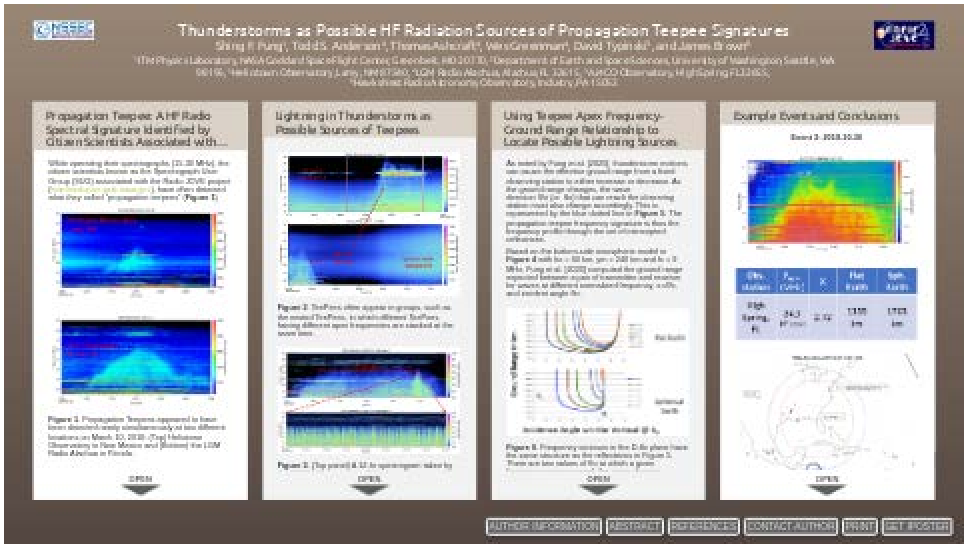
Thunderstorms as Possible HF Radiation Sources of Propagation Teepee Signatures



Shing F. Fung[1], Todd S. Anderson[2], Thomas Ashcraft[3], Wes Greenman[4], David Typinski[5], and James Brown[6]

[1]ITM Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20770, [2]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, [3]Heliotown Observatory, Lamy, NM 87540, [4]LGM Radio Alachua, Alachua, FL 32615, [5]AJ4CO Observatory, High Spring, FL32655, [6]Hawks Nest Radio Astronomy Observatory, Industry, PA 15052

PRESENTED AT:

PROPAGATION TEEPEE: A HF RADIO SPECTRAL SIGNATURE IDENTIFIED BY CITIZEN SCIENTISTS ASSOCIATED WITH THE RADIO JOVE PROJECT

While operating their spectrographs (15-30 MHz), the citizen scientists known as the Spectrograph User Group (SUG) associated with the Radio JOVE project (http://radiojove.gsfc.nasa.gov (http://radiojove.gsfc.nasa.gov)), have often detected what they called “propagation teepees” (**Figure 1**)

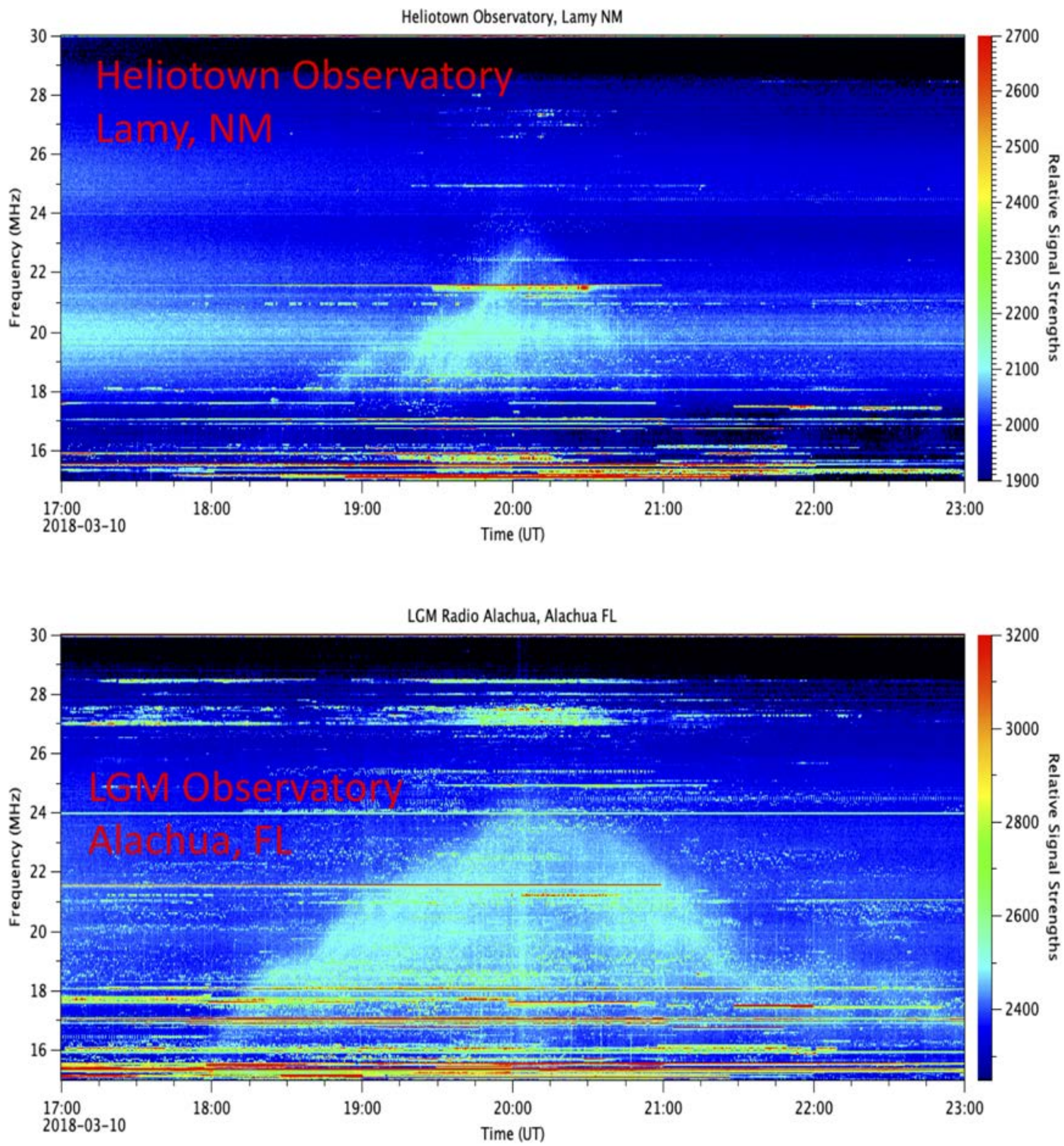


Figure 1. Propagation Teepees appeared to have been detected nearly simultaneously at two different locations on March 10, 2018: (Top) Heliotown Observatory in New Mexico and (Bottom) the LGM Radio Alachua in Florida.

Macro-scale Teepees Characteristics

1)Observed in the high-frequency range of 15-30 MHz;

2)A TeePee event always starts with its upper cutoff frequency increasing with time, reaching a maximum (apex) frequency, then decreasing toward the end of an event, and thus forming a characteristic triangular spectral signature, hence the name TeePee (as shown in **Figure 1**);

3)A TeePee event can last for several hours;

4)While isolated TeePees can occur, they often appear in groups in the form of nested Teepees (**Figure 2**) or in series (**Figure 3**);

5)Teepees are often observed during afternoon through early evening hours, or away from night-time hours when the Galactic radio background appear more prominently (see **Figure 2**).

