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Statistical Analysis of GLE events

Maria Gerontidou [1], Eleni Natalia Proimou [1]

[1] Physics Department, National and Kapodistrian University of Athens

1. Introduction

- High-energy SEP events occasionally manifest in the increase of the count rates of ground-based cosmic ray detectors, e.g. neutron monitors (NMs). Such events are known as Ground Level Enhancements or GLEs.

- Currently, the list of all recorded GLEs includes 76 events.

- This study presents a statistical analysis of various properties of all recorded until now GLE events, i.e. from 1942 until 2024, focusing on their association with solar sources.

- Specifically, we studied the time delay between the onset of the GLE and the start and peak of the associated solar flare, the solar flare class, the solar flare heliographic location, the associated CME linear speed and the time delay between the onset of the GLE and the onset of the proton flux increase for the energy channel >100 MeV.

2. Materials & Methods

- The onset times for the GLE events were provided by the GLE list of the Neutron Monitor Database or NMDB (https://www.nmdb.eu/nest/gle_list.php)

- The percentage of increase of the NM count rates (or amplitude) for each event was deducted from the GLE database of the University of Oulu, Finland (https://gle.oulu.fi/#/) and is corresponding to the NM station that showed the maximum increase during each event

- The solar flare data (start/peak time, class, solar location) were provided by the datasets of the Geostationary Operational Environmental Satellites (GOES) by the National Oceanic and Atmospheric Administration (NOAA)

- The CME data (onset time, linear speed) were provided by the SOHO LASCO CME catalog of CDAW Data Center by NASA and The Catholic University of America (https://cdaw.gsfc.nasa.gov/CME_list/)

- The proton flux data were accessed via the University of Colorado's Space Weather Technology, Research, and Education Center's Space Weather Data Portal (https://lasp.colorado.edu/space-weather-portal) and rely on data collected and processed at the NOAA Space Weather Prediction Center

- For the determination of the onset time of the proton flux increase for the energy channel > 100 MeV we used the 5 min average datasets and selected the 3rd consecutive value above the threshold of 1 pfu

