Using Geospatial Technology to Identify High Risk Areas In Precision Farming

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Introduction

With a growing need to feed the planet's population of 8 billion people, farmers have turned to advanced technology to keep up with high demand. A significant change that farm owners have adopted as a part of their practice is the use of precision farming. Precision farming is a farming management strategy based on observing, measuring, and responding to temporal and spatial variability to improve agricultural production sustainability. Furthermore, precision farming utilizes GPS for a vast number of tasks that has been improved through the inclusion of GPS enabled technologies. These tasks include everything from the planning of the farm, to mapping of the field, sampling of soil, crop scouting, determining the yield of fertilizer, and even tractor guidance.

Unfortunately, GPS signal reception on the ground is notoriously susceptible to space weather events such as, scintillation from aurora during geomagnetic storms and radio black-outs during solar flares. Such events mean that space weather related disruption of GPS signals can occur at all times of the day and night during periods of high solar activity. Recently, advancements in GPS-enabled automation is enabling night-time farming, further increasing the risk of GPS signal disruptions due to space weather events. Therefore, is it necessary to be able to identify the locations that are likely to be more susceptible to space weather events. While geospatial technology such as GIS has supported precision farming, it is not currently equipped to support precision farming needs, as they do not consider regions at risk to GPS signal degradation and the errors that can occur from things such as vertical accuracy.

Case Study: Precision Farming in Idaho

Idaho has the second largest population growth in the United States as of 2023. The current population growth in Idaho is taking farmland at a rapid pace and there are currently no policies to correct it. Because of the reduced availability of land, farmers are searching for land elsewhere and being pushed further to the mountains.

Idaho is located at higher magnetic latitude than the majority of states in the USA. At these latitudes GPS is at a higher risk for signal disruption from space weather events during geomagnetic storms. Since there are mountainous areas in Idaho, these regions are already at risk for GPS signal disruptions due to the blockage of signals by the mountains themselves, which increase multi-path signal reception errors . Therefore, farmers scouting for new land to develop need new GIS tools that can both capture and quantify the unique problems associated with GPS-enabled precision farming in both mountainous and high magnetic-latitude terrain. With a growing need for new tools to identify and mitigate these challenges, the purpose of this project is to outline the development and application of a new GIS tool designed to enhance how precision farming planning is undertaken., This new approach employs the methodologies detailed below in the creation of a new metrics by determining "risk zones" for the degradation of GPS signal reception, especially in regions where space weather susceptibility is high.

Methods

To determine the risk zones for the degradation of GPS signals, "barrier angles" were identified and calculated. The barrier angle, ϴ, is defined as the inclination angle from a location point on the ground to the highest point in the sky of an obstruction that blocks signals from GPS satellites reaching the location point along the line of sight as shown in Figure 3. The angle is found by starting at the horizon (ϴ = 0°) and increasing until the lowest point of the viewable sky over the obstacle is reached (0°≤ ϴ ≤ 90°). For example, when there is a no mountain or geographic barrier, the angle is zero. However, when there are objects such as mountains, they create a barrier by blocking the signals that are received from GPS satellites. Thus, when there is a high barrier angle more signals are blocked and when there is a lower barrier angle, more signals will get through to a ground GPS receiver.

To conduct this study, geospatial technology provided by the software company ESRI was used to perform the analysis through raster and vector data within the software. The study began by collecting, Digital Elevation Models (DEMs) of the ROI's to locate the farmlands that had high potential for large barrier angles due to their close proximity to mountainous terrain. Next, the DEMs were interpolated to display a 3D-image of the elevation data (Figure 1). Upon completing the 3D-image, raster layers of crop-type data was acquired to determine where precision farming was most applicable (Figure 2). Since precision farming is more commonly used for crops that need to produce a high crop yield, such as corn, wheat, soybean, and barely the farms that had crops of barely and wheat along with being in close proximity to a mountain range were selected as regions of interest (ROIs). Based on the imagery and the GIS data, 46 ROIs were identified within the River Valley basin. Once the ROIs were chosen, points of locations were placed at the center point of each ROI by creating a new feature class of point in ArcGIS and manually placing inserting them on the ROIs. Next, topographic measurements required for the calculation of the barrier angles were collected.

