A LOOK INSIDE THE AURORAL ZONE
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Ever wonder what's going on in the auroral zone when the magnetic indices are elevated? Is it chock-full of ionization causing wide-spread absorption? And is absorption the only impact to RF? Read on, and find answers to these questions.

With the explosion of information available on the World Wide Web, it's likely that you've seen the colorful auroral pictures that come out of the Space Environment Center (SEC) in Boulder. SEC, which is a part of NOAA (National Oceanic and Atmospheric Administration), posts these auroral pictures on their web site from current satellite passes. These pictures can be viewed at www.sec.noaa.gov/pmap. By the way, 'pmap' is short for 'power map' – more about the name later.

Let's take a look at the data these pictures give us, with the goal being a physical understanding of the ionization in the auroral zone and how it impacts our RF. I'll restrict the detailed analysis to auroral conditions in the evening hours (local time), but I'll add some comments at the end in relation to auroral conditions around local midnight and in the early morning hours. I'll also take a look at photos from another satellite to give an even better understanding of what's going on in the auroral zone.

The auroral zone, also referred to as an auroral oval, is the annular ring (the reddish-orange area in the pmap) that is centered about the magnetic pole. There is an auroral oval at the north magnetic pole and one at the south magnetic pole. To a first order approximation, they are in step with each other – if one is quiet, the other one is, too. And if one is active, the other one is, too. The auroral oval is thickest in the local midnight sector and thinnest in the local noon sector.

Figure 1 is a sample pmap for November 29, 2000 at 0141 UTC.

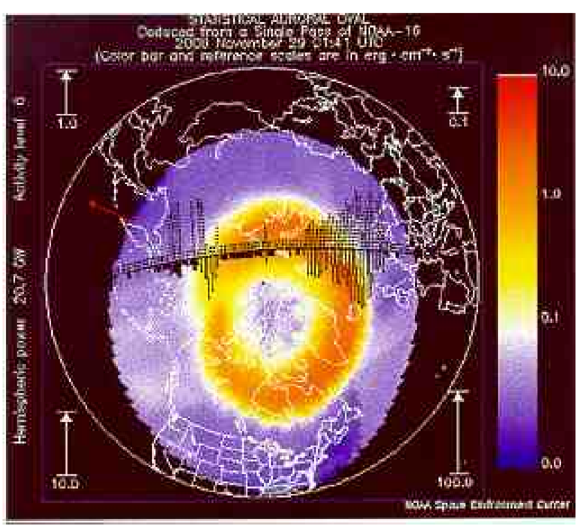

Figure 1 Pmap

The satellite made its pass over the northern polar area at 0141 UTC, which is the time the satellite was halfway through its polar pass. The satellite's track across the northern polar area is the continuous black line running from west to east. The solid black bars perpendicular to the satellite track (the ones extending toward the south) are proportional to the logarithm of the average energy flux observed at that location in erg cm^{-2} sec^{-1}. The scales for these solid black bars are the 0.1, 1.0, 10.0, and 100.0 lines in the four corners of the picture. The length of the solid black bar indicates how much ionization may be present.

From these data, the total power input to the polar region as a result of auroral particles can be estimated. For this specific pass, the power was estimated at 20.7 gigawatts as noted on the left side of the picture. Using observations from over 300,000 satellite passes, this estimate of power (hence the term power map, or pmap for short) is put into one of ten categories called an auroral activity level.

The auroral activity level for this pass was 6, which is noted on the map on the left side of the picture after the estimated power input. The auroral activity level correlates to the 3-hour planetary magnetic K_p index per the following table:

Estimated power into auroral zone	Auroral activity level	K_p (see sidebar)
< 2.5 gigawatts	1	0+
2.5 – 3.9	2	1-
3.9 – 6.2	3	1+
6.2 – 9.8	4	2
9.8 – 15.5	5	2+
15.5 – 24.4	6	3
24.4 – 38.6	7	3+
38.6 – 60.9	8	4
60.9 - 96	9	5-
> 96	10	≥ 5+

Table I Correlation of Power and Auroral Activity Level to Kp

Thus the K_p index at the time of this pass was 3 (unsettled geomagnetic field). Note that the auroral activity level on the pmap is not the same as the K_p index.

Once the auroral activity level is known, one of ten predetermined statistical auroral ovals (one for each of the ten auroral activity levels) is superimposed on the picture. Each predetermined statistical oval was created by averaging NOAA satellite observations from all passes over the auroral regions that had that estimated level of auroral activity. These essentially are the same ovals in Peter Oldfield's DXAID propagation and mapping software (reference 1), and simply indicate where visible aurora is likely to occur. Thus the auroral oval on the pmap is not a real-time picture - it is a canned picture based on the auroral activity level, which comes from the estimate of auroral particle power.