3. Results

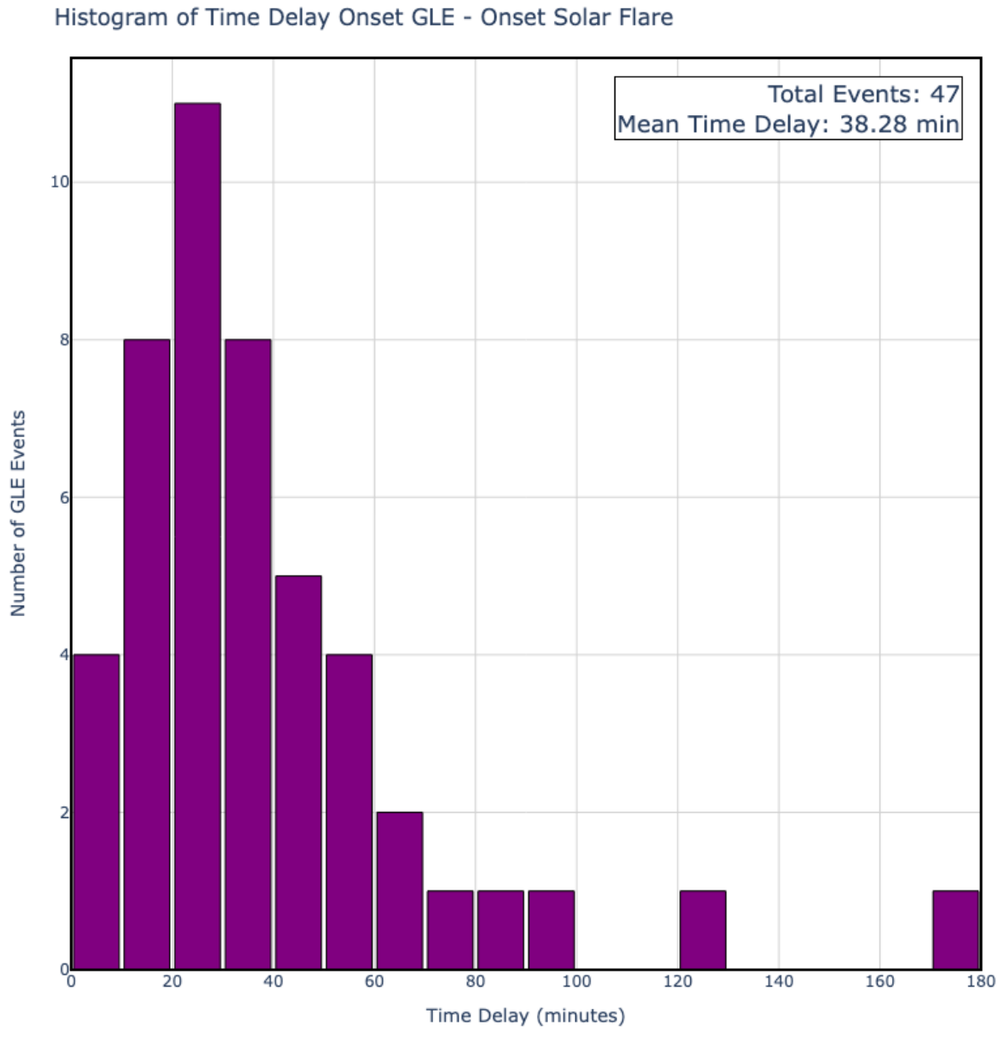

Figure 1 : Distribution of time delay (minutes) between the onset time of the GLE event and the onset time of the solar flare. The data for the solar flare onset were available for 47 events : #27 - #76 (with the exception of an outlier of negative value: event #30 with a time delay -13 min and #29, #61).

