Evidence for Extended Charging Periods Prior to Terrestrial Gamma-Ray Flashes

R.K.Larkey[1], J.G. Sample[1], D.M. Smith[2], M.S. Briggs[3,4], J.L. Lapierre[5], R.H. Holzworth[6]

[1] Department of Physics, Montana State University, Bozeman, MT, USA [2] Department of Physics and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA, USA [3] Center for Space Plasma and Aeronomic Research, University of Alabama in Huntsville, Huntsville, AL, USA [4] Department of Space Science, University of Alabama in Huntsville, Huntsville, AL, USA [5] Research and Development, Earth Networks, Germantown, MD, USA [6] Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA

UNIVERSITY of WASHINGTON

EARTH NETWORKS

MONTANA STATE UNIVERSITY

UC SANTA CRUZ

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

AGU100 ADVANCING EARTH AND SPACE SCIENCE

What are we Trying to Investigate?

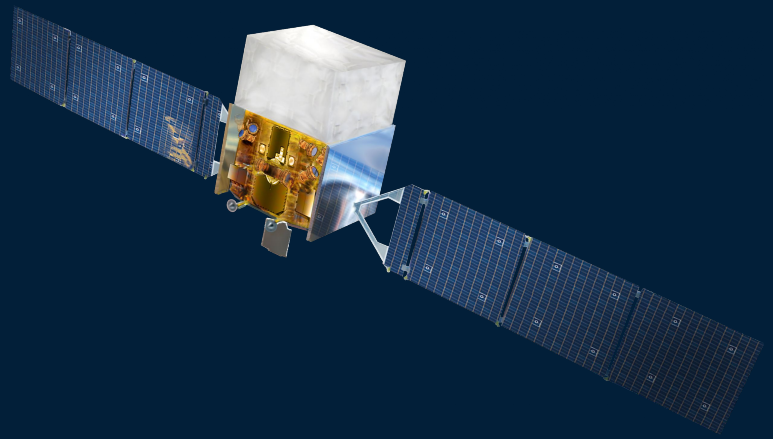
Is there any correlation between interflash intervals and TGF production?

- Do TGFs tend to occur after longer/shorter interflash intervals in thunderstorms? Is there any correlation at all?
    - Constant charging rates → longer interflash intervals would mean a higher electric field
    - Need to compare flash rates within individual storms

Why do some lightning flashes produce TGFs while others do not?

Data and Methods

- Fermi Identified TGFs
  - Latitude, Longitude, Time
- Lightning sferic data from both WWLLN and ENTLN (±10 Minutes of TGF)
- 1,169 TGFs had close WWLLN associations **and** available ENTLN data



Finding the Associated Thunderstorms

We wanted to use data from **only** the TGF-producing thunderstorms

To do this we used spatial clustering:

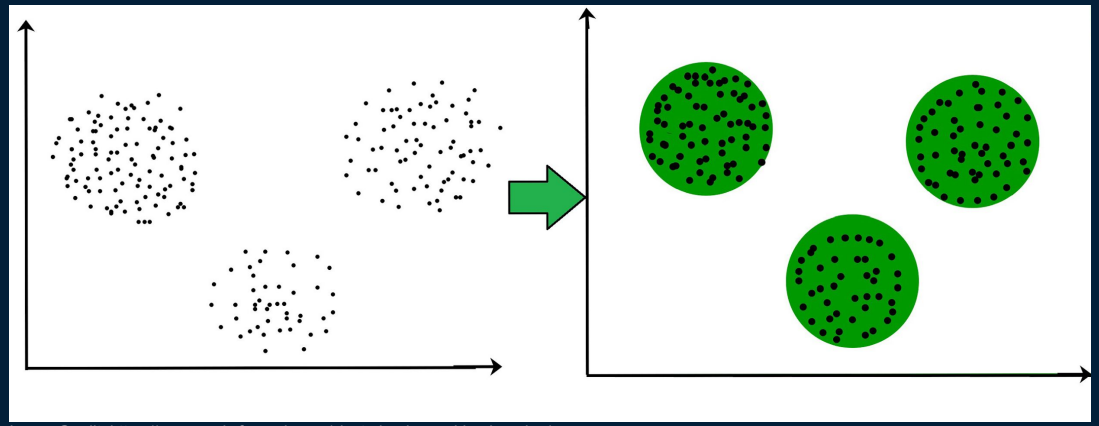


Image Credit: https://www.geeksforgeeks.org/clustering-in-machine-learning/

HDBSCAN Algorithm

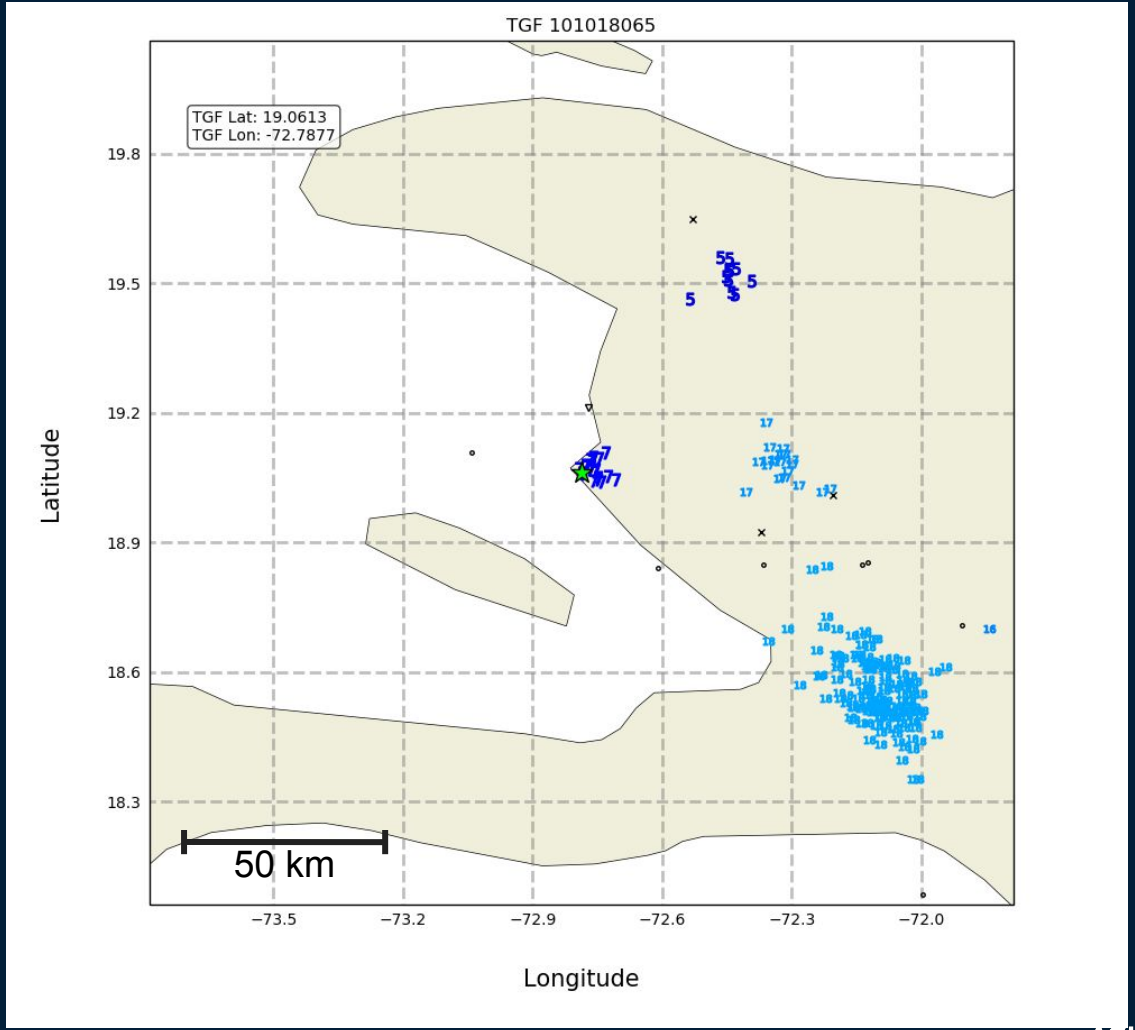
Hierarchical Density Based Spatial Clustering of Applications with Noise[1]

