

Trans-Equatorial Propagation (TEP)

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In the ARRL's Propagation Bulletin (edited by Tad Cook, K7RA) of March 4, 2011, John Shaw, N4QQ, reported on his 6 meter QSOs from PJ2T (Curacao) with South America via trans-equatorial propagation on the Thursday evening before the CW running of the ARRL International DX Contest (the weekend of February 19 and 20).

The goal of this paper is to give a brief history of TEP, explain what mechanism in the ionosphere causes TEP, and review the availability of TEP. And as we'll see, Curacao is in a good place for TEP to South America.

A Brief History of TEP

One of the finest examples of Amateur Radio's contributions to propagation was the discovery and use of trans-equatorial VHF propagation. It was in August 1947 when XE1KE began working Argentine stations, notably LU6DO at first, quite regularly on 50 MHz. These QSOs occurred in the late afternoon and early evening, well after the expected times based on the normal mid day peak of the F₂ region.

QST reported many more similar QSOs in the next several years (which were the maximum years of Cycle 18). There was little trans-equatorial propagation observed in the sunspot minimum period between Cycle 18 and 19. But TEP reappeared in 1955 and throughout the maximum years of Cycle 19.

During the International Geophysical Year (IGY – July 1, 1957 to December 31, 1958), the ARRL set up the Propagation Research Project and collected reports from Amateur Radio operators of possible 50 MHz and 144 MHz ionospheric propagation, evaluated them, and transcribed them onto punched cards (I have to admit I remember using those during my college days). The 50 MHz reports were analyzed by the Radio Propagation Laboratory at Stanford University (notably Southworth W1VLH, Villard W6QYT, and others). I suggest reading Mason P. Southworth's article titled "A Look Back and Ahead at PRP" in the June 1959 QST for an early summary of the Propagation Research Project (ARRL members can download this article by accessing the ARRL's on-line digital archives).

I believe the first theoretical explanation of TEP in an Amateur Radio publication was by R. G. Cracknell, ZE2JV, in his December 1959 article in QST titled "Transequatorial Propagation of V.H.F. Signals". One of his partners in TEP research was R. A. Whiting, 5B4WR, who subsequently published an article in the April 1963 issue of QST titled "How Does TE Work?" Both of these articles are available through the aforementioned ARRL digital archives. Whiting's article went a bit farther with the theory and had a figure that showed the tell-tale ionospheric signature of TEP – areas of high electron density on either side of the geomagnetic equator – and it included a conceptual ray trace from Salisbury, Southern Rhodesia (now Harare, Zimbabwe) to Limassol, Cyprus.

TEP Mechanism

As mentioned in the previous paragraph, the tell-tale signature in the ionosphere for trans-equatorial propagation is the areas of high electron density on both sides of the geomagnetic equator. Figure 1 depicts this characteristic (from Proplab Pro V3, Solar Terrestrial Dispatch, www.spacew.com/proplab). This figure is the ionosphere from PJ2 to extreme southern South America on March 15 at 0000 UTC (early evening local time in PJ2).

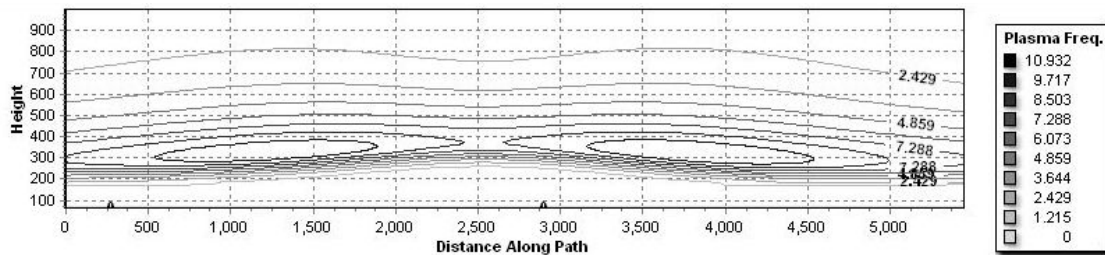


Figure 1 – Ionospheric Signature of TEP

The horizontal axis is distance in kilometers from PJ2 (on the left at 0 km) and extends to extreme southern South America (on the right at about 5400 km). The vertical axis is height in kilometers. This image shows contours of electron density in terms of the plasma frequency. The electron density in electrons per cubic meter equals the square of the plasma frequency in Hz divided by 81. As a side note, the plasma frequencies in the scale on the right side of Figure 1 and on the plot are in MHz.

