Sources of Large Scale Traveling Ionospheric Disturbances Observed using HamSCI Amateur Radio, SuperDARN, and GNSS TEC

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HamSCI
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Traveling Ionospheric Disturbances

- TIDs are Quasi-periodic Variations of F Region Electron Density
- Medium Scale (MSTID)
  - $T \approx 15 - 60$ min
  - $v_H \approx 100 - 250$ m/s
  - $\lambda_H \approx$ Several Hundred km (< 1000 km)
  - May be associated with meteorological or auroral sources
- Large Scale (LSTID)
  - $\boldsymbol{\lambda}_h > 1000$ km
  - $30 < T$ [min] <180
  - Sources are typically attributed to Auroral Electrojet Enhancement, Particle Precipitation
- Both may be associated with Atmospheric Gravity Waves
- Identifying the actual source can be difficult

[Francis, 1975; Hunsucker 1982; Ogawa et al., 1967; Ding et al., 2012; Frissell et al., 2014; 2016]

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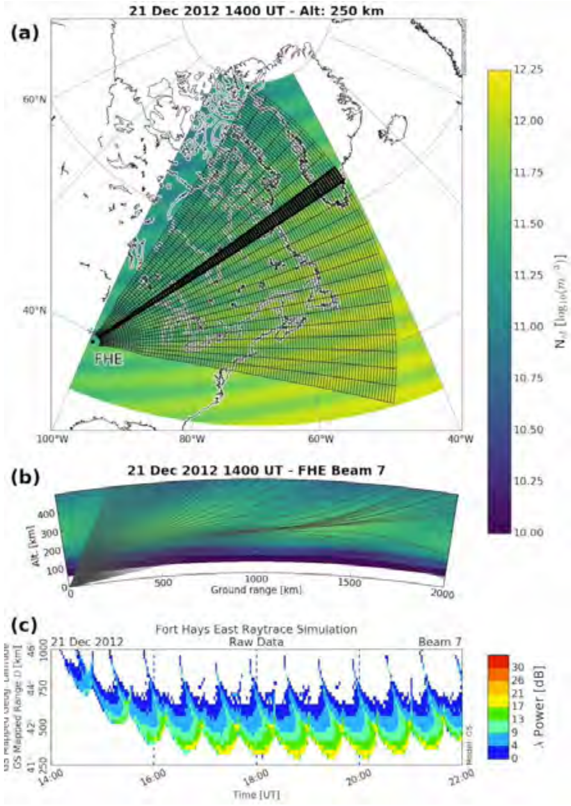
Traveling Ionospheric Disturbances



Ray trace simulation illustrating how SuperDARN HF radars observe MSTIDs.

(a) Fort Hays East (FHE) radar field of view superimposed on a 250 km altitude cut of a perturbed IRI. FHE Beam 7 is outlined in bold.

(b) Vertical profile of 14.5 MHz ray trace along FHE Beam 7. Background colors represent perturbed IRI electron densities. The areas where rays reach the ground are potential sources of backscatter.

(c) Simulated FHE Beam 7 radar data, color coded by radar backscatter power strength. Periodic, slanted traces with negative slopes are the signatures of MSTIDs moving toward the radar.

[Frissell et al., 2016]

Data Sources

- **Amateur Radio**
  - Reverse Beacon Network
  - Weak Signal Propagation Reporting Network (WSPRNet)
  - PSKReporter
  - QRZ.com
- **SuperDARN**
- **Madrigal GPS Total Electron Content (TEC)**
- **NASA OMNI Data**

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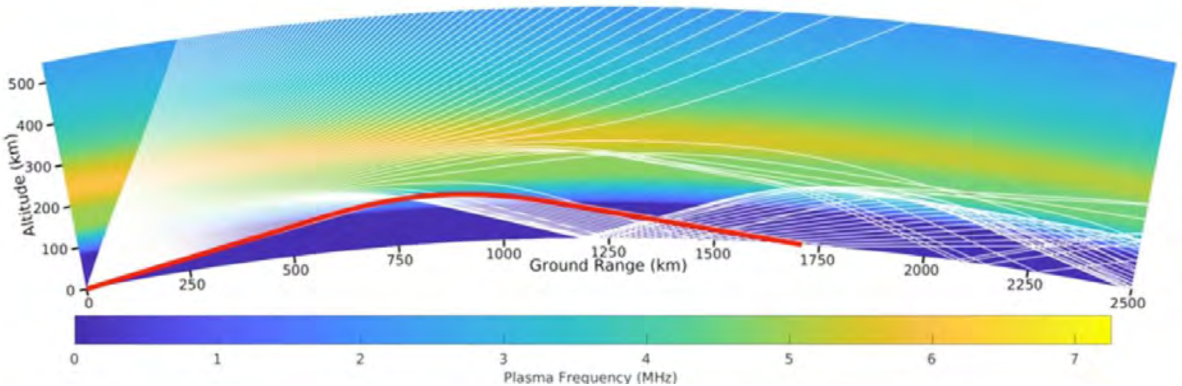
Amateur Radio Frequencies and Modes

Eclipsed SAMI3 - PHaRLAP Raytrace

1600 UT 21 Aug 2017 • 14.03 MHz • TX: AA2MF (Florida) • RX: WE9V (Wisconsin)



PHaRLAP: Cervera & Harris, 2014, https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob, 2017, https://doi.org/10.1002/2017GL073549

- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
  - Data: FT8, PSK31, WSPR, RTTY
  - Morse Code / Continuous Wave (CW)
  - Voice: Single Sideband (SSB)

