NASA DEVELOP National Program
Virginia – Langley

Summer 2024

Glacier & Denali Space Weather

Enhancing Aurora Watch Planning at Glacier and Denali National Parks

DEVELOP Technical Report

August 9th, 2024

Isabel Pullias (Project Lead)
Elise Segal
Brent Bowler
Rachel Thompson

Advisors:
Dr. Xia Cai, NASA Langley Research Center (Science Advisor)
Dr. Yihua Zheng, NASA Goddard Space Flight Center (Science Advisor)
Jamie Favors, NASA Headquarters

Leads:
Marisa Smedsrud (Virginia – Langley)
Laramie Plott (Virginia – Langley)

1. Abstract

The aurora borealis, more commonly known as the northern lights, are vibrant natural lights that are found near the Earth's poles. These lights attract numerous visitors every year to national parks hoping to enjoy this magnificent scenery. National parks rely upon Kp forecasting prediction models as well as the OVATION Prime model to understand where and when the aurora will occur. The accuracy of the prediction models allows the National Park Service to effectively allocate resources where high traffic is expected so that they can provide better viewing opportunities to the public. To verify these models, we used Earth observations such as Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band on the Suomi National Polar-Orbiting Partnership (NPP) satellite to provide images of the aurora. This imager with the combination of ground-based imagery validates current prediction models with confirmation of when and where the aurora occurs. Partnered with Glacier National Park and the Natural Sounds and Night Skies Division from Denali National Park we explored the capability of using another prediction model, a polar disturbance index called the AE index. Using R-squared linear regression tests and Cohens Kappa along with the analysis of ground observations provided through AuroraSaurus, we found the Kp and AE indexes to be reliable indicators to observe the aurora. However, while the aurora can be seen using the VIIRS Day Night Band post event, it is not a feasible tool for aurora prediction.

Key Terms

remote sensing, VIIRS, aurora borealis, Kp index, AE index, OVATION Prime

2. Introduction

The aurora borealis is the result of charged particles that flow within solar winds from the sun. These highly charged particles interact with the magnetic field generated by Earth's core, which strips the magnetic field lines facing the sun (Baranoski et al., 2000). Then these lines that were broken, reconnect and send the trapped particles towards the Earth's poles. When these particles lose energy, they emit light and give rise to the commonly known aurora borealis (Baranoski et al., 2000). These particles create a magnetic disturbance and thus create the aurora borealis around the magnetic meridian or Earth's polar region (Angot, 1897). Observing these lights is considered a once in a lifetime opportunity for many; therefore, predicting their occurrence is of the utmost importance for national parks to help facilitate positive viewing experiences.

Glacier National Park and Denali National Park (Figure 1) are popular locations in the United States for viewing the aurora. These parks are located in northern Montana and southern Alaska, respectively, combining millions of open acres for aurora watching. People come to these parks to view the aurora at specific times of year when high aurora activity is predicted. The National Park Service seeks to better predict high aurora activity to communicate with the public. With better predicting and understanding of the aurora, the National Park Service can better allocate resources to serve areas that expect high tourism activity. Therefore, we partnered with Glacier National Park along with the National Park Service's Natural Sounds and Night Skies Division to assess the feasibility of using Earth observations to enhance aurora watch planning at Glacier National Park and Denali National Park.

Figure 1. Our study area includes the entirety of Glacier and Denali National Park.

Glacier National Park and the Natural Sounds and Night Skies Division share the common goal of improving their methods of informing visitors about optimal viewing of the aurora at the national parks. To meet the needs of the National Park Service and address their community concerns, our project aimed to validate the current practices used by the parks, as well as explore the feasibility of using alternative aurora forecasting and visualization tools. These tools focus on creating digestible space weather content about the aurora and provide guidance to the NPS to better inform their visitors of aurora sightings.

To provide the best possible results, this project focused on a study period from December 2019 – May 2024. With 2025 predicted to be a Solar Maximum, the observed dates allow accurate data and research to provide the parks with the best possible information about viewing dates for this upcoming year. Our goal was to provide evidence for the verification of aurora sightings. Thus, supplying end users with the tools necessary to know when to promote aurora viewing including validation of prediction models and visualization of aurora from the ground and space.

Prior to this project, the National Park Service used prediction models to assess when to inform visitors of aurora viewing through social media. The prediction model used is called the Planetary K-index (Kp index). This model describes when and where the aurora will be based upon the magnetic field disturbance by high-speed particles that come from the sun. This disturbance is measured by thirteen magnetometers around the world, providing a global average value (Elliot et al., 2013). The Kp index hosts forecast times of 3-hour, 3-day, and 27-days ahead of present day. However, there is another prediction model called Auroral Electrojet index (AE index). While Kp models are an averaged global value, AE models take real-time data from twelve observatories located in the northern hemisphere along the aurora oval where the aurora originates (Wu et al., 2024). Because of this, the AE index is known as a polar value and could be considered more reliable. Due to the dependance on real-time data, the AE index differs from the Kp index, hosting solely an hour in forecasted time. Using Earth observations, we confirmed the integrity of the prediction models and provided reliable dates to view the aurora at national parks.

The credibility of both predicted models can be increased by using Earth-based observations to verify the auroral oval. The aurora can be viewed from space using the Suomi National Polar-Orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) that detects light emitted from Earth. The aurora appears bright, diffused, continuous, luminous bands (Frey, 2007) and these bands help with the validation of prediction models by confirming that the aurora is visible on the days it is predicted to be observed.

Another way to confirm aurora occurrences is through statistical distribution of energized electrons and ions in the ionosphere. For example, OVATION Prime 2.3 maps this distribution by coupling different space weather functions and then displaying the probability of aurora occurring geographically over a given area, taking the form of the aurora oval in the polar regions. This oval is analyzed to determine if the aurora is visible at a given location. Online citizen-science tools such as AuroraSaurus use OVATION Prime to determine when the aurora is visible. This website uses ground-up observation of the aurora, verified by anyone around the world to confirm aurora viewings, add images, and report the time and date of the viewing.

3. Methodology

3.1 Data Acquisition

To evaluate numerical prediction models of the aurora, we acquired data from both the Kp and AE index databases (Table 1). To find how accurate the Kp and AE prediction models are, we compared the predicted and observed data values from both Kp and AE indices. We acquired Kp index data from GFZ German Research Centre for Geosciences at Helmholtz Centre Potsdam database (GeoForschungsZentrum, 2021). This public database contains only the observed values, as the predicted values are supplied through the National Oceanic and Atmospheric Administration (NOAA). For the observed values, advancing to user-specified data between the dates December 2019 – May 2024, we downloaded Kp values with the Kp and ap format. Since it is unlikely for an aurora event to occur above Glacier National Park at Kp values <4, the only data collected was on days within our study period in which the observed Kp value was greater than or equal to 4. On these days, we recorded the classification of aurora in Excel every three hours. The predicted values provided by NOAA are not publicly downloadable, but we obtained them through contact with a NOAA representative who supplied an Excel file (Version 2308) containing dates and predicted Kp values for our study period (Steenburgh, 2019).

Table 1
List of sensors and indices utilized for this project

Name	Data Product	Dates	Acquisition
Suomi-NPP VIIRS	Day/Night Band	December 2019 to May 2024	EARTHDATA: NASA Worldview
Observed Kp (Planetary Index) Index	Kp Index	December 2019 to May 2024	GFZ German Research Centre for Geosciences at Helmholtz Centre Potsdam database
Predicted Kp (Planetary Index) Index	Predicted Kp Index	December 2019 to May 2024	NOAA Representative

Observed AE (Auroral Electrojet) Index	AE Index	January 2014 to December 2014, January 2019 to December 2019	World Data Center (WDC) for Geomagnetism, Kyoto AE
Predicted AE (Auroral Electrojet) Index	Predicted AE Index	January 2014 to December 2014, January 2019 to December 2019	LASP (Laboratory for Atmospheric and Space Physics) at University of Colorado, Boulder
OVATION Prime 2.3	Statistical model of Aurora	December 2019 to May 2024	integrated Space Weather Analysis (iSWA) database
AuroraSaurus	AuroraSaurus	December 2019 to May 2024	AuroraSaurus.org

The observed AE data is found at the World Data Center (WDC) for Geomagnetism, Kyoto AE service (World Data Center for Geomagnetism, 1996). This database has a collection of provisional values from 2000 – 2019 readily available. Here we downloaded observed AE values for the years 2014 and 2019. The IAGA2002-like format was the downloaded format. The values from 2020 – present are only available in real-time graphs that estimate the AE index with large margins of error; therefore, these values cannot be used for accurate AE index validation. This allowed us to gather more data on AE behavior during a Solar Maximum (2014) as the 2019 data shows the AE behavior during a Solar Minimum. The predicted values for the AE data are provided through the Laboratory for Atmospheric and Space Physics (LASP) found at the University of Colorado, Boulder (Li, 1995). This data originates from Kyoto's database but is put in a more user-friendly format through LASP. This data has values ranging from 1995 – present. Each year is separated by months and each month has predicted AE values every 10 minutes.

