P29VXX: at the search of a DUCTING mode with Proplab Pro – Part 2

and a great article on the matter by K9LA.

by Pierluigi "Luis" Mansutti, IV3PRK

After the ray tracing, at 17:00 UTC, of all the low elevation angles, I made another run to see what happens at higher angles, from 20 to 40 degrees (Fig. 13).

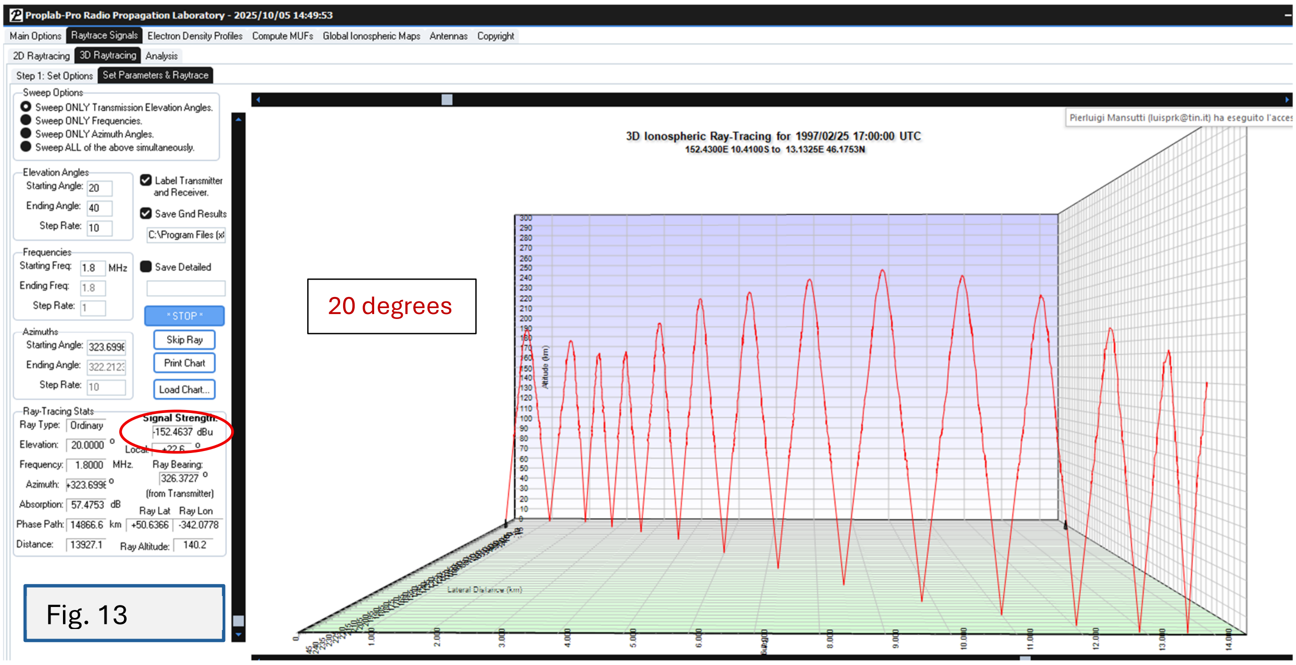

Fig. 13

At these high angles, the ray pierces the E layer along the whole path, and the only propagation mode is via F layer reflections. The absorptions are gradually decreasing for each single hop but their number increases. So, at 20 degrees, after 13 F hops the signal strength is down to -152 dBµV, and two more are required to reach the receiver (with -236 dBµV). This is what happens at 40 degr. (Fig. 14):

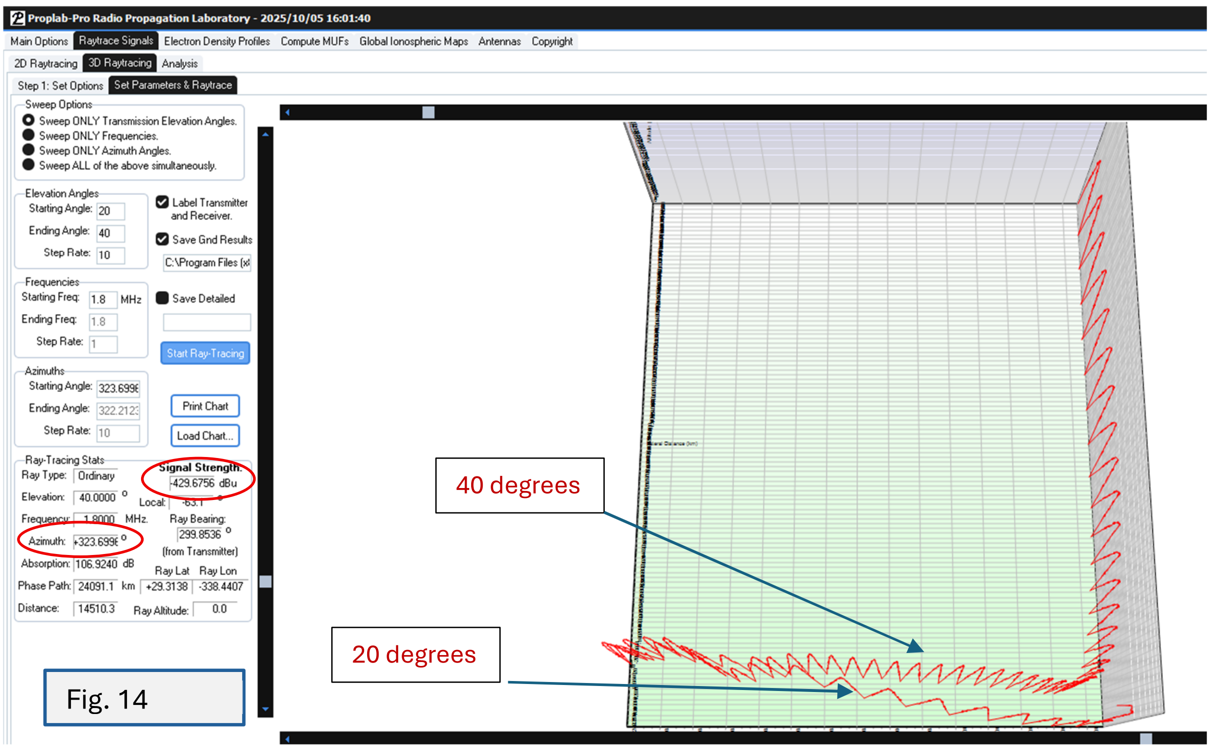

Fig. 14

The 40 degrees path, after over 30 F layer reflections, the first of which reach almost 300 km. of height - pretty unusual for 1.8 MHz signals - ends with an infinitely low, or better to say, inexistent signal strength of - 429 dBµV. But what surprises is the huge skew towards the South, from Poland to Libya, with an incredible number of very steep jumps (Fig. 15). All this has no practical effect, but it must only be seen as one of the 160 m. propagation mysteries!

