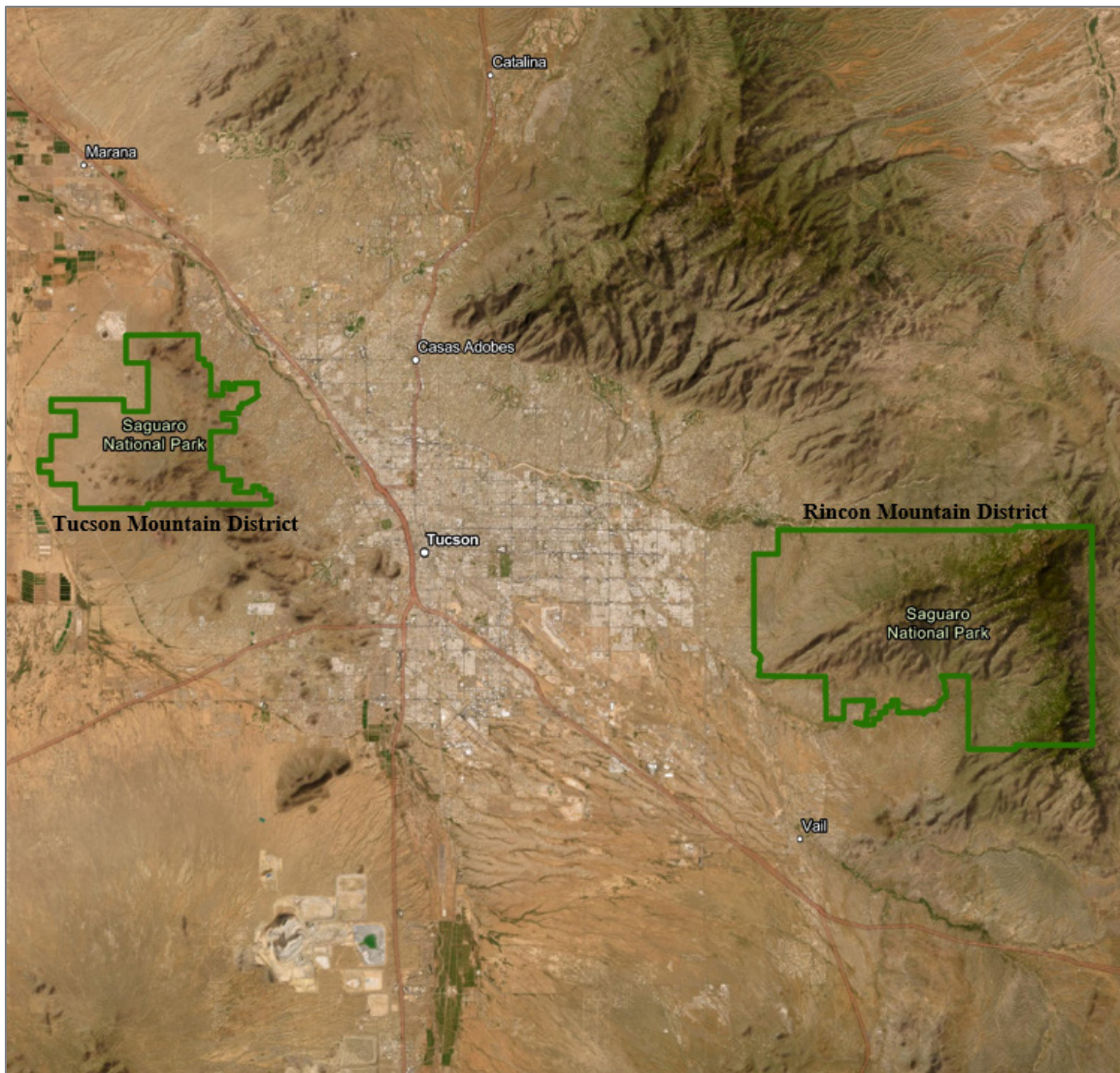




Exploring Spatial Patterns of Overflights at Saguaro National Park



Map of Saguaro National Park.