	Frequency	Wavelength
LF	135 kHz	2,200 m
MF	473 kHz	630 m
	1.8 MHz	160 m
HF	3.5 MHz	80 m
	7 MHz	40 m
	10 MHz	30 m
	14 MHz	20 m
	18 MHz	17 m
	21 MHz	15 m
	24 MHz	12 m
	28 MHz	10 m
VHF+	50 MHz	6 m
	And more…	

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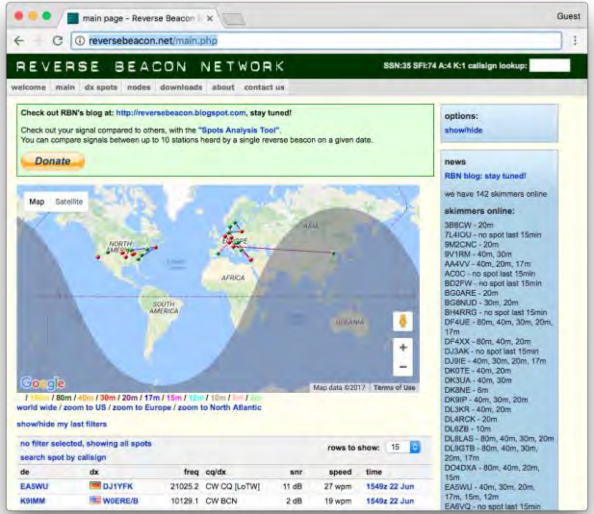
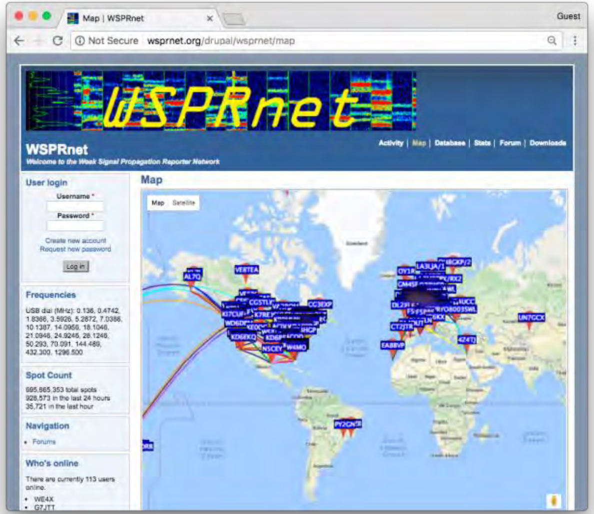
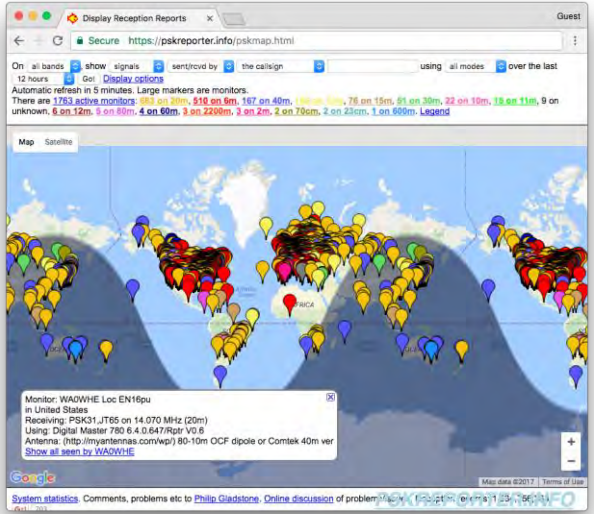
Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org



PSKReporter
pskreporter.info

- Quasi-Global
- Organic/Community Run
- Unique & Quasi-random geospatial sampling

- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

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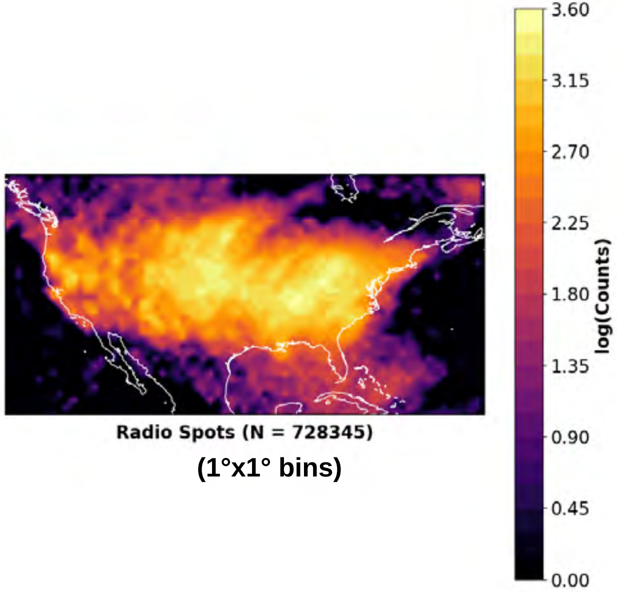
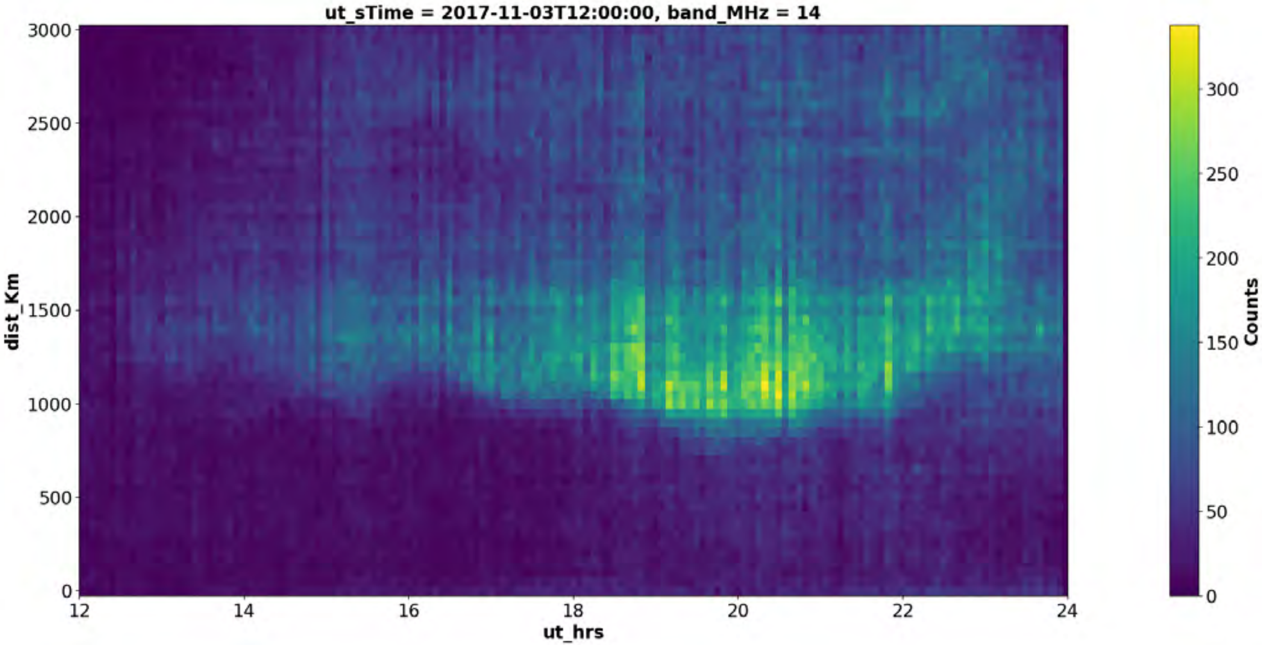
November 3, 2017

20171103.1200-20171104.0000_timeseries.png



