Feb. 1997: S21XX path analysis with Proplab-Pro v. 3. At the search of DUCTING mode.

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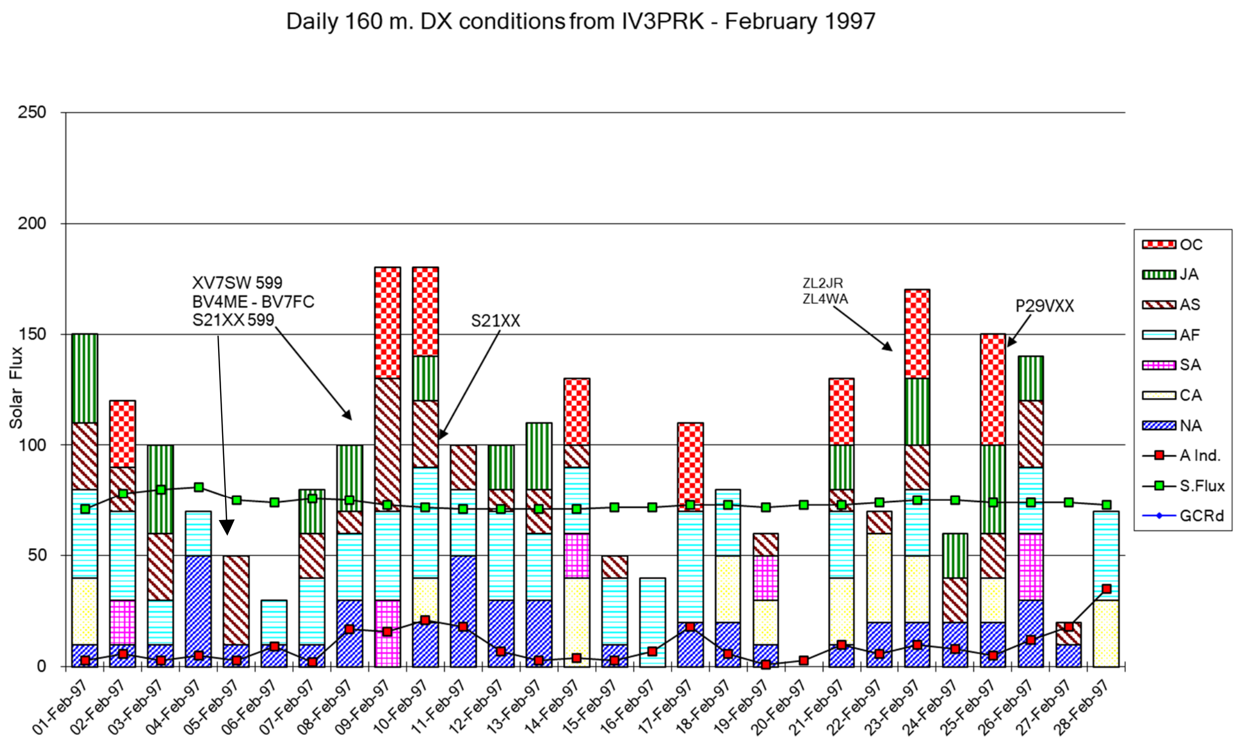
When, in August 2025, I revisited – among all other Pacific DXpeditions analysis – the 1997 P29VXX operation by the Bavarian Contest Club, I reported also the study of prof. Robert Brown NM7M on the same logs and his final comments. Unlike my initial assumption, Professor Brown found that ducting mode propagation did not influence the Papua New Guinea to Europe path on that occasion.

Unfortunately, NM7M died in the year 2010 and, meanwhile, the Solar Terrestrial Dispatch came out with the very powerful version 3 of Proplab-Pro. I was already using version 2 but, when it was first created, computers had only a fraction of the computing and memory power that they do today. The new technology in computers has provided the base structure upon which to build truly useful ray-tracing techniques. The three-dimensional ray-tracing engine used in Proplab-Pro version 3 now makes computations of ionospheric electron densities and three-dimensional layer gradients directly, rather than through the use of pre-built profiles. In addition, the new 2007 International Reference Ionosphere is substantially more complex than the old 1995 version of the IRI that was used in Version 2.

Proplab is equipped with one of the largest location databases in the world. Quickly scrolling over 5 million city and place names included, I found also my small village "Aveacco" (less than one hundred habitants) to look up as TX or RX location with geographic coordinates and precise altitude in meters. Using this large global topographical database (with a resolution of less than one square km.) it has the unique ability to compute accurate ground-reflections, by determining ground tilts (i.e. reflections off mountain ranges) that can cause non-great-circle propagation and signal spreading or multipathing. This is considered a major enhancement for the software which incited me - almost thirty years later - to go back to that old P29VXX analysis, after having examined the easier path of the S21XX DXpedition in the same month.

Propagation conditions were pretty good during February 1997, just at the beginning of cycle 23 but with solar flux very low and stable around 70. Some geomagnetic disturbances, with an aurora event on the 9th, did not have a negative influence on 160 meters, but enhanced signal strengths over medium and low latitude paths (VK3, VK6, VQ9, XV, BV's…. but no JA's), as from this graph:



The conditions with Japan improved again after Febr. 20, with the best day on the 25 (SF 74 – Ap Index 5), the day of the QSO with P29VXX. But now let's start the analysis with S21XX path to my QTH in Italy and set on the "Main Options" of Proplab the date and time of my QSO (Fig.1).

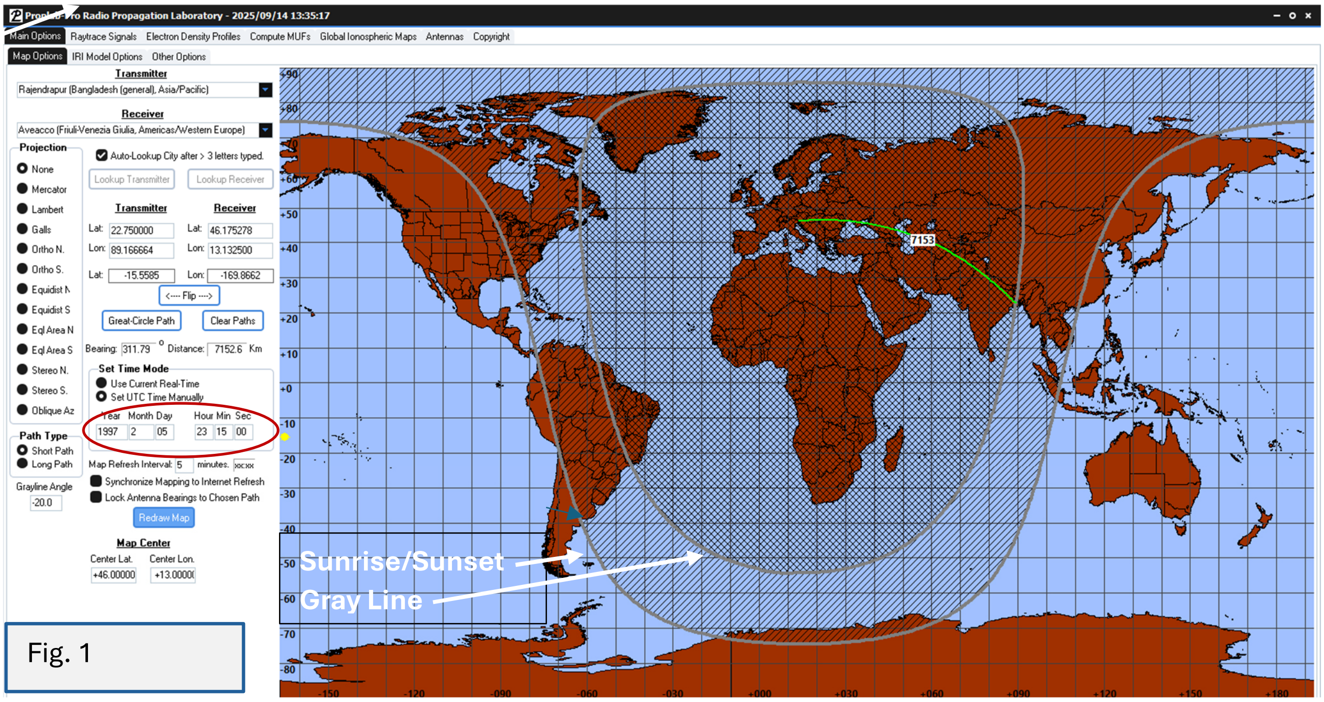


Fig. 1

The program automatically searches on internet the daily solar and geomagnetic numbers (even thirty years back) and produces 18 types of "Global Ionospheric Maps" for that day and time. This is for the critical frequency of the F2 layer - also known as *Plasma Frequency* (Fig. 2):