LIGHTNING IN THUNDERSTORMS AS POSSIBLE SOURCES OF TEEPEES

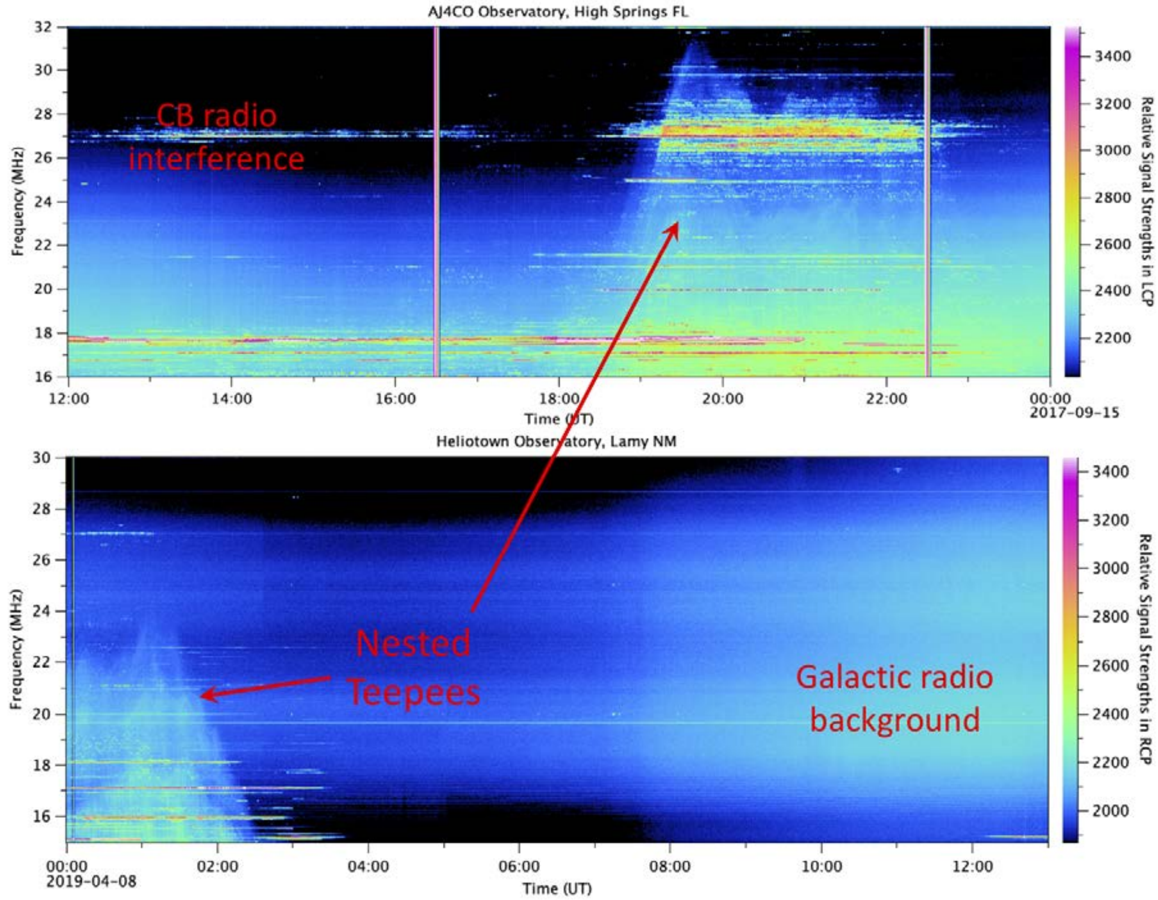


Figure 2. TeePees often appear in groups, such as the nested TeePees, in which different TeePees having different apex frequencies are stacked at the same time.

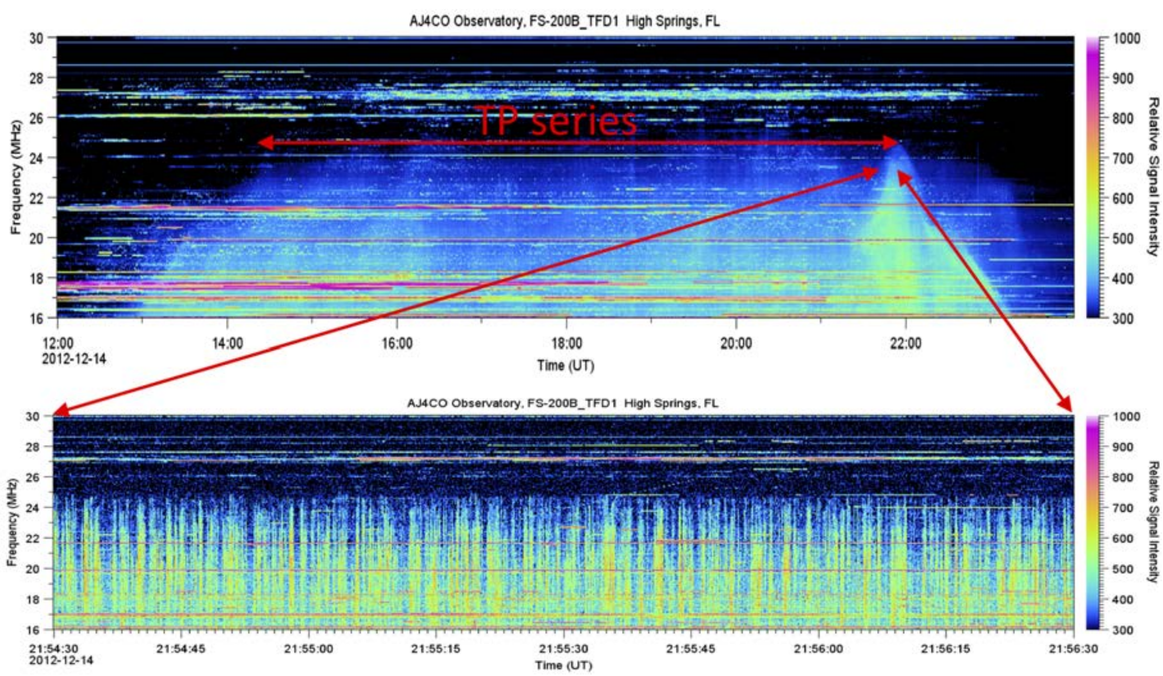


Figure 3. (Top panel) A 12-hr spectrogram taken by the AJ4CO Observatory in Florida on December 14, 2012, showing a series of propagation TPs that occurred only from a few hours after sunrise to a few hours after sunset. The second panel reveals the presence of discrete bursts forming the edges of the TP near its apex.

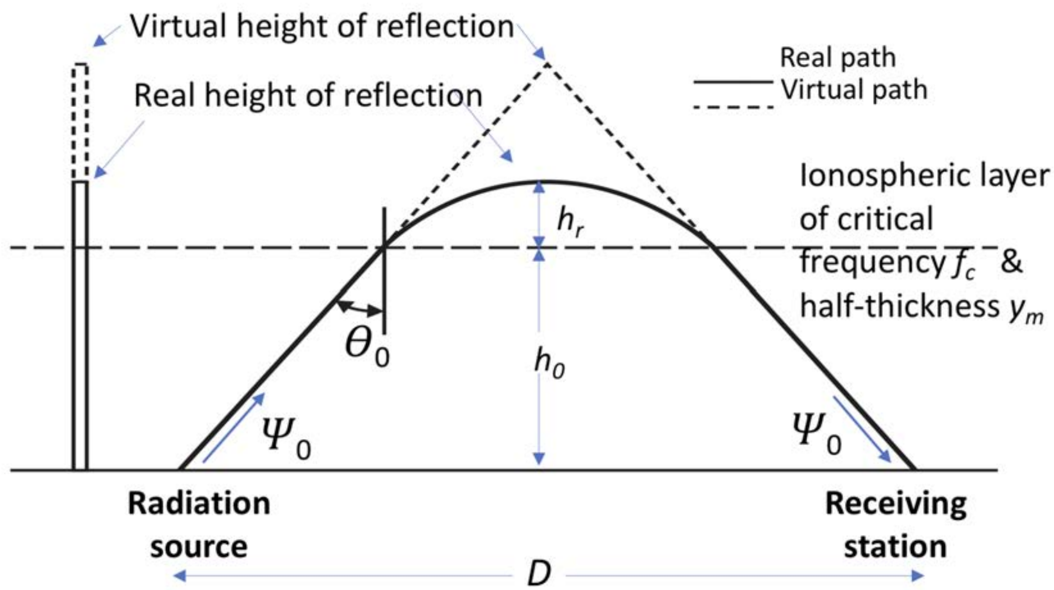


Figure 4. A radio wave of frequency *f* propagating at an incident angle θ_0 can be treated as reflected by an ionospheric layer [after Breit & Tuve, 1926].