Radio Spots (N = 728345)

(1°x1° bins)



(5 min x 50 km bins)

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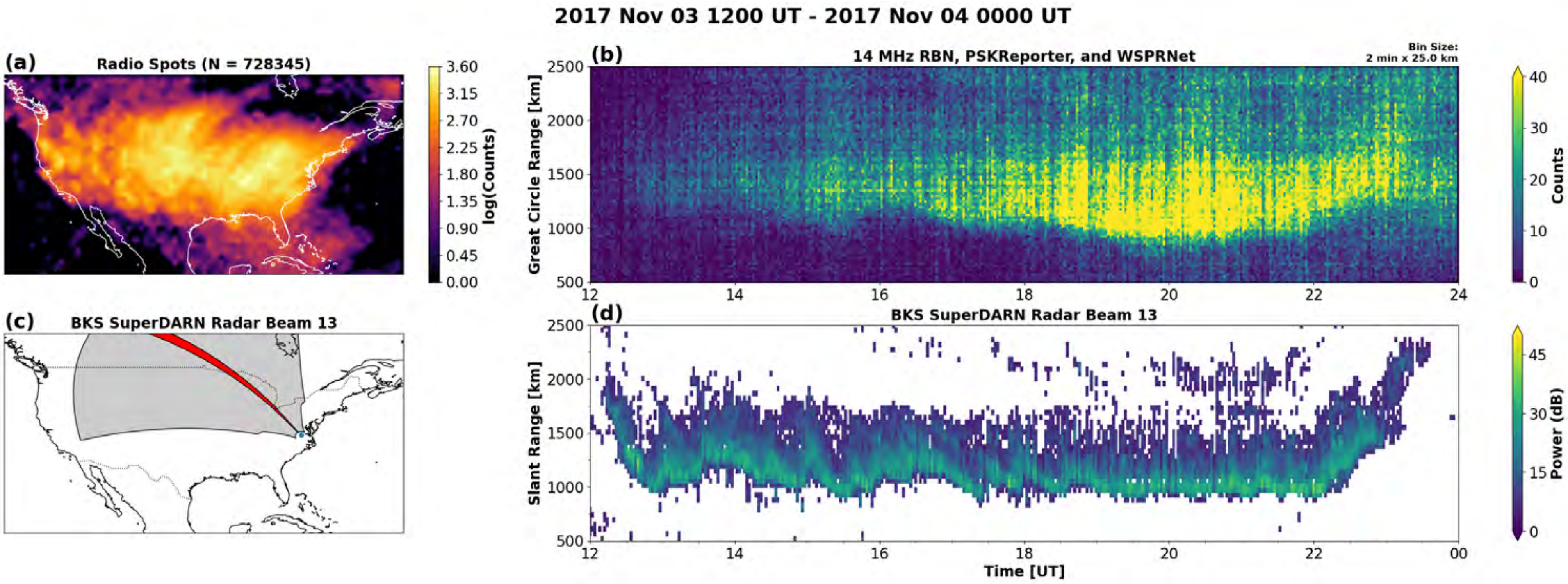
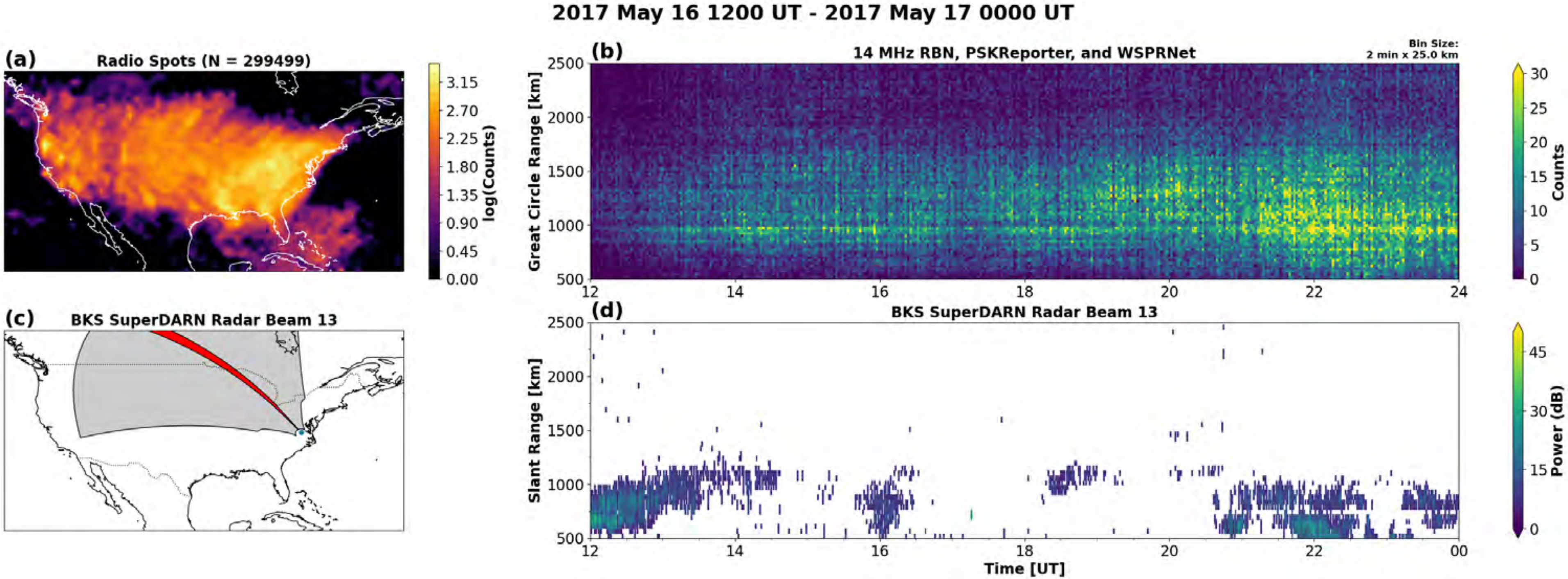
November 3, 2017