The Suomi-NPP VIIRS DNB imagery shows the aurora oval as concentrated light in the polar regions, where Denali National Park is located. Using NASA Worldview, we viewed VIIRS DNB images from December 2019 – August 2023. Worldview stitches together satellite imagery layers to provide a global view of satellite data in one day increments (Boller & NASA, 2016). We used the VIIRS DNB within the Worldview data viewer to identify dates and times of when the aurora oval occurred above the park. By taking note of when the aurora oval visually looked to be over the park, we created a binary in Microsoft Excel to track the occurrence of the aurora over the park. The Enhanced Contrast Nighttime Imagery layer shows illumination on the Earth's surface and in the atmosphere, mapped as a grayscale image with higher contrasts indicating a higher concentration of light. High contrast values along the aurora oval path indicate aurora is present, as seen from space. If a maximum near constant contrast of 255 is over or within an 80-mile radius of the park, then we marked that day as a "Positive" aurora sighting, where any near constant contrast below 255 over the park or outside of an 80-mile radius was marked as a "Negative" aurora sighting. The orbit track of the Suomi NPP satellite is an additional layer in Worldview which shows when the satellite crosses Denali National Park, which we also recorded for each day within our study period.

OVATION Prime 2.3 was developed at Johns Hopkins Applied Physics Laboratory and is found online in the integrated Space Weather Analysis (iSWA) database, which provides a visualization of the aurora oval from electron and ion diffuse aurorae over North America (Newell, 2013). The energy deposition of these diffuse aurorae is mapped on a scale of 0 – 8 erg/s*cm^2, with higher values indicating a higher probability of aurora occurring at a given geographic location, and vice versa. In the iSWA system model of OVATION Prime, you can change the date and select a specific time. To simplify our data collection process, the times we chose to collect data from OVATION Prime align with the times in which the Suomi NPP satellite was crossing over Denali National Park on a given day within the study period. Using OVATION Prime and focusing on Denali National Park geographically, energy deposition values that we acquired for every day within the study period were imported into Microsoft Excel version 2308 for analysis. We sorted these values into a binary in which energy deposition values that are greater than or equal to 4 ergs/s*cm^2 are considered "Positive," while less than 4 ergs/s*cm^2 was considered "Negative".

AuroraSaurus is a citizen science project that tracks aurora based on real-time ground observations and social media reporting (Heavner et al., 2014). AuroraSaurus is powered by Google Earth Engine and maps the aurora oval produced by OVATION Prime in a more user-friendly fashion, while also providing a view line estimate. Since aurora may still be visible at latitudes lower than the occurrence of the aurora oval as predicted by OVATION Prime, AuroraSaurus' view line estimate was used along with the OVATION Prime oval to classify aurora occurrences at Glacier National Park (Table 2).

Table 2
Classification of Aurora occurrences in AuroraSaurus at Glacier National Park

Classification	**Criteria**
Yes	The park is within the view line estimate and the OVATION Prime prediction oval.
Possibly	The park is within the view line estimate, but not within the OVATION Prime prediction oval.
No	The park is below the view line estimate and outside the OVATION Prime prediction oval (but observed Kp value is greater than or equal to 4).

3.2 Data Processing

The downloaded format for observed Kp values includes year, day, and time of produced values. Since we were only looking for the day and time of aurora events and its attached Kp value, we created an Excel file to filter out only the essential data from the downloaded format and disregard the rest. The same is done to both the predicted and actual AE values. The best way to organize these values was to then separate them at the times when the aurora was most likely to be present, which was midnight at local park time within the same Excel file. Since we downloaded the data in universal time (UTC), midnight local park time includes 6:00:00 UTC and 9:00:00 UTC for Glacier and Denali National Park, respectively. We also converted data collected to view the aurora oval from space using the iSWA OVATION Prime model, the VIIRS DNB imagery, and AuroraSaurus into UTC and park local time for multiple analyses and applications, while also factoring daylight-savings into the conversions.

3.3 Data Analysis

A confusion matrix shows the number of predictions that are incorrect or correct from a comparison of two values. Using the binary data of positive and negative aurora occurrences at Denali, sorted in Excel, and acquired from OVATION Prime and the VIIRS DNB imagery, the confusion matrix compares these two models and their viewing of the aurora oval from space (Table 3). To analyze the best time to view the aurora, we plotted these binary data from VIIRS and OVATION Prime versus different measures of time. Using RStudio version 2024.04.2+764, we created visualizations of the binary through grouped and stacked bar charts showing the positive occurrences of aurora with comparison to the month, year, or time of day.

Table 3
Confusion matrix used to calculate Cohen's Kappa for evaluating the accuracy of OVATION Prime data to Suomi-NPP VIIRS data.

Denali National Park Binary Data		**OVATION Prime**		
		Positive	**Negative**	**Total**
VIIRS	**Positive**	72	130	202
	Negative	53	789	842
	Total	125	919	1044

To perform a statistical analysis to compare VIIRS with OVATION Prime, we calculated the Cohen's Kappa coefficient. Cohen's Kappa is a statistical test for comparing two models by calculating how likely that both models agreed versus the models agreeing by random chance. To get the Kappa, a confusion matrix is used (Table 3) showing when the models agreed and disagreed. The Kappa was calculated by finding the probability of agreement (p_o; Equation 1) and the probability that the agreement is random (p_e; Equation 2). Then, these values are combined (Equation 3) to acquire the Kappa ($\varkappa$). The Kappa will be a value between -1 – 1 and any value above 0 means that the agreement between the two subjects is more than random chance, with values of 1 representing true agreement. Since the Kp index is ordinal due to it being a ranking system, we could not use a linear regression. Instead, we repeated the process of calculating Cohen's Kappa to compare the predicted and actual Kp Index values with the confusion matrices (Table A1; Table A2).

$$p_o = \frac{number\ of\ correct\ predication}{total\ number\ of\ data\ points} \quad (1)$$

$$p_e = \sum_{n=1}^{x} \frac{row[n]\ total}{table\ total} \cdot \frac{col[n]\ total}{table\ total} \quad (2)$$

$$\kappa = \frac{p_o - p_e}{1 - p_e} \quad (3)$$

To compare the predicted and actual Kp and AE index values, we first visualized these datasets in a timeseries. To perform a statistical analysis of the AE index, we created scatterplots with the predicted values on the x-axis and actual values on the y-axis. We then conducted a linear regression to generate the R^2 value for comparing the predicted and actual values. An R^2 value closer to 1 show that there is a strong correlation between the predicted values and actual values.

To find trends with the Kp index and its connection to the aurora, we also plotted the Kp index over different intervals of time with values from 2000 – 2024. To do this, we plotted the observed Kp values over different years, and months. We repeated this process with filtered Kp index values to only observe the trends in the higher Kp index values. Specifically, we looked at Kp values greater than 4 to show when the bigger aurora events should be happening.

4. Results & Discussion

4.1 Analysis of Results

After plotting the predicted and actual AE index values for both Glacier and Denali National Park at midnight local time (Figure A3; Figure A4), we calculated a R^2 value of 0.81 for Glacier National Park and 0.71 for Denali National Park. Since these values are close to one, we can classify the correlation between the predicted and actual AE index values at Glacier National Park as strong. We can interpret this to mean that the predicted values are reliable and have a high accuracy. For Denali National Park, we can classify the correlation as good, meaning the predicted values have good accuracy, but there is more error than for Glacier National Park (The visual comparison of predicted and actual AE and Kp values can be seen in Figure A1 and Figure A2, respectively).

For comparing predicted and actual values of the Kp index, the Cohen's kappa coefficient for both Glacier and Denali National Park are above zero (Table 4). This means that the predicted Kp index values match the actual Kp values more than just random chance. However, since the coefficient values are not close to one but rather closer to zero, we can only say there is fair agreement between the predicted and actual Kp values.

Therefore, the predicted Kp values have a decent accuracy but there is still variability. When there is variability between the predicted and actual Kp value, the variability is small and is usually only off by one Kp value.

Table 4

Table showing results of Cohen's kappa calculations to compare predicted and actual Kp values for Glacier and Denali National Park.

Kp Index Calculations	Glacier National Park	Denali National Park
p_o	0.43198	0.47923
p_e	0.27097	0.29988
κ	0.22086	0.25618

The Kp Index follows the Russell-McPherron Effect of there being higher solar activity during the equinoxes in March and September than the solstices (Russell & McPherron, 1973). We found that higher Kp index values, or higher solar activity, occurs in the fall and the spring and then decreases in the winter and summer (Figure B1). The Kp values also follow the solar cycle as there is an increase in higher Kp index values during the Solar Maximums (e.g., 2014) and a lack of them in the Solar Minimums (e.g., 2019; Figure B2). From the Kp index analysis we can conclude the best chance of seeing the aurora is around an equinox in a Solar Maximum year.

By classifying aurora occurrences at Glacier National Park using AuroraSaurus, we determined the best time of day and year to view the aurora. When plotting the aurora with the month, we see that the plot also followed the Russell-McPherron Effect (Figure C1) and by year demonstrated the solar cycle (Figure C2). The aurora by time of day shows that the best time to see the aurora at Glacier National Park is midnight local park time (Figure C3). The chances of seeing the aurora drop at 4 am Mountain Daylight Time (MDT) with no occurrence happening during the day with chances starting again around 10 pm MDT when it is dark again. This is expected as we know that the aurora cannot be seen in daylight and the section of the auroral oval that reaches it southernmost point is never over the United States during the daytime. Lastly, we tested to see if there is a trend with the day of the month and aurora and found no correlation between the day of the month and aurora as expected because the day of the month is not connected to solar activity (Figure C4). For comparing aurora occurrences to Kp index values (Figure C5), most times where the Kp index was greater than 5 the aurora was supposed to be visible at Glacier National Park. However, there were still instances of aurora being visible at a Kp index value of 4 and 5, it was just not as common. Therefore, for Glacier National Park, we can assume the best chance to see the aurora is when the Kp index is at least a 5 around midnight, close to an equinox in a Solar Maximum.

