Operating Near the Equator

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The spring 2016 issue of the Northern California DX Foundation (NCDXF) Newsletter had an article by Glenn W0GJ about the K5P DXpedition to Palmyra in January 2016. Glenn was one of the team members. In talking about the propagation that was experienced during the DXpedition, the article noted that not only was the DXpedition on the downslope of Cycle 24 with high A-indices, there was another curse to contend with: a large Total Electron Cloud hanging directly overhead for the first 10 days of the operation. It was stated that this attenuated both outgoing and incoming high angle signals (note 1).

Pretty much concurrent with this article in the NCDXF Newsletter was the story by Lance W7GJ in "The World Above 50 MHz" column (edited by Jon N0JK) in the March 2016 issue of QST about his 6-Meter EME DXpedition to V6M (Micronesia) in August 2015. This article stated that the high Kp indices, coupled with the high TEC over the V6M area at the time of day of V6M moonrise, was not helping EME propagation to North America.

These two DXpeditions had two things in common. First, they both were located at very low latitudes (near the equator). K5P is at 3° North latitude and 161° West longitude. V6M is at 10° North latitude and 140° East longitude. Figure 1 shows these two locations on a worldwide map.

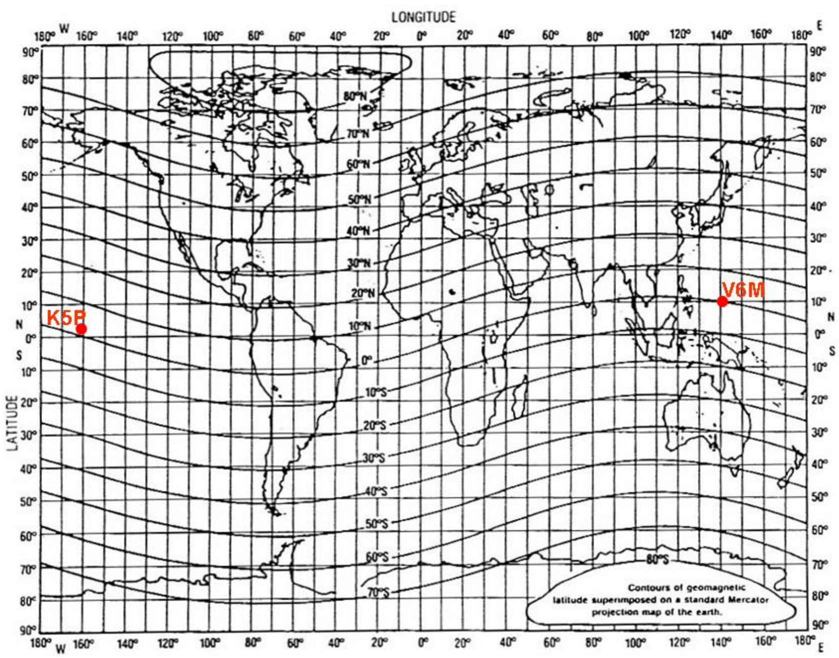


Figure 1 – K5P and V6M

The horizontal axis is geographic longitude and the vertical axis is geographic latitude. Geomagnetic latitudes are superimposed on the map – they are the wavy lines. Note that the geographic latitude of both of these locations translates to pretty much 0° geomagnetic latitude. I'll have more on this later.

Second, both DXpeditions felt that this thing called “total electron content” hindered their efforts. So let’s look at total electron content – what it is and how it affects propagation. Then we can assess its impact to those two DXpeditions.