- No need to specify the number of clusters
- No need to specify a length scale

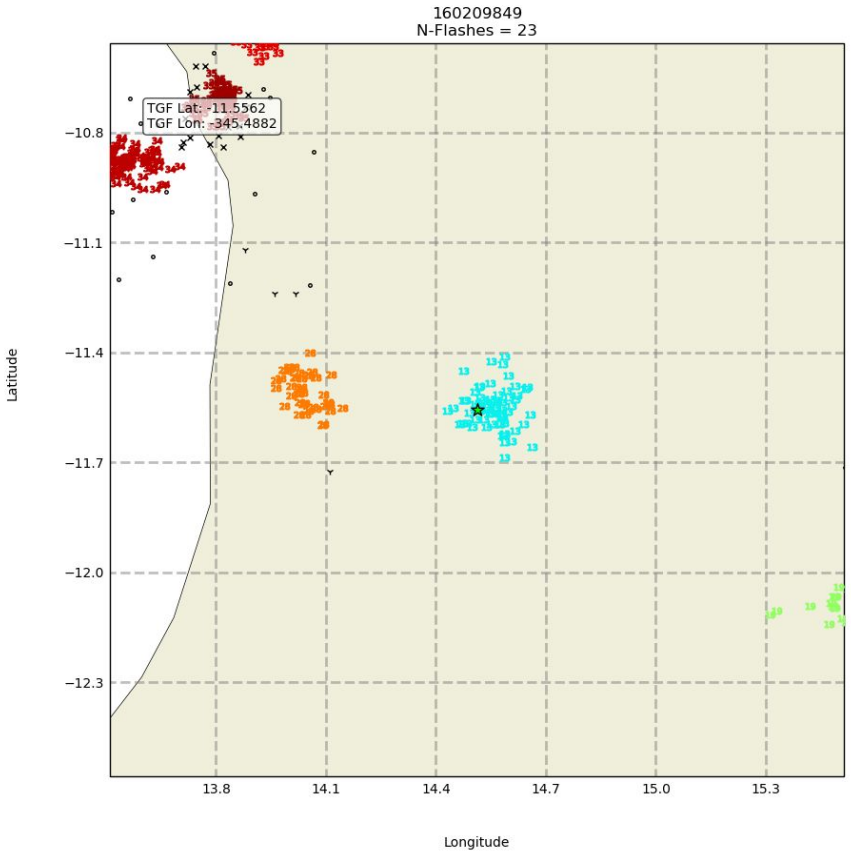
These properties make HDBSCAN an ideal algorithm as compared to K-means or DBSCAN

[1] McInnes, L., Healy, J., & Astels, S. (2017). hdbscan: Hierarchical density based clustering. Journal of Open Source Software, 2(11), 205. https://doi.org/10.21105%2Fjoss.00205

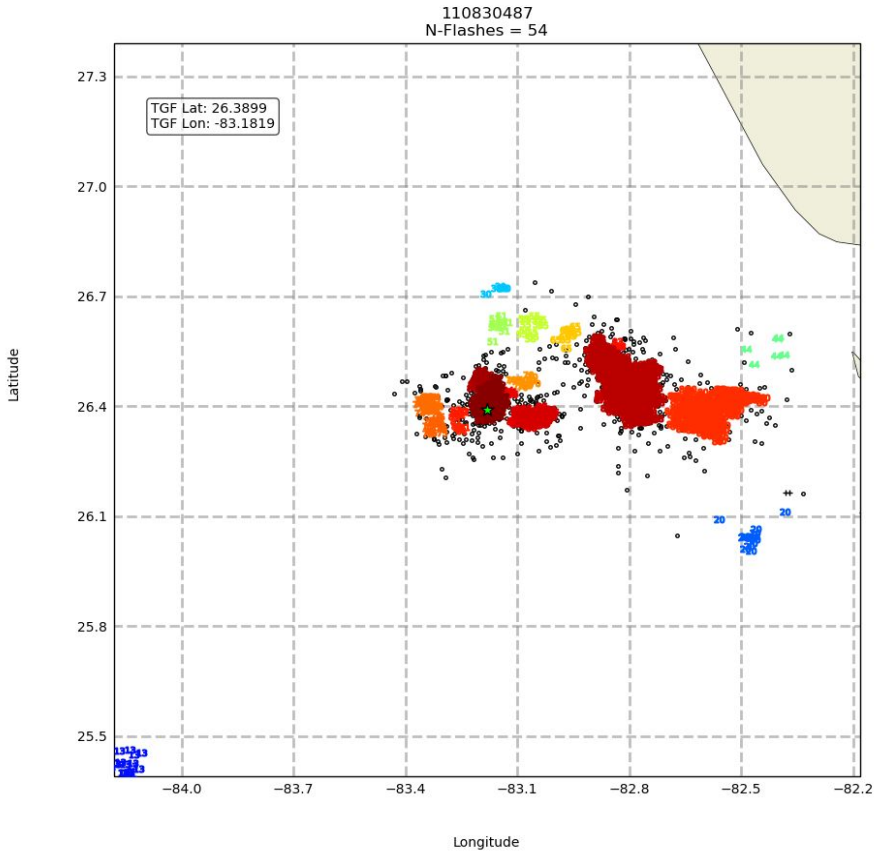
Applying Clustering to Lightning Sferics