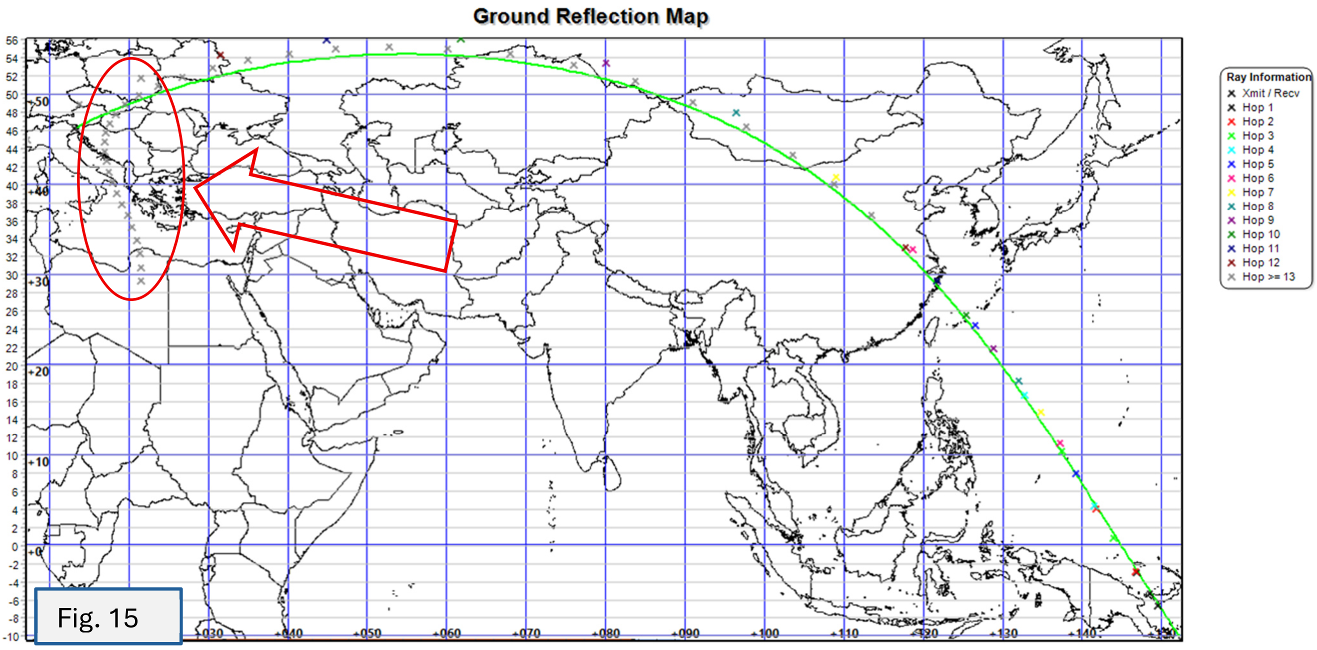

Fig. 15

Anyway, I think to have found an explanation to this skewing by examining the E layer critical frequencies, one of the available Global Ionospheric Maps in Proplab (Fig. 16). At 17.00 UTC, the E layer is going to leave Eastern Europe, which lies between sunset and the gray-line, but it's still strongly ionized and, rather than reflecting the 1.8 MHz rays, forces them to deviate along its gradients towards the South, where they continue with very short and useless F layer reflections.

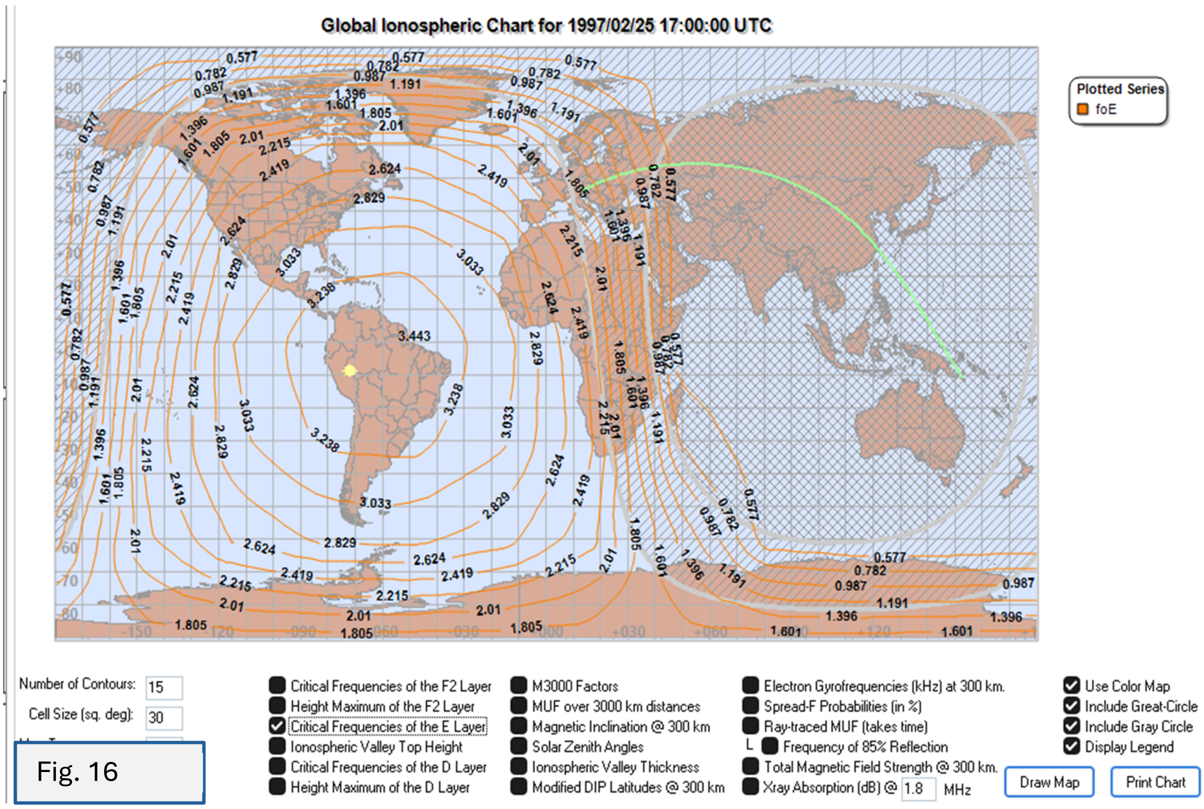

Fig. 16

Now, let's change the time of our analysis to 18.40 UTC, when the whole 14.485 km. path lies in full darkness, balanced and far from the sunset/sunrise limits as shown in Fig. 17. Unfortunately, I must cut off the screenshots of this part to further reduce the file dimensions to be uploaded, so I leave here only the test comments.

Being assured that any chance of contact could be the only at very low angles, I repeated the 3D analysis from 1 to 5 degrees at 18.40 UTC, and we see some differences with those made one hour and forty minutes before.

At 1 and 2 elevation degrees, the ray, after 7 uniform very lossy E layer hops, ends with a useless signal strength (-162, -178 dBµV). At 3 degrees, unlike to what happened at 17.00 UTC, it enters immediately in a very efficient duct, but it travels beyond the target and is unable to get out. a distance between 14 and 15 thousand km., it could find a hole - that is an irregular ionization in the underlaying E layer - too weak at that point to reflect upwards the ray, letting it go down to earth. The signal strength at the receiver could be very loud, thanks to the low absorptions accumulated (only 14 dB). Sometimes this happens, causing a typical spotlight propagation case.

