THE RICHMOND HAM

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THE RICHMOND AMATEUR RADIO CLUB RARC Meeting Virtually Happening and in person!

Our monthly meeting on Friday September 9th, 2022, 7:00PM, at the Bon Air United Methodist Church, 1645 Buford Road, and also a virtual one. The Zoom meeting will start at 7:00pm.
Upon joining the meeting you will be muted. You may exchange greetings with members through the chat feature (keyboard).
Cell phone and tablet users please use Landscape orientation for better imaging.

Kenneth Leidner is inviting you to a scheduled Zoom meeting.

Topic: RARC Monthly Meeting - Virtual
Time:
August 9th, 2022 07:00 PM Eastern Time (US and Canada).
Every month on the Second Friday.
Please download and import the following iCalendar (.ics) files to your calendar system.
Monthly:
https://us02web.zoom.us/meeting/tZwoduGoqzMvEtBdpM3wG1LJ7Ro1ZcdB0qf1/ics?icsToken=98tyKuGgqzoiGtGdtRGDRpw-GYj4WfTwmFxYj7d_mA_IUDd0My_cYdBNY4h8FPqA

Join Zoom Meeting

https://us02web.zoom.us/j/88518058584

Meeting ID: 885 1805 8584
One tap mobile
+13017158592,,88518058584# US (Germantown)
+13126266799,,88518058584# US (Chicago)
Dial by your location
+1 301 715 8592 US (Germantown, MD)
Meeting ID: 885 1805 8584
Find your local number:
https://us02web.zoom.us/u/kbj882gslc

Ken Leidner , WV0L

This Month's Program:

This month's topic: Still to be determined.

Richmond Amateur Radio Club Meeting Minutes August 12, 2022

The regular meeting of the Richmond Amateur Radio Club was called to order at 19:06 on August 12th, 2022 on Zoom and in-person by President John DeMajo, (K5HTZ) with a Quorum present online. Agenda was displayed on screen.

Members Present:

Check-ins on Zoom and in-person at the Church

Last month's Minutes – Approved unanimously.

Treasurer's Report

1)Ken Leidner, (WV0L) gave the Treasurer's Report. We had an ending balance of $19131.76
. The Report was approved unanimously by voice vote.
2) 3 new membership applications: Scott Avery (AD4SA) Extra,, Will Jackson (KA4RAC) Technician, and Kevin McGehee Sr. (KQ4CLH) Technician – Approved unanimously.

President's Report:

1)President John DeMajo, (K5HTZ) Commended Ken Leidner, (WV0L) on his exemplary performance and read this excerpt from Marshall Irvine (N4XVP) who did our audit at N/C:

Ken Leidner, WV0L, requested that I send a copy of my RARC financial review to you for your information. I sent the signed original document to Ken by US mail.
Some observations...

I have been a RARC member about 33 years and around the mid-1990s, I was asked by then Treasurer, Helen Ratcliff, KC4KHH, to review the financial accounts under her control. I have since performed several reviews for past club treasurers. Occasionally, I have found small errors, usually in transposition or omission, as most record keeping was done by paper and pencil or manual computer input. All were reconciled during the reviews. I also made recommendations concerning record keeping that I thought necessary.

The RARC financial records maintained by Ken Leidner are the most comprehensive and well documented that I have reviewed for the club. I found no errors, and I have no recommendations for change.

As stated in the review letter, Ken has entered RARC financial records from 2011 forward into his accounting program. I was asked by the previous treasurer, Richard Arnold, WA4FEH, to perform detailed reviews for some of those years. I was the RARC Registered Agent for several years during that time period, and I am familiar with expected club income and expenditures.

My thanks to Ken for his good work, and thanks to all the RARC officers and directors for keeping the club active during the pandemic.

Marshall Ervine
N4XBP

2) RATS is holding a special meeting on August 18th at 18:00 to elect a new Board and an FCC trustee, they are reorganizing the Club.

3) President John DeMajo, (K5HTZ) introduced Mac McNeer, who gave an update on the nominating committee. Nominations from the floor will be entertained at the September Meeting. Elections will take place at the October Meeting.

4) Audit of Club Assets.:D-Star site inventory is complete

Fall Classes and Club Station

1) Fall 2022 Class Schedule is on the ARC website. Seminars are still to be set up.

2) Club Station is being plagued with short internet outages that kick the station offline. We are still trying to determine the source of them.

2 meter Simplex

Mike Friedman(W4MAF) reported on 2 Meter Simplex Net. Held 1st of every month at 19:00. Information at N4POW.com.

Builder's Group

Ken Zutavern(K4ZUT) will be starting the Builder's Group back up in September. Contact Ken at K4ZUT.ham@gmail.com

RARC By-Laws update

Ken Leidner, (WV0L) presented proposed By-Laws changes for discussion. Both Changes were voted on and passed. The amended By-Laws will be posted on RARClub.net

Meeting adjourned at 19:51

Program

Tonight's presentation is by Brian Szewczyk, (NJ1F) – "Hardware Store Antennas"

The next general meeting: September 9th, 2022 at 20:02.

Minutes respectfully submitted by:

David F. Robinson,(KJ4LHP),

Secretary

From The Prez

Well, summer is about over, the kiddies are back to school, and cool weather is not far off. At our last meeting, we saw quite an increase in turnout at the meeting. It's great to see members joining the meeting in person again. This coming month, we again ask that as many people as possible join us at the meeting location. We will continue to Zoom meetings for those who can not, or do not wish to venture out in public, but please consider joining us in person for this and future meetings if possible.

73,
John K5HTZ

RARC VE News

We have two different groups that provide testing.

1. One is free, but only offers testing sessions on the second Saturday of odd months except June (Field Day) replaces July. **The next session will be on Saturday September 10th.**

2. The other one cost $15.00, but offers testing sessions on the 1st Saturday of every month.

1. RARC offers Free VE Testing Sessions on the second Saturday of odd months except June (Field Day) replaces July. Currently all testing starts at 10:00 AM and is at: Chesterfield Library Bon Air Branch 9103 Rattlesnake Rd North Chesterfield, VA 23235.

Pre-registration Required. Walk-ins Accepted. Pre-Registration required for Techs and for special needs applicants. Anyone taking the Tech exam needs a FRN from the FCC (Google obtaining a FCC FRN) and bring that info to the session. If you have questions about a session, please see our website, www.rarclub.net or contact Allan, WA3J, at 804-399-8724, or ve@rarclub.net

2. KC4TS Cats Vet (Cats Volunteer Examination Team) offers VE Testing Sessions that cost $15.00 on the 1st Saturday of every month. Currently all testing starts at 10:00 AM and is at: Gospel Light Church 2109 Anderson Hey Powhatan VA.
Check-in is between 10am and 12pm and we stay as long as needed to finish all the exams. Walk-in candidates are welcome! You just need a valid ID, an individual FCC FRN, and the testing fee of $15 which goes directly to the ARRL (cash or check made payable to "ARRL VEC"). We can provide pencils and a very simple calculator or you can bring your own. See http://kc4ts.org/ for more information.

Club Info...

RARC meets on the second Friday of each month at 7:00 PM, at the Bon Air United Methodist Church, 1645 Buford Road.

We offer 10-week license prep classes in September and March with exams following. Members provide VE testing sessions on odd-months during the year.

Join the Richmond Amateur Radio Club.

You don't have to have a ham license, just have a genuine interest in the hobby.

Annual Dues are:

80 and over	$0
Regular Membership	$22.00

Lots of information about the Club and our activities is available on our website, www.rarclub.net.

Nets

RARC has the first and only D-STAR digital repeater in the area: 147.255 (+ 600), 443.7125 (+ 5) and 1284.0000 (-20). In addition to our Wednesday local D Star net (below), we link Module C (VHF) to REF062A for the National Capital Region D Star Net on Wednesday nights at 9pm. On Tuesday nights at 9pm, we link Module C (VHF) to REF 054C for the North Carolina D Star Net.

The RARC D Star Net meets on Wednesday nights at 8:00pm and is accessible on our three D Star modules, all of which will be linked together via REF 062D. So if you are in RF range of the repeater, you can join the net on any of the three RF modules and be heard by everyone.

If you participate in the net via DVAP, DV Dongle or a Hotspot (such as Pi Star), you should link your device to REF 062D rather than to any of our modules which will allow you to be heard by everyone.