Example of “good” clustering



Example of “bad” clustering



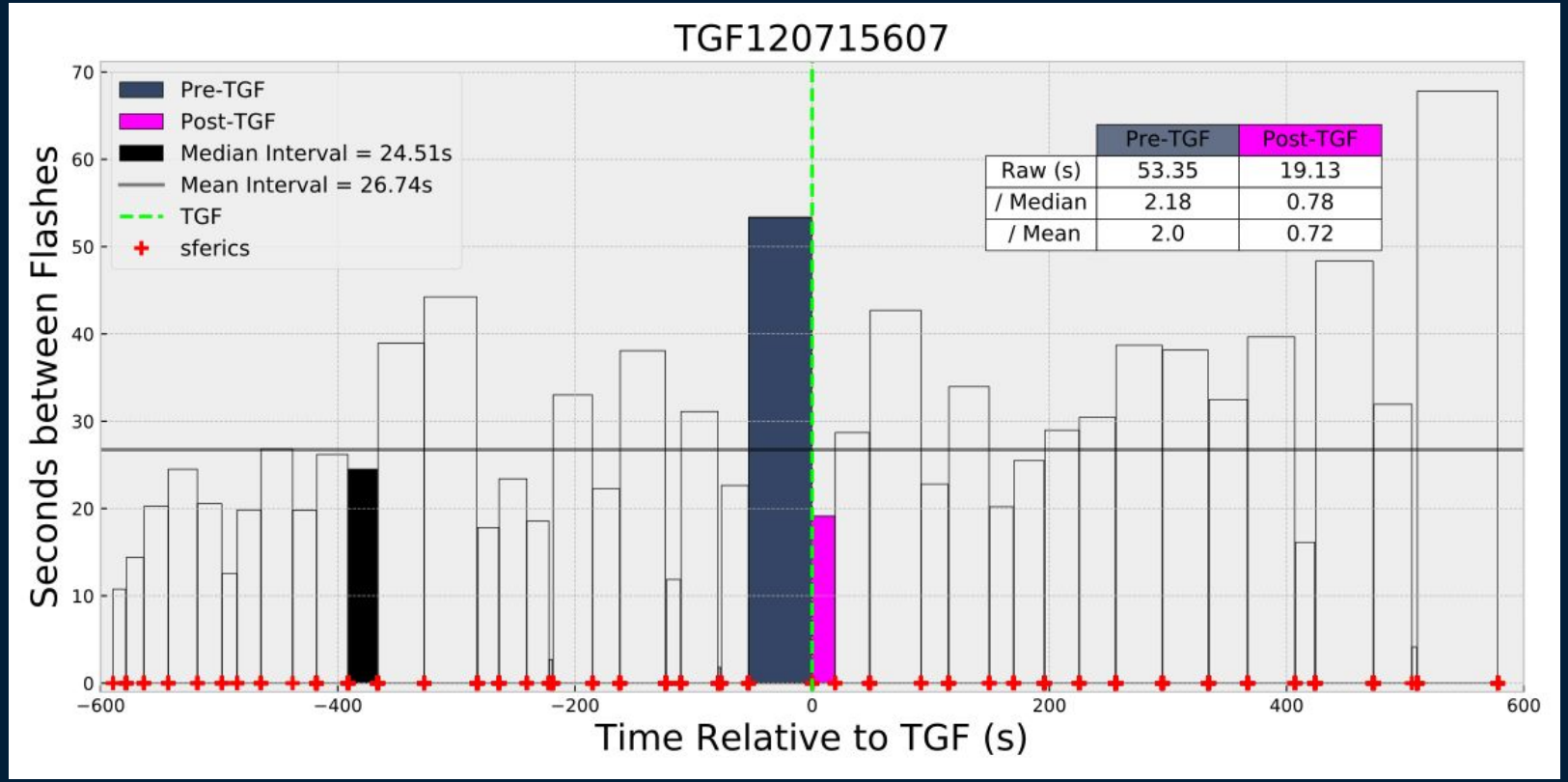
Selection Criteria

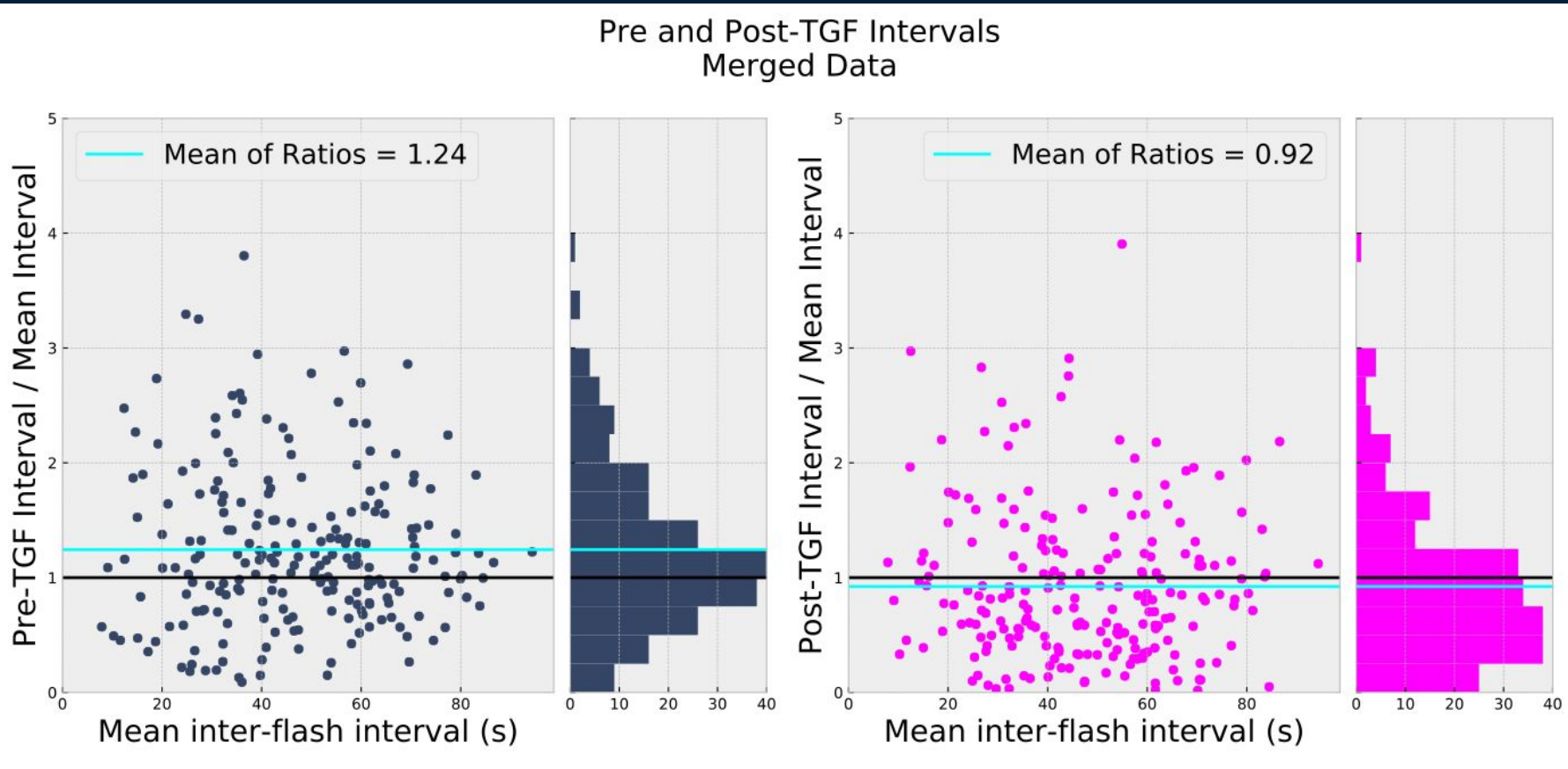
Useable clusters must:

- Be isolated --> manually inspected
- Contain at least 15 distinct flashes
- Have a total extent of less than 60 km