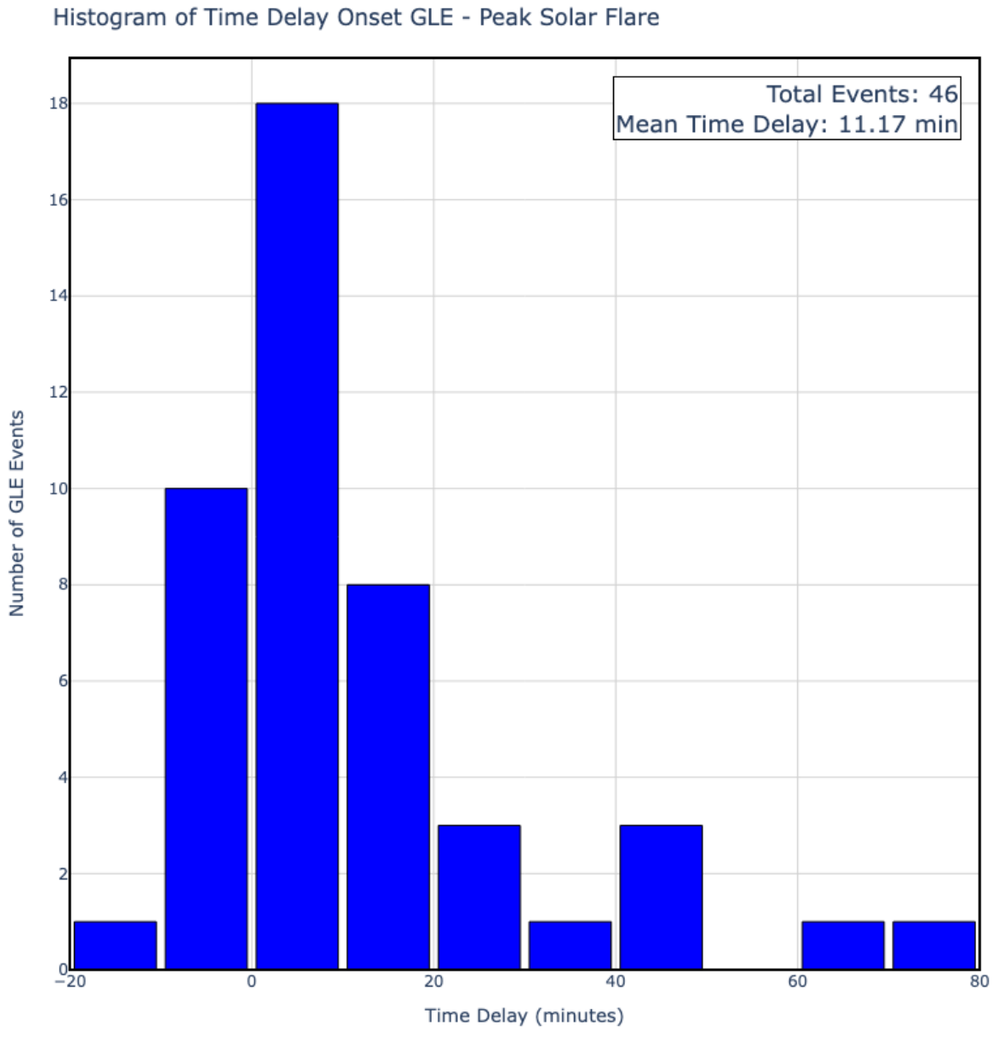

Figure 2 : Distribution of time delay (minutes) between the onset time of the GLE event and the peak time of the solar flare. The data for the solar flare peak were available for 46 events : #27 -#76 (not including #29-#31 and #61)