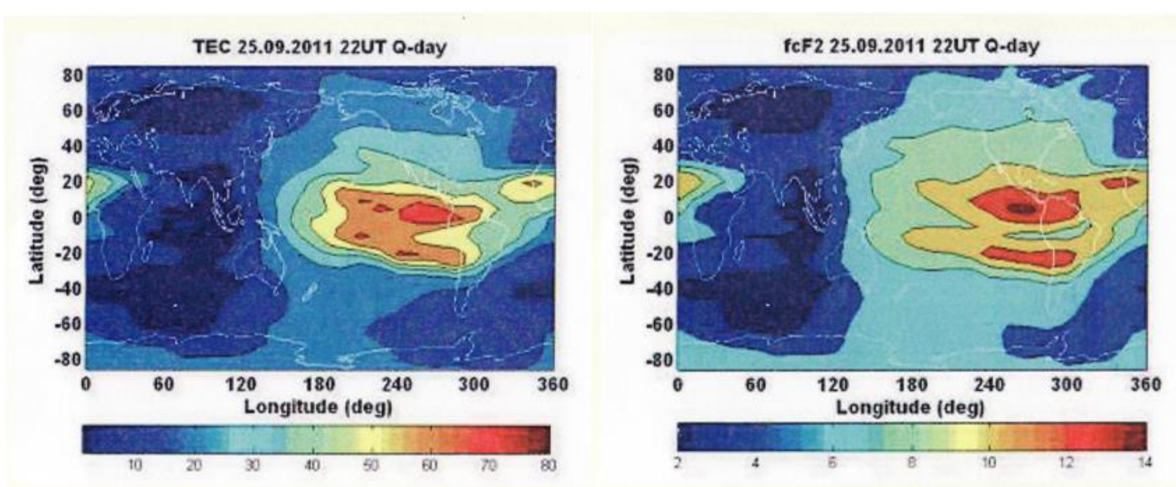
<u>What is Total Electron Content?</u>

The total electron contest (TEC) is a side benefit of GPS (global positioning system). Each of the twenty-four GPS satellites (at an altitude of about 20,162 km) transmits on two frequencies. These two frequencies are 1575.42 MHz and 1227.6 MHz.

When these two frequencies pass through the ionosphere (from the satellite to an Earth-based receiver), they both undergo a change in phase – but at different amounts due to the different frequencies. From the difference in phase between the two frequencies, we can calculate the total number of electrons per square meter along the line of sight between the satellite and receiver. Thus this is what TEC is – the total numbers of electrons in a square meter column from the satellite (well above the F2 region peak) to the receiver (on the ground).

One TEC unit (TECu) is 1 x 10^{16} electrons per square meter. To use TEC data for propagation purposes, two issues must be addressed. First, TEC is a measure along a slant distance as the receiver is usually not right under a satellite. With some math, the slant TEC (sTEC – what is measured) can be converted to a vertical TEC (vTEC), which is how the traditional electron density is defined – vertically (straight up) in terms of altitude.

Second, TEC is in terms of electrons per square meter whereas our traditional electron density is in terms of electrons per cubic meter (or cubic cm). Knowing that most of the electrons in an electron density profile are in the F2 region, it’s reasonable to assume that most of the electrons in the TEC data are also in the F2 region (and it’s the F2 region that mostly affects the two GPS frequencies). With this assumption, vTEC can be translated to a true electron density (or critical frequency). Figure 2 shows a representative translation, with TEC on the left and electron density (in terms of the F2 region critical frequency foF2) on the right (note 2).



TEC   electron density

Figure 2 – TEC and Electron Density

The maximum TEC on the left in Figure 2 is around 70 TECu, which is 70 x 10^{16} electrons per square meter. The maximum foF2 on the right in Figure 2 at the same location is around 14 MHz.

What Figure 2 shows most noticeably is that the vTEC and the foF2 (called fcF2 on the figure) in the Pacific Ocean on September 25, 2011 at 2200 UTC on a quiet day (that's what Q-day signifies) look very similar. It's obvious that the two parameters are closely related. Thus looking at a vTEC map will tell you in general what the F2 region is doing.

How TEC Relates to Propagation

I can't stress enough that TEC is for all intents and purposes a measure of the electron density in the F2 region. It tells us nothing directly about the E region (which can take away long F2 region hops if the E region critical frequency is high enough) nor the D region (where ionospheric absorption occurs during the day).

In summary, TEC is a good real-time indicator of the F2 region, allowing us to estimate the MUF (maximum useable frequency) for low angles by multiplying the equivalent foF2 (roughly based on the data in Figure 2) by about 3. But it doesn't tell us directly about signal strength. Remember that both MUF and signal strength must be acceptable for a QSO to occur.

As for those two high TEC areas and high electron density areas on either side of the equator, they are the signature of the equatorial ionosphere, and the magnitude of the crests depends on the month and time of day. The crests are most pronounced in the afternoon and evening (local time) around the equinoxes. During other months the crests may still been seen to a certain extent, again in the afternoon and evening. The crests are responsible for trans-equatorial propagation on 10-Meters and 6-Meters (and even higher when it is especially good). The crests are from 10-15 degrees on either side of the geomagnetic equator.