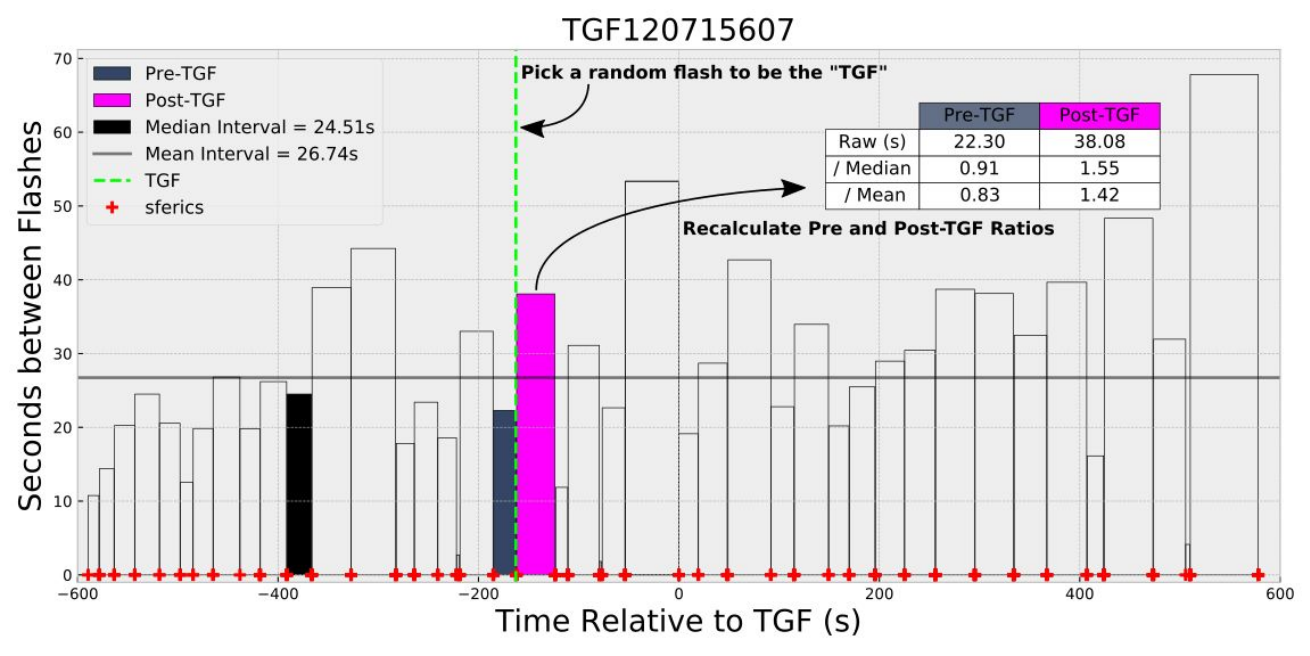
219 TGF-producing storms satisfied these conditions and were used in this study

How do the pre-TGF and post-TGF intervals compare to “typical” intervals in TGF-producing storms?



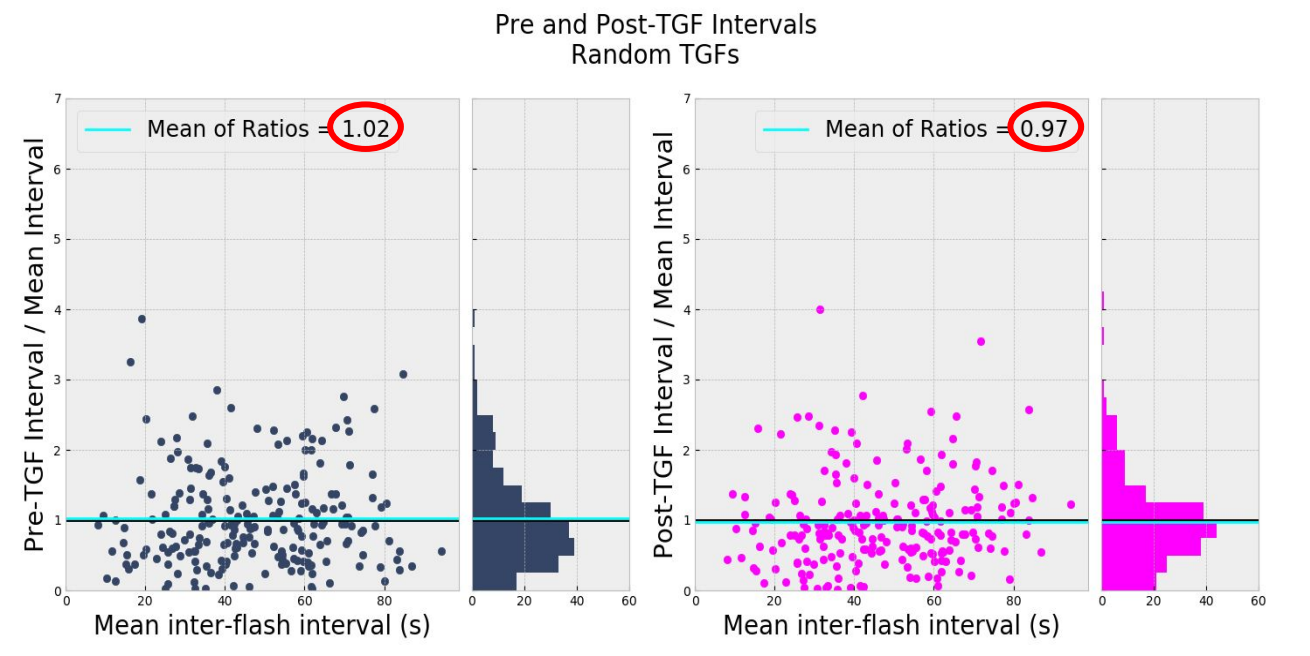

Pre and Post-TGF Intervals
Merged Data
Mean of Ratios = 1.24
Pre-TGF Interval / Mean Interval
Mean inter-flash interval (s)
Mean of Ratios = 0.92
Post-TGF Interval / Mean Interval
Mean inter-flash interval (s)

Significance Testing



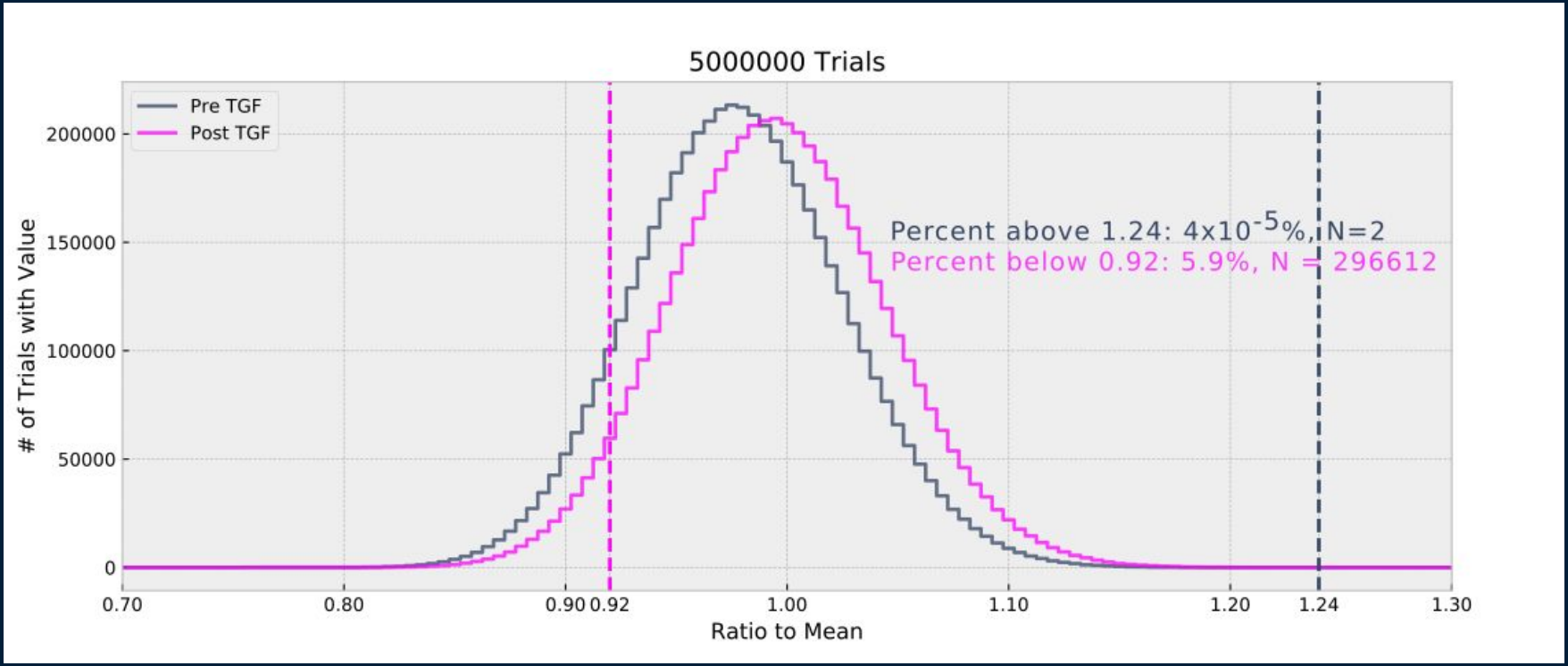
Repeat for all 219 storms to reproduce scatter plots

