

Utilizing Citizen Contribution to Track Cosmic Material Entry into Earth's Atmosphere: Insights from Mexico

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Abstract

In this paper, the importance of information posted on social networks in the study of meteoroid entry into the Earth's atmosphere is shown. This kind of networks work thanks to the information shared by many people, which is stored on different servers. Using these reservoirs, we identified 24 such events between April 2013 and November 2023, most of which were not recorded even by satellites such as GOES or other U.S. government sensors. Furthermore, from the collected information we estimated the trajectory of five meteoroids and the mean angular velocity of three of these.

Key words: Social networks, asteroids, meteors, bolides, trajectory estimation.

Resumen

En este trabajo mostramos la importancia de la información publicada en redes sociales para estudiar la entrada de meteoroides a la atmósfera terrestre. Este tipo de redes funciona gracias a un gran número de personas quienes comparten información, la cual se conserva en distintos servidores. Usando estos reservorios, identificamos 24 eventos de este tipo entre abril de 2013 y noviembre de 2023, la mayoría de los cuales no fueron registrados incluso por satélites como los GOES u otros sensores del gobierno de Estados Unidos. A partir de la información recopilada estimamos la trayectoria de cinco meteoroides y la velocidad angular media de tres de ellos.

Palabras clave: Redes sociales, asteroides, meteoros, bólidos, estimación de trayectorias.

Received: April 29, 2024; Accepted: October 16, 2024; Published on-line: January 1, 2025.

Editorial responsibility: Dr. Juan Américo González Esparza

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<https://doi.org/10.22201/igeof.2954436xe.2025.64.1.1802>

1. Introduction.

Historically, the fall of space material was passed down orally or through writing by people who witnessed this phenomenon; in fact, the series of observations made by many persons convinced even more skeptics that rocks indeed fall from the sky and, after the discovery of asteroids, that meteorites are related to them (McCall *et al.*, 2006). Since then, meteorites have been important in understanding the formation of the solar system, assessing the age of the Sun and planets, and elucidating the primordial composition of these bodies (Sohl & Schubert, 2009; Jones, 2007). On the other hand, studying meteors has allowed the assessment of the place of origin of the planetary bodies that enter Earth's atmosphere, the study of their interaction with it, and the delimitation of the fall area to recover meteorites (Ceplecha, 1987; Popova *et al.*, 2013; Brown *et al.*, 2023). From 1936 to 1951, the United States carried out a series of observations of bolides employing a small camera network. But it was in the 1960s when two fireball networks were established: The Prairie Network in the United States which operated from 1964 to 1975, and the European Fireball Network (EFN) which is still active (Colas *et al.*, 2020).

In 1987, the International Meteor Organization (IMO) was founded (Brown, 1988). This group gathers amateur and professional people interested in the observation and study of meteors. Currently, IMO has more than 250 members from all over the world, most of them European. It has created and developed the Visual Meteor Database (VMDDB) which contains information about almost 4,000,000 meteors collected since 1982. This information is accessible to IMO members and professional astronomers (IMO, n.d.). Besides this, EDMOND (European viDeo Meteor Observation Network) is a multi-national network whose objective is to compile information from amateur and professional meteor observers to study this phenomenon. In 2012, collaboration with IMO members was established. Since then, this alliance has made it possible to monitor the inflow of cosmic bodies throughout Europe (Kornoš *et al.*, 2013).

On February 10th, 2010; a fireball occurred on the border of Hidalgo and Puebla States located in central Mexico, a little over 100 km northeast from Mexico City. Cordero *et al.* (2011) interviewed more than one hundred witnesses that heard the atmospheric burst although only twelve of them saw the bolide. With this, Cordero and colleagues were able to draw a possible entry direction of the cosmic body (almost SW to NE), and with the information collected from all witnesses, it was concluded that the object must have been a few meters long. Even though the testimonies were not enough to study the fall of the cosmic object in detail, it was enough, firstly, to know that the phenomenon actually occurred and, secondly, to determine some information about it, such as possible direction and likely size.

Deriving from this event and another one that occurred in February of the following year (which was also studied by Cordero and colleagues but was not published because of insufficient data), it was clear that it was necessary to have a way to record these events systematically. This is how the idea of creating a meteor network in Mexico was born. Since 2014, the Instituto de Geofísica at Universidad Nacional Autónoma de México (UNAM) has been developing *Citlalin Tlamina*: the Mexican Meteor Network. *Citlalin Tlamina* (*meteor* in Nahuatl language) has the main objective of recording the entry of asteroidal or cometary material into Earth's atmosphere on Mexican territory to study its interaction with the atmosphere, estimate its place of origin, and recover meteorites. Another of its objectives is to inform Civil Protection agencies to avoid panic among the public, since with the increasingly widespread use of social networks, misinformation could become a serious problem. Even though many problems have been solved during the development of *Citlalin Tlamina*, there are still more issues left to do before consolidating a robust network (Cordero *et al.*, 2016; Esparza-Posadas, 2023; Reyes-Lara, *et al.*, 2023).

Javier Mendieta, former director of the Mexican Space Agency, identified the lack of support for space projects as a national deficit in science investment, placing the country at a disadvantage in space research compared to other nations (Universidad Nacional Autónoma de México, 2012). Due to this, Mexican scientists tend to limit themselves to doing research and developing theories based on studies or data from foreign countries. *Citlalin Tlamina* is, in this context, a way to generate data locally to study sky phenomena with feet on Earth at a low cost.

In addition to the labor in the Mexican Meteor Network, theoretical work has been carried out in Mexico to study the passage of meteoroids/asteroids through atmospheres. Cordero & Mendoza (1999) solved the entry equations considering the drag due to the winds to study the fall of meteoroids into Venus's atmosphere. Cornejo Patiño's BSc thesis (2017), consisted in studying the equations of transformation that enable the calculation of meteor paths from data of reference stars and their position on images taken by video cameras. Gutiérrez-Zalapa *et al.* (2024) model numerically the effects of the impact on a NEO in Mexico and take Chicxulub as their case of study. Finally, Moctezuma-Soto (2024) model the position, velocity and mass loss to make a bayesian estimation of some physical parameters of the object.

Even though meteor networks have been established in several countries, particularly in Europe, information from people who have witnessed and recorded meteors and fireballs is still important. One example of this is the useful information provided by cars and surveillance cameras to study the trajectory and origin of the asteroid that produced the Chelyabinsk event on February 15th, 2013 (Popova *et al.*, 2013; Zuluaga *et al.*,

2013). Another recent example is the Golden meteorite fall that occurred on October 4, 2021. In this case, a person, that was taking a series of photographs, captured the fireball and posted the first images of this meteor on social media. Researchers that studied this event requested his material to carry out their study (Brown *et al.*, 2023).

In recent years, social media platforms like Instagram, X (formerly Twitter), and Facebook have been useful in sharing not only personal information but also interesting material about natural phenomena, including meteors. The extensive use of mobile phones allows people to record meteors and then upload videos on social media. Journalists and other users take this material and make the news go viral. This is helpful because more people can upload their recordings allowing us to get information from different places.

Another very useful source of information is WebCams de México (WebCamsMx). This is an online platform that presents in real time what cameras capture in various areas of tourist interest in Mexico. Most of these cameras are fixed and have a wide field of view. The WebCamsMx platform grants access to consulting videos taken in the previous 24 hours (in several cases even the previous 48 hours), or a previous week but only snapshots with intervals of 15 minutes. After this period, the information is no longer available. The cameras belonging to this net are located in Baja California , Baja California Sur, Chiapas, Chihuahua, Ciudad de México (CDMX), Colima, Durango, Estado de México, Guanajuato, Guerrero, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Nuevo León, Oaxaca,

Puebla, Querétaro, Quintana Roo, San Luis Potosí, Sinaloa, Sonora, Veracruz, and Yucatán (twenty-five of the thirty-two states of the Mexican Republic). There are around one-hundred and thirty cameras (Webcams de México, n.d.).