The barrier angles are calculated by applying the basic trigonometric function arcsine to the topographic data obtained at each node. To do this for each ROI, the distance from the location point to the base of the mountain is measured to find the base. Next, the base height, defined as the altitude of the mountain peak relative to the location point, is measured. These quantities are illustrated in Figures 4. Once the base and base height are obtained, the hypotenuse of the right triangle is easily calculated using the following equation:

$$A^2 + B^2 + C^2 .$$

Once the hypotenuse is determined, the barrier angle, ϴ, can be calculated through the arcsin of the angle opposite the base height using the following equation:

$$\text{Sin}\Theta = (\text{Base Height/Hypotenuse}) \rightarrow \Theta = \text{Sin}^{-1} (\text{Base Height/Hypotenuse})\backslash$$

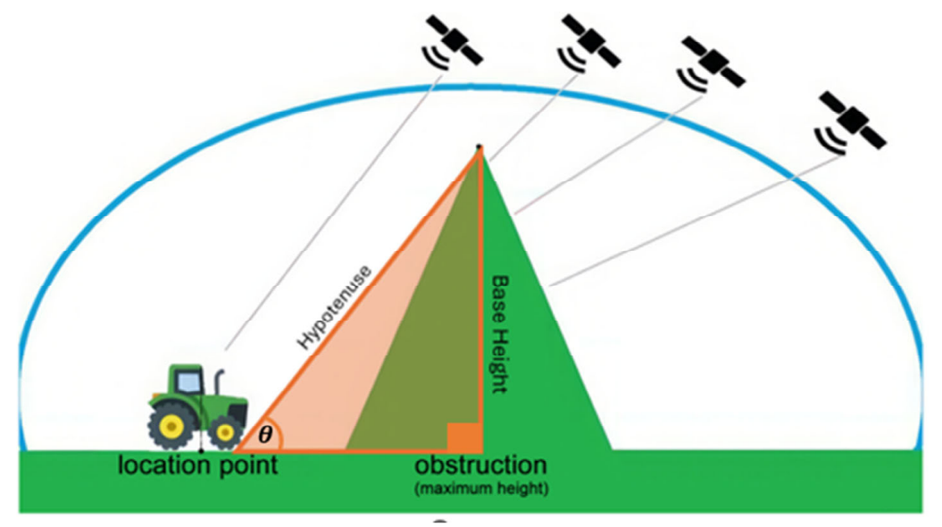


Figure 3

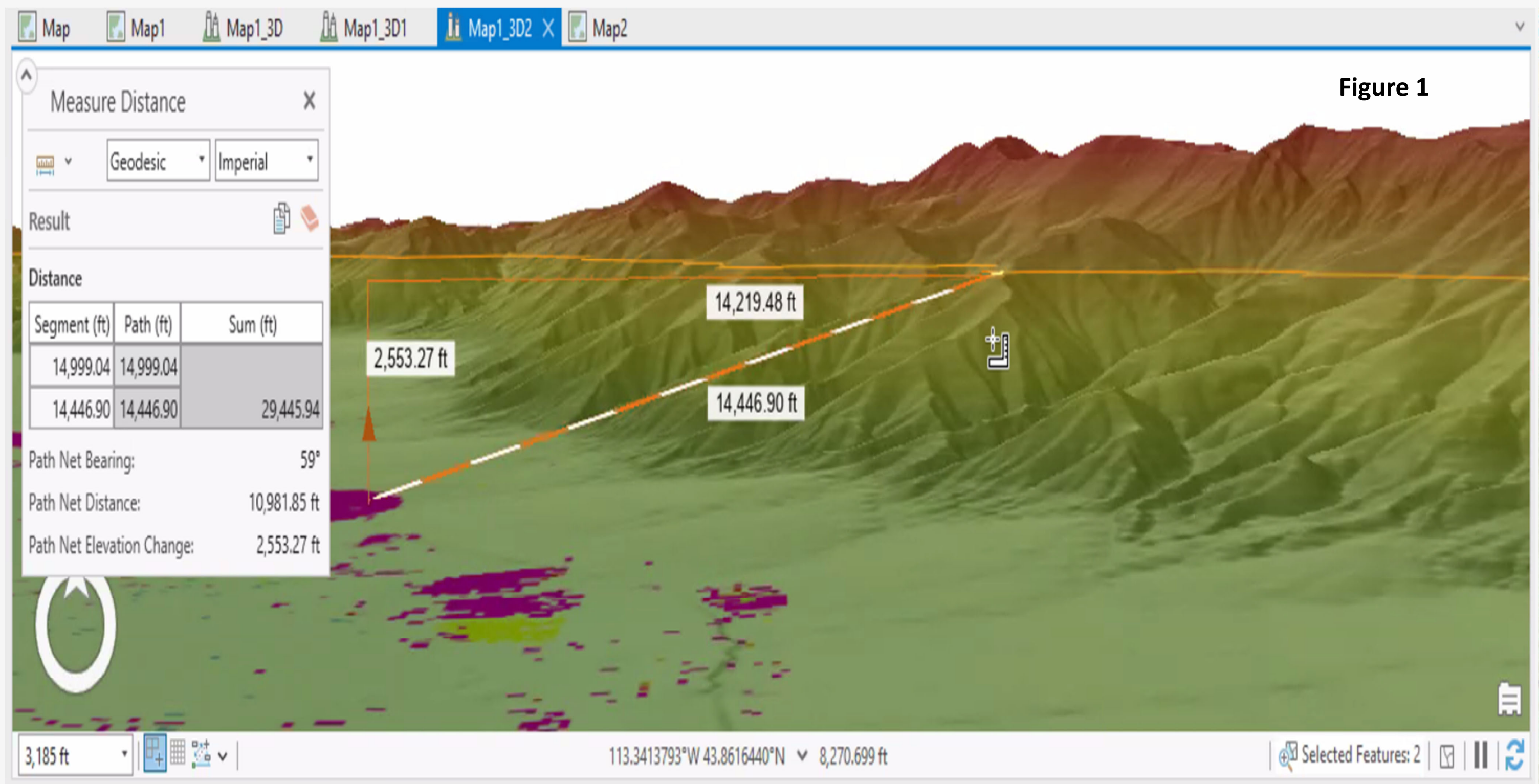
After all the barrier angles for the forty-six ROIs were calculated, the angles were grouped into three risk zones. These zones, labelled low, medium, and high are defined according to several risk factors analyzed by Langley (Langley, 99). In this study, the authors looked at the change in GDOP with increasing masking angle and latitude. The authors found that at their study location in New Brunswick Canada at a latitude of 46.57 degrees with a masking angle above 15, GDOP is impacted severely when the GPS satellites are aligned near 0000 UTC time. At that time, GDOP increases to over 12. However, when the mask angle is below 5 degrees, the GDOP remains below 3.5 for all local times (see Figure 4 Langley, 99). As such, Langely demonstrates that DOP values at their location in New Brunswick Canada, has a high enough GDOP value when the masking angle is above 15 degrees there will be significant impacts to the operations used in precision farming. Furthermore, the authors explain that this spike in GDOP values is due to the alignment of the satellites above the elevation mask angle of more than 12 (Langley, 99). On the other hand, if the mask angle is at or below 5, the GDOP impacts are low despite the location and satellite alignment (See Figure 5). This study also considered the information provided from the article by Wang et al., titled "Dependency of GPS Positioning Precision on Station Location. Wang found that for when the masking angle is at 0 degrees and at the latitude similar to that of the Lost River Valley, GDOP is already 2.5 (See Figure 6 Wang et al (2002)). Wang's article provided evidence that there is a slight increase in position error compared to lower latitudes, before other factors such as barrier angles are even considered.