Significance Testing



Keep track of these values and repeat process many times

Significance Testing



Conclusion

TGFs are more likely to occur after longer inter-flash intervals

These results could imply that a stronger electric field is necessary for the production of TGFs and may help to explain why some lightning strikes produce TGFs while others do not.

Questions?

Acknowledgements

Thank you to WWLLN and ENTLN for providing the lightning data used in this study. We'd also like to thank Paul Krehbiel, Ken Cummins, Phil Krider, and Eric Bruning for their valuable insight into the physics of thunderstorms. Finally, the authors wish to thank Will Early and Matthew Thompson for their assistance in helping identify valid clusters.

Larkey, R. K., Sample, J. G.,Smith, D. M., Briggs, M. S.,Lapierre, J. L., & Holzworth, R. H.(2019). Evidence for extended charging periods prior to terrestrial gamma ray flashes. Geophysical Research Letters, 46 10,619-10,626. https://doi.org/10.1029/2019GL083827

Backup Slides

Clustering Examples

Image credit: https://hdbscan.readthedocs.io/en/latest/comparing_clustering_algorithms.html

Clusters found by KMeans

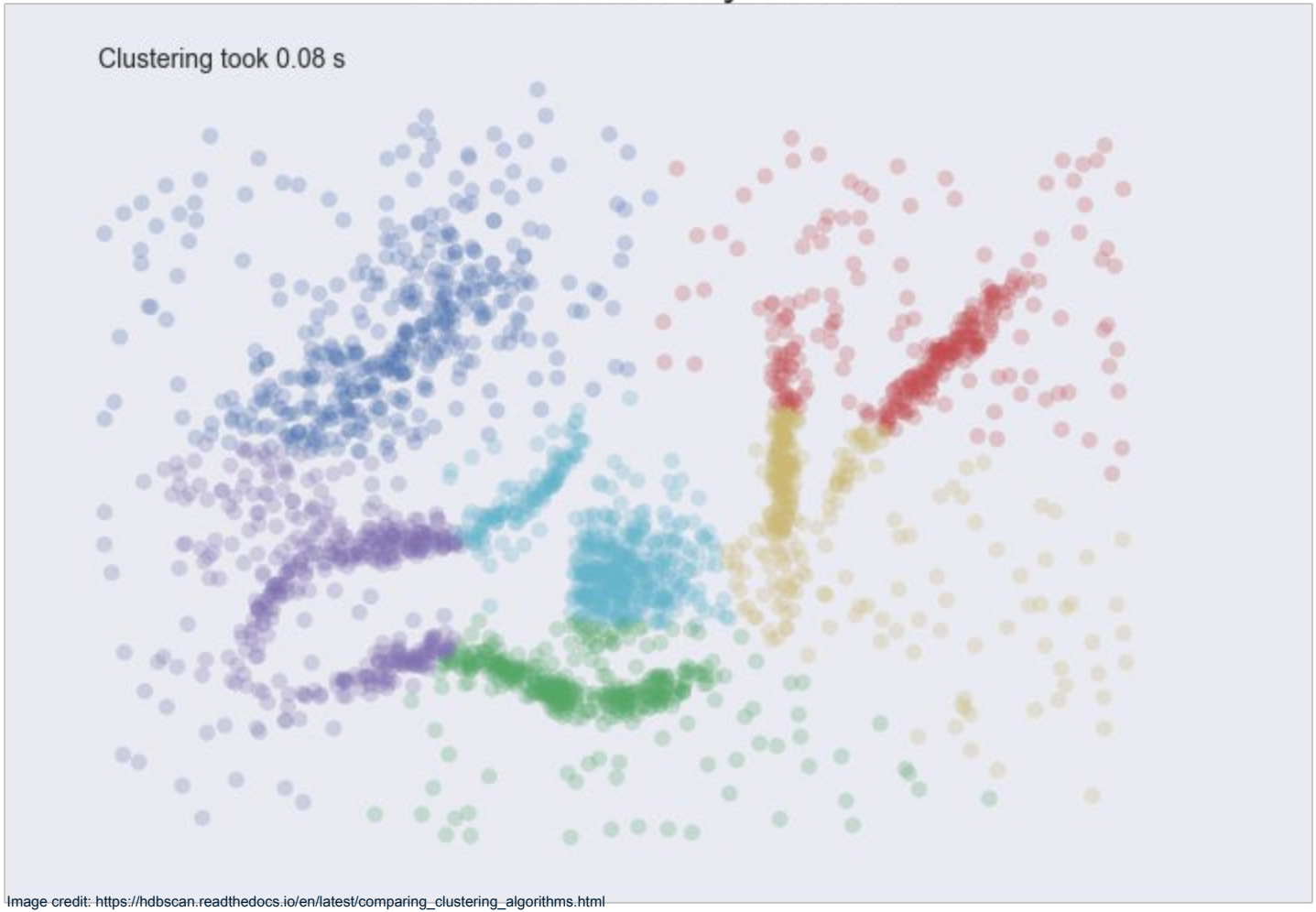


Image credit: https://hdbscan.readthedocs.io/en/latest/comparing_clustering_algorithms.html

