Article

Title

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Keywords: keyword 1; keyword 2; keyword 3 (List three to ten pertinent keywords specific to the article; yet reasonably common within the subject discipline.)

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1. Introduction

The Earth's magnetic field represents a final obstacle to the Solar Wind (SW) flux. When descelerated and defected by a non colisional shock wave in the flux direction, generates a cavity known as magnetosphere [**?**]. Since the Earth is embedded in this SW flux, is known that under adequated physical conditions (e.g magnetic reconnection) may exist some coupling between the magnetosphere and the Earth's ionosphere [**? ?**].

The Sun plays an important role in the physical proccesses that occur in the terrestrial magnetosphere-ionosphere system. When the SW interacts with the Earth's magnetosphere, particles may permeate the internal region via magnetic reconnection and penetrate to polar zones and generate boreal or austral auroras thus altering the system [**? ?**]. By the other hand, the Extreme Ultraviolet Radiation (EUV) and X-rays coming from the Sun may interact with the neutral atmoshere via photoionization [**?**]. However, in both cases the final result is that the ionosphere's free electrons population is altered.

Some Ionospheric Perturbations (IP) become relevant due to their spatial and temporal scale in the Space Weather scenario. At intermediate latitudes, the most common in the ionosphere are known as Traveling Ionospheric Disturbances (TIDs). Typically they divide into two groups: a) large scale TIDs, associated with geomagnetic storms with sizes of $\sim$2000 km, periods of $\sim$1 h and velocities of $\sim$700 km s^{-1}, and b) Medium-scale TIDs, which are not fully associated with geomagnetic storms, present sizes of $\sim$100 km, periods from 10 minutes to 1 hour and velocities between 50 km s^{-1} and 1×10^2 km s^{-1} [**?**]. Diverse methods have benn used to study TIDs, such as incoherent dispersion radars, high frequency Doppler emmisors, data from Global Positioning System (GPS) stations or even radiotelescopes like the VLA or the Mexican Array Radio Telescope (MEXART) [**? ?**].

On the other side, the Earth's ionosphere may be affected or modified by other proccesses, particularly there are studies that show how the Vetical Total Electron Content (vTEC) due to shock waves generated for rockets launched to space [**?**]. Similar proccesses modify the Earth's ionosphere due to objects entering the athmosphere from space, such as meteoroids like the one which fell on Chelyabinsk at 2013 [**?**]. Previously, the ionospheric perturbations produced by this object were studied using two independent methods: a) detecting vTEC pertubations using GPS station near the impact location. And b) a wavelets analysis for detection of ...

In 2020 a meteoroid passed in mexican territory through mexican territory, which also was studied [**?**]. The meteoroid was recorded with outdoor cameras in different locations. The trajectory could be estimated, as well as other physical parameters.

In this work we will show a similar analysis for a sample of meteoroids detected in mexican territory by different methods. The first subsample consists in objects detected by the Geostationary Lightning Mapper (GLM) whose sizes are estimated between a few decimeters to meters in diameter [**? ? ?**]. The second subsample will consist in objects detected by ocular witnesses from the American Meteor Society and as comparisson we will include the morelian meteoroid reported in **?**] and the Chelyabinsk event **?**]. The paper is arranged in the following way: §**??** describes the samples of meteoroids as well of the properties that can be obtained from direct observations. Also describes the GPS data corresponding to the dates and locations where each object was located. §**??** shows physical parameters of meteoroids obtained from the observed heights and energies. Finally, section §**??** shows the vTEC maps and scintillation indices obtained from GPS observations.