When people see something interesting (in particular meteors) in WebCamsMx videos, they download the part of the video they are interested in and then upload it to their social networks. It is useful because it allowed us to confirm that the event really happened due to the fact that there are several sources that are easy to track, and are preserved on the web.

Therefore, the objective of this paper is to show the importance of social networks and online platforms (Facebook, X, YouTube, Webcams de México, and NASA databases) as tools to gather information to develop studies on space risks as a part of the Citlalin Tlamina project.

2. Methodology

2.1. Data

To show the importance of public information on social networks related to the entry of asteroidal or cometary material into the Earth's atmosphere, first, we looked for information about meteors or bolides that occurred in Mexico according to NASA databases and other sources to compare this information with what was available on other websites. Our results are shown in Tables 1 and 2.

Table 1. Data of fireballs that occurred on Mexican territory registered by the US Government Sensors. These data are ordered chronologically from the first event recorded in 1995 to the last one corresponding to the last event listed at the time of writing this paper. Columns 4 and 5 show the longitude and latitude, respectively, of the probable place where the object fell. Column 6 is an estimate of the impact energy. Information taken from (CNEOS, n.d.)

#	Hour (UTC)	Date	Longitude (West)	Latitude (North)	Impact Energy (kt)
1	17:14:10	1995/08/05	104.30°	11.60°	0.56
2	14:04:45	1996/07/12	93.60°	20.70°	0.11
3	18:47:15	1997/10/09	106.00°	31.80°	0.53
4	08:33:58	2000/01/18	94.90°	24.30°	0.12
5	01:12:25	2000/08/25	106.10°	14.50°	3.10
6	05:19:07	2005/11/15	113.40°	26.30°	0.09
7	13:16:23	2006/04/08	113.20°	17.30°	0.37
8	04:19:37	2010/08/17	114.30°	20.70°	0.08
9	16:50:33	2012/04/02	95.20°	28.10°	0.11
10	06:47:42	2014/02/13	110.70°	13.30°	1.50
11	07:06:26	2015/07/19	87.60°	20.60°	0.08
12	18:17:10	2019/02/01	83.80°	22.50°	1.40
13	05:43:17	2020/04/28	109.40°	20.10°	0.08
14	03:41:54	2023/07/26	103.40°	18.90°	0.44

Table 2. Fireballs captured by GOES East and GOES West satellites. The longitude and latitude shown refer to the projection in space where these events were located. The last column shows the duration of the meteor. Information taken from Bolide Detections from the Geostationary Lightning Mapper (Bolides, n.d.).

#	GOES 16-18	Hour (UTC)	Date	Longitude (West)	Latitude (North)	Duration (s)
1	GLM-16	16:36:18	2019/05/23	102.20°	24.30°	0.197
2	GLM-16	14:30:30	2019/07/18	103.70°	27.20°	0.058
3	GML-17	08:22:09	2019/07/29	97.00°	17.00°	0.145
4	GLM-16	11:18:48	2019/08/10	103.10°	21.50°	0.145
5	GLM-16	11:12:27	2019/10/12	111.30°	28.80°	0.006
6	GLM-16	10:14:13	2019/11/16	103.30°	29.20°	0.102
7	GLM-16	17:43:25	2020/04/18	107.20°	29.00°	0.146
8	GLM-16	13:25:27	2020/05/07	102.30°	22.50°	0.071
9	GLM-16	15:35:57	2020/08/04	100.30°	27.30°	0.023
10	GLM-16	12:28:26	2020/08/21	103.70°	25.90°	0.063
11	GLM-16	03:14:22	2020/10/07	100.10°	26.10°	0.044
12	GLM-16	13:49:00	2020/10/10	106.20°	24.90°	0.068
13	GLM-16	12:47:32	2020/10/20	109.80°	26.40°	0.026
14	GLM-16	12:57:43	2020/10/22	99.60°	24.20°	0.123
15	GML-16	14:19:10	2020/10/24	95.40°	18.50°	0.157
16	GLM-16	17:52:18	2020/10/25	110.60°	28.90°	0.012
17	GML-16	10:18:55	2020/11/16	98.10°	17.60°	0.014
18	GLM-16	09:36:04	2020/11/16	101.20°	20.30°	0.386
19	GLM-16	12:53:41	2020/11/17	103.10°	23.00°	0.385
20	GLM-16	14:41:53	2020/11/17	101.90°	24.10°	0.066
21	GLM-16	16:37:50	2020/11/18	101.20°	18.80°	0.054
22	GLM-16	13:41:49	2020/12/01	104.20°	25.80°	0.015
23	GLM-16	16:59:46	2020/12/19	98.60°	22.00°	0.040
24	GLM-16	08:46:13	2021/01/15	105.70°	28.90°	0.012
25	GML-16	12:55:42	2021/02/22	97.50°	18.30°	0.070
26	GLM-16	11:22:50	2021/05/03	102.10°	20.10°	0.016
27	GLM-16	11:40:21	2021/05/03	109.70°	26.80°	0.018
28	GLM-16	11:31:16	2021/07/27	112.60°	30.40°	0.036
29	GLM-16	10:20:58	2021/08/25	105.80°	27.80°	0.511
30	GLM-16	13:26:26	2021/11/11	107.60°	27.30°	0.065
31	GML-16	08:11:16	2021/12/27	98.80°	18.70°	1.356
32	GML-16	09:02:04	2022/05/06	95.7°	19.30°	0.129
33	GLM-16	14:14:45	2022/05/07	100.00°	22.20°	0.040
34	GLM-16	18:41:18	2022/06/30	110.50°	27.00°	0.046
35	GLM-16	15:22:59	2022/07/18	111.20°	28.20°	0.185
36	GLM-16	13:02:42	2022/07/28	105.50°	28.40°	0.081
37	GLM-16	06:39:26	2022/08/11	104.80°	20.30°	0.057
38	GLM-16, GLM-18	03:41:52	2023/07/26	103.4°	19°	1.683
39	GLM-16, GLM-18	07:23:50	2023/11/21	98°	20°	1.432

According to the Center for Near Earth Object Studies website (CNEOS, n.d.), the US Government Sensors have registered fireballs from April 15, 1988, until the present time. Table 1 shows the events that occurred on Mexican territory during this period.

Geostationary Operational Environmental Satellites, GOES, are a series of satellites that have recorded continuously the atmospheric conditions and solar activity from 1975 to date. They are geostationary and orbit 35,786 km above Earth's equator. GOES 16 is at 75.2° W and GOES 18 is at 137° W, both of them are able to observe half the planet and their fields of view overlap on a great portion of the American continent, in particular on Mexico (GOES satellite network, n.d.). Onboard GOES is the Geostationary Lightning Mapper (GLM) whose objective is to map lightning activity, but has also been able to record meteors (Ozerov et al., 2024). The first meteor captured by the GLM in Mexico occurred in May 2019 (Table 2) (Bolides, n.d.).

Comparing the information on Tables 1 and 2, we saw that only one event was registered in both of them, this event occurred on July 26, 2023, in the central-west region of Mexico. The low coincidence between these databases is due to the starting date of the fireballs captured by GLM and maybe because of the intensity of the event or the coverage of the satellites.

For the second part of our research, we looked for information on platforms such as Facebook, YouTube, and X, being the latter the main source of consultation, in order to evaluate the significance of the data in these reservoirs. Once an event was identified, we looked up more information about it on digital newspapers of the places where it could have been observed. In Mexico there are neither government institutions nor protocols that verify the content of the news on social networks. The government only raises people's awareness about how to avoid rumors and spot fake-news (Gobierno de México, n.d.). So, to rule out fake-news, we made sure that the information posted by several users was concordant both in time and space. In the case that people shared videos, we checked that the meteor was similar, i.e., that if there were two bursts, we verified that the same two bursts were observed separated by the same period of time between them in all the videos. If videos came from WebcamsMx, the verification was easier because we had additional data like time and date. In addition, the watermarks validate the authenticity of the videos.