We repeated this process for Denali National Park using OVATION Prime and VIIRS. Both models follow the Russell-McPherron Effect (Figure D1) and the solar cycle (Figure D2). We compared the aurora occurrences with the Kp index at the time (Figure D3). The most aurora occurrences happened at a Kp value of 2 and 3; however, aurora occurrences happened at every Kp value, including zero. This shows that the Kp index is not the best indicator for aurora at Denali National Park because the aurora can be present at all values. All the graphs show that the VIIRS DNB reported aurora occurrences more than OVATION Prime did (Table 1). This is explained by OVATION Prime being a model of the auroral oval while the VIIRS DNB shows the actual auroral oval. Furthermore, OVATION Prime usually under predicts the auroral oval (Mooney et al., 2021) and we recorded positive occurrences of aurora only when the probability was greater than 50%. Since the Cohen's Kappa coefficient was greater than zero, the agreement between OVATION Prime and the VIIRS DNB occurs more than just random chance (Table 5), suggesting that OVATION Prime is a good tool for predicting the aurora at Denali National Park.

Table 5

Table to show results of Cohen's kappa calculations to compare OVATION Prime and VIIRS at Denali National Park

Kp Index Calculations	OVATION Prime vs VIIRS

p_o	0.824713
p_e	0.733115
$\varkappa$	0.343211

4.2 Errors & Uncertainties

During our project, we experienced several limitations while studying the aurora. For ground observations, we received sky camera footage from Glacier National Park (Smith, 2024); however, the footage was only for 2 days in our study period. Additionally, there was light pollution in the video due to outdoor lights, buildings, and passing cars (Figure 2). AuroraSaurus also has the ability for users to report if they saw the aurora; however, there were very few reports near our study areas. Additionally, we found some reports that lasted for day or month-long periods, which prevented us from recording those sightings in our dataset. Lastly, there is a collection of sky cameras specifically for the aurora with the satellite Time History of Events and Macroscale Interactions During Substorms (THEMIS), a probe in Earth's orbit built specifically for analysis of the aurora, but due to time constraints and the ability to access the software needed, we were not able to analyze the data from those sky cameras.

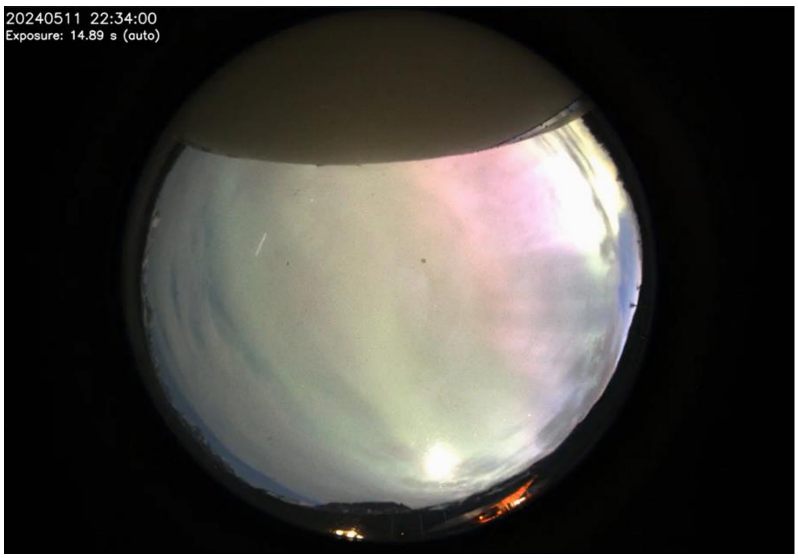

Figure 2. Shows a picture from the Glacier sky camera on 5/11/2024 footage with the aurora and light pollution present.

VIIRS was the only source for Earth observation data we used as it showed the auroral oval. VIIRS did have limitations as the satellite only passed over Denali National Park between 3 – 5am Denali local time. In addition, they stopped generating the artic polar view of VIIRS on July 8, 2023. Furthermore, the VIIRS data received showed all light from the Earth with no way for us to separate the aurora from other factors such as city lights, cloud reflections, and moonlight. Due to this, we had to manually input whether the auroral oval was over Denali National Park. This opened our data to error due to human bias for determining if the light source was aurora or not and if it was over Denali National Park.

In the project, we used different models for the aurora in addition to Earth observations. OVATION Prime is the main model for mapping the auroral oval. While it is useful, it is not very user friendly as it only shows one view of North America and does not allow the map to be manipulated or zoomed in. This allowed for error as we could not confirm the study areas in the model's location. Instead, we had to rely on an estimate of where the study areas were on the map introducing human bias into the project yet again.

To get the actual Kp values, we had to organize the data to ensure that we analyzed the correct dates and times of the values. This allowed for error in the project as data could have been mixed in the process leading to incorrect ordering. While the Kp index can be forecasted up to 27 days in advance, the AE index is only forecasted one hour in advance, limiting our ability to access AE forecasts as a long-term option. Also, due to AE data still being filtered to remove background noise, there were no values after 2019 preventing us from analyzing data for our study period. Furthermore, since the Kp index is ordinal and the AE index is numerical, we had to perform different statistical analyses to evaluate their forecast abilities. Due to using different tests to compare actual and predicted values, we could not directly compare the Kp and AE forecasts to evaluate which one is more accurate, we could only estimate.

Glacier National Park posed difficulties for our project due to its location as the auroral oval does not reach its latitude often. This prevented us from using OVATION Prime to study the auroral oval at Glacier National Park as it rarely showed the model reaching Glacier, and when it did, it was always at the lowest probability. Additionally, we could not use VIIRS for Glacier as the auroral oval was never directly above the park (even when it can be seen at the park) due to the visibility from the ground having a greater area than the oval seen from space. Lastly, there were gaps in the models used during our study period or data not being present from sources for our study period that limited our ability to fully analyze the aurora (Table 6).

Table 6
Date range of when VIIRS and OVATION Prime did not have data due to off periods

Model	**Range of No Operation**
VIIRS	12/1/2019, 2/18/2020, 2/27/2020 – 3/1/2020, 3/14/2020, 3/15/2020, 3/20/2020 – 4/2/2020, 4/12/2020 – 4/16/2020, 4/19/2020, 4/20/2020, 4/27/2020, 11/26/2020, 12/8/2020, 12/15/2020, 12/16/2020, 12/24/2020 – 1/8/2021, 1/15/2021, 1/22/2021, 2/2/2021, 2/24/2021, 3/25/2021, 3/31/2021, 8/4/2021, 11/17/2021, 11/26/2021, 11/30/2021, 12/4/2021 – 12/6/2021, 1/6/2022, 1/7/2022, 1/23/2022, 2/17/2022 – 2/22/2022, 3/28/2022, 4/2/2022, 4/4/2022, 4/17/2022, 5/21/2022, 5/22/2022, 6/27/2022, 6/28/2022, 7/13/2022, 7/27/2022 – 8/25/2022, 9/9/2022, 9/29/2022, 12/15/2022, 12/16/2022, 12/28/2022, 2/8/2023, 3/9/2023, 5/3/2023 – 5/22/2023, 6/14/2023 – 6/21/2023, 7/14/2023 – 7/19/2023
OVATION Prime	5/10/2020, 5/11/2020, 5/16/2020, 5/17/2020, 6/20/2020, 11/1/2020, 11/2/2020, 2/8/2021, 3/12/2021, 6/12/2021 – 6/14/2021, 9/6/2021, 9/7/2021, 10/1/2021 – 2/24/2022, 3/4/2022, 4/5/2022, 6/29/2022, 9/1/2022, 2/14/2023, 5/2/2023, 7/6/2023

4.3 Feasibility & Partner Implementation

Currently, our partners use a version of OVATION Prime and predicted Kp values from the University of Alaska Fairbanks Geophysical Institute (Geophysical Institute, 1994). From our results, the Kp index is feasible for Glacier National Park as there is a good chance that aurora will be seen at the park with a value greater than five. Furthermore, the predicted Kp value can also be used by Glacier National Park but for increased accuracy they should rely on the short-term predictions. The Kp index is not feasible for Denali National Park to use as aurora can occur at all Kp values, including zero. Therefore, the Kp index is not a good indicator of when the aurora will be visible at Denali. In addition to the Kp index, it is also feasible to use the predicted AE index as our results show that it has a strong accuracy. However, the AE index might not be practical for the parks to show the public as it requires background knowledge to understand and read the graph in order to get the predicted AE values. Additionally, the AE predictions are only an hour in advance, which gives it a small prediction window for being helpful.