May 16, 2017



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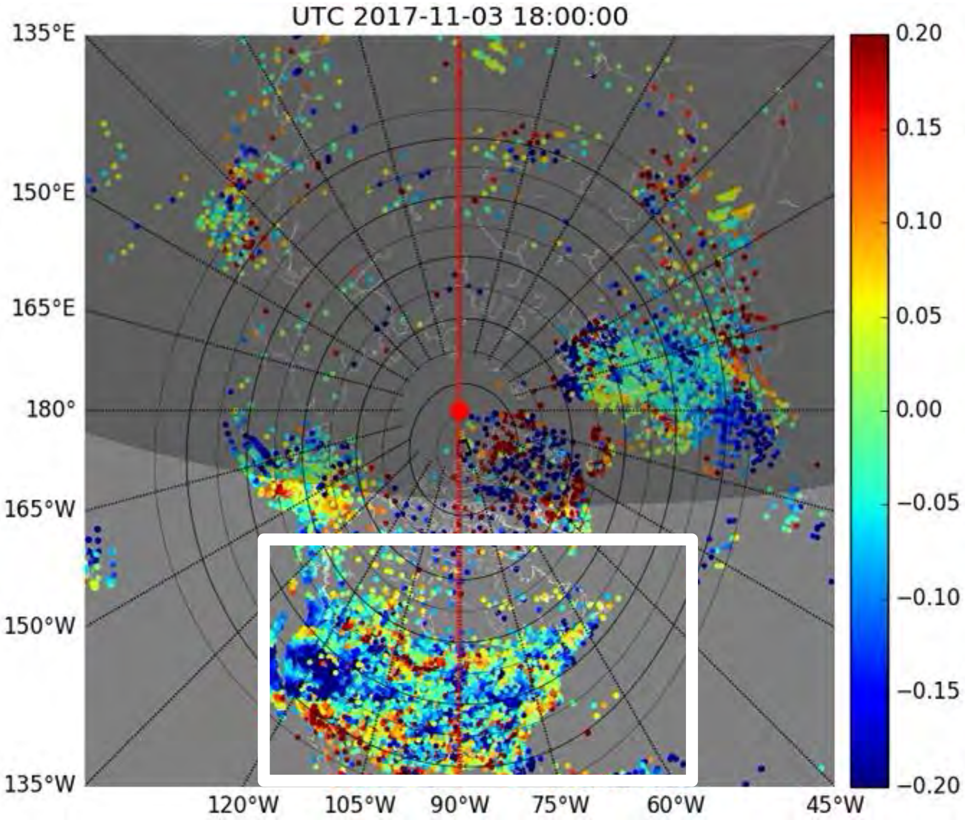
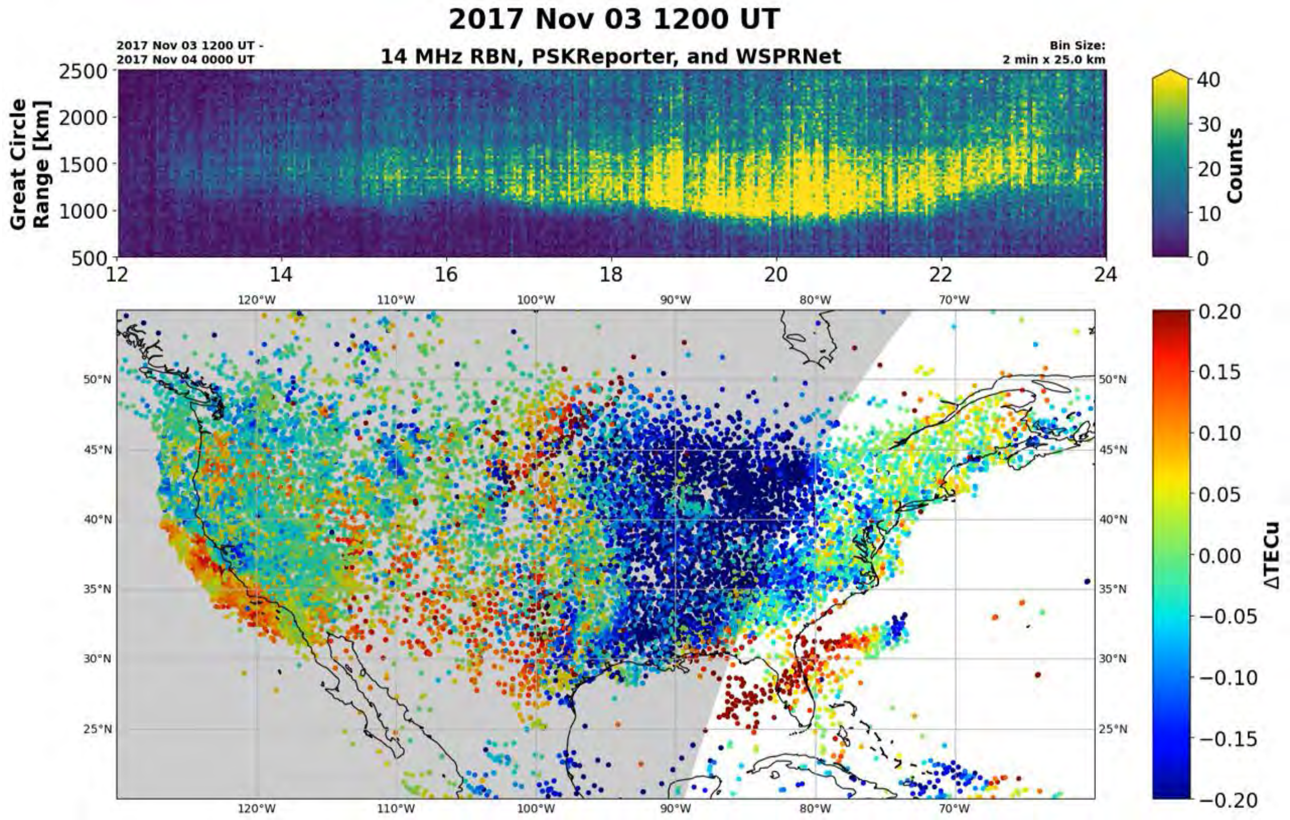
GNSS dTEC 18:00 - 21:00



GNSS TEC data courtesy of Anthea Coster, MIT Haystack Observatory.

Amateur Radio Compared with GNSS dTEC



- Radio range is shortest when TEC is red (higher TEC)
- Higher electron densities → More HF refraction, communication range decreases

