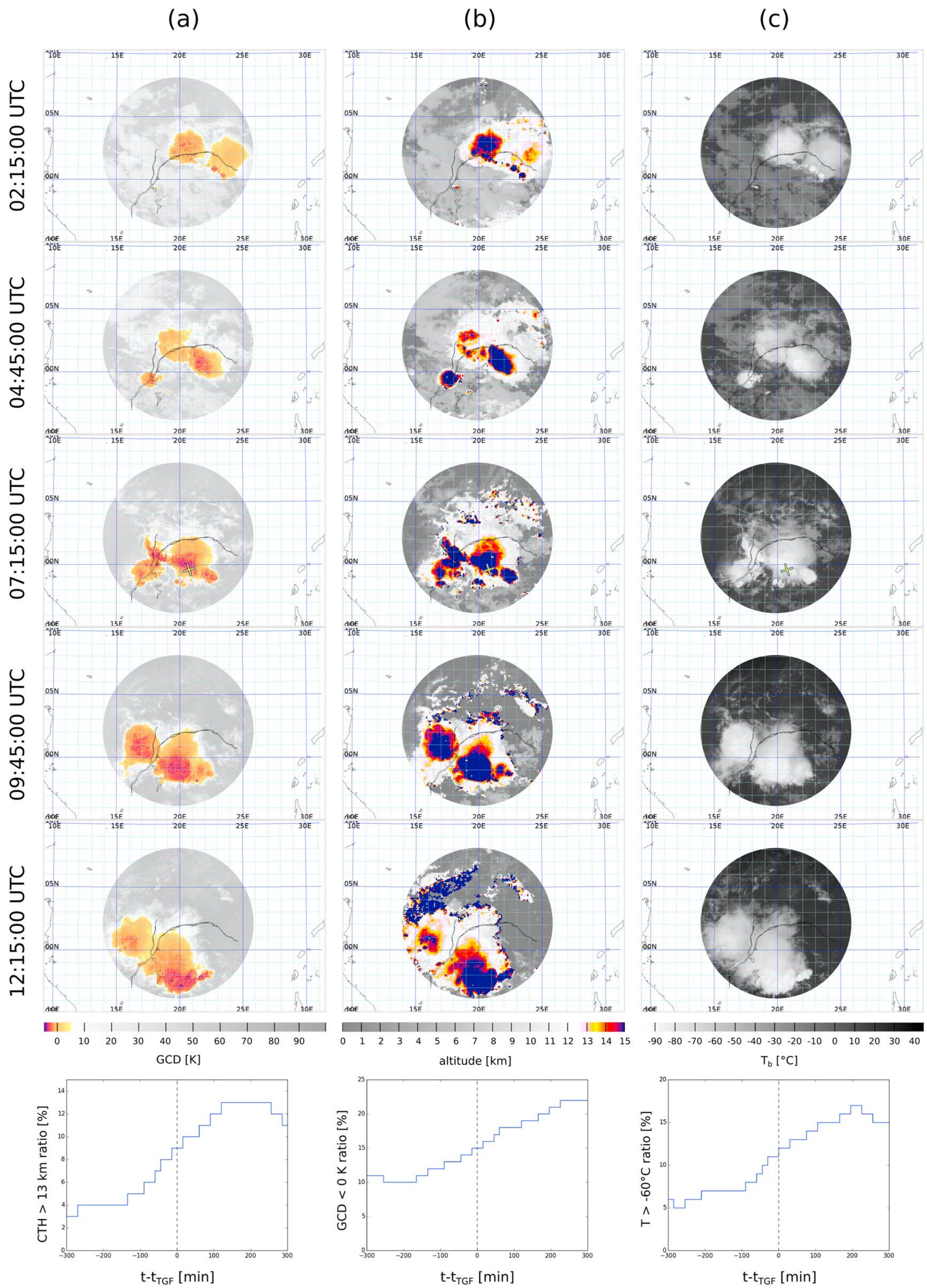

Figure 4. Some of the meteorological products used for the analysis of TGF150408.30022. The three columns refer to the time history of the region below the subsatellite point, represented by means of the (a) GCD algorithm, (b) CTH product, and (c) IR 10.8 μs brightness temperature, respectively. Below each product, the corresponding time evolution of the characterizing parameter is represented, showing that the TGF occurred during the development phase of the storm.

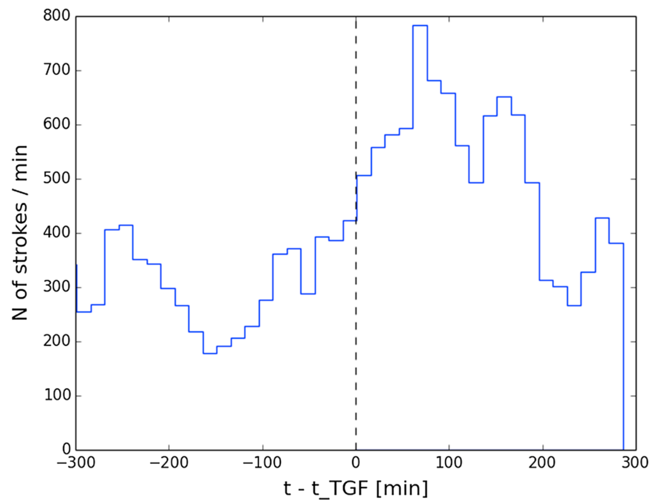

Figure 5. Lightning stroke ratio, as detected by the WWLLN radio stations, within the 10 h from the TGF150408.30022 time and within the uncertainty region around the subsatellite point. As for the cases shown in Figure 4, the TGF occurs during the increasing phase of the convective system.

showing a complex cluster of storms, characterized by high-level clouds with small ice particles (typically associated with cumulunimbus clouds with strong updraft and severe weather). This system is structured in two large storms and several smaller and presumably younger convective cores. The same system is investigated with the Severe Storm RGB composite that enhances the deep convective cores of the identified thunderstorm. On each image, the cross corresponds to the reconstructed geographic point, where the associated WWLLN sferic took place.