The geomagnetic equator is about 2500 km south of PJ2. The geomagnetic equator is different from the geographic equator due to the Earth's magnetic axis being tilted about 11 degrees with respect to the Earth's geographic axis. Note the two oval-shaped contours of high plasma frequencies (hence high electron densities) on either side of the geomagnetic equator. The scale of the plasma frequency is unfortunately a gray scale, but the smallest oval contours are the darkest lines, indicating the highest values.

For this path, each degree of latitude is approximately 111 km (20,000 km over 180 degrees of latitude). Thus the center of each area of high density is about 11 degrees north and south of the geomagnetic equator. This puts Curacao in a good location to work TEP – the first F₂ hop out of PJ2 would encounter the ionosphere around the southern tip of the northern area of high electron density.

The two peaks in the plasma frequencies occur because of what is commonly called the *fountain effect*. Electrons that are created at the magnetic equator through the normal photo-ionization process rise upwards due to the influence of the eastward electric field and the northward horizontal magnetic field in the equatorial region (remember the right hand rule for vector cross-products?).

The electrons then move down magnetic field lines on either side of the magnetic equator to produce these areas, or crests, of high electron density. They can range from about 10

to 20 degrees of latitude on either side of the magnetic equator. Visualizing this process brings to mind a fountain, hence the name *fountain effect*.

Ray Tracing

To see what happens when an electromagnetic ray traverses the equatorial ionosphere under the condition of Figure 1 (which is for medium solar activity, as was happening when N4QQ made his 6m QSOs), let's do a ray trace for mid March at 0000 UTC using Proplab Pro V3. Figure 2 shows the ray tracing results.

