The Auroral Oval and Auroral Zone

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Coronal mass ejections (CME) from the Sun on 27 and 28 November, intercepted Earth early on 1 December and caused a severe geomagnetic storm (figure 1). The interaction of the interplanetary magnetic field (IMF) with Earth's magnetic field opened a gap, allowing energetic particles in the solar wind to enter the magnetosphere. These particles rained down on Earth's high-latitude atmosphere where they collided with neutral atoms and molecules and, in the process, produced aurora and radio propagation effects. Events like this provide a good opportunity to discuss the *auroral oval* and *auroral zone*, the subjects of this article. The effects of the 1 December geomagnetic disturbance on radio propagation are published separately.

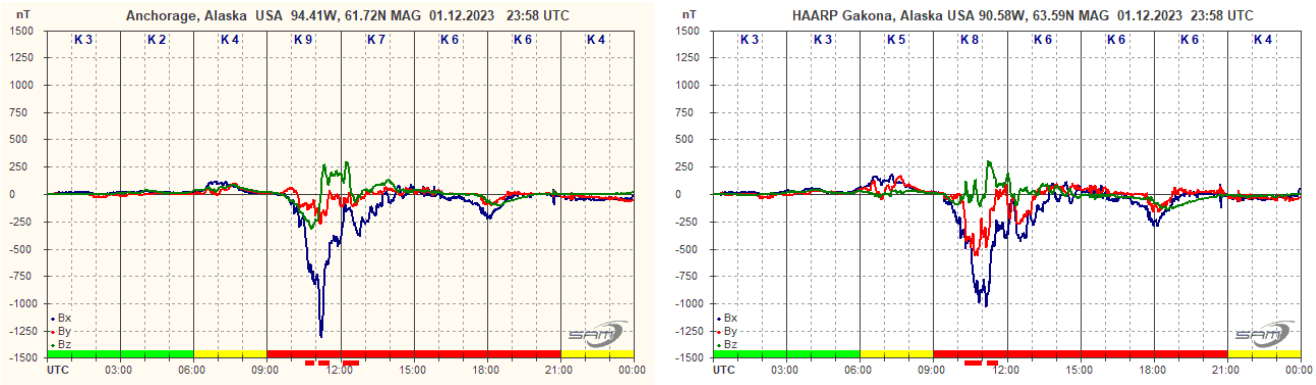

Figure 1 ~ Magnetograms from the SAM-III magnetometers at Anchorage and Gakona, Alaska for the 24-hour period 1 December 2023. The two sites are about 290 km apart and differ in magnetic latitude by about 2° and longitude by about 4°. The CME impact occurred at 0020 UTC and cannot be discerned in the traces because of the high vertical scale. About 6 hours after the sudden impulse, the magnetic field showed a brewing storm and just before 1000 experienced a major disturbance with the K-index going to maximum value (K9).

Auroral Oval & Auroral Zone

Two concepts are used to discuss where aurora occurs and is observed - the auroral oval and auroral zone. The *auroral oval* is a belt of auroral emission around the north and south geomagnetic poles. The ovals are fixed in space with respect to the Sun, and the Earth rotates below them. The poleward and equatorward boundaries of the auroral ovals depend on conditions in the solar wind including speed, density, and magnetic field orientation as well as conditions in Earth's ionosphere and magnetosphere. The solar wind pushes the ovals toward the nightside of Earth so they exist at lower latitudes on the nightside than on the dayside. The aurora itself occurs at altitudes of about 100 to 400 km but sometimes as high as 700 km.

When the Sun and its solar wind are quiet (figure 2-left), the auroral ovals shrink and their equatorward boundaries move poleward. Under these conditions, the oval belts are approximately 23° from the geomagnetic poles on the nightside of Earth and 15° from the poles on the dayside. Under these relatively quiet space weather conditions, aurora still occurs but only in a relatively narrow band.

During active conditions the ovals expand in diameter and width such that aurora occurs at much lower latitudes; however, the poleward boundaries do not change much (figure 2-right). The ovals reflect the footprints of closed geomagnetic field lines at higher latitudes that thread through the Earth's plasma sheet (figure 3).

Inside each auroral oval is a *polar cap*, which is threaded by magnetic field lines that are stretched to the magnetotail and are open to the IMF. It is the gap between the closed and open field lines that allows particles from the solar wind to enter the magnetosphere and produce the aurora.

