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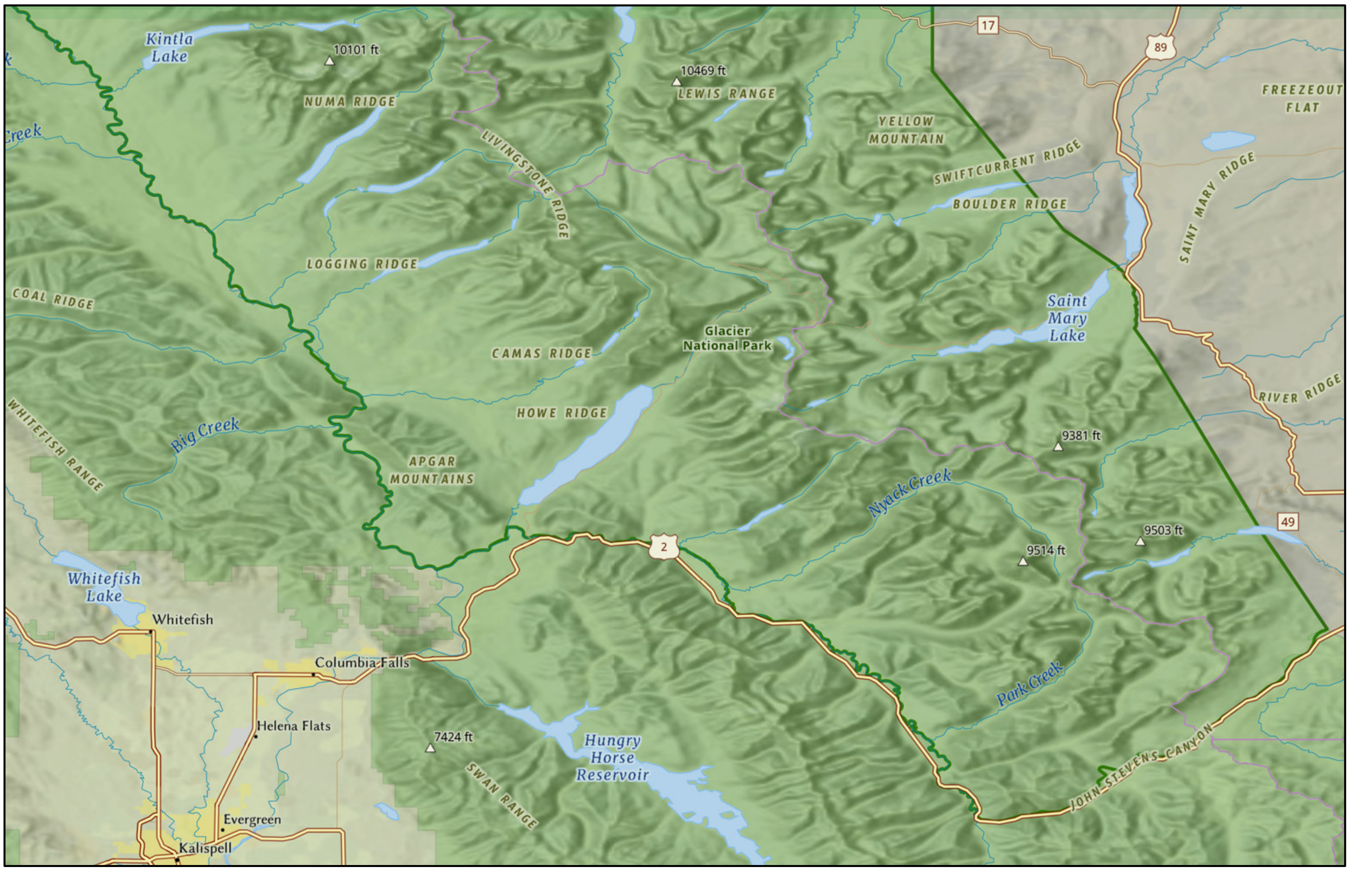
Exploring Spatial Patterns of Overflights at Glacier National Park



Map of Glacier National Park. Map service layer credits: Esri, USGS, Montana State Library, TomTom, Garmin, SafeGraph, FAO, METI/NASA, BLM, EPA, NPS, and USFWS.

NPS / BRIAN PETERSON

Exploring spatial patterns of overflights at Glacier National Park

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Abstract

This study explored spatial patterns of overflights at Glacier National Park (GLAC). Data were collected at Apgar Mountain. Overflights were analyzed from September 1st, 2021–September 19th, 2024 (1,115 total days; 37 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. Phase 1 of the analysis focused on all overflights and found concentrations of overflights above GLAC. Phase 2 of analysis focused on low-level overflights that flew between 3,000 and 12,000 feet above mean sea level (MSL) and flew within 10 miles of the GLAC boundary finding that the majority of waypoints were between 3,000–9,000 feet MSL. Phase 3 of analysis removed all overflights that were government flights, major airlines, and survey flights. The remaining flights were low-level overflights. Kernel density analysis was conducted using waypoints segmented into 500 feet above ground level (AGL) altitude intervals. The altitude interval with the highest density of overflights was 0–500 feet AGL. This information can be used for planning and management purposes, and this study serves as a resource for future research that intends to use more advanced analytics.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic information systems

GLAC: Glacier National Park

MSL: Mean sea level

NPS: National Park Service

Acknowledgments

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Introduction

In 1910, Glacier National Park (GLAC) was designated as a national park (National Park Service, 2024a). In 1974, it was designated as an International Biosphere Reserve under the United Nations Educational, Scientific and Cultural Organization (UNESCO). In 1995, it was named as a World Heritage Site. GLAC encompasses more than 1 million acres with 93% managed as wilderness. The landscape is dominated by the Rocky Mountains with the highest elevation being the summit of Mount Cleveland at 10,448 feet and the lowest elevation being the Flathead River at 3,150 feet. Presently, GLAC has 26 glaciers with the largest being Harrison Glacier. GLAC is home to 71 species of mammals including black bears, grizzly bears, bighorn sheep, mountain goats, elk, lynx, mountain lions, and wolverines. Wildlife viewing opportunities and the unique landscape attract a lot of visitors. In 2023, GLAC received 2,933,616 recreation visits (National Park Service, 2024b). A popular park destination is Going-to-the-Sun Road which is more than 50 miles and traverses through mountains with views of glaciers, forests, and lakes (National Park Service, 2024a).

Scenic air tours have also been a popular way for tourists to see the landscape of GLAC. In September 2022, an Air Tour Management Plan (ATMP) was adopted for GLAC (https://parkplanning.nps.gov/projectHome.cfm?projectId=103520). Among other requirements, the ATMP established a specific air tour route that follows the Going-to-the-Sun Road from GLAC's west boundary and then loops back when the road pivots towards the southeast. Additionally, the ATMP limited the number of tours each of the three approved air tour businesses could conduct. While the ATMP also requires air tour operators to submit tracking data, as of the year 2024, this requirement is not active. Therefore, this report will include a cursory examination of air tour travel patterns. The primary purpose of this report is to examine spatial patterns of overflights at GLAC more broadly.

As of January 1, 2020, the FAA requires all aircraft that enter designated airspace to be equipped with ADS-B technology (see 14 CFR § 91.225 and 14 CFR § 91.227) (Federal Aviation Administration, 2023a). However, no airspace requires ADS-B technology over GLAC (Federal Aviation Administration, 2023b). Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States (Peterson et al., 2022; Peterson et al., 2023). The extent of ADS-B adoption by GLAC air tour operators is unknown.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency. This study analyzed overflights above GLAC that are equipped with ADS-B transmitter technology. The data discussed in this report were collected at Apgar Mountain. Overflights were analyzed from September 1st, 2021–September 19th, 2024 (1,115 total days; 37 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data.

Methods

Data Collection

Data were collected by one ADS-B data logger positioned at Apgar Mountain (48.51827, −4.02060) (Figure 1). The data logger was positioned with an unimpeded and expansive skyward exposure and placed about approximately 17 feet above ground level. The logger recorded ADS-B signals as text files.

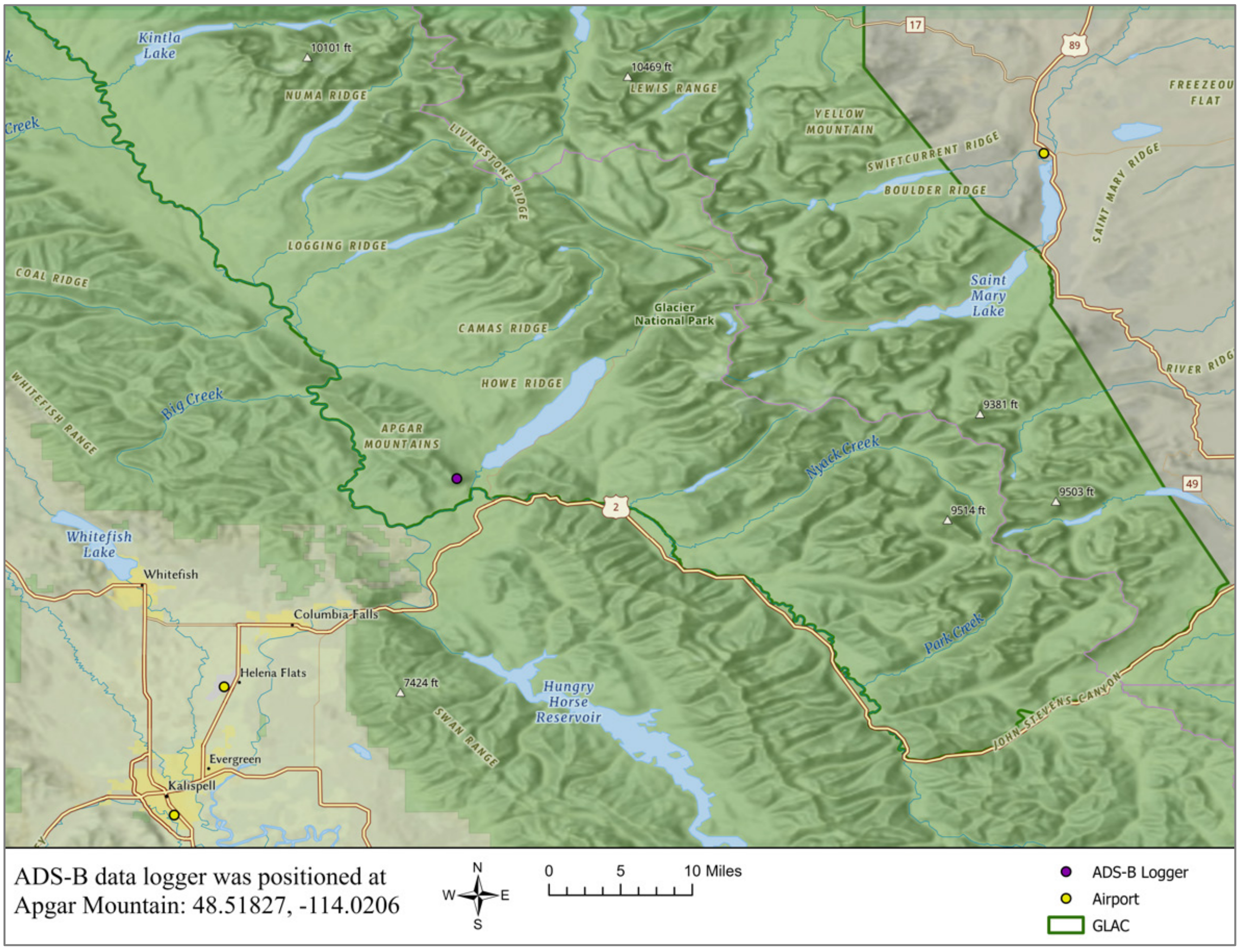

Figure 1. The location where the ADS-B data logger was positioned. NPS / BRIAN PETERSON

Data Processing and Cleaning

Data processing, cleaning, and analysis were accomplished using a custom ArcGIS Pro toolbox with multiple Python-based geoprocessing tools that automated and simplified processing and analysis of ADS-B data. The toolbox conducted the following tasks: processed raw ADS-B data files, created waypoint and flightline feature classes (datum = NAD1983), merged daily waypoints and flightlines, screened for suspected flights known not to be air tours (discussed in the next paragraph), conducted kernel density analysis, summarized waypoint altitudes, summarized number of flights across several temporal scales (monthly, daily, hourly), and summarized number of flights across aircraft types (rotorcraft, fixed-wing single engine, fixed-wing multi engine).

This report expresses altitude using mean sea level (MSL) and above ground level (AGL). Altitude expressed in MSL refers to the altitude of an aircraft above sea level, regardless of the terrain below it, whereas altitude expressed in AGL is a measurement of the distance between the ground surface and the aircraft. To calculate AGL altitudes for each waypoint, a 10-meter digital elevation model (DEM) was used (United States Geological Survey, 2021). The AGL altitudes were calculated by subtracting the reported altitudes of the ADS-B logger minus the elevation of the DEM for every point location (x,y) (see Beeco et al., 2020 for exact method).

ADS-B technology can use barometric altitude or geometric altitude. Barometric altitude is determined by measuring air pressure and must be regularly calibrated. Geometric altitude is calculated using the Global Positioning System (GPS). While error can result from each type of technology, GPS is generally considered a more reliable and accurate measure, but the aviation industry has long used barometric altitudes during flight. Aircraft owners/operators determine which system to use on their aircraft. The analysis in this report does not attempt to correct error associated with altitude information, as this would be nearly impossible and overly burdensome. Therefore, calculations of AGL can in some cases be negative. This can occur for low flying aircraft that have an ADS-B system reporting an altitude lower than actual. Negative AGL calculations can also be due to an aircraft's ADS-B system malfunction. Further, AGL is calculated using 10x10m Digital Elevation Models (DEM). This level of resolution can also introduce error. Negative AGL values are reported in the analysis.

To explore spatial patterns of overflights at GLAC, analysis was conducted in three phases. Phase 1 is a visual examination of all overflights within 10 miles of the park. Phase 2 reports altitudes using MSL, while Phase 3 uses AGL. This is because MSL is better suited for understanding aircraft patterns across a larger space or scale because the baseline (sea level) does not change. However, because Phase 3 includes more detailed examinations of the data, AGL analysis was used because it better contextualizes how flights pass over variable terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, USGS, Montana State Library, TomTom, Garmin, SafeGraph, FAO, METI/NASA, BLM, EPA, NPS, and USFWS.

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above GLAC regardless of flight type. Thus, the flightline feature class was not cleaned of any flight types. To understand how flight paths extended beyond the park boundary, a 10-mile buffer around the GLAC boundary was used. Four maps were produced that showed data for each year (2021, 2022, 2023, and 2024).

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above GLAC regardless of flight type. Similar to Phase 1, a 10-mile buffer was used. Low-level overflights were identified as having an altitude less than 12,000 feet MSL. This altitude was chosen because the highest point at GLAC is Mount Cleveland at 10,448 feet MSL (National Park Service, 2024a), and approximately 1,500 feet above the highest point would capture flights that had the greatest impact on the acoustic environment in the park. To understand flight altitudes, a waypoint feature class was used. Three maps were produced which show low-level overflight waypoints across the following MSL altitudes: 1) 3,001–6,000 feet MSL; 2) 6,001–9,000 feet MSL; and 3) 9,001–12,000 feet MSL.