But Proplab-Pro works with smoothed numbers and doesn't find daily irregularities. Thus, the ray continues its journey in the duct reaching West Africa after 17.668 km., with a - 35 dBµV/m signal strength (-118 dBm), above the MDS level of a good receiver, enough to be detected. At 4 and 5 degrees, following a first F hop, the ray enters in a full ducting mode and exits just beyond our target with good signals. These might be stronger exiting before, under spotlight conditions, but no way at higher angles.

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At last, I set the time of analysis to 20.00 UTC – sunrise on Misima is. – which was the time of my QSO with P29VXX, the only one in Italy and the European westernmost for this DXpedition: that was the reason for all this effort trying to understand the mysteries of 160 m. propagation.

Let's give a look, in Fig. 21, at the *"Plasma freq. along path"* which changed from that of Fig. 3, taken three hours before.

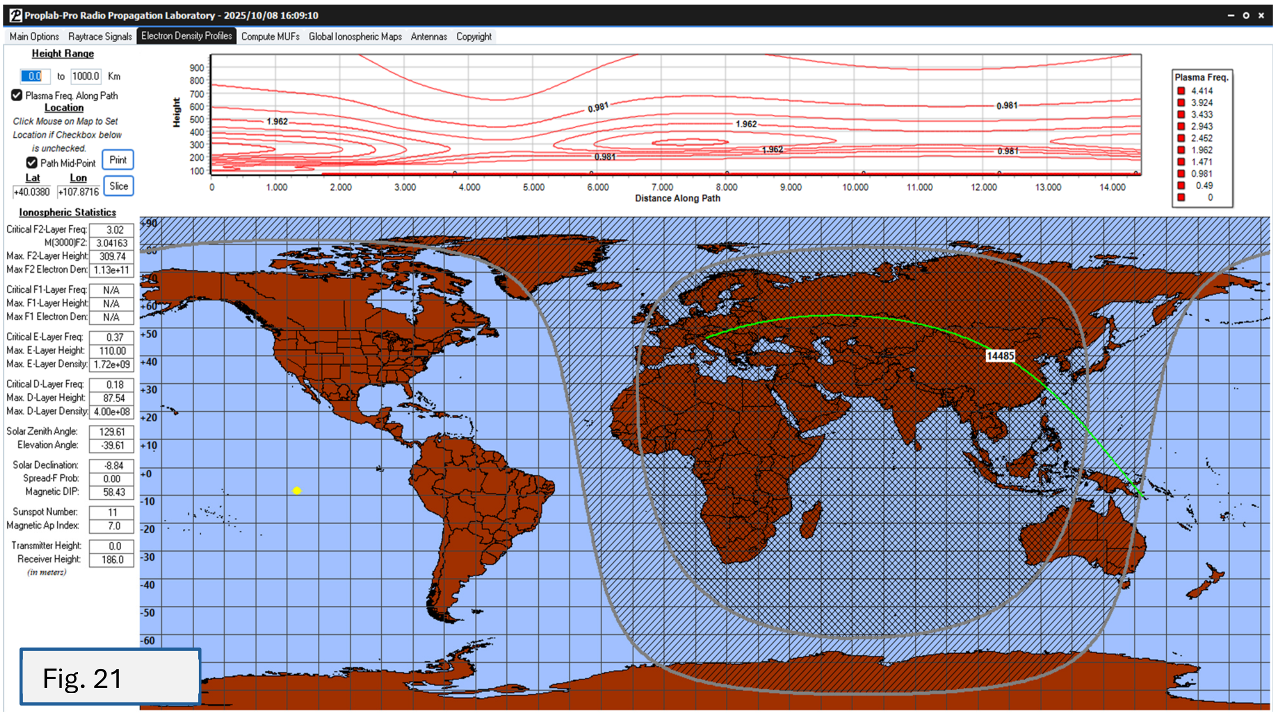


Fig. 21

Despite the differences in the plasma frequency along the path, the results of the 3D analysis at the lowest elevation angles (1 and 2 degrees) do not show any change after three hours. That is, at 1 - and only at 1 degree - the ray, after 3 E hops, enters in a very small duct and is trapped there until dying due to excessive losses, skewed to the south, just as seen before (Fig. 22).

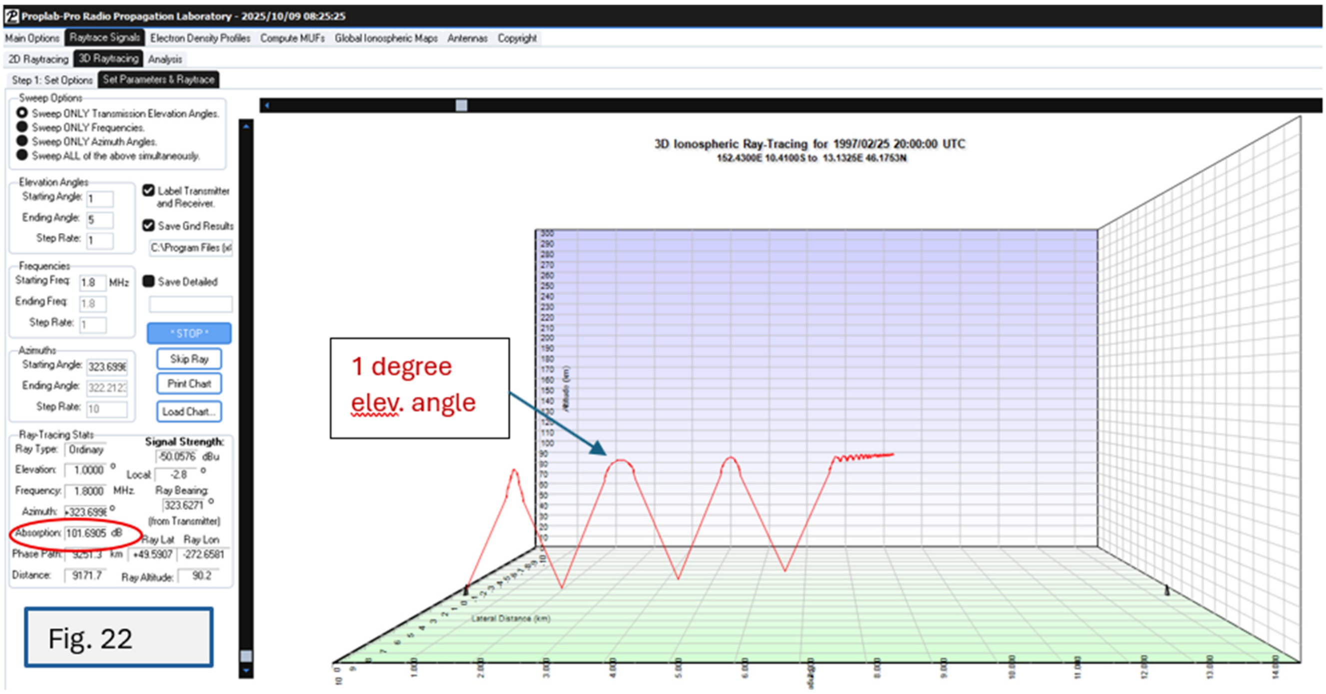


Fig. 22

At 2 degrees elevation angle the ray travels via 2,000-kilometer E layer hops but suffers about 30 dB of ionospheric and ground losses for each hop; Proplab carries it at the end with an incredible -203 dBμV signal strength but, of course, it is already useless immediately after the second hop.