Any questions, contact Win – W4WIN at wingrant@gmail.com

Sunday	7:00 pm	50.135	USB
	7:30 pm	52.525	FM
Wednesday	7:00 pm	28.475	USB
	8:00 pm	147.255	D-Star Rptr
	8:15 pm	145.730	Packet

MRA 145.43 repeater new website and features

The 145.43 VHF repeater run by the Metropolitan Repeater Association (MRA) has an updated website URL: http://mrarichmond.org/. The website also has a "DUES PAID STATUS" page so you can see if you are up-to-date on your dues. In the picture you see the rectangle on the left of the tower with 4 folded dipole antennas 730 feet up for the 145.43 repeater.

Not to be missed is the 220 repeater inherited from the former trustee, W4MEV who moved to Atlanta. He kindly donated it to the MRA. It's input frequency is 224.42 with its antenna also on that tower. It features the AllStar network connections at certain times of the day. Interconnections are to Charlottesville and the Shenandoah Valley 220 network. It's a very active ragchew net.

The ONLY source of funds to run these two repeaters are from dues,of $15 per year. To join and pay dues, go to https://sites.google.com/view/kg4mra/home/documents and in the list of documents click "MRA Membership Application." Call Ed, KG4SNK, at 804-513-1947 for information.

(Note that an older version of the website still pops up depending on your search so http://mrarichmond.org/ is the best way to get the current site.)

Special Report

At the end of this month's newsletter, you will find a twelve page special report on Geophysical conditions that will be affecting ham radio. Because of the length of the report, it was not included in the body of the newsletter, but it is of interest, so please take the opportunity to view it.

Fall Exam preparation classes

registration dates differ by course, see below

Technician (first license) ◦ Wednesday nights, 7pm to 9pm ◦ 10 weeks, Sept 7th to November 9th ◦ Zoom only ◦ Registration ends Labor Day, September 5th ◦ Textbook: "ARRL Ham Radio License Manual 5th Edition," ISBN: 978-1-62595-156-4, https://home.arrl.org/action/Store/Product-Details/productId/2002476141 ◦ Instructors: George Starke, WB4VWR, John DeMajo, K5HTZ, & Lauren Ware, WD4FMG

General (second license) ◦ Thursday nights, 7pm to 9pm ◦ 5 weeks, October 11th to November 8th ◦ In-person only ◦ Textbook: "2019-2023 General Class Study Manual," https://www.w5yi.org/catalog_details.php?pid=87 ◦ Registration ends October 3rd ◦ Instructors: Ken Zutavern, K4ZUT & Maylon Pearman, N4EG

Extra (highest license) ◦ Three Saturdays ◦ Demo morning, 9am to noon, Saturday, October 22nd – in-person only, Room 205 ◦ Two long classes, 9am to 4:30pm, Saturdays, October 29th & November 5th – Zoom only ◦ Registration ends October 17th ◦ Textbook: "2020-2024 Extra Class Study Manual," https://www.w5yi.org/catalog_details.php?pid=91&sort=7 ◦ Instructors: Bruce MacAlister, W4BRU & Ken Liedner, WV0L

Spring Skills Seminars – seeking instructors

Remote Station setup and operation, instructor
Bruce MacAlister, W4BRU

DStar setup and operation
Antenna Modeling with EZNEC

Request For ELMERS

We have a few newer members who are requesting Elmering. Anyone interested in assisting new hams in this important role, please contact Bruce McAlister W4BRU. Ideally we would like to build a team of Elmers who could share these requests.

Harry Dannals W2HD, Silent Key

Harry Dannals W2HD, of Charlottesville, VA, on August 30th at the age of 95. A name synonymous with ham radio for seven decades, he served as president of the American Radio Relay League from 1972-1982. He was first licensed in 1946 and was a member of the Albemarle ARC. An electrical engineer and veteran of the US Navy, he served in a number of high security positions and was also credited with inventions in the field of Radar.

Show and Tell!

If you have an item, idea, latest and greatest, or whatever gizmo; please bring it to the RARC meeting. We have a table (usually) set up near the front where you can place your item and share/discuss it with others as they arrive. We also have a section of the agenda set aside for members to discuss their "Show and Tell" item(s). No need to be tentative; we are INTERESTED in what you are doing, how you are doing it and, in true Ham fashion, how much it costs!

Nomination Committee Report

For the term 2022/2023, Committee nominations are:

President: Rick Waller, KA4OHM
Vice President: Darrell Basinger, WW4F
Secretary: Dave Robinson, KJ4LHP
Treasurer: Ken Leitner, WV0L
Director: Lauren Ware, WD4FMG
Director: Armand Hamel, WA1UQO

Additional nominations may be made at the upcoming September meeting.

RARC remote station does Omaha and rural Utah

By Bruce McAlister W4BRU

John Drum, W4BXI, is a member who moved to North Carolina. His radio shack is three laptops. He uses them for connections to remote control stations like ours. Now that we have it (almost) as stable as the 145.43 MRA repeater, he's using it daily. There are some remote "stations" that are SDR receivers for listening. It's a good way to check the reach of your signal.

Recently John has been reporting good SSB signals from Bon Air United Methodist Church – the site of our remote station – to the far west. I am always amazed how a 94-foot long-wire hanging just above the roof of the church gymnasium does. It was Tom Flippin's (KD4CMK) idea and it was a good one.

This fall I'll do a program for a meeting on how to use the remote station. The full seminar is 3 to 4 hours long so I can only do a summary in a club meeting.

Bruce MacAlister, W4BRU

Home-Brew Fun and Failures

By Ed Hlywa W4YWA

I'm not much of an amateur radio operator, but I enjoy the electronics and the home brewing aspects of our hobby. Here's an account of my latest effort.

While trying to re-learn CW, I discovered web-based SDR sites with waterfall displays, all kinds of filtering and better performance than my vintage station receiver. So, I'm thinking….. If I had a little transmitter and a simple antenna, along with my ChromeBook, I'd have a capable station to take on vacations to the beach. Yes I know, there are web based amateur radio stations, but remember the operative words here are "Home Brew."

After pinging the Google machine, I came up with a two-stage 1-1/2 watt transmitter sometimes referred to as the "Universal QRP transmitter," or the "Little Joe Transmitter." There's lots of variations of this circuit but it is essentially a colpitts oscillator coupled to a class-C PA.

I chose 20 meters because I didn't want to hire an arborist to string my antenna. My design modifications included a transistor switch that keys both the oscillator and PA, a VXO circuit to chase down that Op calling CQ at 8WPM, power transistor protection, and a 5-th order Chebychev Low Pass Filter to ensure spectral purity.

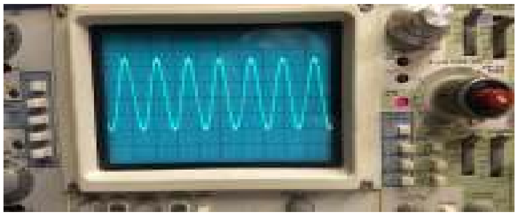
Here's what the end result looks like:

Notice the (do I dare say - good looking?) enclosure. In a former life, it was a SD card reader from a defunct PC. BTW, gutted CD/DVR drive cases also make fine enclosures for your home brew projects.

I opted for a "foil side up – without holes" for my PCB design. All the parts are soldered down on the lands - no PCB holes. I wanted to easily change parts without having to do open heart surgery to get to the parts. Functional placement was also important to me. I took more time than I'd like to admit to organize the circuit layout as I did, but I'm glad I did.

When all was said and done, it was time to power it up and….. and nothing! Not a single function worked.

I won't bore you with the debug stories that took forever, but the only part I didn't have in my junk box was PA transistor. I got 10 of them for $5 off Ebay and they all failed to deliver. I could only get a few tenths of a watt from my design. In a fit of desperation, I un-soldered a PA transistor from an old CB radio I had lying around and it immediately gave me 1.8 watts of pure CW ! ! ! !



Now save your accolades, there were lots of other problems, but they were my problems not component issues. For example, before you design your own RF filter be sure you understand cutoff frequencies. They are not the same for every filter design. I suggest Paul Harden's NA5N site to learn about PA output filters. My first couple of filter attempts had the transmit frequency well down on the attenuation curve. I was attenuating my own signal !

So, after weeks of "why don't the damn thing work," I got a clean signal.

Now it was time to unshackle the dummy load and see where I can be heard. And, Oh boy… I'm beaming into Pennsylvania, Georgia and Northern VA all from an inverted V on a tripod held apart with two tent stakes.

But then, reality took over. My grandiose plan of using the web-based SDRs as a station receiver (and a side tone oscillator for my transmitter) didn't account for the latency delays of the SDR ! If you listen talk radio and the host says to the caller, "Turn your radio off – the delay will make you sound like a …," you know what I'm talking about.