Phase 3 Methods

The purpose of the third phase was to remove flights known not to be either low-level overflights or air tours. The toolbox joined ADS-B data to the FAA Releasable Database via aircraft unique identifiers to determine aircraft tail number, type registrant (e.g., government), and engine type. Using this info along with ADS-B data, the toolbox screened for suspected flights known not to be either low-level overflights or air tours by 1) cleaning the data of government flights, 2) straight-line flights, 3) major airlines, 4) flights with a flight path less than a mile in length, and 5) survey flights. Government flights were identified as government aircraft (FAA Releasable Database type registrant = 5). Straight-line flights were assessed by calculating sinuosity values. Sinuosity is a measure of how much a linear feature deviates from a straight-line condition and can be calculated as the ratio of total flight path length to the straight-line distance between a flight's initial and final waypoint. A perfectly straight flight path would have a sinuosity of one, but as the number of meanders in the path increases (e.g., the characteristic back and forth of survey flight behavior) sinuosity will begin to approach zero. All overflights that received sinuosity values greater than or equal to 0.99 were visually inspected to validate straight-line paths were flown and these were subsequently removed from analysis. Next, major airlines were identified using a list of major airlines (e.g., American Airlines, Delta Airlines, Southwest Airlines, etc.) inputted into the tool. Flights less than a mile in length were removed due to data integrity issues. Lastly, survey flights were removed from analysis because of their undue influence on analysis, infrequent nature, and known flight purpose. Survey flights were clearly identifiable by their flight patterns. Removal of survey flights was the last cleaning procedure because this step requires visual analysis which is easier to conduct after the other cleaning procedures have been accomplished. Survey flight behavior can be identified when a flight route consists of consecutive back and forth lateral movements in a parallel progression. Conversely, air tour behavior generally consists of flight routes that veer toward sightseeing locations and consist of sporadic S-turns and loops (Beeco & Joyce, 2019). After this cleaning step, the remaining flights are more likely to be low-level overflights and air tours, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are low-level overflights including air tours is not possible.

Consistent with other aircraft tracking reports, a 0.5-mile buffer around the park was used for Phase 3 to understand spatial patterns of low-level overflights that likely have the biggest impact on GLAC's acoustic environment. Using a 500 feet AGL altitude interval, waypoint data were segmented (<0 feet; 0–500 feet AGL; 501–1,000 feet AGL; 1,001–1,500 feet AGL; 1,501–2,000 feet AGL; 2,001–2,500 feet AGL; 2,501–3,000 feet AGL; 3,001–3,500 feet AGL; 3,501–4,000 feet AGL; 4,001–4,500 feet AGL; 4,501–5,000 feet AGL) and kernel density analysis was conducted for each altitude interval. Because each altitude interval had different density results, density classifications were normalized across altitude intervals. To do this, the altitude interval with the highest maximum density of waypoints (0–500 feet AGL) was used to normalize density classification, which required two steps. First, the 0–500 feet AGL altitude density was classified using equal interval percentage breaks with five intervals of 20%. These percentage breaks were determined using the maximum density per square kilometer as the ‘100%’ value. Second, the maximum density was segmented across two 20% equal interval classifications. Finally, the resulting density classifications were applied to the other altitude intervals. These steps are necessary to ensure density was calculated the same across altitude intervals regardless of the number of waypoints.

Results

Results—Phase 1

The research team mapped overflights for all flights (*n*=97,349). Figure 2 shows overflights from September 1st, 2021 to December 31st, 2021 (*n*=5,568). Figure 3 shows overflights from January 1st, 2022 to December 31st, 2022 (*n*=29,767). Figure 4 shows overflights from January 1st, 2023 to December 31st, 2023 (*n*=33,127). Figure 5 shows overflights from January 1st, 2024 to September 19th, 2024 (*n*=28,887). Areas with opaque lines indicate where there is greater flight density.

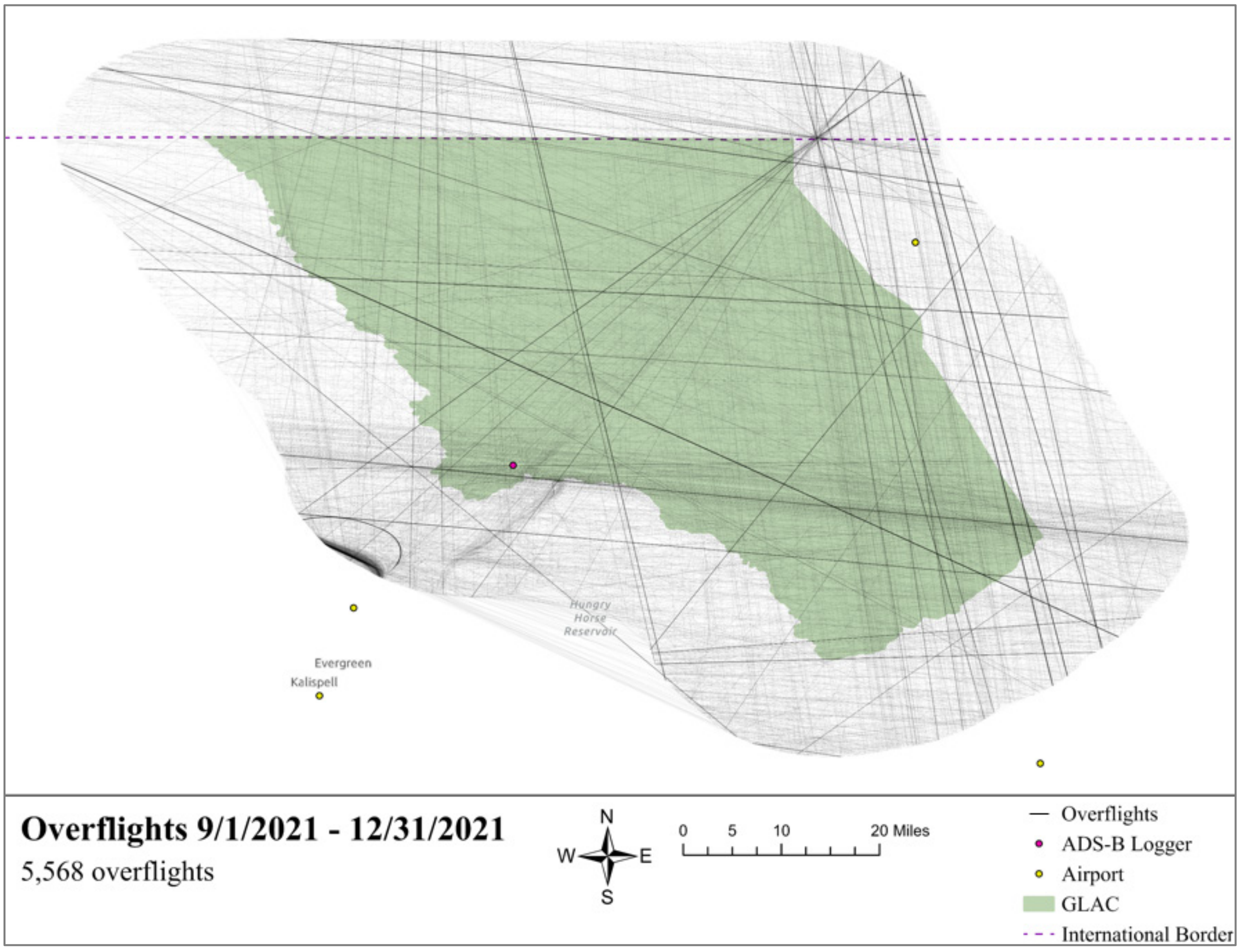

Figure 2. Overflights from September 1st, 2021 to December 31st, 2021 (*n*=5,568).
NPS / BRIAN PETERSON

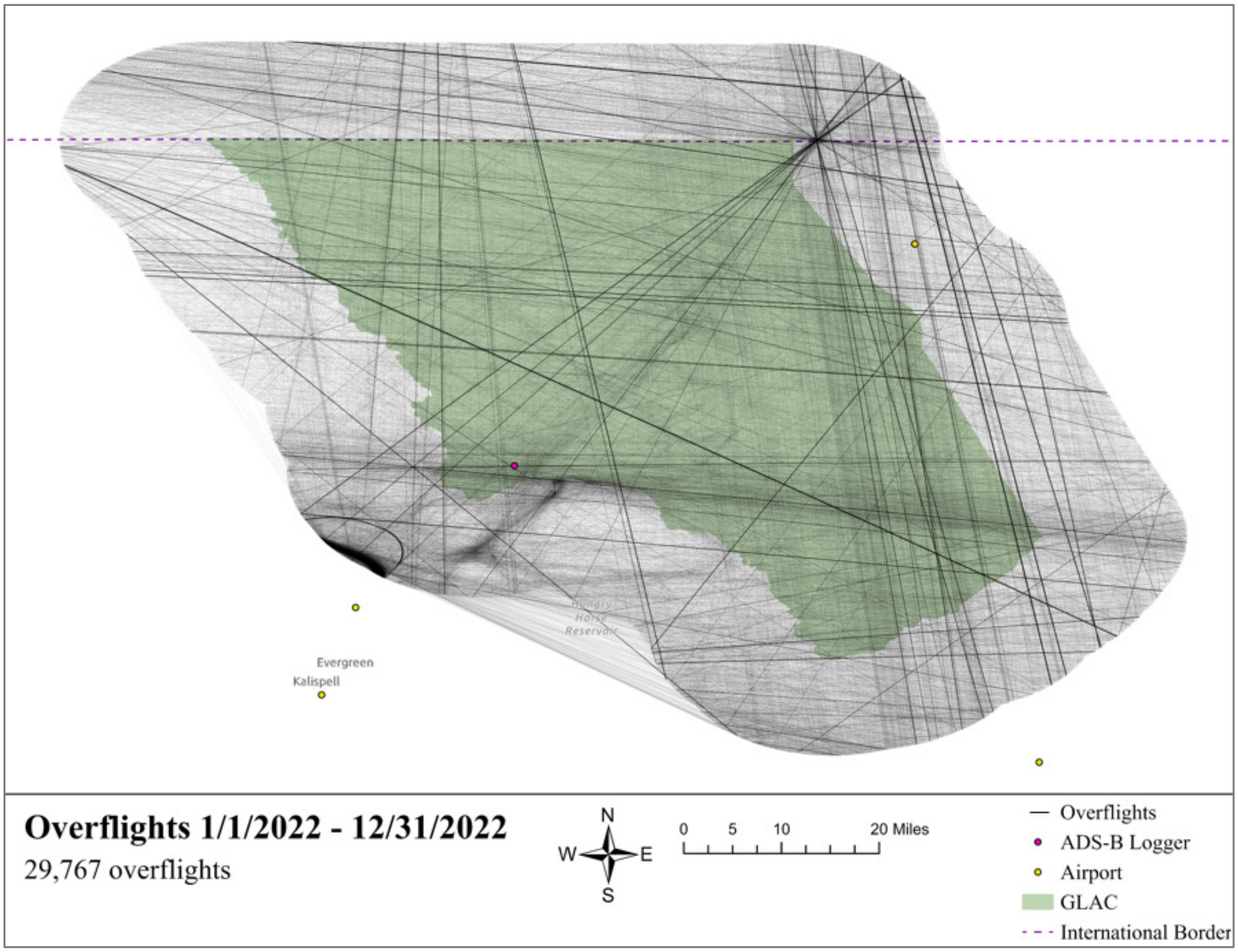

Figure 3. Overflights from January 1st, 2022 to December 31st, 2022 (*n*=29,767).
NPS / BRIAN PETERSON

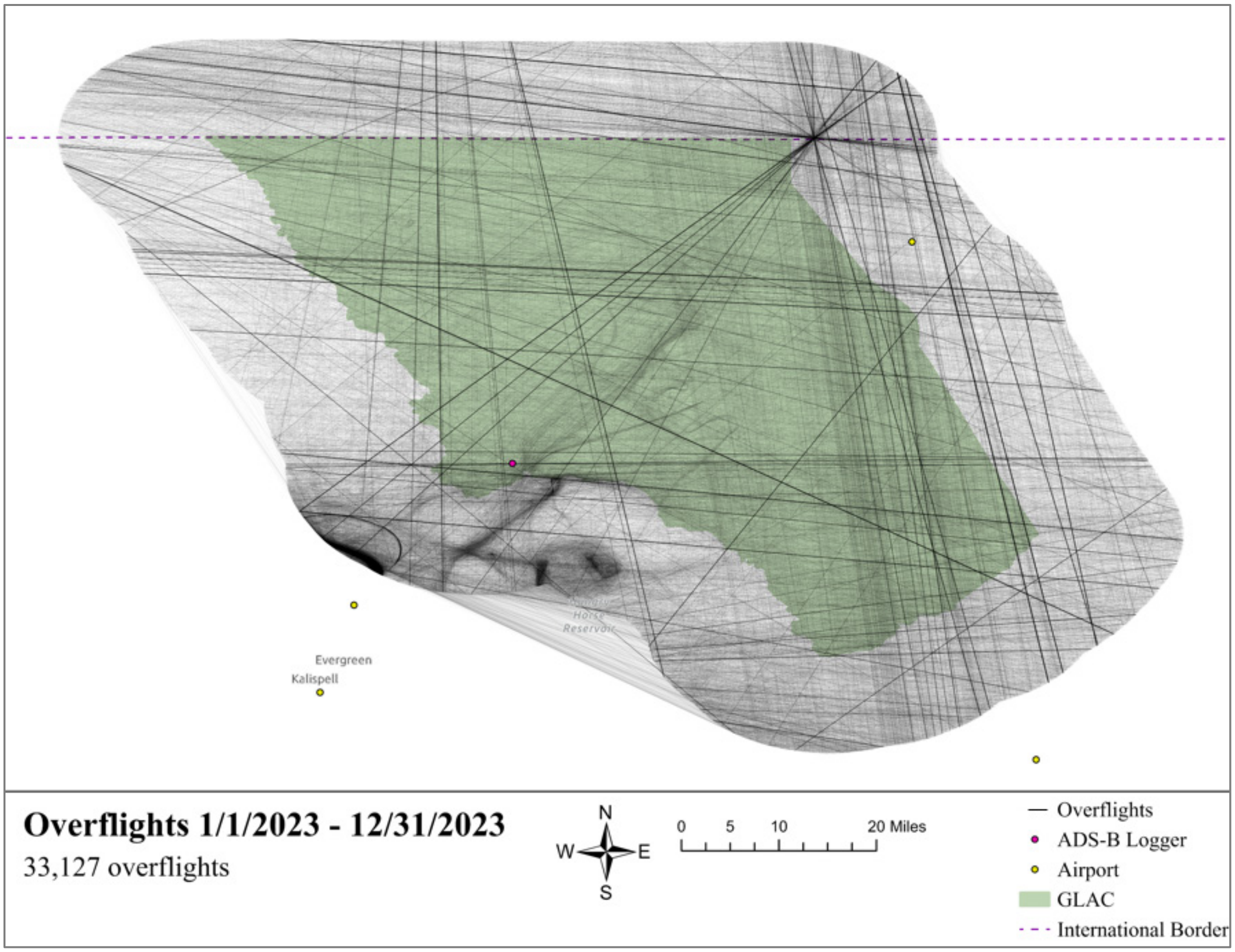

Figure 4. Overflights from January 1st, 2023 to December 31st, 2023 (*n*=33,127).
NPS / BRIAN PETERSON