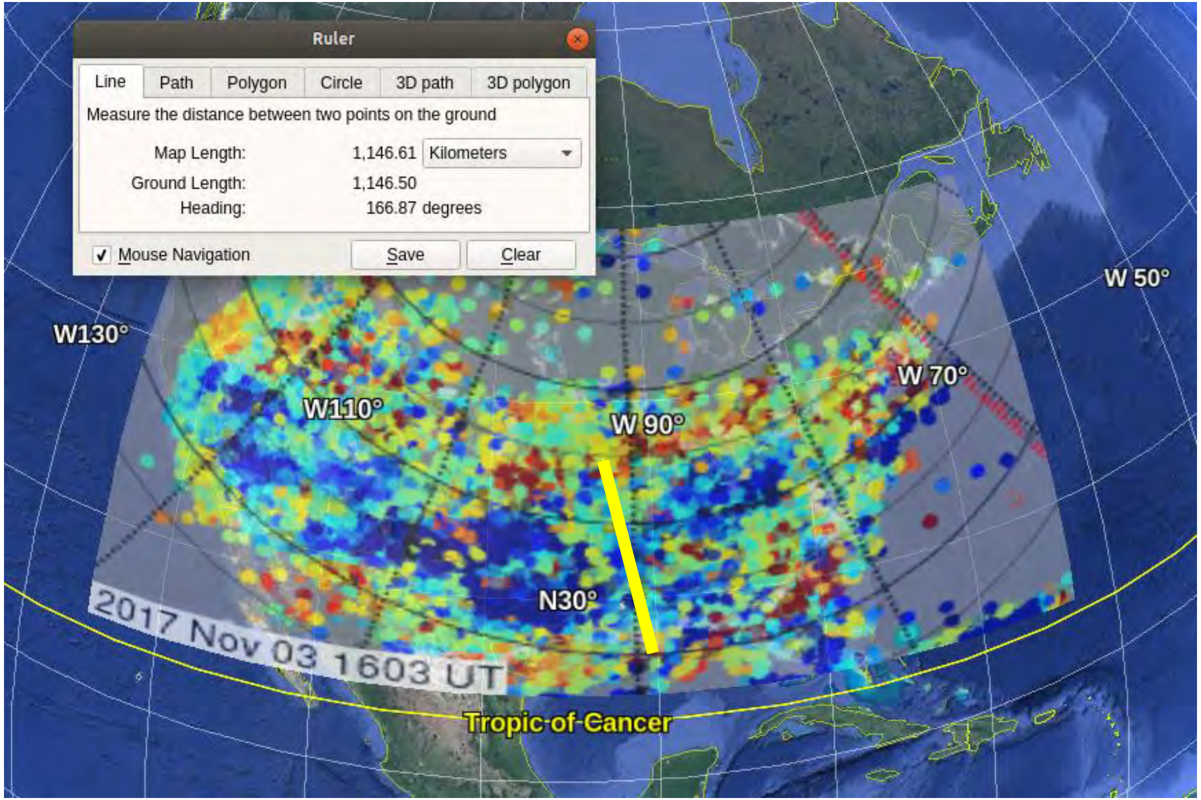
Estimated GNSS TEC LSTID Parameters

$\lambda_h \approx$ 1,100 km

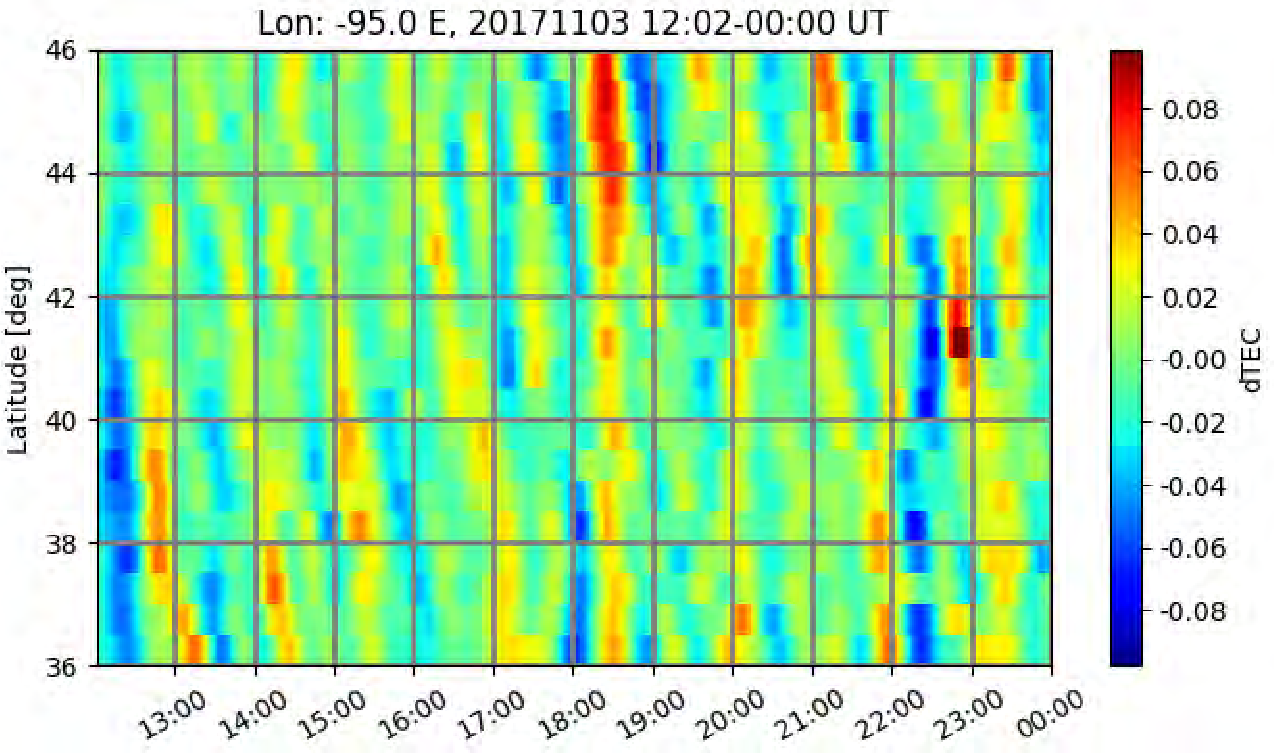
$v_p \approx$ 950 km/hr

$T \approx$ 70 min

$\Phi_{Azm} \approx$ 135°



GNSS dTEC MUSIC Analysis



$\lambda_h \approx 1{,}136$ km

$v_p \approx 1280$ km/hr

$T \approx 53$ min

$\Phi_{Azm} \approx 167°$

TEC MUSIC Analysis by E. G. Thomas.
For algorithm description, see
Bristow et al. (1994) and
Frissell et al. (2014).