At 3, 4, and 5 degrees, after a single E hop, the ray enters a very efficient duct but, again, it's unable to get out, and returns to earth after 19,000 kilometres, in the Atlantic Ocean. As mentioned previously, it's possible for the ray to encounter irregularities in the ionospheric gradients at any point - due to daily variations - which block its reflections in the duct, allowing it to descend. Probably, this was the spotlight propagation of my QSO with P29VXX (dashed lines in Fig.23).

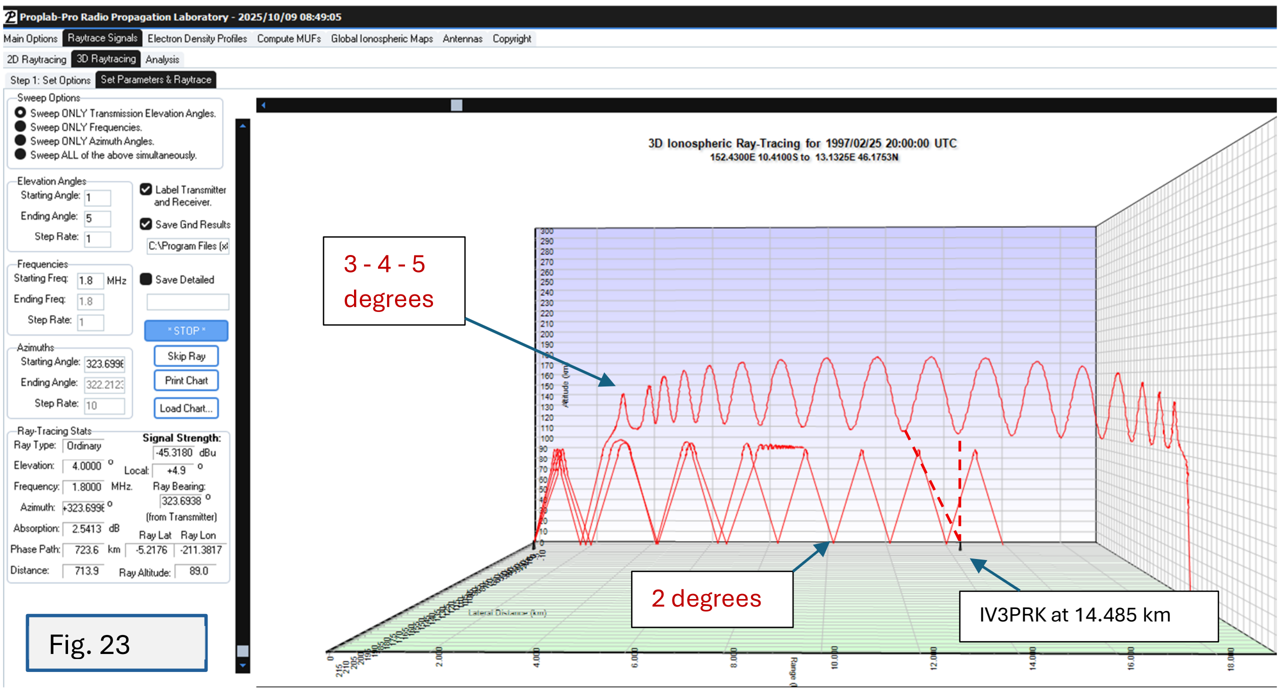


Fig. 23

In the following map, we see the points where the 160 m P29VXX ray touches ground and the relative signal strength (although extremely low) for all five elevation levels.

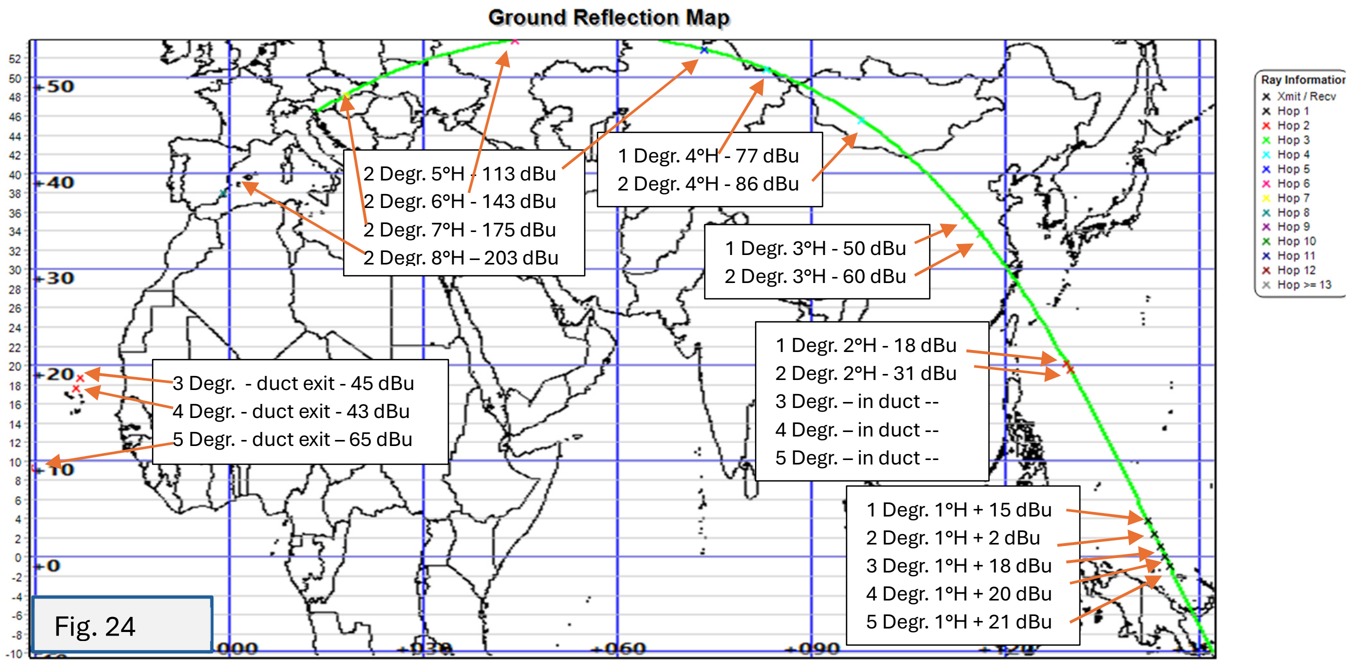


Fig. 24

We must realize that no 160-meter QSO could be possible in western Europe, neither via ordinary ionospheric hops - due to the excessive losses - nor via ducting mode - too long - unless a spotlight, i.e. the ray encounters some kind of irregularity at our latitudes and exits from the duct.

Naturally, at 3, 4, and 5 degrees - being in the duct - there is no trace of the ray until its exit point, which is much further away than the previous ones. The ducting mode propagation extends well beyond the intended path towards Northern Italy, reaching Cape Verde islands area (Fig. 24).

Let's check, at this time, 3D ray tracing at next higher angles: at 6 degrees we see a ducting mode very similar to 5 degr., reaching Cape Verde islands, while at 8 degrees, after two E hops, due to the higher elevation angle, the ray reaches the lower part of the F layer and makes two F hops before entering in a short ducting mode and exits in northern Italy, but with a weak signal (-79 dBμV), which was already reduced by absorptions and ground reflection losses in the first four hops. (Fig. 25).