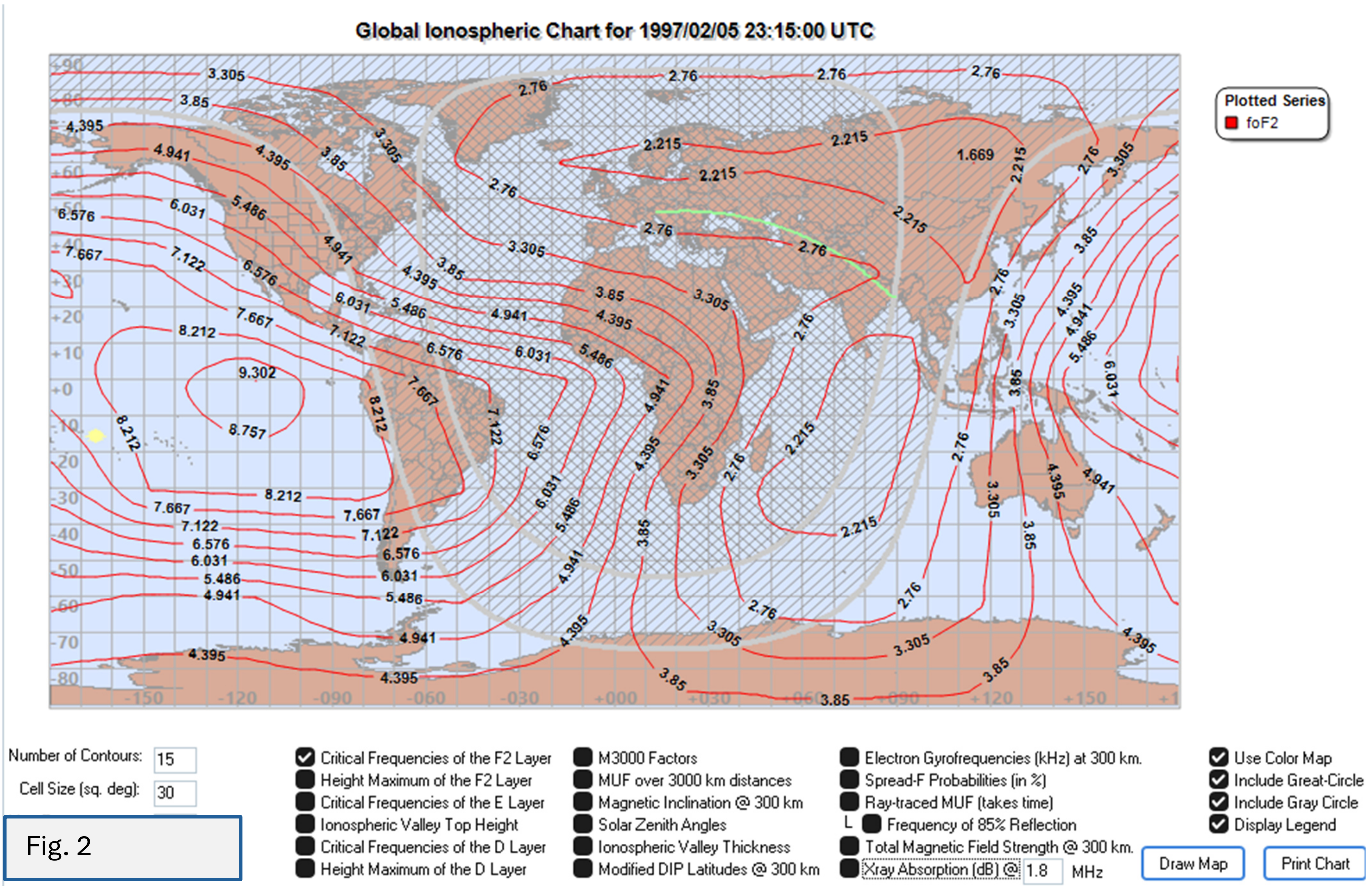


Fig. 2

The plasma frequency contours along the entire great-circle path from S21 to IV3 is shown in this “Electron Density Profile” chart and is useful to see ionospheric gradients and tilts (Fig.3):

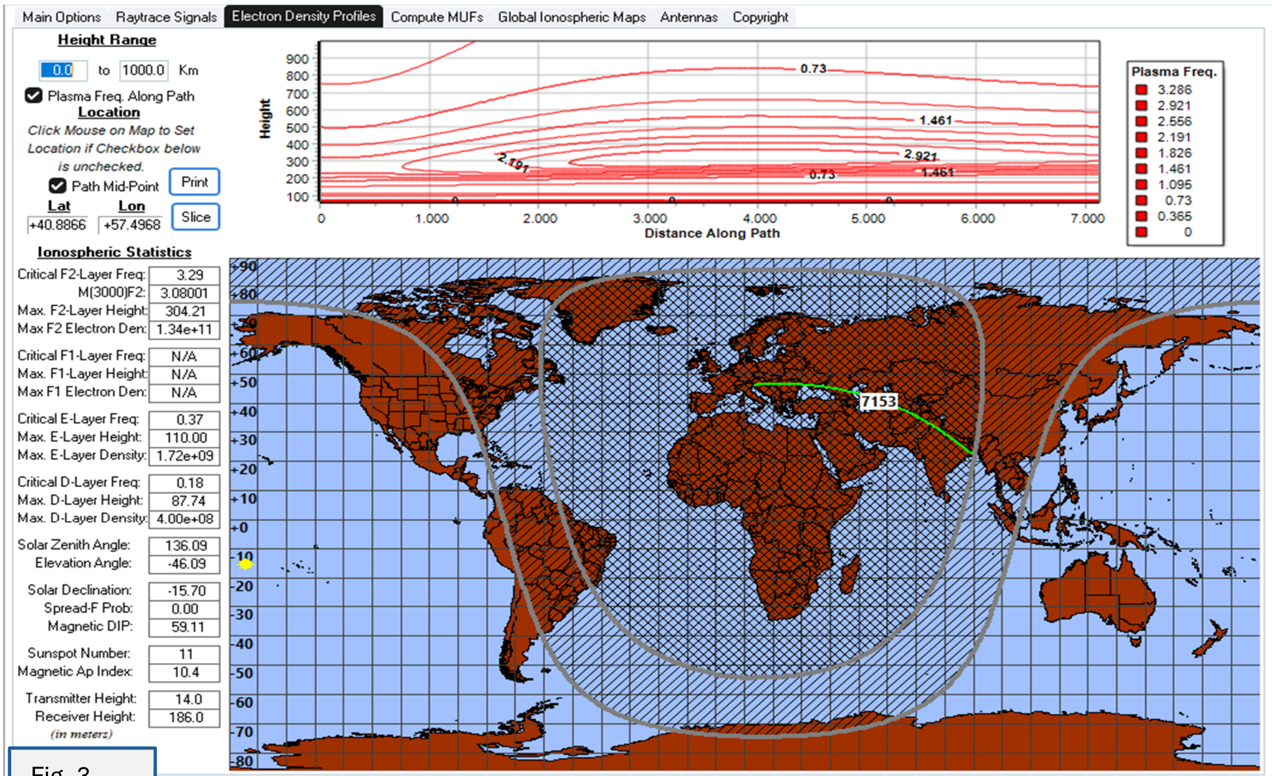


Fig. 3

Un-checking this button, the top graph changes to the vertical electron density profile over the path mid-point, or where we click along it, to find a possible DUCT (Fig. 4).