Clusters found by DBSCAN

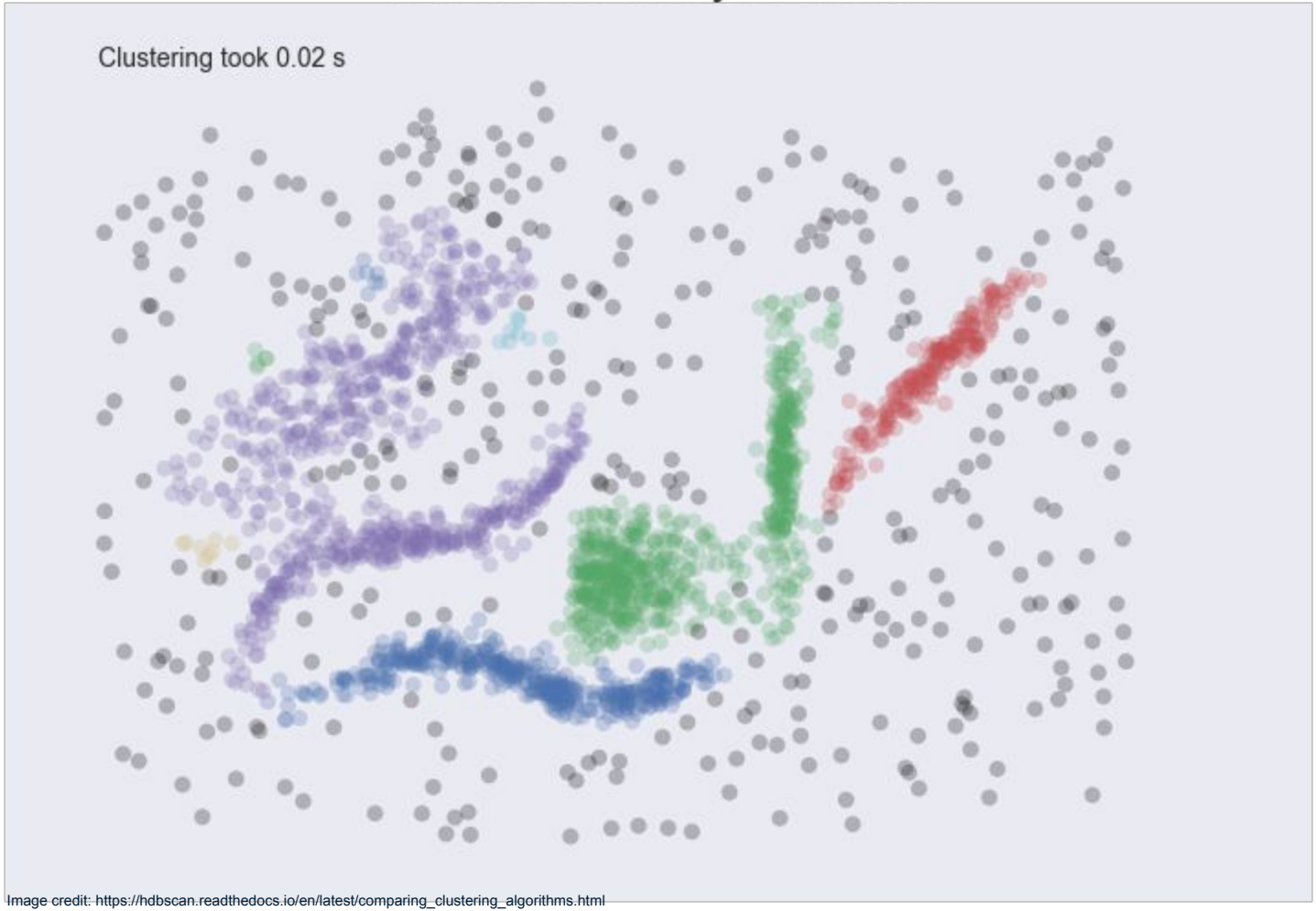


Image credit: https://hdbscan.readthedocs.io/en/latest/comparing_clustering_algorithms.html

Clusters found by HDBSCAN

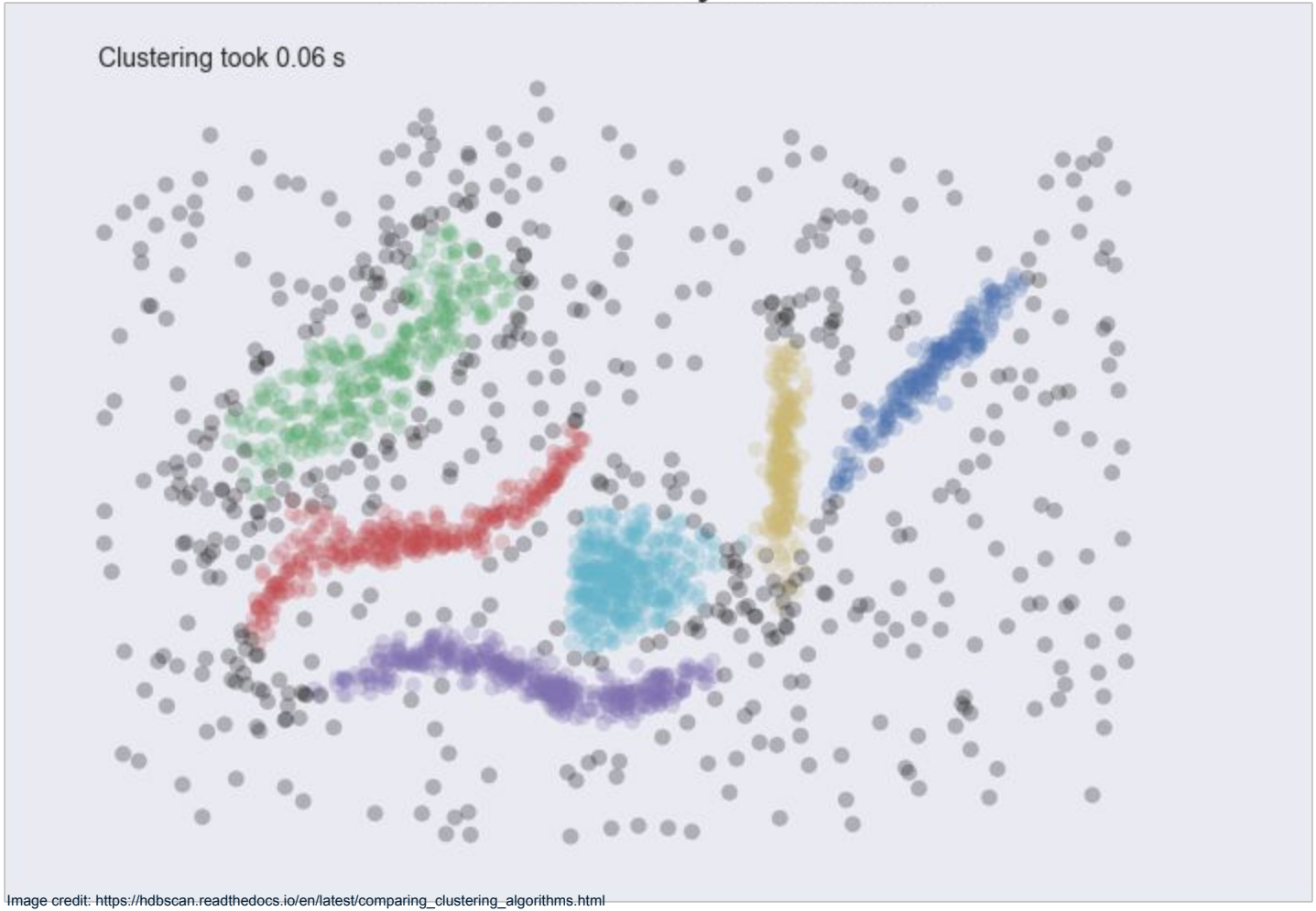


Image credit: https://hdbscan.readthedocs.io/en/latest/comparing_clustering_algorithms.html