Now let's drill down into the specifics of the comments from the K5P DXpedition in relation to TEC.

K5P DXpedition and TEC

The K5P DXpedition said that the large Total Electron Cloud hanging directly overhead for the first 10 days of the operation attenuated both outgoing and incoming high angle signals. Figure 3 shows TEC on one of the days of the K5P DXpedition – specifically at 2350 UTC on January 17, 2016 (note 3). The K5P location is the red dot.

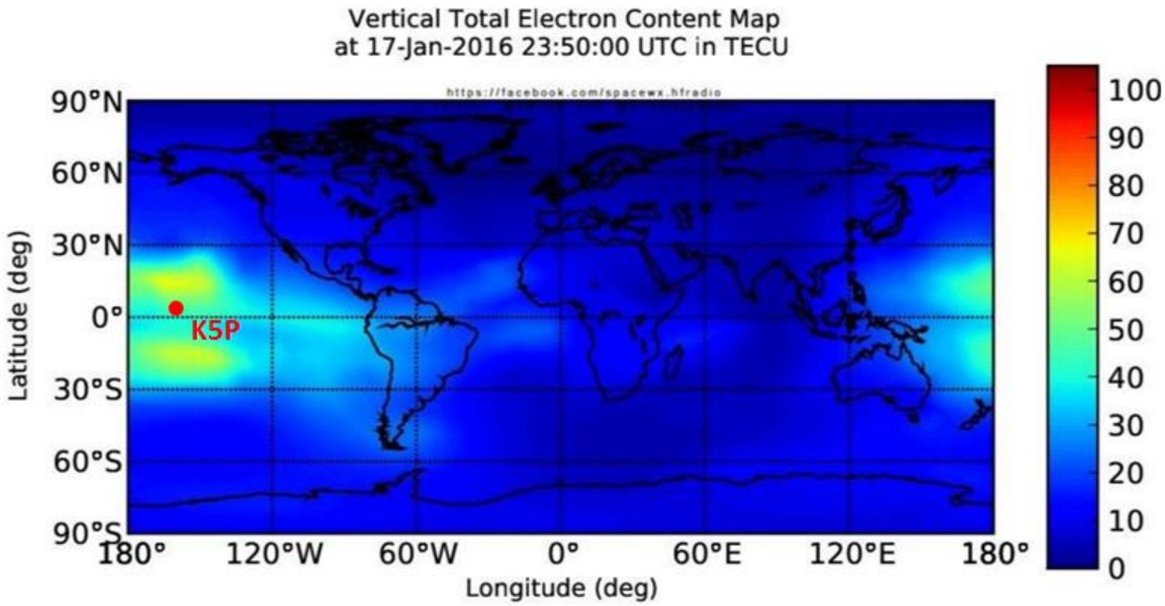


Figure 3 – TEC over K5P

The first observation from Figure 3 is that, indeed, the northern crest of the equatorial ionosphere is close to K5P. As stated earlier, the crests are from 10-15 degrees on either side of the magnetic equator, which would put them from 1100-1600 km north and south of K5P. That's about the midpoint of a normal low angle F2 region hop on the higher bands.

The second observation from Figure 3 is that there are some pretty high values of TEC on paths to the northwest thru north to northeast from K5P (and similarly to the southeast thru south to southwest) due to these crests. This is expected as it's the equatorial ionosphere where electron densities are the most robust. Using Figure 2, we can estimate that the F2 region critical frequencies were as high as 13 MHz during the K5P DXpedition. That puts the MUF (maximum useable frequency) well above 28 MHz for the first hop out of K5P to the north if the northern crest is the midpoint of a low-angle hop. To reiterate, these crests depend on the month and local time of day.

Thus the crests help the MUF, but have little to do with signal strength as ionospheric absorption occurs down at lower altitudes. In general a higher F2 region electron density translates to higher E region densities, and even to higher D region densities – which is not good for signal strength. Let's use VOACAP to take a detailed look at the path from K5P to my QTH in northeast Indiana.

The following assumptions were made for the VOACAP run:

1) 20-Meters
2) Smoothed sunspot number of 50 for the K5P DXpedition in January 2016
3) 1 kW transmitter power
4) Verticals on the beach at K5P
5) 12 dBi gain antenna at K9LA (small tri-bander)

Figure 5 plots many pertinent parameters.

