

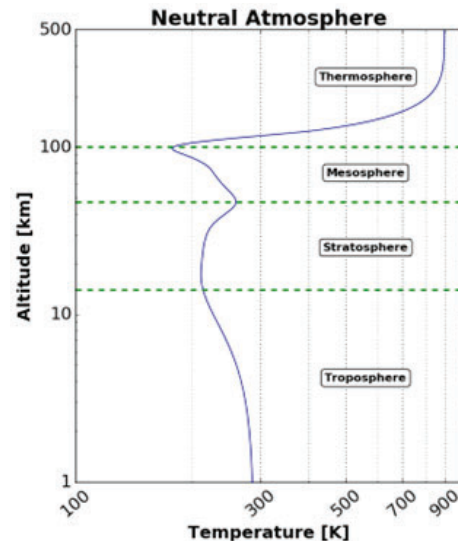


## About Traveling Ionospheric Disturbances

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On the basis of publicly available ionosphere maps, one might conclude that the ionosphere is relatively smooth in space and time. However, if you have spent much time operating on the HF bands, you know that reality is quite different — the bands are constantly changing where the openings are, fading causes signals to come and go. This article is about the science behind a common source of short-period (15-minute to several-hour) variability observed in the ionosphere: the *traveling ionospheric disturbance*, or *TID*. TIDs are an important source of variability, particularly for HF propagation, and they represent a larger source of variability that is often overlooked: the (neutral) atmosphere. (Hines 1974, <https://doi.org/10.1029/GM018p0014>)

To understand TIDs, we need to review the processes that govern the state of the ionosphere and radio wave propagation through the ionosphere. Scientists divide the neutral atmosphere into four different regions (see Figure 1). The region boundaries are defined by the temperature profile inflection points; each region has several characteristic physical properties. For example, the *troposphere*, the region closest to the surface of the Earth, is warm, moist, and subject to convective instabilities. The *stratosphere* above it is cold, dry, and very stable. The *mesosphere* above the stratosphere is still well-mixed like the layers below it — for example, in the troposphere, the relative concentrations of



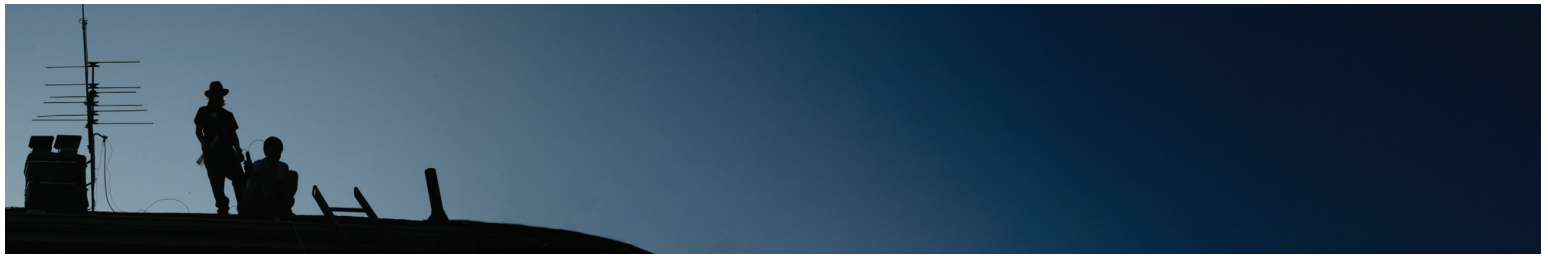
**Figure 1** — Neutral atmosphere temperature profile generated using the MSIS (Emmert et al. 2020, [www.doi.org/10.1029/2020EA001321](https://doi.org/10.1029/2020EA001321)) model for 1200 UTC 21 Jan 2013, 40°N, 80°W. Atmospheric regions are defined by the inflection points of the temperature profile.

nitrogen, oxygen, and carbon dioxide are relatively constant no matter where you are in the layer. As the atmosphere transitions from the mesosphere to the *thermosphere*, this mixing transitions to stratification (layering) by the mass (density) of the molecules, with larger molecules at low altitudes transitioning to atomic (single) hydrogen at the highest altitudes as the atmosphere transitions into space.