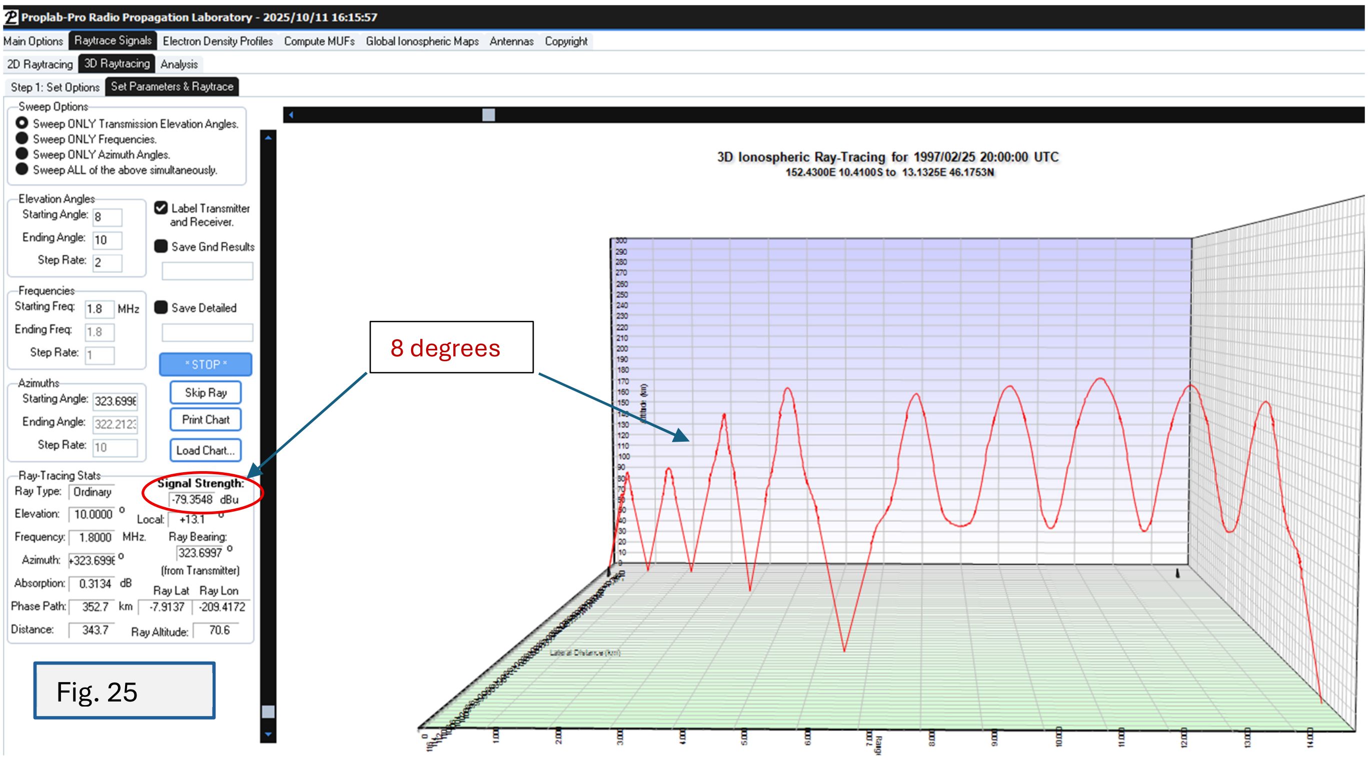
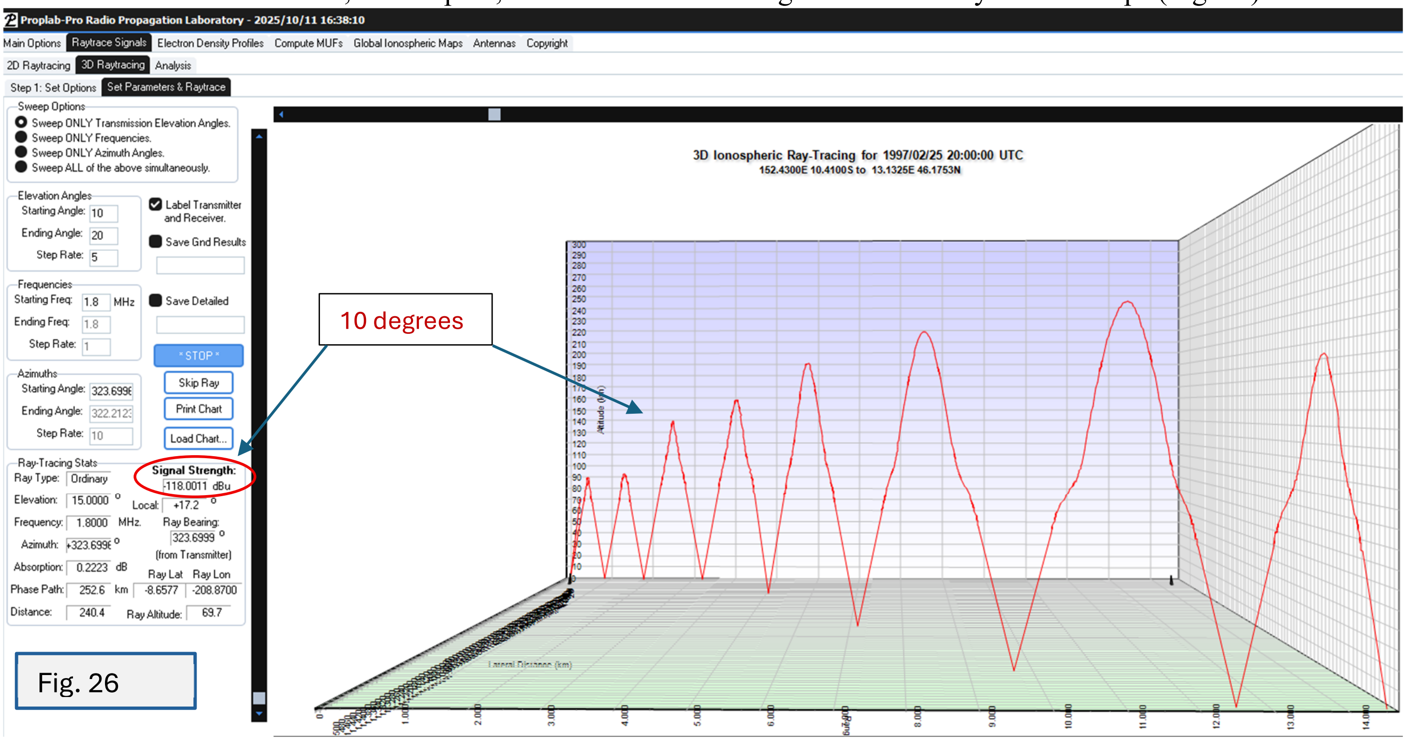
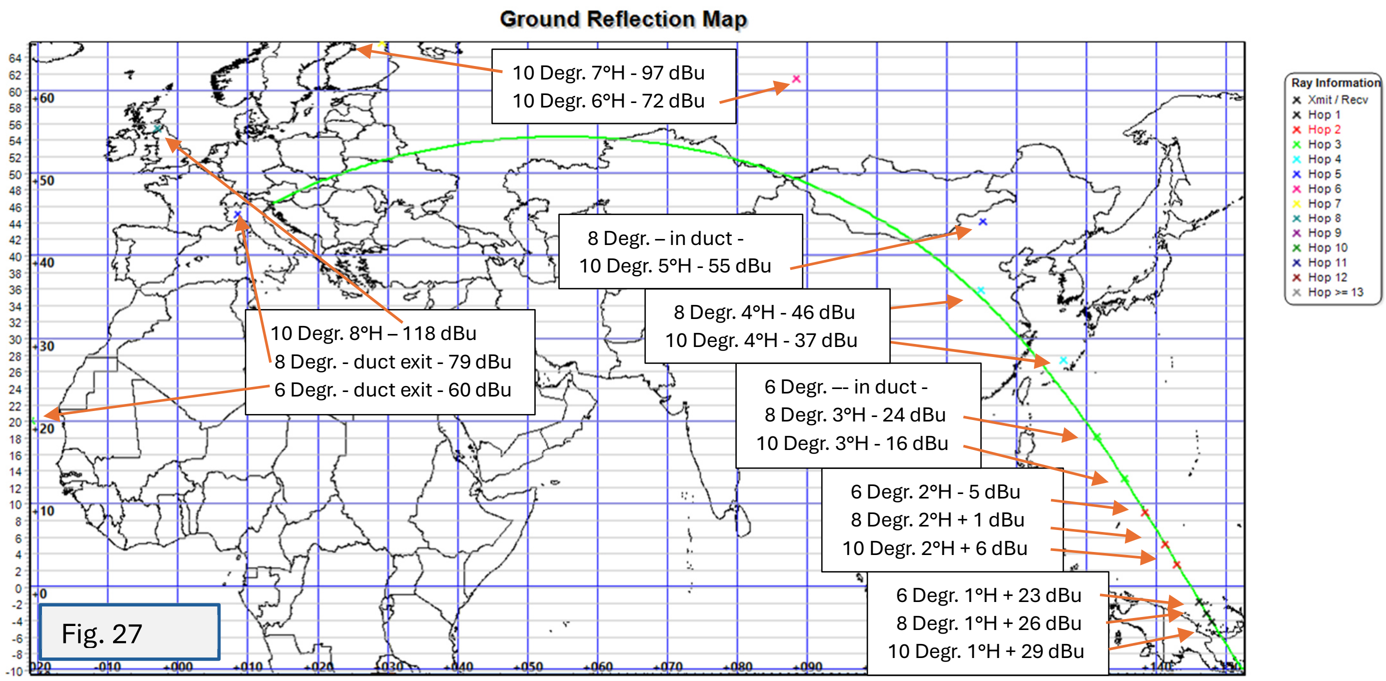