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Exploring Spatial Patterns of Overflights at Saguaro National Park

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Abstract

This study explores spatial patterns of overflights at Saguaro National Park. Data were collected from on top of a tack shed located along the western boundary of the Rincon Mountain District. Overflights were analyzed from December 24, 2024–February 11, 2025 (50 total days; 13 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. Phase 1 of analysis focused on all overflights and found more overflights above the Tucson Mountain District than the Rincon Mountain District. Phase 2 of analysis focused on low-level overflights that fly between 2,000 to 10,000 feet above mean sea level (MSL) and flew within 10 miles of the SAGU boundary and found that most low-level overflights occur near the west boundary of the Rincon Mountain District and that the Tucson Mountain District has a distinct low-level overflight corridor. 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. For the Rincon Mountain District, the altitude interval with the highest density was 500 to 1,000 feet AGL and for the Tucson Mountain District, the altitude interval with the highest density was the 2,500 to 3,000 feet AGL altitude interval. 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

MSL: Mean sea level

NPS: National Park Service

SAGU: Saguaro National Park

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The authors would like to thank the National Park Service Natural Sounds and Night Skies Division for funding and supporting this project. Also, the authors would like to thank Adam Springer from Saguaro National Park for his help with maintaining and collecting data from the ADS-B logger. Additionally, the authors would like to thank Damon Joyce and Warren Deeds for their support in designing and building the logging units.

Introduction

Saguaro National Park (SAGU) was designated as a national park in 1994 (National Park Service, 2025a) and is located in southern Arizona in the Sonoran Desert. SAGU is comprised of two districts with the city of Tucson situated between them. The Rincon Mountain District is located to the east of Tucson and the Tucson Mountain District is located to the west of Tucson. More than 75% of the park has been designated as wilderness. The Rincon Mountain District is comprised of 67,476 acres and features 128 miles of hiking trails. The highest elevation in the Rincon Mountain District is the summit of Mica Mountain at 8,666 feet and the lowest elevation is 2,670 feet. The Tucson Mountain District is comprised of 25,391 acres and features 43 miles of hiking trails. The highest elevation in the Tucson Mountain District is the summit of Wasson Peak at 4,687 feet and the lowest elevation is 2,180 feet. SAGU is situated within the Sky Island region, containing a diversity of vegetation ranging from desert scrub at the low elevations to mixed conifer forests at the high elevations. SAGU is a popular destination where visitors can view saguaro cacti, observe up to 150 species of birds, explore numerous archaeological sites, and enjoy extensive trails and scenic drives. In 2024, SAGU received 946,369 recreation visits (National Park Service, 2025b).

SAGU is located near Tucson International Airport, Ryan Airfield, Marana Regional Airport, and Davis-Monthan Air Force Base which results in the park receiving a variety of overflights, including low-level overflights that are likely departures and arrivals from nearby airports. Additionally, the Tucson International Modelplex Park Association, which is for recreational radio control airplane and heli flying, is located 1.75 miles to the west of the Tucson Mountain District. The primary purpose of this report is to broadly examine spatial patterns of overflights at SAGU. The two SAGU districts were analyzed independently.

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, 2023). SAGU is located under designated airspace where ADS-B technology is required (Federal Aviation Administration, 2025). Regardless of 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).

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 SAGU that are equipped with ADS-B transmitter technology. The data discussed in this report were collected from on top of a tack shed located along the west boundary of the Rincon Mountain District. Overflights were analyzed from December 24th, 2024–February 11th, 2025 (50 total days; 13 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data.

Methods

Data Collection

Data were collected by one ADS-B data logger in the Rincon Mountain District positioned at 32.177261, -110.736162 (Figure 1). The data logger was positioned with an unimpeded and expansive skyward exposure. The logger recorded ADS-B signals as text files.