### Introducing Hams to the TID Phenomenon

HamSCI is interested in any physical process that impacts radio wave propagation. Amateur radio operators typically hear about the sun and space weather impacts, including those caused by solar cycles, solar flares, coronal mass ejections, geomagnetic storms, auroras, and more. In this

article, we highlight the ionosphere's connection to the neutral atmosphere and discuss a propagation phenomenon likely less familiar to amateur radio operators: *traveling ionospheric disturbances*, or *TIDs*.

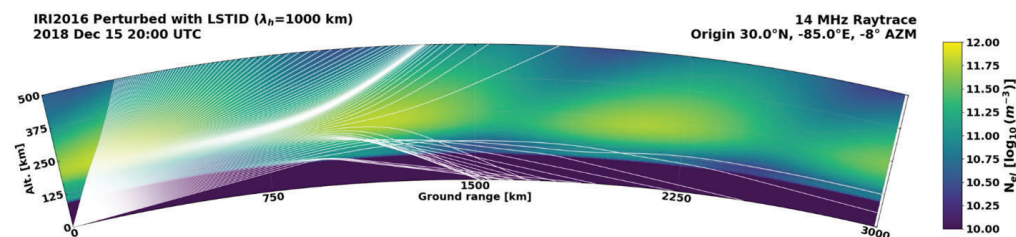


## The Role of Ionospheric Plasma

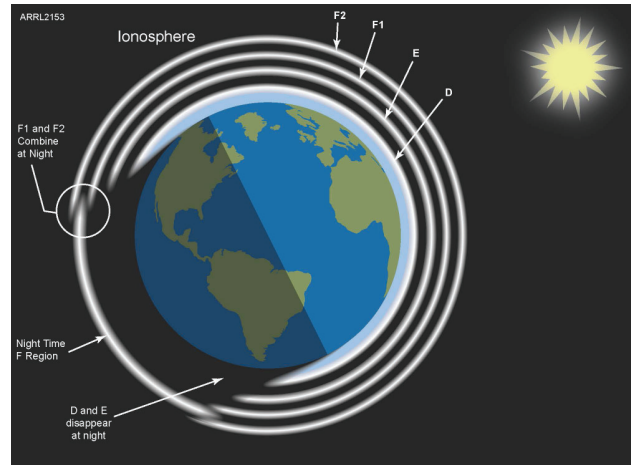
None of the foregoing discussions has treated the key parameter for skywave radio propagation: the ionospheric plasma. The ionosphere, illustrated in Figure 2, coexists alongside the mesosphere and thermosphere at altitudes from 70 km to over 700 km. A small fraction (about 3%) of the neutral atmosphere is ionized by solar EUV (extreme ultraviolet) radiation that has such high energy that it knocks loose one electron (usually, sometimes more) from the gases in the mesosphere and lower thermosphere. Unlike a neutral gas, the plasma also has electrical conductivity and behaves like a circuit, in addition to behaving like a gas. This enables skywave propagation because the index of refraction (parameter that controls the bending of a radio wave's path) in the plasma becomes a function of plasma density and radio frequency. The 14 MHz ray trace simulation shown in Figure 3 illustrates how ionospheric refraction can enable communications of 1500 km or more. (Davies 1965, [www.nvlpubs.nist.gov/nistpubs/Legacy/MONO/nbsmonograph80.pdf](http://www.nvlpubs.nist.gov/nistpubs/Legacy/MONO/nbsmonograph80.pdf))

The amount of plasma at a given location in the ionosphere is governed by a balance or continuity equation. The continuity equation for the ionosphere states that the change in electron density at a point is increased by production (ionization from the sun), decreased by loss (recombination — electrons and ions coming back together), and either increased or decreased by transport (motion of plasma from place to place).

Most of the literature available to radio amateurs focuses on the production (ionization) term because it controls the maximum amount of plasma available



**Figure 3** — Illustration of the mechanism in which Traveling Ionospheric Disturbances can cause HF fading (i.e., QSB). This simulation shows 14 MHz radio waves transmitted through an International Reference Ionosphere (IRI) model run perturbed with a TID (Bilitza et al. 2022, [www.doi.org/10.1029/2022RG000792](https://doi.org/10.1029/2022RG000792)). The ionospheric variations caused by the TID will either focus rays (i.e., strong signals, as seen around 1500 km ground range) or defocus rays (i.e., weak signals, as seen between about 1700 and 3000 km ground range). The TID will move overhead with time, causing stations on the ground to experience periodic fading as the skip focusing distance moves with the TID.