We analyzed two aurora models for the project, OVATION Prime and AuroraSaurus. For Denali National Park, it is feasible to use OVATION Prime to see where the auroral oval will be. In addition, it would be easy for the park to utilize to inform visitors if they can see the aurora or not. However, it might not be feasible to give directly to visitors as the user must estimate the location of the park in reference to the auroral oval. For Glacier National Park, it is not feasible to use OVATION Prime. On the rare occasions that we saw OVATION Prime showing the aurora at Glacier, there was a low probability of seeing the aurora. We know this not to be true as the aurora is visible at Glacier more than OVATION Prime shows. AuroraSaurus is feasible to use as it takes the OVATION Prime model with Google Earth Engine allowing users to zoom into specific locations and find where Denali and Glacier National Park are located. Furthermore, it is very user friendly and includes a view line estimate, making it a great tool to show visitors at the park what their chances are of seeing the aurora that night. Additionally, the parks can use the report feature to record when aurora is at the park to help visitors and keep record of auroral occurrences. Also, encouraging others to report the aurora will help AuroraSaurus improve. Lastly, Glacier National Park can use their sky camera to record aurora occurrences and to know when to send announcements that the aurora has started to occur at the park; however, we do recommend trying to reduce the light pollution around the camera to better see the night sky and aurora.

Remote sensing for our project had both feasible and non-feasible elements. VIIRS is used to identify the auroral oval above Denali National Park. This is used to help the parks record and study the auroral oval. Additionally, VIIRS is capable of being used as an educational tool by the parks on the aurora to demonstrate what the aurora looks like from space. As well, it is not feasible to use VIIRS to see the auroral oval at Glacier National Park because the aurora is never directly above the park due to its lower latitude even though aurora sightings were confirmed through AuroraSaurus. Finally, we could not fully determine the feasibility of using the VIIRS DNB to determine the distance away from the auroral oval that the aurora can be seen on the ground. However, due to the height and sky horizon, we consider it likely that the aurora can be seen in a larger area on the ground than in the VIIRS DNB. To quantify this, one would need to take external factors interfering with the VIIRS DNB into consideration such as clouds, city lights, and haze interfering, which was beyond the abilities of our project. In addition, viewing the aurora via the VIIRS DNB depends on the brightness of the aurora as it might not show on VIIRS but still be visible on the ground and vice versa.

5. Conclusions

The scope of this study aimed to better understand aurora occurrences and optimize the viewing experience of the aurora borealis at Glacier and Denali National Parks. We started out by validating the current practice used by the National Park Service, which uses OVATION Prime to determine whether aurora will occur at the parks. Based on data from AuroraSaurus at Glacier National Park, OVATION Prime is a valid statistical model of the aurora oval, since its predictions of the oval coincide with the Russell-McPherron effect, which was established in a previous study. This means that the National Park Service can expect more aurora activity during the spring and fall equinoxes.

To improve the current practice, we explored alternatives for forecasting aurora occurrences by using a polar magnetic disturbance index, since aurora activity occurs primarily in the polar regions. Based on the statistical analysis of the predicted and actual real-time AE index values, the National Park Service can use the AE index instead of the Kp index for short-term predictions of aurora occurrences. However, the AE index is limited to an hour-long maximum forecast time, much shorter than the 27 day (about 4 weeks) maximum forecasted time with the Kp index. Because of this, the National Park Service has the option to rely on AE index predictions for hourly aurora watch planning and use Kp predictions as a foundation for potential future aurora events for predictions more than a day in advance.

Another alternative we explored was the feasibility of using Earth observation data to view the auroral oval from space. Because there is no current NASA mission dedicated to viewing the aurora, there is limited data available. The aurora as seen by the VIIRS DNB has limitations since it monitors all light pollution and illumination from the Earth. However, it is feasible to view the auroral oval from the VIIRS DNB, but other factors and limitations must be considered when using VIIRS to view the aurora. The National Park Service can use the VIIRS DNB in this capacity, but due to the lack of reliable ground observation data and a lack of isolated aurora data, the VIIRS DNB cannot definitively confirm whether the aurora is visible at Glacier and Denali National Parks.

6. Acknowledgements

Project Partners

- Debby Smith (Glacier National Park)
- Sharolyn Anderson (Natural Sounds and Night Skies Division)
- Tim Connors (Intermountain Regional Office)
- Mark Biel (Glacier National Park)
- Phil Wilson (Glacier National Park)

Science Advisors

- Xia Cai (NASA Langley Research Center)
- Yihua Zheng (NASA Goddard Space Flight Center, Community Coordinated Modeling Center)
- Jamie Favors (NASA Headquarters)
- Lisa Winters (NASA Headquarters)

Leads

- Marisa Smedsrud (Project Coordination Fellow, Virginia – Langley)
- Laramie Plott (Senior Fellow, Virginia – Langley)

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

This material is based upon work supported by NASA through contract 80LARC23FA024.

7. Glossary

AE Index – Auroral Electrojet Index
Aurora Borealis – Also known as the Northern Lights, is a natural display of light that appears near the Earth's poles
AuroraSaurus – A citizen science project that maps the probability of aurora and includes ground observation reports
Cohen's Kappa – A statistical measure to quantify the degree of agreement between two models
Day/Night Band (DNB) – Sensor designed to capture low light emissions on the Suomi-NPP satellite
GFZ – *GeoForschungsZentrum*, German Research Centre for Geosciences
Kp-Index – Planetary K-Index, a scale used to characterize the magnitude of geomagnetic disturbances that ranges from 0 to 9
Linear Regression – A statistics calculation to predict the value of a variable based on another variable
Magnetic Meridian – A line joining the magnetic north pole and magnetic south pole of the Earth
OVATION Prime – Shows statistical distribution of auroral precipitation in the ionosphere
R-Squared – A statistic used to measure the variance between the independent and dependent variable
Remote Sensing – The acquiring of information from a distance via remote sensors on satellites and aircraft that detect, and record reflected or emitted energy
Russell-McPherron Effect – The semi-annual increase in solar activity due to the Earth's orbit and rotation
UTC – Coordinated Universal Time, by international agreement, the local time is at the prime meridian, which passes through Greenwich, England
VIIRS – Visible Infrared Imaging Radiometer Suite

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9. Appendices

Appendix A: *Predicted vs. Actual Kp Index Values*

Table A1

Confusion matrix of predicted vs. actual Kp indices at Glacier National Park local midnight

Glacier National Park		**Predicted Kp Index**								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	***Total***
Actual Kp Index	**0**	12	101	78	15	3	0	1	0	*210*
	1	0	370	222	78	29	2	0	0	*701*
	2	0	156	275	96	39	9	1	0	*576*
	3	0	44	95	133	18	8	1	0	*299*
	4	0	6	28	26	31	5	3	0	*99*
	5	0	1	5	11	4	10	1	0	*32*
	6	0	0	0	0	3	1	0	0	*4*
	7	0	1	1	0	1	0	1	1	*5*
	Total	*12*	*679*	*704*	*359*	*128*	*35*	*8*	*1*	*1926*

Table A2

Confusion matrix of predicted vs. actual Kp indices at Denali National Park local midnight

Glacier National Park		**Predicted Kp Index**								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	***Total***
Actual Kp Index	**0**	5	89	57	9	2	0	0	0	*162*
	1	0	429	244	61	12	3	2	0	*751*
	2	0	189	317	95	18	6	0	0	*625*
	3	0	24	92	125	11	4	1	1	*258*
	4	0	9	29	26	34	3	0	0	*101*
	5	0	1	3	2	7	9	0	0	*22*
	6	0	0	0	0	1	1	2	0	*4*
	7	0	0	0	0	1	0	0	2	*3*
	Total	*5*	*741*	*742*	*318*	*86*	*26*	*5*	*3*	*1926*

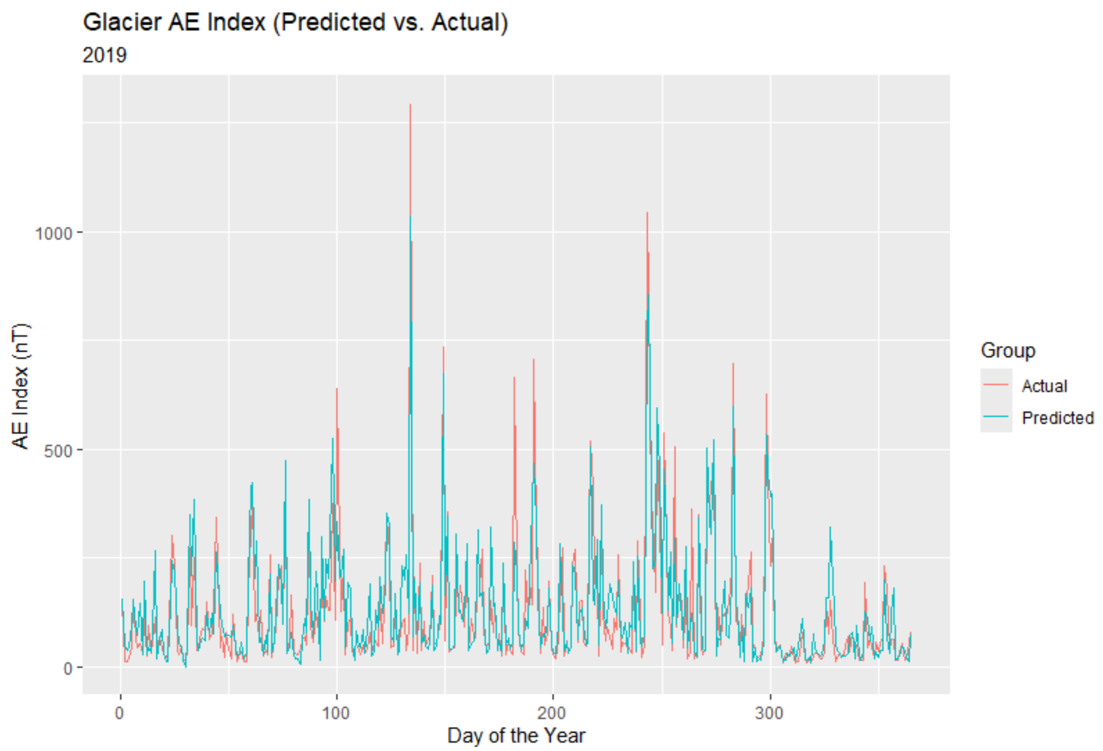

Figure A1. Shows the predicted and actual AE Index values at Glacier National Park local midnight for 2019.