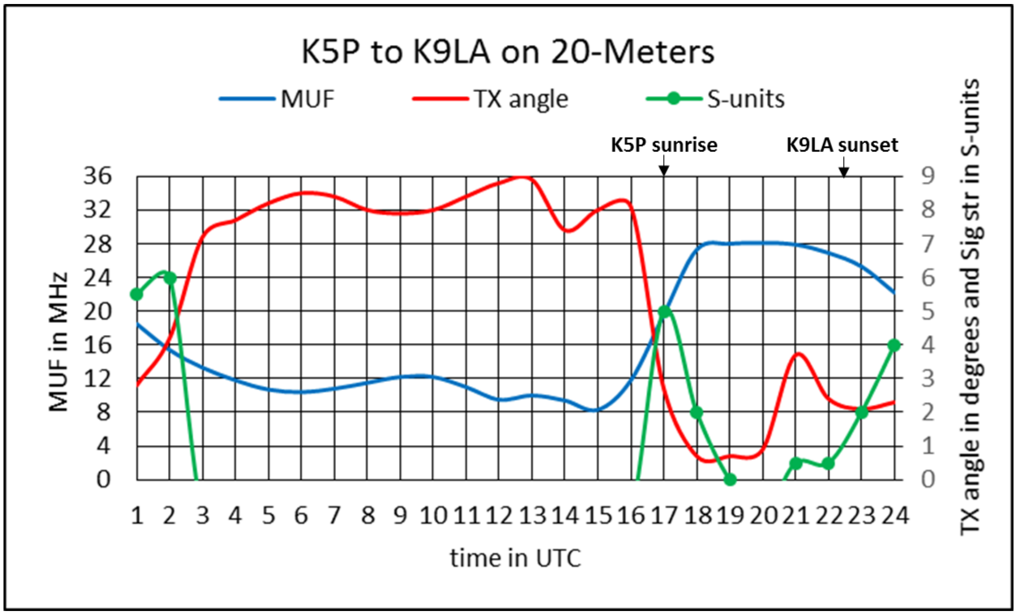


Figure 5 – K5P to K9LA on 20-Meters

There are lots of interesting things happening throughout the day on this path. With respect to the F2 region MUF, after sunrise at K5P (around 1700 UTC), the path MUF rises from its nighttime value. At this time the K9LA end of the path is in daylight. After sunset at K9LA (around 2230 UTC), the path MUF begins dropping and decreases to its nighttime value (which is below 14 MHz).

With respect to the TX angle, the angle required coming out of K5P during the night is around 8 degrees. Of course that is irrelevant as the MUF isn't high enough to support 20-Meters. When the MUF is high enough, the elevation angle required is quite low.

With respect to signal strength, sunrise at K5P and sunset at K9LA are important for propagation from K5P to K9LA. Around sunrise at K5P, the F2 region MUF has risen rapidly where the RF out of K5P encounters the F2 region (a long distance east of K5P). But where the RF out of K5P encounters the D region (much nearer to K5P) is still in darkness. Similarly, around sunset at K9LA, the D region has disappeared but the MUF is still high enough (because recombination between electrons and positive ions in the F2 region is a much slower process than the ionization process).

Why is the signal strength so low between K5P sunrise and K9LA sunset? There are two reasons for this. First, although the MUF is certainly high enough, unfortunately the southern end of the path being near the equator results in a significant amount of D region absorption during the day. Second, for several hours after K5P sunrise, the mode converts from 3 hops via the F2 region to 4 hops via the E region (another indication of lots of ionization). This extra hop means one more transit through the absorbing region.

In summary for K5P, the above paragraph is the reason why the K5P signals weren't that strong on 20-Meters. The TEC map doesn't tell the story directly, but the fact that the F2 region was so highly ionized points to much ionospheric absorption in the D region. Ionospheric absorption on 20-Meters and above during the day at relatively low elevation angles (when the RF spends more time getting through the D region than high angle RF) is an unfortunate signature of DXpeditions that are very near the equator (note 4).

V6M DXpedition and TEC

The V6M article stated that the high Kp indices, coupled with the high TEC over the V6M area at the time of day of V6M moonrise, was not helping EME propagation to North America.

Whereas the K5P DXpedition hoped for an adequate amount of ionization for refraction to bring the higher frequency signals back to Earth, the V6M DXpedition hoped for minimal ionization to allow 6-Meter RF to get to the Moon and back unimpeded.