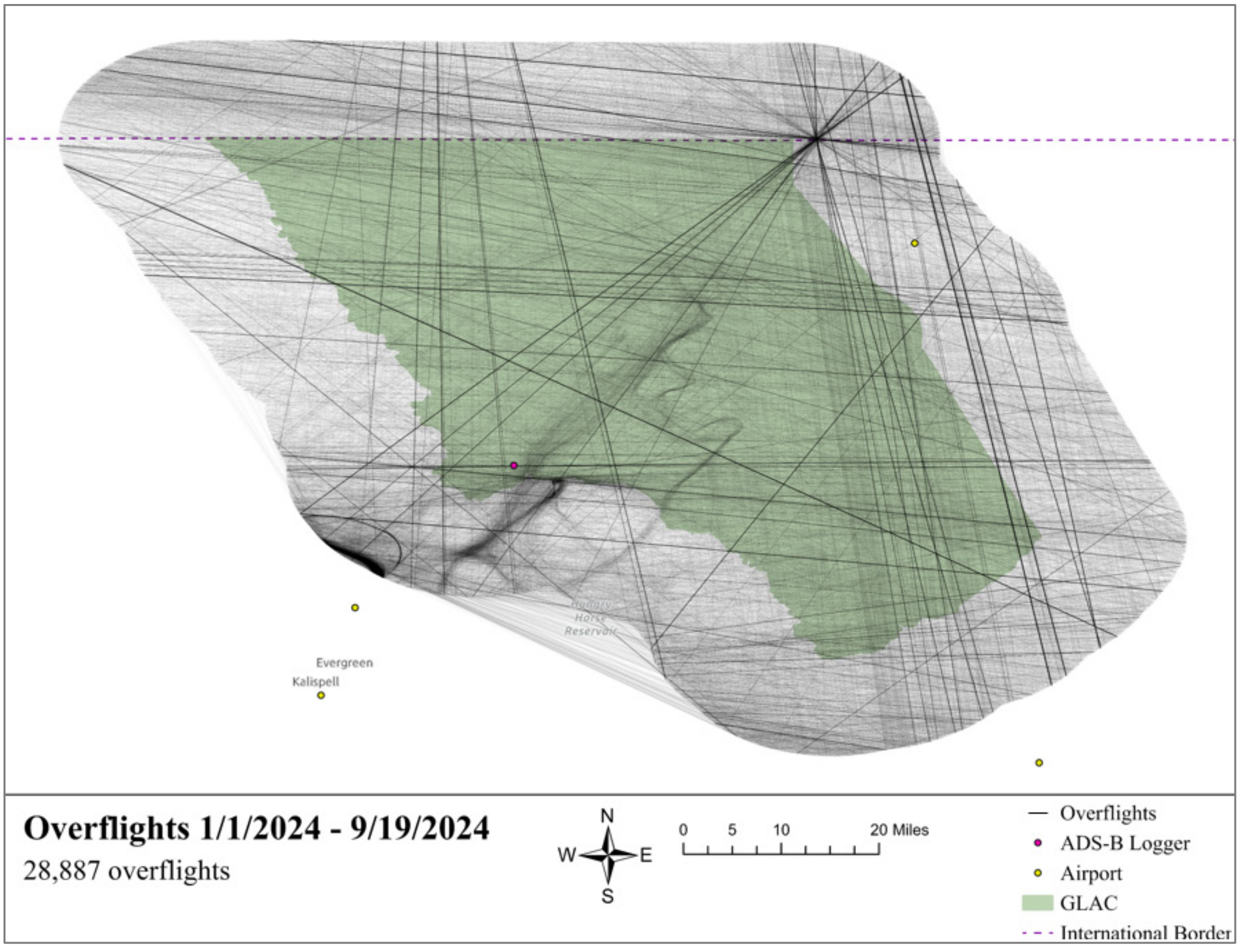

Figure 5. Overflights from January 1st, 2024 to December 31st, 2024 (*n*=28,887).
NPS / BRIAN PETERSON

Results—Phase 2

The research team mapped waypoints for all overflights that flew between 3,000–12,000 feet MSL (5,617,344 total waypoints), which is displayed across Figures 6–8. These figures show that most waypoints are between 3,000–9,000 feet MSL. Figure 6 shows waypoints between 3,000–6,000 feet MSL (2,055,502 waypoints). Figure 7 shows waypoints between 6,001–9,000 feet MSL (2,421,272 waypoints). Figure 8 shows waypoints between 9,001–12,000 feet MSL (1,140,570 waypoints).

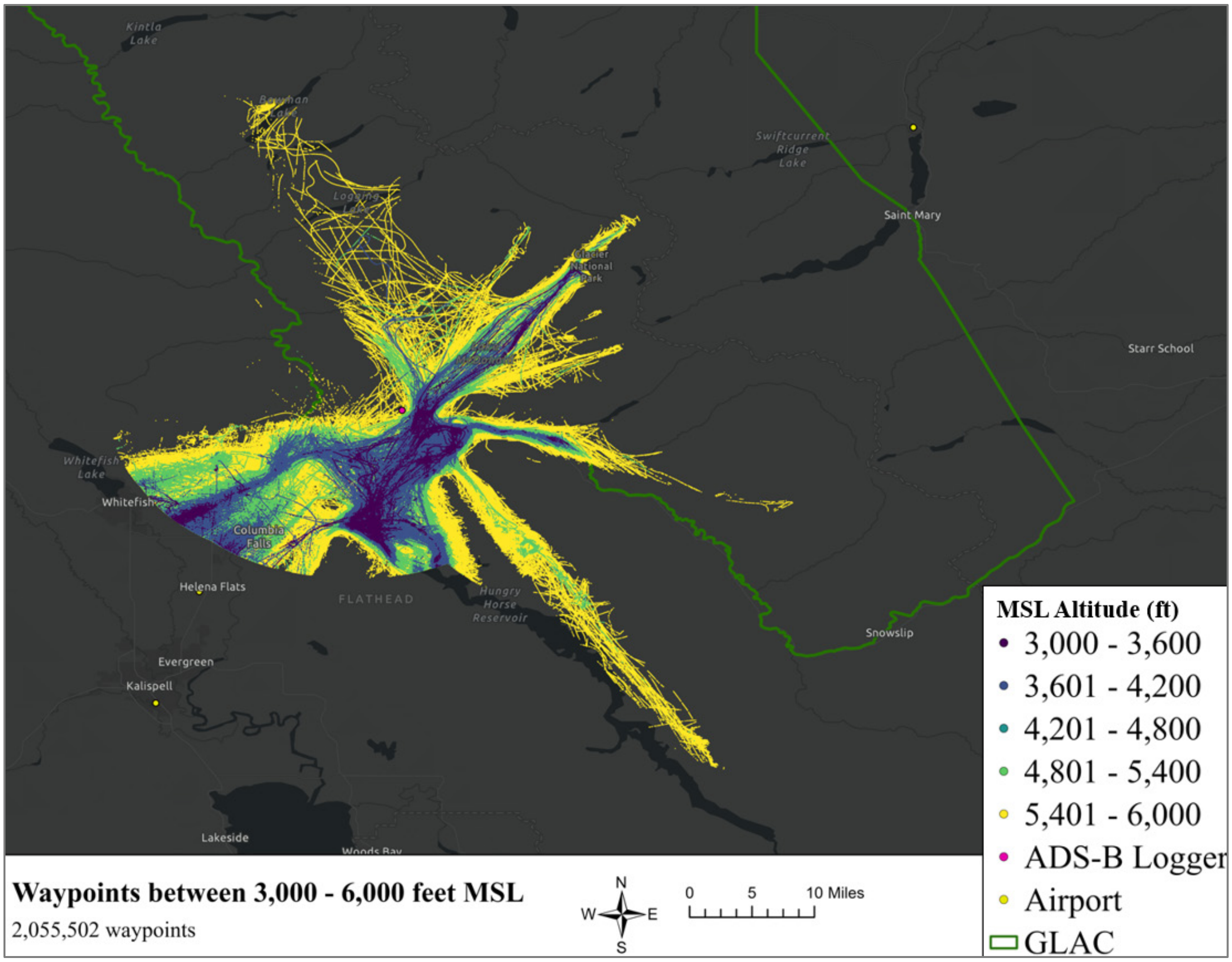

Figure 6. Waypoints between 3,000–6,000 feet MSL. NPS / BRIAN PETERSON

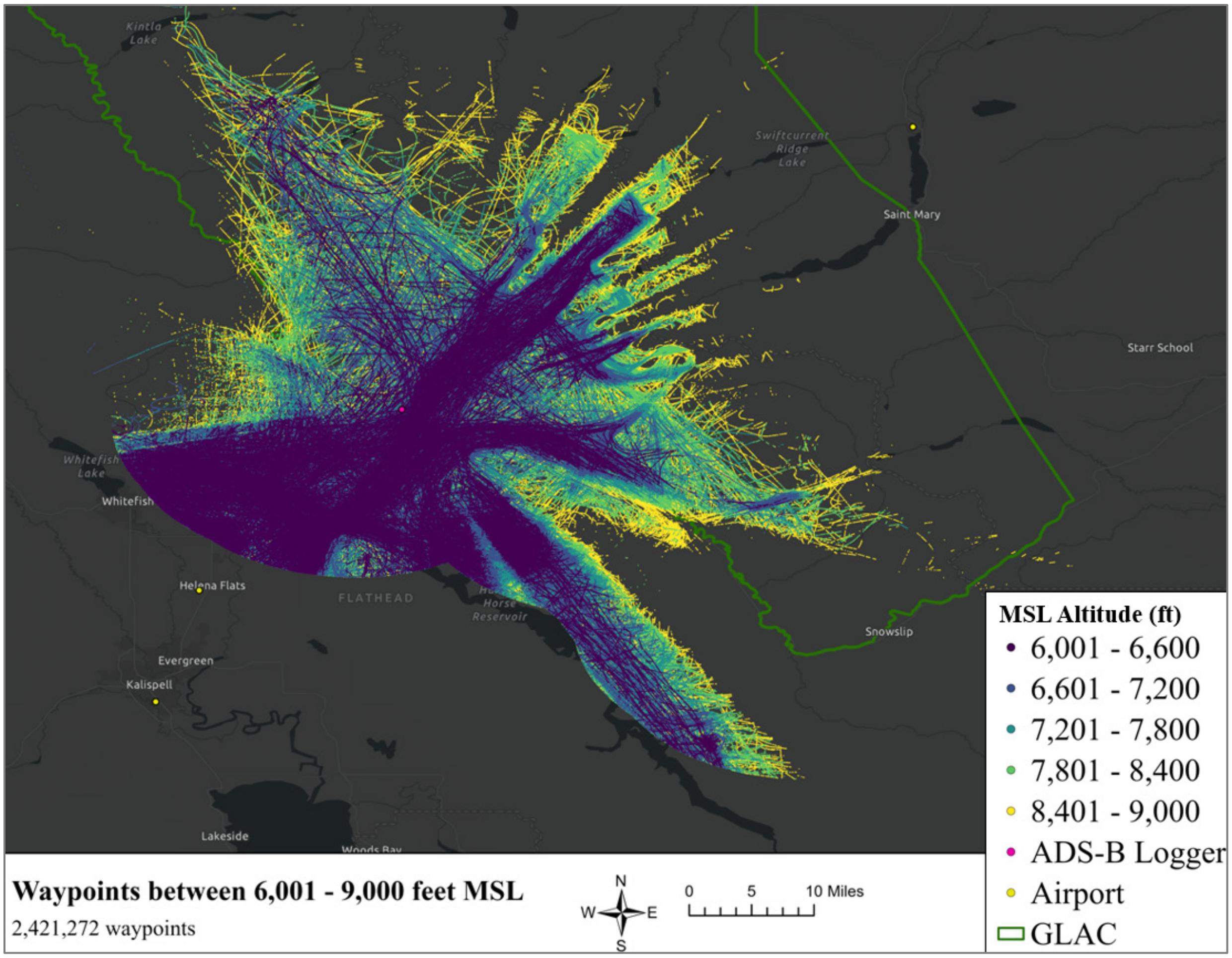

Figure 7. Waypoints between 6,001–9,000 feet MSL. NPS / BRIAN PETERSON

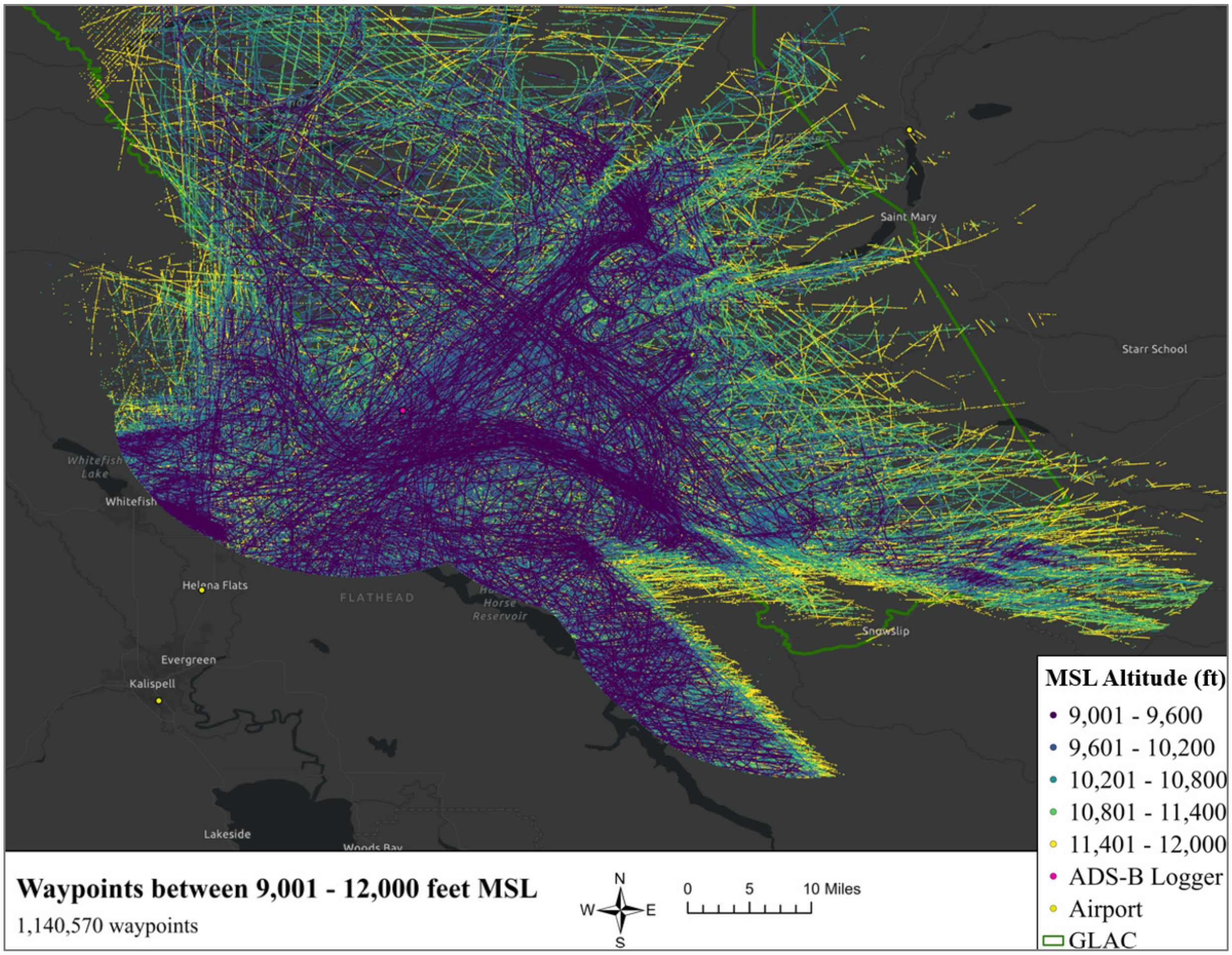

Figure 8. Waypoints between 9,001–12,000 feet MSL. NPS / BRIAN PETERSON

Results—Phase 3

Data were cleaned to focus analysis on low-level overflights including air tours, which resulted in the following numbers of flights removed: 195 government flights, 73,762 straight-line flights, 188 flights with a flight path less than a mile in length, 6,666 commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights), and 3 survey flights. This left 16,519 flights within 10 miles of the GLAC boundary (Figure 9). Next, these flights were clipped to a 0.5-mile boundary of GLAC, which left 4,374 flights. Using this dataset, kernel density analysis was conducted and the altitude interval that showed the highest density was 0–500 feet AGL. As described in the Methods, this density altitude was then used as the baseline to normalize the other altitude ranges. After normalization, one other altitude interval showed a density hot spot which was the 501–1,000 feet AGL altitude interval. The 0–500 feet AGL altitude interval shows two density hot spots and the 501–1,000 feet AGL altitude interval shows one density hot spot (Figure 10). The density outputs were statistically compared using a spatial correlation test and it was found that these two density layers were highly correlated with a correlation coefficient of 0.81. This confirms that flights between 0–1,000 feet AGL are concentrating in similar areas.