From the information provided in both articles, the ROI's within the Big Lost River Valley are already predisposed to having GDOP impacts because of their high latitude at 43.79 degrees. Although the latitude of the Big Lost River Valley is not quite as high as New Brunswick Canada, the latitudes are within 3 degrees. Thus, it was decided to define the medium risk zones to start at 10 degrees. In total, the values of the risk zones were chosen to encompass the many variables that factor into the calculation of (geometric) dilution of precision (GDOP) and simplify the perceived impact terrain has on GPS reception to aid in decision support. For example, if an ROI has a high barrier angle, then there is a high risk that the signals to the ground GPS receiver will be disrupted. For ROIs that have barrier angles of 15 degrees or greater those ROIs are then considered to be a high risk to support precision farming. Lastly, ROI's where the barrier angles have measurements between 14.9 to 10 degrees, then those ROIs are medium risk. Barrier angles whose measurements are 9.9 or lower are low risk.

Upon applying this methodology, polygons were then drawn to display where the risk zones are for the farms as well as the surrounding area. The polygons were symbolized based on the three risk levels. For example, red indicates high risk, orange indicates medium risk, and green indicates low risk (Figure 7 and Table 1).

Table 1: Barrier Angle (ϴ) Risk Level

Barrier Angle ϴ	Risk Level
ϴ ≤9.9°	Low
10°≤ ϴ ≥14.9°	Medium
°15≤ ϴ	High



Distance

Segment (ft)	Path (ft)	Sum (ft)
14,999.04	14,999.04	
14,446.90	14,446.90	29,445.94

Path Net Bearing: 59°
Path Net Distance: 10,981.85 ft
Path Net Elevation Change: 2,553.27 ft