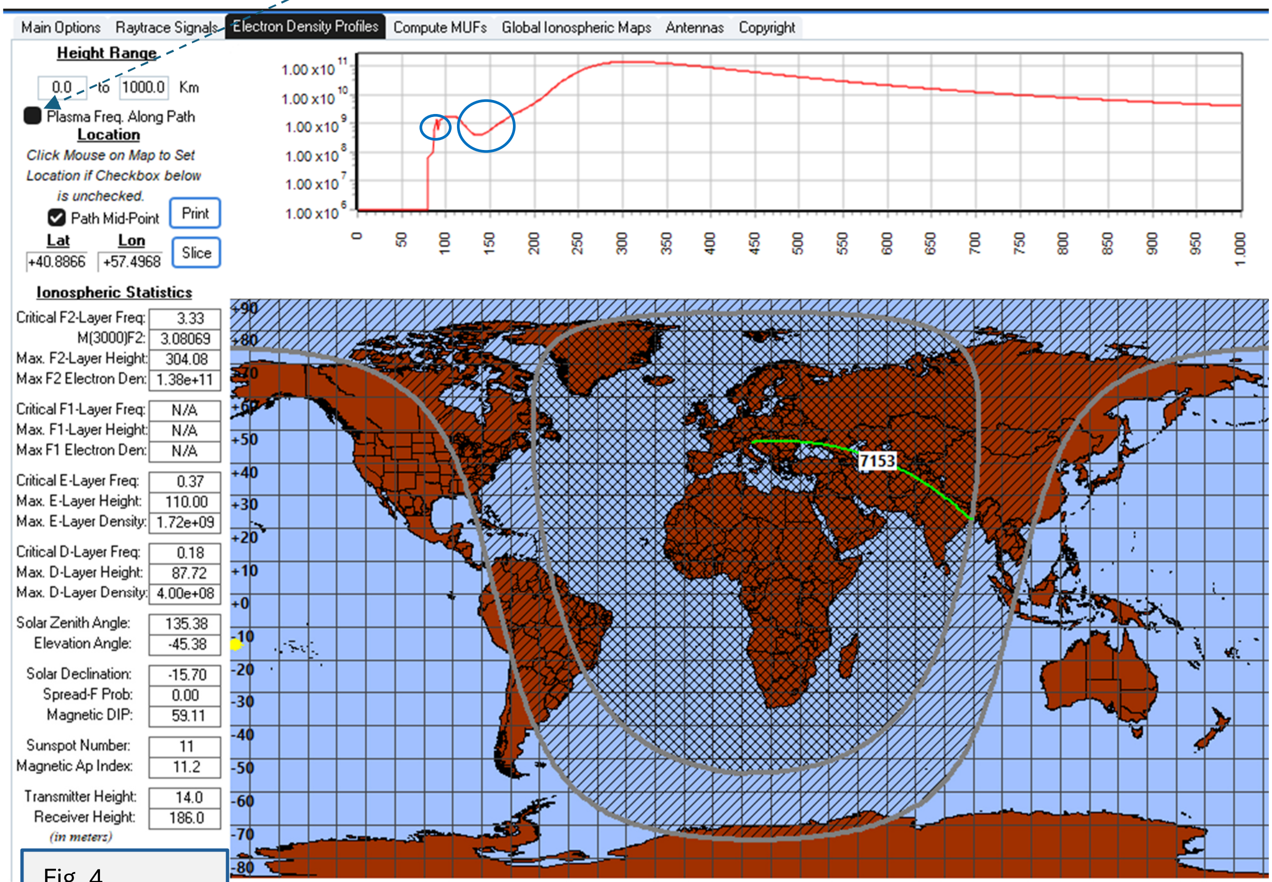


Fig. 4

The duct is a valley formed by a different electron density between E layer and the lower part of F layer, where a low frequency radio signal can enter and travel for thousands of kilometres without reflections on the ground. Fig. 4 shows a pronounced one with a small irregularity below it. Clicking with the mouse, we see them almost along the entire path, but we'll search at which elevation angle the radiated signal finds the way to enter in the duct and how - or if - it can get out to the receiver.

I started my 3D Raytracing analysis by sweeping on 5-, 15- and 25-degrees elevation angles:

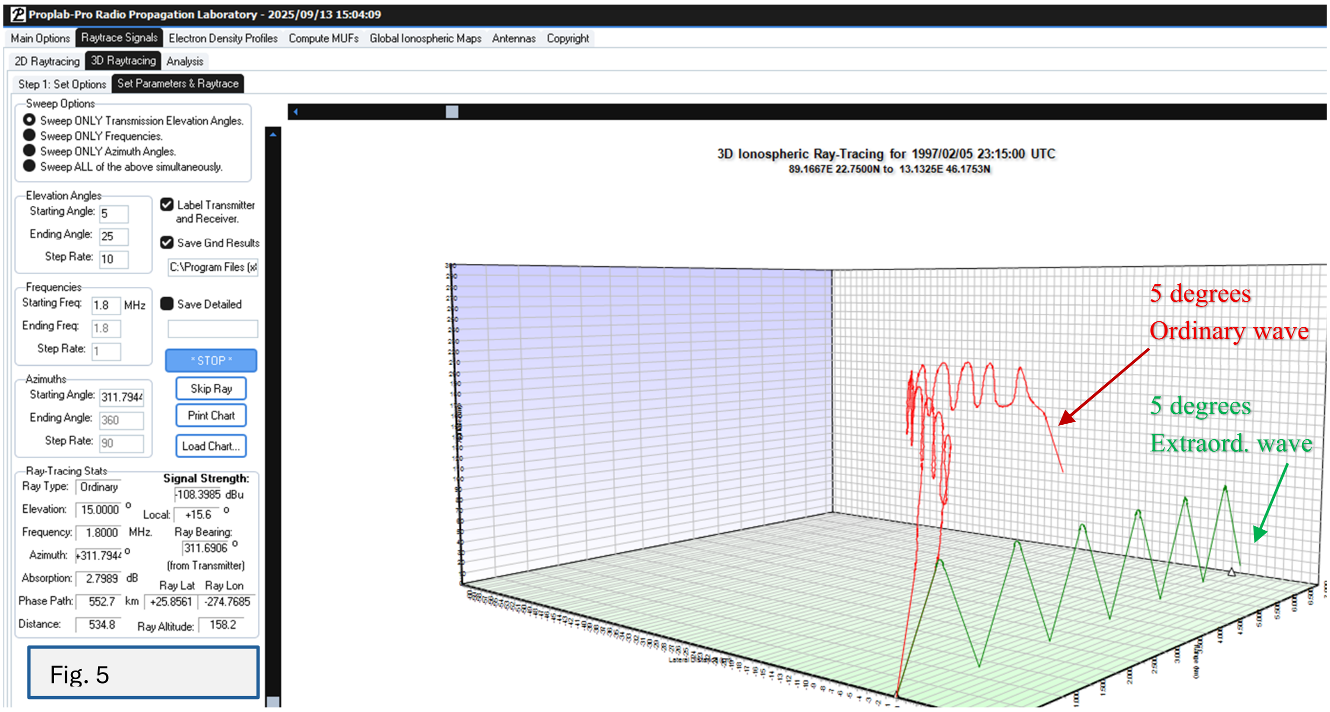


Fig. 5

At 5 degrees elevation, the ordinary ray enters in ducting mode, but it is trapped there and travels over 13 thousand km. - without absorptions - before going down to earth in the Atlantic Ocean with a good signal strength (- 13.82 dBμ). The extraordinary ray reaches the receiver with six E layer hops, but it's extremely weak – no useful at all – and thus I will not take it into consideration anymore.

At 15 degrees, the ray does not find the duct entrance but reaches the receiver area with four or five F layer hops - something skewed to the south - and a weaker signal due to absorptions (Fig.6).

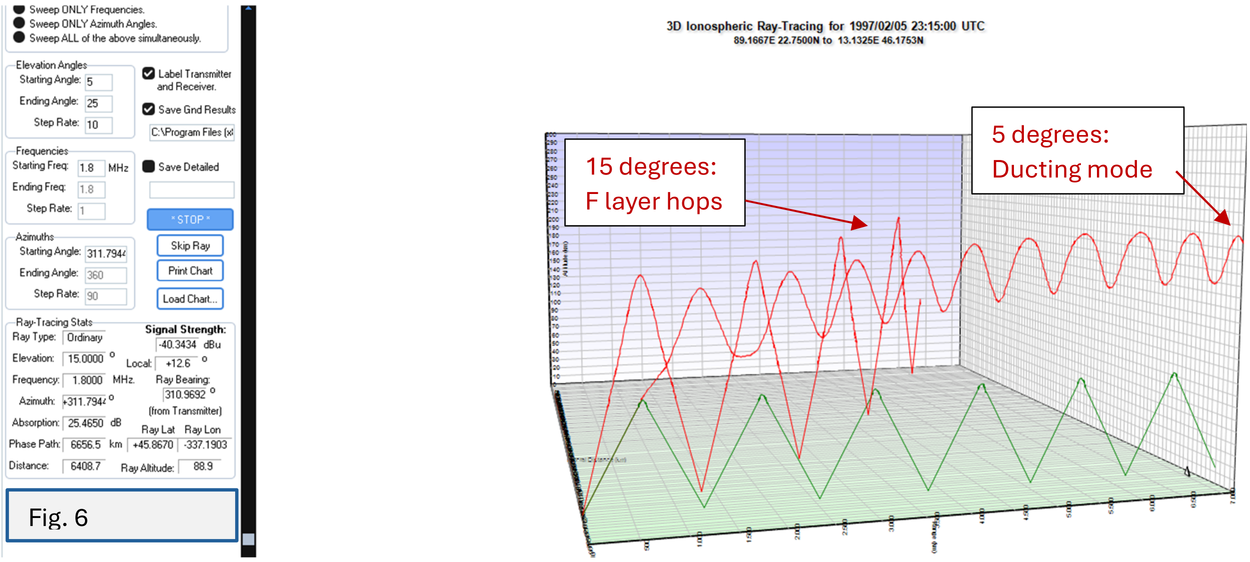


Fig. 6

At 25 degrees, continuing with F layer hops, the ray is further skewed to the South with more ground and ionospheric absorptions which reduce too much the signal strength (Fig. 7).