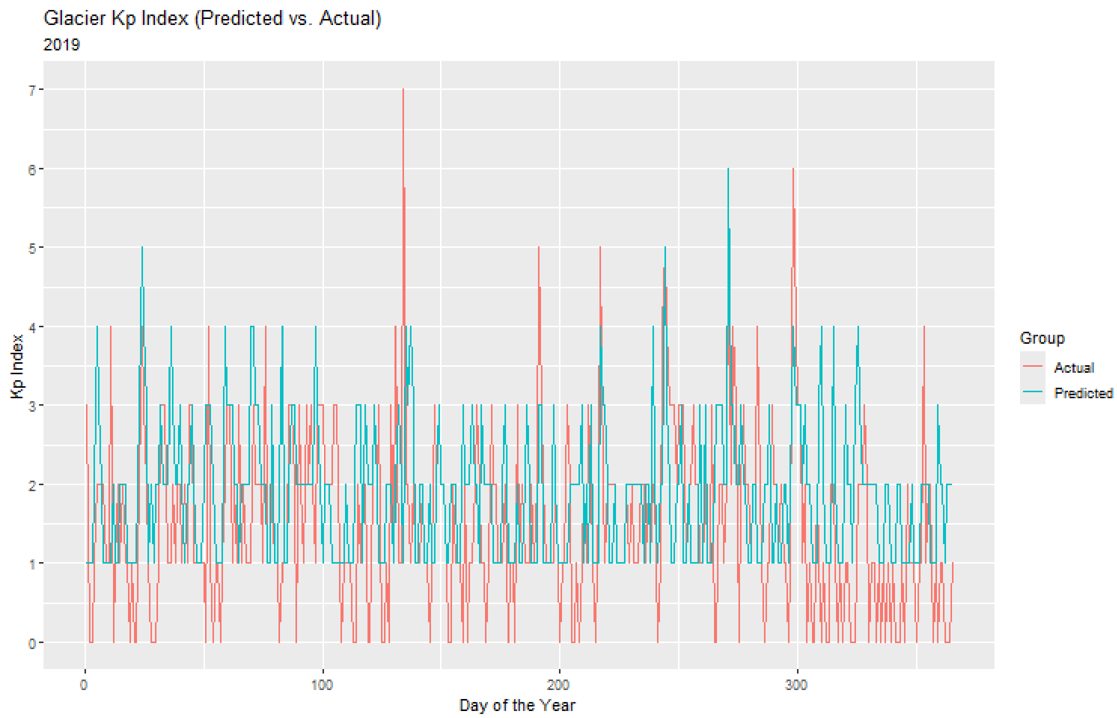

Figure A2. Shows the predicted and actual AE Index values at Denali National Park local midnight for 2019.

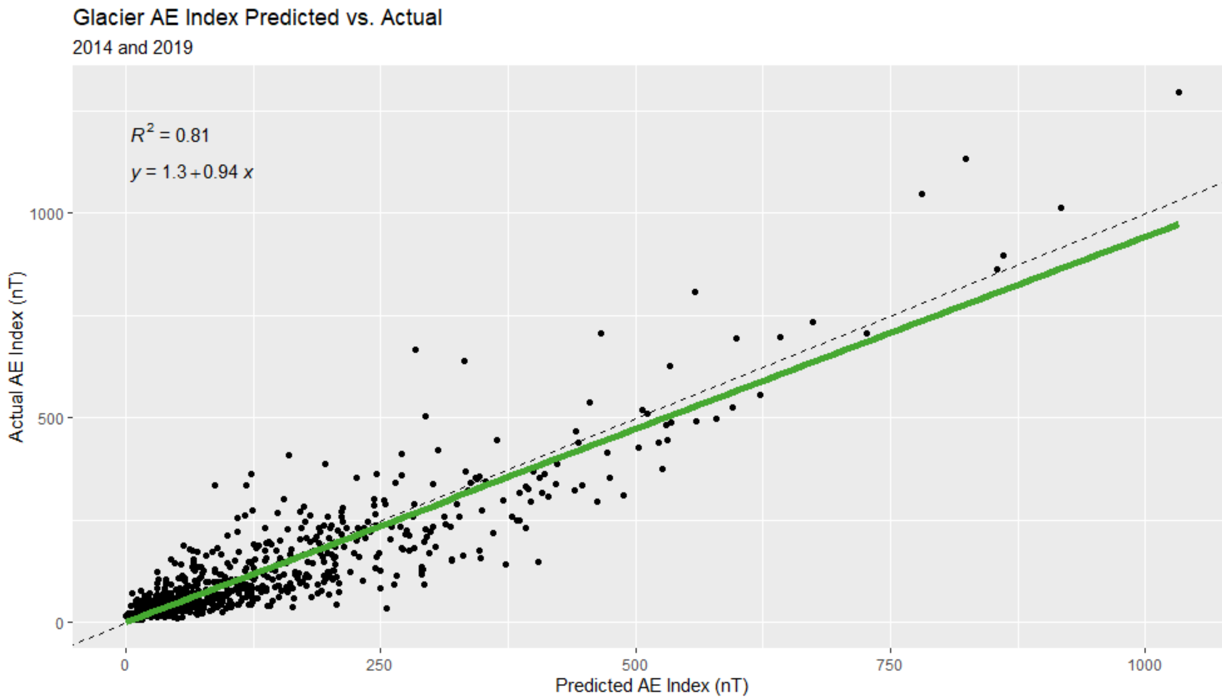

Figure A3. Shows the predicted AE and actual AE values at Glacier National Park local midnight for 2014 and 2019. The green line shows the linear regression, and the dashed lines shows the line if the predicted values were always accurate.

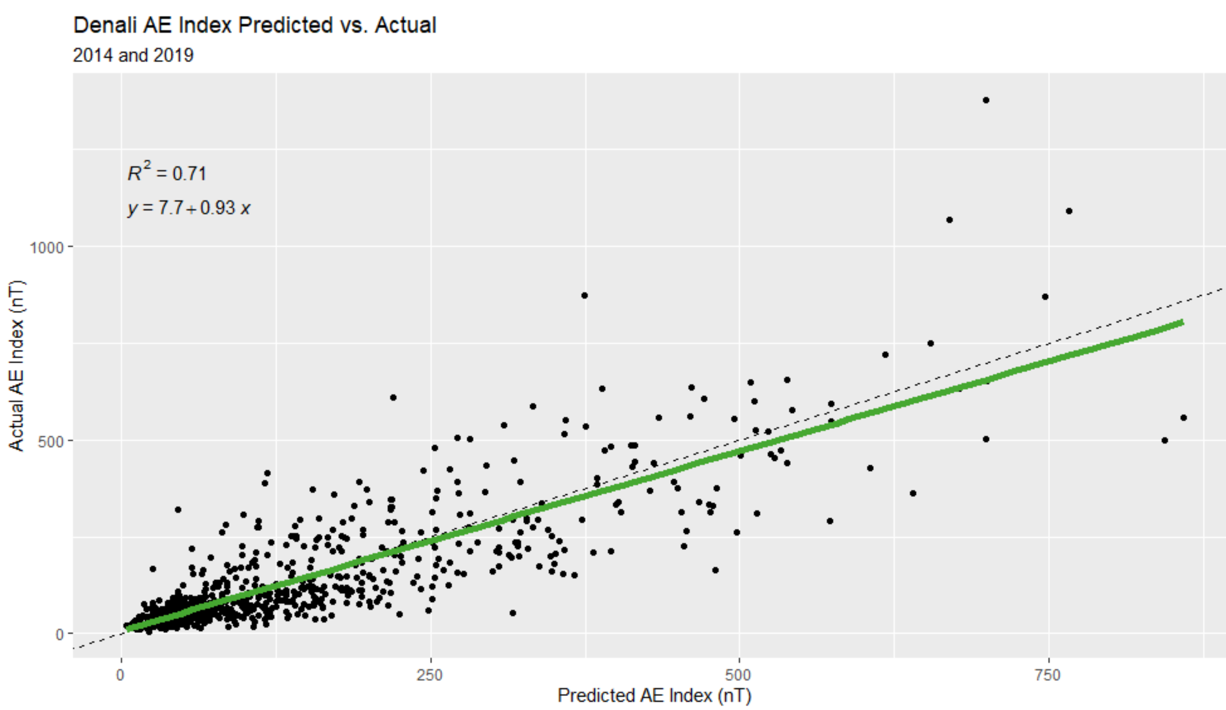

Figure A4. Shows the predicted AE and actual AE values at Denali National Park local midnight for 2014 and 2019. The green line shows the linear regression, and the dashed lines shows the line if the predicted values were always accurate.