Fig. 25

Beginning at 10 degrees of elevation, ducting is no more encountered, and the only propagation mode on 160 meters, on this path, occurs via an increasing number of lossy E and F hops (Fig. 26).



Noteworthy is the pronounced skew to the northern direction which begins at elevation angle of 10 degrees carrying the ray to end up in Scotland, as well shown in the following map (Fig. 27).



As a conclusion of this ray tracing analysis of P29VXX path to Europe on February 25, 1997, we see that, if any chance of a 160-meters contact happened, it was at very low elevation angles – between 3 and 8 degrees – by means of ducting propagation mode but if, and only if, some hole or irregularity occurred in the ionosphere underlaying the duct, due to daily solar or geomagnetic variations: a case of not predictable SPOTLIGHT propagation. Proplab Pro v.3 uses the *"2007 International Reference Ionosphere"* which is, for all intents and purposes, smooth and homogeneous, and does not reflect the daily real-world variations.

P29VXX was transmitting on the *Titanex* vert. antenna, and IV3PRK was receiving on a well performing 4-square phased vertical array, both with very low angles, thus making possible the QSO.

A last run from 15 to 25 degrees confirms that, as we rise the elevation angle, the reflections are sharper, with reduced single absorption losses, due to the more vertical incidence through the ionosphere, but the skip distance is increasingly shorter and thus many more are needed to cover the whole path. As the elevation angle is raised, the ray enters more deeply in the F layer (Fig. 28).

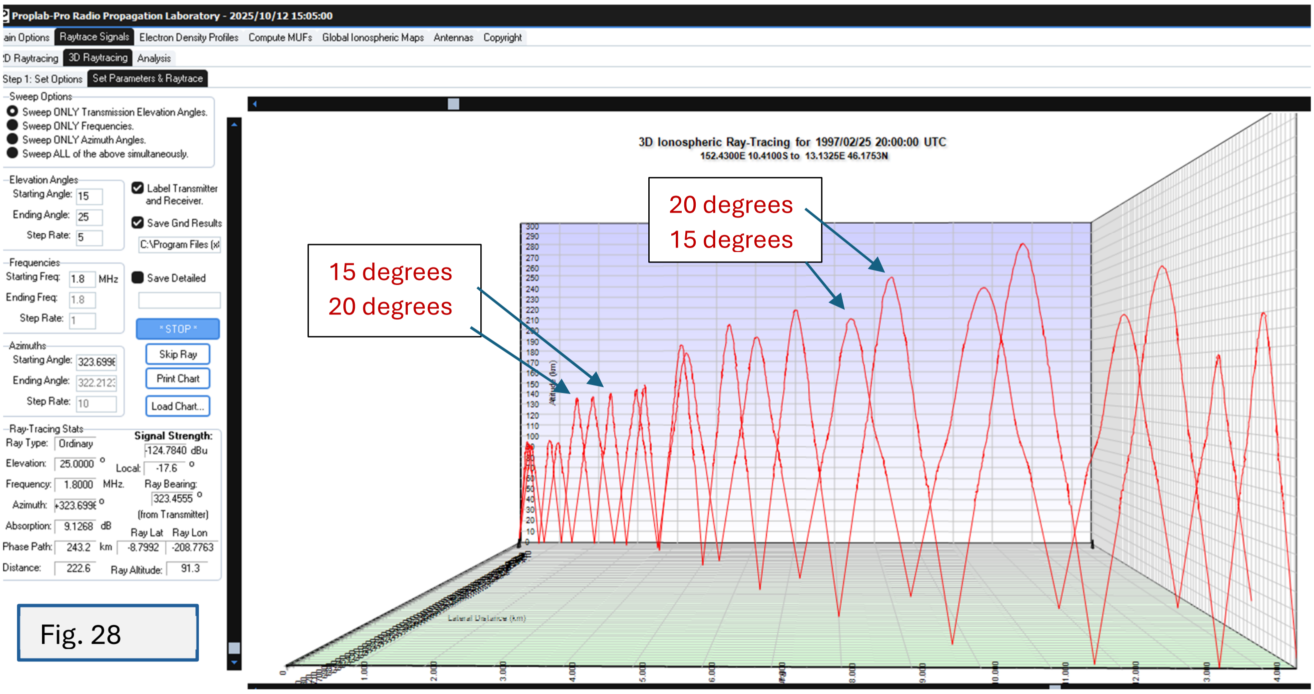


Fig. 28

Furthermore, confirming the trend which began at 10 degrees, as the angle is raised, the ray is skewed towards north, but the absorptions are so high to render the signal strength useless in the second half of the path, as shown in Fig. 29.