The information gathered by journalists was distinctly useful as it allowed us to get more information because they usually cite other videos or narrate witnesses' experiences. In this case, it is possible to know if they saw fireballs, or if they heard deafening sounds, or even if they felt tenuous earthquakes. Journalists can also obtain information from X users who showed material from Webcams de México or videos of their own. The information

provided by social network users is of great importance considering that Webcams de México does not keep their videos on its webpage for more than 24 hours. Then, X and YouTube have become a kind of reservoir of videos with no apparent expiration date.

After a comprehensive search of meteor events on the social networks mentioned, we found twenty-four events from April 21st, 2013 to November 21st, 2023 (Table 3).

2.2. Data analysis

As mentioned, much of the research presented here was possible thanks to footage from Webcams de México (WebCamsMx), whose objective is to promote and encourage tourism in Mexico through live recordings of everyday Mexican culture using cameras located at the front of several buildings. As these cameras record all that happens inside their field of view, it is possible to look for meteors in these recordings.

The format used by Webcams de México provides the date, time, and the name of the building from where the footage was recorded. These data permitted us to locate the place from where the meteor recording was made. The field of view of the cameras is wide enough to allow taking reference points and estimating the trajectory of a meteor. This was possible using tools such as Google Earth Pro (GEP, -Google Earth, n.d.-). The procedure is described in the next paragraphs.

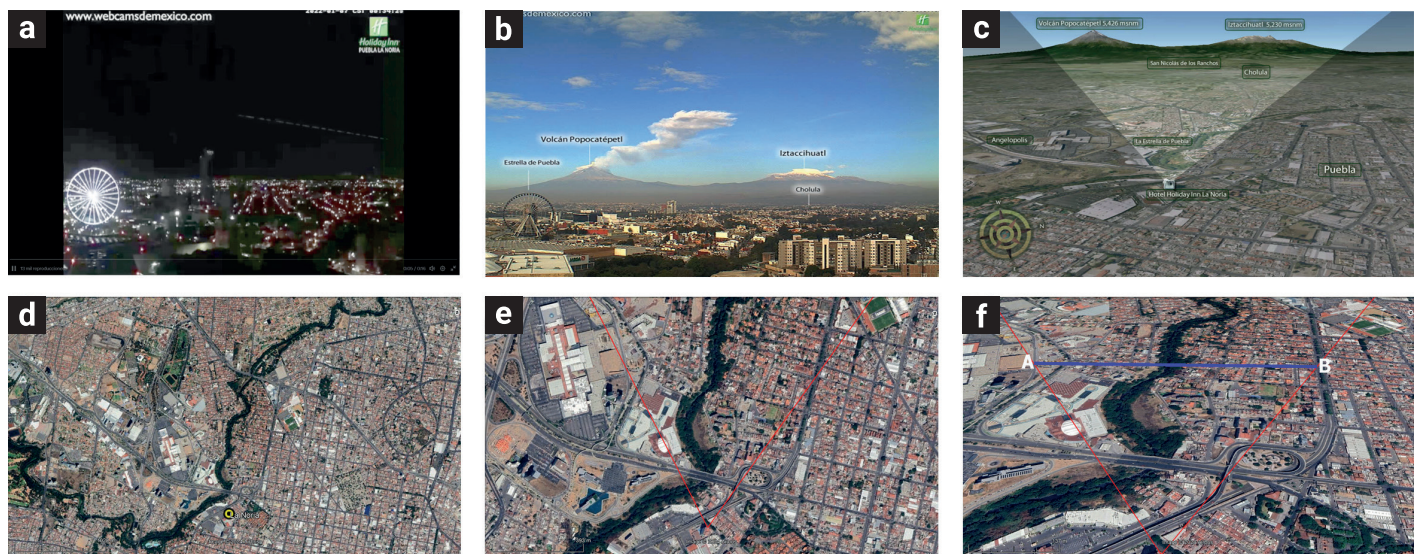
To estimate the trajectory as well as the angular velocity of the meteoroids using the videos from WebCamsMx, the first thing we looked for was the location of the camera that recorded the event. This was done with the help of the watermark on the upper right corner of each frame (Figure 1(a)). Then we searched the location using GEP (Figure 1(d)). Employing images of the camera's field of view provided by WebCamsMx (Figure 1(b) and (c)), we took reference points that permitted us to draw the red lines on Figure 1 (e). Finally, we measured the angle between these two lines. The purple line in Figure 1(f) is parallel to the camera's focal plane as seen from above, then it is perpendicular to the direction towards which the camera points. This process was made for all the videos we worked with.

Once the purple lines were obtained and the location of all the cameras was determined, we represented them on a map (Figure 2). Long segments represent the camera's focal plane. With this information alongside the length, duration and time of the recording, it was possible to estimate a trajectory for each one of the meteoroids/asteroids (Figures 2 and 3). Snapshots for each event are shown in Figures 4 to 8.

To calculate the angular velocity of the cosmic object, the following was made: 1) the angles between the red lines (Figure 1(e)) and the north were measured using the "ruler" tool of GEP,

Table 3. Meteors observed over Mexican territory and found through the use of online platforms and social networks.

#	Hour (Local time)	Date	Approximate Location	Platform
1	19:30-20:30	2013/04/21	Toluca, Estado de México	YouTube
2	Early morning	2015/07/19	Playa del Carmen, Quintana Roo	News
3	17:50-18:20	2018/07/23	Veracruz	News
4	07:40-08:00	2018/10/26	Ciudad Juárez, Chihuahua	News
5	Overnight	2018/12/08	Xochimilco, Ciudad de México	Facebook
6	21:00 - 21:30	2019/05/26	Uruapan, Michoacán	News
7	20:00-20:30	2020/02/18	Between Puebla and Michoacán	News
8	02:45:00	2020/05/18	Mexicali, Baja California.	Twitter
9	22:00 - 22:30	2020/10/06	Ciudad Victoria, Tamaulipas	News
10	Overnight	2020/11/29	Morelos	Twitter
11	Overnight	2021/08/26	Cancún, Quintana Roo	Twitter
12	00:00-01:00	2022/01/07	Between Puebla and Michoacán	Facebook
13	23:30-1:00	2022/02/05	Dimas, Sinaloa	Facebook
14	Overnight	2022/03/22	Telesecundaria. Cedral, San Luis Potosí	News
15	Overnight	2022/03/29	Sinaloa	Twitter
16	00:52:00	2022/03/30	Estado de México	Twitter
17	00:24:00	2022/04/06	Between Acapulco and Michoacán	Twitter
18	03:45-04:20	2022/05/06	Papaloapan Basin	News
19	3:02:02	2023/03/02	Altzomoni, Puebla	Twitter
20	3:10:59	2023/04/01	Popocatepetl, Puebla	Twitter
21	1:15:27	2023/06/01	Tlamacas, Puebla	Twitter
22	21:41:55	2023/07/25	Colima	Twitter
23	21:35-21:45	2023/11/16	Azcapotzalco, Ciudad de México	Twitter
24	1:20-1:25	2023/11/21	Ciudad de México y Querétaro	Twitter

**Figure 1.** a) Meteor trace of Event 12 observed from La Noria, Puebla; b) y c) reference images provided by Webcams de México; d) Camera location (yellow circle), e) angular view of the camera f) points of reference.