**Figure 2** — The ionosphere, created primarily by a balance between photoionization, recombination, and transport, coexists alongside the mesosphere and thermosphere at altitudes from 70 km to over 700 km. It is separated into several regions of ionized particles at different heights above the Earth. At night, the D and E regions disappear and the F1 and F2 regions combine to form a single F region. While illustrations like this one make the ionosphere look smooth and stable, reality is quite different.

and, therefore, the peak maximum usable frequency (MUF) for a specific path. Production is driven by solar EUV emissions for which the smoothed sunspot number (SSN) and 10.7-centimeter solar radio flux index (SFI) are easily observed proxies. Recombination is a more complicated function of local ion and electron densities and recombination rates (essentially probabilities) of plasma loss for different kinds of ions. Introduction of recombination into this discussion serves two purposes: 1. awareness of the process; 2. recombination produces weak light emissions (similar

to the auroras, but much lower energy and much weaker) from the ionosphere that may be used as tracers for ionospheric structures. These “airglow” emissions are not shown in this article, but they are a popular way to study nighttime TIDs.

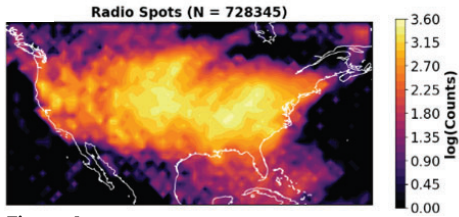
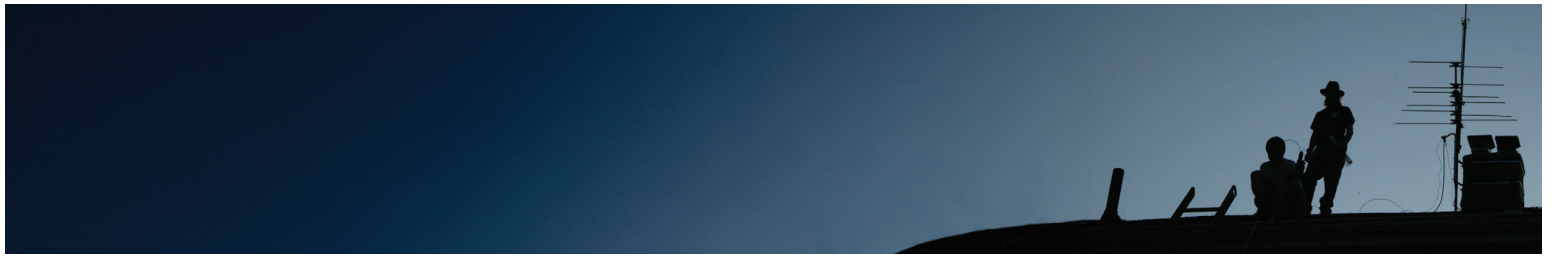