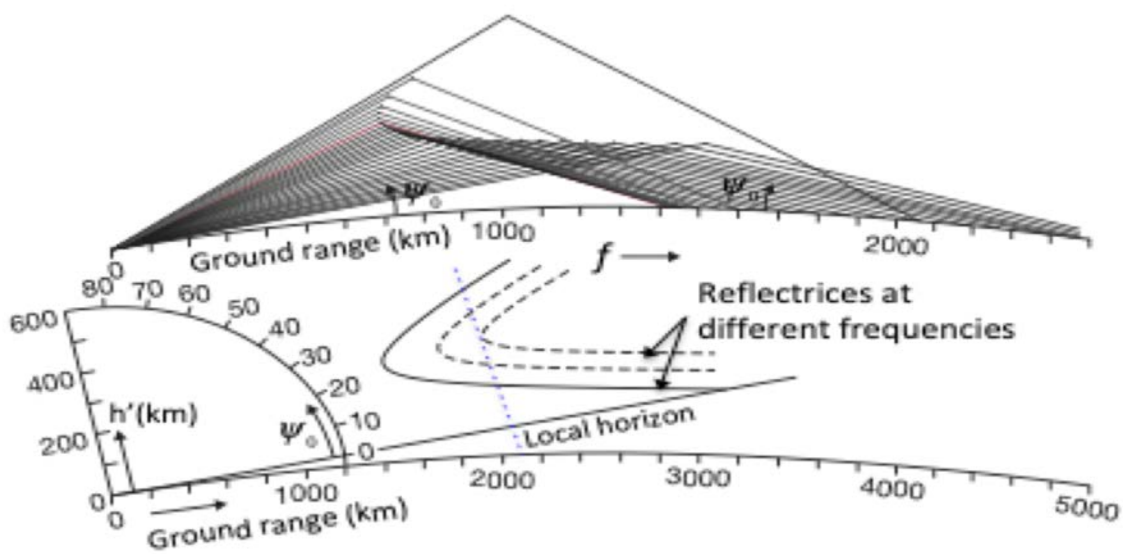


Figure 5. Results of 2-D calculations by Croft [1967] of virtual propagation wave paths at a fixed frequency transmitted at different elevation angles Ψ_0 from *a fixed point* at zero ground range. The red ray is the MUF ray (with $\theta_0 = \theta_s$) having the minimum range for that frequency. The locus of all the virtual reflection points is called the reflectrix (black solid curve). The two dashed lines represent schematically the reflectrices at two higher frequencies (from Fung et al. [2020]).

USING TEEPEE APEX FREQUENCY-GROUND RANGE RELATIONSHIP TO LOCATE POSSIBLE LIGHTNING SOURCES

As noted by Fung et al. [2020], thunderstorm motions can cause the effective ground range from a fixed observing station to either increase or decrease. As the ground range changes, the wave direction Ψo (or θo) that can reach the observing station must also change accordingly. This is represented by the blue dotted line in **Figure 5**. The propagation teepee frequency signature is thus the frequency profile through the set of intercepted reflectrices.

Based on the bottom-side ionospheric model in **Figure 4** with ho = 60 km, ym = 240 km and fc = 9 MHz, Fung et al. [2020] computed the ground range expected between a pair of transmitter and receiver for waves at different normalized frequency, x=*f/fc*, and incident angle θo.

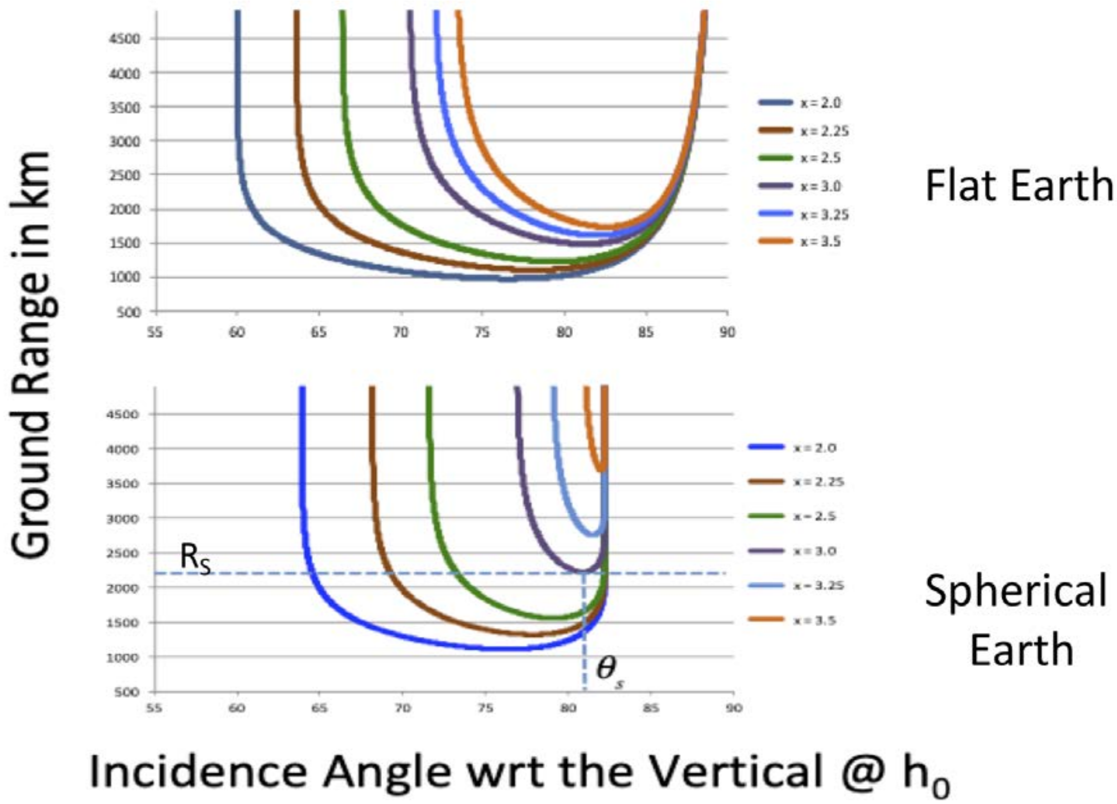


Figure 6. Frequency contours in the D-θo plane have the same structure as the reflectrices in Figure 5. There are two values of θo at which a given frequency wave can reach the same observer. As θo approaches θs , however, the wave frequency then becomes the maximum usable frequency (MUF) at the range Rs.

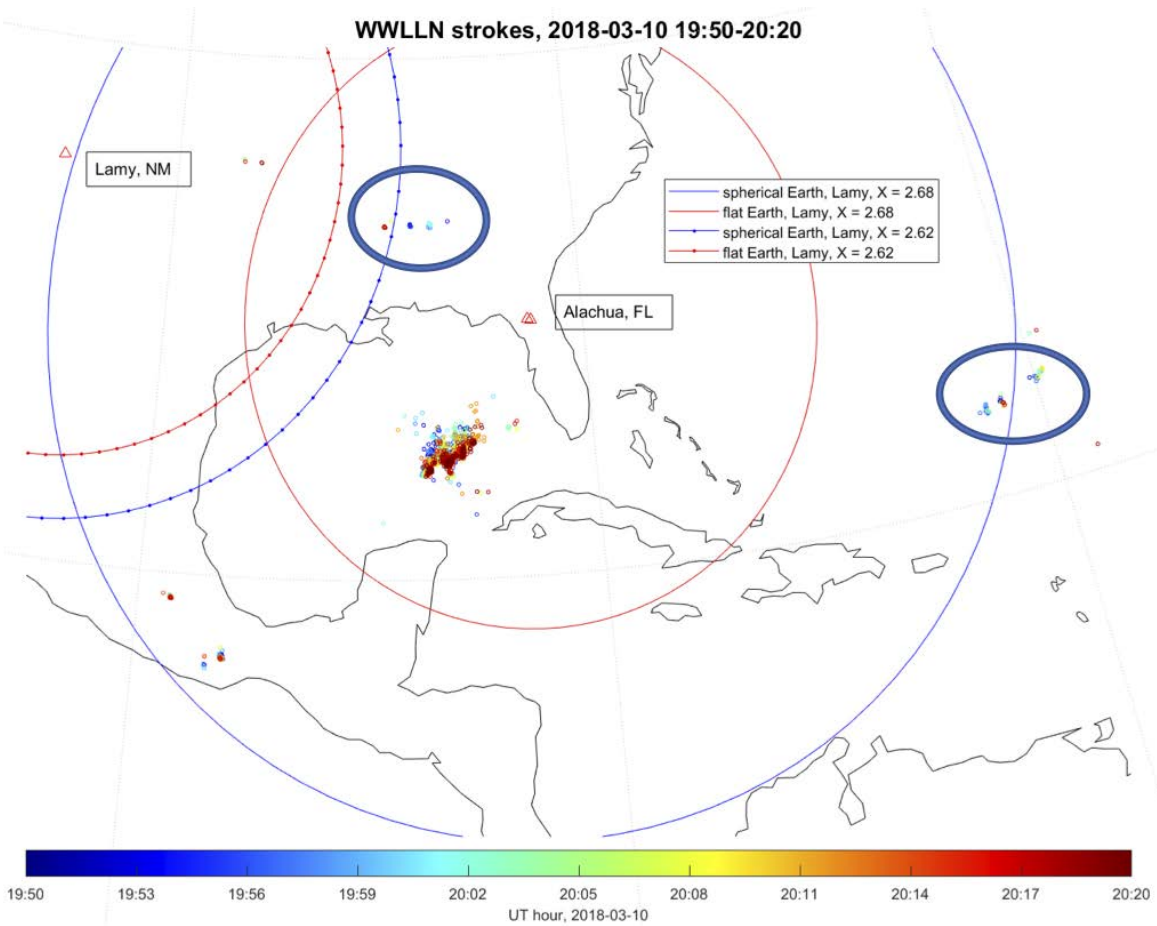
Identifying Lightning Source by Ground-Range Analysis