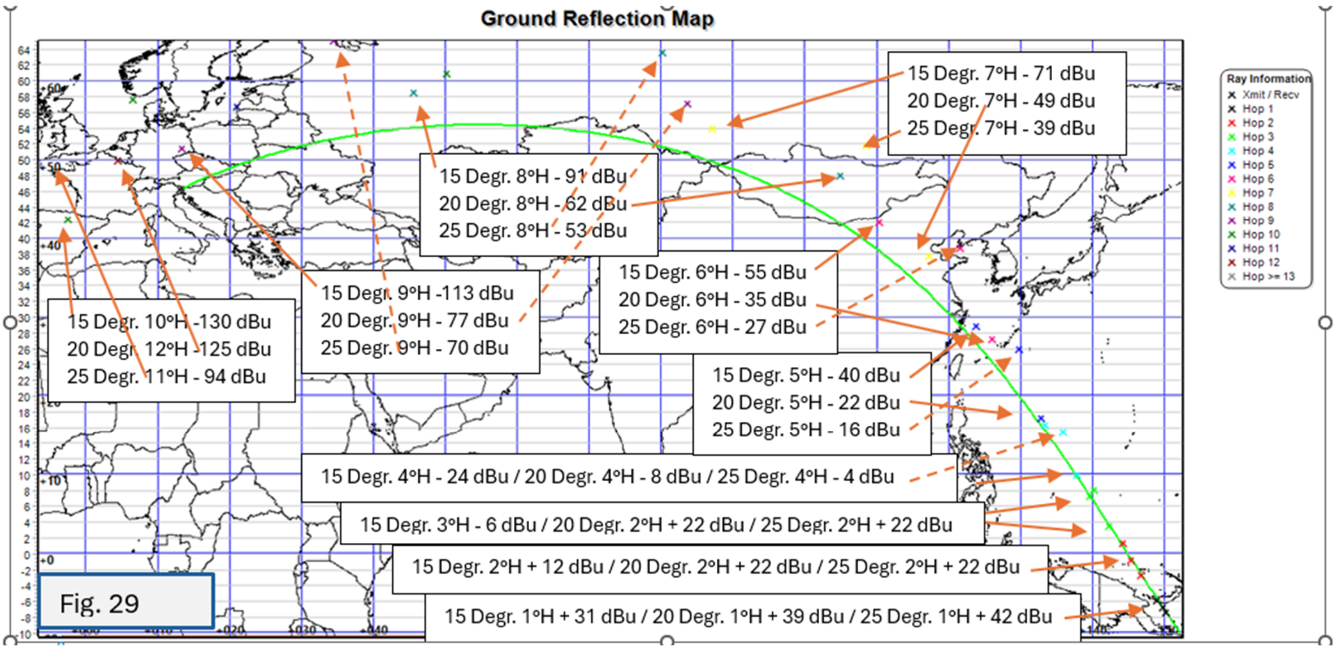


Fig. 29

In summary, Proplab Pro's advanced ray tracing method does not agree with Prof. Brown, NM7M, earlier analysis. Bob used an older Proplab version and found no evidence of ducting to Europe, attributing my QSO with P29VXX to standard ionospheric reflections. However, all the iterations performed with Proplab-Pro version 3, at all radiation angles and at different times, demonstrated that no QSO was possible on 160 via normal E- or F-layer reflections, neither at low nor high elevation angles, due to prohibitive losses. The only possibility could be provided by exceptional propagation conditions focused on very narrow areas—SPOTLIGHT, in fact—after a long ducting journey, achievable only at very low radiation angles.

To reinforce my conclusions, I add some extracts of a very interesting article written by Carl Luetzelschwab, K9LA, in 2005 and published on December issue of *CQ Magazine* with the title: *"Ducting and Spotlight Propagation on 160m",* downloadable from my website.

It's a follow-up of another great article published in *CQ Magazine* of March and April 1998 by Cary Oler (Solar Terrestrial Dispatch) and T. Cohen, N4XX: *"The 160-Meter Band: An Enigma Shrouded in Mystery"* also downloadable from "Propagation" page (at the bottom) of my website.

Carl, after analysing with Proplab the ST0RY path to his QTH in Indiana (another German DXpedition in March 2003), concluded with these comments:

The physical mechanism for ducting.

«As Oler and Cohen mentioned in their article, there is a good reason for ducting to occur on 160m. To see this, let's look at the electron density versus altitude at the midpoint of the path at 0330 UTC. Figure 3 shows what an electromagnetic wave would see along the path as it travels from STØRY to my QTH. The horizontal axis is electron density (per cubic meter) and the vertical axis is height above ground in km. (*It's, clearer, the same type of ionospheric profile we have seen before, in part 1 and Fig. 4, concerning the path from P29VXX to IV3PRK).*

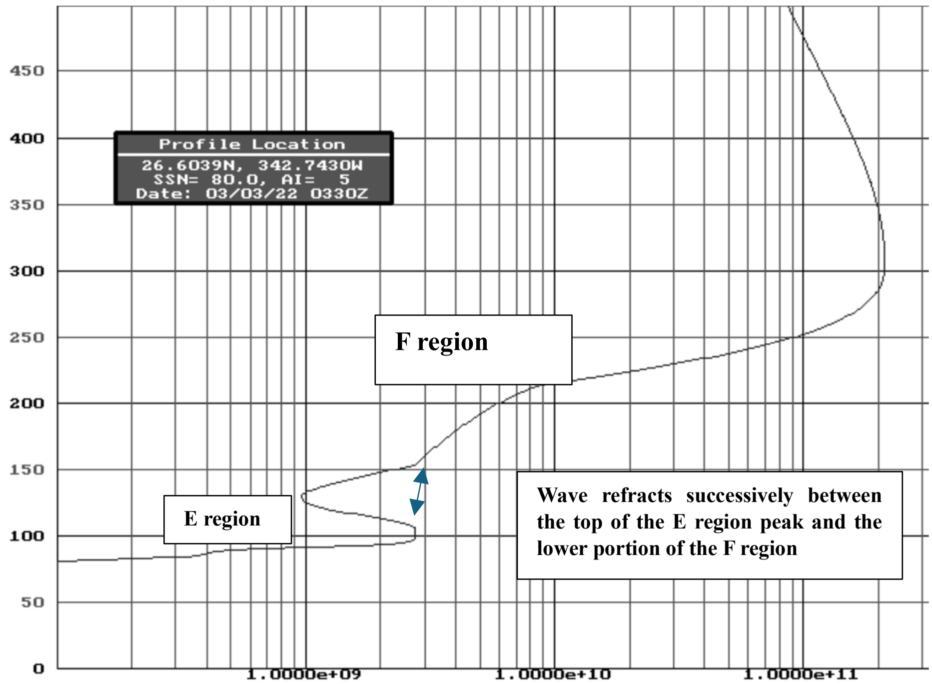


Figure 3 – Electron Density versus Altitude in the Dark Ionosphere

The nighttime ionosphere, under quiet geomagnetic field conditions, has an electron density valley above the E region peak (Note 2). This forms a natural upper and lower boundary for an electromagnetic ray to duct in. Going back to Figure 2 and noting the apogee (about 155km) and the perigee (about 110km) of the ray trace when in the duct indicates that it successively refracts between the topside of the E region peak and the lower portion of the F region.