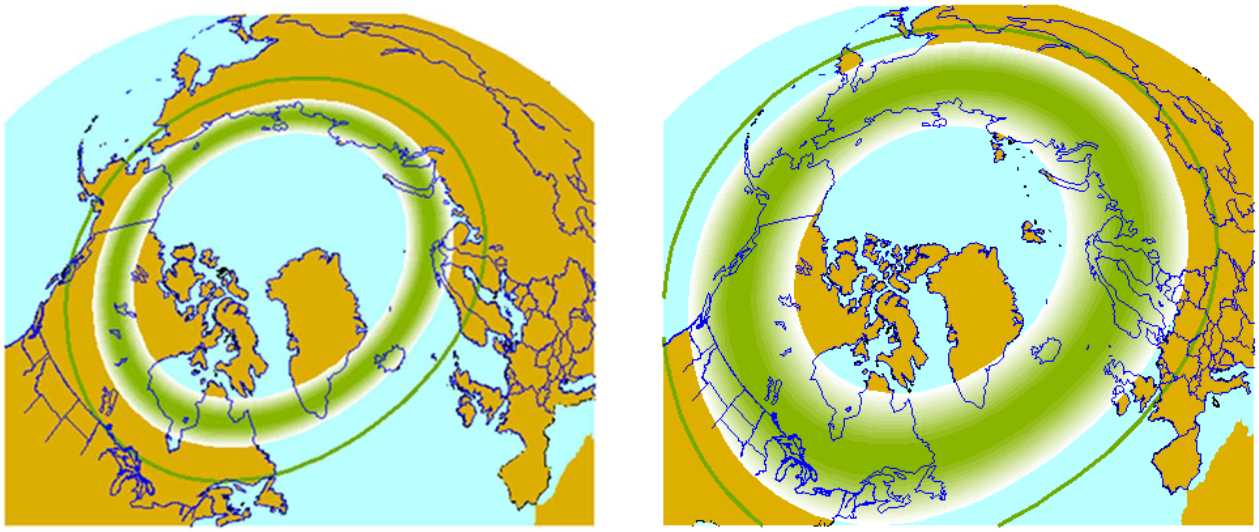

Figure 2 ~ Predictions of the auroral oval and auroral zone in the northern hemisphere. Left: Quiet conditions on 22 September 2023; Right: Comparatively active conditions on 1 December 2023. The wide green belt with white boundaries indicates the predicted auroral oval on the date of the image and the thin green line indicates the approximate boundary for viewing the aurora on the equatorward side of the oval. Note that the poleward boundary of the auroral oval changes very little. Images source: https://www.gi.alaska.edu/monitors/aurora-forecast

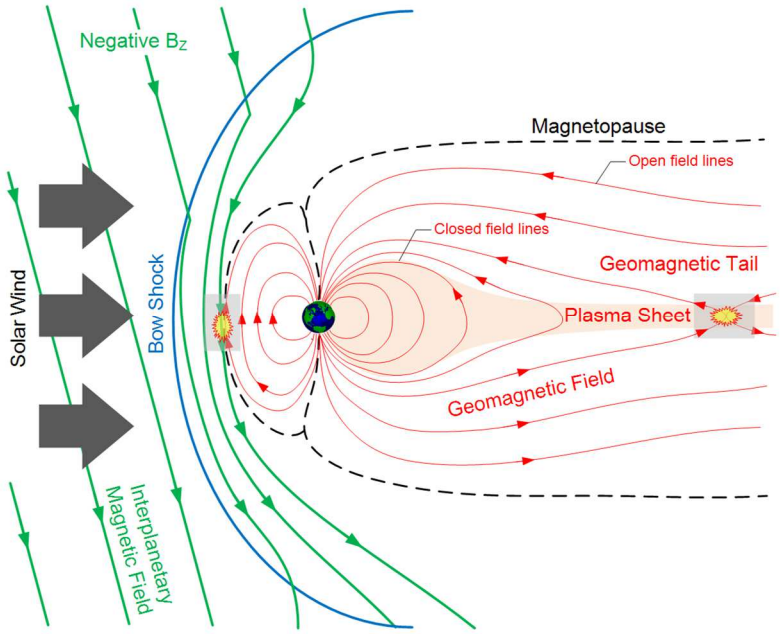

Figure 3 ~ Magnetosphere schematic. The Earth is the circle in the middle and its magnetic field lines are shown in red. The solar wind blows from the left and compresses the magnetosphere on the dayside and stretches it out on the nightside. The IMF is shown in green with a southward component opposite Earth's northward dipole field. Reconnection (red circle on the dayside) opens the geomagnetic field at the magnetopause and allows solar wind particles to enter the magnetosphere. The open field lines fold over into the magnetotail where they eventually close through another reconnection (red circle in the tail). The plasma sheet is a sheet-like region of relatively hot, dense plasma and lower magnetic field in the magnetotail near Earth's equatorial plane.

The *auroral zone*s are where the likelihood of seeing nighttime aurora is highest for observers on the ground. As with the auroral oval, there is an auroral zone in each hemisphere, and they similarly expand and contract depending on solar activity. The difference between auroral ovals and auroral zones is that the ovals are a projection onto the ground, whereas the auroral zones are the locations where aurora may be viewed from the

ground. Because of their high altitude, aurora may be viewed some distance from the oval, both poleward and equatorward, so the auroral zone is always somewhat larger than the auroral oval.

The auroral zone is limited by Earth's curvature – if an observer is too far away, the aurora (in the auroral oval) will be below the horizon and out of sight. As a rule of thumb, aurora can be observed 500 km (300 miles) from the oval based on a 20° line-of-sight elevation angle at the observer's location and 225 km altitude for the aurora. Observers farther away than 500 km could see aurora if they have line of sight with an elevation angle below 20° or the aurora is above 225 km altitude. The opposite is true if the observer's location is blocked by mountains or high trees or the aurora is confined to lower altitudes. And, of course, the sky must be clear between the observer and aurora.

For the geomagnetic storm of 1 December, aurora was reported to be visible in the northern hemisphere as far south as Arizona and California as well as in the southern hemisphere in New Zealand {SpcWx}, indicating that the auroral oval was pushed to at least 40° geographic latitude from its quiet resting place of around 70°.

{SpcWx} https://spaceweather.com/archive.php?view=1&day=03&month=12&year=2023