KDE Flash Grouping

KDE Explanation

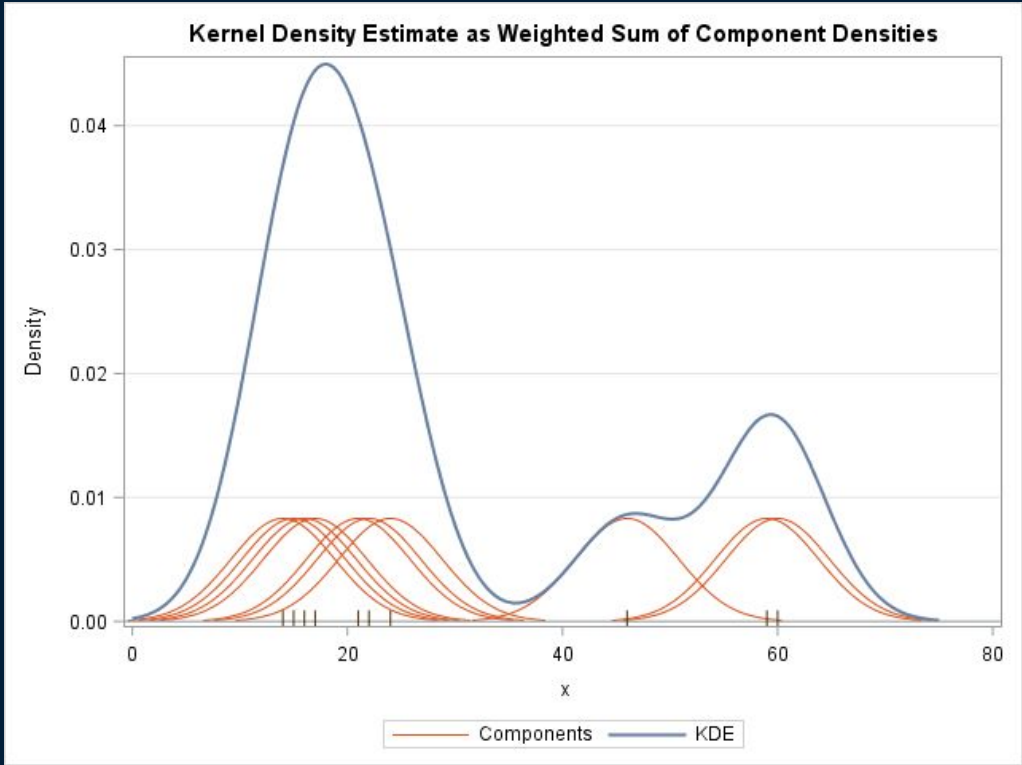
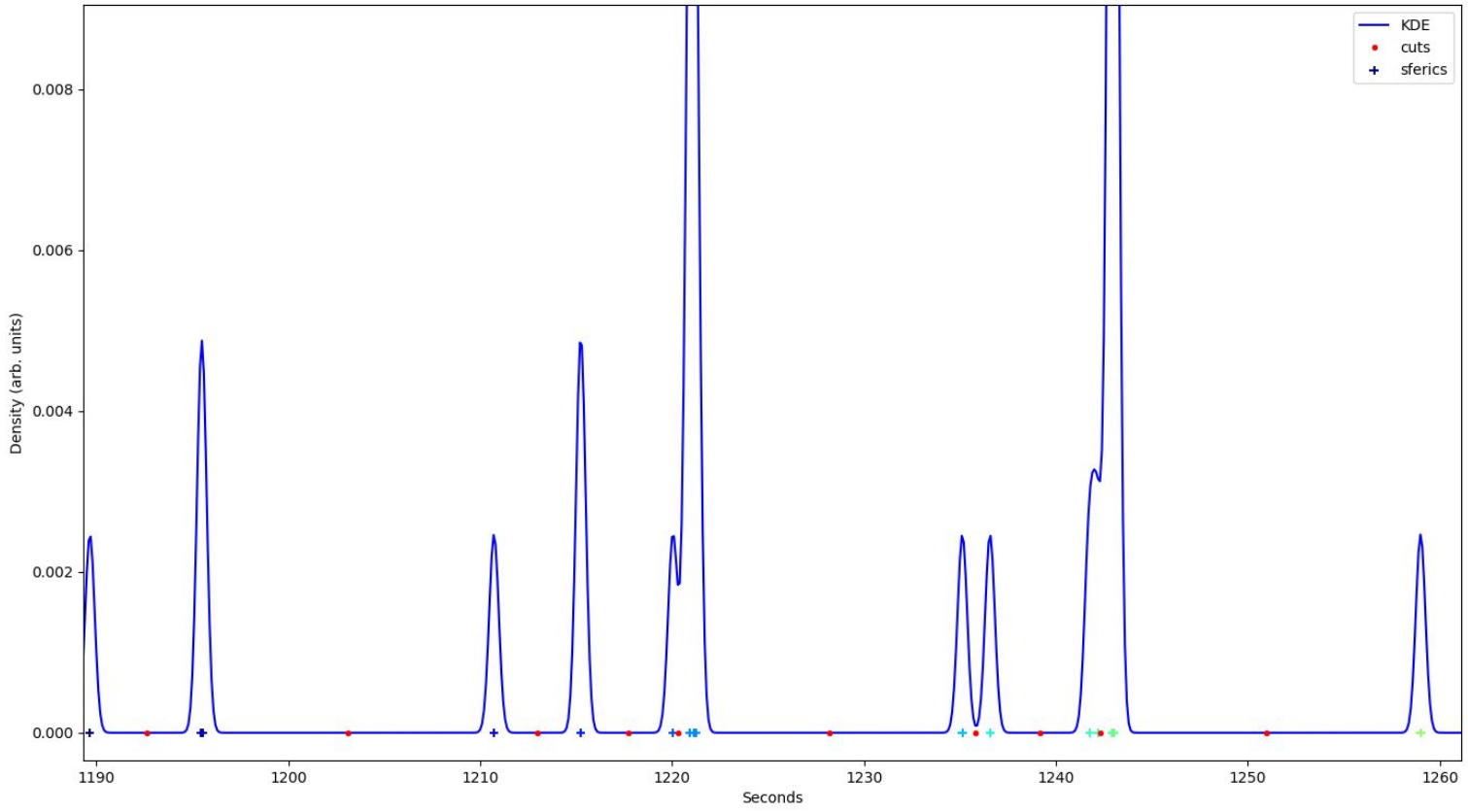
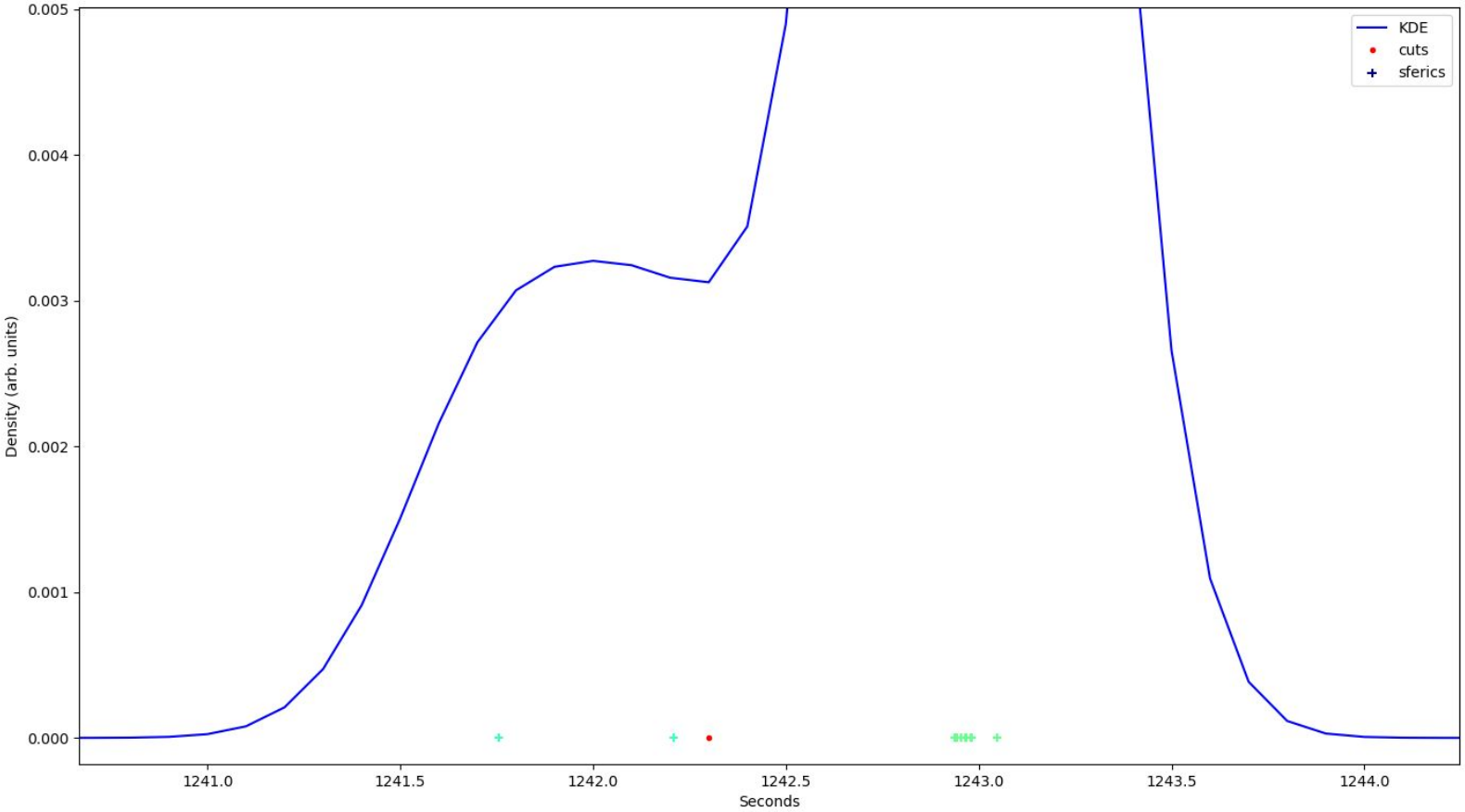