We present below four event examples of "ground-range analysis" for identifying the potential lightning sources for the teepees observed. Figures 5 & 6 shows that the teepee apex frequency fapex corresponds to an MUF. The ground range RS for that MUF would thus provide the nominal range of the lightning source at the time of the teepee apex. Based on the normalized apex frequencies (x = *fapex/fc*) determined for the four event below, we have applied the simple model shown in Figure 6 to determine the expected nominal ground range to locate lightning storms that might have powered the teepees observed.

Event 1: 2018-03-10

(see teepee signatures in Figure 1)

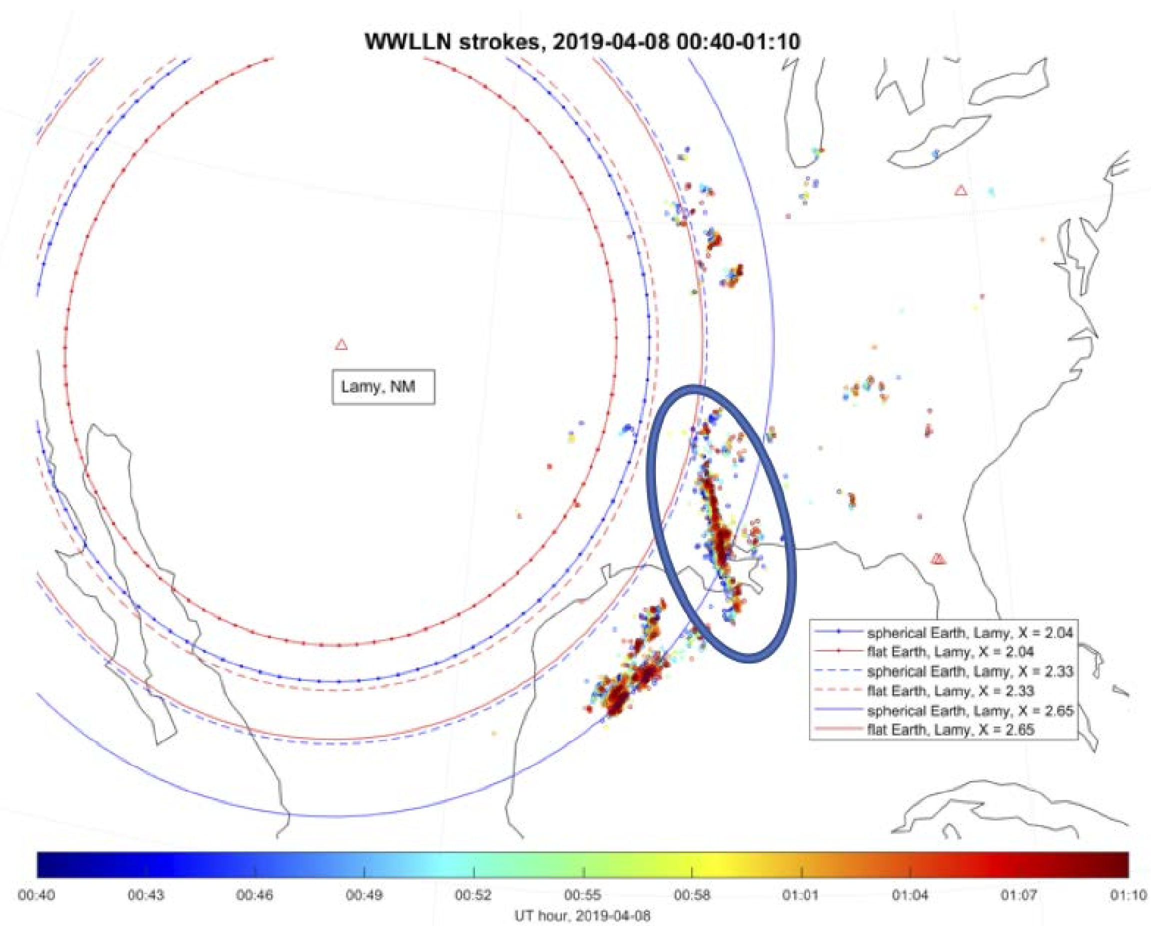
Obs. station	F_{apex} (MHz)	X	Flat Earth	Sph. Earth
Alachua, FL	24.1	2.68	1318 km	2225 km
Lamy, NM	23.6	2.62	1288 km	1559 km



- Teepee apex times ~ 19:50-20:20 UT.
- Dark blue ovals mark the potential lightning sources for the teepees detected in NM and FL.

Event 2: 2019-04-08

Obs. station	F_{apex} (MHz)	X	Flat Earth	Sph. Earth
Lamy, NM	18.4 (1st apex)	2.04	992 km	1112 km
Lamy, NM	21 (1st apex)	2.33	1141 km	1319 km
Lamy, NM	23.9 (1st apex)	2.65	1303 km	1559 km



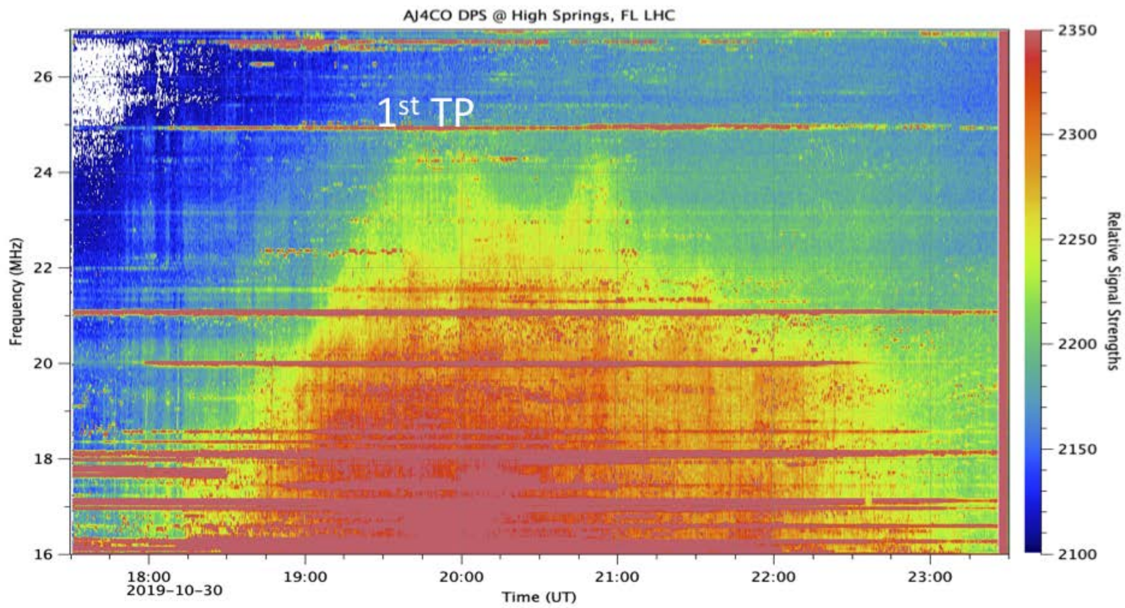
- 1st teepee apex times ~ 0:40-1:10 UT.