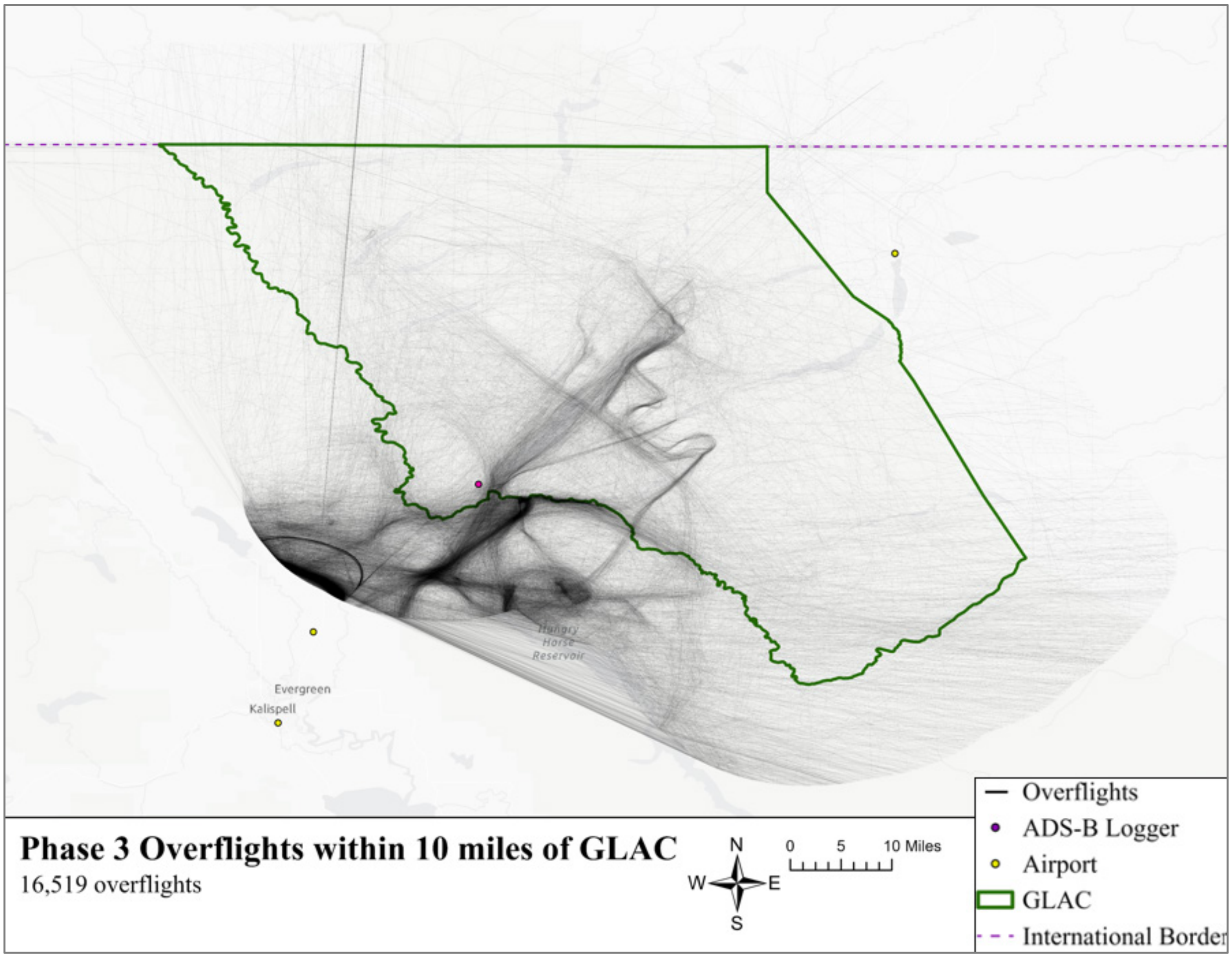

Figure 9. Overview of Phase 3 flights. NPS / BRIAN PETERSON

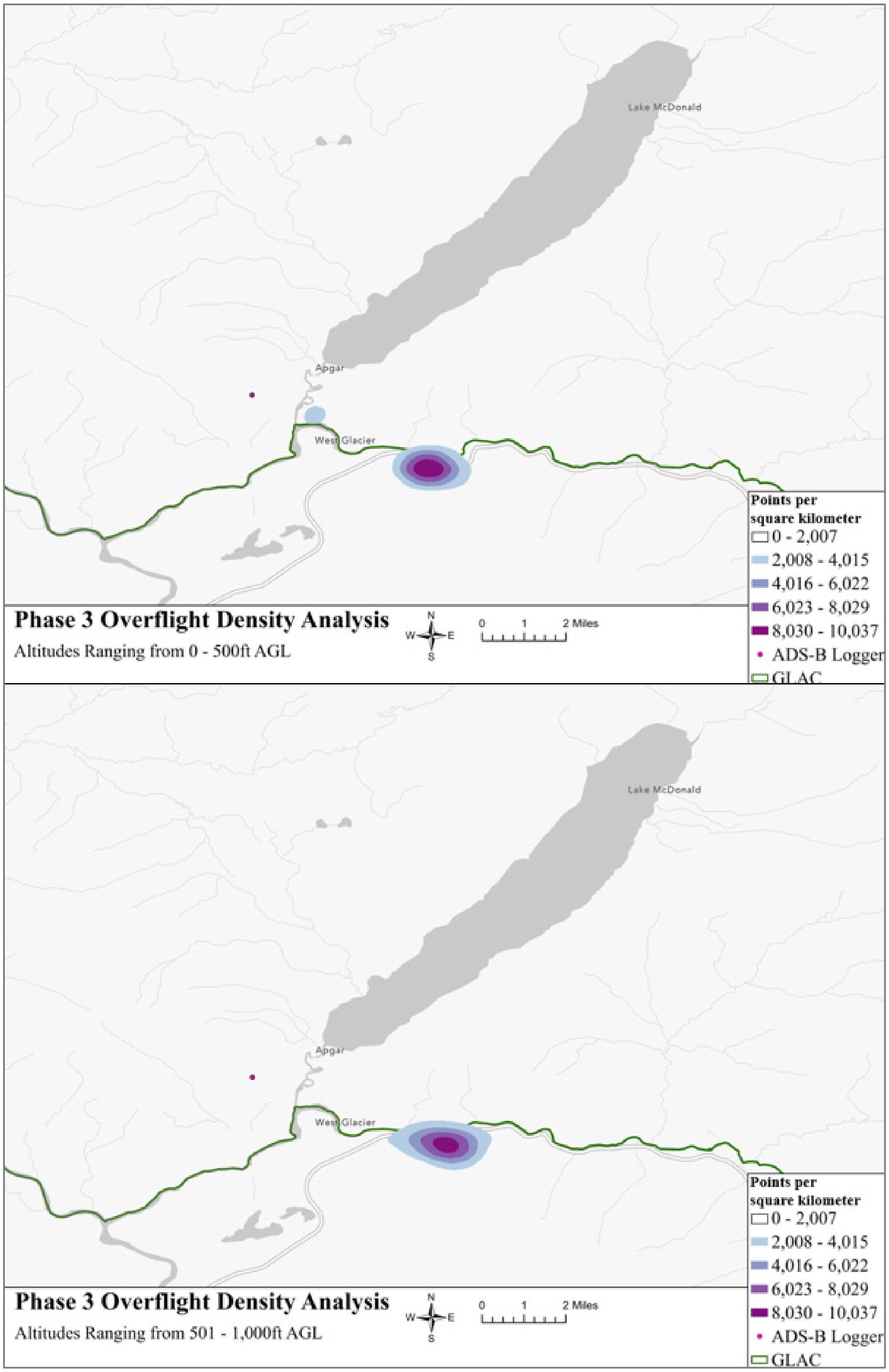

Figure 10. Overview of kernel density analysis showing AGL altitudes ranging from 0–500 feet and 501–1,001 feet. NPS / BRIAN PETERSON

To further understand altitude trends of waypoints, six visualizations were produced that focus on waypoints within 0.5-mile of the GLAC boundary. Figure 11 examines altitudes less than 0 feet AGL. Any tracking point with a negative AGL is due to error, although identifying the exact error can be difficult. However, further examination of these data revealed that eight tail numbers accounted for 75.38% of these waypoints. Broadly, error sources could be aircraft flying exceptionally low (including for takeoff and landing operations) combined with DEM generalization errors and errors between barometric altitude estimates and actual altitude, or a malfunction with the aircraft's ADS-B equipment.

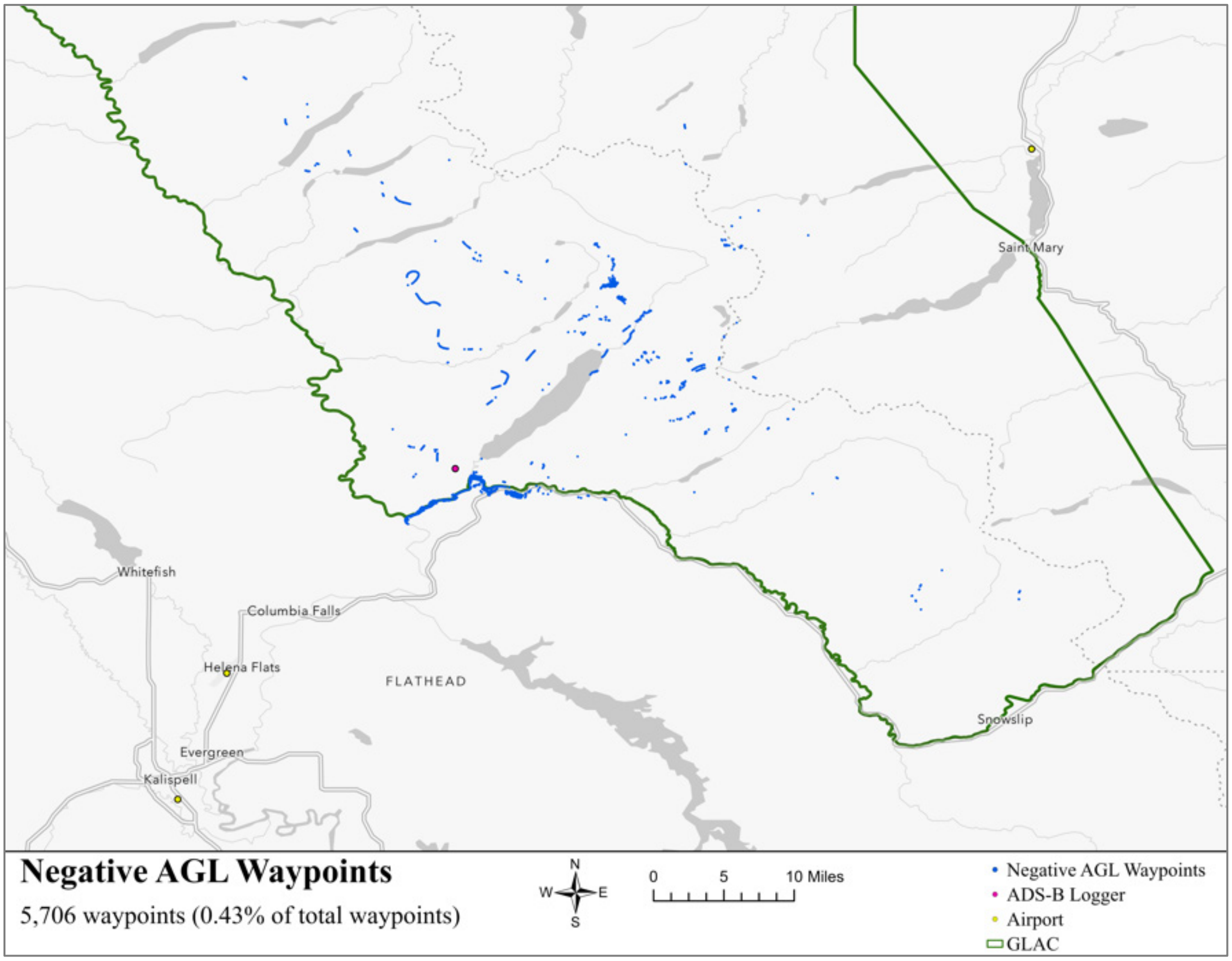

Figure 11. AGL altitude trends of altitudes less than 0 feet AGL for waypoints within 0.5-mile of the GLAC boundary (*n*=5,706 waypoints). NPS / BRIAN PETERSON

Figure 12 (altitudes ranging from 0–2,500 feet AGL) and Figure 13 (altitudes ranging from 2,501–5,000 feet AGL) display AGL altitude trends above the west side of GLAC. Figures 14, 15, and 16 display waypoints expressed in MSL. The maximum altitude used was 12,000 feet MSL because the highest point in GLAC is on the summit of Mount Cleveland at 10,448 feet MSL. The lowest altitude used was 3,000 feet MSL because the lowest point in GLAC is the Flathead River at 3,150 feet. Figure 14 (altitudes ranging from 3,000–6,000 feet MSL), Figure 15 (altitudes ranging from 6,001–

9,000 feet MSL), and Figure 16 (altitudes ranging from 9,001–12,000 feet MSL) display MSL altitude trends directly above GLAC and show waypoint altitudes trended between 6,001–9,000 feet MSL.

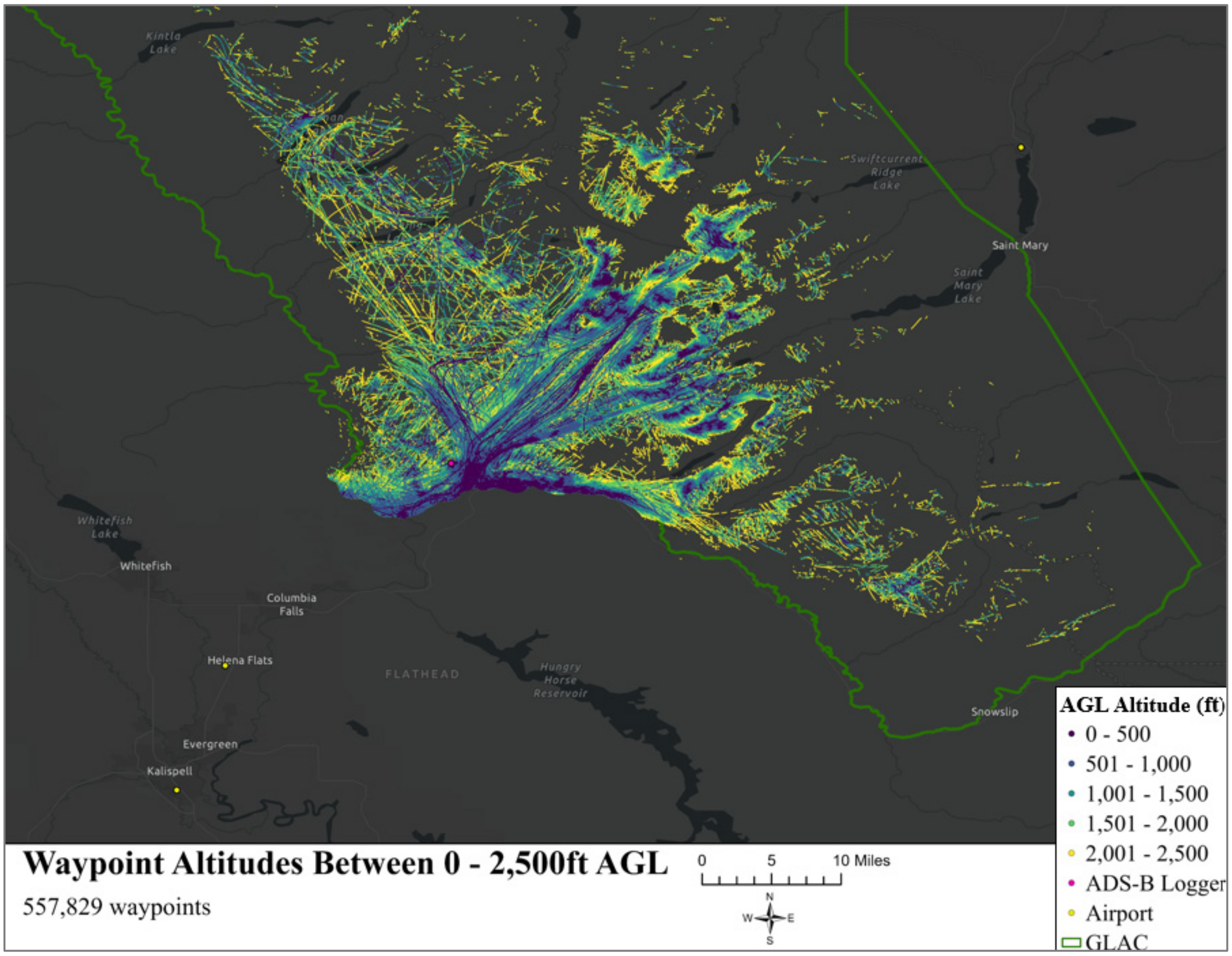

Figure 12. AGL altitude trends of altitudes ranging from 0–2,500 feet AGL for waypoints within 0.5-mile of the GLAC boundary (*n*=557,829 waypoints). NPS / BRIAN PETERSON