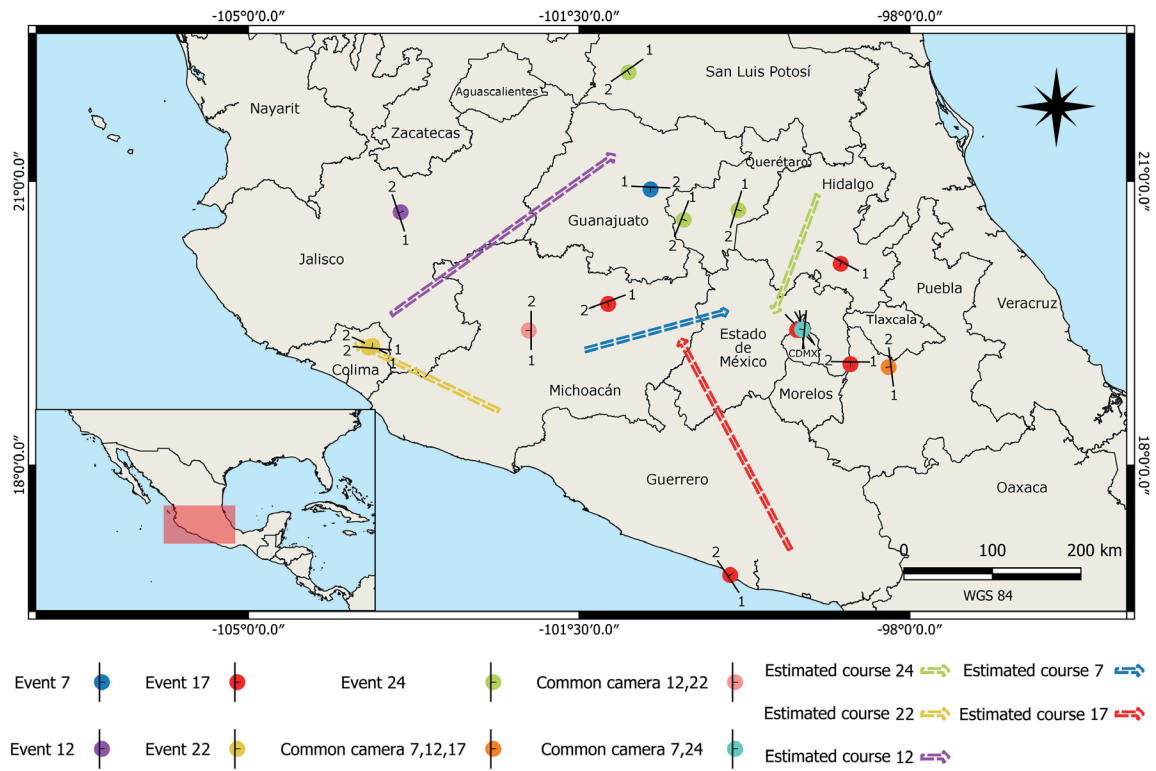


Figure 2. Map of central Mexico that shows the location of the cases captured by at least three cameras. Each circle is accompanied by a long and a short segment perpendicular to the first one. The short segment indicates the direction in which the camera is pointing. Numbers 1 and 2 at each end of the long segment indicate that the object moves from 1 to 2. On this map, the navy-blue symbology is related to Event 7, the purple one is associated with Event 12, the red one to Event 17, the yellow one to Event 22, and the green one to Event 24. Circles point to the camera's location according to the symbology. The arrows show the approximate trajectory of the object.

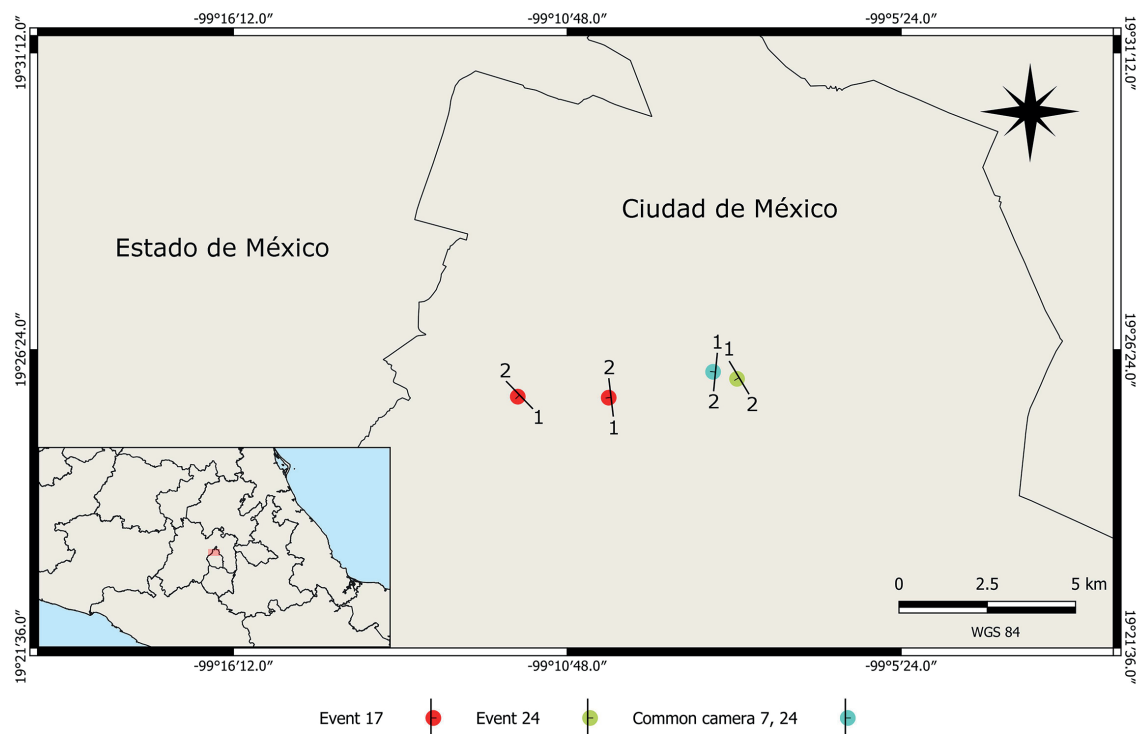


Figure 3. Zoom of area around Mexico City. These are piled up in Figure 2. The symbology is the same as in Figure 2. Numbers 1 and 2 associated with the blue circle point in the direction of event 24, the direction of event 7 is the opposite.



Figure 4. Meteor traces of the Event 7 (February 18, 2020) observed from a) Allende Park, Guanajuato, b) La Noria, Puebla, and c) the Latin American Tower, Mexico City. In (a), the meteor can be seen to the right of the church dome.



Figure 5. Meteor traces of Event 12 (January 7, 2022) observed from a) La Noria, Puebla, and b) Uruapan, Michoacán (the meteor is in the upper right corner), and c) Fiesta Americana, Guadalajara.