3. Results

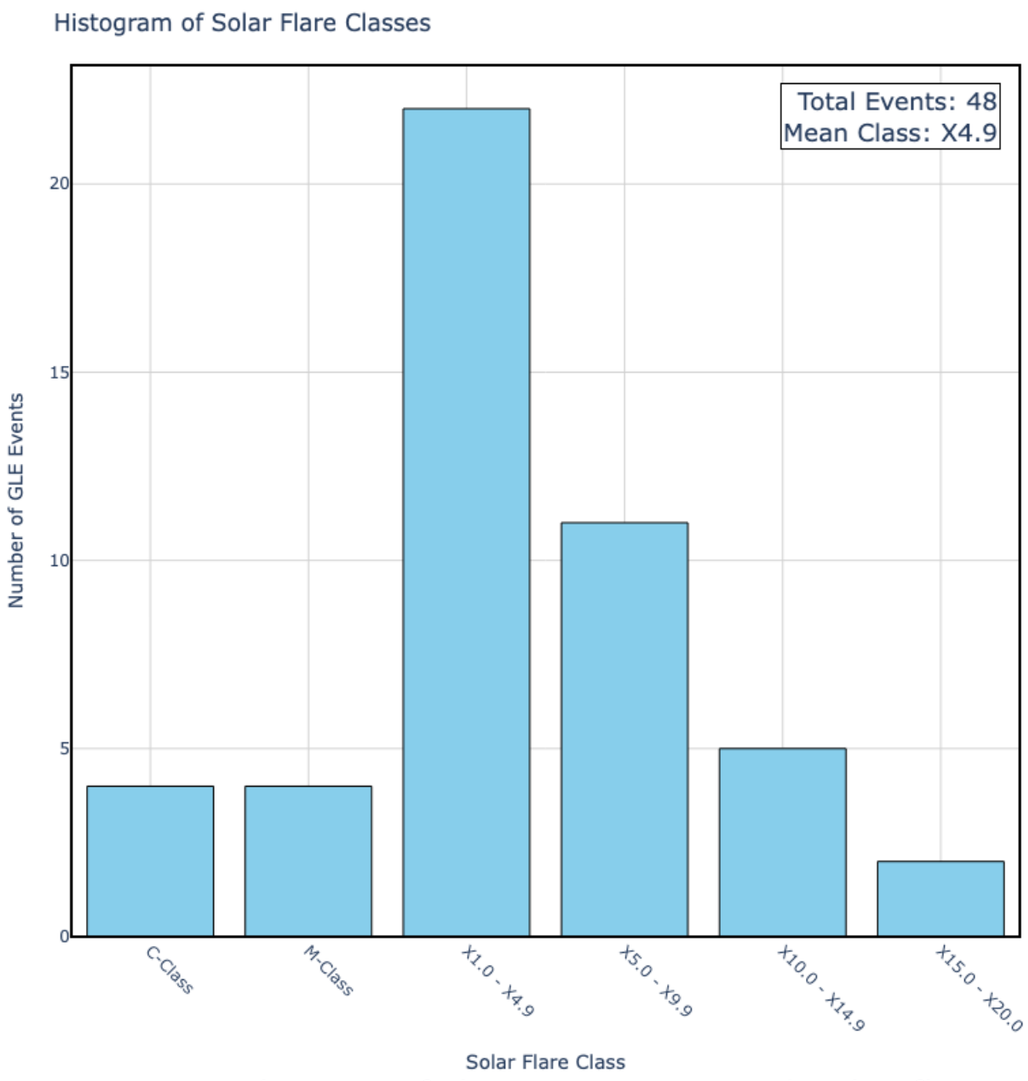

Figure 3 : Distribution of the GLE-associated solar flare class. The data for the solar flare class were available for 48 events : #27 - #76 (not including #29 and #61 – events behind west limb)