- The line of lightning marked by the blue oval could be the nested teepee source [Fung et al. (2020)].

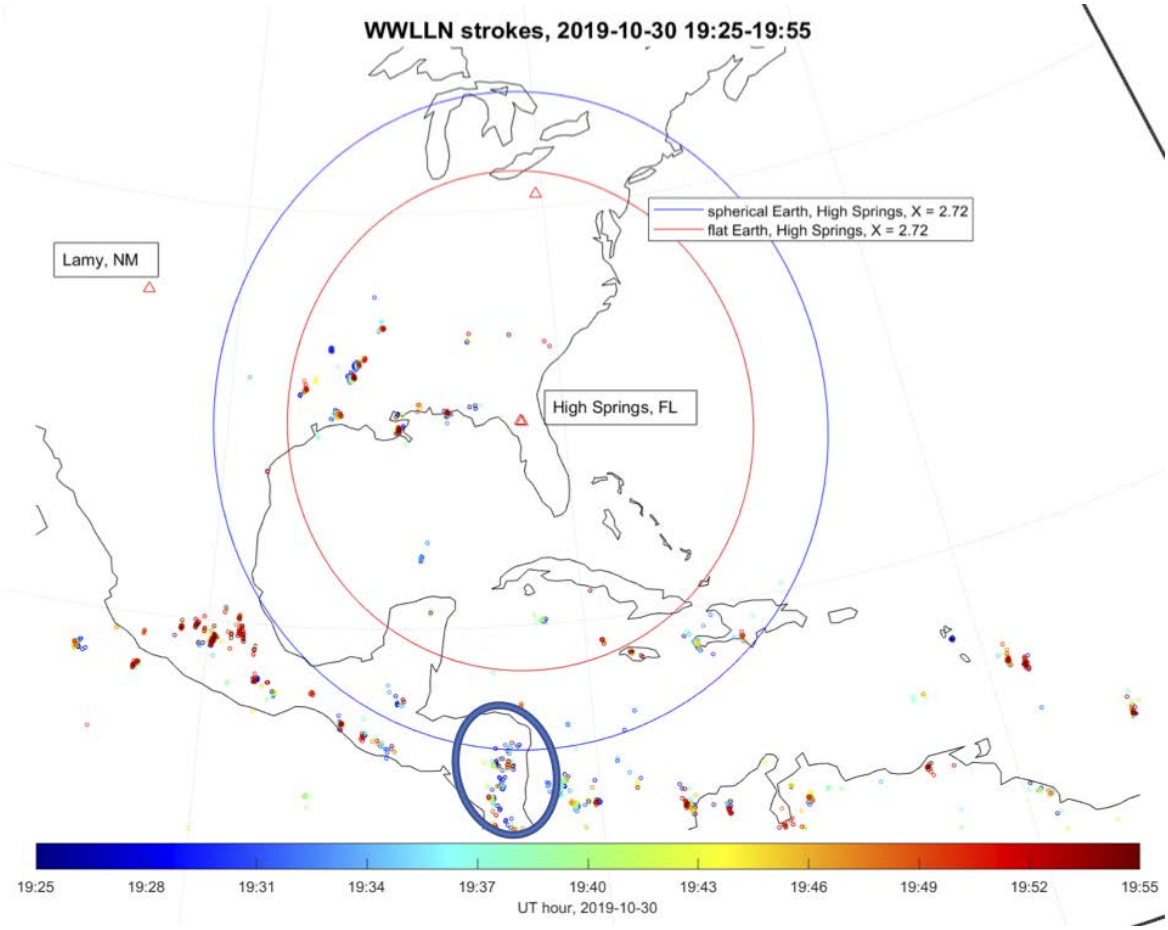
- Smaller model ground range could be due to uncertainties in ho, *fc* and ym.

EXAMPLE EVENTS AND CONCLUSIONS

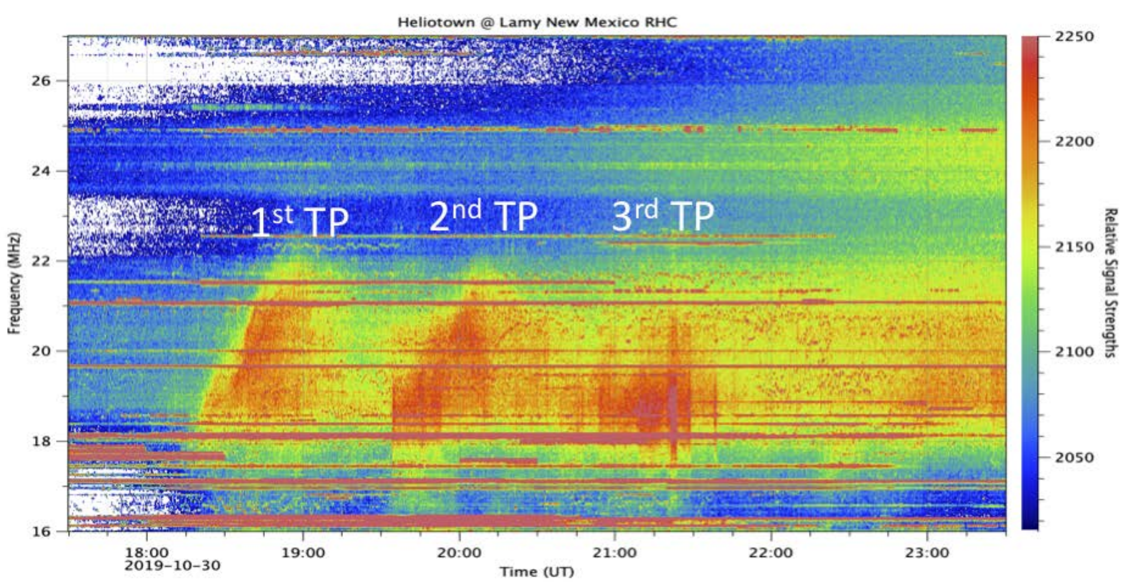
Event 3: 2019-10-30



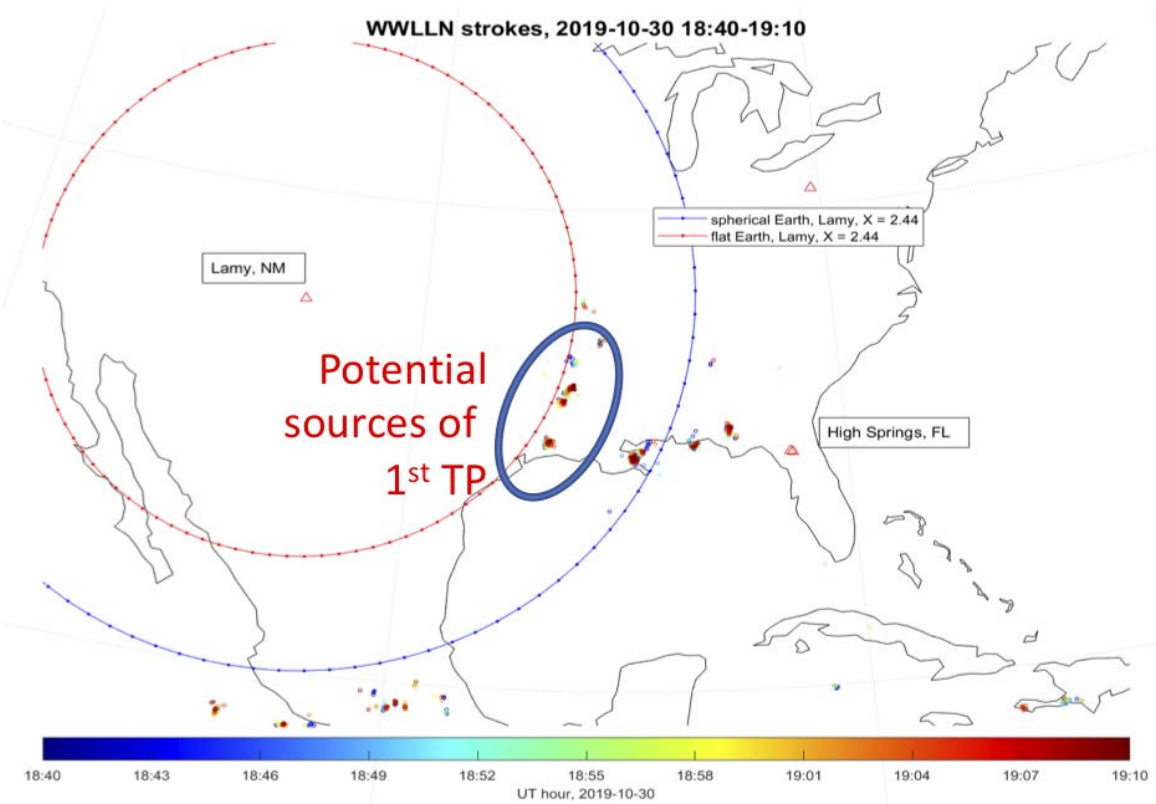
Obs. station	F_{apex} (MHz)	X	Flat Earth	Sph. Earth
High Spring, FL	24.5 (1st apex)	2.72	1339 km	1763 km