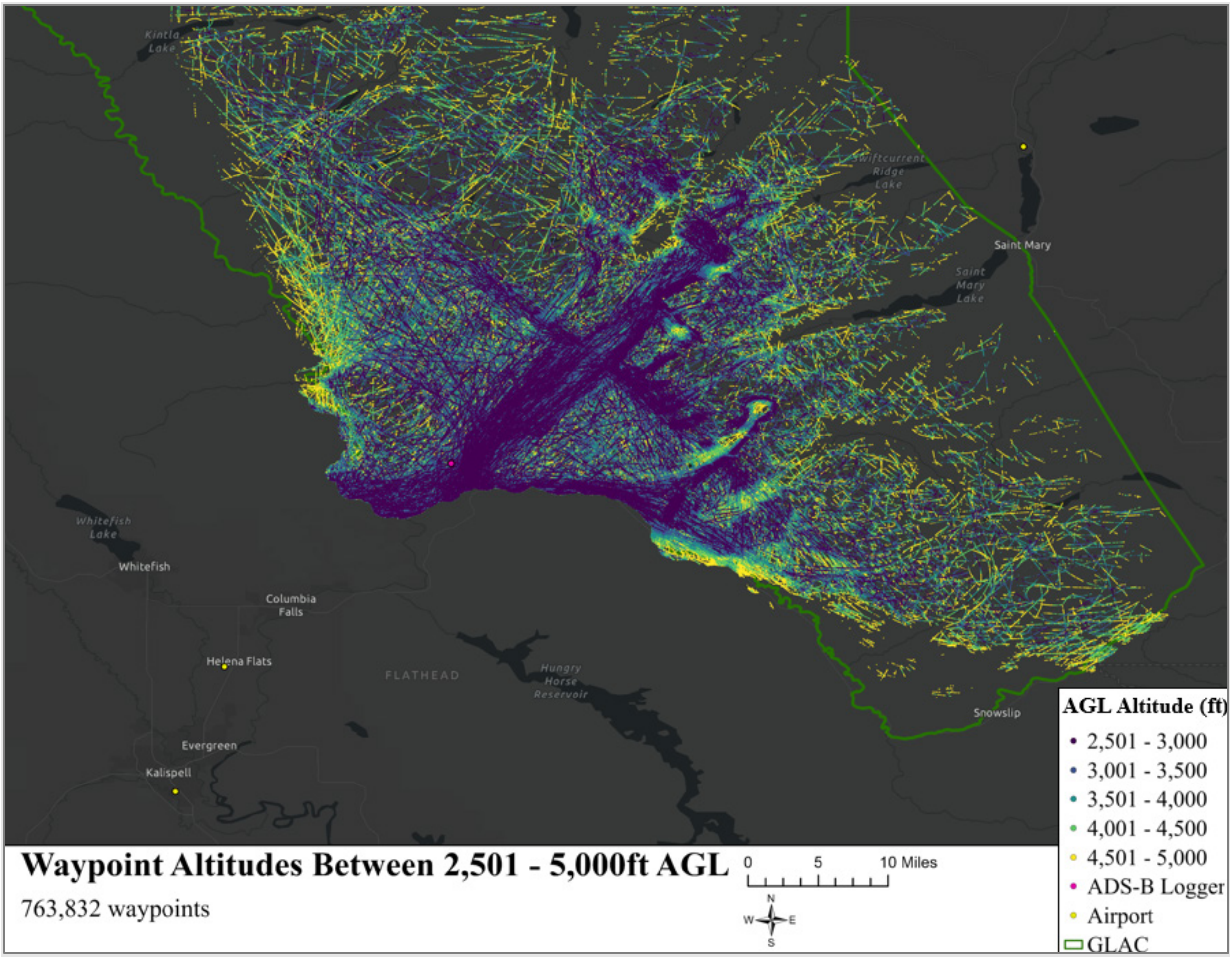

Figure 13. AGL altitude trends of altitudes ranging from 2,501–5,000 feet AGL for waypoints within 0.5-mile of the GLAC boundary (*n*=763,832 waypoints). NPS / BRIAN PETERSON

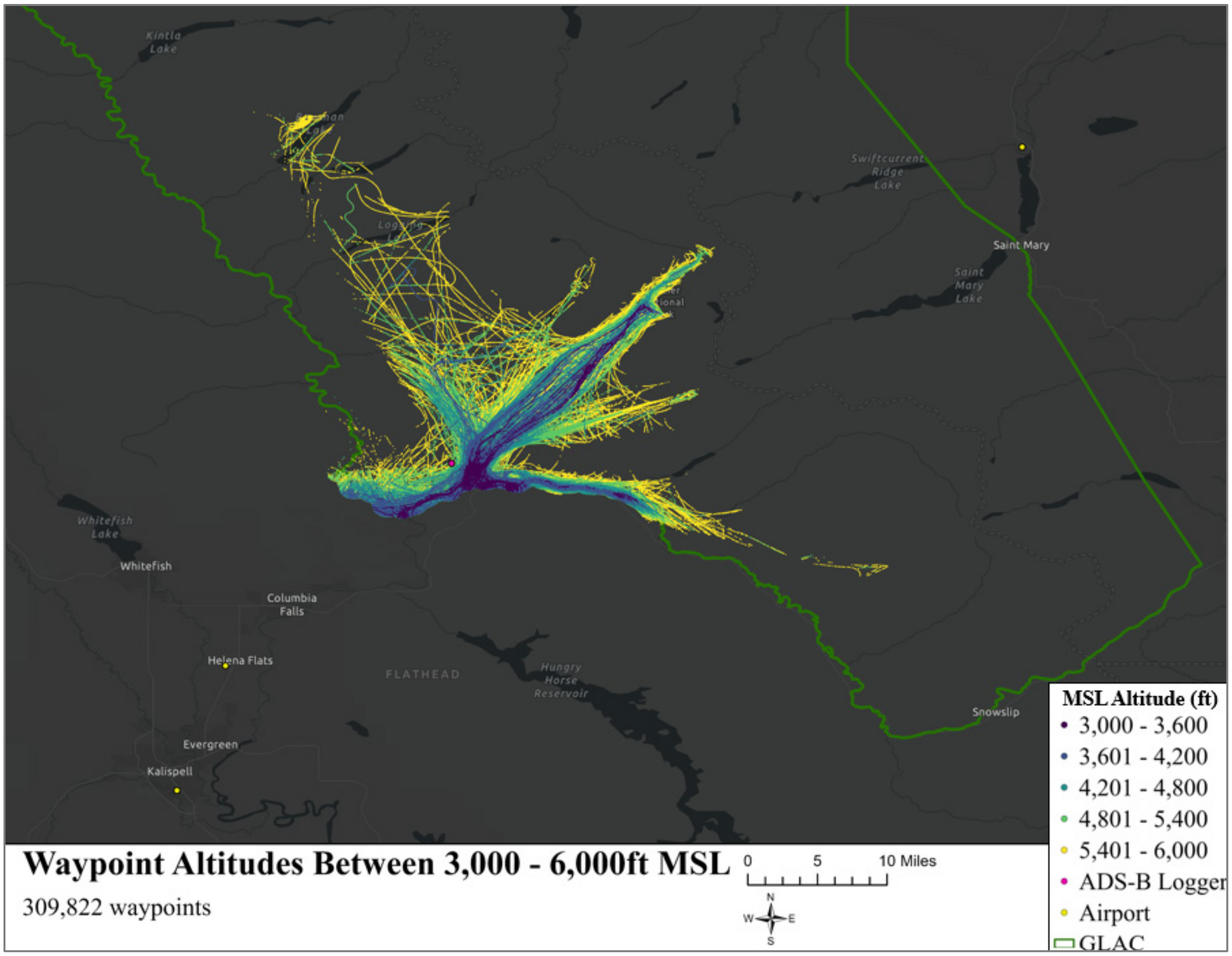

Figure 14. MSL altitude trends of altitudes ranging from 3,000–6,000 feet MSL for waypoints within 0.5-mile of the GLAC boundary (*n*=309,822 waypoints). NPS / BRIAN PETERSON

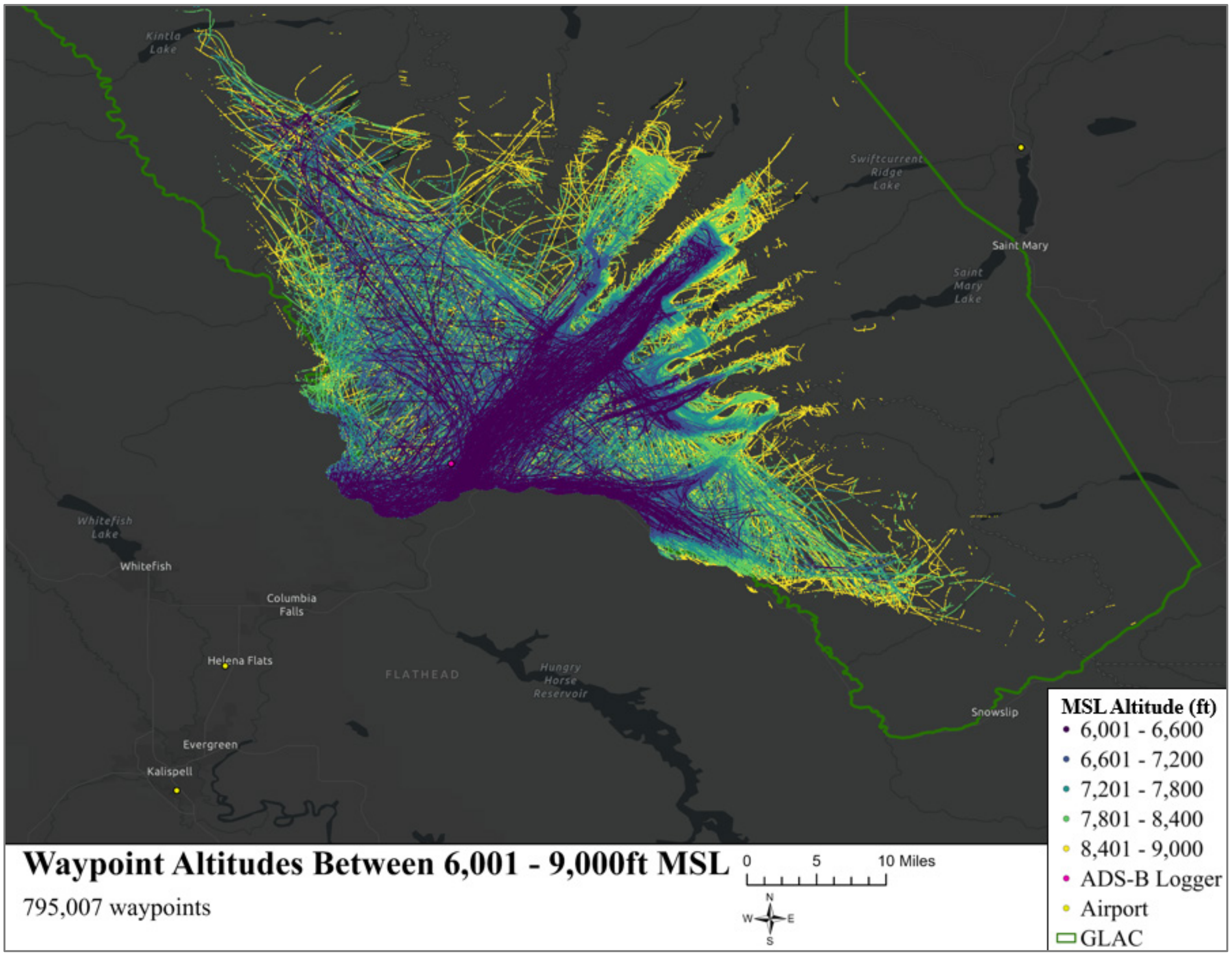

Figure 15. MSL altitude trends of altitudes ranging from 6,001–9,000 feet MSL for waypoints within 0.5-mile of the GLAC boundary (*n*=795,007 waypoints). NPS / BRIAN PETERSON

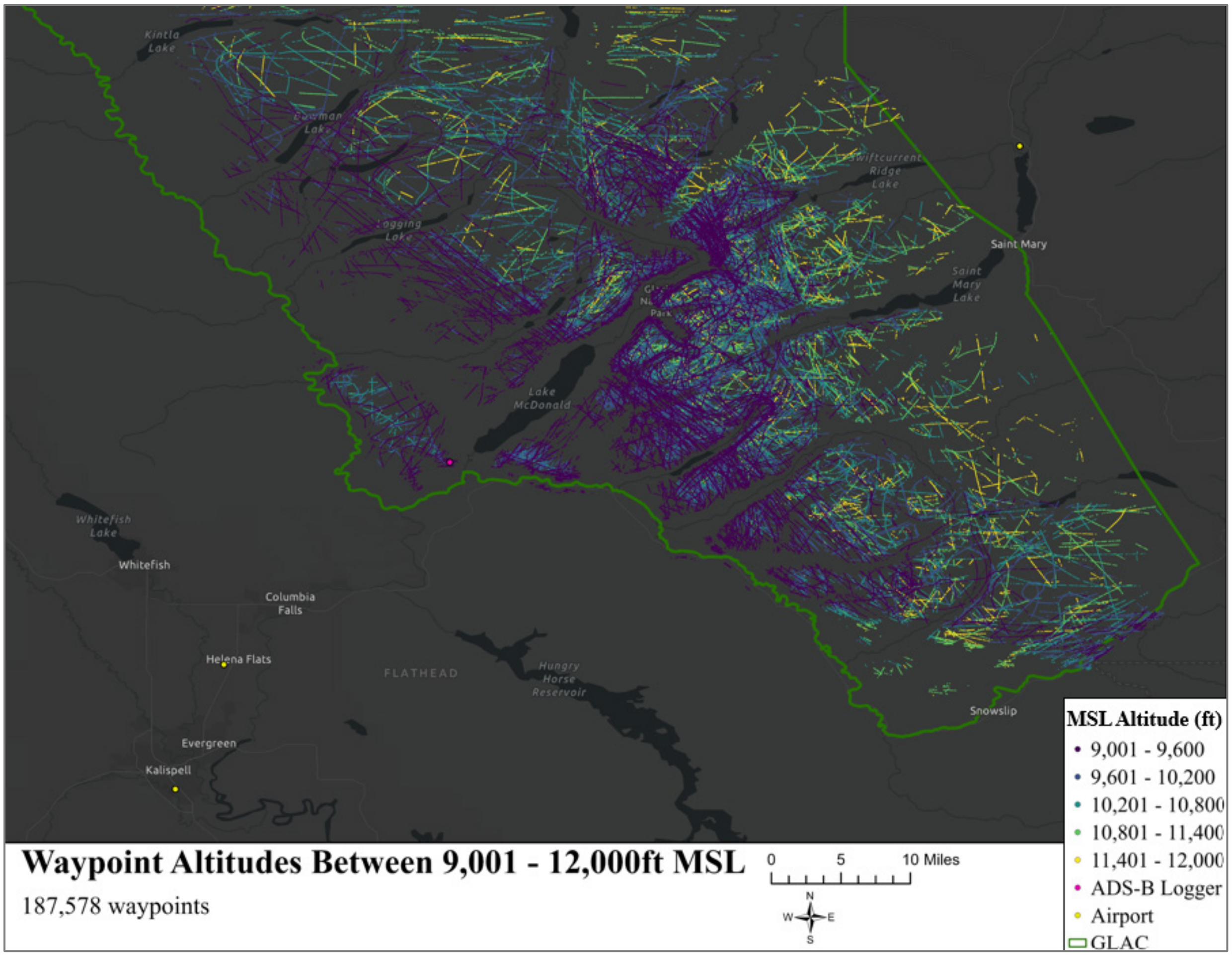

Figure 16. MSL altitude trends of altitudes ranging from 9,001–12,000 feet MSL for waypoints within 0.5-mile of the GLAC boundary (*n*=187,578 waypoints). NPS / BRIAN PETERSON

The information displayed in Figures 11–16 was inputted into tables to quantitatively understand which altitude intervals had the highest percentage of observed waypoints. Table 1 shows analysis of 1,327,367 waypoints across AGL altitudes and Table 2 shows analysis of 1,679,643 waypoints across MSL altitudes. The AGL altitude interval that received the highest percentage of waypoints was 3,001–3,500 feet (Table 1), but note that most of the altitude intervals, except between 0–1,500 feet AGL, had a large number of waypoints. The MSL altitude interval that received the highest percentage of waypoints was 8,001–9,000 feet (Table 2) but note that the 7,001–8,000 feet MSL altitude interval also had a large number of waypoints.