Figure 4a

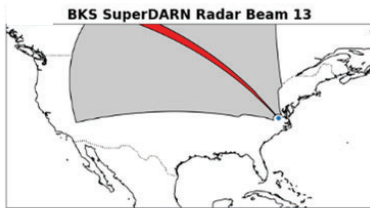


Figure 4b

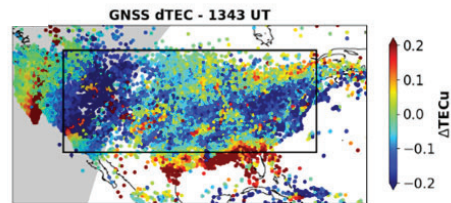


Figure 4c

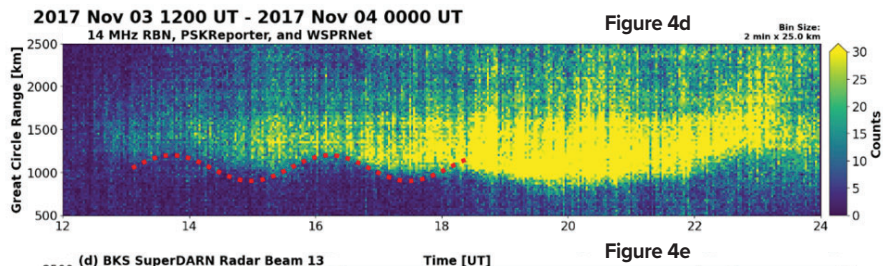


Figure 4d

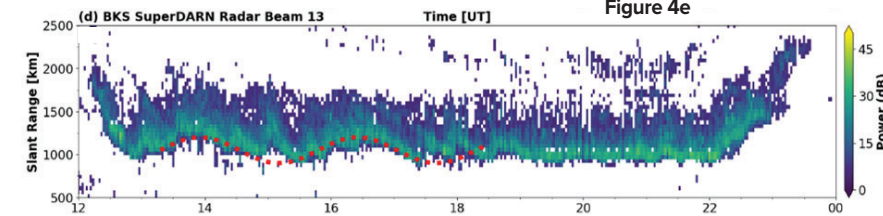


Figure 4e

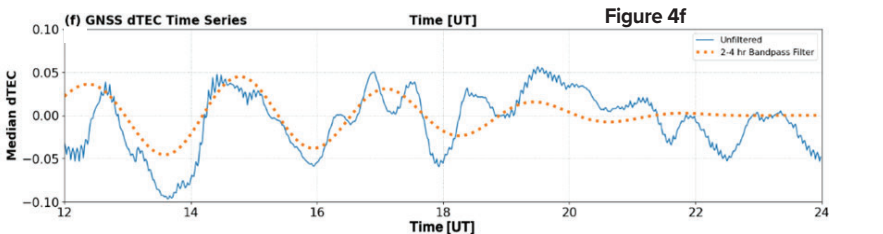


Figure 4f

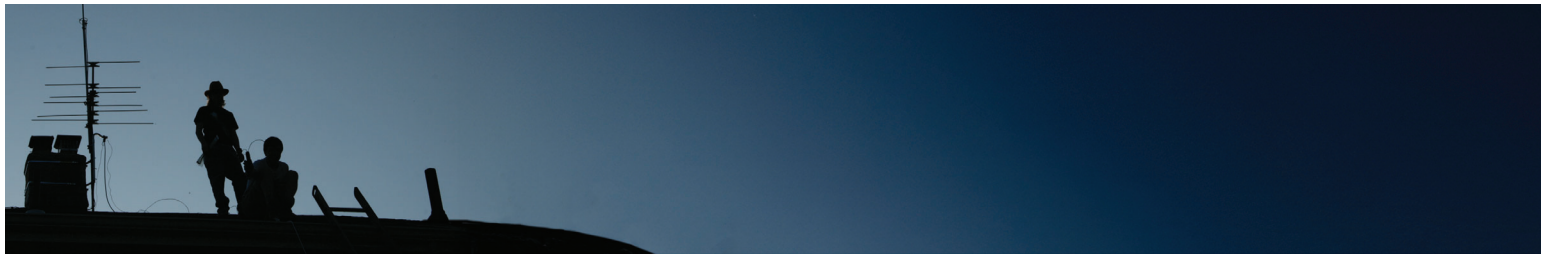
**Figure 4** — Example of Large Scale Traveling Ionospheric Disturbances (LSTIDs) observed using (a & d) amateur radio networks, (b & e) the Blackstone (BKS) SuperDARN radar, and (c & f) Global Navigation Satellite System (e.g., GPS) differential Total Electron Content (dTEC). Dots overlaid on (d) and (e) show a sinusoidal 2.5 hr oscillation in skip distance common to both the amateur radio and SuperDARN observations. (From Frissell et al., 2022, <https://doi.org/10.1029/2022GL097879>).

## The Matter of Transport

The final term of the continuity equation is transport. As we discussed previously about the atmosphere, the layers of the ionosphere also have key physical characteristics: the D region (70 – 90 km) is dominated by collisions between ions and neutral atoms — this is what produces the absorption we observe on lower frequencies during daylight; the E region (90 – 120 km) is dominated by collisions between electrons and ions, as well as electrons and neutrals; the F region (above 120 km) transitions from the E region properties to being almost completely collision-less at altitudes above the F-region peak density around 300 – 350 km. Collisions between plasma constituents (ions and electrons) result in recombination described previously; collisions between the neutral constituents and the plasma result in one form of transport: neutral wind. Winds in the mesosphere and lower thermosphere “push” plasma around. In the D and E regions, the collision rates are great enough that the plasma follows the flow of the wind faithfully. In the F region, the collision rates are lower, and the plasma tends to move easily only along the geomagnetic field.