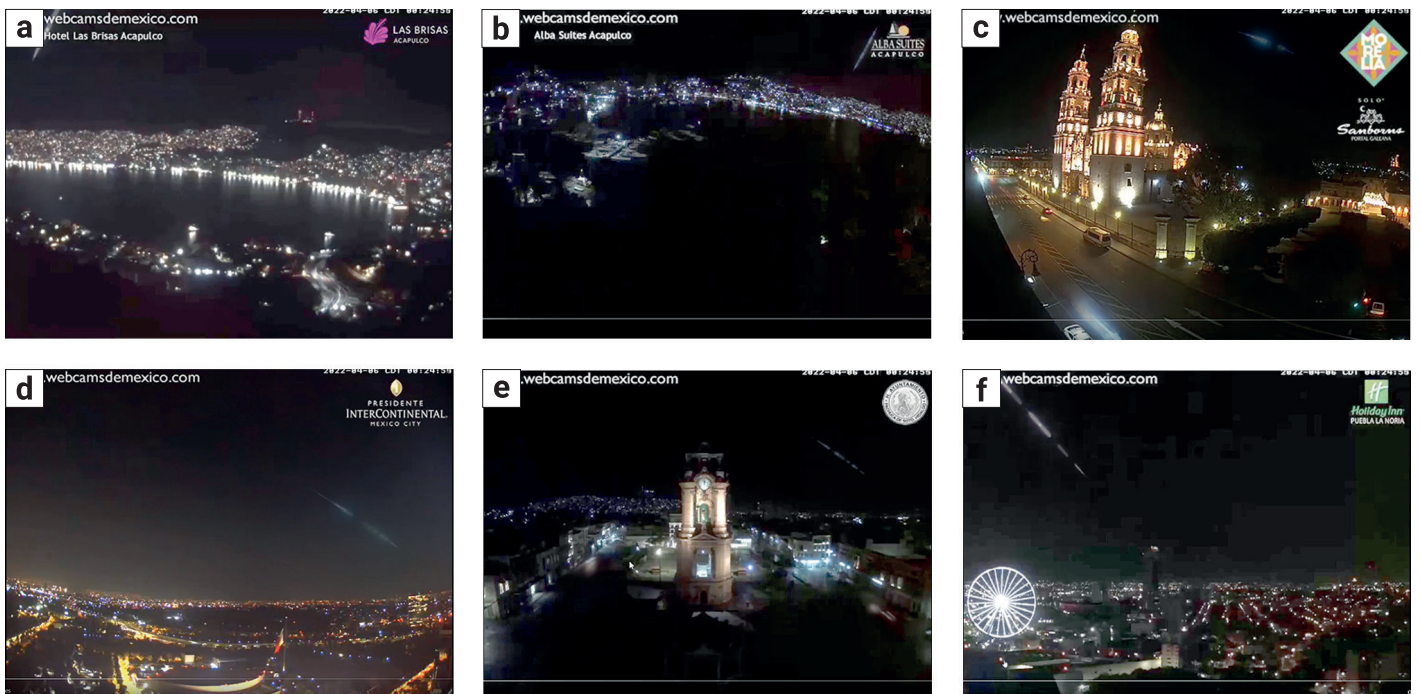


Figure 6. Meteor traces of the Event 17 (April 6, 2022) observed from a) Las Brisas Acapulco, Guerrero, b) Alba suites, Acapulco, Guerrero c) Morelia Cathedral, Michoacán d) Presidente Intercontinental, Mexico City e) Plaza Independencia, Pachuca, Hidalgo, f) La Noria, Puebla.

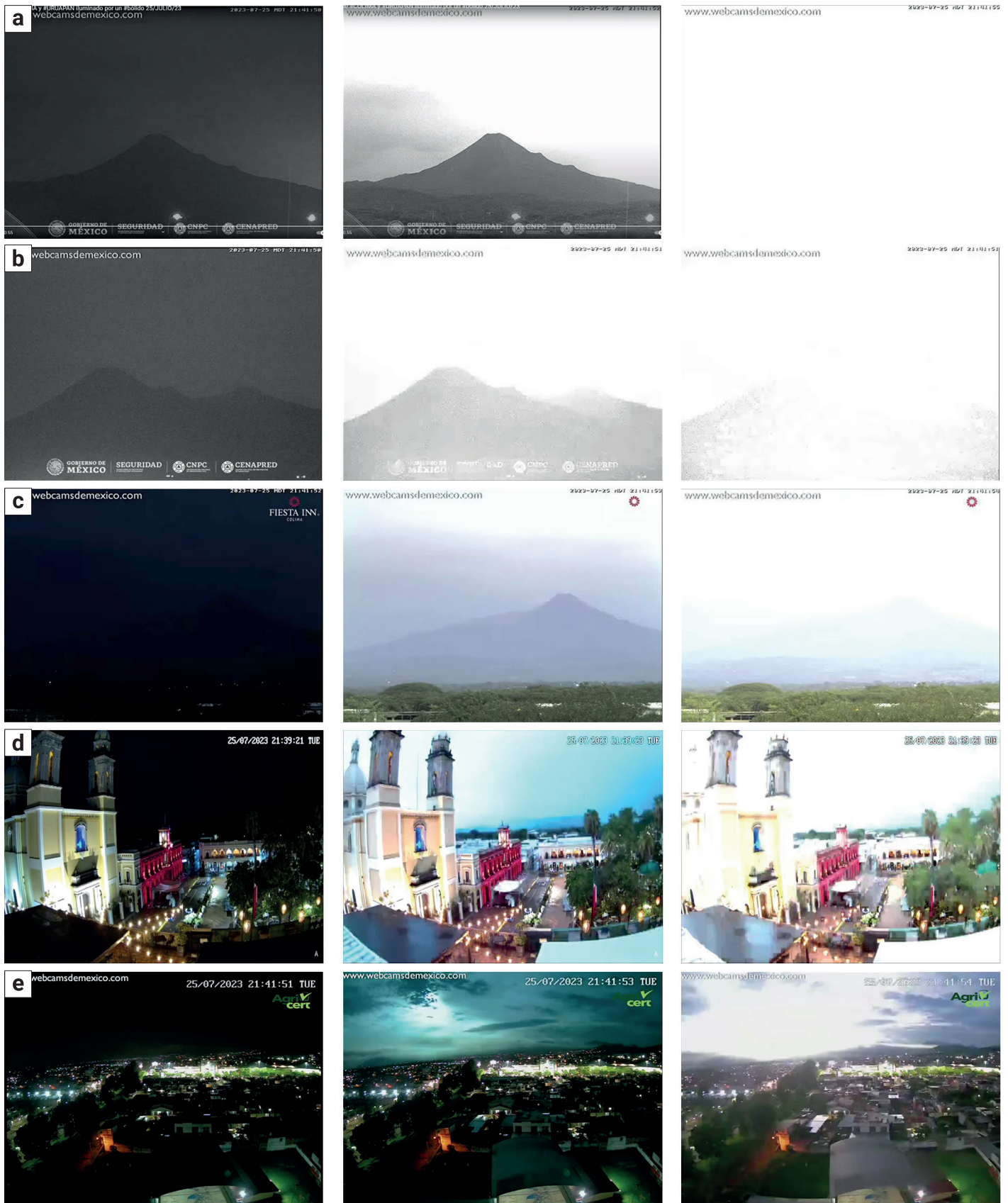


Figure 7. Each panel in this image shows three snapshots of the videos that recorded Event 22 (July 25th, 2023). In panels (a) to (d) there is not a trace, only a light burst was observed. Panels (a) and (b) show images coming from cameras belonging to CENAPRED located in the neighborhood of Colima volcano, the rest of the panels show snapshots from videos of WebCamMx located in the Hotel Fiesta Inn, Colima (c), Hotel Concierge C, Colima (d), and Holiday Inn Uruapan, Michoacán (e).