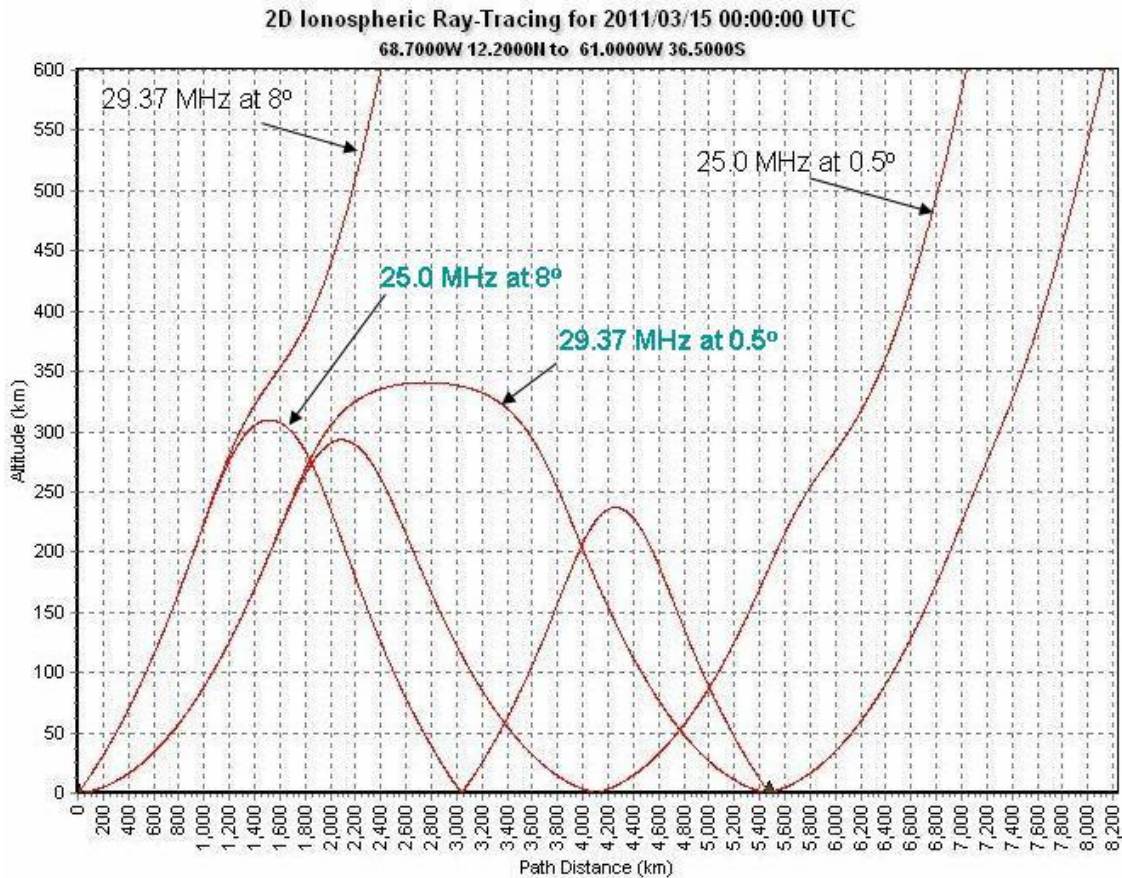


Figure 2 – Ray Tracing Over the PJ2 to Extreme South America Path

PJ2 is on the left at 0 km, and the target in extreme southern South America (the dark triangle on the horizontal axis) is down the road at about 5400 km. The two important ray traces are annotated in green. The other two ray traces are a result of setting up Proplab Pro V3 to run two ray traces at different frequencies and take-off angles.

The highest frequency for a normal two-hop F₂ mode from PJ2 to the target is 25.0 MHz at a take-off angle of 8 degrees (any higher frequency for two hops to 5400 km goes through the ionosphere). The highest frequency for a long single-hop TEP mode to the target is 29.37 MHz at a take-off angle of 0.5 degrees (TEP will usually require a low take-off angle). Thus TEP for this path, date, and time offers a MUF (maximum useable

frequency) about 1.2 times the normal two-hop F_2 mode. The literature says TEP can offer a MUF up to 1.5 times the normal multi-hop F_2 MUF.

TEP Paths

Since the areas of high electron densities on either side of the geomagnetic equator can occur all around the world at the right time (we'll look the daily variation and other variations in a bit), in theory there are trans-equatorial paths over the full circumference of the Earth. But population density, specifically the density of Amateur Radio operators, results in the occurrence of trans-equatorial propagation being limited to three general paths: the Caribbean (Curacao, for example) to extreme southern South America, southern Europe to extreme southern Africa, and VK/ZL to JA. Figure 3 depicts these general paths, with the geomagnetic equator in red and the TEP paths in dark blue.

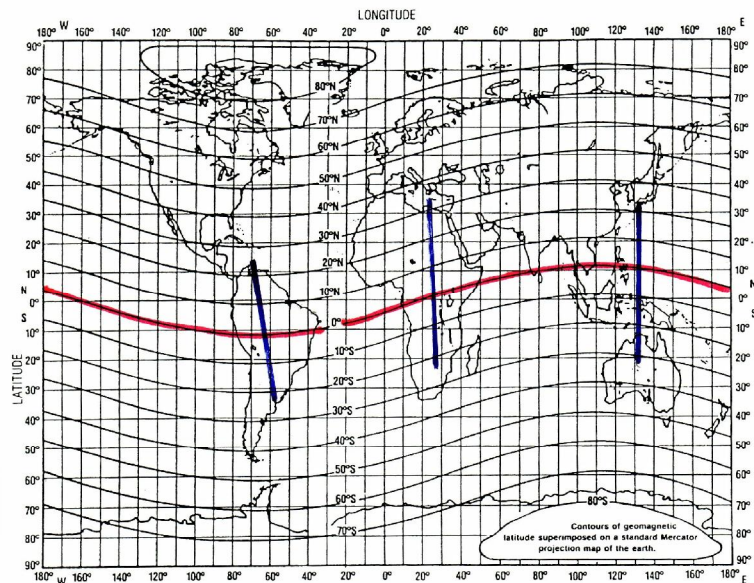


Figure 3 – General TEP Paths

All three of these paths are pretty much centered about the geomagnetic equator. Although North-South paths are shown, TEP can occur at angles other than N-S – up to about +/- 30 degrees off strict N-S.

Diurnal Variation

Figure 1 was for one time of day on March 15, so let's look at the diurnal (daily) variation of the equatorial ionosphere on this date. As mentioned earlier, Figure 1 is at medium solar activity – we'll take a look at high solar activity in a bit.