Table 1. Number and percentage of waypoints across AGL altitude intervals (*n*=1,327,367).

AGL Altitude	Number of Waypoints	Percentage of Waypoints
< 0ft	5,706 [A]	0.4
0–500ft	51,065	3.8
501–1,000ft	98,204	7.4
1,001–1,500ft	120,632	9.1
1,501–2,000ft	136,363	10.3
2,001–2,500ft	151,565	11.4
2,501–3,000ft	163,928	12.3
3,001–3,500ft	168,427	12.7
3,501–4,000ft	156,251	11.8
4,001–4,500ft	141,924	10.7
4,501–5,000ft	133,302	10.0

[A] 75.38% of these data were accounted for by eight aircraft.

Table 2. Number and percentage of waypoints across MSL altitude intervals (*n*=1,679,643).

MSL Altitude	Number of Waypoints	Percentage of Waypoints
3,001–4,000ft	51,672	3.1
4,001–5,000ft	111,897	6.7
5,001–6,000ft	146,253	8.7
6,001–7,000ft	202,060	12.0
7,001–8,000ft	305,046	18.2
8,001–9,000ft	342,621	20.4
9,001–10,000ft	232,815	13.9
10,001–11,000ft	172,848	10.3
11,001–12,000ft	114,431	6.8

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 4,374). Table 3 shows the number of days low-level overflight data were collected, overflights per month, and average number of flights per day for the data collection duration, which occurred from September 1st, 2021–September 19th, 2024. GLAC received the most overflights during July of 2024 (13.19 average number of flights per day). For each year of data collection, July received the most overflights.

Table 3. Number and percentage of overflights across months (*n*=4,374).

Month	Number of Data Collection Days [A]	Number of Overflights	Average Number of Overflights Per Day
September 2021	30	156	5.20
October 2021	21	35	1.67
November 2021	28	22	0.79
December 2021	31	17	0.55
January 2022	30	22	0.73
February 2022	28	32	1.14
March 2022	31	30	0.97
April 2022	30	44	1.47
May 2022	31	95	3.06
June 2022	30	293	9.77
July 2022	7	76	10.86
August 2022	31	293	9.45
September 2022	30	150	5.0
October 2022	31	132	4.26
November 2022	30	11	0.37
December 2022	31	7	0.23
January 2023	31	17	0.55
February 2023	28	15	0.54
March 2023	31	44	1.42
April 2023	30	45	1.50
May 2023	31	94	3.03
June 2023	30	293	9.77
July 2023	31	366	11.81
August 2023	31	216	6.97
September 2023	30	226	7.53
October 2023	31	137	4.42
November 2023	30	40	1.33
December 2023	31	20	0.65
January 2024	31	19	0.61
February 2024	29	42	1.45
March 2024	31	39	1.26
April 2024	30	44	1.47
May 2024	31	85	2.74
June 2024	30	267	8.9

[A] For some months, data collection did not occur at all or every day.

Table 3 (continued). Number and percentage of overflights across months (*n*=4,374).

Month	Number of Data Collection Days [A]	Number of Overflights	Average Number of Overflights Per Day
July 2024	31	409	13.19
August 2024	31	338	10.90
September 2024	19	203	10.68
Total	1,078	4,374	4.06

[A] For some months, data collection did not occur at all or every day.

Table 4 shows the percentage of flights across days of the week. The day of the week with the highest percentage of flights was Fridays (16.4%). Table 5 shows the percentage of overflights across hour of the day. Most overflights occur from 9:00am to 1:00pm. Table 6 shows percentage of overflights across aircraft type. Fixed wing single engine is the aircraft type most common among low-level overflights at GLAC.

Table 4. Percentage of overflights across days of the week.

Day of the Week	Percentage of Overflights
Monday	13.1
Tuesday	12.3
Wednesday	13.1
Thursday	15.0
Friday	16.4
Saturday	15.8
Sunday	14.4

Table 5. Percentage of overflights across hours of the day.

Hour	Percentage of Overflights
6:00am–7:00am	0.5
7:00am-8:00am	1.6
8:00am–9:00am	6.2
9:00am–10:00am	10.6
10:00am–11:00am	14.2
11:00am–12:00pm	12.0

Note. Percentage of overflights does not add up to 100% because some flights occurred beyond the hours reported.

Table 5 (continued). Percentage of overflights across hours of the day.

Hour	Percentage of Overflights
12:00pm–1:00pm	11.4
1:00pm–2:00pm	8.3
2:00pm–3:00pm	7.9
3:00pm–4:00pm	6.7
4:00pm–5:00pm	5.8
5:00pm–6:00pm	4.8
6:00pm–7:00pm	3.5
7:00pm-8:00pm	2.6
8:00pm-9:00pm	1.8
9:00pm–10:00pm	1.4

Note. Percentage of overflights does not add up to 100% because some flights occurred beyond the hours reported.

Table 6. Percentage of overflights across aircraft type.

Aircraft Type	Percentage
Fixed-wing single engine	70.0
Fixed-wing multi engine	2.9
Rotorcraft	17.2

Note. Percentage of overflights does not add up to 100% because some aircraft types had a null value retrieved from the FAA Releasable Database.

Using the cleaned Phase 3 dataset, three more figures were produced to show overflight travel patterns across aircraft type. Figure 17 displays overflight travel patterns for fixed-wing single engine. Figure 18 displays overflight travel patterns for fixed-wing multi engine aircraft. Figure 19 displays overflight travel patterns for rotorcraft aircraft.

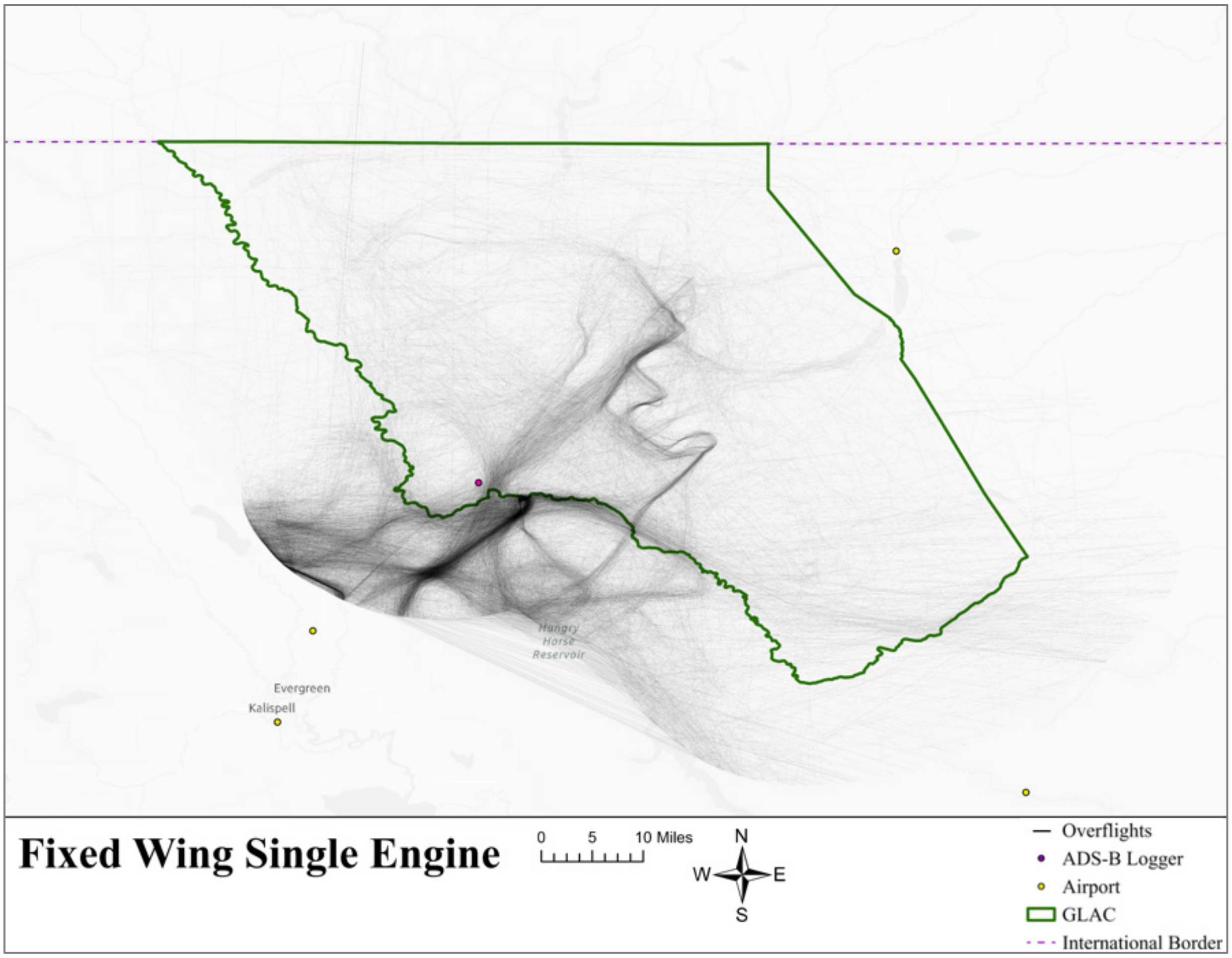

Figure 17. Phase 3 fixed-wing single engine overflight travel patterns. NPS / BRIAN PETERSON

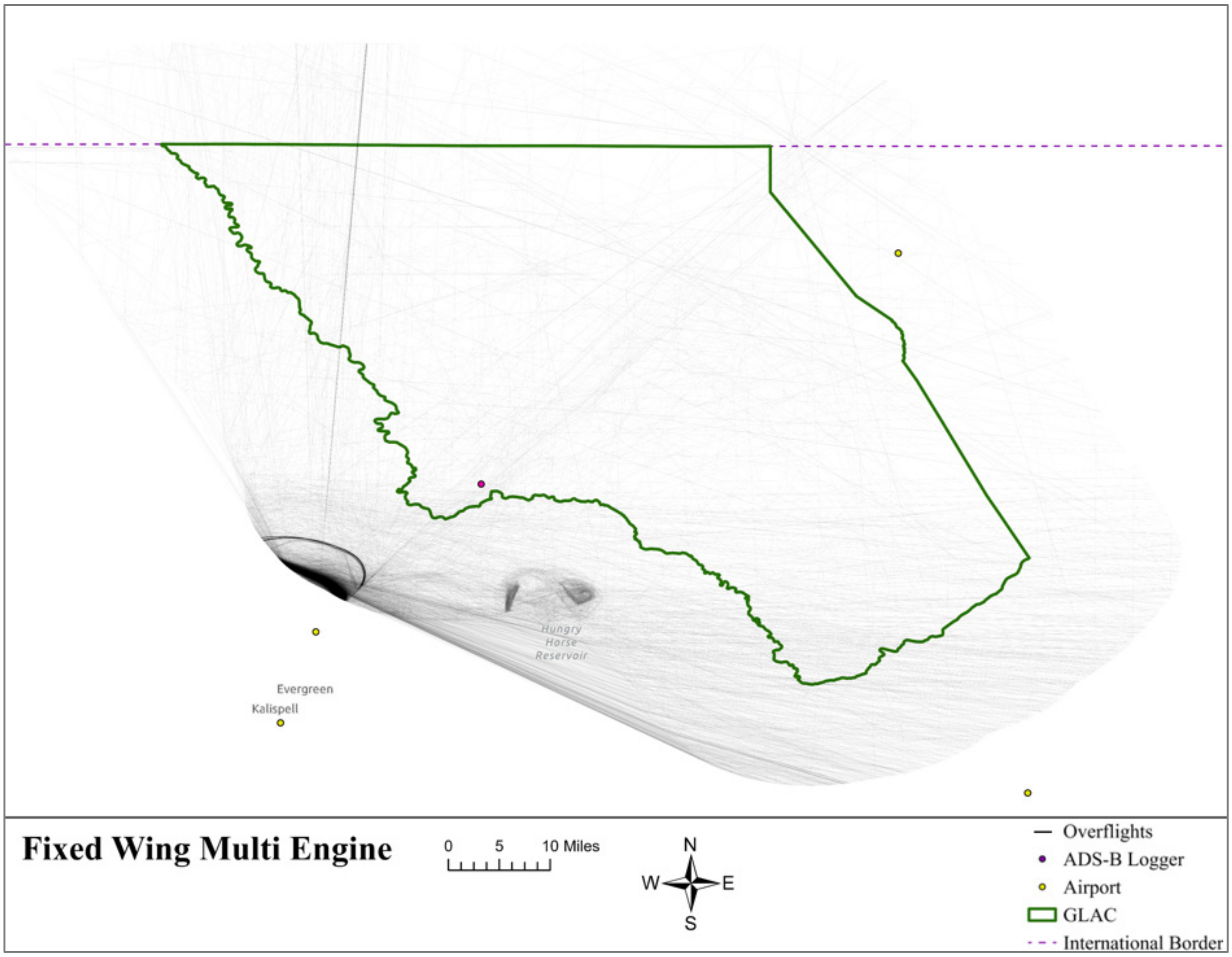

Figure 18. Phase 3 fixed wing multi engine overflight travel patterns. NPS / BRIAN PETERSON