Note 2: This valley develops in the dark ionosphere. The valley is essentially non-existent during the day. During disturbed geomagnetic field conditions, the valley (especially at the higher latitudes) can fill in with precipitating electrons, thus negating the ducting mechanism.

Getting into the duct.

«Proplab Pro shows that the range of elevation angles for getting into the duct is quite small. This makes sense, since two conditions with respect to elevation angle have to be met to get into a duct.

The elevation angle must be high enough to get through the E region peak. But it can't be too high, or it will also go through the F region. What makes this complicated is the index of refraction – it determines how much the electromagnetic wave is refracted. The amount of refraction depends on two critical factors: how close the signal frequency is to the electron gyrofrequency, and the angle between the Earth's magnetic field and the direction of travel of the electromagnetic wave. Even though the ducting mechanism (the electron density valley) may be present worldwide in the nighttime ionosphere, getting into the duct may be easier on certain paths compared to other paths – even from the same QTH – due to these considerations.

<u>Staying in the duct.</u>

«Once the electromagnetic wave gets into the duct, it has to stay in it – sometimes for very long distances. That requires the nighttime ionosphere to be stable so that the electron density valley retains its necessary characteristics. Generally, this is the case, except as cited in note 2 – when electron precipitation from auroral activity can fill in the valley along the high latitude portion of a path.

<u>Getting out of the duct.</u>

«The most plausible explanation for bringing the ray down in the dark ionosphere is an irregularity in the ionosphere. These irregularities are the result of the day-to-day variability of the ionosphere. We know that these irregularities exist, but we don't have a good handle on them (or on the day-to-day variability of the ionosphere) because they are so dynamic. The model of the ionosphere in Proplab Pro (the 1995 version of the International Reference Ionosphere) is, for all intents and purposes, smooth and homogeneous in the dark ionosphere, and does not reflect the real-world ionosphere….

I think a very good analogy for irregularities in the ionosphere is a stratus cloud layer. When viewed from afar, a stratus cloud layer looks very homogeneous – like a solid overcast. But upon closer examination, there are small valleys in the stratus layer, small clumps, and even possibly some small holes. This translates to possible irregularities in the valley mechanism (*shown above in Figure 3, 4 and 21*). Remember that the amount of refraction incurred by a wave by a given electron density gradient is inversely proportional to the square of the frequency. Thus, of all our HF bands, 160m needs the least gradient (smallest irregularity) to have an impact on refraction. This is also the reason why 160m RF does not get too high into the ionosphere – essentially up to 200km or so. For example, looking back at Figure 3, there might be too much ionization in the upper boundary at some point, which would refract an up-going wave down at a steeper angle so that it would go through the E region to ground instead of continuing along in the duct. Or there might not be enough ionization in the lower boundary at some point, which would not refract a down-coming wave back up to continue ducting.

To summarize the three sections "getting into the duct", "staying in the duct", and "getting out of a duct", I think it's best to say that the entire process of ducting can be a fragile affair – which implies a low probability.

<u>Spotlight propagation.</u>

«Spotlight propagation is defined as a small geographic area that is favoured with good propagation at any given time. Oler and Cohen suggested that spotlight propagation is simply the unpredictable result of coming out of a duct. I agree wholeheartedly with this, and further I believe that irregularities in the ionosphere are generally the cause.

This is an interesting concept to ponder. It very well could be that there's lots of RF rattling around up there in the duct (based on many Proplab Pro ray traces that indicate getting into a duct and staying in the duct is easier than getting out of the duct), but the luck of the draw in terms of an irregularity to bring the wave down at your QTH in the dark ionosphere determines if you have a QSO or not.

<u>The day-to-day variability of the ionosphere</u>.

«Earlier I mentioned that irregularities in the ionosphere are the result of the day-to-day variability of the ionosphere. It's interesting to dig into this deeper to understand what causes these day-to-day variations.

Two scientists with the *Center for Space Physics* at Boston University did just this. They analysed 34 years (1957 – 1990) of F2 region critical frequency data. Although this was a study about the F2 region, the results are very relevant to propagation on 160m in the lower ionospheric regions.

The two scientists started by listing the causes of F-layer variability, which fell into three broad categories as listed in the following Table.

Solar ionizing radiation	**Solar wind/geomagnetic activity/electrodynamics**	**Neutral atmosphere** (see note below)
Solar flares	Day-to-day 'low level' variability	Solar and lunar tides
Solar rotation (27 day) variations	Substorms	Acoustic and gravity waves
Formation and decay of active regions	Magnetic storms	Planetary waves
Seasonal variation of Sun's declination	IMF/Solar wind sector structure	Quasi-biennial oscillation
Annual variation of Sun-Earth distance	Energetic particle precipitation	Lower atmosphere coupling
Solar cycle variation (11 and 22 yrs)	Fountain effect at low latitudes	Surface phenomena (earthquakes)
Longer period solar epochs	Magnetospheric electric fields	Surface phenomena (volcanoes)
	Plasma convection at high latitudes	
	Field-aligned plasma flows	
	Electric fields from lightning	

Note - The term 'neutral atmosphere' refers to the fact that only about one of every one million atoms and molecules in the atmosphere is ionized. Thus, the bulk of the atmosphere consists of neutral (not ionized) particles, and its motion can be influenced by those items in the 'Neutral atmosphere' column. Since positive ions have the same mass as neutral particles and collide with them at a high rate, positive ions are carried along by the motions of the neutral particles. Electrons then follow the positive ions to maintain charge neutrality. The bottom line is that electrons are tied to the neutral particles, and therefore the ionosphere is subject to the same motions as the rest of the atmosphere.

Think about these results. The category that we probably understand the best, solar ionization radiation, contributes the least to the day-to-day variability of the F2 region. The other two categories are significantly greater than the solar ionizing radiation category and are about equal in contribution. We're learning more and more each day about the contribution of solar wind/geomagnetic activity/electrodynamics category, but I think we still have a long way to go to understand the processes involved in the contribution of the neutral atmosphere category.

Let me reiterate that the analysis by the two Boston University scientists was done for the F2 region. But the three broad categories should be very relevant to the day-to-day variability of the lower ionospheric regions, too, where our 160m RF propagates. In fact, I would guess that the neutral atmosphere category plays an even more important role on 160m than it does on our higher HF bands (where the F2 region is very important). In other words, for propagation on 160m in the lower ionospheric regions the neutral atmosphere category may be a bigger contributor to the total variability than the 15% cited in previous studies.

Summary.

«This article has shown why ducting is needed to explain long distance QSOs on 160m. It also hypothesized that the general cause of spotlight propagation is an irregularity in the ionosphere dumping the signal out of a duct. This article also reviewed some new information about the pertinent day-to-day variability of the ionosphere. Finally, this article suggests, as have others, that complicated processes in the neutral atmosphere are likely to play a very important role in our 160m DX QSOs.

Unfortunately, we don't have a good handle on these processes yet, so being on 160m every night is the only real way to make sure you take advantage of those 'good' nights.

December 2005, Carl Luetzelschwab K9LA». November 2025, Luis IV3PRK