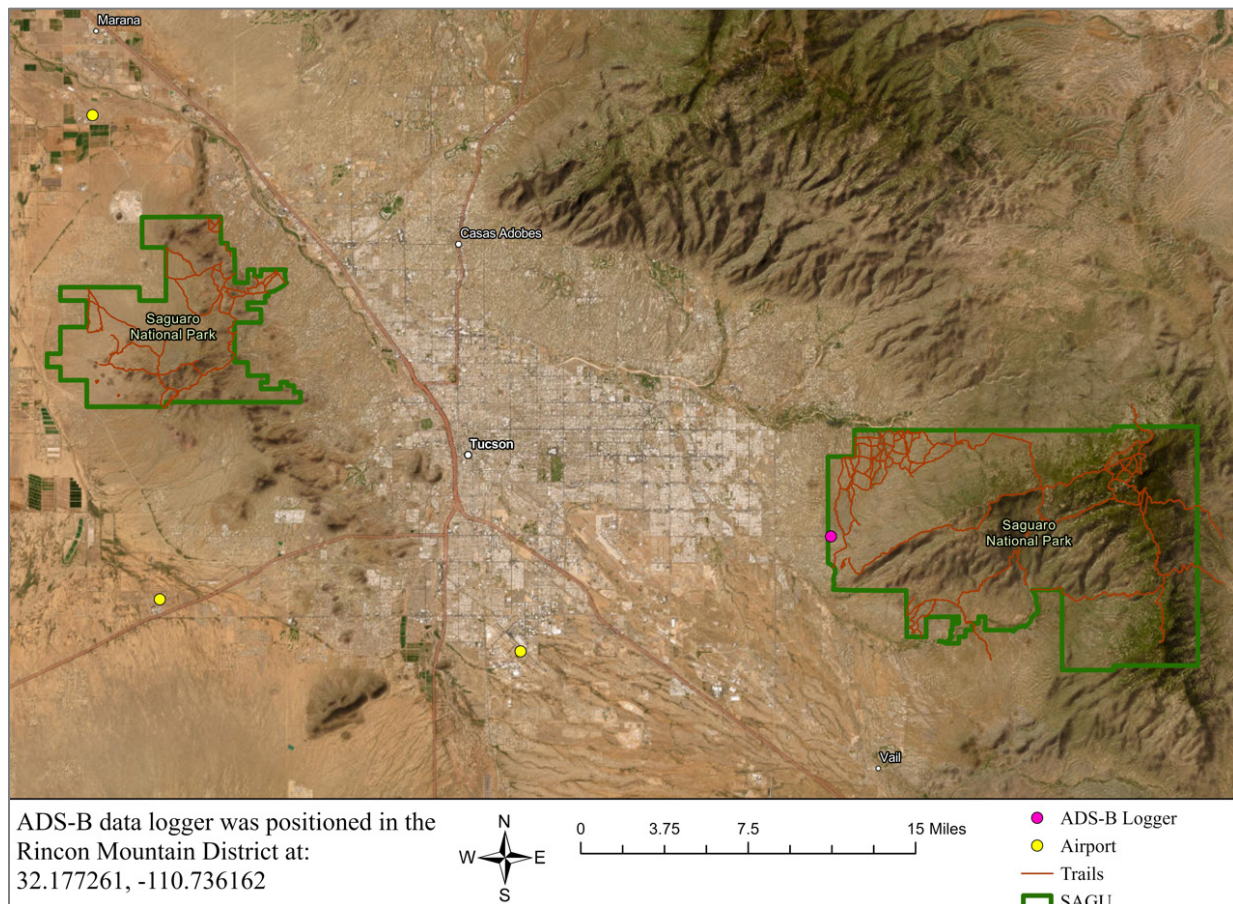


Figure 1. The location where the ADS-B data logger was positioned.

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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 (fixed-wing single engine, fixed-wing multi engine, and rotorcraft).

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, 2025). The AGL altitudes were calculated by subtracting the elevation of the DEM from the reported altitudes of the ADS-B logger for each 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 10×10 m 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 SAGU, analysis was conducted in three phases and each district was analyzed independently. Phase 1 is a visual examination of all overflights within 10 miles of each district. 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, TomTom, Garmin, FAO, NOAA, USGS, OpenStreetMap, and the GIS User Community.

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above SAGU regardless of flight type. Thus, the flightline feature class was not cleaned of any flight types. One map was produced that shows flights for both districts and air traffic around Tucson International Airport. Next, two additional maps were produced displaying flights for each district. To understand how flight paths extend beyond the park boundary, a 10-mile buffer was used around the Rincon Mountain District and Tucson Mountain District boundaries.

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above SAGU regardless of flight type. Similar to Phase 1, a 10-mile buffer was used around each district's boundary. Low-level overflights were identified as having an altitude less than 10,000 feet MSL. This altitude was chosen

because the highest point at SAGU is Mica Mountain at 8,666 feet MSL (National Park Service, 2025a), 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. One map was produced for each district that showed low-level overflight waypoints across the following MSL altitudes: 2,000–4,000 feet MSL; 4,001–6,000 feet MSL; and 6,001–8,000 feet MSL.

Phase 3 Methods

The purpose of the third phase was to remove flights known not to be either low-level overflights or possible 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 cleaning the data of 1) government flights, 2) straight-line flights, 3) major airlines, 4) flights with a flightpath 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 inverse sinuosity values. Inverse 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) inverse 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, flights departing or arriving at airports, air tours, or other flights that move about airspace in non-linear ways, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are low-level overflights is not possible.