3,185 ft
113.3413793°W 43.8616440°N 8,270.699 ft
Selected Features: 2

Figure 1

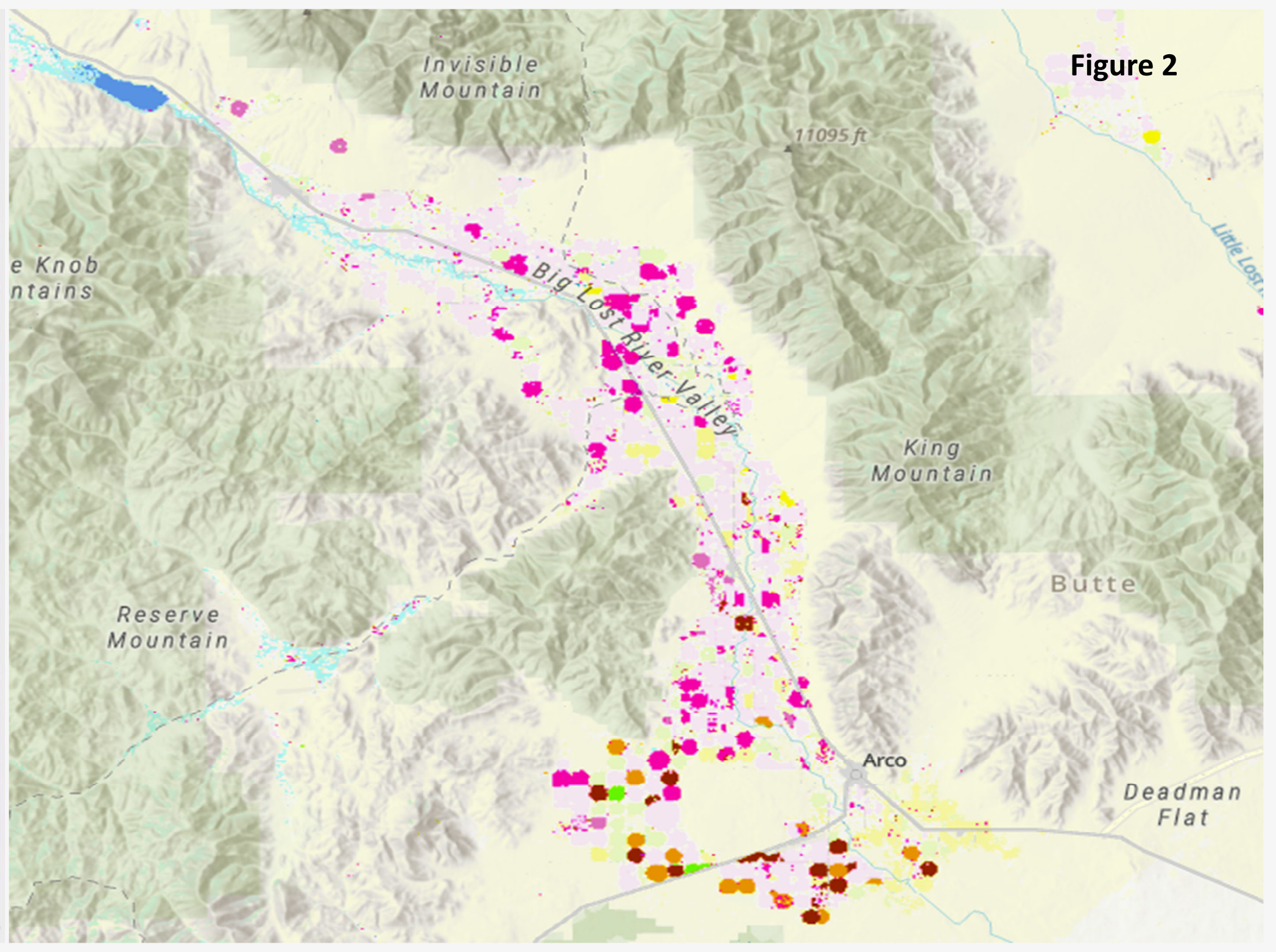


Figure 2

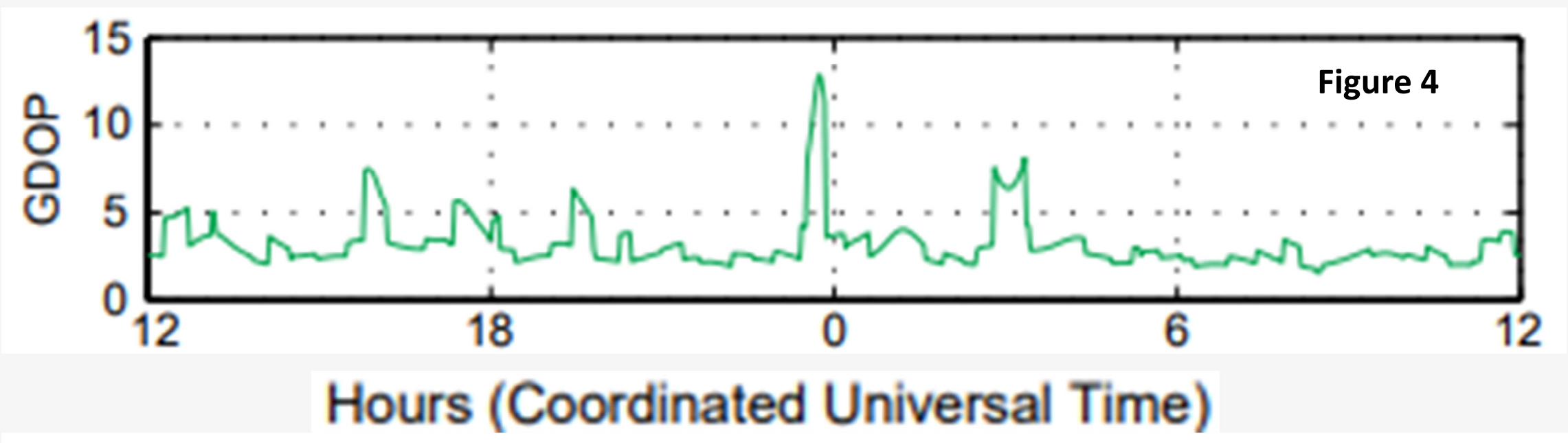


Figure 4

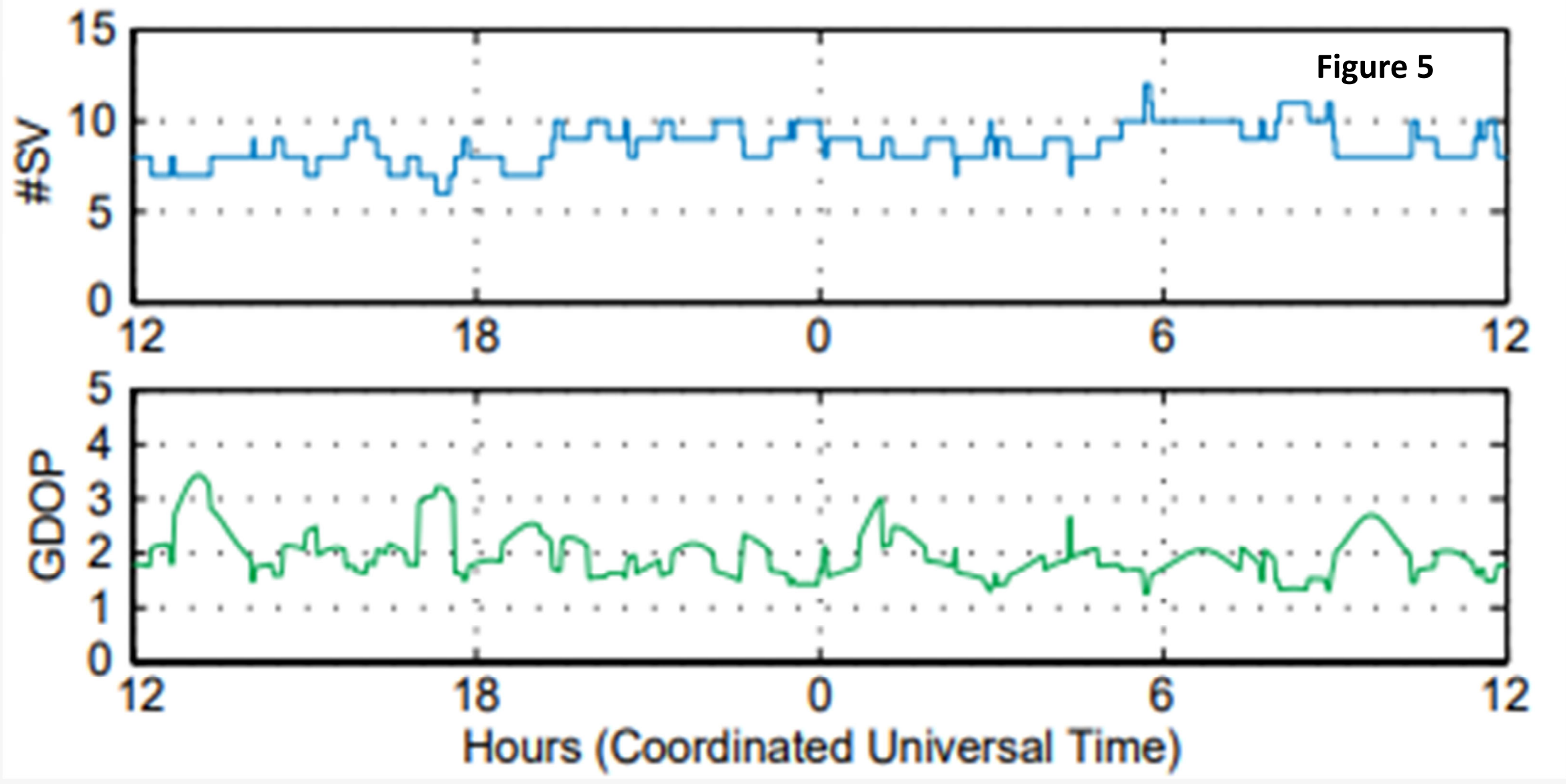


Figure 5

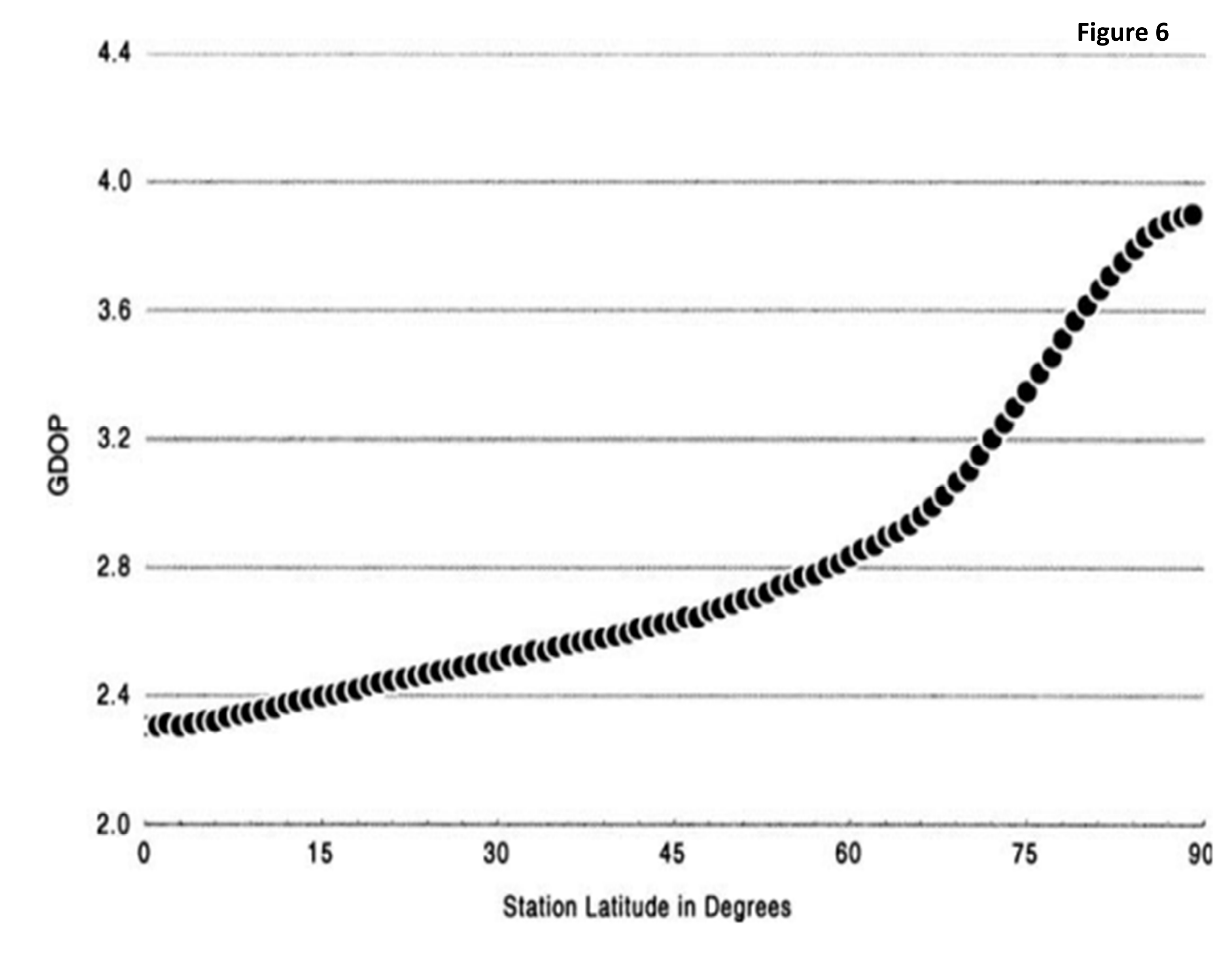


Figure 6

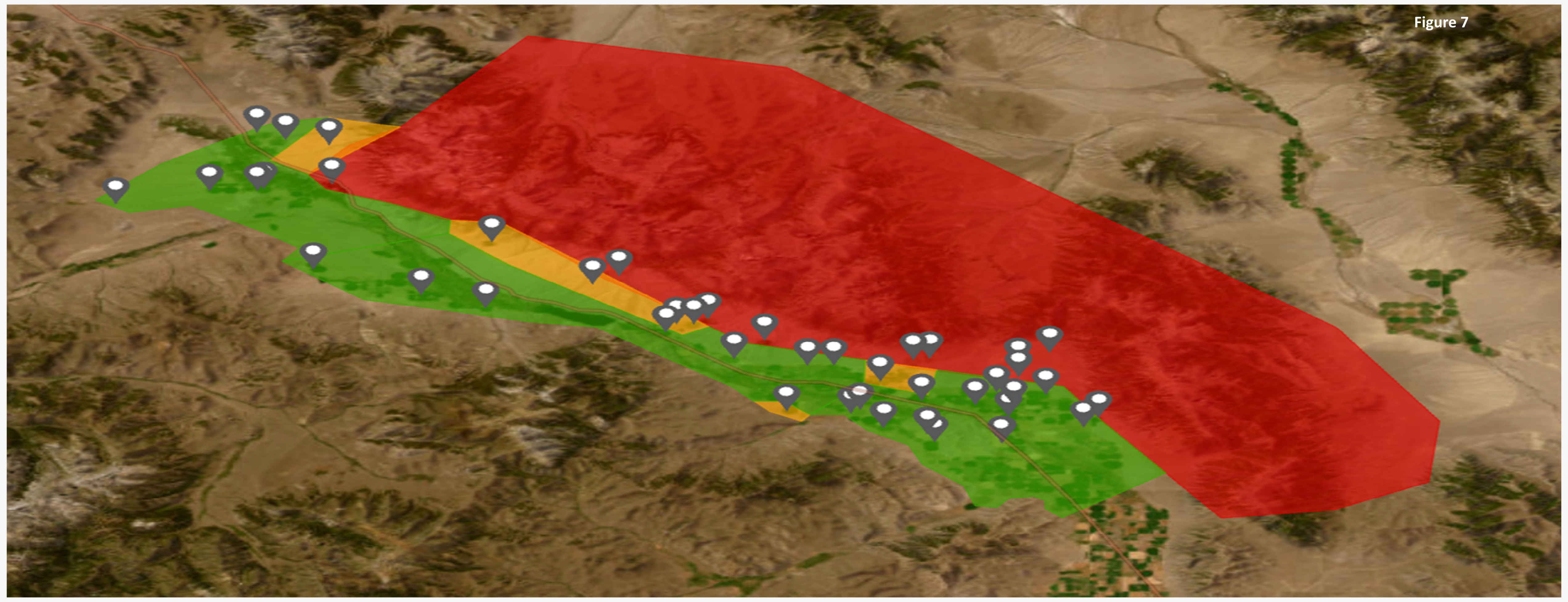


Figure 7

Discussion

This study found that 59.09% percent of the ROI's within the basin have a low risk, 18.18% of ROI's have a medium risk, and 22.73% of the ROI's have a high risk of GPS signal disruption due to barrier within the terrain (Table 2). These findings are significant because they show that roughly one-third of the farms within the basin have a high risk of GPS disruption has the potential to greatly impact the use or consideration of use for precision farming.

Table 2

Risk Level	# of ROI's	Percentage
Low	26	59.09%
Medium	8	18.18%
High	10	22.73%