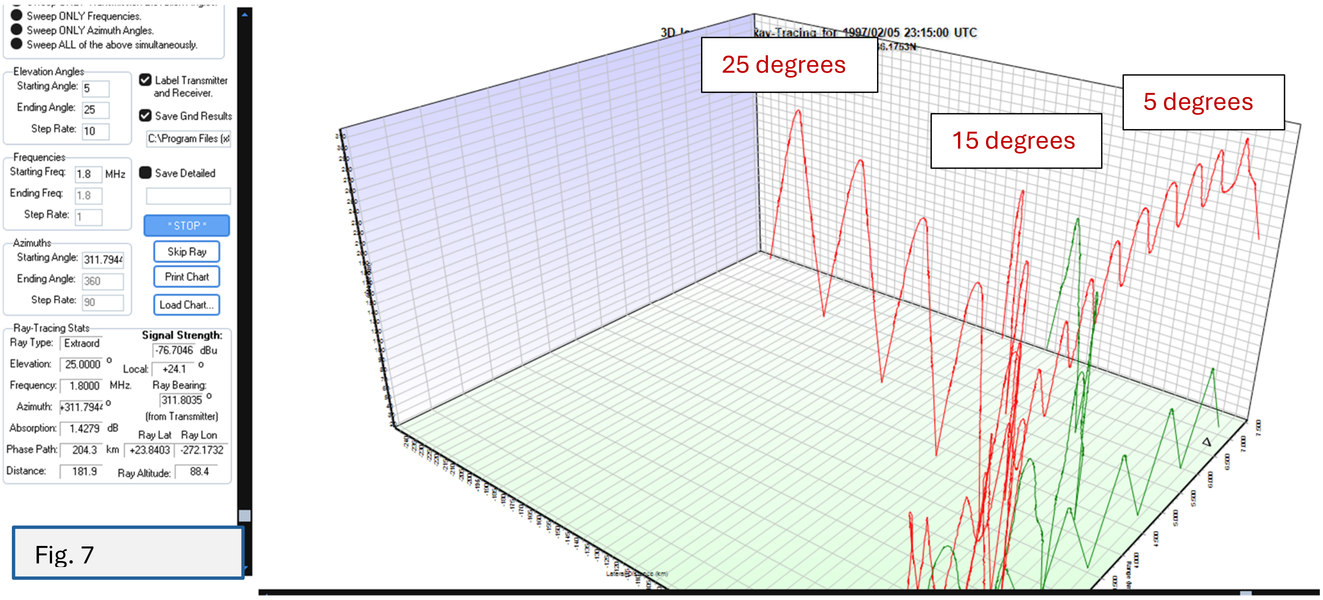


Fig. 7

At this point it was clear that we should look at low elevation angles which, by the way were the preferred by vertical antennas on both sides: S21XX was transmitting on Titanex V80 and I was using my best 4 square vertical receiving array. made some further sweeps. So, the next screen shot shows ray tracing at 6-, 8- and 10-degrees elevation angles (Fig. 8).

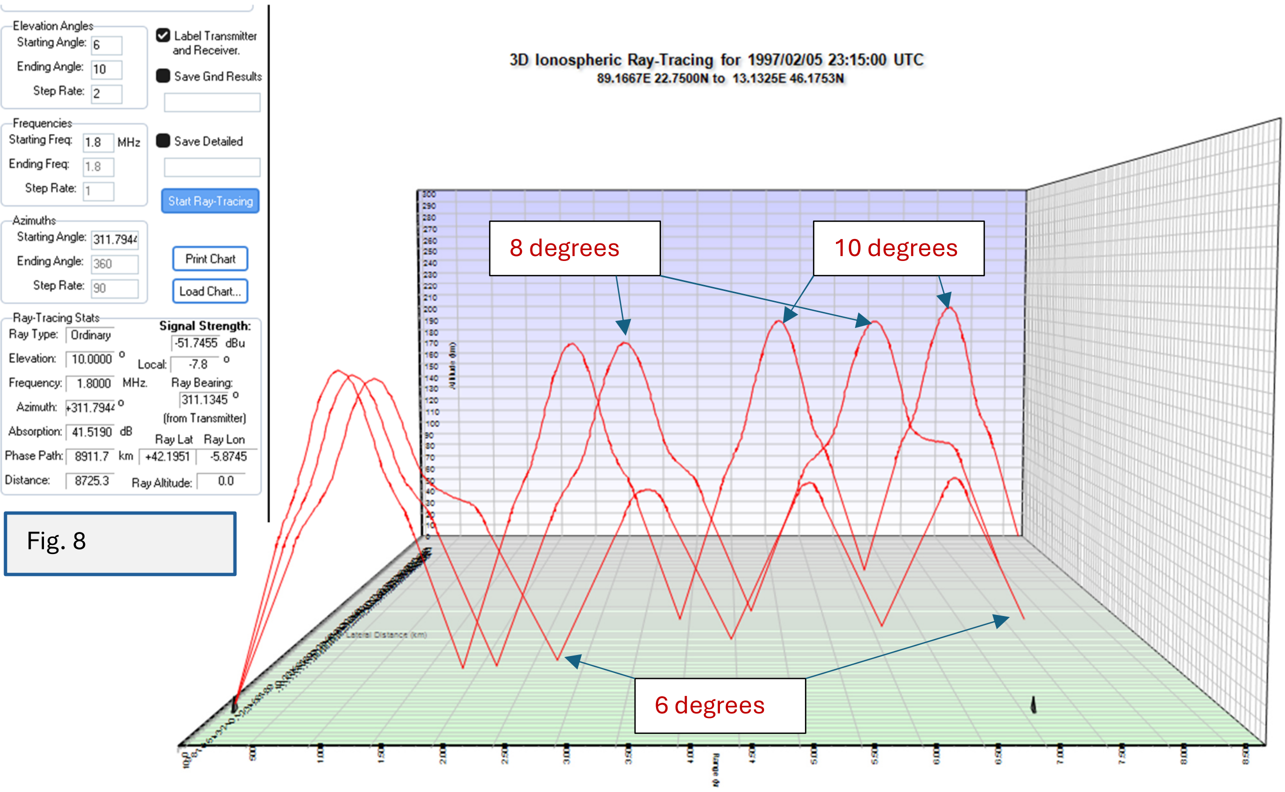


Fig. 8

Here we see how the propagation mode changes by varying only two degrees of elevation angle: At 6 degrees there is a high F layer hop, something elongated in the duct area, followed by three E layer hops. At 8 degrees, the path is covered by only three F layer hops, all with some kind of lengthening in the duct area and, as a result, it ends with about 20 dBu better signal strength. At 10 degrees, we see four simple F layer hops, but they reach the earth at a point which is 1600 km behind the receiver.

3D ray tracing is very elaborated, with thousands of computations employing several minutes which can be utilized to examine the status of the ray, during its route, with a lot of info given in the left table of Fig.8. Geographical coordinates and signal strength in dBu, registered at each ground reflection, can be saved in a separate file for further analysis. They can overlay a rough geographic map, useful to evaluate the ground reflection points. In this case, the first ground reflections occur in the mountain region of northern Pakistan and Afghanistan, where the topographic data of Proplab is used to determine tilted hops; so, the second hop (red) starts the skewing to the south of the path (Fig.9).