Appendix B: *Historical Kp Indices*

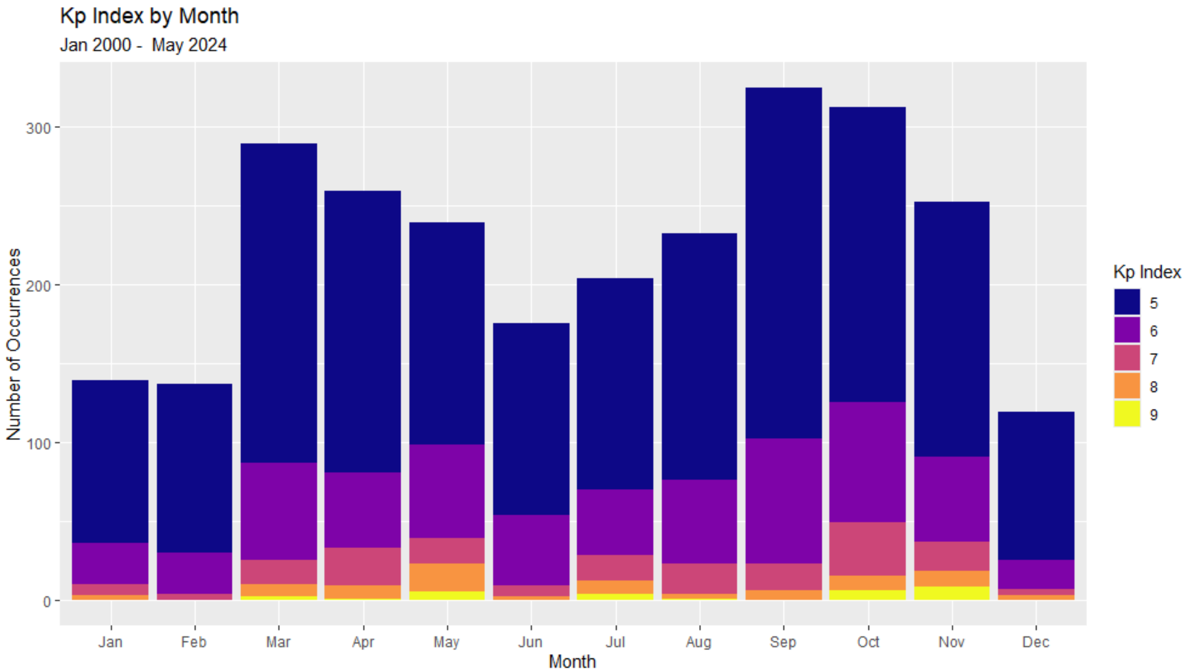

Figure B1. Shows the distribution of Kp Index values for each month from January 2000 – May 2024 for every 3 hours.

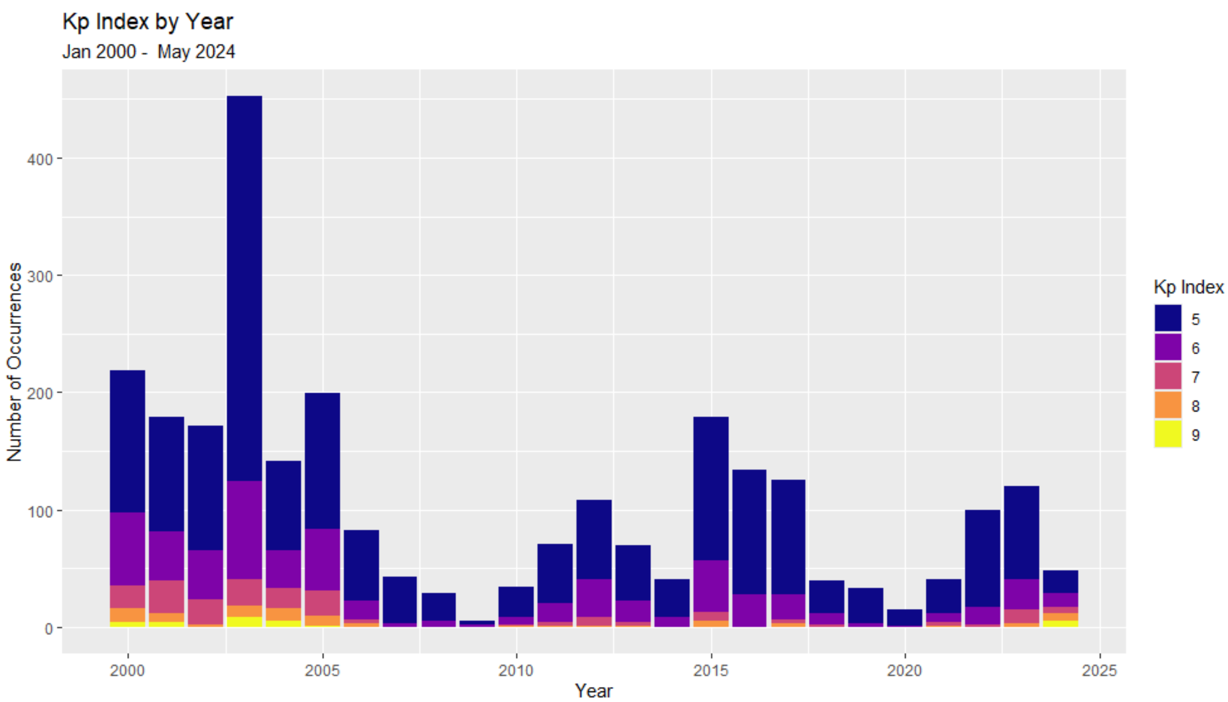

Figure B2. Shows the distribution of Kp Index values for each year from January 2000 – May 2024 for every 3 hours.

Appendix C: *AuroraSaurus Classification at Glacier National Park*

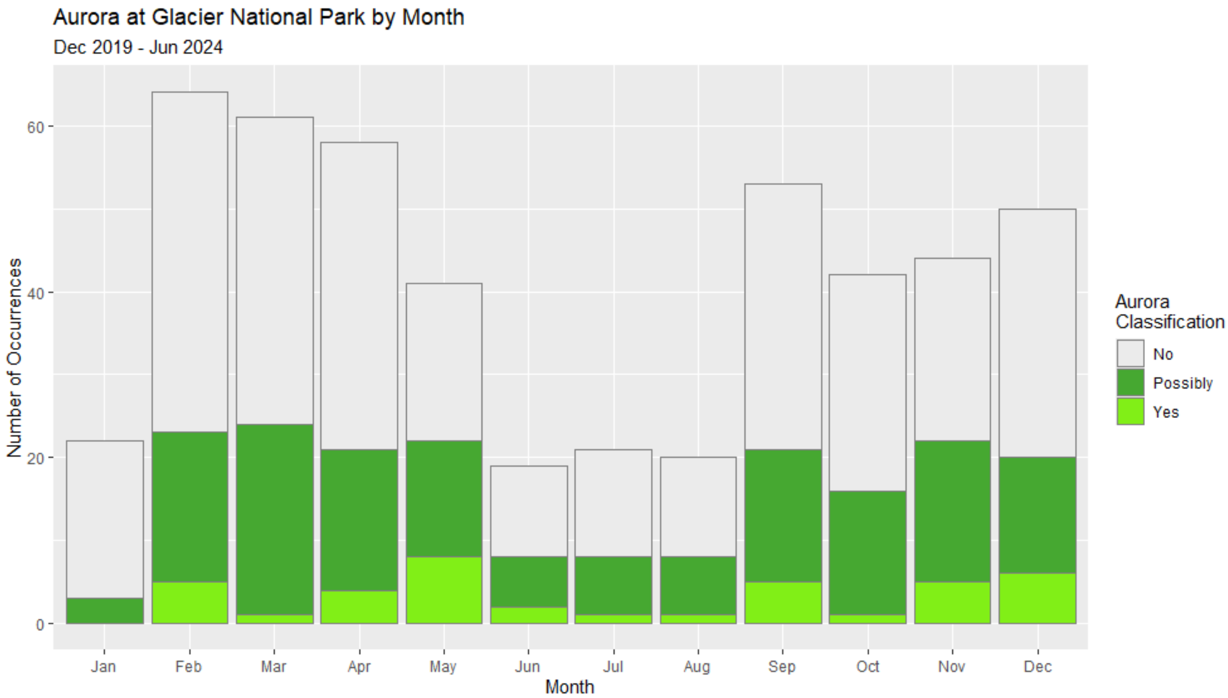

Figure C1. Shows the distribution of aurora classification from AuroraSaurus by month from December 2019 – June 2024.