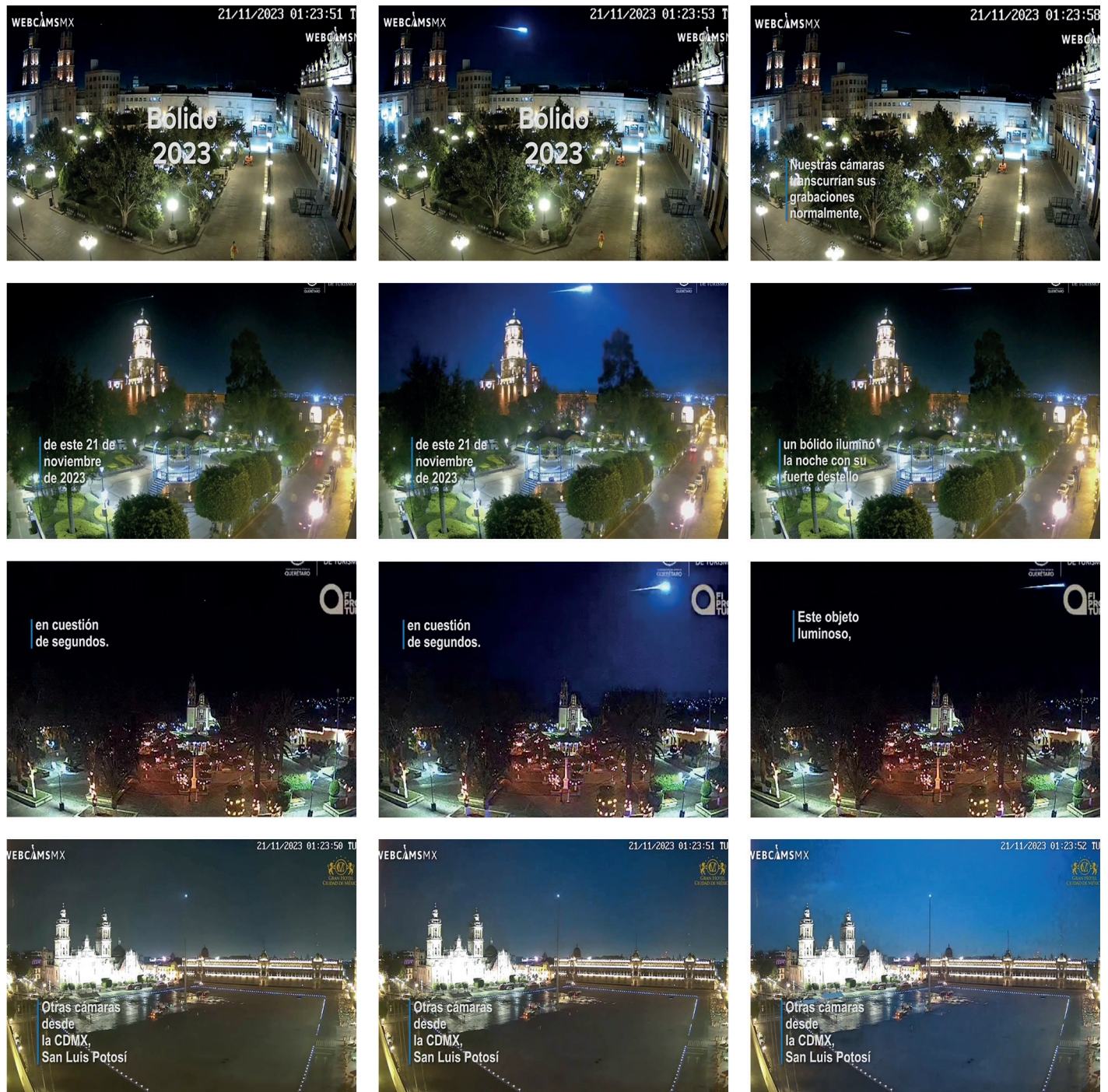


Figure 8. Each panel in this image shows three snapshots of the videos that recorded Event 24 (November 21st, 2023). Panels (a) to (c) show three snapshots of the meteors. In panel (d) only a light burst was observed. The cameras are in Downtown, San Luis Potosí (a), Zenea Park, Querétaro (b), Cadereyta de Montes, Querétaro (c), and Gran Hotel, CDMX (d).

2) with this information, the angle between the two red lines was obtained; 3) the angle of the meteor path was calculated comparing the length of the purple line with the length of the meteor trace, 4) the angular velocity was calculated with the length obtained by the procedure in (3) and the time given by the videos. Two points should be noted: firstly, that the angular length of the meteor path is the angle projected on the horizontal, so the calculated velocity is a minimum value; and secondly, that

we did not calculate the angular velocity in all videos, only in those where the meteor path was the largest available, i.e. when the direction of the camera observation was perpendicular or near perpendicular to the meteor track.

The reference points determined in each video were useful to assess the direction of the movement of the entry object, even though this could only be done for five events out of the twenty-four in Table 3. For these five events we had at least three

videos taken from three different places. The analysis of these events is shown in the following section.

3. Results

From the information in Table 3, we chose those events recorded with at least three cameras to obtain as much information as possible concerning each meteor. The events that fulfilled this criterion were cases 7, 12, 17, 22 and 24. Table 4 shows the information from these cases. The location of each of the cameras (most of them belonging to WebCamsMx), and the meteor trajectory, were identified with the help of GEP, the information provided in the videos (watermarks with the name of the building where the camera is located), and the landscape

within the field of view (roads, buildings or other notorious places). The results are shown in Figures 2 and 3.

The images shown in Figures 4 to 8 were useful in two ways: 1) to determine the orientation and field of view of the camera, and 2) to estimate, in some cases, the angular mean velocity of the object.

Comparing the trace of the meteor from each camera, we chose the video that showed the largest trace, this implied that the camera was oriented in such a way that its optic axis was as perpendicular as possible to the path of the meteoroid or asteroid. Using the reference points that we already had from that video, and the time given by it, we estimated the angular mean velocity of the object for the events 7, 12, and 17, obtaining 2.30 %/s, 5.38 %/s, 4.17 %/s, respectively. For cases 22 and 24 it was not possible to get their angular velocity because in most of

Table 4. Meteor recordings taken by at least three of the cameras of WebCams de México. All of them were stored on the Twitter platform by users.

Event	Date	Camera	Location of the camera	Initial time (Local time)	Final time (Local time)	Place
7	2020/02/18	1	Puebla	20:18:46	20:18:51	Holiday Inn La Noria
7	2020/02/18	2	CDMX	20:18:46	20:18:51	Latin American Tower
7	2020/02/18	3	Guanajuato	20:18:46	20:18:51	Allende Park
12	2022/01/07	1	Guadalajara	0:34:30	0:34:41	Fiesta Americana
12	2022/01/07	2	Michoacán	0:34:26	0:34:29	Holiday Inn Uruapan
12	2022/01/07	3	Puebla	0:34:25	0:34:32	Holiday Inn La Noria
12	2022/01/07	4	CDMX	0:34:22	0:34:39	Unknown
17	2022/04/06	1	CDMX	0:24:53	0:24:56	Presidente Intercontinental
17	2022/04/06	2	Michoacán	0:24:53	0:24:56	Morelia Cathedral
17	2022/04/06	3	Hidalgo	0:24:54	0:24:56	Plaza Independencia
17	2022/04/06	4	Puebla	0:24:54	0:24:56	Holiday Inn La Noria
17	2022/04/06	5	Estado de México	0:24:54	0:24:56	Tlamacas Station
17	2022/04/06	6	Acapulco	0:24:54	0:24:56	Alba suites Acapulco
17	2022/04/06	7	CDMX	0:24:55	0:24:56	Monte Cristo Reserve
22	2023/07/25	1	Colima	21:41:50	21:41:55	CENAPRED
22	2023/07/25	2	Michoacán	21:41:51	21:41:55	Holiday Inn Uruapan
22	2023/07/25	3	Colima	21:39:21	21:39:25	Hotel Concierge C
22	2023/07/25	4	Colima	21:41:52	21:41:55	Fiesta Inn Colima
22	2023/07/25	5	Colima	21:41:53	21:41:54	CENAPRED
24	2023/11/21	1	Querétaro	1:23:52	1:23:58	Cadereyta de Montes
24	2023/11/21	2	CDMX	1:23:51	1:23:52	Santa Fe
24	2023/11/21	3	Querétaro	1:23:49	1:23:59	Zenea Park
24	2023/11/21	4	CDMX	1:23:51	1:23:54	Gran Hotel CM
24	2023/11/21	5	CDMX	1:23:51	-	Latin American Tower
24	2023/11/21	6	Guanajuato	1:21:14	1:21:21	La Onza Ranch
24	2023/11/21	7	San Luis Potosí	1:23:51	1:23:59	Historic Center
24	2023/11/21	8	CDMX	1:23:49	1:23:54	East of the city

the videos only the flash is seen (Figures 7 and 8).