You would think that some one who over thinks everything, would have foreseen this issue before spending countless hours of breathing solder fumes? Humility and eating crow are my better traits.

I'm not ready to give up, stay tune for more adventures of Home-Brew Fun and Failures.

73s

W4YWA

ehlywa@gmail.com

David Hines, K4HIN SK

David grew up working on the family farm near Aldie in Loudoun County. He graduated from Loudoun County High School and from the University of Virginia with a degree in electrical engineering. He then worked in information technology for his entire career. For the last 25 years until retirement, he worked at the Supreme Court of Virginia where his last position was Chief Information Security Officer.

David volunteered with the Fan Free Clinic and the Richmond AIDS information network. He was an avid cyclist for 20 years. He was an amateur radio operator for 10 years and was a member of the Richmond Amateur Radio Club, K4HIN(SK). In retirement he joined and trained with Piedmont Search and Rescue. David was a member of Richmond Friends Meeting (Quaker), Baltimore Yearly Meeting, and he served on the board of Friends House in Sandy Spring, Maryland, for six years. He tutored countless young people in

The SWAP SHOP

Club members may list their wares in the newsletter. Send descriptive information to Armand at wa1uqo@arrl.net, or call me at 508-838-8353. The Swap Shop is presented in the newsletter as a benefit to our members. RARC takes no responsibility for items sold or traded in this newsletter. The ad will appear three times unless extended. Interested parties will contact you directly. ***You must be an RARC member to place an ad.***

For Sale: Harman Kardon AVR146 5.1 Channel HDMI Home Theater Surround Audio Video AV Receiver
Specs: Output Power / Channel 30 Watt
Output Impedance / Channel 8 Ohm
Frequency Response 20 - 20000 Hz
Total Harmonic Distortion (THD) 0.07 %
Connections - 5.1 channel audio line-in, AM antenna, FM antenna, HDMI input, HDMI output, S-Video input, S-Video output, audio line-in, audio line-out, component video input, component video output, composite video input, composite video output, composite video/audio input, digital audio input (coaxial), digital audio input (optical), digital audio output (coaxial), headphones, speakers output, subwoofer output. Bose Cube speakers and subwoofer
$70.00

Ken Zutavern K4ZUT, 11136 Lantern Way, N. Chesterfield, VA. 23236

H (804) 379-1136 C (703) 472-0998

Estate Sale! I have a long list of Ham equipment I am going to sell either locally, on QRZ or eBay. Hams can email me at n4nqy@arrl.net for a spreadsheet of what's for sale. Included is HF equipment, VHF and UHF mobile radios and handheld radios (both analog and DMR) and various accessories. JB Edmonds, N4NQY.

Test equipment, misc. Electronics: An aquaintnce of Scott, AE4TC is trying to clean up his dad's collection of avionics, electronics, test equipment, racks, transceivers, receivers, surplus etc. This is Mr Sternheimer's collection, he owned the A&N stores here in Richmond. There's several rooms full of equipment. Some new stuff still in the box. There's ham equipment, meters, cable, and so on. He is looking to get rid of this stuff and looking for people who can appreciate it. Please contact him directly, his name is Zach. zastarri@comcast.net

For Sale: 1924 Freshman Masterpiece TRF receiver. Has small crack in front panel and new wood cabinet, but all electronics are original and in immaculate condition. Includes rare tubes. $100. A rare find for collectors. If interested, contact John

DeMajo 504-858-7689 or jdemajo@demajo.net.

For Sale:

1. Ameritron AL-80A linear amplifier. Very good condition. Bought 3 years ago (used) and I never used it. Made full power when I got it. $500. IF interested, call Dennis, KG4UT, cell (804) 709-5717.
2. MFJ Kilowatt dummy load. Bought new, never used. $75. If interested, call Dennis, KG4UPT, cell (804) 709-5717.
3. Boonton Model 250-A Impedance Bridge. Very Good condition. I replaced filter caps. This reads the parallel combination of resistance and reactance over the range of 500 KHz to 250 MHz. I bought this for a project I was working on, and it did fine, but no longer have a need for it. $75. If interested, call Dennis, KG4UPT, cell (804) 709-5717.

ANTENNA ROTATOR FOR SALE:

THIS IS A YAESU G-800SA. IT IS BRAND NEW NEVER REMOVED FROM THE BOX. NEVER HOOKED UP OR USED. SOLD AS IS. COMES WITH A GC-038 BRACKET AND 125 FEET OF NEW 8-CONDUCTOR ROTOR CABLE. PRICE: $ 550.00. Contact JERRY WILLIAMS, KJ4IT. 804-730-0221.

Thought For The Day

Inflation is when you pay fifteen dollars for the ten-dollar haircut you used to get for five dollars when you had hair.

John DeMajo	**K5HTZ**	**President**	**(504) 858-7689**	jdemajo@demajo.net
Allan Johnson	**WA3J**	**Vice President**	**(804) 318-6951**	wa3j@arrl.net
Dave Robinson	**KJ4LHP**	**Secretary**		
Ken Leidner	**WV0L**	**Treasurer**		

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ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2022GL097879

First Observations of Large Scale Traveling Ionospheric Disturbances Using Automated Amateur Radio Receiving Networks

Nathaniel A. Frissell[1], Stephen R. Kaeppler[2], Diego F. Sanchez[3], Gareth W. Perry[3], William D. Engelke[4], Philip J. Erickson[5], Anthea J. Coster[5], J. Michael Ruohoniemi[6], Joseph B. H. Baker[6], and Mary Lou West[7]

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Key Points:

- Amateur radio data provides a new method for studying Large Scale Traveling Ionospheric Disturbances and HF communications impacts
- Large Scale Traveling Ionospheric Disturbances are seen for the first time simultaneously in amateur radio, SuperDARN, and GNSS TEC data
- Observed midlatitude Large Scale Traveling Ionospheric Disturbances are likely driven by auroral zone electrojet surges and Joule heating

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

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Author Contributions:

Conceptualization: Nathaniel A. Frissell
Data curation: Nathaniel A. Frissell, Stephen R. Kaeppler, William D. Engelke, Philip J. Erickson, Anthea J. Coster, J. Michael Ruohoniemi, Joseph B. H. Baker
Formal analysis: Nathaniel A. Frissell
Funding acquisition: Nathaniel A. Frissell
Investigation: Nathaniel A. Frissell, Diego F. Sanchez, Gareth W. Perry, William D. Engelke

Abstract

We demonstrate a novel method for observing Large Scale Traveling Ionospheric Disturbances (LSTIDs) using high frequency (HF) amateur radio reporting networks, including the Reverse Beacon Network (RBN), Weak Signal Propagation Reporter Network (WSPRNet), and PSKReporter. LSTIDs are quasi-periodic variations in ionospheric densities with horizontal wavelengths >1,000 km and periods between 30 and 180 min. On Nov 3, 2017, LSTID signatures were observed simultaneously over the continental United States in amateur radio, SuperDARN HF radar, and GNSS Total Electron Content with a period of ∼2.5 hr, propagation azimuth of ∼163°, horizontal wavelength of ∼1680 km, and phase speed of ∼1,200 km hr^{-1}. SuperMAG SME index enhancements and Poker Flat Incoherent Scatter Radar measurements suggest the LSTIDs were driven by auroral electrojet intensifications and Joule heating. This novel measurement technique has applications in future scientific studies and for assessing the impact of LSTIDs on HF communications.

Plain Language Summary

Large Scale Traveling Ionospheric Disturbances (LSTIDs) are variations in the ionosphere with wavelengths greater than 1,000 km, periodicities between 30 min and 3 hr, and speeds greater than about 1,400 km per hour. Auroral zone disturbances are generally cited as the energy source for LSTIDs. In this paper, we show for the first time that LSTIDs can cause variations in the distances amateur (ham) radio operators can communicate using data from the Reverse Beacon Network (RBN), Weak Signal Propagation Reporter Network (WSPRNet), and PSKReporter amateur radio networks. The LSTID signatures in the amateur radio data are in excellent agreement with LSTID observations from two well-established instruments: the Blackstone, Virginia SuperDARN radar and a large scale network of GNSS based ionospheric Total Electron Content receivers. The observed LSTIDs appear 2–3 hr after auroral zone disturbances are detected by ground magnetometers in the SuperMAG network and the Poker Flat Incoherent Scatter Radar (PFISR) in Alaska. Results suggest that auroral zone disturbances were the ultimate cause of the observed LSTIDs. This paper provides a foundation for using large-scale, crowd-sourced amateur radio observations of LSTIDs as a new method for the study of LSTIDs.