Going off in the opposite direction from the solid black bars are a series of black dots. The number of dots is the average energy of the precipitating electrons involved at that location. The number of dots goes from a minimum of two dots (an energy of 350 electron volts) to a maximum of 22 dots (17,500eV). This is the range of the detector onboard the satellite.

The number of dots tells us to what depth electrons penetrate into the atmosphere. The higher the energy, the farther down they penetrate. Figure 2 gives the relationship between the number of dots (electron energy) and altitude (reference 2):

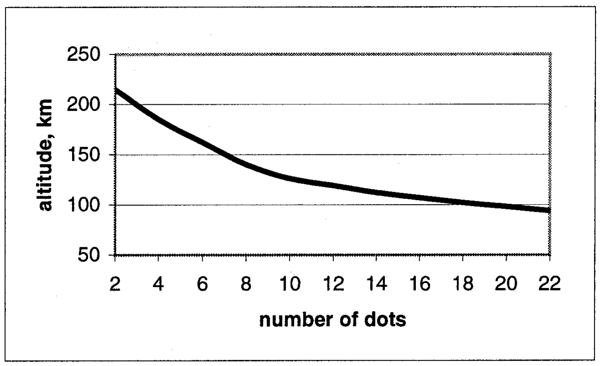

Figure 2

From Figure 1, the highest number of dots (about 18) occurred at the equatorward edge (the outer perimeter) of the auroral oval during this pass over the northern polar area. Using Figure 2, we see that these precipitating electrons got down to around the 105km level – the E region. Inside the auroral oval, the highest number of dots was about 8. Figure 2 indicates these electrons only got down to around the 140km level – the lower F region.

It is important to realize that the detector onboard the satellite only measures low energy precipitating electrons that get down to 100km or so. These are the electrons that can cause visible aurora. The higher energy electrons that get down to the D region (below 90km) to cause auroral absorption are not measured.

We can now qualitatively summarize the pmap information. We know where visible aurora is likely to occur (anywhere in the annular ring), and we know that the less energetic electrons precipitate into the auroral oval and that the more energetic electrons precipitate at the equatorward (and poleward) edge of the auroral oval. And to reiterate, the oval on the pmap tells us nothing about absorption.

This is good information, but unfortunately it really doesn't tell us much about the potential impact to an RF signal that is following a specific path through the auroral zone. Just because there is ionization doesn't necessarily mean it'll have an effect on RF. Somehow we need to determine where both auroral absorption and significant E region ionization is occurring – the two items that can affect our RF.

To answer the 'auroral absorption' question, it is known that auroral absorption in the evening hours generally occurs equatorward of visible aurora. The brighter the visible aurora, the more likelihood there is that absorption is also occurring.

To answer the 'significant E region ionization' question, we can use a technical paper by Bob Hunsucker AB7VP, et al (reference 3). Bob and his colleagues monitored the auroral event of March 16, 1972 with an all-sky camera, a scanning photometer, an incoherent scatter radar, a three-component magnetometer, a 30MHz riometer, and two VHF/UHF auroral radars. See the sidebar for brief descriptions of these measurement techniques.

The comparison of all their data showed that intense discrete auroral forms could be associated with enhanced E region electron densities of up to 1×10^6 electrons per cubic centimeter. That works out to a critical frequency of about 9.0MHz. This increased ionization can affect our RF with respect to refraction or reflection.

The possibility of our RF being refracted or reflected increases with the increased ionization. Depending on how the RF encounters the increased ionization, this can give us a normal hop when the MUF gets high enough for the frequency of interest or it can give us a non-great-circle path. The latter is what I believe happened on a 160m QSO on the night of March 10, 1999 as explained in my CQ article (reference 4).

Now we know what to look for – intense discrete auroral forms. But where do intense discrete auroral forms occur? The dots on the pmap, indicating electron energy, give us a clue – generally at the equatorward and poleward edges of the auroral oval where the number of dots is highest and the bars are long.

Let's take a look at a Defense Meteorological Satellite Program (DMSP) photo, Figure 3, on the same night as the pmap of Figure 1. The time of this photo is 0153 UTC. That's 12 minutes after the time of the pmap picture.

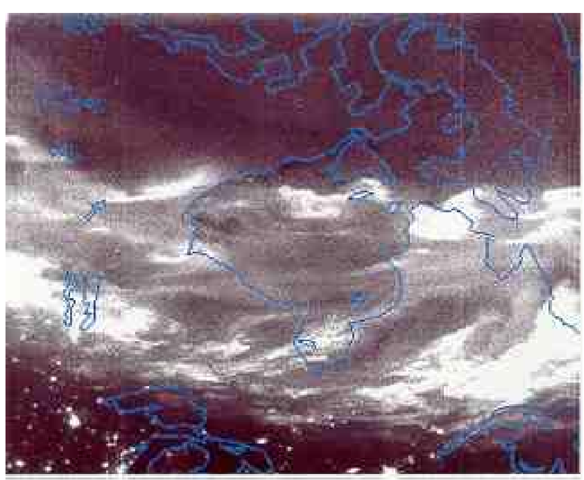

Figure 3 DMSP photo

Before discussing the visible auroral forms, let’s get oriented with Figure 3. Right in the middle of the photo is Hudson Bay in Canada. The two lakes running north-south at the left center of the photo are Lake Winnipegosis and Lake Winnipeg in Manitoba. The Great Lakes are toward the lower left. The big bright light just southwest of Lake Superior is Minneapolis, MN. The big bright light on the West side of Lake Michigan right at the bottom of the photo is Milwaukee, WI.