Consistent with other aircraft tracking reports, a 0.5-mile buffer around each district's boundary was used for Phase 3 to understand spatial patterns of low-level overflights that are likely to have the biggest impact on SAGU'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 was used to normalize density classification, which required two steps. First, the altitude interval with the maximum 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 five 20% equal interval classifications. Finally, the resulting density classifications were applied to the other altitude intervals. The density normalization process was conducted independently for each district and is necessary to ensure density was calculated the same across altitude intervals for each district regardless of the number of waypoints.

Results

Results—Phase 1

The research team mapped overflights for flights from December 24th, 2024 to February 11th, 2025 (50 total days; 13 days of missing data). Both districts and overflights are displayed in Figure 2. The Rincon Mountain District received 6,427 flights (Figure 3). The Tucson Mountain District received 17,593 flights (Figure 4). Areas with opaque lines indicate where there is greater flight density.

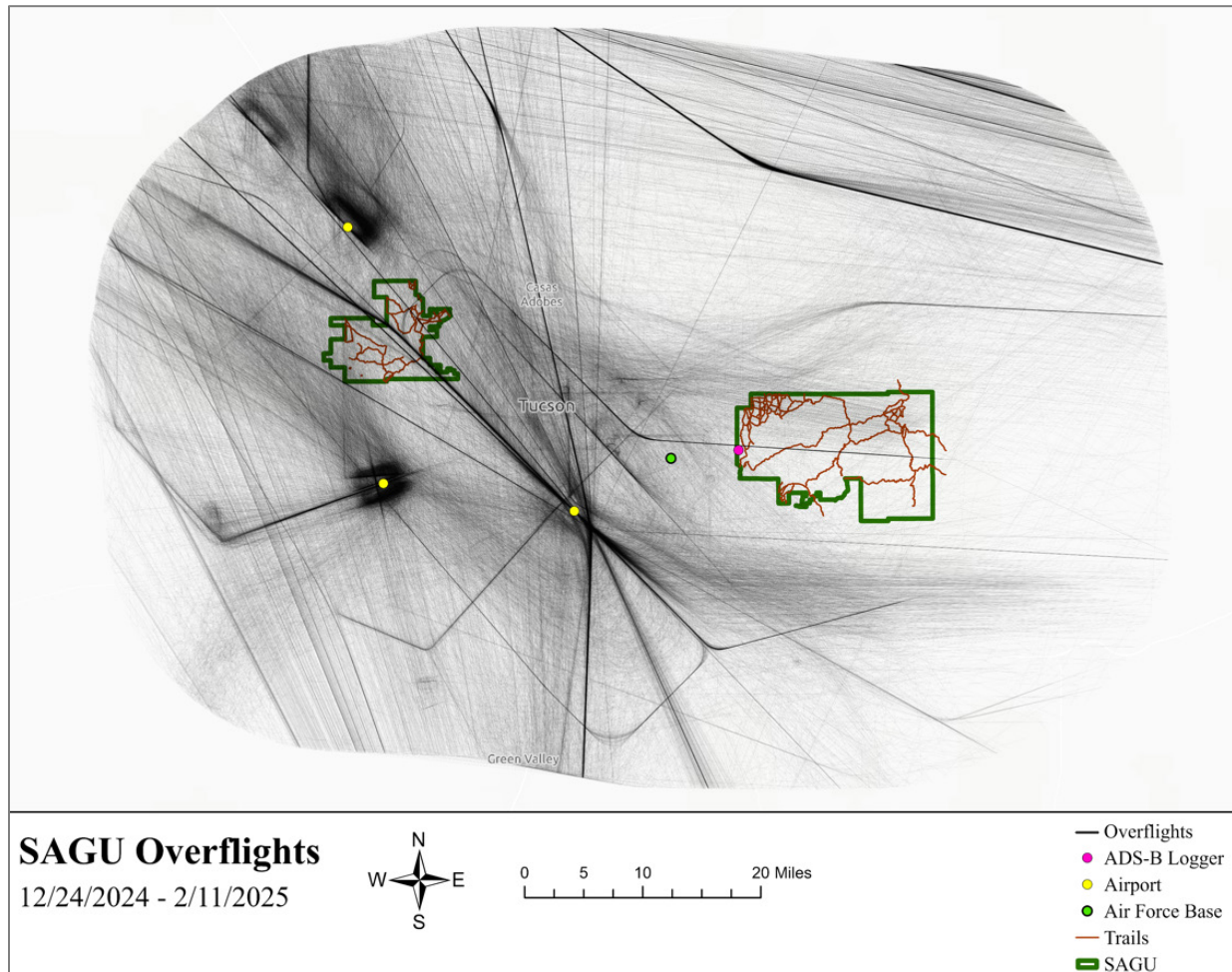


Figure 2. Saguaro National Park overflights from December 24th, 2024 to February 11th, 2025.