1. Introduction

Traveling ionospheric disturbances (TIDs) are quasi-periodic variations of ionospheric densities in the Earth's upper atmosphere, believed to be the ionospheric signatures of atmospheric gravity waves (AGWs; Hines, 1960). TIDs are generally categorized as either Large Scale TIDs (LSTIDs, horizontal speeds between 400 and 1,000 m s^{-1}, periods between 30 min and 3 hr, horizontal wavelengths greater than 1,000 km) or Medium Scale TIDs (MSTIDs, horizontal speeds between 100 and 250 m s^{-1}, periods between 15 min and 1 hr, and horizontal wavelengths of several hundred km; e.g., Francis, 1975; Georges, 1968; Ogawa et al., 1987). LSTIDs are typically associated with AGWs generated by Joule heating and particle precipitation from auroral zone disturbances (Hunsucker, 1982; Lyons et al., 2019). These AGWs may propagate equatorward for long distances, transporting energy from the auroral zone to middle and low latitudes (Richmond, 1979) and can even reach the opposite hemisphere (Zakharenkova et al., 2016).

Methodology: Nathaniel A. Frissell, Stephen R. Kaeppler, Gareth W. Perry, Philip J. Erickson
Project Administration: Nathaniel A. Frissell
Resources: Nathaniel A. Frissell
Software: Nathaniel A. Frissell
Supervision: Nathaniel A. Frissell, Gareth W. Perry
Validation: Nathaniel A. Frissell
Visualization: Nathaniel A. Frissell
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Since first reported by Munro (1948), TIDs have been studied using many different techniques. These include ionosondes (e.g., Altadill et al., 2020; Galushko et al., 1998; Galushko et al., 2003), incoherent scatter radars (e.g., Kirchengast et al., 1996; Nicolls & Heinselman, 2007; Thome, 1964; Zhang et al., 2021), HF Doppler radars (e.g., Bristow et al., 1994; Frissell, Baker, et al., 2014; Frissell et al., 2016; Samson et al., 1989; Samson et al., 1990), broadcast AM Doppler receivers (Chilcote et al., 2015), global navigation satellite system (GNSS) total electron content (TEC) receivers (e.g., Dinsmore et al., 2021; Tsugawa et al., 2007; Zakharenkova et al., 2016), and airglow imagers (e.g., Mendillo et al., 1997; Otsuka et al., 2004; Ogawa et al., 2009). Each of these different techniques provides a unique and complementary view into understanding the nature of TIDs.

In addition to their scientific value, TIDs are of interest technologically due to their impact on high frequency (HF, 3–30 MHz) terrestrial communications systems. The time-dependent variations in ionospheric electron density associated with TIDs cause a focusing and de-focusing of ionospherically refracted HF radio signals (Bristow et al., 1994; Frissell, Baker, et al., 2014; Samson et al., 1990). These effects can manifest as quasi-periodic fading and enhancements of HF communications signals. Work by the Ham Radio Science Citizen Investigation (HamSCI; hamsci.org) collective have demonstrated that data collected by global-scale, automated HF receiving systems built and operated voluntarily by amateur (ham) radio operators can be used for both scientific study of ionospheric phenomena and as a way to assess ionospheric impacts on real communications systems. This work includes the impacts of solar flares and geomagnetic storms (Frissell, Miller, et al., 2014; Frissell et al., 2019), total solar eclipses (Frissell et al., 2018), and plasma cutoff and single-mode fading (Perry et al., 2018).

In this paper, we present the first observations of LSTIDs in the ionosphere through data collected from the Reverse Beacon Network (RBN), Weak Signal Propagation Reporter Network (WSPRNet), and PSKReporter amateur radio networks. These observations are compared to Blackstone Super Dual Auroral Radar Network (SuperDARN) radar and GNSS differential Total Electron Content (TEC) observations. Enhancements of the SuperMAG Electrojet (SME) Index and electron densities observed by the Poker Flat Incoherent Scatter Radar (ISR) prior to TID observation suggest auroral activity as the main driver for the observed LSTIDs.

2. Datasets and Methodology

2.1. Amateur Radio

Amateur radio operators are communications hobbyists licensed to transmit on amateur radio frequencies. Radio signals that occur in the high frequency (HF, 3–30 MHz) bands can be refracted back to Earth by the ionosphere, thereby enabling long-distance, over-the-horizon communications. Variability in received signals may be related back to the variations in the ionospheric state. Amateur radio observations have been previously used to show the impacts of solar flares and geomagnetic storms (Frissell, Miller, et al., 2014; Frissell et al., 2019), and also to study the impact of a total solar eclipse (Frissell et al., 2018).

In this paper, we use observations from the RBN (Sinanis et al., 2022), PSKReporter (Gladstone, 2022), and WSPRNet (Walker, 2022) amateur radio networks to study LSTIDs. Each of these networks consists of geographically distributed automated receiving stations that are able to identify and log Morse code and/or digital amateur radio transmissions. Each observed radio transmission is referred to as a "spot" that includes the observation time, frequency, call signs of the transmitter and receiver, and sometimes the transmitter and receiver locations as reported by the radio operator. When station location is not provided, it is determined by looking up the station's licensed callsign in the HamCall Database (2022).

2.2. SuperDARN

The Super Dual Auroral Radar Network (SuperDARN) is a global network of coherent-scatter HF Doppler radars that operates between 8 and 20 MHz (Chisham et al., 2007; Greenwald et al., 1995; Nishitani et al., 2019). Although SuperDARN is primarily designed to study ionospheric convection by measuring the Doppler velocity of field aligned ionospheric irregularities, it also routinely observes ground scatter. Ground scatter occurs when radar signals undergo ionospheric refraction back to Earth, reflect off the ground, and then return back to the radar via an ionospheric path. Although the radar returns are from ground reflections, ground scatter can still be used for ionospheric study because the ionosphere will modulate the signals as they propagate through the medium.

Samson et al. (1990), Bristow et al. (1994), Frissell, Baker, et al. (2014), and Frissell et al. (2016) have shown that TIDs moving through the field of view of a SuperDARN radar focus and de-focus the radar rays such that the ground scatter range and signal-to-noise ratio (SNR) vary with the period of the TID. In many ways, SuperDARN ground scatter observations are analogous to amateur radio HF communication links. In both cases, HF radio signals are modulated by the ionosphere before being returned to Earth. Therefore, TIDs have the potential to affect amateur radio HF communications range and SNR in a manner similar to SuperDARN ground scatter observations.

2.3. GNSS Total Electron Content

Dual-frequency GNSS receiver measurements are now routinely used to measure the TEC in a column between a ground receiver and a satellite in space by measuring the phase difference between the two signals (Coster et al., 1990, 1992). In this paper, we use GNSS TEC data from the continental United States (CONUS) region processed according to the algorithms by Rideout and Coster (2006) and Vierinen et al. (2016). Using a similar approach as Coster et al. (2017), Zhang et al. (2017), and Zhang et al. (2019), we use a differential TEC (dTEC) analysis rather than absolute TEC to observe the TIDs. In this approach, dTEC values were calculated by subtracting a background TEC variation computed with a low-pass Savitzky-Golay filter (Savitzky & Golay, 1964) using successive windows of 60 min length. Only GNSS satellite-to-ground ray paths with elevations ≥30° were used.

2.4. Geomagnetic and Auroral Measurements

We use the SME index and Poker Flat Incoherent Scatter Radar (PFISR) observations to quantify possible driving of LSTIDs from auroral sources. SuperMAG is an international collaboration of institutions that combines the observations from over 200 ground-based magnetometers (Gjerloev, 2012). To observe auroral electrojet intensifications, we use the SuperMAG-derived SME index. This value is calculated using data from all available magnetometers between 40°N and 80°N magnetic latitude. Over this range, ∼110 stations are available, providing sufficient sampling density to allow for the geographic localization of SME intensifications (Newell & Gjerloev, 2011a, 2011b). The SME index is comparable to the traditional auroral electrojet (AE) index derived by Davis and Sugiura (1966). We employ the SME index because the AE index is derived from only 12 magnetometer stations, making geographic localization of AE enhancements difficult.

PFISR is located near Fairbanks, Alaska (Geographic: 65.13°N, 147.47°W; Magnetic: 65.3°N, 92.1°W). Magnetic midnight occurs at ∼UT − 9.8 hr. For the interval of interest, two radar modes were used: GPSAC5 and IPY27. The GPSAC5 mode is comprised of alternating code observations providing sufficient range resolution to measure E-region electron density (Lehtinen & Häggström, 1987). The IPY27 mode is a low duty cycle background mode composed of both alternating code and uncoded (long) pulse observations. The long pulse observations in the F-region are further processed to estimate the electric field vector using the methodology described by Heinselman and Nicolls (2008). The GPS mode and the IPY27 mode were integrated to 1 and 5 min resolution, respectively.