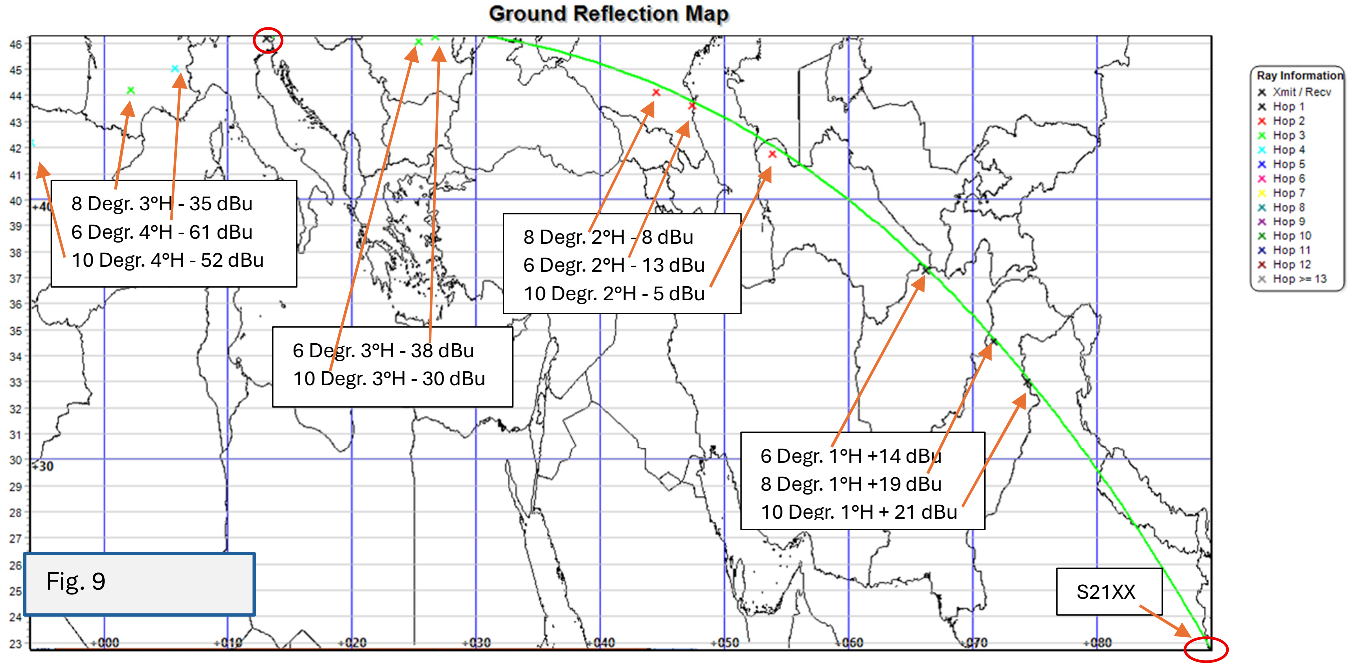


Fig. 9

As no ducting mode was found above 5 degrees, let's make another run at the lowest elevation angles with only 1 degree sweeping step (Fig. 10).

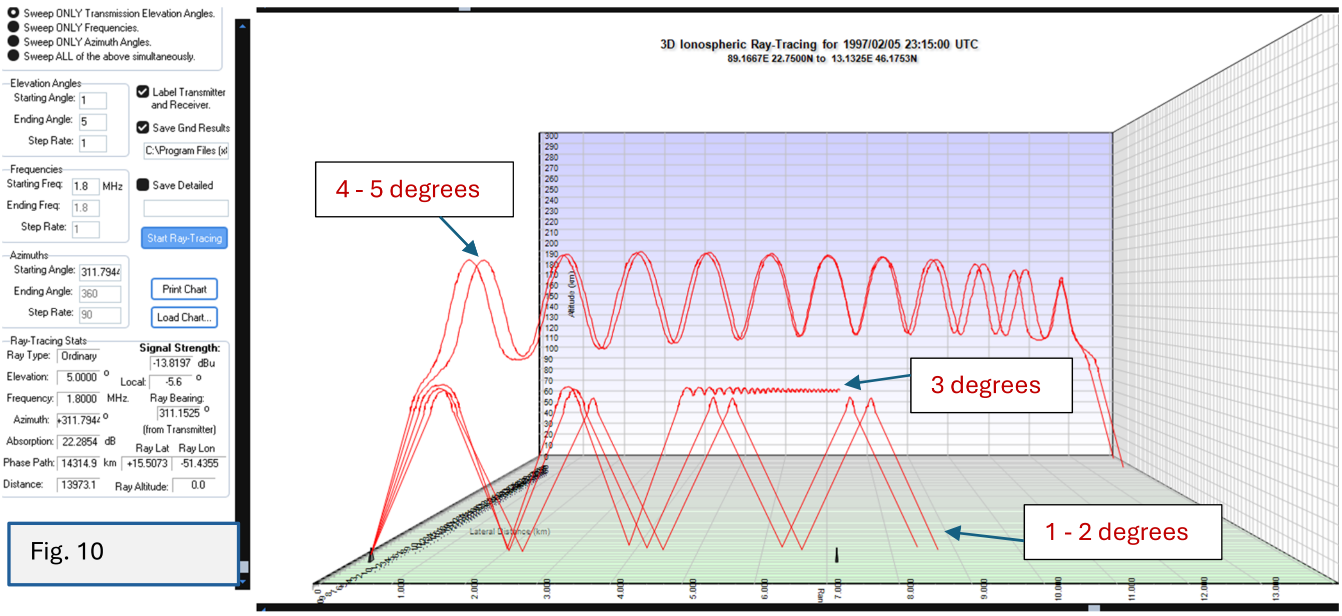


Fig. 10

<u>At 1 and 2 degrees</u>, the elevation angle is too low to pass through E layer, and thus it reaches and go beyond the receiver point with 4 E hops, but it suffers too much ionospheric absorptions and the resulting signal strength is below -80 dBu, not detectable. <u>At 3 degrees,</u> a very strange and unique occurrence happens: the ray at the third E layer entrance (abt. 4.900 km. from the Tx) is trapped there in a small duct at 90 km. height (see fig. 4) and continues its journey endless, for thousands of kilometres, but with exaggerated absorptions and I truncated it when they reached 170 dB....

Thus, only <u>at 4 and 5 degrees</u> the ray enters in a complete and very efficient DUCTING mode, without ground reflections and no more than 22 dB of ionospheric absorptions over an entire 14 thousand km. path. But that's the problem: the receiver is half the way, and the signal passes beyond it!

The ground reflection points with their signal strengths for the previous 5 step runs are reported on this map:

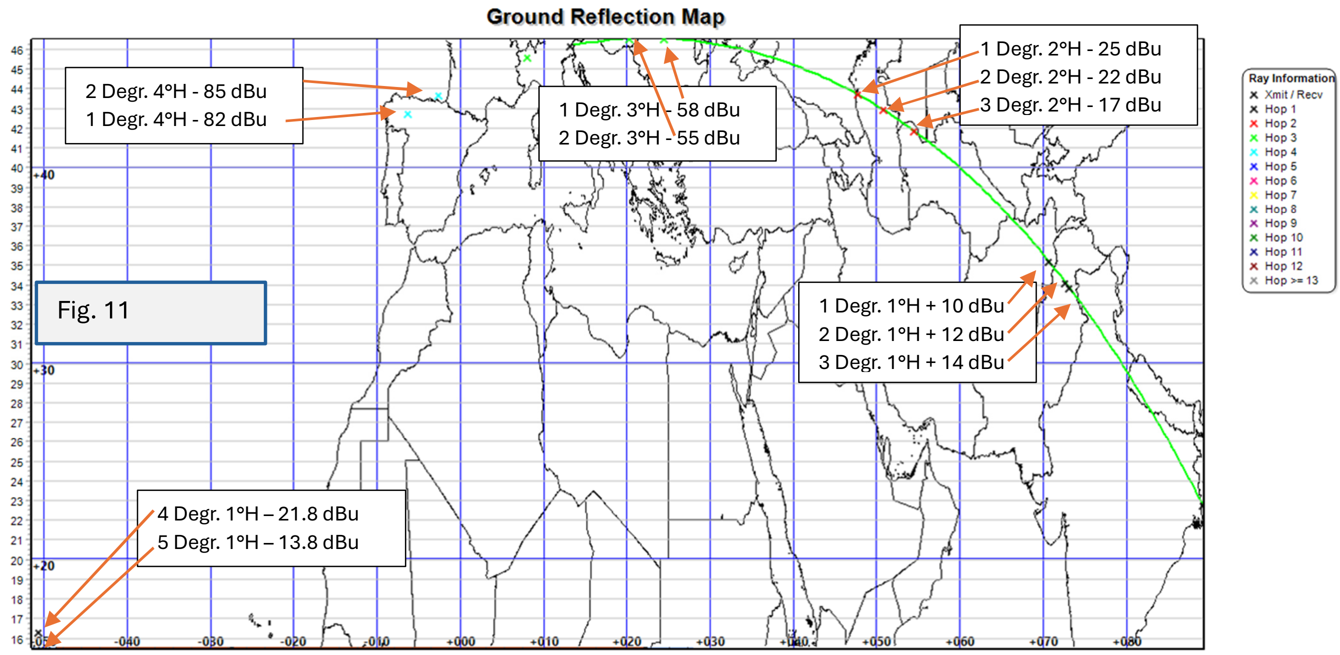


Fig. 11

Since the propagation conditions in ducting mode take us to the end of a path of almost 14 thousand km with a signal certainly above the noise threshold, let's check it by setting the receiver on the coasts of Venezuela, just a little bit longer. The entire path fits within the Gray-line area.

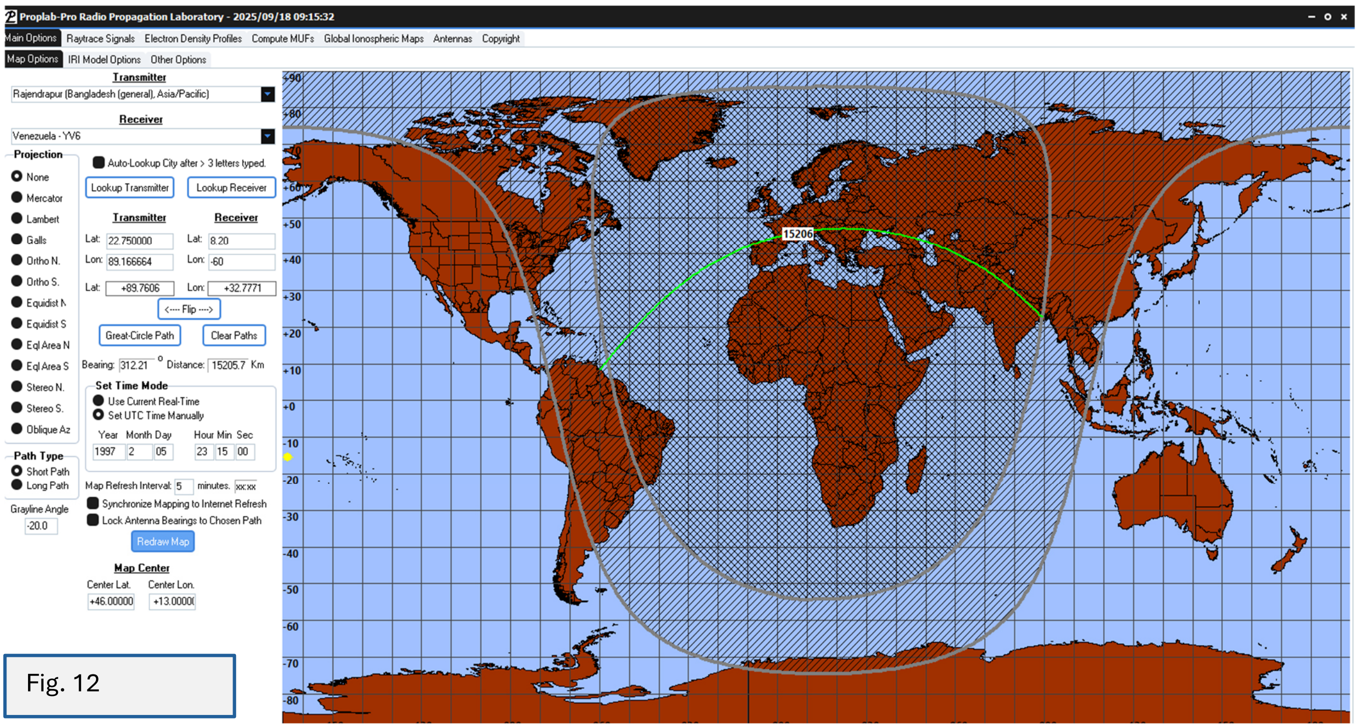


Fig. 12

Down here, is displayed the electron density profile along the 15.000 km. path, which is uniform at low altitudes with changing gradients beyond 12.000 km. The vertical profile on path mid-point is the same of fig.4, clearly indicating the ducting valley between 110 and 180 km. height.

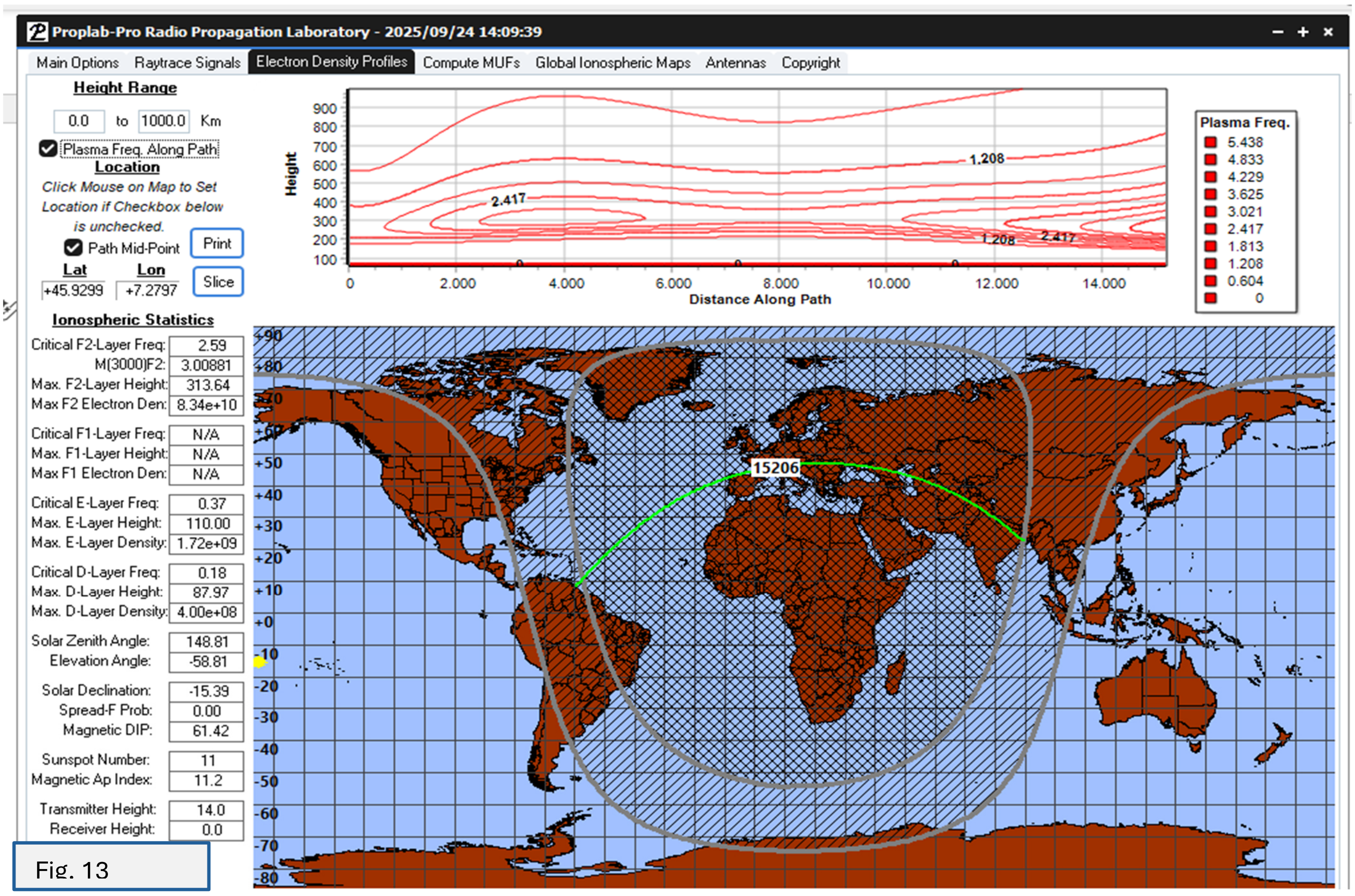


Fig. 13

It's interesting to block the first 5 degrees ray tracing at mid-point of the path – just above northern Italy – where the ionospheric absorption is only 10 dB (Fig. 14).