The utility of the pipeline relies not only in producing meteorological data at the TGF time but also in the possibility of displaying the previous and successive hours from the event. Figure 4 shows the evolution of the thunderstorm system responsible of the emission of TGF150408.30022, in a time interval of 10 h around the TGF time. For clarity, only data within the uncertainty circle around the subsatellite point are displayed, with time steps of 150 min, although Meteosat-10 data are available with a timeliness of 15 min. In Figure 4a, the GCD algorithm is used to identify the thunderstorm and to see its evolution in time, showing more cells merging together. The central frame corresponds to time 07:15:00 (UTC), the closest available to TGF time: in each image, the cross corresponds to the reconstructed position of the associated WWLLN sferic. Figure 4b shows the same set of frames by means of the CTH algorithm, providing an estimate of the cloud top altitude of the observed storm, mostly reflecting the same behavior of the GCD. Figure 4c shows the IR brightness temperature T_b at 10.8 μm, corresponding to the cloud top temperature of the observed atmospheric scenario. The below-standing plots represent the GCD, CTH, and IR ratios, corresponding to the number of pixels within the uncertainty region, satisfying GCD ≤ 0 K, CTH ≤ 13 km, and $T_b \leq -60°$ C, respectively, normalized to the total number of pixels contained in the whole circle: all these quantities provide an estimate of the convective activity in the region of interest, allowing for its monitoring in space and time. The time resolution of these plots is given by the 15 min timeliness of the Meteosat-10 satellite data. The storm cluster moves in southwest direction, anticipated by a line of young intense storms. All these graphs show that the TGF under study took place during the development phase of the thunderstorm, when the system was increasing its size and altitude, reaching cooler cloud top temperatures and increasing the area identified as deep convective. At the time TGF150408.30022 occurred, the deep convective region was occupying about 9% of the total surface within the uncertainty circle, corresponding to an extension of about 140,000 km^2. Moreover, due to the associated sferic, it is possible to identify and track the cumulonimbus cloud within the storm cluster, in which the TGF was generated. The overshooting top of this cloud is highly persistent, lasting for more than 10 h and growing in dimension and intensity.

It is interesting to see whether the lightning flash rate in the same region and time scale follows the same trend and to establish in which related phase the TGF occurred: taking advantage of WWLLN data, it was possible to plot the lightning stroke rate, reported in Figure 5. Although the total number of lightning discharges detected by WWLLN in this time interval and uncertainty circle is quite large and more systems may contribute to the whole picture, the global behavior shows an increasing trend of the flash rate and the TGF under study seems to occur during this stage. This is in agreement with what was found by means of the other parameters, but not with what was found in *Smith et al.* [2010], who observed a main occurrence of TGFs during the decreasing phase after the lightning flash rate peak.

It is worth noting that the thunderstorm system, responsible of TGF150408.30022, produced other two events, after a few hours from the first one, at 13:56:21 (UTC) and 13:56:29 (UTC), respectively. This observation was possible, due to the AGILE near-equatorial orbit that puts the satellite in the privileged position of observing the same region throughout successive orbital overpasses, and shows that single storms, as well as larger multicell or Mesoscale Convective System, are capable of producing multiple TGFs during their lifetime, as illustrated in *Ursi et al.* [2016].

5. Conclusions

In this paper we present a real-time pipeline that retrieves meteorological data acquired by GEO satellites and reconstructs the meteorological scenario associated to the regions where the AGILE TGFs occurred, with a fast time processing. All meteorological data are continuously stored into a 1 week buffer memory, which allows the investigation of the initial stages of the thunderstorm evolution, together with its onset and successive development. To identify convection in the atmosphere, strictly correlated to TGF production, we take advantage of the GCD algorithm that makes use of infrared energy channels available on every GEO satellite and that works well both during daytime and nighttime. Moreover, we process brightness temperature data in the 10.8 μs wavelength, providing information on the cloud top temperature. For Meteosat-10 data, CTH products are also directly processed, giving an estimate of the cloud top altitude. The SS RGB composite for convection identification is applied, whenever possible. During daytime, also, visible images are reconstructed. Data from other non-GEO satellites, MW sensors, and lightning detection networks can be implemented in the pipeline in a successive moment, in order to obtain new information on the region of interest and about the TGF-associated storm. By exploiting this pipeline and the associated meteorological archive, it is possible to perform both precise studies on individual events and associated storms, as well as statistical analyses on large-scale samples. This could help shed light on the thunderstorm type, stage, and degree of association correlated to the TGF production. Data are currently stored in an archive that can be made available to the community in the near future. Furthermore, the capability of fast TGF detection and data processing (both for gamma ray and meteorological data) provides the basis for implementing a TGF alert service open to the scientific and aeronautic community. This possibility will be considered in future developments.

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