Electron density observations spanning the interval of interest are provided by the high range resolution alternating code data. For this study, we use the electric field observations, which are limited to the IPY mode observations only, to quantify the passive energy deposition rate, $Q(z) = \sigma_P(z)E^2$, where $\sigma_P(z)$ corresponds to the altitude resolved Pedersen conductivity. More details regarding how the passive energy deposition rate was calculated using PFISR observations can be found in Zhan et al. (2021). The passive energy deposition rate is a proxy for the Joule heating rate, although it excludes the effects from the neutral winds.

3. Observations

3.1. LSTID Observations

Figures 1a and 1b show combined 14 MHz observations from the RBN, PSKReporter, and WSPRNet networks on Nov 3, 2017 for the period of 1200–2359 UT for transmitter-receiver (TX-RX) pairs with great circle distances <3000 km (to avoid multi-hop situations). This event was selected by making daily summary plots of amateur radio data in a format similar to Figures 1a and 1b and identifying a period with clear LSTID signatures. Figure 1a shows a map of the distribution of TX-RX midpoints of communications observed over the CONUS. TX-RX

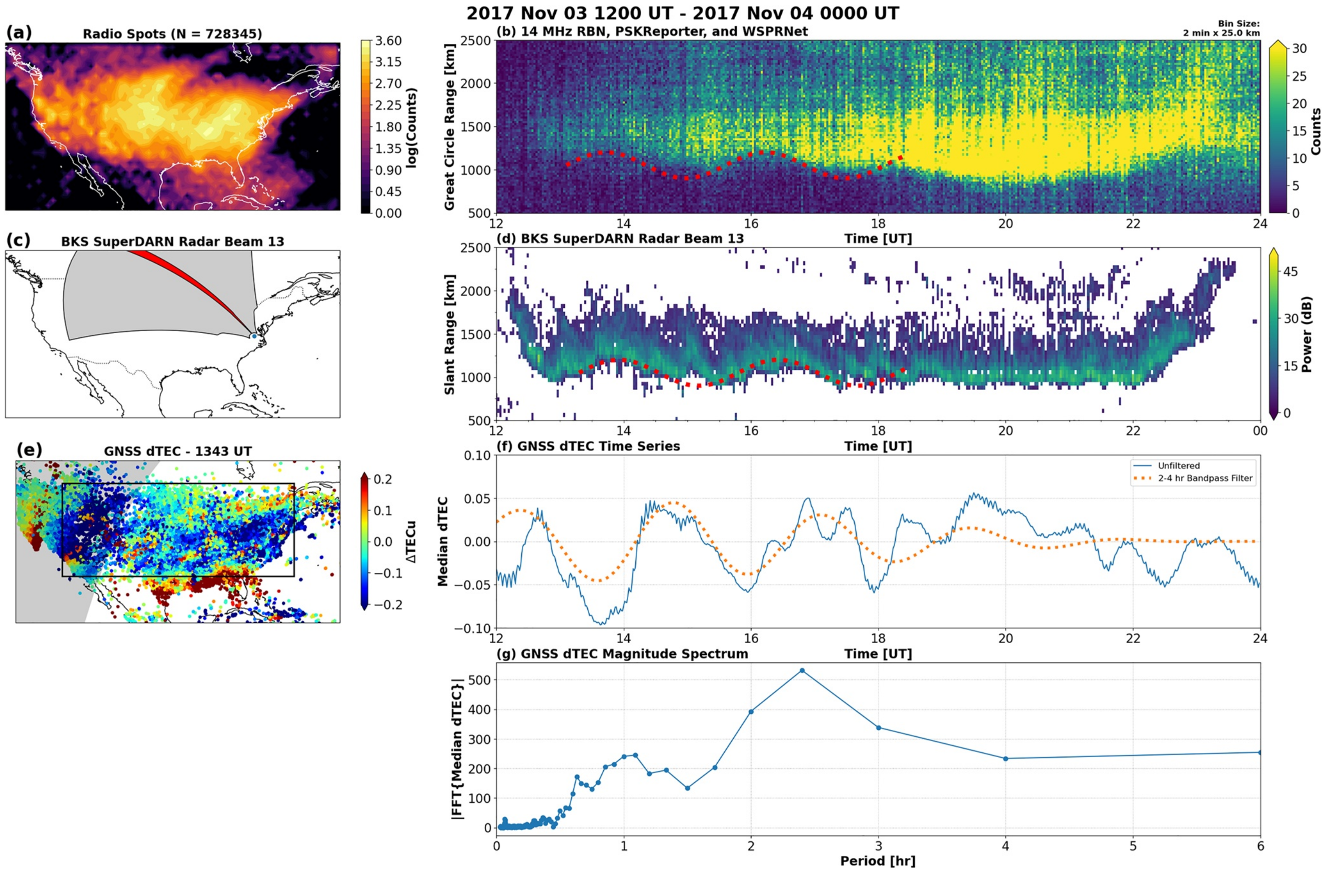

Figure 1. LSTIDs observed using amateur radio networks, the BKS SuperDARN radar, and GNSS dTEC. (a) Geographic distribution of TX-RX midpoints of amateur radio communications observed over the continental United States on Nov 3, 2017 from 1200 to 2359 UT. (b) Time series showing the TX-RX distance for 14 MHz amateur radio spots in 2 min by 25 km bins. (c) Location and FOV of the BKS SuperDARN radar; Beam 13 is highlighted in red. (d) Ground scatter power observations of BKS Beam 13 with ∼11 MHz transmit frequency. (e) GNSS dTEC measurements at 1343 UT. (f) Time series (blue line) of GNSS dTEC median values calculated from measurements in the black box region in (e). Dotted orange line shows data filtered with a 2–4 hr bandpass filter. (g) FFT Magnitude spectrum of the unfiltered data in (f). Red dots overlaid on (b) and (d) show a sinusoidal 2.5 hr oscillation in skip distance common to both the amateur radio and SuperDARN measurements.

midpoints are calculated based on the assumption that ionospheric refraction occurs at the half-way point between the two stations. Figure 1b presents a time series showing the TX-RX distance for the number of 14 MHz amateur radio spots in 2 min by 25 km bins. The bottom edge of the green-yellow region shows the communications skip focusing distance varying with time, especially between 13 and 18 UT. This skip-distance variation is highlighted by red dots overlaid on the data, which shows a manually fit fiducial sinusoid with a 2.5 hr period centered around 1,050 km range with a 150 km amplitude. A version of this figure without the overlaid sinusoid is presented in Figure 4e.

Figures 1c and 1d show observations from the Blackstone, Virginia (BKS) SuperDARN radar in a format comparable to the amateur radio observations of Figures 1a and 1b. Figure 1c shows the location of the BKS radar and its field-of-view (FOV). Comparison of Figure 1c with Figure 1a reveals that BKS Beam 13 (highlighted in red) looks northwest over a region of dense amateur radio spot coverage. Figure 1d shows power parameter observations from BKS Beam 13. The radar transmit frequency ranged between 10.802 and 11.736 MHz during this time. The scatter is predominantly ground scatter, which is analogous to the amateur radio TX-RX communications distances shown in Figure 1b. Large-scale features can be observed that are common to both the amateur radio and SuperDARN observations. Most importantly, skip distance oscillations are observed in the SuperDARN data that match those observed in the amateur radio data. The large-scale component of these oscillations is highlighted in Figure 1d with a red dotted sinusoid with identical parameters as the sinusoid in Figure 1b. In both Figures 1b and 1d, it is noted that the sinusoid best matches the data at skip distance maximum, and less so at