With respect to auroral forms, there’s a lot going on in this photo. In addition to intense (bright) discrete auroral forms, there is quite a bit of diffuse aurora (the lighter shade of white) in the oval. Note that the equatorward boundary of the auroral forms is just north of the northern extremities of the Great Lakes, and compares favorably with Figure 1. The poleward boundary of the auroral forms appears to be just north of Hudson Bay, and this also compares favorably with Figure 1.

Applying the aforementioned conclusions says that those intense discrete auroral forms would be the likely areas that could impact our RF, both with respect to absorption and refraction/reflection. Since those areas are so widespread, it is obvious that our RF might have a bit of a problem getting through the auroral zone on this night at the time indicated. So can we say that an elevated K_p index will *always* create havoc with our RF? No, we can’t, for two reasons. First, our RF could sneak under those intense discrete auroral forms as suggested by Cary Oler and Ted Cohen N4XX (reference 5) or it could even sneak through the gaps between those intense discrete auroral forms. Second, auroral events are dynamic in nature – in other words, wait a bit and things will change (hopefully for the better!).

To show how variable auroral events can be, Figure 4a and 4b show a pmap and the DMSP photo in the same geographical area as Figure 3 but for another night.

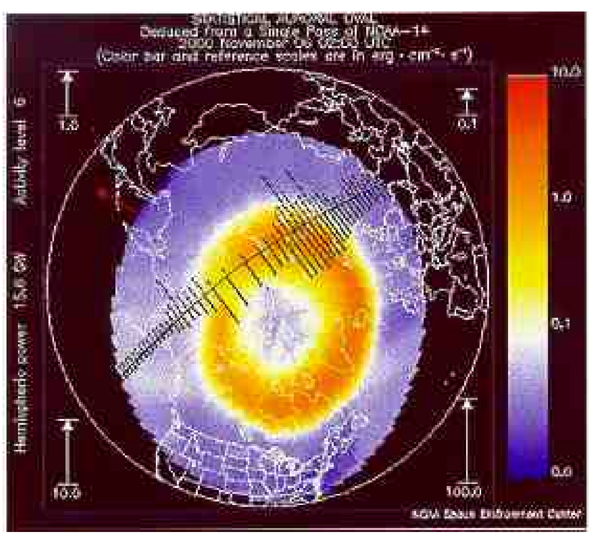

Figure 4a Pmap

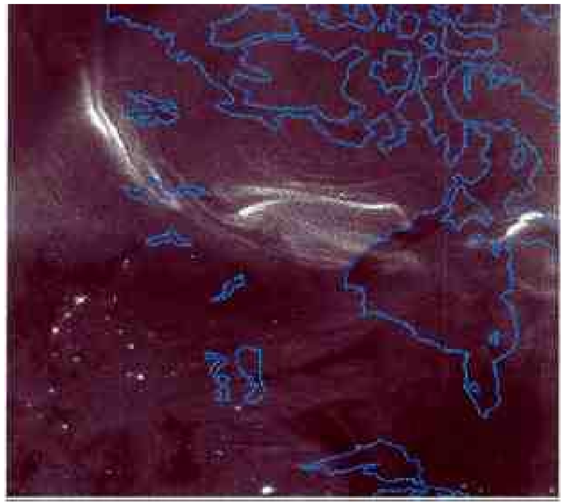

Figure 4b DMSP photo

For the Figure 4 pictures, the time for the pmap is 0200 UTC and the time for the DMSP photo is 0204 UTC. The auroral activity level is 6, which is the same as in Figure 1. So one might expect roughly the same amount of auroral activity as seen in Figure 3. But the auroral activity is limited to several intense but very thin arcs. There doesn't appear to be as much diffuse aurora, either. If you look very closely, you'll also see thin cloud layers obscuring all but the real bright city lights. And the earlier comment about our RF sneaking under or through gaps might have been applicable for this night.

Figure 5a and 5b show another pmap and the corresponding DMSP photo for yet another night.