Imagine how loud would be the signal received if the ray finds a hole in the E layer to go down to earth, and sometimes it happens with S9 unexpected DX signals. This is one of the events that occurs on 160 meters – due to ionospheric irregularities or geomagnetic field variations – and can explain one of the Topband propagation mysteries!

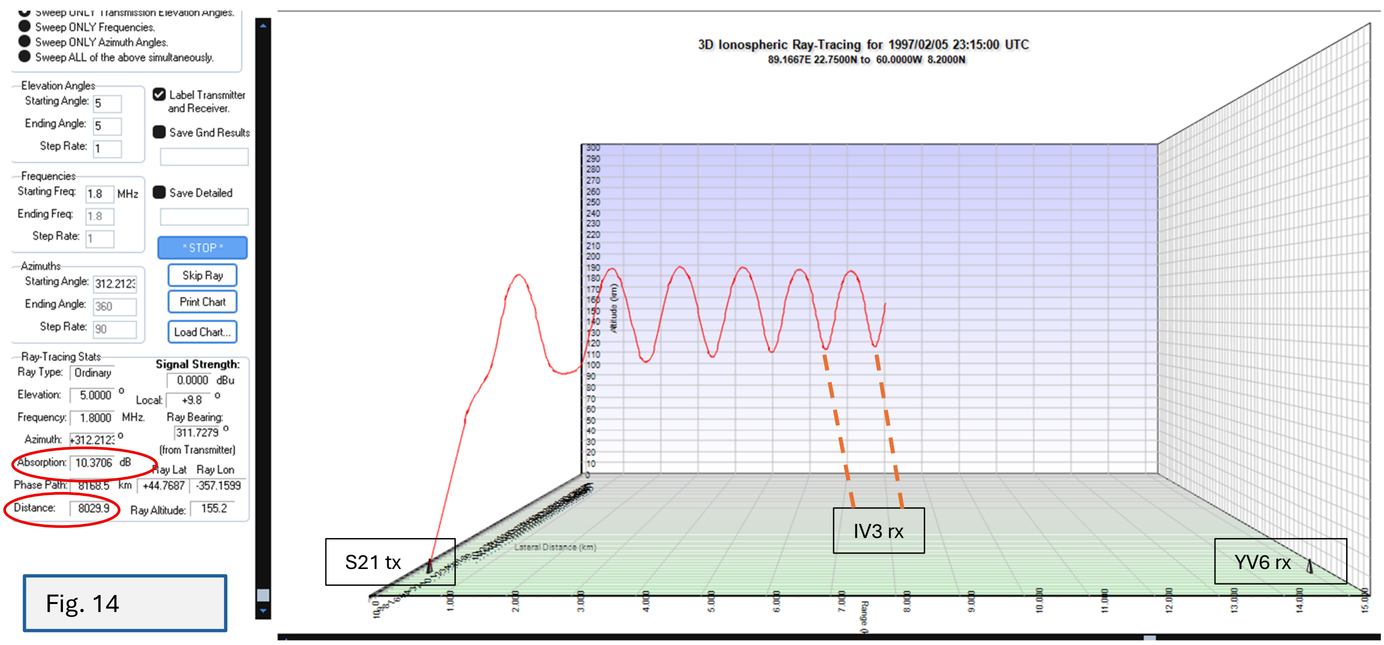


Fig. 14

But, in this case, the ray finds a strong ionization both in the E layer and in the lower part of the F layer and continues its journey with ten reflections inside the duct, with very low absorptions. It reaches the earth at 14.140 km. distance with a signal strength of -14 dBu, equivalent to -121 dBm, well above any receiver noise threshold (now around -140 dBm).

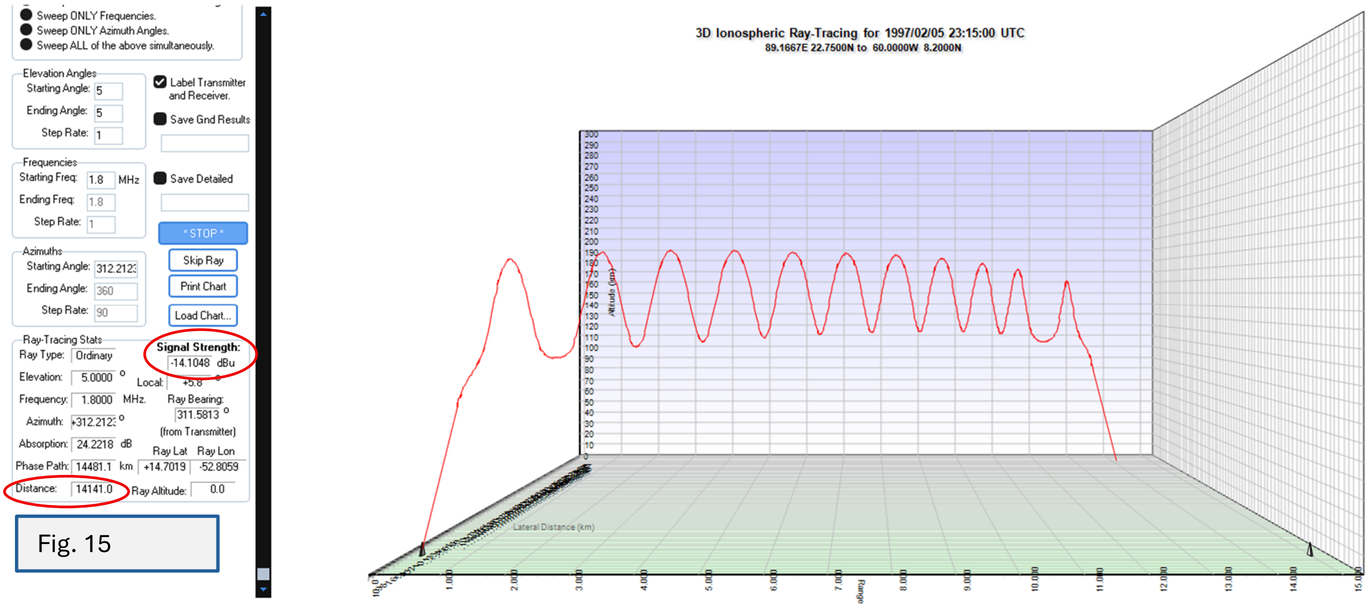


Fig. 15

From there, the ray continues with a last F layer hop reaching a 16 thousand km. distance, inside the South American continent, but useless, as ionospheric and ground reflection losses are added for 25 dB and the signal strength is reduced to -39 dBu, corresponding to -146 dBm, below the noise floor. The last 2.000 kilometres path has double losses than the previous 14.000 ones in ducting mode.