I don't have a TEC map for the August 2015 V6M DXpedition, but I can show predicted worldwide F2 region critical frequency levels from Proplab Pro V3. As we learned from Figure 2, TEC will translate to the F2 region critical frequency nicely, and vice versa. Figure 5 shows foF2 for a representative V6M moonrise on one of the days of the V6M DXpedition.

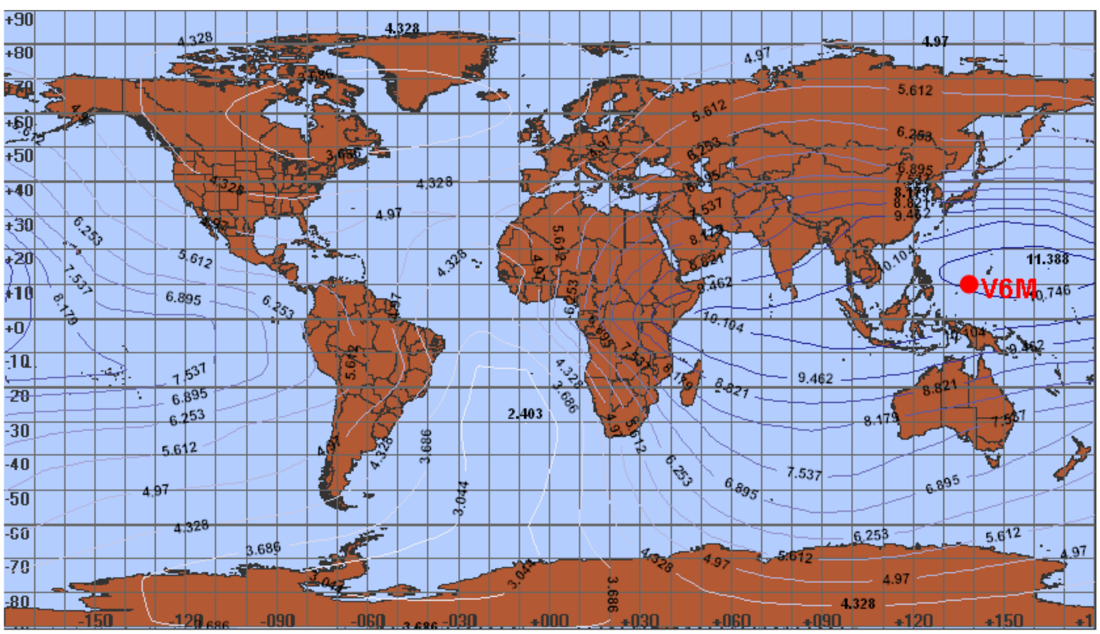


Figure 5 – Worldwide foF2 map at 0600 UTC on August 27, 2015

Note that the highest foF2 values in the world are over V6M, which translates to the highest TEC values as W7GJ stated. So how could this affect the V6M 6-Meter EME propagation?

The amount of ionospheric absorption is inversely proportional to the square of the frequency. The higher the frequency, the less the absorption. Thus the absorption on 6-Meters should be quite a bit less than on 20-Meters, and as such I believe the high foF2 values (and high TEC values) are not a hindrance to 6-Meter EME with respect to ionospheric absorption. But we have to temper that with the fact that 6-Meter EME could be a weak signal mode (especially with SSB), and every dB of loss would be very important.

What could have been detrimental to the V6M DXpedition was ionospheric scintillation. This causes a rapid fluctuation of radio-frequency signal phase and/or amplitude, generated as a signal passes through the ionosphere that has small scale irregularities in electron density.

Scintillation occurs in two regions of the world – at the high latitudes at F region and E region altitudes and in the equatorial ionosphere at F2 region altitudes. Scintillation in the equatorial ionosphere is typically more severe than at high latitudes due to the much higher electron densities (and thus irregularities). I don't know the scintillation conditions during the V6M DXpedition – perhaps there is an archive of these old maps. A source of worldwide maps of scintillation is http://www.trimble.com/Positioning-Services/Ionosphere-Scintillation-map.aspx.

Ionospheric scintillation in the equatorial ionosphere appears to be independent of geomagnetic field activity. Although the Kp (planetary) index spiked up to 6 during several 3-hours periods during the V6M DXpedition, scintillation data suggests that a high K index is not a major contributor to scintillation in the equatorial ionosphere.