Figure 4 shows the data from 1400 UTC (mid morning in PJ2) to 0800 UTC (wee hours of the morning in PJ2). This data is also from Proplab Pro V3, which uses IRI2007 (the 2007 version of the International Reference Ionosphere) for the model of the ionosphere.

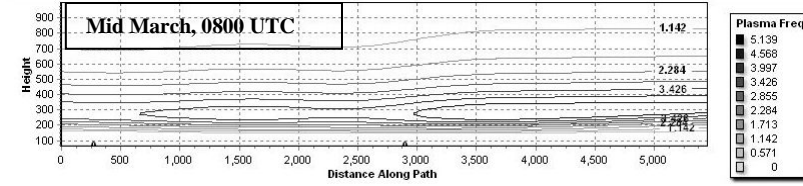
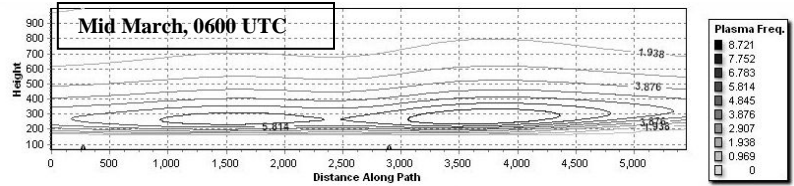
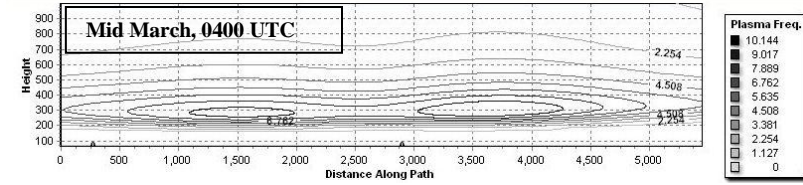
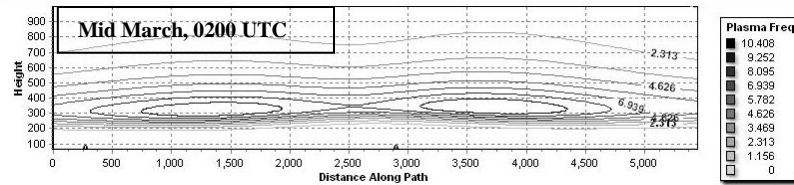
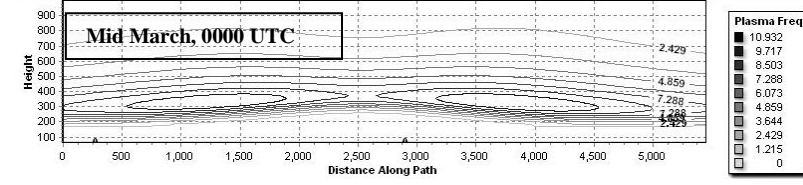
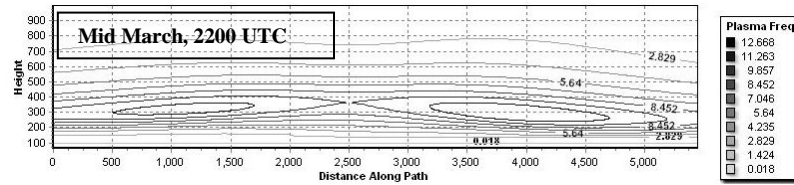
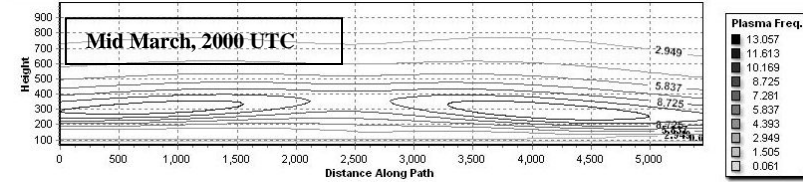
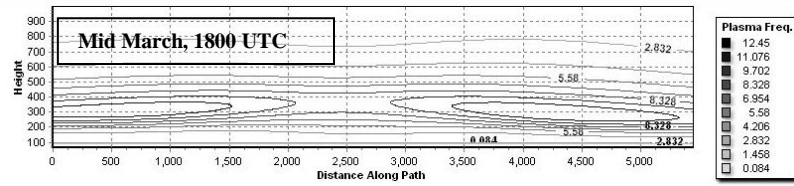
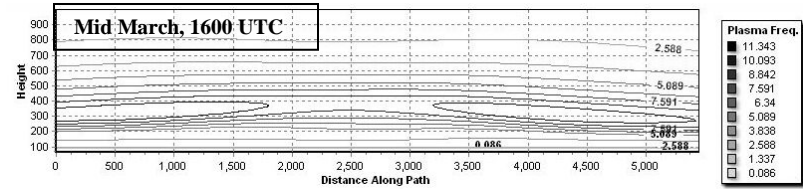
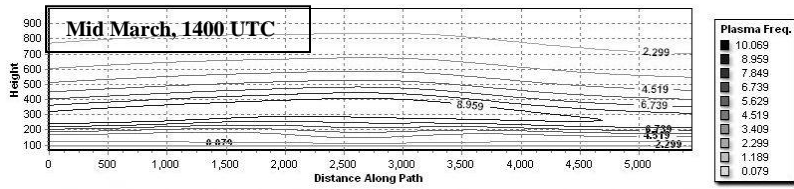