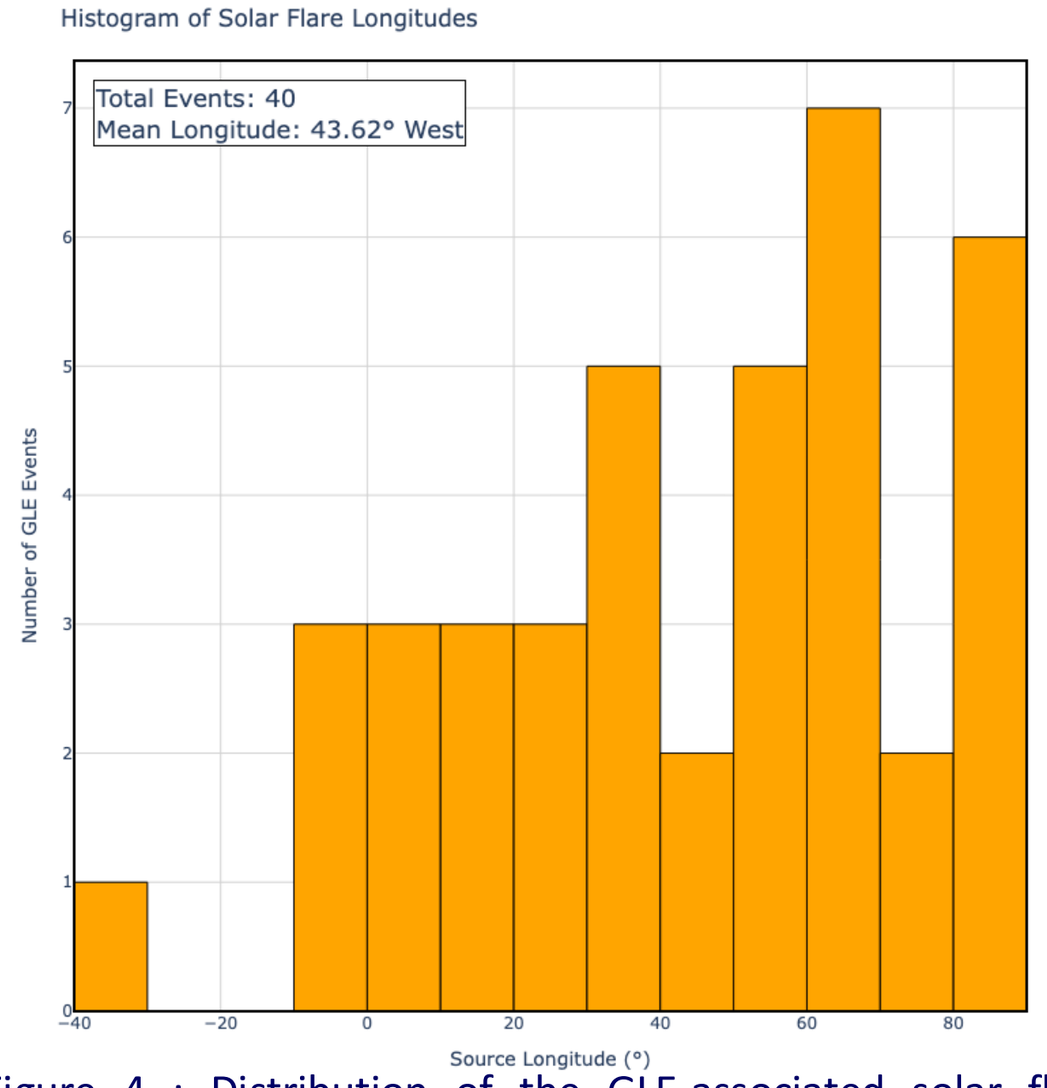

Figure 4 : Distribution of the GLE-associated solar flare longitude (degrees). Positive values indicate West, while negative values indicate East. The data for the solar flare locations were available for 40 events : #27 - #76 (minus #29, #35, #36, #38, #39, #42, #49, #50, #54, #61)

3. Results

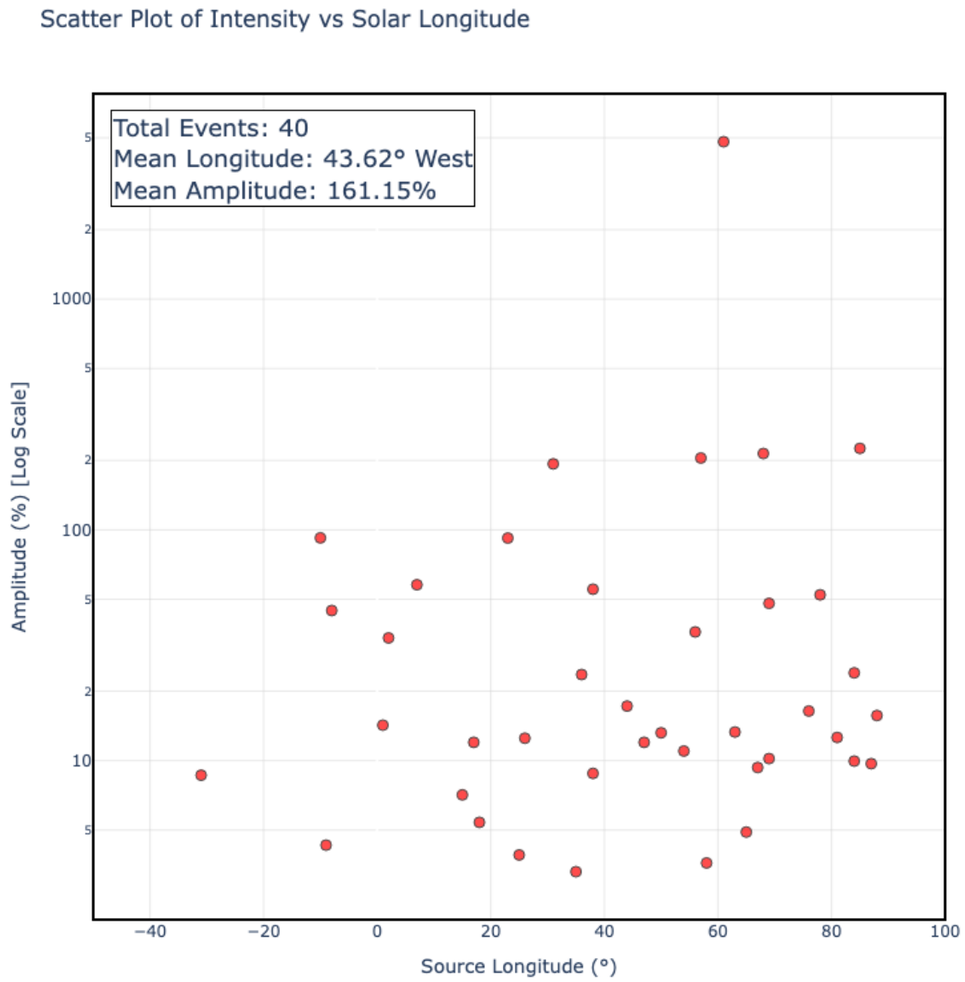

Figure 5 : Scatter plot of GLE max amplitude (%) as it was recorded by ground based NM stations vs. solar flare longitude (degrees). The data for the solar flare locations were available for 40 out of 76 events (mentioned in the previous slide).