2. Methodology

2.1. Meteors Databases

We selected a sample of meteors which were observed in mexican territory from the Geostationary Lightning Mapper [**?**]. Orignally this project was designed to detect ligthning activity in earth's athmosphere, but has been proven that also can detect bolides entering the athmosphere. The detection comes from two satellites called GOES-16 and GOES-17 orbiting the earth in geostationary orbits. We used the interactive database available at https://neo-bolide.ndc.nasa.gov/#/. These data are publicly available and easily downloaded from the same website. For each event we can obtain the recorded trajectory of meteors and the corresponding light curve. THe GLM satellites have an umbral magnitude for detection of -14. At this magnitude, a meteor is considered a bolide, and is expected to be at least decimeter-sized (in diameter) to reach such brightness. In the other hand, too bright meteors will saturate the detectors, and thus, lowering the quality of data. The result of this factors implies that the range in size of the objects in our sample varies in diameter between decimeter to meter size. Each event also has assigned a confidence ratio, from low confidence to high, depending in how bright is the event itself and if the trajectory recorded by GLM ressembles (or not) a straight line. We chose only events whose confidence ratio is high, in order to be sure we chose the brightest objects, and thus, in the diameter size of bolides, we favored the meter-sized ones. In table 1 we list the object we chose to do this work, order in chronological order. The columns of the table, from left to right are and ID to enumerate the meteors in the sample, the date and time each meteor was detected, the duration of the detection, their respective coordinates and the estimated height of the meteor over the ground at the time of the detection. GOES-16 and GOES-17 systematically detect the meteors at slightly different positions and at slightly different times, so we calculated the mean of the duration, latitude and longitude reported by both satellites for each event, and used the standard deviation as the uncertainties.

From table 1 is also clear that the duration of all the bolides detection last less than a second. This obsevation suggests that the bolides remain undetected by the GLM satellites until they get fragmented due to stagnation presure when they release a huge amount of energy and thus they become detectable.

By the other hand, we got another sample of 10 bolidesfrom US Goverment (USG) sensors from the Center for Near Earth Object Studies (CNEOS), publicly available at https://cneos.jpl.nasa.gov/fireballs/, where we may obtain directly data about bolides position, the date and time each bolide was detected, the energy released at fragmentation, the velocity and the height (the last two not availble for all bolides). As seen in table 2, the time span is quite larger, and the released energy is generally larger. Both energy

Table 1. List of bolides detected in mexican territory (plus one detected near Venezuela and one detected near Cuba), detected by the Geostationary Lighning mapper. The events are listed in chronological order. The listed duration, latitude and longitude correspond to the mean of the measurements of both GOES satellites. The uncertainties correspond to the respecting mean deviation.