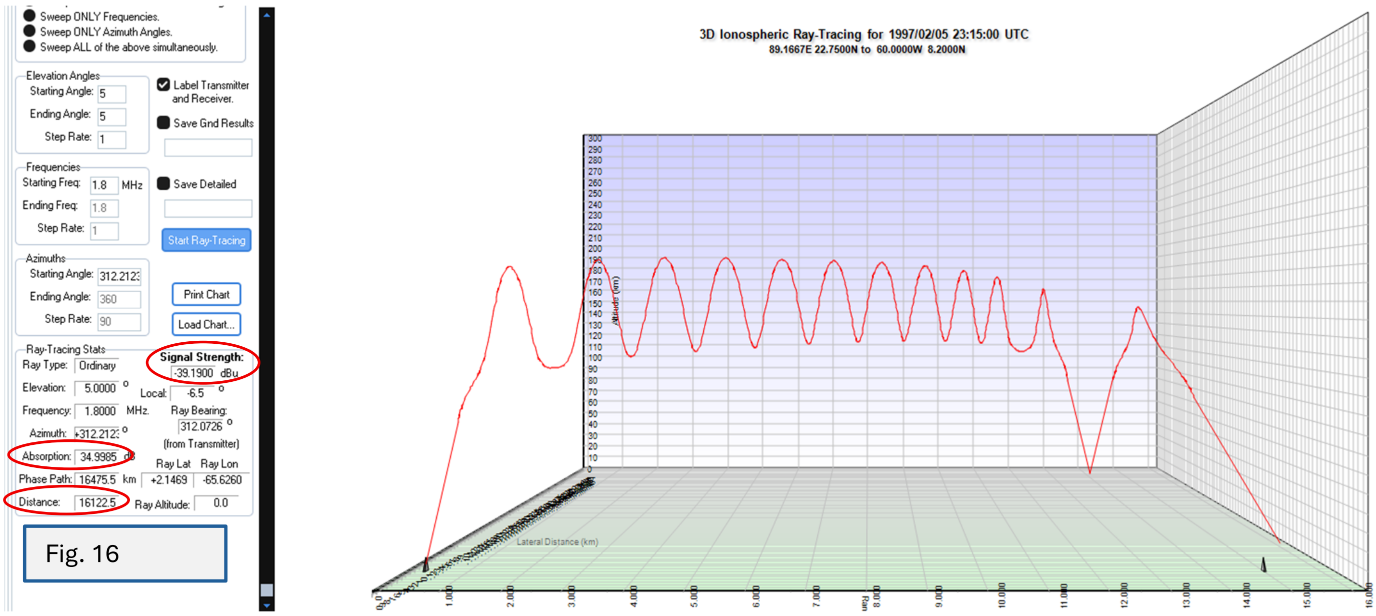
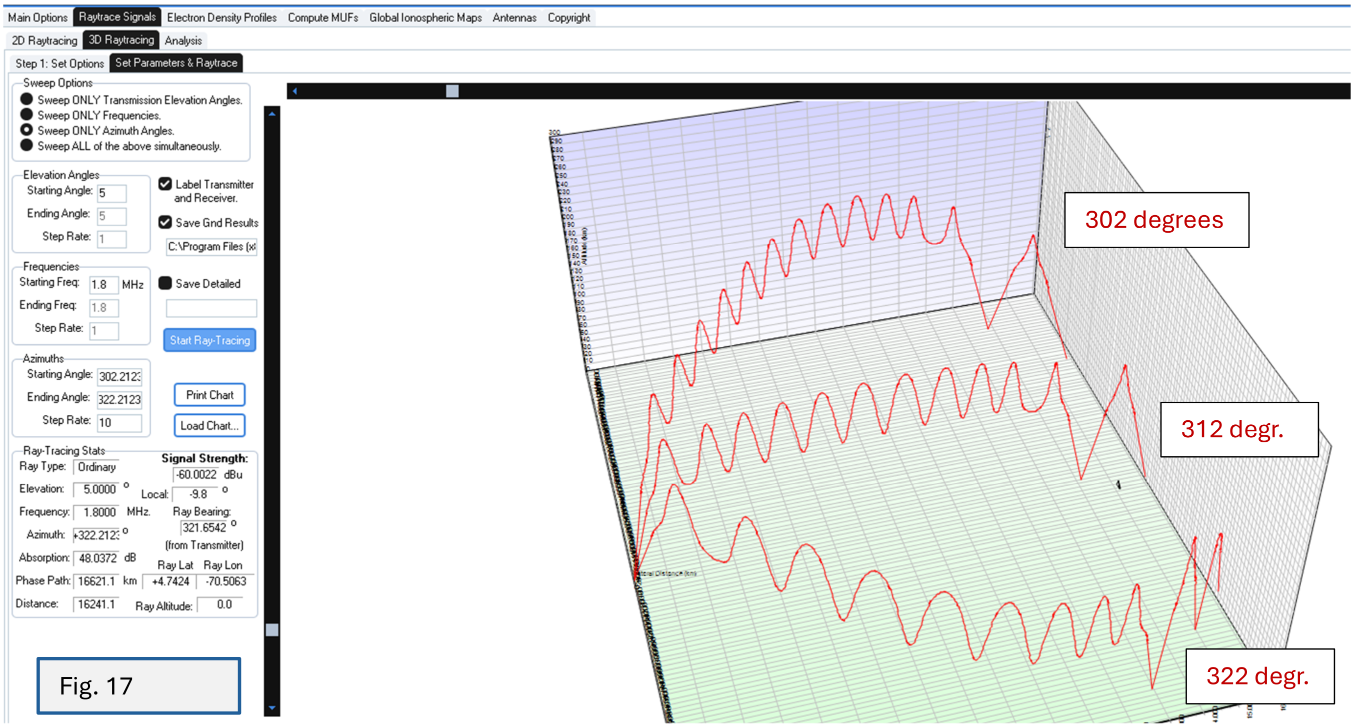
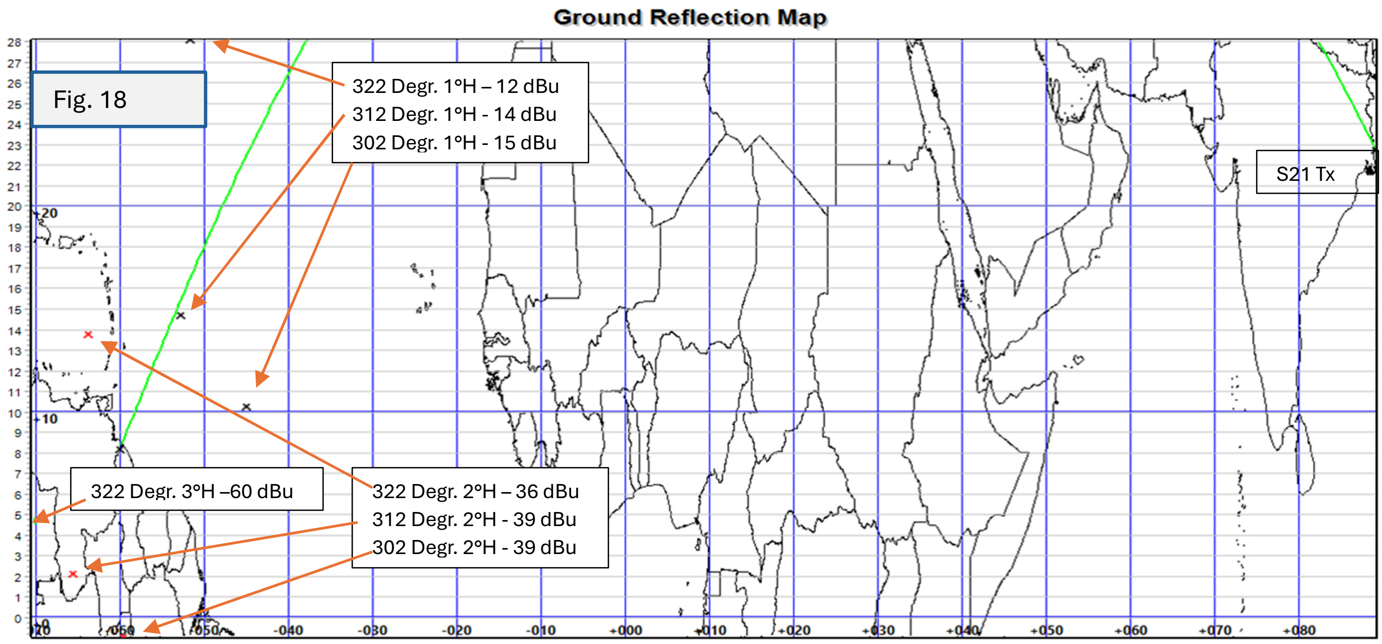


Fig. 16

At the conclusion of this 3D ray tracing analysis from Bangladesh I make a last run keeping the elevation angle at 5 degrees and sweeping the azimuth angle from 10 degrees below to 10 degrees above the great circle bearing (Fig. 17). Then, the ground reflections results are reported by the program on a rough map, sufficient to show where the three rays did reach the South American continent and with which signal strength (Fig. 18).



In all cases we see that the ray signal strength is quite sufficient at the first reflection point but, despite occurring over the salt sea, the absorptions and losses in next hop are disruptive. Nevertheless, on 160 meters unexpected things may happen and these signal strengths are not too far and t's always a good idea to be ready to take such opportunities.



In the lower left of the map, we see that apparently all the three rays reach Northern Brazil but, if we look at the Fig. 17, the higher latitude path (322 degrees) enjoys fewer ducting hops, and the need of a second F layer hop causes a 21 dBu reduction in signal strength.

A second set of analysis on this path - during a different season - (S21DX in Dec. 2024 on FT8) will shortly follow.

October 2025 Luis IV3PRK