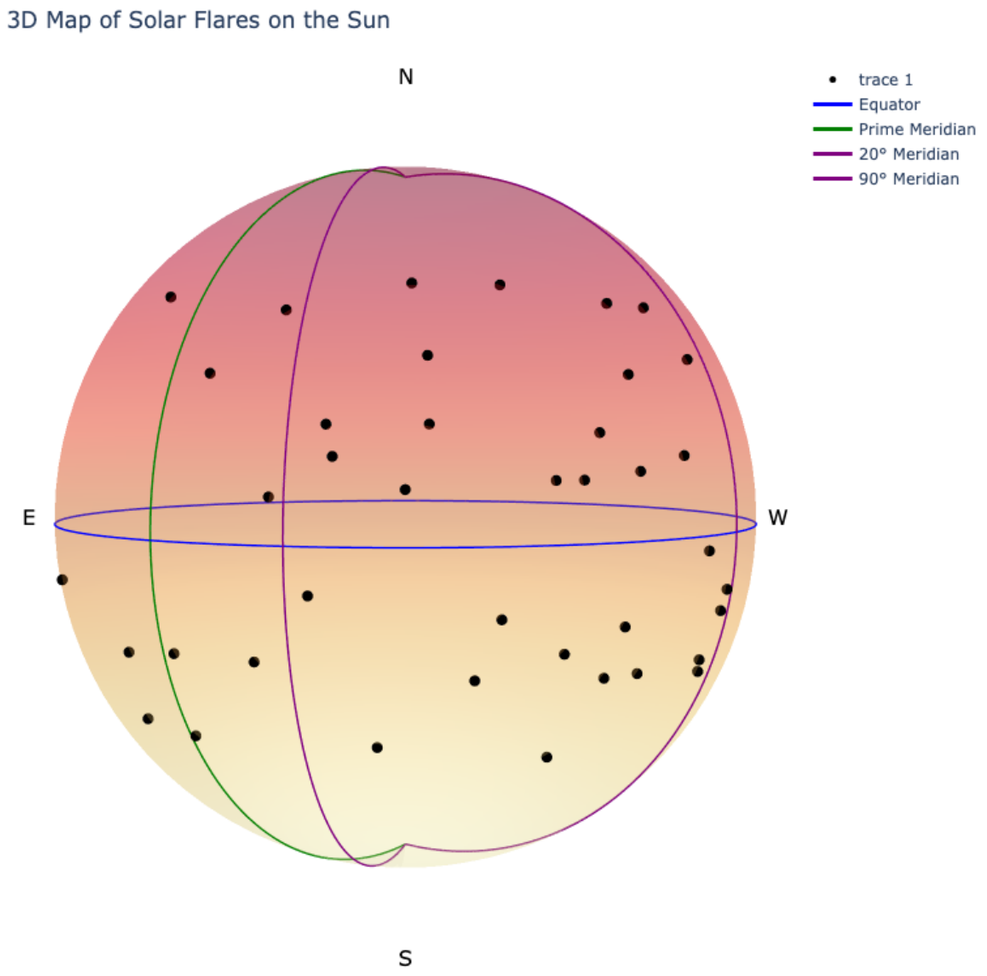

Figure 6 : 3D illustration of the heliographic locations of 40 GLE-associated solar flares. The blue line indicates the equator and the green line the prime meridian. The two purple lines enclose the well-connected area between Sun and Earth (20°-90° West).