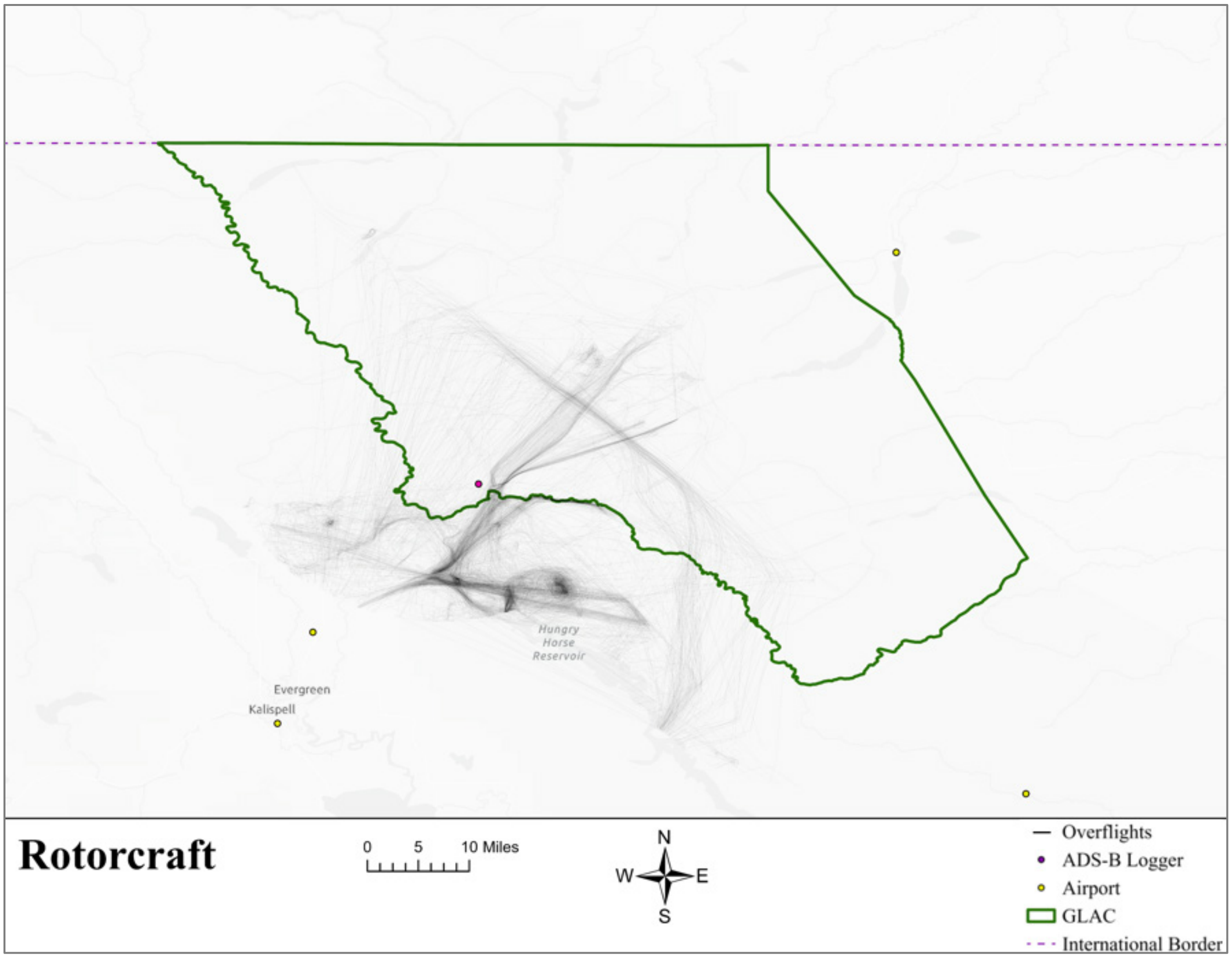

Figure 19. Phase 3 rotorcraft overflight travel patterns. NPS / BRIAN PETERSON

Lastly, analysis was conducted to assess if air tour companies changed their routes in accordance with GLAC's ATMP which went into effect during the winter of 2022 to 2023. To determine whether a flight might be an air tour, two searches were conducted. First, specific operator names were searched in the dataset. These operator names were derived from the ATMP and internet searches. However, not all operators use the same name when registering aircraft with the FAA or operators may lease aircraft. Second, flights with flight patterns displaying patterns similar to air tours (Beeco & Joyce, 2019) and flights along the known ATMP route were selected. Meta data from these flights indicated the aircraft owners, and subsequent searches occurred. Overflight travel patterns for Minuteman Aviation (Figure 20), Sierra Sky Aviation (Figure 21), Glacier Aviation Services (Figure 22), Wings and Rotors LLC (Figure 23), and Backcountry Flying Experience (Figure 24) are displayed along with the ATMP route. Flights were segmented pre (2021 and 2022) and post (2023 and 2024) air tour management plan. Each operator had flights for 2021, 2022, 2023, and 2024, except for Backcountry Flying Experience which had flights for 2022, 2023, and 2024.

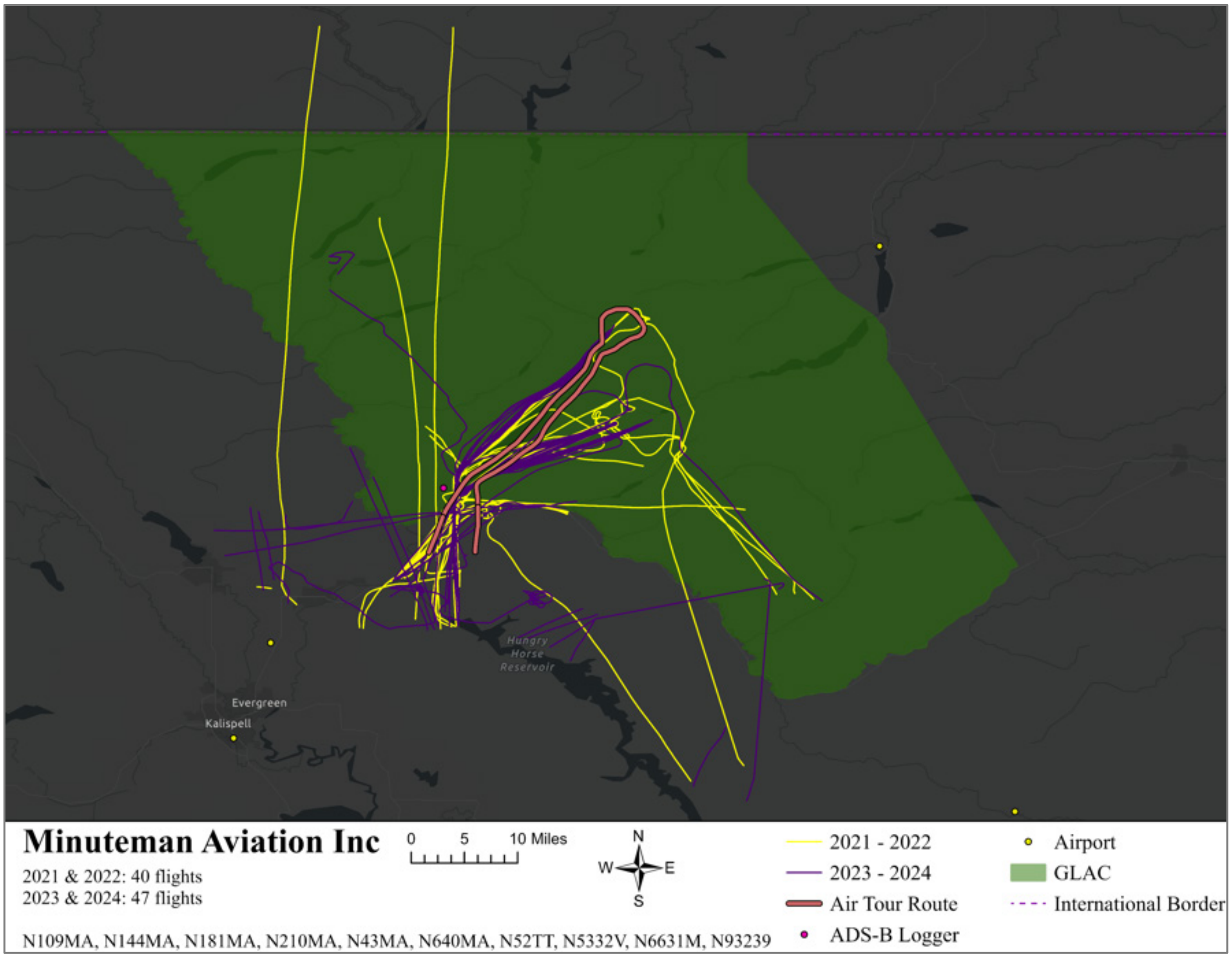

Figure 20. Minuteman Aviation overflights for 2021–2022 and 2023–2024. NPS / BRIAN PETERSON

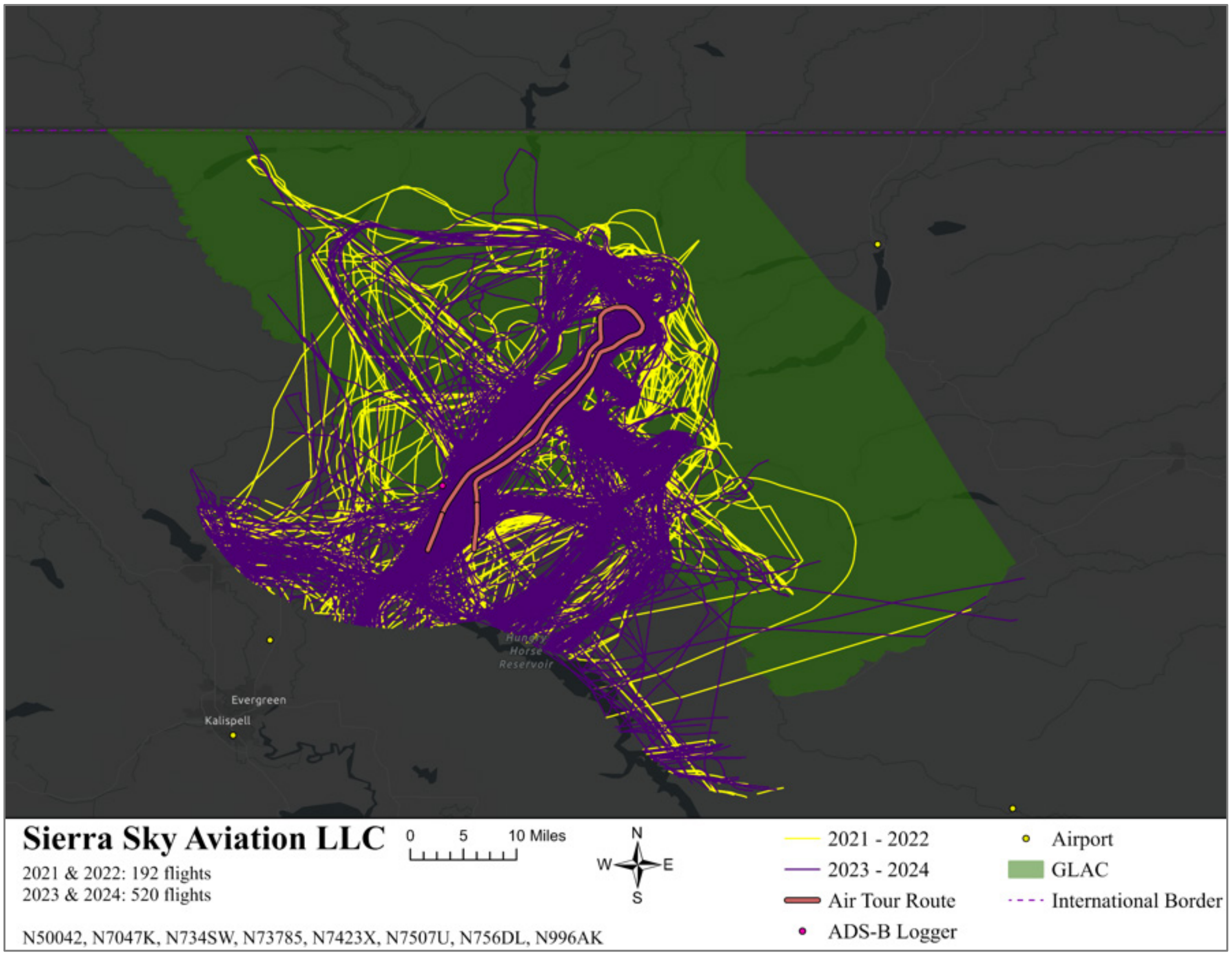

Figure 21. Sierra Sky Aviation overflights for 2021–2022 and 2023–2024. NPS / BRIAN PETERSON

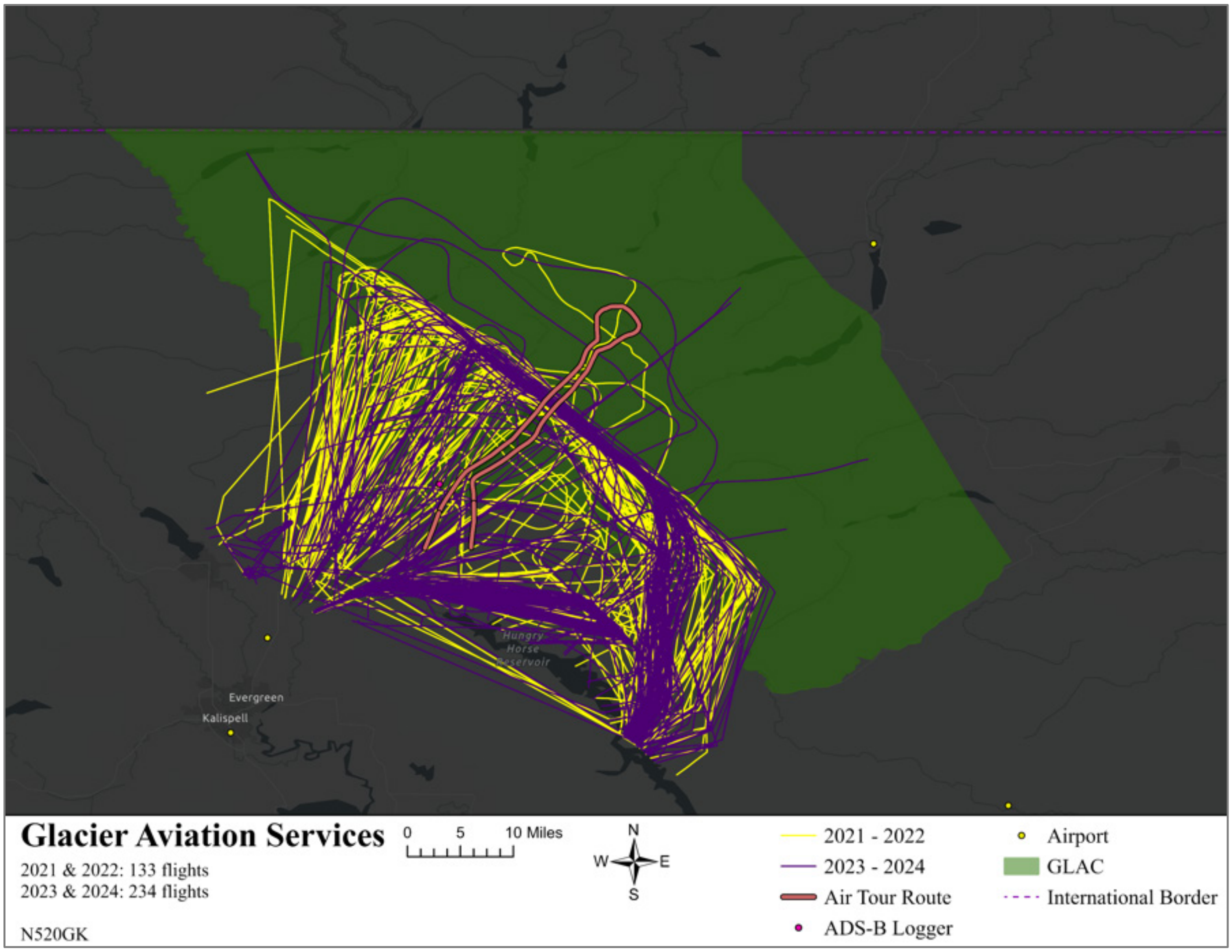

Figure 22. Glacier Aviation Services overflights for 2021–2022 and 2023–2024.
NPS / BRIAN PETERSON