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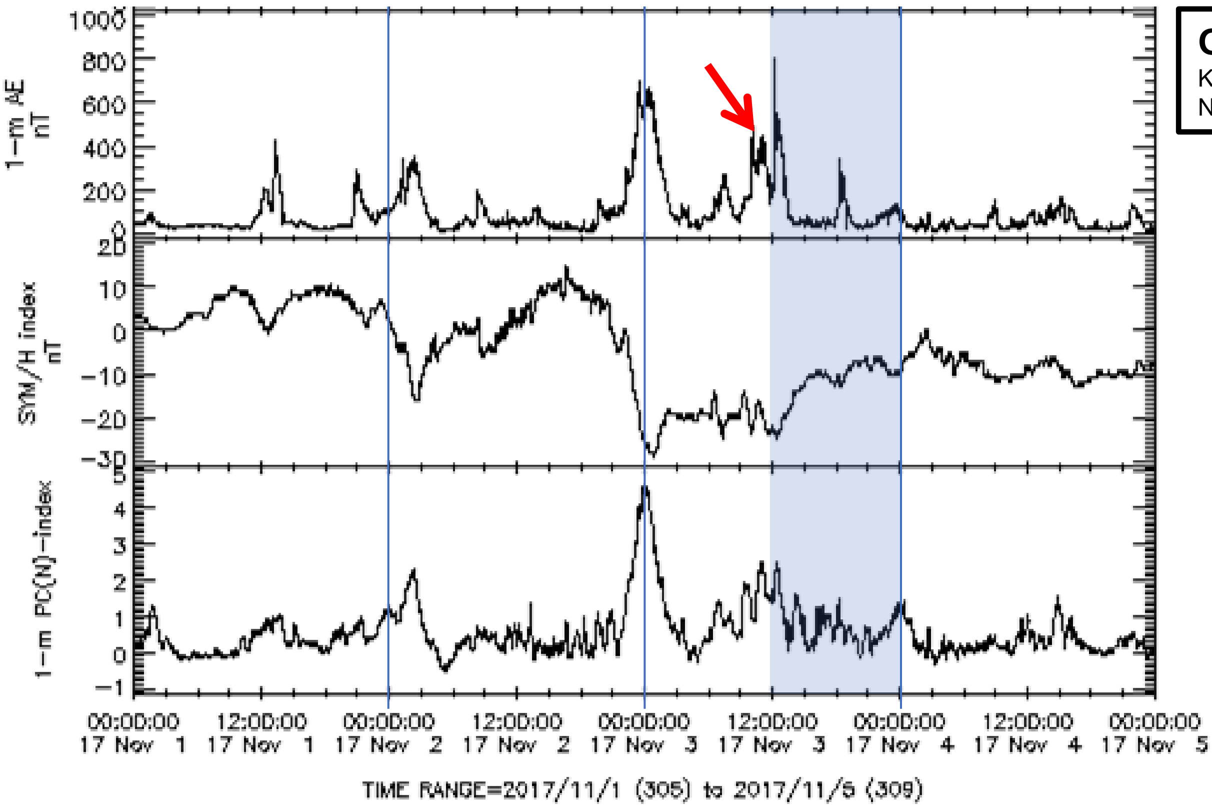
Geomagnetic Environment: 1-5 Nov 2017

Auroral Electrojet

Sym-H
(Geomagnetic Storm Index)