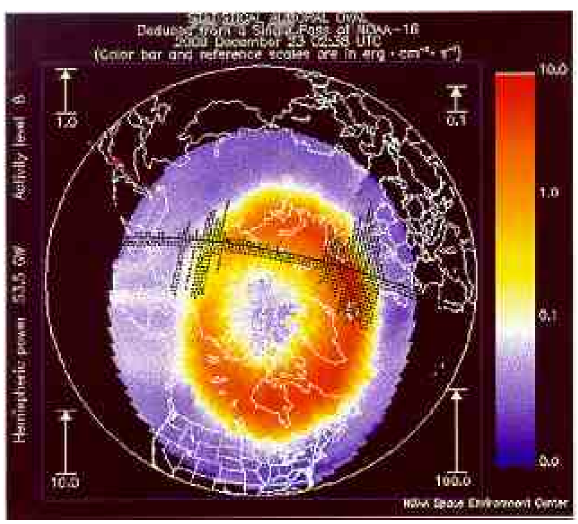

Figure 5a Pmap


Figure 5b DMSP photo

The time for the pmap in Figure 5a is 0238 UTC. The time for the DMSP photo in Figure 5b is 0256 UTC. The auroral activity level is 8 (K_p = 4, indicating an active geomagnetic field), which is two levels *higher* than in Figure 1 and Figure 4. So one might expect even more activity than in Figure 1 (and certainly more than in Figure 4). But the auroral activity is limited to many intense but long thin arcs. There is some diffuse aurora equatorward of the intense arcs. This was a nice cloudless night, as evidenced by the numerous city lights showing up. As for RF sneaking under or through gaps, it's quite obvious that the best possibility in this area on this night might have been sneaking under due to the longitudinal extent of the arcs.

Summarizing this investigation for auroral activity in the evening hours, we can say that the auroral oval in the pmap or in DXAID only tells us where visible aurora is likely to occur. The auroral activity that may have an absorption or refraction/reflection impact to our RF is generally at the equatorward and poleward edges of the auroral oval. But it's possible that our RF could sneak under or through gaps in these intense auroral forms. As the K_p index becomes ever higher, there is less likelihood for our RF to sneak under or through.

Around local midnight things are more active. There is very intense auroral activity, including bright active regions coming down field lines, strong negative excursions on magnetometer records, and rapid and strong increases in auroral absorption on riometers. This also makes it less likely for our RF to sneak under or through gaps unimpeded.

In the early morning hours, auroral activity is pretty structureless and is tough to see. But the amount of particle energy deposited into the auroral zone is generally more than in the evening hours. Moreover, the number of precipitating electrons with energy greater than 30KeV can be pretty significant, giving rise to more absorption. Thus we may not see much looking up at the sky, but nonetheless our RF may have a problem getting through the auroral zone unimpeded.

In closing, auroral events can disrupt direct path propagation via absorption and/or refraction/reflection, or your RF may manage to sneak through unimpeded. If the direct path is disrupted, the auroral activity may also provide an alternate path – a non-great-circle path. So hang in there - you may be pleasantly surprised with an opening that others miss.

I'd like to thank Dave Evans and Sue Greer of SEC for their help in acquiring the pmap and DMSP data. And thanks to Dave and Sue and Bob Brown NM7M for their review of this article.

References:

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K_p Index

Usually the K_p index is reported from 0 to 9 in steps of 1. For better resolution, the K_p index is often broken up into steps of one third: 0, $^1/_3$, $^2/_3$, 1, 1 $^1/_3$, 1 $^2/_3$, 2, 2 $^1/_3$, and so forth. The K_p index is then designated as a whole number, or as a whole number with a + or - sign following it to indicate if it's one third more or one third less, respectively. For example, 1+ means one third more than 1, which is 1 $^1/_3$. Likewise, 2- would be one third less than 2, which is 1 $^2/_3$.

Measurement Techniques

all-sky camera – A downward-looking camera mounted above a convex mirror to enable it to take a picture of the sky from overhead to the horizon at all azimuth angles around the compass.

scanning photometer – Measures the intensity (in Rayleighs) of visible light, specifically at wavelengths of auroral emissions.

incoherent scatter radar – Operating at 1290MHz in conjunction with a 27m dish, it was used to measure electron density down to 70km. When this investigation was undertaken, the radar was located at Chatanika (Alaska). It has since been moved to Sondre Stromfjord in Greenland.

three-component magnetometer – Used to measure variations in the H, D, and Z components of the Earth's magnetic field. This data is also used to determine the local k index.

30MHz riometer – An acronym for <u>r</u>elative <u>i</u>onospheric <u>o</u>pacity <u>meter</u>. It measures incoming cosmic noise at 30MHz. If the level of cosmic noise decreases from the quiet baseline, that indicates additional absorption.

two VHF/UHF auroral radars – One was a NOAA radar at 50MHz at Anchorage, and the other was a similar radar operating at either 139MHz, 398MHz, or 1210MHz at Homer (near Anchorage).