Upon completion of the calculation of the barrier angles, risk zones for the basin were identified. The risk zones were identified by the barrier angles. The higher the barrier angle, the greater the risk for signal loss from multiple satellites. For example, if a parcel of farmland is in a location where the barrier angle measures 15 degrees or greater, that parcel is in at high risk for losing multiple satellite signals. On the other hand, if the barrier angle for a parcel of farmland measures below 10 degrees, that location has a lower change of losing signal from multiple satellites.

The results of the calculations for the barrier angles and their associated risk zones indicate whether existing or potential farmland parcels will have consistent disruptions in their ground GPS receivers. For example, if a farmer is not currently using precision farming but is considering switching to precision farming methods, their location within a potential risk zone will help guide their decision. The risk zones also aid in the appraisal of potential plots to be used as farmland by identifying whether a potential parcel is suitable for precision farming. Furthermore, the risk zones also help determine locations that will be greatly impacted when space weather events occur.

Future Work

While the results of this study have provided appropriate identification of areas that have a risk for GPS disruption, this study has three limitations. The first limitation is that the measurements of the barrier angles were taken remotely and were confirmed with ground truthing. It is recommended that future studies confirm the calculations with collecting data in the field. The second limitation to this study is that this study did not factor in geomagnetic storm data to show the risk posed by G-level storms. Since the area of interest in this study is located within the aurora oval zone (See Figure 8, (Kevin-Palmer, 2015)), adding space weather data to this study would solidify the areas where GPS disruption is greatest when there is a space weather event and when one is not occurring. The third limitation this study did not account dependency of the GPS positioning precision on station location. For example, a study by Wang and Bakzi (Wang et al.2002) found that the position precision in the north-south direction is worse than that in the east-west. Since this study only consider mountain ranges in the east-west direction, future work should consist of mountain ranges located in the north-south direction because mountain ranges in the south pose a bigger problem to GPS signals. The addition of the north-south direction has the potential to change the boundaries of the risk zones.