ID	Date of event	Start Time (UT)	Duration (seconds)	Latitude (deg)	Longitude (deg)	Altitude (k
GLM-00	2019-02-01	18:17:09	2.651 ± 0.4907	22.45 ± 0.071	-83.50 ± 0.424	
GLM-01	2019-05-23	16:36:18	0.197 ± 0.0000	24.30 ± 0.000	-101.60 ± 0.849	
GLM-02	2019-07-18	14:30:30	0.058 ± 0.0000	27.20 ± 0.000	-103.15 ± 0.778	
GLM-03	2019-08-10	11:18:48	0.199 ± 0.0757	21.50 ± 0.000	-102.50 ± 0.849	
GLM-04	2019-10-03	07:55:33	0.106 ± 0.0297	25.65 ± 0.071	-96.25 ± 0.778	
GLM-05	2019-10-09	06:08:11	0.103 ± 0.0078	23.60 ± 0.000	-111.95 ± 0.212	
GLM-06	2019-11-16	09:36:04	0.396 ± 0.0134	20.30 ± 0.000	-100.55 ± 0.919	
GLM-07	2019-11-17	15:36:01	0.116 ± 0.0035	31.70 ± 0.000	-117.70 ± 1.131	
GLM-08	2019-11-19	07:57:40	0.097 ± 0.1138	20.00 ± 0.000	-88.40 ± 1.131	
GLM-09	2019-11-26	13:23:20	0.078 ± 0.0290	23.90 ± 0.000	-108.70 ± 0.849	
GLM-10	2019-12-04	09:42:54	0.173 ± 0.0028	31.50 ± 0.000	-113.65 ± 0.919	
GLM-11	2019-12-15	14:50:49	0.127 ± 0.0134	27.70 ± 0.000	-114.10 ± 0.849	
GLM-12	2019-12-29	16:16:35	0.062 ± 0.0134	29.60 ± 0.000	-116.35 ± 0.919	
GLM-13	2020-01-03	14:10:17	0.113 ± 0.0085	30.20 ± 0.000	-117.65 ± 0.919	
GLM-14	2020-01-06	16:39:27	0.118 ± 0.0042	31.40 ± 0.000	-108.20 ± 0.990	
GLM-15	2020-01-15	15:00:33	0.213 ± 0.1351	19.45 ± 0.071	-95.55 ± 0.919	
GLM-16	2020-02-12	09:25:40	0.210 ± 0.0226	18.90 ± 0.000	-93.50 ± 0.849	
GLM-17	2020-03-03	12:33:27	0.062 ± 0.0007	18.25 ± 0.071	-106.35 ± 0.636	
GLM-18	2020-03-31	19:31:52	0.105 ± 0.0573	28.45 ± 0.071	-112.05 ± 0.636	
GLM-19	2020-04-08	16:25:28	0.120 ± 0.0926	26.10 ± 0.000	-93.90 ± 0.849	
GLM-20	2020-04-18	17:43:25	0.139 ± 0.0106	29.00 ± 0.000	-106.55 ± 0.919	
GLM-21	2020-04-20	16:05:22	0.318 ± 0.1655	28.15 ± 0.071	-97.85 ± 1.061	
GLM-22	2020-04-25	11:03:09	0.323 ± 0.0813	32.15 ± 0.071	-111.60 ± 1.131	
GLM-23	2020-04-28	19:31:52	0.105 ± 0.0573	28.45 ± 0.071	-112.05 ± 0.636	
GLM-24	2020-05-08	10:06:16	0.490 ± 0.0750	21.60 ± 0.000	-92.40 ± 0.849	
GLM-25	2020-07-15	19:58:28	0.693 ± 0.0495	24.00 ± 0.000	-108.35 ± 0.495	
GLM-26	2020-08-07	13:29:57	0.163 ± 0.0057	28.80 ± 0.000	-106.05 ± 0.919	
GLM-27	2020-09-13	16:41:59	0.184 ± 0.0078	28.45 ± 0.071	-113.75 ± 0.919	
GLM-28	2020-09-30	12:28:11	0.100 ± 0.0078	24.90 ± 0.000	-110.90 ± 0.849	
GLM-29	2020-11-16	12:28:11	0.100 ± 0.0078	24.90 ± 0.000	-110.90 ± 0.849	1
GLM-30	2020-11-17	12:53:41	0.404 ± 0.0262	23.00 ± 0.000	-102.45 ± 0.919	
GLM-31	2020-12-19	10:18:14	0.407 ± 0.0110	21.95 ± 0.071	-101.60 ± 0.990	
GLM-32	2020-12-23	09:43:01	0.148 ± 0.0014	25.75 ± 0.071	-111.25 ± 0.778	
GLM-33	2020-12-29	15:20:54	0.118 ± 0.0014	16.80 ± 0.000	-102.20 ± 0.707	
GLM-34	2021-03-31	09:01:17	0.753 ± 0.3083	20.15 ± 0.071	-92.95 ± 0.212	
GLM-Ven	2019-06-22	21:25:45	4.873 ± 0.0000	14.9 ± 0.000	-65.8 ± 0.000	