## Atmospheric Gravity Waves

Revisiting the neutral atmosphere (no charged particles) for a moment, the atmosphere is a fluid; so, like bodies of water, it supports buoyancy waves — a displacement of the fluid is restored by gravity, for example, a rock thrown into a calm pond or puddle. Likewise, for the atmosphere, tropospheric winds blowing over a mountain range, for example, produce buoyancy waves in the atmosphere. These are called “atmospheric gravity waves” because gravity is the restoring force. (These should not be confused with “gravitational waves” produced by black holes, which are a completely different and unrelated process.) Like waves at the beach, many gravity waves produced in the lower atmosphere “break” as the atmosphere becomes “thinner” (less dense) in the stratosphere and mesosphere. Breaking gravity waves are responsible for wind shears thought to



contribute to the formation of sporadic-E layers. Gravity wave breaking can occur at multiple different altitudes in the atmosphere, each time creating new, higher-order gravity waves that continue propagating upward. Ultimately, these gravity waves can reach the thermosphere and interact with the plasma of the lower F region via the collisional process described previously.

The gravity waves in the thermosphere appear in the ionosphere as a TID that produces observable effects on HF skywave communications channels. This is illustrated in the Figure 3 ray trace. Because more than one path frequently connects stations communicating by skywave, and each path's length is affected differently by the passage of the TID, constructive and destructive interference between the waves on multiple paths produce potentially strong peaks and deep fades on some paths. Furthermore, the orientation of TID wavefronts with respect to the geomagnetic field introduces gradients that focus and defocus bundles of waves. This can also control whether the waves penetrate into the ionosphere at all. This produces the spotlight effects contest operators experience while running population centers (for example, Europe, Asia, or even parts of the US during a 160-meter contest).

### The Study of TIDs

Professional instrumentation, such as the Super Dual Auroral Radar Network (SuperDARN, <http://vt.superdarn.org/>) often used to study TIDs, and climatological studies can sometimes produce new insights into underlying mechanisms. For instance, Frissell et al. (2016, <https://doi.org/10.1002/2015JA022168>), used a climatology of SuperDARN MSTID observations to show that midlati-

tude medium scale TIDs (MSTIDs) primarily occur when the polar vortex is strong, which is typically during the late fall and early winter. MSTIDs are less likely when the polar vortex is weak, such as following a Sudden Stratospheric Warming (SSW) and during the spring and summer. For amateur radio operators, this means that 15- to 60-minute HF QSB (fading) is more likely in the fall and winter months.

It is possible to see TIDs affect amateur radio communications. Figure 4 shows a large-scale TID, which can have a period of 1 to 3 hours, observed in RBN, PSKReporter, and WSPRNet data. This observation is corroborated with independent measurements by a SuperDARN radar and Global Navigation Satellite System (e.g., GPS) differential Total Electron Content (dTEC). This figure introduces amateur radio as a novel method for studying TIDs that is not only complementary to traditional techniques, but also directly shows the impact of TIDs on real communications systems. A major HamSCI effort is under way to automate the detection of these amateur radio-observed TIDs and see what their climatology tells us. Current progress was presented at the 2025 HamSCI Workshop by Diego Sanchez, KD2RLM (see "Amateur Radio as a Scientific Tool for Understanding the Climatology of TIDs" below for more information).

While this article barely scratches the surface of the deep and complex subject of TIDs, the authors hope that readers now have a better appreciation for what the ionosphere is doing when they experience deep QSB or a long run of German stations that slowly moves to Poland and the Czech Republic.

### Amateur Radio as a Scientific Tool for Understanding the Climatology of TIDs

At the 2025 HamSCI Workshop held in March, Diego Sanchez, KD2RLM, a graduate student in software engineering at University of Scranton, presented "Climatology of Large-Scale Traveling Ionospheric Disturbances Observed with 14 MHz Amateur Radio Using a Novel Automated Detection Technique." This oral session described how KD2RLM and his colleagues used data from WSPRNet, the Reverse Beacon Network, and

PSKReporter, as well as ham radio data from 14 MHz to detect phenomena of ionospheric variability and magnetosphere-atmosphere coupling processes. The oral session, which can be viewed at <https://hamsci.org/publications/climatology-large-scale-traveling-ionospheric-disturbances-observed-14-mhz-amateur>, presents a multi-year climatology of Large Scale Traveling Ionospheric Disturbance period oscillations.