Figure 4- Diurnal Variation for Mid March at Medium Solar Activity

At 1400 UTC there is no tell-tale sign in the equatorial ionosphere that would suggest trans-equatorial propagation. At 1600 UTC (around noon), the crests are seen, and they last throughout the afternoon and evening. By 0800 UTC, the crests have disappeared.

The maximum plasma frequency (highest electron density) occurs around 2000 UTC (early afternoon local time), and the height of the center of the crests is around 300 km. As the ionosphere progresses into the evening hours, the maximum plasma frequency decreases but the height of the center of the crests increases. The early evening hours (0000 UTC, for example) also provide a more tilted ionosphere, which is seen if you visualize a line from one tip of either oval to its other tip. All of these factors would come into play to determine if TEP occurs and how high a frequency could be supported.

Also remember that this data is monthly median data from our model of the ionosphere (essentially an average for March). What's not shown is the dynamic nature of the daily variations which would result in lower or higher values on any given day. This comment also applies to the ray trace in Figure 2 – on some days the MUFs would be even higher.

Seasonal Variation

Let's now compare the 0000 UTC equatorial ionosphere for March, June, September and December at medium solar activity. Figure 5 does this.

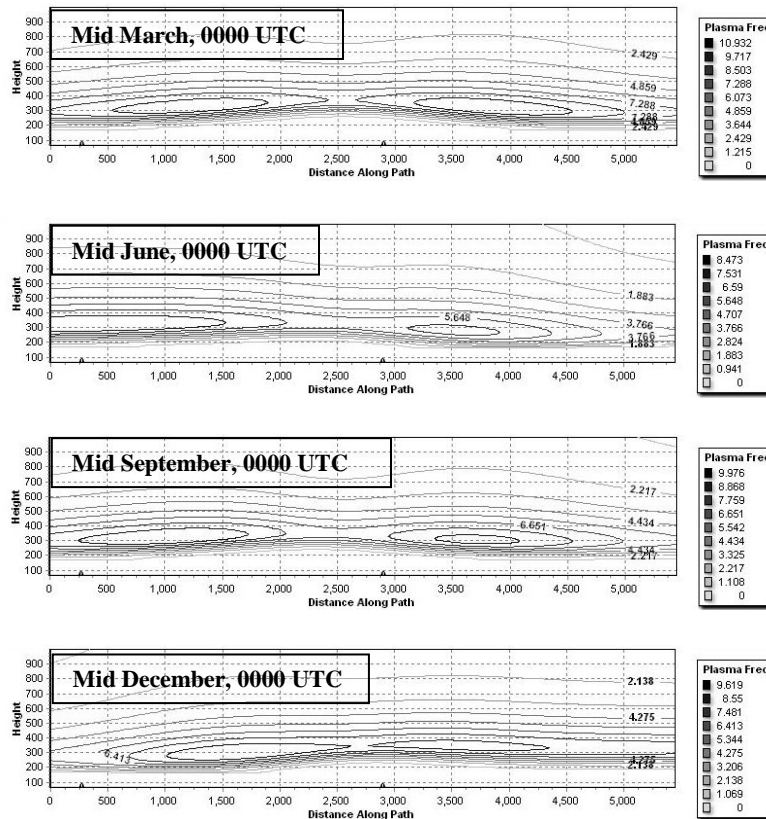


Figure 5 – Seasonal Variation at 0000 UTC at Medium Solar Activity

In June the crests are not as well developed as in March, and they have a lower maximum electron density. They are also at a lower height. In December the crests are closer together than in March and don't have as much of a tilt. The ionosphere in September looks similar to the ionosphere in March, except for slightly lower maximum electron densities. This data indicates the equinoxes are best for TEP.

Solar Cycle Variation