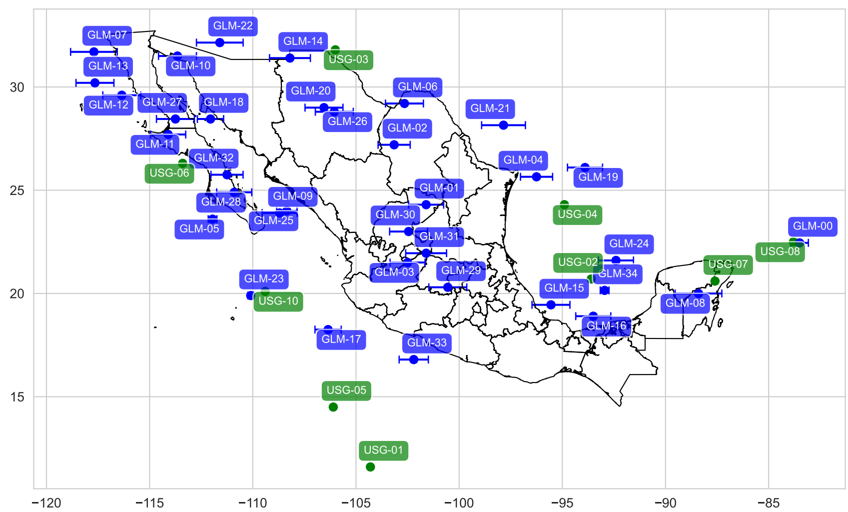

Figure 1. Positions of events from table 1 (blue) and table 2. The events GLM-00/USG-08 actually correpond to the same bolide, but there are little discrepancies about the position where the bolide was detecte. The same applies for the events GLM-23/USG-10 and GLM-Ven/USG-09, which not appears in the map.

Table 2. List of bolides detected in mexican territory (plus one detected near Venezuela and one detected near Cuba), detected by USG sensors.

ID	Date of event	Start Time (UT)	Velocity (km/s)				Latitude (deg)	Longitude (deg)	Altitud
			v	v_x	v_y	v_z			
USG-01	1995-08-05	17:14:10					11.6	-104.3	
USG-02	1996-07-12	14:04:45					20.7	-93.6	
USG-03	1997-10-09	18:47:15					31.8	-106.0	
USG-04	2000-01-18	08:33:58					24.3	-94.9	
USG-05	2000-08-25	01:12:25					14.5	-106.1	
USG-06	2005-11-15	05:19:07					26.3	-113.4	
USG-07	2015-07-19	07:06:26	17.8	9.4	13.0	7.8	20.6	-87.6	
USG-08	2019-02-01	18:17:10	16.3	-2.4	13.6	8.7	22.5	-83.8	
USG-09	2019-06-22	21:25:48	14.9	-13.4	6.0	2.5	14.9	-66.2	
USG-10	2020-04-28	05:43:17					20.1	-109.4	

distributions are compared directly in figure 2. Some elements appear in both samples, since are bright enough to be detected regardless the project involved. In USG sample, the total energy of each meteor is obtained directly, but is not the case for the GLM sample. In appendix **??** and **??** we give details about how this total energy is obtained.

2.2. GPS data

We got RINEX data from 3 to 7 stations depending of the event location and data availability that surround the event place in all directions as possible. A list of the stations where we got RINEX data is available in table. Most of the stations lie in mexican territory, but in some cases we required data from other stations to cover events near the mexican frontier at north or south.

The obtained RINEX files are compressed in Hatanaka format, developed at the Geographical Survey Institute by Y. Hatanaka [**?**]. From this files we may estimate the Slant Total Electron Content (sTEC) and the Vertical Total Electron Content (vTEC) which may be computed in the following way:

The Total Electron content along the integrated path of the link (s_i) at the frequency f_i can be inferred from the phase delay L_i of the frequency f_i [**?**]:

$$L_i = s_i - \frac{40.3082\,\mathrm{m}^3\,\mathrm{s}^{-1}}{f_i^2} sTEC_i \tag{1}$$

Combining two observations at two different frequencies f_1 and f_2 we may obtain two different phase delays L_1 and L_2 and derive the TEC along the signal path:

$$sTEC = \frac{f_1^2 f_2^2 (L_1 - L_2)}{40.3082\,\mathrm{m}^3\,\mathrm{s}^{-1} (f_1^2 - f_2^2)} \tag{2}$$