4. Discussion

Of the twenty-four events shown in Table 3, only two of them were also recorded by the US Government Sensors and/or GOES satellites: the event on July 25th, 2023 (local time), recorded by both of them and the event on November 21st, 2023 (local time), recorded only by GOES (16 and 18). This means that not even all these sensors can record all the events that happen on Mexican territory and that observations from residents, WebCamsMx, or surveillance cameras provide important information, either to identify that a meteor occurred or to obtain specific data about the phenomenon.

We compared our estimated trajectories for events 22 and 24 with data from GOES satellites (this is because only these two events are in both Tables 2 and 3), and we found that the trajectories are similar, particularly in the event 22 (Figures 9 and 10). From these images we observed that the methodology employed in this work gives a similar result to that of GOES and the United States Sensors and it can be used to get a good estimation. The more videos we have, the better estimation of the trajectory is possible, even if in the video only the flash is seen, because this gives us an idea of where it was or was not, and it is useful to delimit the trajectory. In Figure 9, it can be observed that the meteor path is different from GOES-16 and GOES-18, this is due to the difference in the data projection of these satellites because they recorded the event from two different places. In addition, it is noteworthy that the trajectory we estimated is nearer to the trajectory given by the GOES closest to that region of Mexico; that is, our estimated trajectory is more similar to the data from GOES 18 in the Event 22 and GOES 16 in the Event 24.

On the other hand, event 7, occurred on February 18th, 2020 was also studied by Sergeeva *et al.* (2021) using another method. In Figure 11, the red polynomial delimits the initial and final points of the meteor path given in that work and considering the uncertainties. The direction of our estimated path is consistent with their results even though our approximate length is longer.

Social networks such as X, YouTube, and Facebook, among others, being platforms connected to the Internet, mainly serve as: 1) a means of recording many events thanks to their thousands of users, 2) a way to keep people and authorities informed about some important news (vaccines, scholarships, crimes, etc.), and 3) a storage for information that would otherwise be lost like the one coming from sites such as WebCamsMx videos.

Cameras used by the Webcams de México network are in continuous operation. However, they are focused on buildings,

natural structures, or roads. For this reason, recording the entry of objects into Earth's atmosphere is not a priority. Therefore, many times the track of the meteor is not complete or optimum. Nevertheless, as we showed, the videos recorded by these cameras are still valuable for estimating the probable trajectory of a meteoroid, and in some cases its angular mean velocity.

Another aspect to consider is that most of the cameras in the Webcams de México network are located in the center of the country, as well as in populated cities, thus our information has a bias because it excludes the rural and less touristic areas of the territory. We reckon that there is a greater number of events that are not captured by this network, meaning that these events were lost.

In social networks, it is also possible to find videos taken by people using their cell phones. The problem with this kind of videos is that they do not provide precise information about the place where it was recorded and, in many cases, users move their device "to follow" the meteor, making it impossible to extract suitable reference points from them. Still, this information is valuable to determine that a meteor occurred, and to increase people's interest in this phenomenon.

An event of particular importance took place on July 25th, 2023 (Tables 1 – 4) which we learned about through social networks. Between 21:00 and 22:00 local time, a meteor was observed by monitoring cameras of the Colima volcano and others. The atmospheric shockwave of this meteoroid was recorded by several seismic stations as well. The study of these seismic data could offer more information about this meteor.

Another event that was not considered in this work, occurred on March 28th, 2024 (17:04:36 h). It shows once more the importance of social networks to record the entry of cosmic material into our atmosphere.

People often think that the biggest threat coming from space is a collision with a large asteroid (Tapia and Trigo-Rodríguez, 2017), but collisions with asteroids of even a few tens of meters could be a greater risk as the cases of Tunguska and Chelyabinsk showed (Farinella *et al.*, 2001; Popova *et al.*, 2013). Moreover, collision with objects of these sizes is much more common than with larger ones (Poveda *et al.*, 1999), which is why their study, detection, and search for fallout patterns should be considered a priority. In this sense, our work is an invitation to look at social networks as a source of information to complement the efforts made to study the fall of extraterrestrial material. Another important point is that data from these sources are posted immediately after the meteor happened, then this helps to know the occurrence of meteors in a short time.

Currently, the webpage of Citlalin Tlamina, the Mexican Meteor Network, is under construction (<https://meteoros.geofisica.unam.mx/>). The website will include a section similar to the one in the National Seismological Service webpage titled:

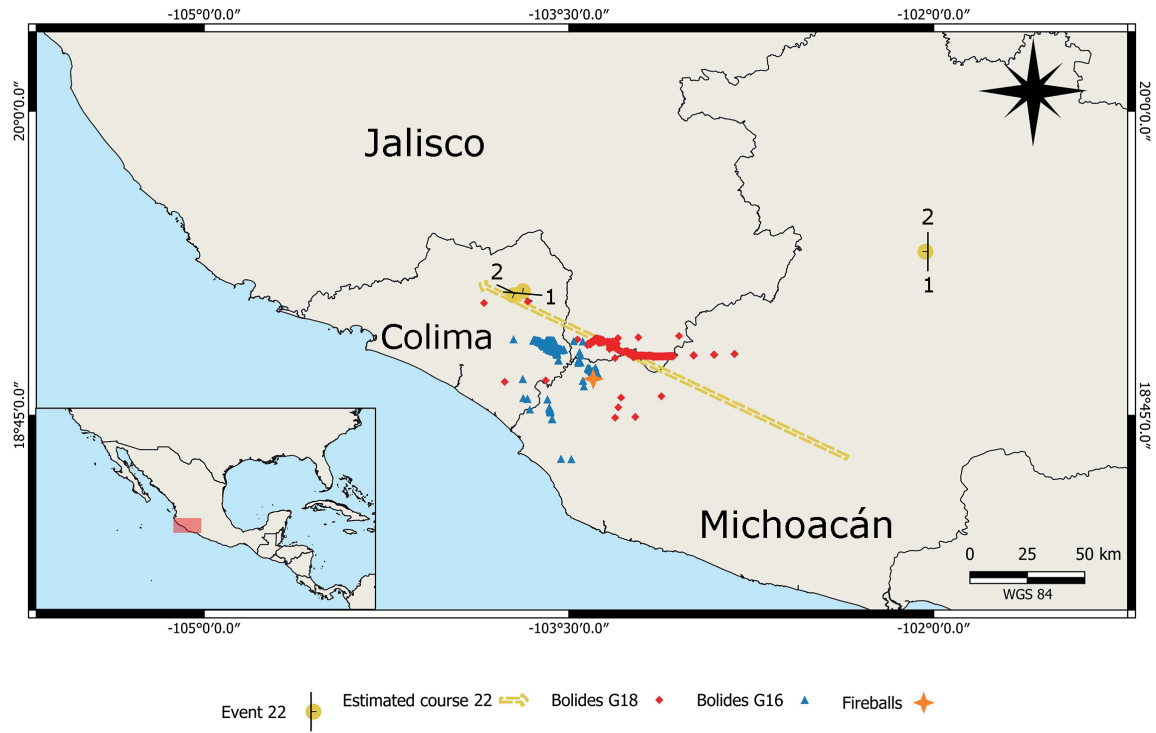


Figure 9. Meteor on July 25th, 2023 (local time). Red rhombuses are data from GOES 18, and blue triangles are data from GOES 16. The orange star is the location given by the US Government Sensors, and the yellow arrow is the estimated path obtained in this work.