We'll finish up by comparing the 0000 UTC equatorial ionosphere for March 15 at medium solar activity to the same time and date but at high solar activity. Figure 6 shows this comparison.

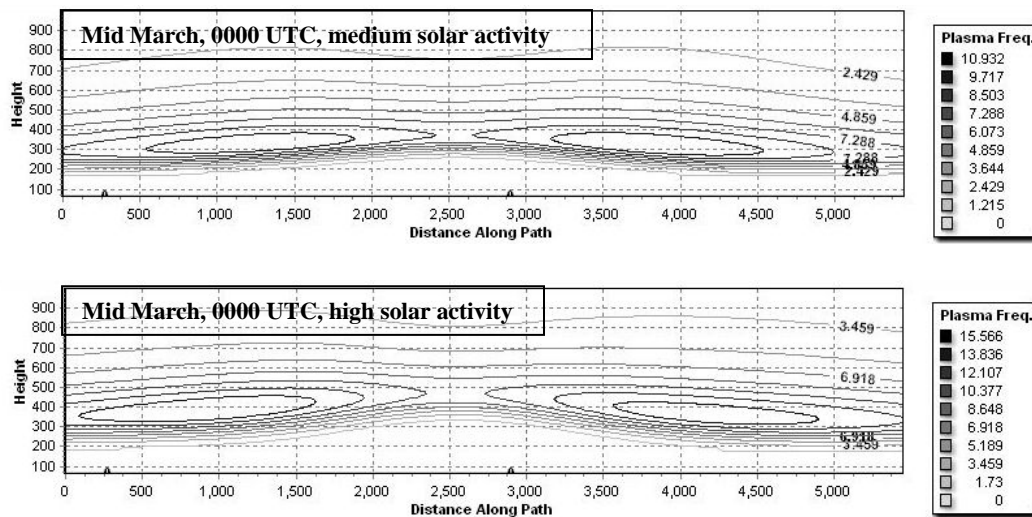


Figure 6 – Solar Cycle Variation for March at 0000 UTC

Compared to medium solar activity, the areas of high electron density on either side of the geomagnetic equator for high solar activity are similarly well developed, the tilts are still there, and the maximum plasma frequencies are about one and a half times as high – making 6m TEP even more likely at high solar activity.

Is All TEP The Same?

We've reviewed the mechanism in the ionosphere that causes TEP and we've reviewed the patterns of this mechanism over a 24-hour period, over the four seasons, and over solar cycle activity.

Does all this mean there's only one kind of TEP? Unfortunately, no – there is an afternoon TEP and an evening TEP, with the evening TEP even involving a condition of the ionosphere called spread F that can give evening TEP a flutter sound.

For more on TEP in general, and specifics about afternoon and evening TEP, visit the following web sites.

<http://www.ips.gov.au/Educational/5/1> - then click on the Transequatorial Radio Propagation (PDF) link

<http://home.iprimus.com.au/toddemslie/aTEP-Harrison.htm> - details about afternoon TEP by Roger Harrison VK2ZRH

<http://home.iprimus.com.au/toddemslie/eTEP-Harrison.htm> - details about evening TEP by Roger Harrison VK2ZRH

Summary

TEP affords those in the right location an interesting mode of F₂ propagation on 6m. And with links via sporadic E or the normal F₂ region, it can help those farther away from the geomagnetic equator.

TEP is most prevalent in the late afternoon and early evening hours of the equinoctial months at high solar activity, but don't rule out TEP at lower solar activity (as experienced by N4QQ). And make sure you check 10m, too – TEP on 6m may not be occurring, but it may be happening on this band.