In the other hand, the Vertical Total Electron Content (vTEC) is computed from the sTEC as follows [**?**]:

$$vTEC = \frac{sTEC - [b_R + b_S]}{S(\theta_I)} \tag{3}$$

where b_R and b_S are receiver and satellite biases, respectively. θ_I is the elevation angle in degrees, $S(\theta_I)$ is the obliquity factor with zenith angle ψ at the Ionospheric Pierce Point (IPP):

$$S(\theta_i) = \frac{1}{\cos\psi} = \left\{1 - \frac{R_E \cos\theta_I}{R_E + h}\right\}^{-1/2} \tag{4}$$

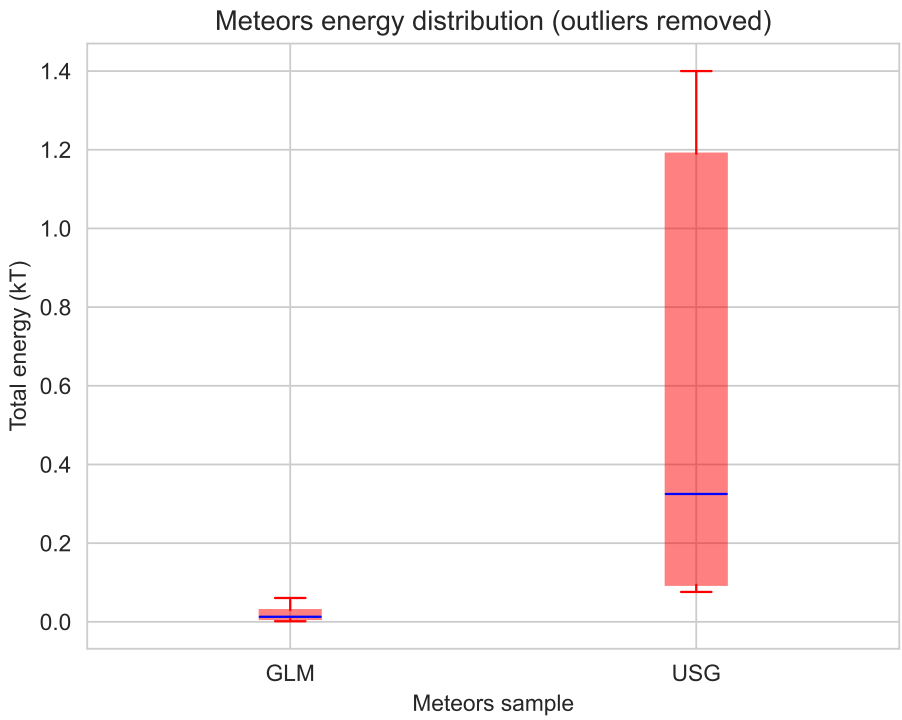

Figure 2. Comparison between released energies of bolides detected by the Geostationary Lightning Mapper and USG sensors.

Where R_E is the Earth radius in km and $h = 350$ km is the ionospheric shell above the earth's surface.

Using a software developed by Gopi K. Seemala, publicly available at https://seemala.blogspot.com/, we computed the slant TEC (TEC) and vertical TEC (vTEC) for a several number of GPS satellites, each one identified with a PseudoRandom Noise code (PRN). For each station, we filtered all the PRN and data that lie in a window of 30 minutes around the time the event was reported. Then we estimated the signal trend using a Savitsky-Golay filter and substracting the original signal from the trend.

2.3. Wavelet analysis

3. Results

%subsectionSubsection

3.1. Formatting of Mathematical Components

This is the example 1 of equation:

$$a = 1, \tag{5}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{6}$$

Figure 3. This is a wide figure.

Please punctuate equations as regular text. Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

Theorem 1. *Example text of a theorem.*

The text continues here. Proofs must be formatted as follows:

Proof of Theorem 1. Text of the proof. Note that the phrase "of Theorem 1" is optional if it is clear which theorem is being referred to. □

The text continues here.

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Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

6. Patents

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	Linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

Table A1. This is a table caption.

Title 1	**Title 2**	**Title 3**
Entry 1	Data	Data
Entry 2	Data	Data

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled, starting with "A"—e.g., Figure A1, Figure A2, etc.

Author 1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.