There is another issue that may be tied to the high electron densities – more appropriately the gradient in the electron density. With the amount of refraction inversely proportional to the square of the frequency, there is less refraction (bending) as the frequency is increased. Generally we'd assume that 50 MHz would pass through the ionosphere with no refraction at all. But with foF2 values around 11 MHz and the resultant MUF around 33 MHz, could the 50 MHz RF have been bent enough so that pointing the antenna directly at the Moon did not put the strongest signal on the Moon? Figure 6 is a ray trace using Proplab Pro V3 on August 27, 2015 at moonrise at V6M (the condition in Figure 5). The path to the moon is east-southeast.

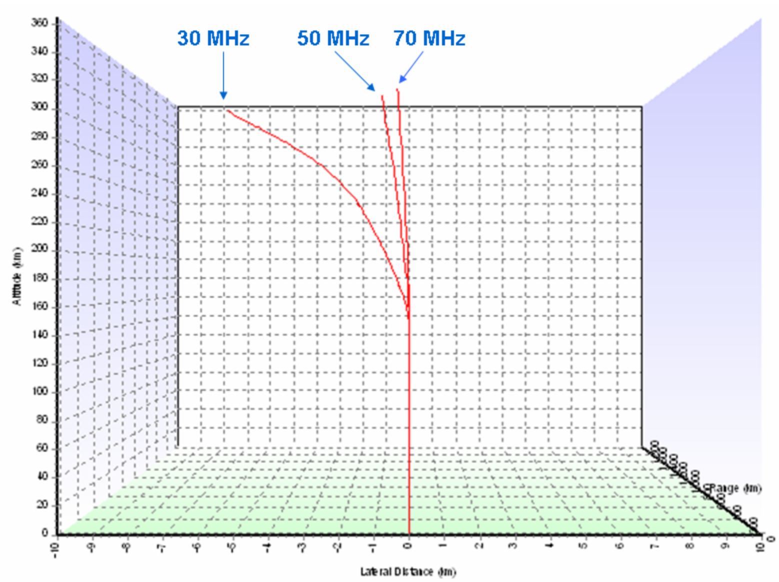


Figure 6 – Ray Trace Out of V6M at Moonrise to the ESE

We're looking along the ray path for three frequencies: 30 MHz, 50 MHz and 70 MHz. The elevation angle in all three cases is 10 degrees. As expected, the 70 MHz trace deviates the least from going straight through the ionosphere – it's off the true path by about 0.3 km after penetrating the ionosphere at 1500 km down the road. That's only 0.01^o off the true path.

The 30 MHz trace deviates the most. It's off the true path by about 8 km when it penetrates the ionosphere at 1200 km down the road (that's still only 0.04^o – by the way, 30 MHz bends the most of these three frequencies, so it will also take a shorter hop).

The 50 MHz trace deviates from the true path by about 1 km after 1500 km (0.4^o). With some math, the 50 MHz trace would be off the true path by about 250 km at the Moon. With the Moon's diameter about 2160 km, the refraction of the 50 MHz RF still places it on the Moon. So this idea doesn't appear to have any merit. That's good, as we don't need another variable to worry about.

In summary for V6M, ionospheric scintillation is the most likely detrimental effect for 6-Meter EME propagation near the equator.

Summary

We've looked at TEC for the K5P DXpedition and the V6M DXpedition, and we've seen how high TEC values could impact propagation.

Notes:

1) The comment about high angles came from me in an e-mail exchange with W0GJ while the K5P team was on the island. My cursory estimate of the closeness of K5P to the northern high-TEC area prompted the high angle comment. The term 'high angle' is somewhat relative. For the path from K5P to K9LA, using N6BV's statistical elevation angle data from the ARRL Antenna Book shows that 95% of the elevation angles required for this path are below 25 degrees. This is likely very similar to other NA and EU paths.

2) T.L. Gulyaeva, F. Arikan, M. Hernandez-Pajares, I. Stanislawska; Synthesized maps of the F2 layer peak electron density and peak height based on hourly GPS-TEC Global Ionospheric Maps; IRI, Hermanus, SAR; 10-15 Oct 2011

3) Worldwide TEC maps are available at http://iono.jpl.nasa.gov/latest_rti_global.html. US TEC maps are available at http://www.swpc.noaa.gov/products/us-total-electron-content.

4) The highest K index was only up to 3 for a handful of 3-hour periods during the K5P DXpedition – so I don't think geomagnetic field activity played much of a role.