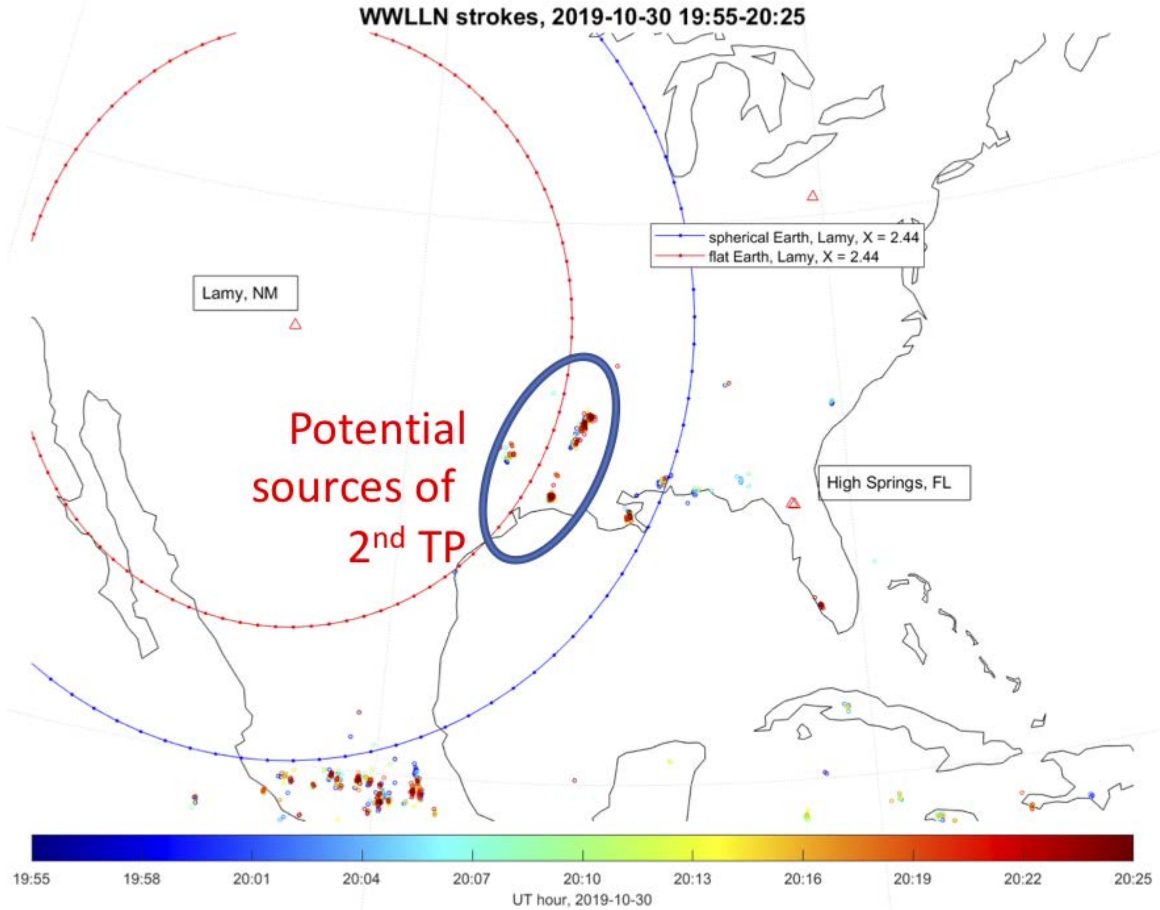


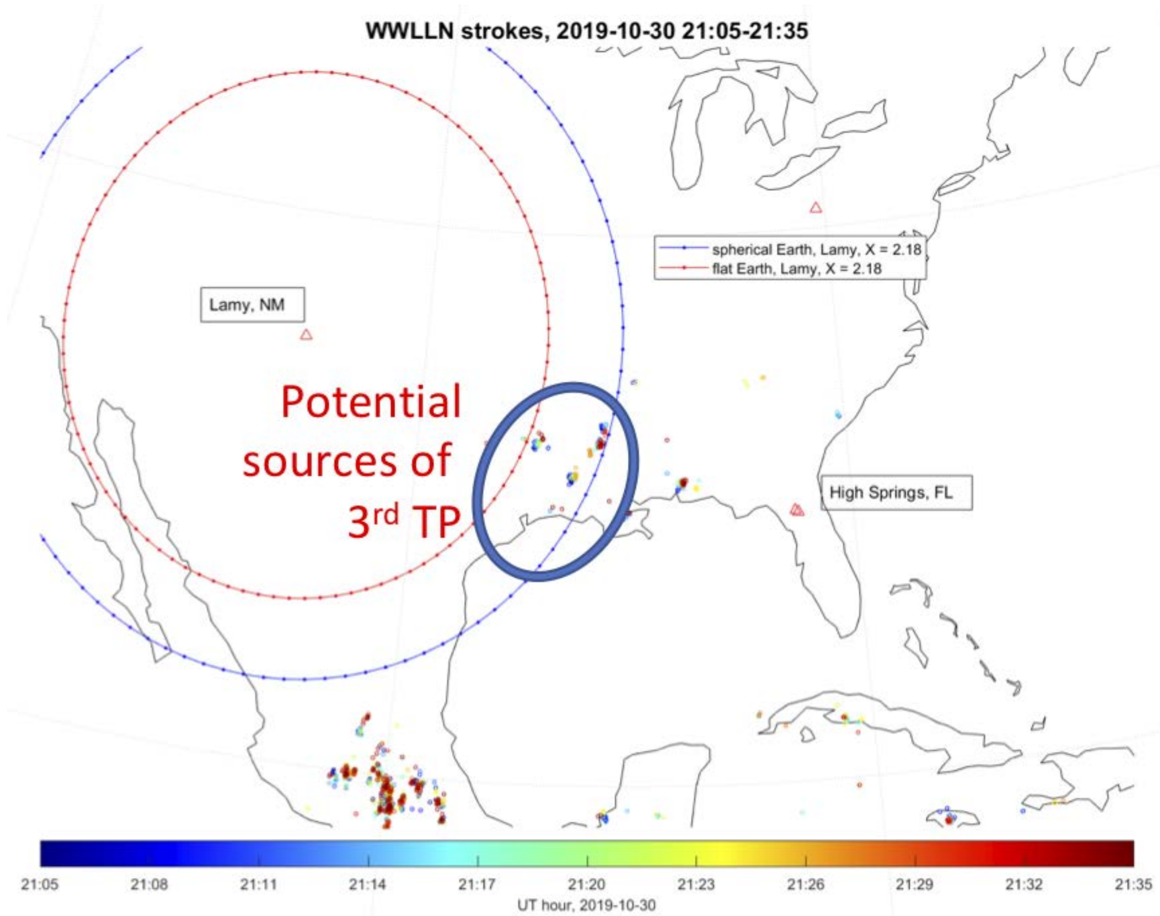
Event 3A, B, C: 2019-10-30



Obs. station	F_{apex} (MHz)	X	Flat Earth	Sph. Earth
Lamy, NM	22 (1st TP)	2.44	1197 km	1727 km
Lamy, NM	22 (2nd TP)	2.44	1197 km	1727 km
Lamy, NM	19.7 (3rd apex)	2.18	1064 km	1391 km