3. Results

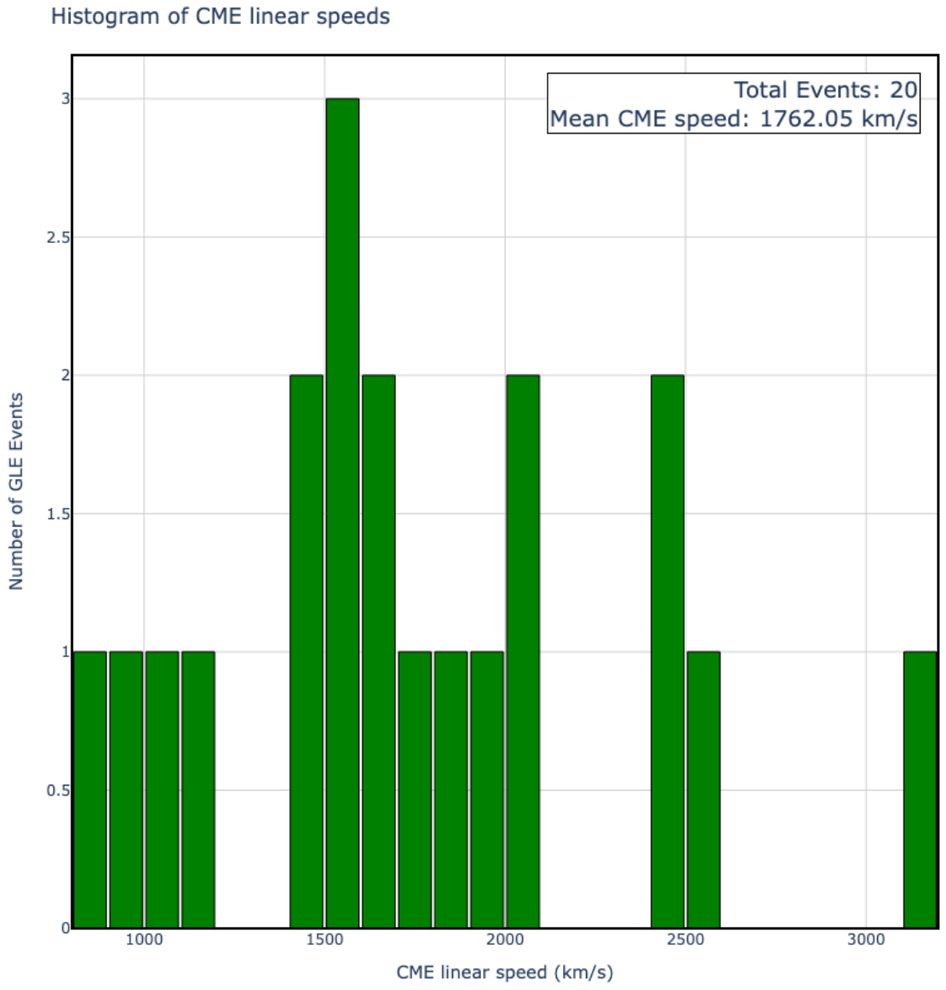

Figure 7 : Distribution of GLE-associated CMEs linear speeds (km/sec). The data for CMEs was available for 20 events : #55 - #75 (not including #58)