Polar Cap Index



OMNI Data
King and Papatashivilli
NASA GSFC CDAWeb

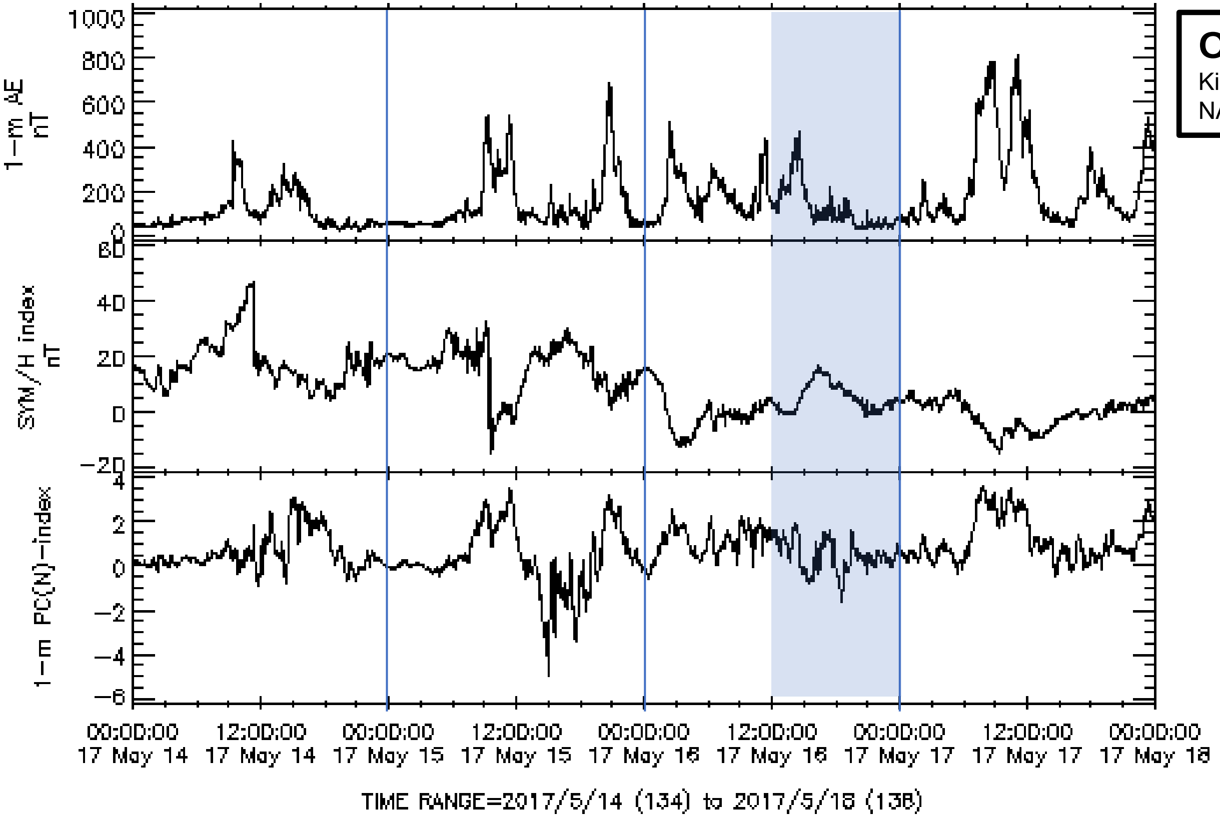
Geomagnetic Environment: 14-18 May 2017

OMNI Data
King and Papatashivilli
NASA GSFC CDAWeb

Auroral Electrojet

Sym-H
(Geomagnetic Storm Index)

Polar Cap Index



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Discussion

- Auroral activity seems the mostly likely cause of the LSTID we observed.
    - Equatorward traveling wave observed in SuperDARN, Amateur Radio, and GPS TEC.
    - Using the LSTID phase velocity of ~1000 km/hr, a > 400 nT AE enhancement is identified at the time the wave would be leaving the auroral zone.
    - Consistent with the published literature.

(See Ding et al., 2012 and references therein.)

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Discussion

- But what about the lack of LSTIDs in May?
  - 16 May 2017 had similar >400 nT AE enhancements to the 3 Nov 2017.
  - However, there is no observed TID activity in the amateur radio data in May.

Discussion

- Why the difference?
  - It is possible that on both days auroral activity is sufficient to generate gravity waves.
  - However, the only neutral atmospheric state in November is such that the waves can propagate successfully to midlatitudes.
  - In May, the neutral atmospheric wind and temperature profile may not allow the waves to propagate.
  - More research is needed…

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Discussion

- It is worth noting that this seasonal result is consistent with:
  - Sanchez et al. statistical study of amateur radio LSTIDs being presented as a poster this CEDAR.
  - Frissell et al. (2016) statistical study of Northern Hemisphere SuperDARN MSTIDs

Conclusions and Future Work

- LSTID Observed on 3 Nov 2017 starting at ~12 UT
  - ~1.5 hr periodicity
  - Observed with Amateur Radio, BKS SuperDARN Beam 13 and GNSS dTEC
  - GNSS dTEC Wave Parameter Estimate (using MUSIC)
    - λ_h≈1136 km, v_p≈1280 km/hr, T≈53 min, Φ_{Azm}≈167°
  - Candidate Source: >400 nT AE Enhancement @ 9 UT on 3 Nov 2017
- No TID Activity Observed on 16 May 2017
  - Similar AE activity to 3 Nov 2017, but no LSTIDs observed
- Future Work
  - More carefully study activity in the candidate source region
  - Understand the neutral atmospheric conditions on both days and evaluate for the ability of appropriate AGWs to propagate.

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Acknowledgments

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- support of NSF AGS-200227 and NASA 19-LWS19_2-0069.
- use of SuperDARN data. SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Italy, Japan, Norway, South Africa, United Kingdom and the United States of America.
- PyDARN Analysis Toolkit made available by the SuperDARN Data Analysis Working Group, Schmidt, M.T., Billett, D.D., Martin, C.J., Huyghebaert, D., Bland, E.C., … Sterne, K.T. (2021, February 23). SuperDARN/pydarn: pyDARNio v2.0.1 (Version v2.0.1). Zenodo. http://doi.org/10.5281/zenodo.4558130.
- GNSS TEC data used is provided by the Millstone Hill Geospace Facility under NSF grant AGS-1952737.
- use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and others (e.g., Millman & Aivazis, 2011).

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Thank you!

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Abstract

Large Scale Traveling Ionospheric Disturbances (LSTIDs) are quasi-periodic variations in F region electron density with horizontal wavelengths > 1000 km and periods between 30 to 180 min. On 3 November 2017, LSTID signatures were detected in simultaneously over the continental United States in observations made by global High Frequency (HF) amateur (ham) radio observing networks and the Blackstone (BKS) SuperDARN radar. The amateur radio LSTIDs were observed on the 7 and 14 MHz amateur radio bands as changes in average propagation path length with time, while the LSTIDs were observed by SuperDARN as oscillations of average scatter range. LSTID period lengthened from T ~ 1.5 hr at 12 UT to T ~ 2.25 hr by 21 UT. The amateur radio and BKS SuperDARN radar observations corresponded with Global Navigation Satellite System differential Total Electron Content (GNSS dTEC) measurements. dTEC was used to estimate LSTID parameters: horizontal wavelength 1136 km, phase velocity 1280 km/hr, period 53 min, and propagation azimuth 167°. The LSTID signatures were observed throughout the day following ~400 to 800 nT surges in the Auroral Electrojet (AE) index. As a contrast, 16 May 2017 was identified as a period with significant amateur radio coverage but no LSTID signatures in spite of similar geomagnetic conditions and AE activity as the 3 November event. We hypothesize that atmospheric gravity wave (AGW) sources triggered by auroral electrojet intensifications and associated Joule heating are the source of the LSTIDs, and that seasonal neutral atmospheric conditions may play a role in preventing AGW propagation in May but not in November.