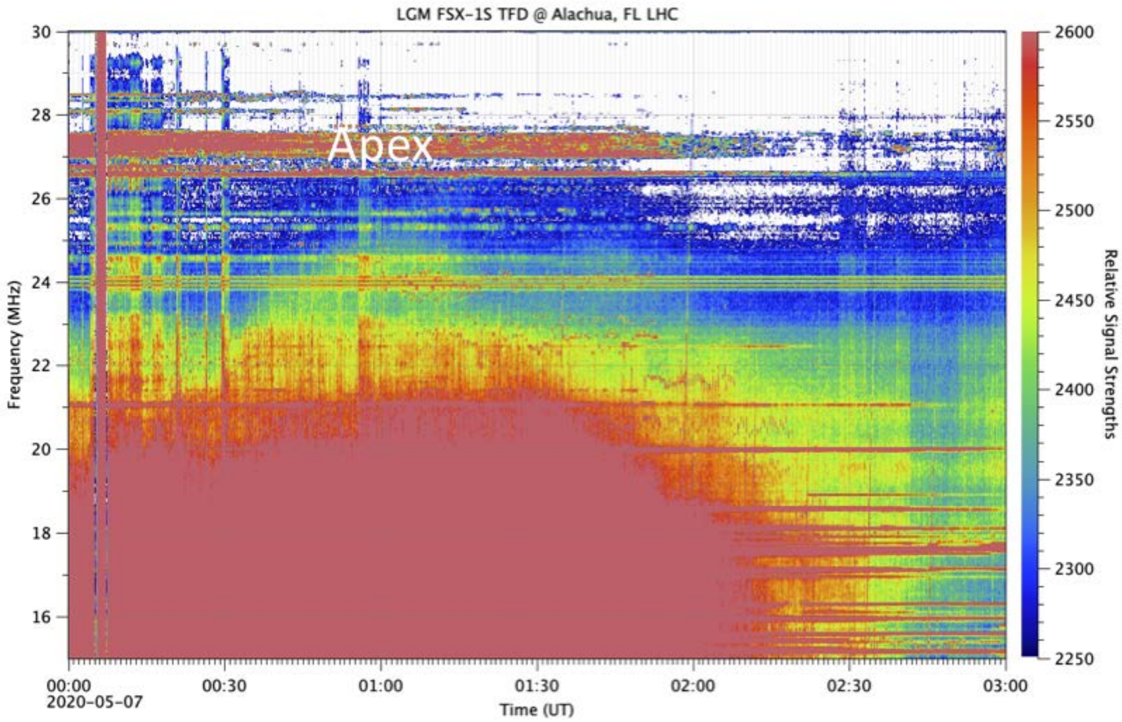


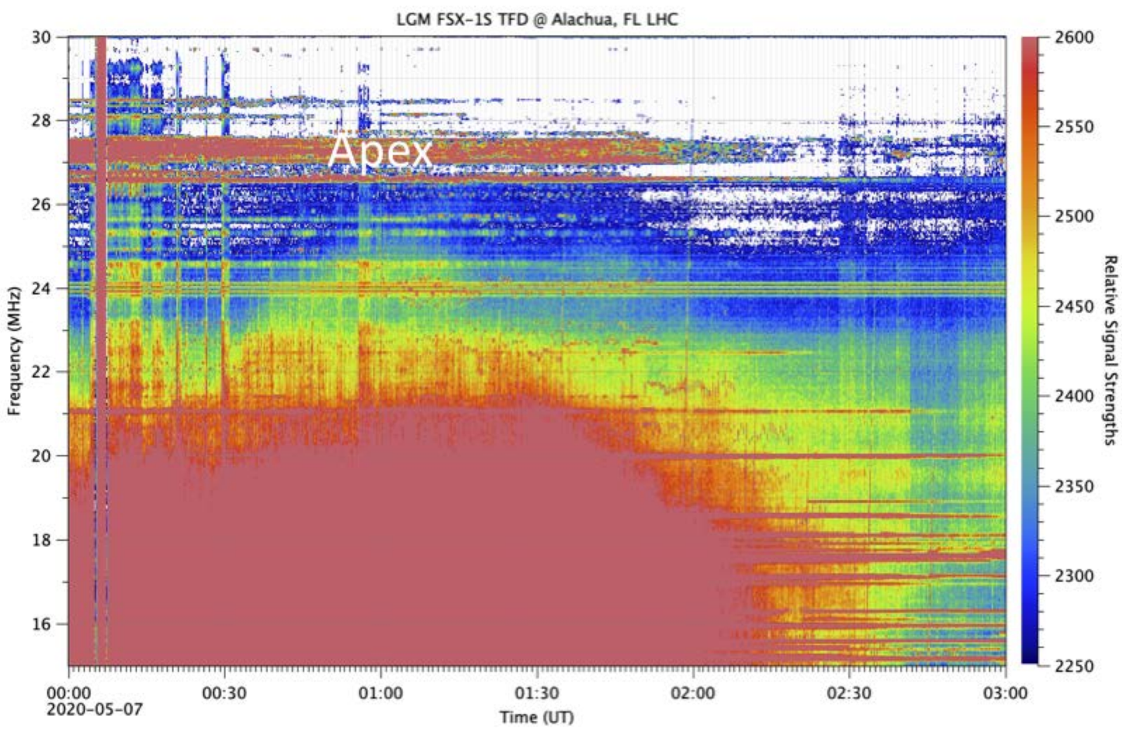

WWLLN strokes, 2019-10-30 19:55-20:25
spherical Earth, Lamy, X = 2.44
flat Earth, Lamy, X = 2.44
Lamy, NM
High Springs, FL
Potential sources of 2nd TP
19:55 19:58 20:01 20:04 20:07 20:10 20:13 20:16 20:19 20:22 20:25
UT hour, 2019-10-30

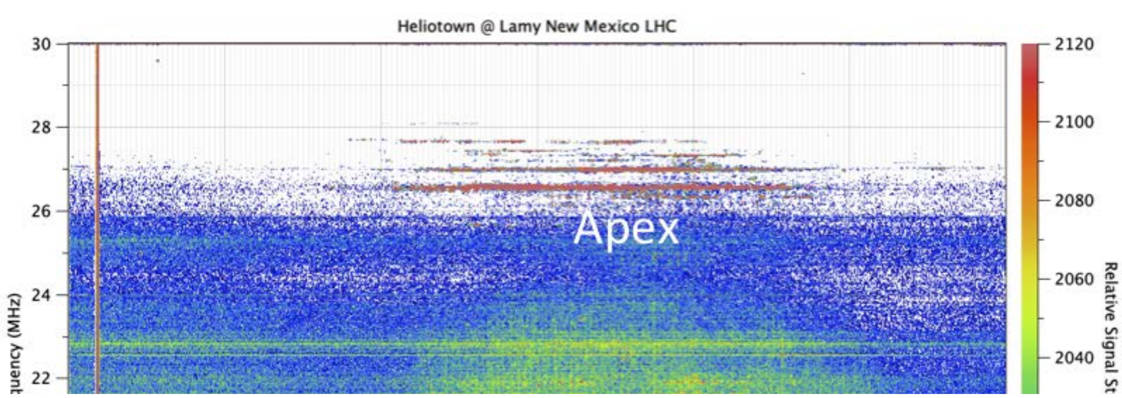

WWLLN strokes, 2019-10-30 21:05-21:35
spherical Earth, Lamy, X = 2.18
flat Earth, Lamy, X = 2.18
Lamy, NM
High Springs, FL
Potential sources of 3rd TP
21:05 21:08 21:11 21:14 21:17 21:20 21:23 21:26 21:29 21:32 21:35
UT hour, 2019-10-30

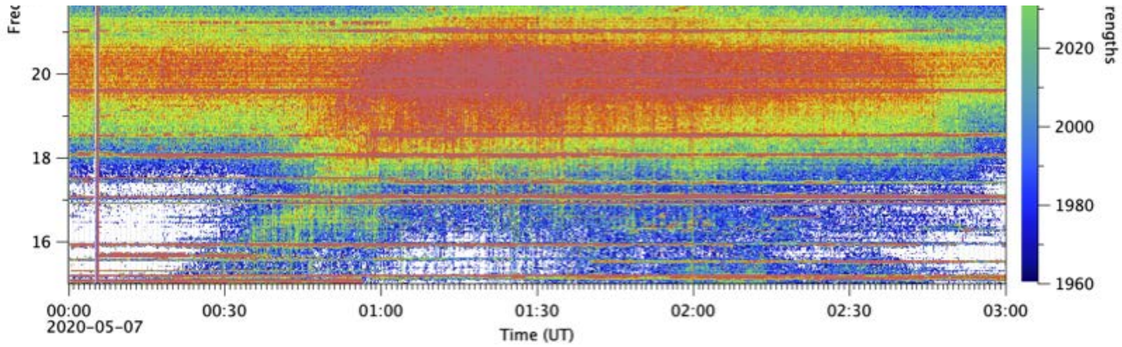
- Both Event 3 & 3(A,B,C) were observed on the same day by two different stations in (A) FL and (B) NM. The different spectral signatures suggest different sources. Sure enough, ground-range analyses show that the different teepee apexes were likely powered by different storms.