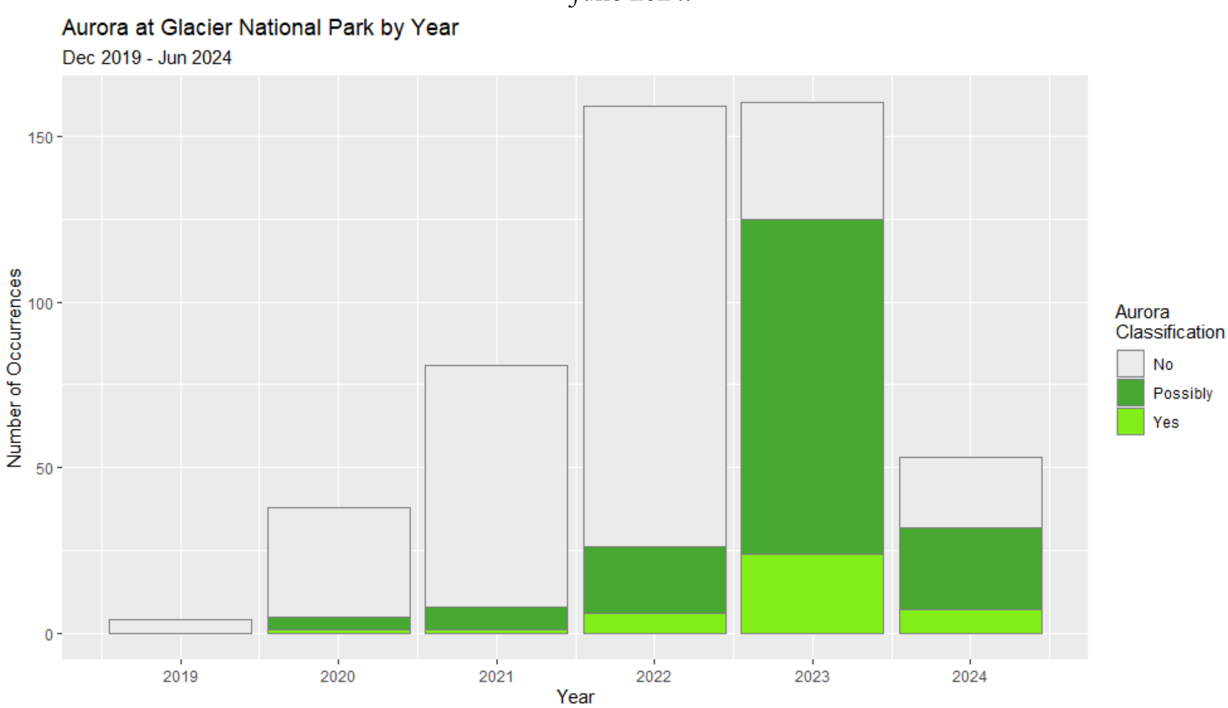

Figure C2. Shows the distribution of aurora classification from AuroraSaurus by year from December 2019 – June 2024.

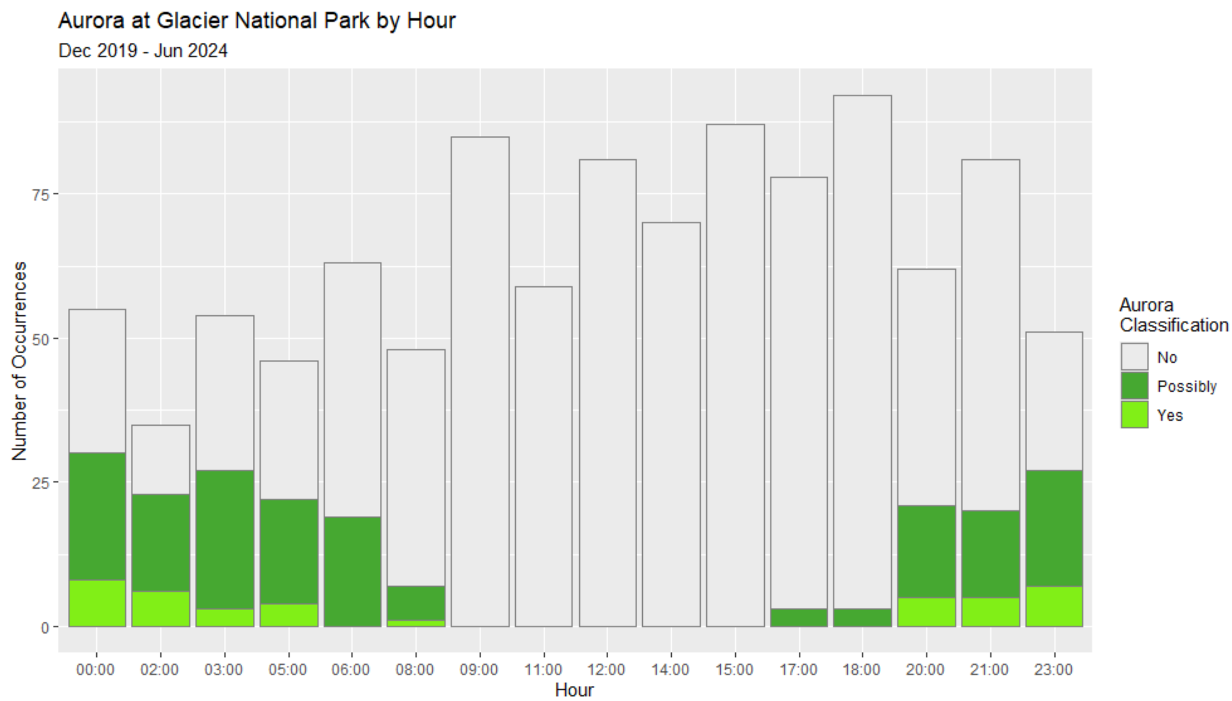

Figure C3. Shows the distribution of aurora classification from AuroraSaurus by hour from December 2019 – June 2024.

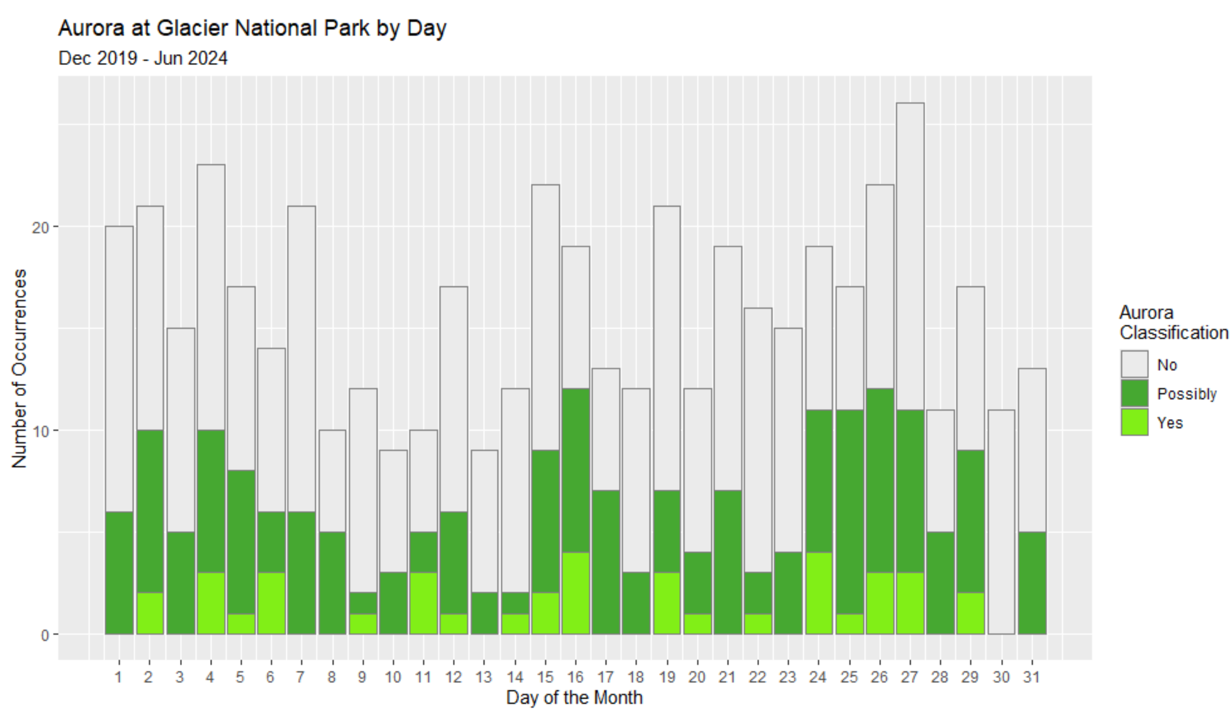

Figure C4. Shows the distribution of aurora classification from AuroraSaurus by day of month from December 2019 – June 2024.