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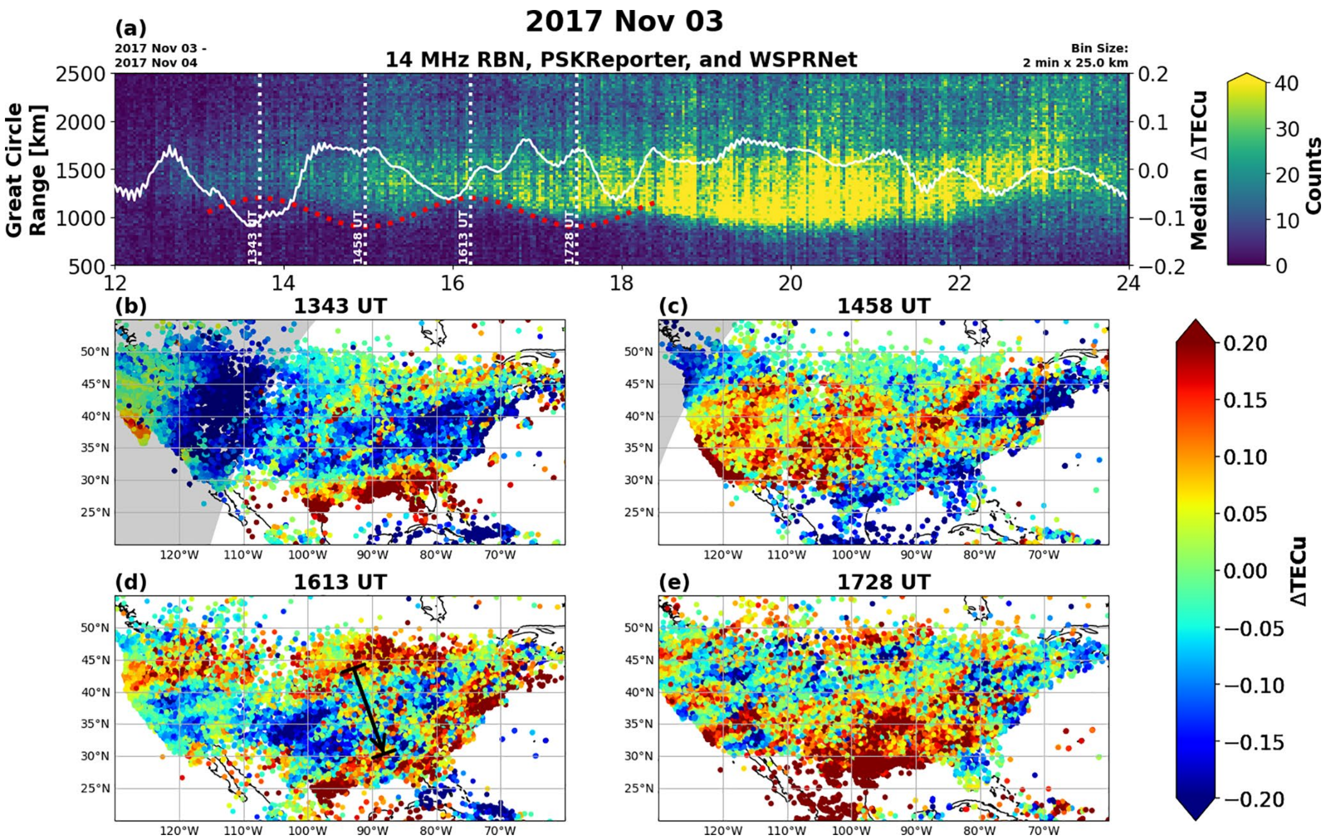

Figure 2. Amateur radio and GNSS dTEC observations of the Nov 3, 2017 LSTIDs. (a) Continental United States amateur radio observations in the same format as Figure 1b. The red dashed sinusoid highlights the 2.5 hr skip distance oscillation; the white solid line shows the median dTEC values first presented in Figure 1f. Vertical white dashed lines indicate sinusoid maxima and minima times. (b)–(e) GNSS dTEC maps corresponding to the skip distance maxima and minima times indicated in (a). A black arrow is drawn on (d) indicating the estimated horizontal wavelength ($\lambda_h \approx 1680$ km) and direction of travel ($\alpha \approx 163°$) of the GNSS LSTIDs corresponding with the amateur radio LSTIDs. A decrease of ∼0.2 TECu is observed in the central region of the maps during skip distance maxima, while an increase of ∼0.2 TECu is observed during skip distance minima. Movie versions of this figure are provided in Supporting Information S1 and S2.

skip distance minimum. This can be attributed to smaller-scale variations consistent with MSTIDs mixing with the LSTID activity.

We next compare the amateur radio and SuperDARN observations with GNSS dTEC measurements. Figure 1e shows a map of CONUS dTEC at 1343 UT, corresponding to the time of the first skip-distance maximum of the sinusoid in Figure 1b. LSTID wavefronts occurred with a southwest to northeast orientation, especially in the central and Eastern portions of the CONUS. 1343 UT corresponds to a negative phase of the LSTIDs over the CONUS, as indicated by dTEC values of ∼−0.2 for a large portion of the map. The black inset box in Figure 1e indicates the region from 30° to 50°N latitude and 70° to 120°W longitude. A time series of the median dTEC values within this region is presented in Figure 1f (blue line). The dotted orange line shows the data filtered with a 2–4 hr bandpass filter. Significant wave activity occurred in this time series data, and comparison to amateur radio and SuperDARN observations show a general trend: depressions in median dTEC correspond to increases in skip distance, and vice-versa. The FFT spectral analysis of the median dTEC time series shown in Figure 1g shows that the dominant spectral component of dTEC had a period of 2.4 hr, in excellent agreement with 2.5 hr oscillations measured with the sinusoid fit to the amateur radio and SuperDARN data.

Figure 2 further shows the spatial and temporal relationship between amateur radio and GNSS dTEC LSTID observations. Figure 2a presents the amateur radio data first shown in Figure 1b. The 2.5 hr sinusoid from Figure 1b is overlaid with red dots and the median dTEC values from Figure 1f are overlaid as a solid white line. The dotted sinusoid and the median dTEC values exhibit an anti-correlated relationship. Four times, corresponding with the maxima and minima of the 2.5 hr sinusoid, are identified with vertical dashed lines. Maps of GNSS dTEC observations corresponding to these times are shown in Figures 2b-2e. Results show an inverse relationship between the amateur radio skip distances observed in Figure 2a and the dTEC measurements in Figures 2b-2e. Specifically, when maxima in amateur radio skip distances occur at 1343 and 1613 UT, a decrease of ∼0.20 TECu is observed in the central regions of the maps. Conversely, when minima in amateur radio skip distances occur at 1458 and 1728 UT, an increase of ∼0.20 TECu is observed. Wavefronts oriented from southwest to northeast can be observed in the dTEC maps. This is most clearly seen in Figure 2d, where a black arrow indicates the estimated horizontal wavelength ($\lambda_h \approx 1680$ km) and propagation azimuth ($\alpha \approx 163°$) of the largest wave feature in the map. Movie versions of Figure 2 showing the full progression of dTEC with time are provided in Supporting Information S1 and S2. Using this movie and the open-source Tracker Video Analysis and Modeling tool (Brown & Cox, 2009), the phase speed of the southeastward propagating LSTID trough between 1300 and 1400 UT was estimated to be ∼1220 km hr^{-1}.

In order to estimate the phase speed of the LSTIDs in the amateur radio data, Figure 3 shows time series of latitudinal and longitudinal data slices plotted using a saturated filled contour from 1400 to 1800 UT. This time range is centered around the 1618 UT skip distance maximum identified in Figure 2a. The top four rows show 1° latitudinal slices that range from 42° to 38°N and extend from 88° to 74°W longitude. The bottom four rows show 2° longitudinal slices that range from 85° to 79°W and extend from 37° to 44°N latitude. Red arrows indicate the time of the skip distance maxima manually identified in each time series plot. The arrows in the latitudinal slices indicate a steady forward progression in time from the slice centered at 41.5°N to the one centered at 39.5°N, consistent with a north-to-south propagating LSTID. Using a linear regression of distance traveled versus time, the north-to-south phase velocity was estimated to be ∼1,206 km hr^{-1}. Note that the skip distance maximum in the 38.5°N slice appeared to move backwards in time. We ascribe this non-coherent behavior (compared to higher latitude bins) to the multi-dimensional complexity of the wave field the radio signals propagated through at that time. The red arrows in the longitudinal slices (Figure 2b) show almost no progression with time, which is consistent with a predominantly north-south propagating LSTID that has east-west oriented wavefronts spanning the entire longitudinal observational range.