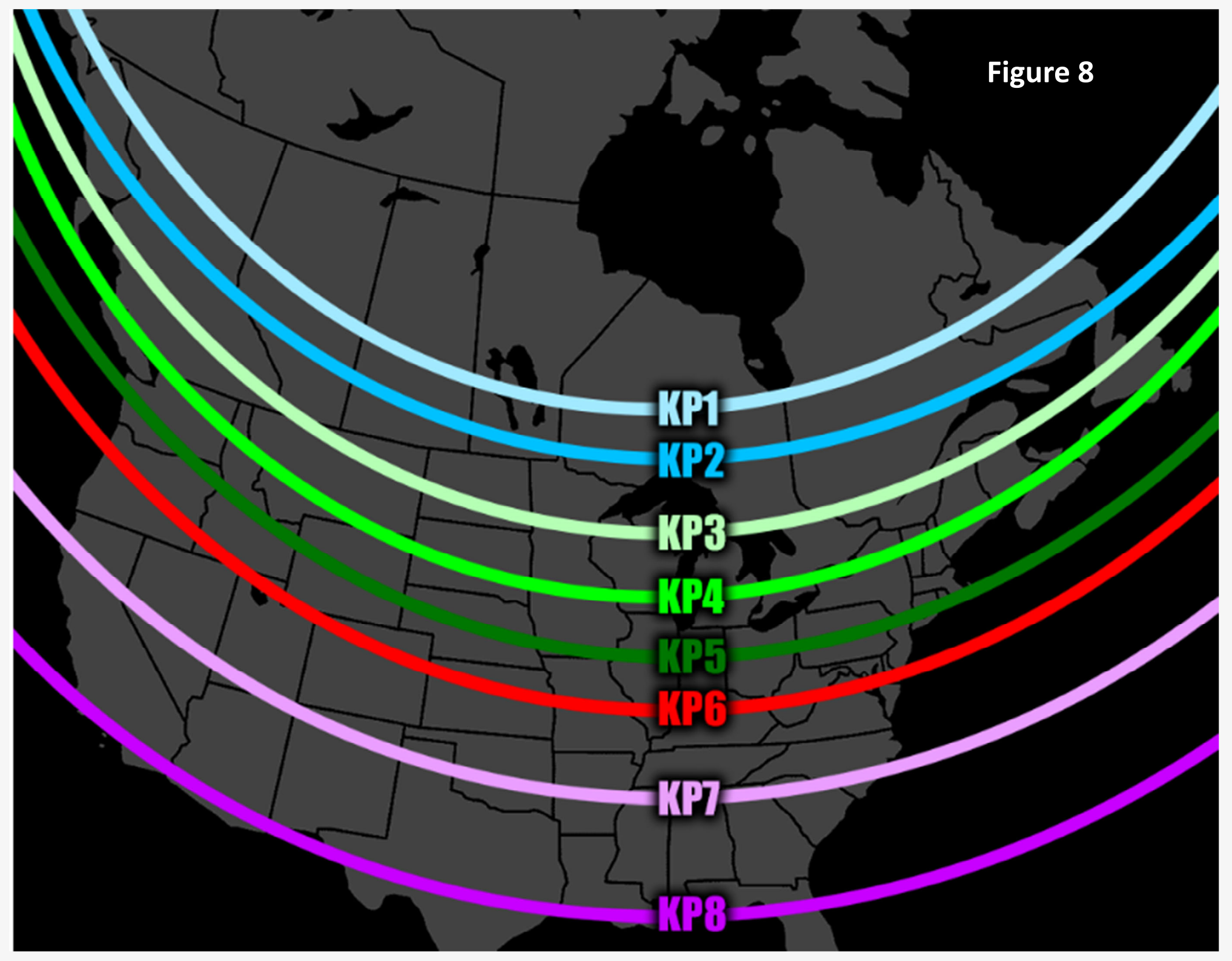


Figure 8

Citation

- Dilution of Precision - UNB - Geodesy & Geomatics Engineering, gge.ext.unb.ca/Resources/gpsworld.may99.pdf. Accessed 8 Apr. 2024.
- Wang, Jiexian, et al. "Dependency of GPS positioning precision on station location." GPS Solutions, vol. 6, no. 1–2, 1 Nov. 2002, pp. 91–95, https://doi.org/10.1007/s10291-002-0021-7.
- Kevin-Palmer. "Reading Aurora Charts." Dark Site Finder, 4 Sept. 2015, darksitefinder.com/reading-aurora-charts/.