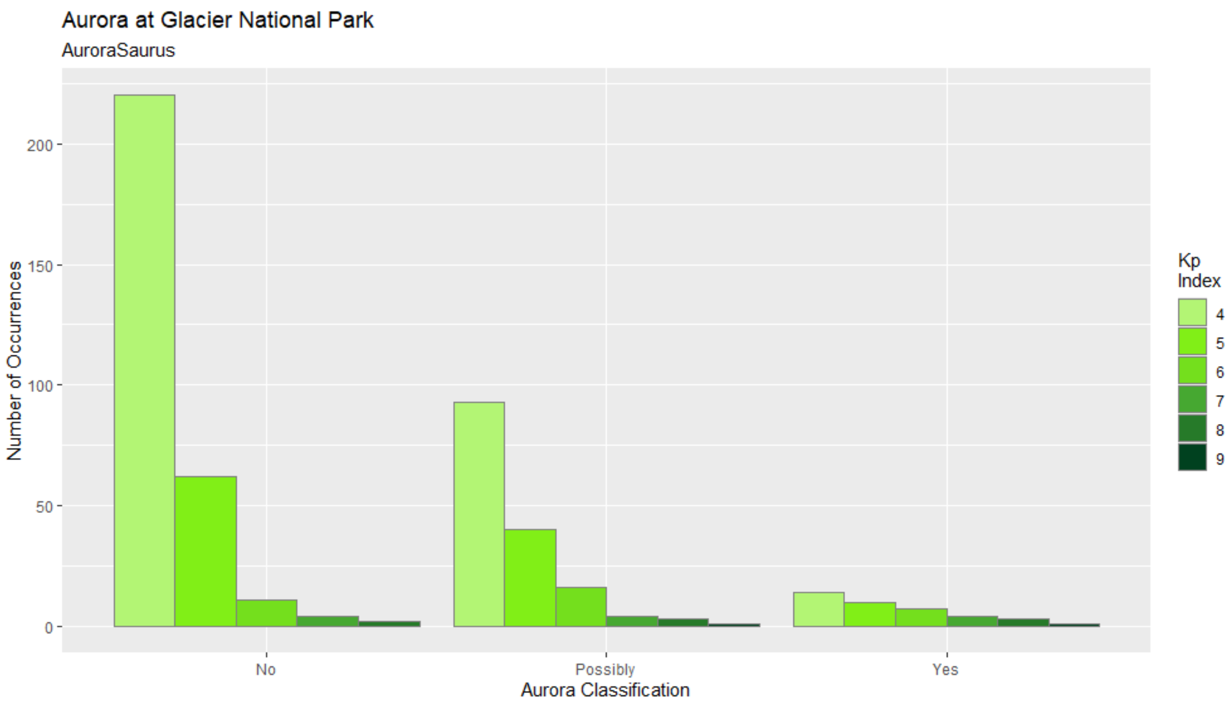

Figure C5. Shows the distribution of aurora classification from AuroraSaurus with the Kp Index from December 2019 – June 2024.

Appendix D: *Aurora at Denali National Park*

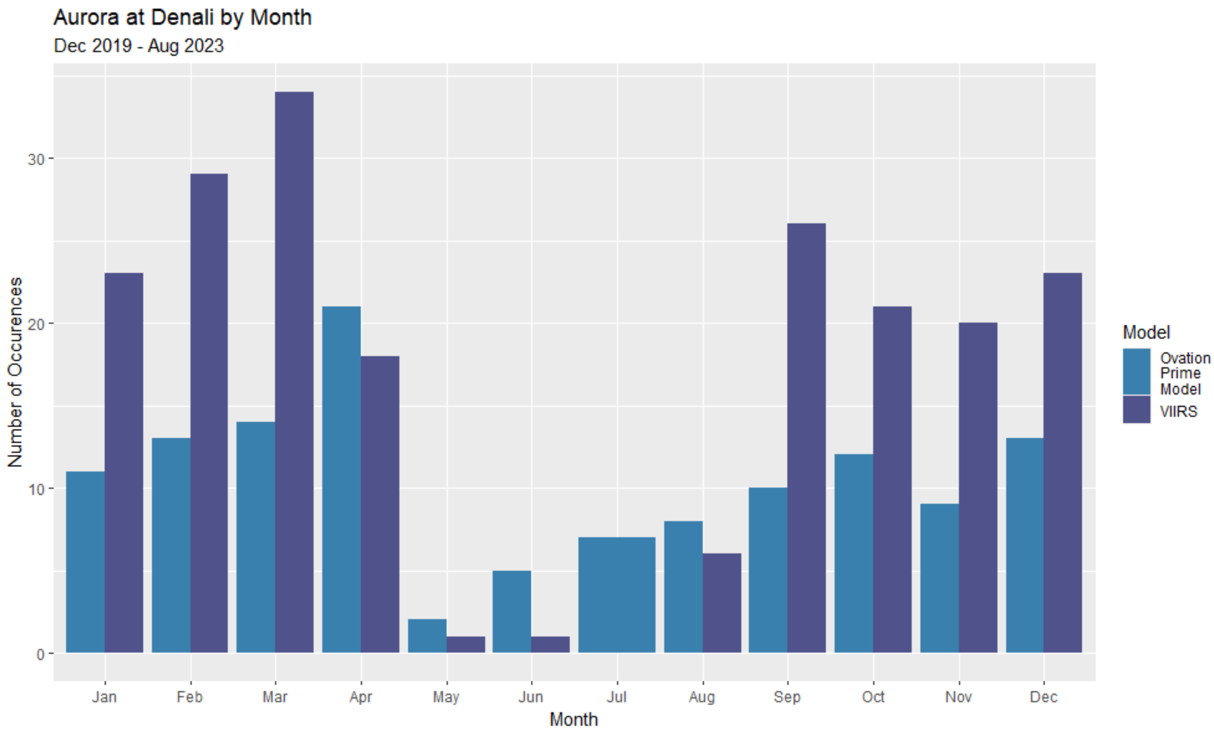

Figure D1. Shows the distribution of aurora classification from OVATION Prime and VIIRS by month from December 2019 – August 2023.

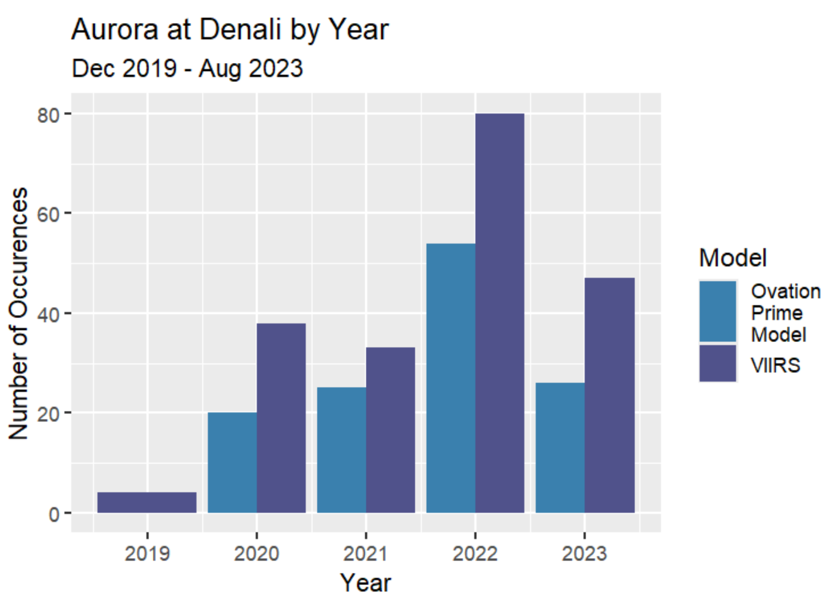

Figure D2. Shows the distribution of aurora classification from OVATION Prime and VIIRS by year from December 2019 – June 2023.

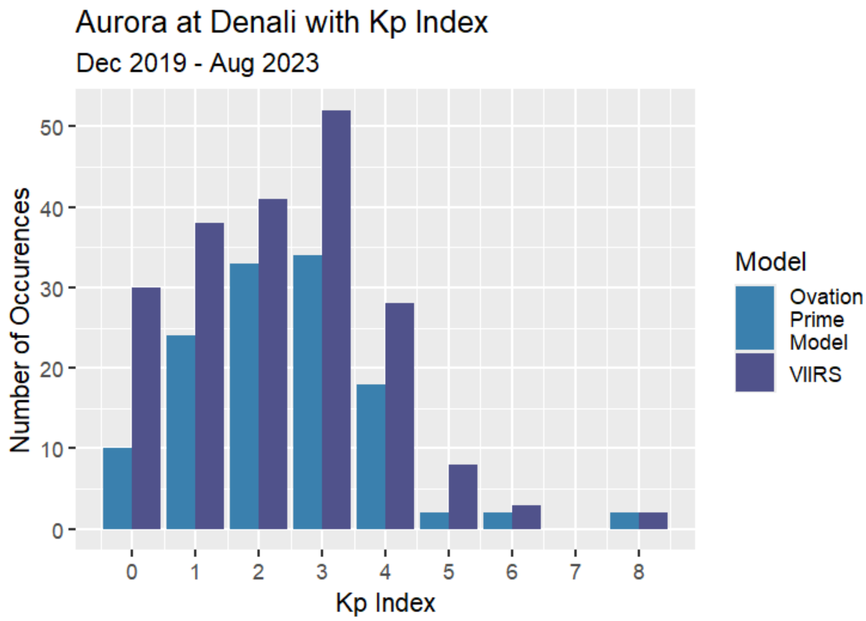

Figure D3. Shows the distribution of aurora classification from OVATION Prime and VIIRS with the Kp Index from December 2019 – August 2023.