3.2. Geomagnetic Conditions and Auroral Zone Drivers

Figure 4 shows evidence of auroral zone activity preceding the midlatitude observation of LSTIDs by amateur radio. Signatures of two AE enhancements can be seen in Figure 4a, where the SME index first peaked to ∼500 nT between 10 and 12 UT, and then subsequently increased to ∼700 nT between 12 and 13 UT. Figure 4b presents the regional SME index, which indicates that these enhancements occurred within the 22–04 magnetic local time (MLT) sector. This occurs during the recovery phase of a minor geomagnetic storm with Kp ≤3+ and minimum Sym-H ≈ −30 nT at 00 UT. Figure 4c shows that these electrojet surges were associated with electron density enhancements from 90 to 150 km altitude as measured by PFISR, whose observation point migrated from 2125 MLT at 8 UT to 0230 MLT at 13 UT. These electron density enhancements were also associated with significant Joule heating measured by PFISR at these same altitudes, as shown in Figure 4d. Figure 4e again presents the amateur radio data in a similar format to Figure 1a, now starting at 08 UT. Figure 4e shows that the TIDs are observed at midlatitudes by the amateur radio networks ∼2–3 hr after the onset of auroral zone activity. Note that no radio spots were observed between 8 and 12 UT because of a lack of 14 MHz radio propagation, due to lower nighttime mid-latitude ionospheric electron densities.

The large-scale nature of the observed mid-latitude LSTIDs and their predominantly equatorward propagation suggest that an auroral zone source is likely. We can relate the TID observations to the auroral zone disturbances by estimating the location of the source region using the measurements of LSTID phase speed, propagation azimuth, and timing. To estimate the location of the LSTID source region, we start at the point corresponding to the arrow tail in Figure 2d at the top of the LSTID observation region (44°N, 93°W). We then project backwards from the 163° propagation azimuth at the phase speeds determined using the amateur radio and GNSS dTEC data. A low estimate using a 2 hr propagation time and 1,100 km hr^{-1} speed places the source region at geographic (62°N, 105°W) and magnetic (70°N, 43°W, 0239 MLT). A high estimate using a 3 hr propagation time and 1,300 km hr^{-1} speed places the source region at geographic (76°N, 132°W) and magnetic (77°N, 87°W, 2341 MLT). Both of these estimates place the source region in areas consistent with the AE enhancement observed using the SME index and the Joule heating enhancement observed using the PFISR radar. This supports the hypothesis that LSTIDs are generated by AGWs generated by auroral zone Joule heating and particle precipitation (e.g., Hunsucker, 1982; Lyons et al., 2019).

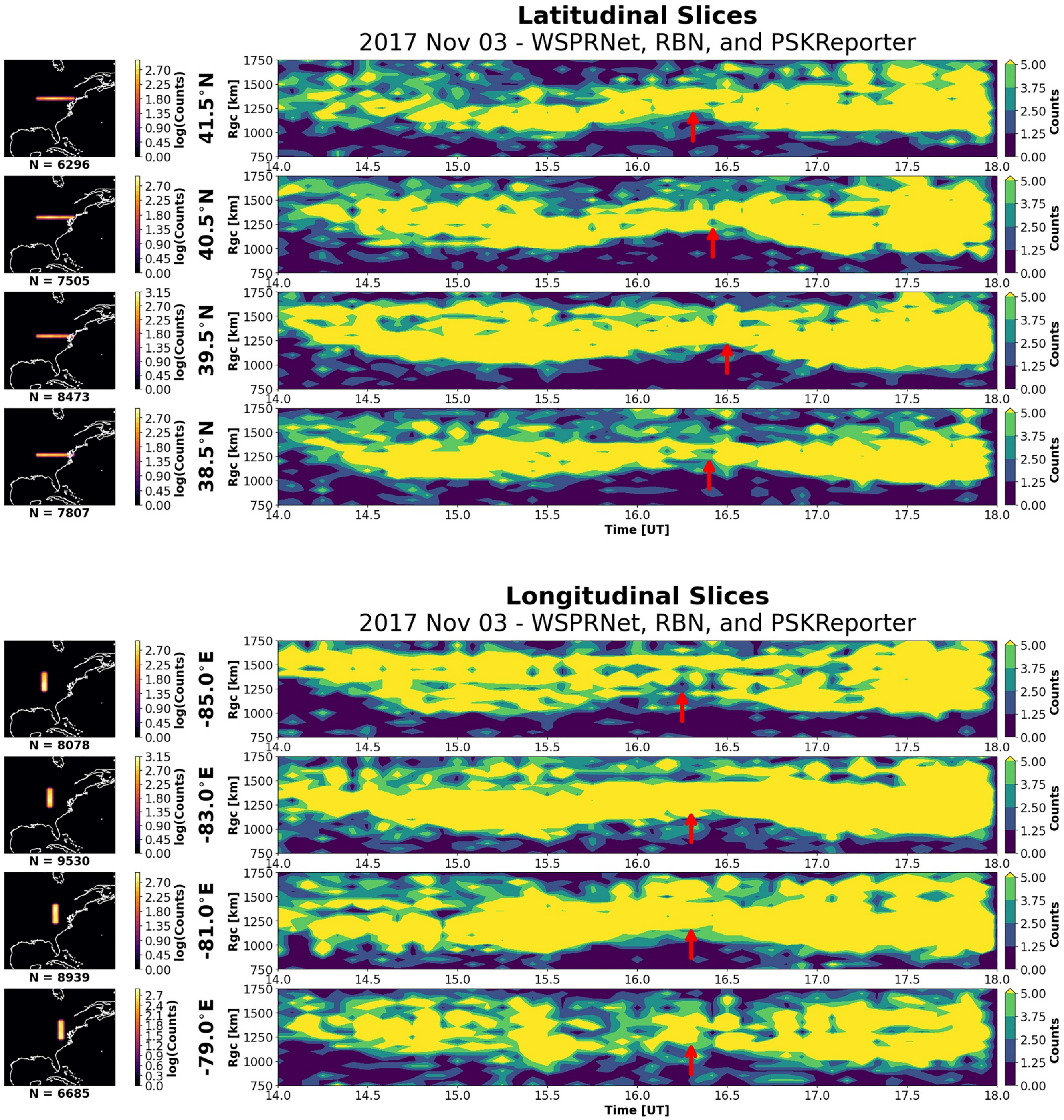

Figure 3. Plots of amateur radio data in latitudinal and longitudinal slices to estimate the phase speed of the LSTIDs. The top four rows show 1° latitudinal slices that range from 42° to 38°N and extend from 88° to 74°W longitude. The bottom four rows show 2° longitudinal slices that range from 85° to 79°W and extend from 37° to 44°N latitude. Red arrows indicate the time of the skip distance maxima manually identified in each time series plot.

4. Discussion

We used data from large-scale, automated, crowd sourced amateur radio networks to observe the effects of LSTIDs on 14 MHz HF communications paths over the continental United States. These observations are in excellent agreement with skip-distance measurements made by the Blackstone, VA SuperDARN radar and dTEC measurements made by ground-based GNSS receivers. Observations of LSTIDs by these amateur radio networks