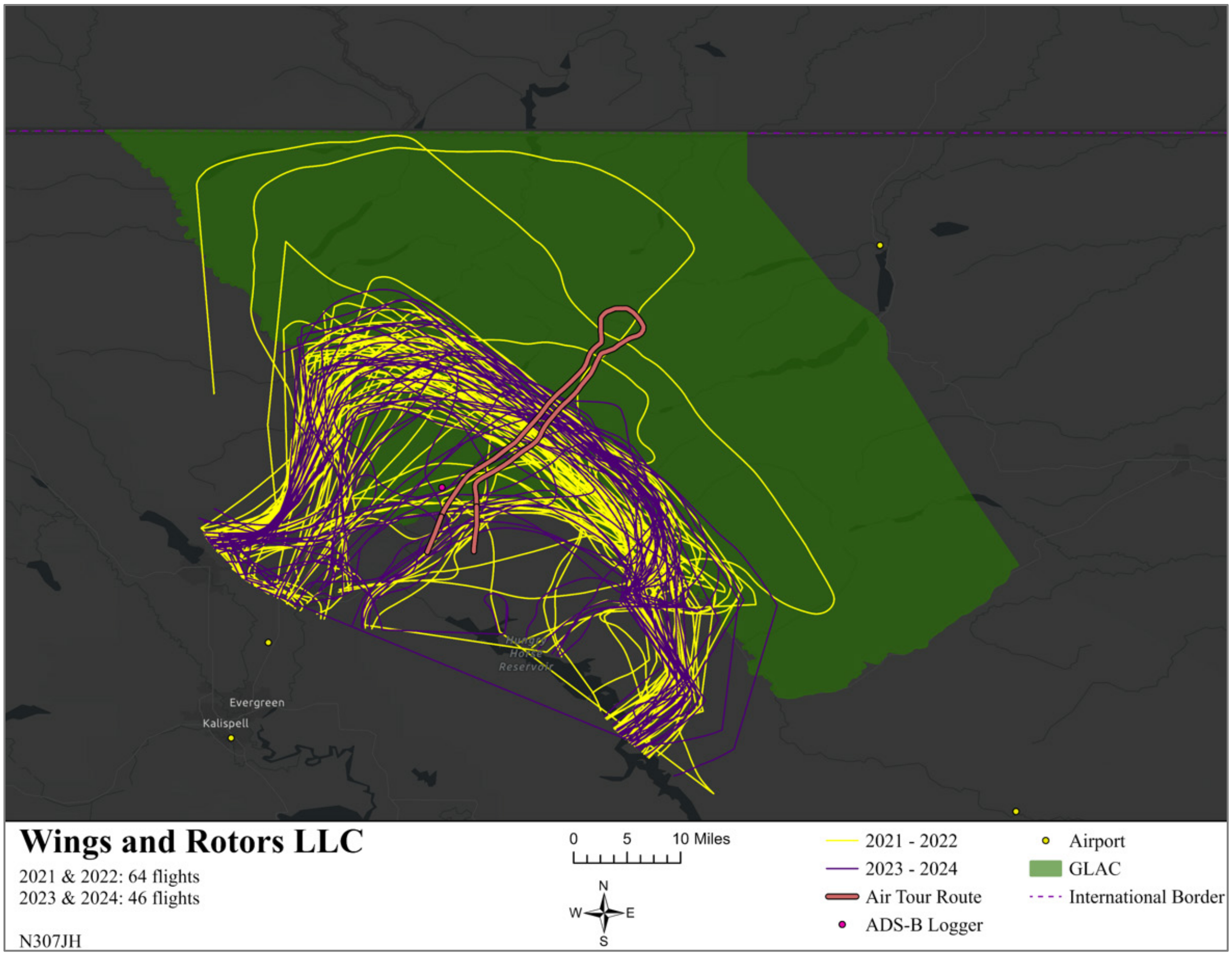

Figure 23. Wings and Rotors LLC overflights for 2021–2022 and 2023–2024. NPS / BRIAN PETERSON

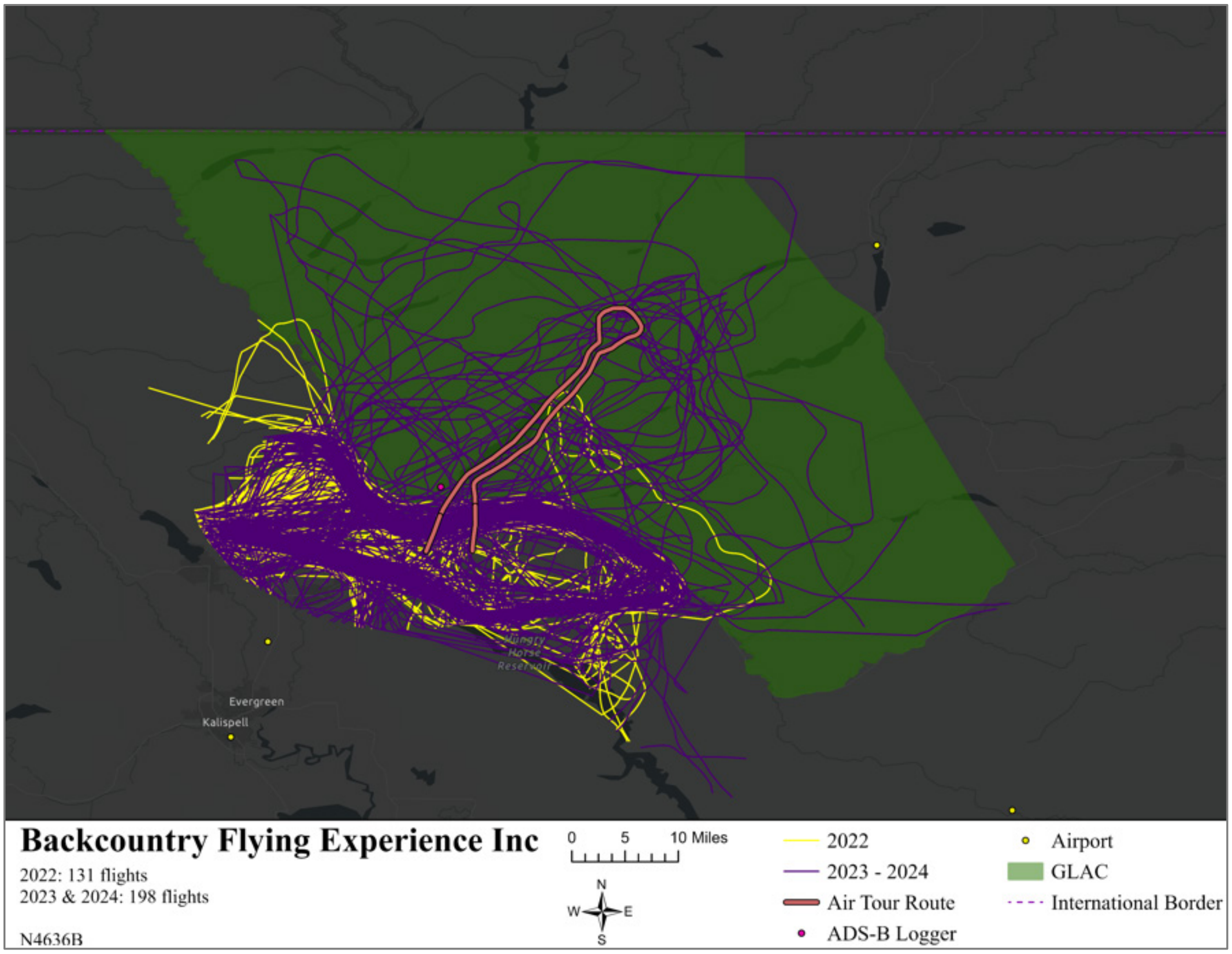

Figure 24. Backcountry Flying Experience overflights for 2021–2022 and 2023–2024.
NPS / BRIAN PETERSON

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at GLAC. Flight tracking data were analyzed from September 1st, 2021–September 19th, 2024 (1,115 total days; 37 days of missing data). Analysis consisted of three phases.

The first phase focused on all overflights. Observations showed a concentrated trend of overflights and distinct corridors above GLAC (Figures 2–5). Visual analysis of these data suggests overflights are concentrated to the northeast of Kalispell along the west boundary of GLAC near Apgar. The airport(s) in the Kalispell area likely account for these trends. However, terrain shielding from mountains may have blocked the data logger from receiving ADS-B signals from flights along the east side of GLAC. The ADS-B logger was deployed on top of Apgar Mountain because this location provided a feasible high point in the park with electricity.

The second phase focused on low-level overflights (defined as flights up to 12,000 feet MSL) that were not cleaned of any flight type (i.e., major airlines, government flights, and survey flights). Three maps were produced for 3,000–6,000 feet MSL, 6,001–9,000 feet MSL, and 9,001–12,000 feet MSL (Figures 6–8). These maps showed concentrated waypoints on the west side of GLAC and most waypoints were between 6,001–9,000 feet MSL. Also, these maps show concentrated flights above Going-to-the-Sun Road corridor west of the continental divide at a wide range of altitude levels.

The third phase attempted to focus more specifically on low-level overflights that excluded government flights, straight-line flights, commercial airline flights, flights with a flight path less than a mile in length, and survey flights. The dataset was cleaned of 195 government flights, 73,762 straight-line flights, 6,666 commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights), 188 flights with a flight path less than a mile in length, and 3 survey flights. This left 16,519 flights, which is 16.97% of all the flights in Phase 1.

Figure 9 shows Phase 3 overflights with a few distinct trends. Most of the flights stay southwest of the park. For flights over the park, there are three distinct trends. First, are the flights concentrated over the corridor following the air tour route above Going-to-the-Sun Road. The second trend is a stair stepped pattern moving south over the park from center. And the third pattern is seen as a fainter concentration of flights moving northwest to southeast.

Figure 10 displays density analysis and revealed that flight density is highest for the altitude interval of 0–500 feet AGL. The other altitude interval that showed flight density was for 501–1,000 feet AGL. Analysis found the density results for these two altitude intervals to be highly correlated (correlation coefficient of 0.81) which confirms that flights between 0–1,000 feet AGL are concentrating in the same area. For both altitude intervals, analysis revealed density hot spots along the border of GLAC near West Glacier. These could be the result of Ryan Field airstrip which is a private airstrip located in the vicinity of these density hot spots.

Several analyses in this report focus on altitude of aircraft above ground level. Table 1, which displays number of waypoints within specific AGL altitude intervals, shows that the 3,001–3,500 feet AGL interval received the highest percentage of waypoints. Except for altitudes between 0–1,500 feet AGL, all other altitude intervals received high percentages of waypoints. These findings show that most waypoints are between 1,501–5,000 feet AGL. This indicates similar aircraft patterns across altitude levels. Flights at lower AGL altitudes, such as less than 2,000 feet are concerning because they typically produce more intense noise than higher level flights. The FAA recommends pilots fly above 2,000 feet AGL over parks, wildlife refuges, and areas with wilderness characteristics; but this is a recommendation, not a regulation (Peterson et al., 2023).

Error associated with altitude is a limitation of this analysis (see the Methods section for more details). Negative AGL values were calculated but only represent 0.4% of the data (5,706 waypoints). Eight aircraft accounted for 75.38% of these waypoints. Figure 11 displays the patterns of the <0 feet AGL tracks. There is a concentration of negative AGL altitude waypoints along the western boundary of GLAC. These could have been the result of aircraft landing and taking off at Ryan Field airstrip.

The mountains likely caused terrain shielding for ADS-B signals of flights at lower altitudes on the east side of GLAC. This is noticeable in Figures 12 (waypoint altitudes between 0–2,500 feet AGL), 14 (waypoint altitudes between 3,000–6,000 feet MSL), and 15 (waypoint altitudes between 6,001–9,000 feet MSL). However, higher altitude waypoints are more prominent on the east side of GLAC in Figures 13 (waypoint altitudes between 2,501–5,000 feet AGL) and Figure 16 (waypoint altitudes between 9,001–12,000 feet MSL). This suggests that terrain shielding obscures observation of many flight segments on the east side of GLAC.

Temporal patterns of flights were also examined. Table 3 shows that for each year data were collected, July received the most overflights. Table 4 shows that the percentage of flights across days of the week are similar with the lowest percentage of flights occurring on Mondays (13.1%), Tuesdays (12.3%), and Wednesdays (13.1%). The highest percentage of flights occurred on Thursdays (15.0%), Fridays (16.4%), and Saturdays (15.8%). Table 5 displays percentage of overflights across hours of the day, revealing a significant number of flights occur from 9:00am to 1:00pm. The mornings and the evenings are least impacted by low-level aircraft noise.

Figures 17, 18, and 19 show overflight travel patterns for fixed wing single engine aircraft, fixed wing multi engine aircraft, and rotorcraft. Fixed wing single engine were the most common aircraft type for Phase 3 data. Note the similarities between Figures 9 and 17.

Figure 20, 21, 22, 23, and 24 show flights that mostly begin and end in the same airports just west of GLAC, and the travel patterns appear similar to that of air tours (Beeco & Joyce, 2019). These flights were identified by two different searches. First, specific operator names were searched in the dataset. However, not all operators use the same name when registering aircraft with the FAA or operators may lease aircraft. Second, flights displaying patterns similar to air tours (Beeco & Joyce, 2019) and flights along the known ATMP route were selected. Meta data from these flights indicated the aircraft owners, and subsequent searches occurred. Minuteman Aviation, Sierra Sky Aviation, Glacier Aviation Services, Wings and Rotors LLC, and Backcountry Flying Experience are displayed. The figures also display flights before and after the air tour management route went into effect. It is impossible to determine by these data alone if these flights were indeed air tours. The air tour management plan is designed to protect GLAC's resources, visitor experience, and tribal lands from the effects of commercial air tours. What is clear is that very few of the 2023–2024 patterns in these figures follow the established ATMP route. Perhaps most concerning is Figure 21. This figure displays flight patterns for 2023–2024 data that are much more similar to operators' air tour routes prior to the implementation of the ATMP.

In conclusion, this study produced results to further understand overflights at GLAC at a fine spatial scale. This information can be used for planning and management purposes. This study serves as a resource for future research that intends to use more advanced analytics.

Literature Cited

Beeco, J. A. & Joyce, D. (2019). Automated aircraft tracking for park and landscape planning. Landscape and Urban Planning, 186, 103–111. https://doi.org/10.1016/j.landurbplan.2019.03.001

Beeco, J. A., Joyce, D., & Anderson, S. 2020. Evaluating the use of spatiotemporal aircraft data for air tour management planning and compliance. Journal of Park and Recreation Administration, 39(1).

Federal Aviation Administration. 2023a. Automatic Dependent Surveillance-Broadcast (ADS-B). Available at: https://www.faa.gov/air_traffic/technology/adsb

Federal Aviation Administration. 2023b. Airspace. Available at: https://www.faa.gov/air_traffic/technology/equipadsb/research/airspace

National Park Service. 2024a. Glacier National Park Fact Sheet. Available at: https://www.nps.gov/glac/index.htm

National Park Service. 2024b. Welcome to Visitor Use Statistics. Available at: https://irma.nps.gov/Stats/

Peterson, B. A., Brownlee, M. T., Beeco, J. A., Hallo, J. C., White, D. L., & Joyce, D. 2022. Spatiotemporal analysis to understand overflight travel patterns at Hawai‘i Volcanoes National Park. *Journal of Outdoor Recreation and Tourism*, *37*, 100476.

Peterson, B. A., Shively, R. D., Jackson, S. K., Rogowski, J., Beeco, J. A., & Joyce, D. 2023. Using ADS–B Data to Understand Overflight Altitude Characteristics at Hawai‘i Volcanoes National Park. *The Professional Geographer*, *75*(1), 118–130.

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