Event 4: 2020-05-07


LGM FSX-1S TFD @ Alachua, FL LHC
Apex
Frequency (MHz)
30
28
26
24
22
20
18
16
00:00
2020-05-07
00:30
01:00
01:30
02:00
02:30
03:00
Time (UT)
Relative Signal Strengths
2600
2550
2500
2450
2400
2350
2300
2250

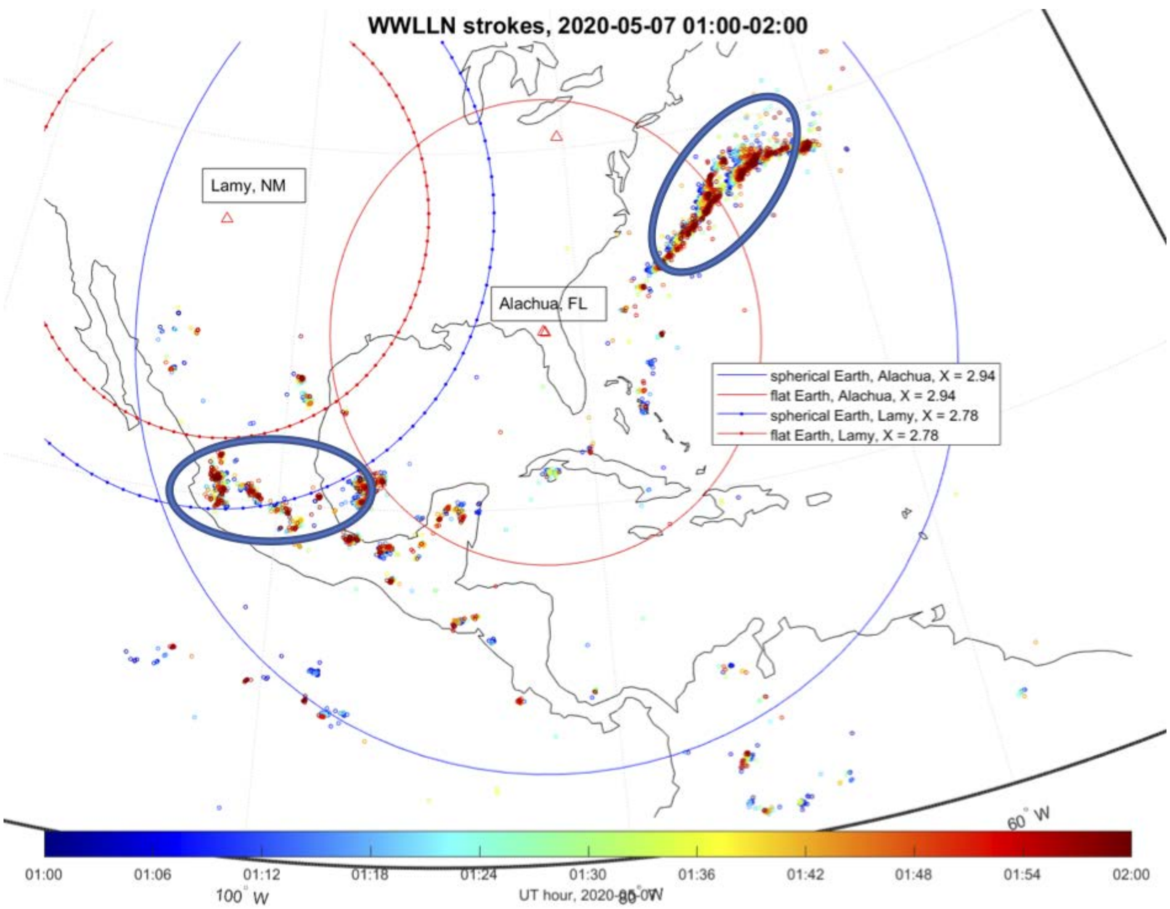

LGM FSX-1S TFD @ Alachua, FL LHC
Apex
Frequency (MHz)
30
28
26
24
22
20
18
16
00:00
2020-05-07
00:30
01:00
01:30
02:00
02:30
03:00
Time (UT)
Relative Signal Strengths
2600
2550
2500
2450
2400
2350
2300
2250


Heliotown @ Lamy New Mexico LHC
Apex
30
28
26
24
22
2120
2100
2080
2060
2040



Freq
20
18
16
00:00
2020-05-07
00:30
01:00
01:30
02:00
02:30
03:00
Time (UT)
2020
2000
1980
1960
rengths

Obs. station	F_{apex} (MHz)	X	Flat Earth	Sph. Earth
Lamy, NM	25	2.78	1369 km	1812 km
High Spring, FL	26.5	2.94	1450 km	2755 km
Alachua, FL	26.5	2.94	1450 km	2755 km



Analogous to event 3 & 3(A,B,C), the teepees observed independently in Lamy, NM, and Alachua, FL, seem to be powered by two different lightning clusters.

Conclusion

Ground-range analysis based on observed fapex and nominal ionospheric model parameters seems to yield ground ranges, along flat and spherical Earth surfaces, at which potential lightning sources can be identified, consistent with the notion that they are the teepee sources.

AUTHOR INFORMATION

Shing F. Fung[1], Todd S. Anderson[2], Thomas Ashcraft[3], Wes Greenman[4], David Typinski[5], and James Brown[6]

[1]Ionospheric, Thermospheric, Mesospheric Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt MD 20771,

[2]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195,

[3]Heliotown Observatory, Lamy, NM 87540,

[4]LGM Radio Alachua, Alachua, FL 32615,

[5]AJ4CO Observatory, High Spring, FL 32655,

[6]Hawks Nest Radio Astronomy Observatory, Industry, PA 15052

ABSTRACT

Propagation teepee is a type of HF spectral feature often recorded at 15-30 MHz by a group of citizen scientists whose main interest is in observing radio emissions from Jupiter. The feature is characterized as spectral enhancements with the frequency of enhancement first increasing and then decreasing with time, resulting in a “triangular spectral feature.” Its shape is reminiscent of teepee tents (or TPs for short), the moveable dwellings of some groups of native-Americans. TPs usually have sharp or well-defined upper frequency limits for both the leading and trailing edges (see figure). While some TPs are observed in isolation, they are often seen in groups, distributed either in time or in apex frequency as a nested group at a particular time. As reported by Fung et al. [2020], most TPs appear to be diffuse even at high time resolution, but a few TPs seen at high time resolution reveal that those TPs consist actually of discrete bursts, strongly suggestive that the band noise could be produced by lightning storms. TP signatures are thus believed to be HF signals produced by remote lightning storms and reflected by the bottom-side ionosphere. By analyzing a few events with TP signatures detected simultaneously by multiple spectrograph stations, we will use a relationship between the TP apex frequency and the distance to its radiation source to identify the lightning storms responsible for the observed TP signatures.

REFERENCES

Breit, G, and M. A. Tuve (1926) A test of the existence of the conducting layer, Phys. Rev. 28, 554.

Fung, S. F., Typinski, D., Flagg, R., Ashcraft, T., Greenman, W., Higgins, C., et al. (2020). Propagation Teepee: A possible high-frequency (15–30 MHz) remote lightning signature identified by citizen scientists. Geophysical Research Letters, 47, e2020GL087307. https://doi.org/10.1029/2020GL087307 (http://dx.doi.org/10.1029/2020GL087307)