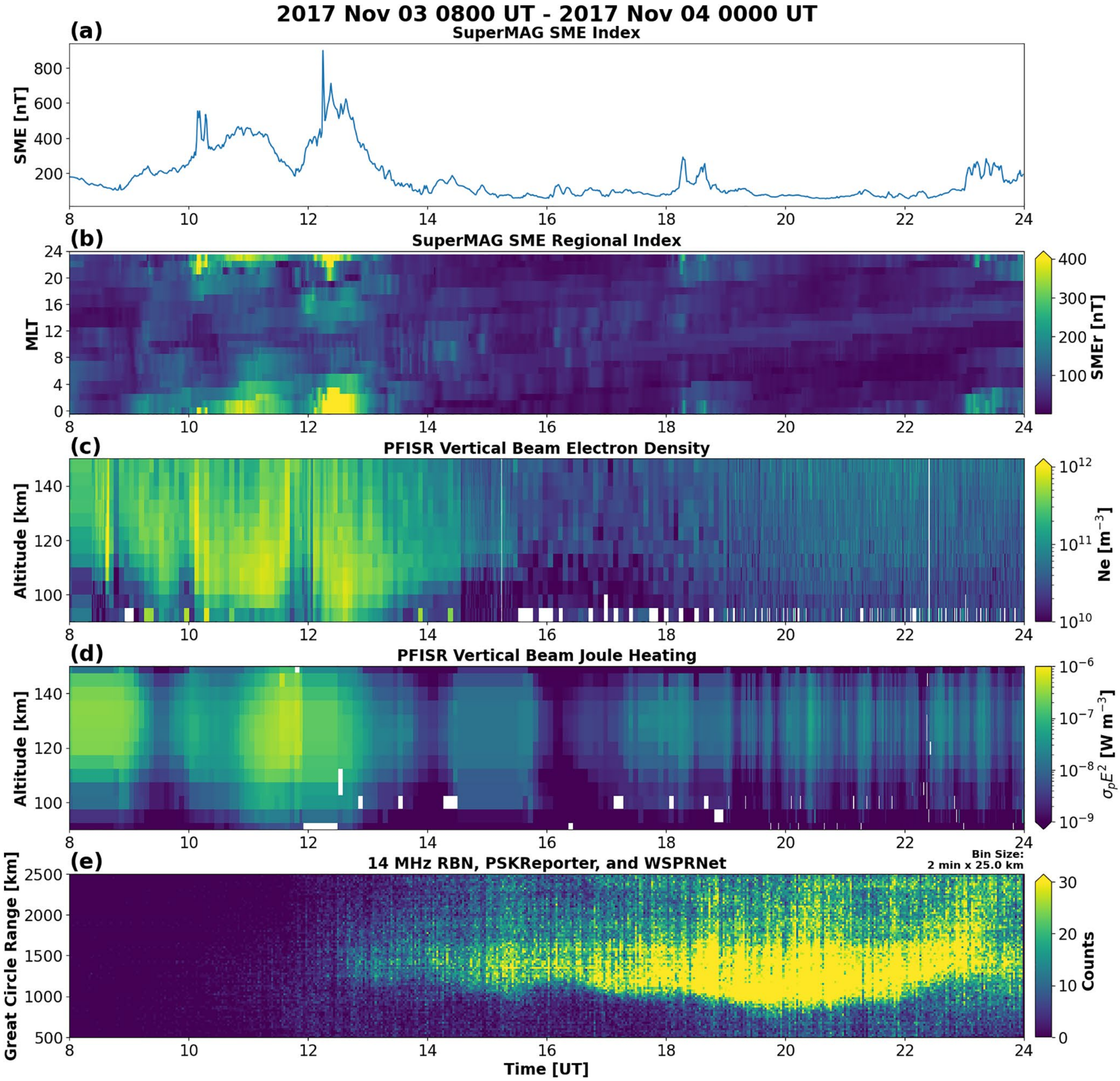

Figure 4. Measurements of auroral zone activity followed by midlatitude amateur radio LSTID observations for 0800 UT 3 Nov 2017–0000 UT 4 Nov 2017. (a) SuperMAG Electrojet (SME) Index. (b) Regional SuperMAG Electrojet Index. (c) Poker Flat Incoherent Scatter Radar (PFISR) vertical beam electron density measurements. (d) PFISR vertical beam Joule heating measurements. (e) Time series showing the TX-RX distance for continental U.S. 14 MHz RBN/WSPRNet/PSKReporter amateur radio spots in 2 min by 25 km bins.

are significant for two reasons. First, these observations demonstrate a novel technique for the scientific study and characterization of LSTIDs. The RBN, WSPRNet, and PSKReporter amateur radio networks have global-scale data that extends over an entire solar cycle back to 2008 and simultaneously observes multiple frequency bands from 1.8 to 30 MHz. These datasets have the potential to complement and extend existing professional instrumentation networks both in geographic and spectral extent. The results here indicate that these datasets are appropriate for statistical searches of LSTIDs similar to Frissell et al. (2016), and such analyses can provide further understanding of the nature of LSTIDs and their connection to space and the neutral atmosphere. Secondly, this new technique now allows LSTID impacts on actual HF communications systems to be assessed and directly related to measurements made by professional scientific instrumentation. This has the potential to enable the future development of methodologies to better understand and potentially predict the impacts of space weather and the atmosphere on HF communications systems.

While we have highlighted the agreement of the amateur radio, SuperDARN, and GNSS dTEC TID observations, it is also important to note some of the differences and recognize that each technique does in fact provide a unique view of the ionosphere. Amateur radio and SuperDARN both sense TIDs through bottomside oblique HF ionospheric sounding and therefore have similar measurements. Still, the amateur radio observations are able to show a continental-scale ionospheric behavior that may not be appreciated with SuperDARN radars. Conversely, SuperDARN is able to better resolve fine-scale TID structures than the amateur radio technique.

It is also not reasonable to assume a strict one-to-one mapping of TIDs observed with the bottomside HF sounding techniques and the GNSS dTEC technique. GNSS TEC is a height integrated measurement that is not guaranteed to be sensitive to ionospheric structures at the same altitudes as the HF systems. This is evidenced in the backward phase progression seen at 38.5°N in Figure 3. This dichotomy has been reported in other studies. Chilcote et al. (2015) showed, for example, that TIDs detected using Doppler shift observations of AM broadcast signals propagated in the opposite direction of TIDs detected with GNSS dTEC. In general, we emphasize that different techniques may be useful for extracting greater information through collective multi-technique study of a single event, and also emphasize that each technique may provide unique information in its own right.

This paper demonstrates only the first example of using amateur radio networks to study LSTIDs. Future work includes automating amateur radio LSTID detection, improving the ability to localize LSTID measurements and estimate propagation direction, conducting statistical studies, and working toward the development of methods to better resolve smaller-scale features such as MSTIDs. There are also important implications for ionospheric citizen science, as the HamSCI Personal Space Weather Station project (Collins et al., 2021) will be capable of contributing to both the WSPRNet and PSKReporter datasets. We recognize that the amateur transmissions employed here are not guaranteed to be regular or continuous. Therefore, certain challenges exist in extending this technique to a larger statistical study. However, these data gaps are similar in nature to gaps due to propagation conditions in the SuperDARN data set and could be addressed in a manner similar to Frissell, Baker, et al. (2014) and Frissell et al. (2016). Additionally, a manual LSTID climatology for 2017 by Sanchez et al. (2021) shows that sufficiently regular amateur radio observations exist to support statistical studies, especially over North America and Europe.

5. Summary

We demonstrated a novel method for observing Large Scale Traveling Ionospheric Disturbances (LSTIDs) using high frequency (HF) amateur radio reporting networks, including the Reverse Beacon Network (RBN), Weak Signal Propagation Reporter Network (WSPRNet), and PSKReporter. On Nov 3, 2017, LSTID signatures were observed simultaneously over the continental United States in amateur radio, SuperDARN HF radar, and GNSS TEC with a period of ∼2.5 hr, propagation azimuth of ∼163°, horizontal wavelength of ∼1,680 km, and phase speed of ∼1,200 km hr^{-1}. SuperMAG SME index enhancements and Poker Flat Incoherent Scatter Radar measurements suggest the LSTIDs were driven by AE intensifications and Joule heating. This novel measurement technique has applications in future scientific studies and for assessing the impact of LSTIDs on HF communications.

Data Availability Statement

Amateur radio data from the Reverse Beacon Network (RBN), Weak Signal Propagation Reporter Network (WSPRNet), and PSKReporter used in this paper has been aggregated and deposited into a Zenodo repository (Frissell & Engelke, 2021). SuperDARN data used in this paper is available from Ruohoniemi et al. (2022) and can be visualized with the open-source pyDARN toolkit (Schmidt et al., 2021). SuperMAG data are available from SuperMAG database (SuperMAG CEDAR Madrigal Database, 2022). The Kp and SymH indices were accessed through the OMNI database at the NASA Space Physics Data Facility (NASA CDAWeb, 2022). We acknowledge the 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). The GNSS TEC and Poker Flat Incoherent Scatter Radar data are available for download from the Madrigal database system maintained by Massachusetts Institute of Technology's Haystack Observatory (CEDAR Madrigal Database, 2022). Data for the TEC processing is provided from the following organizations: UNAVCO, Scripps Orbit and Permanent Array Center, Institut Geographique National, France, International GNSS Service, The Crustal Dynamics Data Information System (CDDIS), National Geodetic Survey, Instituto Brasileiro de Geografia e Estatística, RAMSAC CORS of Instituto Geográfico Nacional de la República Argentina, Arecibo Observatory, Low-Latitude Ionospheric Sensor Network (LISN), Topcon Positioning Systems, Inc., Canadian High Arctic Ionospheric Network, Institute of Geology and Geophysics, Chinese Academy of Sciences, China Meteorology Administration, Centro di Ricerche Sismologiche, Système d'Observation du Niveau des Eaux Littorales (SONEL), RENAG: REseau NAtional GPS permanent, GeoNet - the official source of geological hazard information for New Zealand, GNSS Reference Networks, Finnish Meteorological Institute, SWEPOS - Sweden, Hartebeesthoek Radio Astronomy Observatory, TrigNet Web Application, South Africa, Australian Space Weather Services, RETE INTEGRATA NAZIONALE GPS, Estonian Land Board, Virginia Tech Center for Space Science and Engineering Research, and Korea Astronomy and Space Science Institute.

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