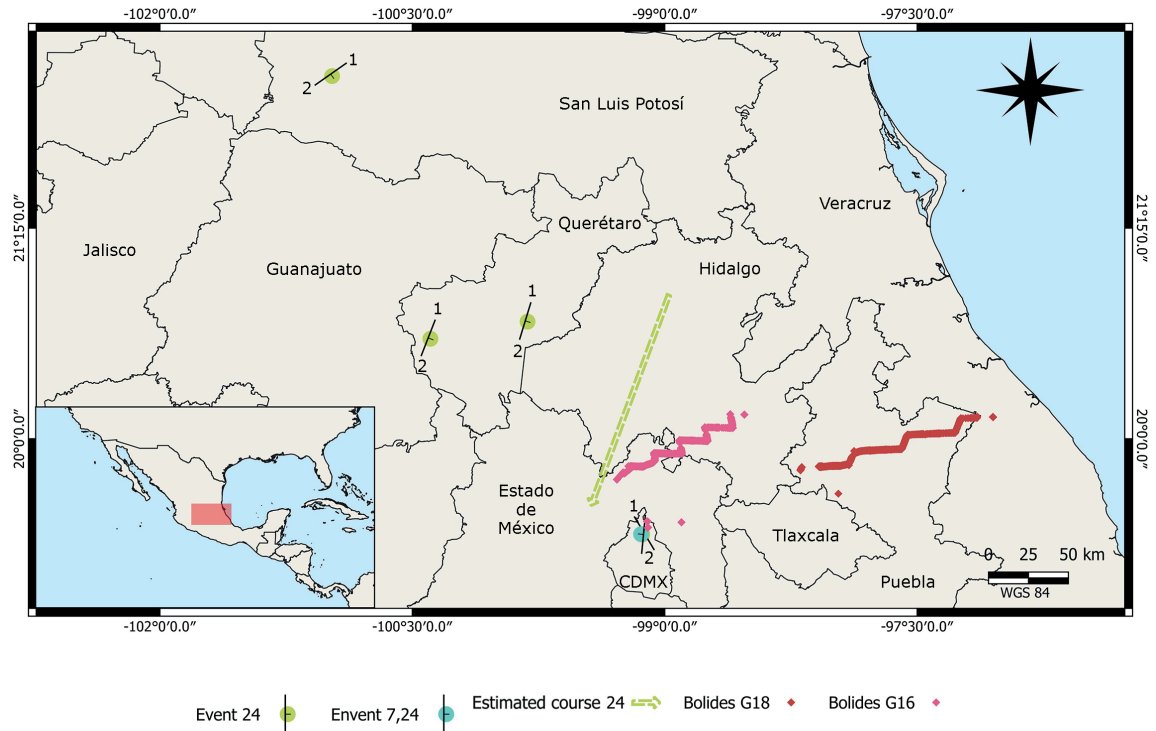


Figure 10. Meteor of November 21st, 2023 (local hour). Red rhombuses show data from GOES 18, and pink rhombuses are GOES 16 data. The green arrow is the estimated path obtained in this work.

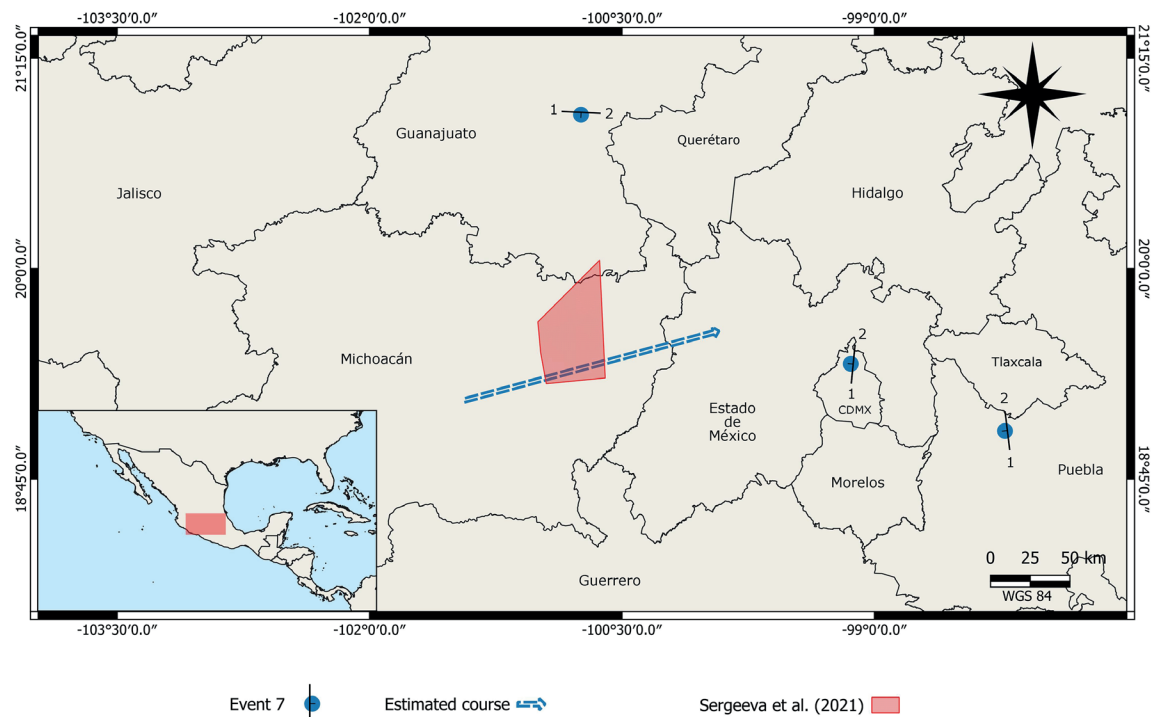


Figure 11. Comparison of our estimation for Event 7 with the results obtained by Sergeeva *et al.* (2021).

“Did you feel an earthquake? Report it here”, where people will be able to register their meteor observations to complement the studies carried out by Citlalin Tlamina. The objective is to start a network similar to IMO or EDMOND in Mexico.

5. Conclusions

Information shared in social networks can help in the search and/or investigation of events of space origin because it encourages the diffusion, interaction of observers, and the publication of valuable and useful material. This has been an important tool to verify that an event happened by providing study material and information that otherwise will be lost.

Even though several sensors and satellites provide cardinal data about the entry of meteoroids and small asteroids into the Earth’s atmosphere, they do not record all the events. This is evidenced by the information from social networks where people have posted events that were not recorded by sensors or satellites. Serving as a reservoir, social networks are a source of useful information for meteor studies.

The Mexican territory is not sufficiently covered or monitored by satellites to carry out a rigorous study about meteors. To improve this, we are currently working in the creation of the Mexican Meteor Network. As part of this project we have the section “¿Has visto un meteorito?” (Have you seen a meteor?)

in which we invite people to upload useful information about a meteor occurrence in a similar way IMO has done. This will allow us to create our own database on meteors in Mexico. We think that it will work because during the preparation of this article, we noticed a deep interest on behalf of the population in space phenomena, behavior manifested from the monitoring of the occurrence of the entry of asteroidal material into the atmosphere, to its constant circulation in social networks.

Information found in social networks provided data to create a meteor database of 24 events which took place in Mexico from April 2013 to November 2023, to plot the approximate trajectory of five of these events and to estimate the angular mean velocity of three of them.

6. Acknowledgments

G. Cordero is thankful for the support of the project PAPIIT IT102823 and to Miguel Angel Vela for his support in the creation of Citlalin Tlamina’s web page as well as his suggestion to create the section “Have you seen a meteor?”. A. Cuevas and A. Gallegos are grateful for the “Silvia Bravo” scholarship granted by Instituto de Geofísica, UNAM. All the authors thank Mariana Palencia, Gonzalo Ramírez y María Inés Francisco for their useful suggestions and to anonymous reviewers for the comments that improved this manuscript.

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