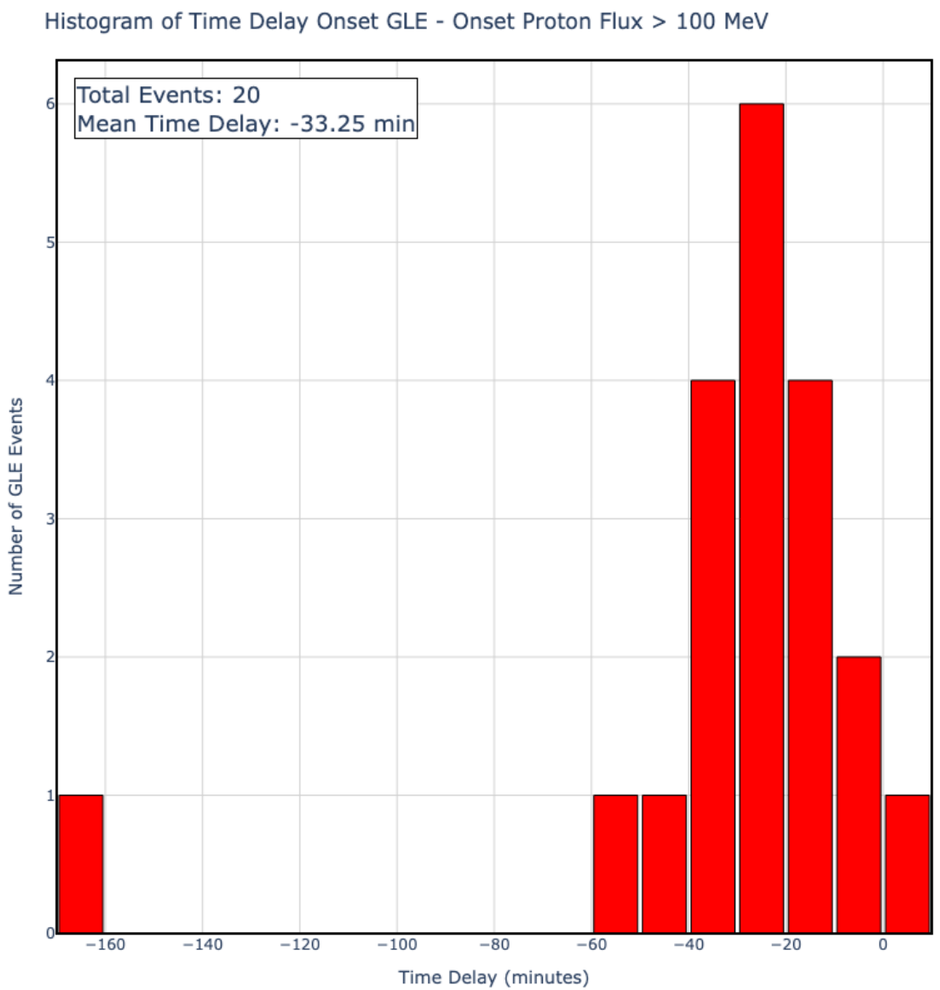

Figure 8 : Distribution of time delay (minutes) between the onset time of the GLE event and the onset of the proton flux increase for the energy channel > 100 MeV. The data for the proton flux was available for 20 events : #55 - #75 (with the exception of an outlier of very large value : #66 with a time delay of 2015 min – two day event)

4. Conclusions

1. The mean time delay between the onset time of the GLE events and the onset time of the associated Solar Flares is **38.28 minutes**

2. The mean time delay between the onset time of the GLE events and the peak time of the associated Solar Flares is **11.17 minutes**

3. The mean GLE – associated Solar Flare Class is **X4.9**

4. **83%** of GLE events were caused by X-Class Solar Flares

5. The mean GLE-associated Solar Flare longitude is **43.62 ° West**

6. The solar flare longitudes are widely distributed with a slight preference in the region 60°-70° with 7 GLE events

7. **75%** of GLE events were caused by Solar Flares that originated inside the well – connected solar region (20°-90° West)

8. The mean CME linear speed is **1762.05 km/s**

9. The CME linear speeds are widely distributed with a slight preference in the region 1400-1700 km/s with 7 GLE events

1. The mean time delay between the onset time of the GLE events and the onset time of the Proton Flux increase for the energy channel >100 MeV (based on the aforementioned criteria) is **-33.25 minutes**

5. References

- Gopalswamy, N., Xie, H., Yashiro, S. et al. Properties of Ground Level Enhancement Events and the Associated Solar Eruptions During Solar Cycle 23. Space Sci Rev 171, 23–60, 2012, https://doi.org/10.1007/s11214-012-9890-4

- Poluianov, S., Batalla, O., Mishev, A., et al. Two New Sub-GLEs Found in Data of Neutron Monitors at South Pole and Vostok: On 09 June 1968 and 27 February 1969, Solar Physics, 299, 2024, https://doi.org/10.1007/s11207-023-02245-z

- GLE list of the Neutron Monitor Database, https://www.nmdb.eu/nest/gle_list.php

- GLE database of the University of Oulu, Finland, https://gle.oulu.fi/#/

- Solar Flare data, GOES, NOAA, https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs/ (1975-2017) , https://data.ngdc.noaa.gov/platforms/solar-space-observing-satellites/goes/ (2017-2025)

- CME data, SOHO LASCO CME catalog, CDAW Data Center, https://cdaw.gsfc.nasa.gov/CME_list/

- Proton flux data, University of Colorado's Space Weather Technology, Research, and Education Center's Space Weather Data Portal, NOAA Space Weather Prediction Center, https://lasp.colorado.edu/space-weather-portal