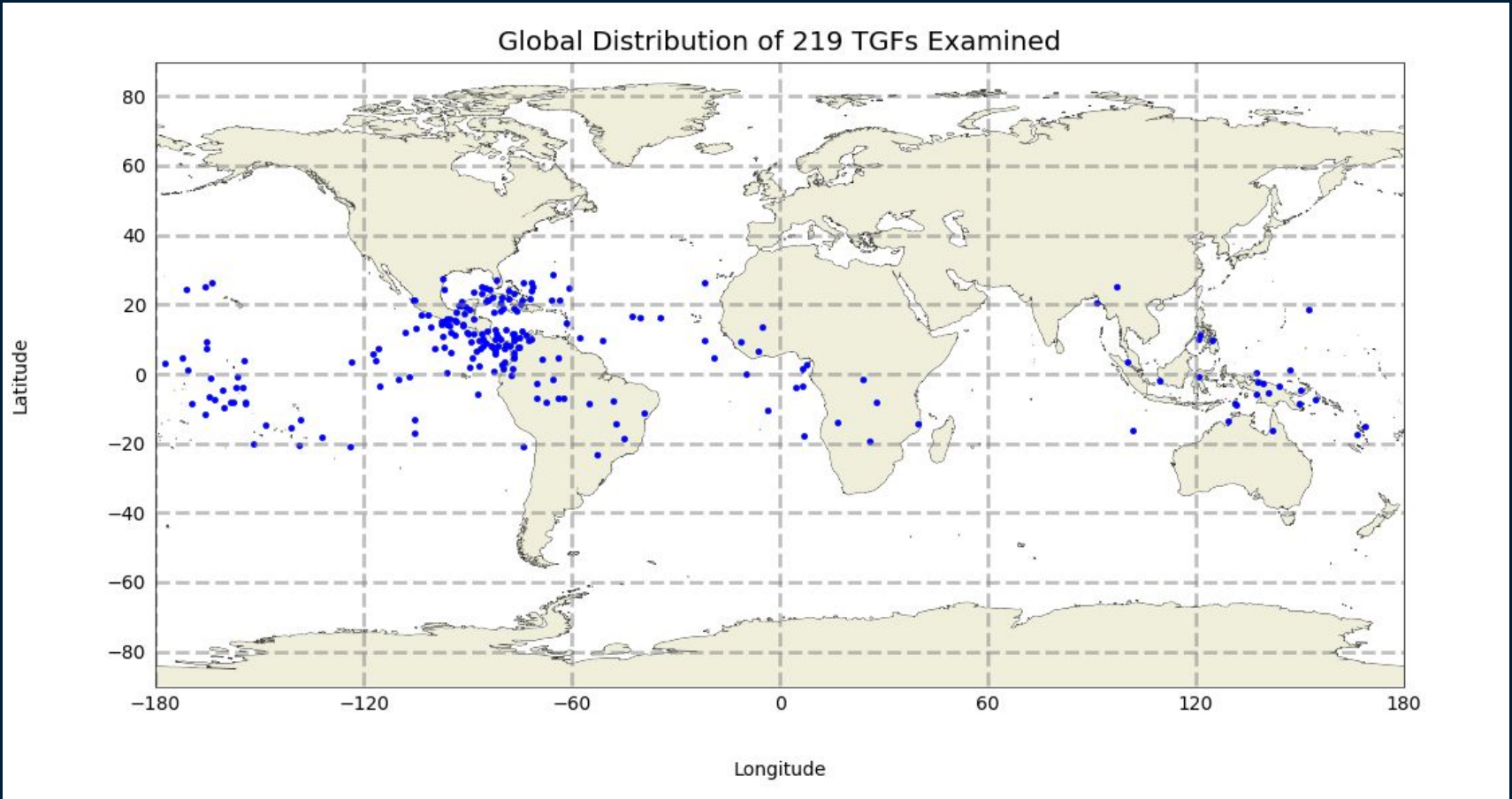
Image credit: https://blogs.sas.com/content/iml/2016/07/27/visualize-kernel-density-estimate.html

- User specified bandwidth (standard deviation of gaussian)
  - We used a bandwidth of 0.25s
- This bandwidth allows for flash-groupings with durations usually less than 1 second which is typical for lightning flashes [1]

[1] Dwyer, J. R., & Uman, M. A. (2014). The physics of lightning. Physics Reports, 534 , 147-241. doi:10.1016/j.physrep.2013.09.004


KDE
cuts
sferics
Density (arb. units)
0.000
0.002
0.004
0.006
0.008
1190
1200
1210
1220
1230
1240
1250
1260
Seconds


KDE
cuts
sferics
Density (arb. units)
0.005
0.004
0.003
0.002
0.001
0.000
1241.0
1241.5
1242.0
1242.5
1243.0
1243.5
1244.0
Seconds


Global Distribution of 219 TGFs Examined
Latitude
Longitude
80
60
40
20
0
−20
−40
−60
−80
−180
−120
−60
0
60
120
180