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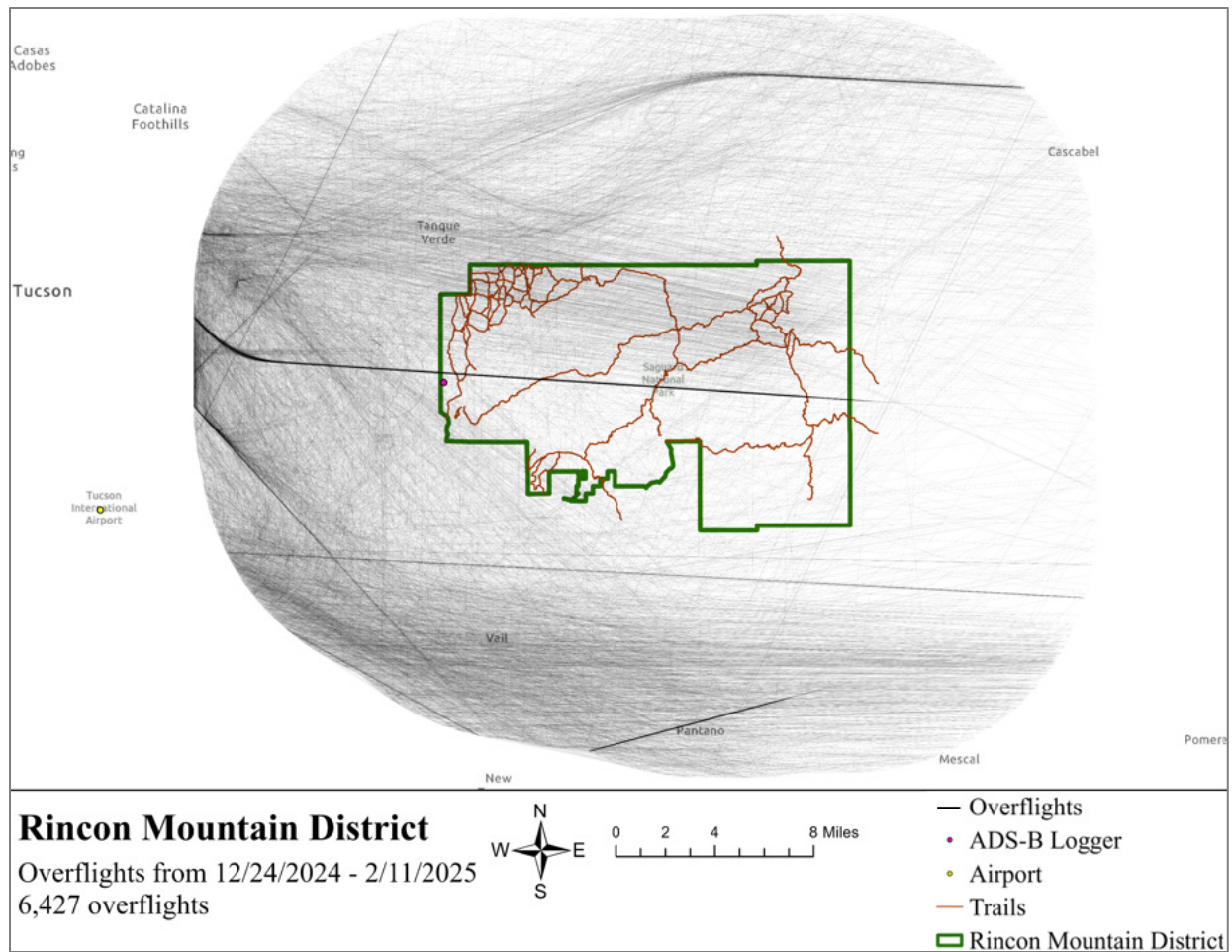


Figure 3. Rincon Mountain District overflights from December 24th, 2024 to February 11th, 2025 ($n = 6,427$).

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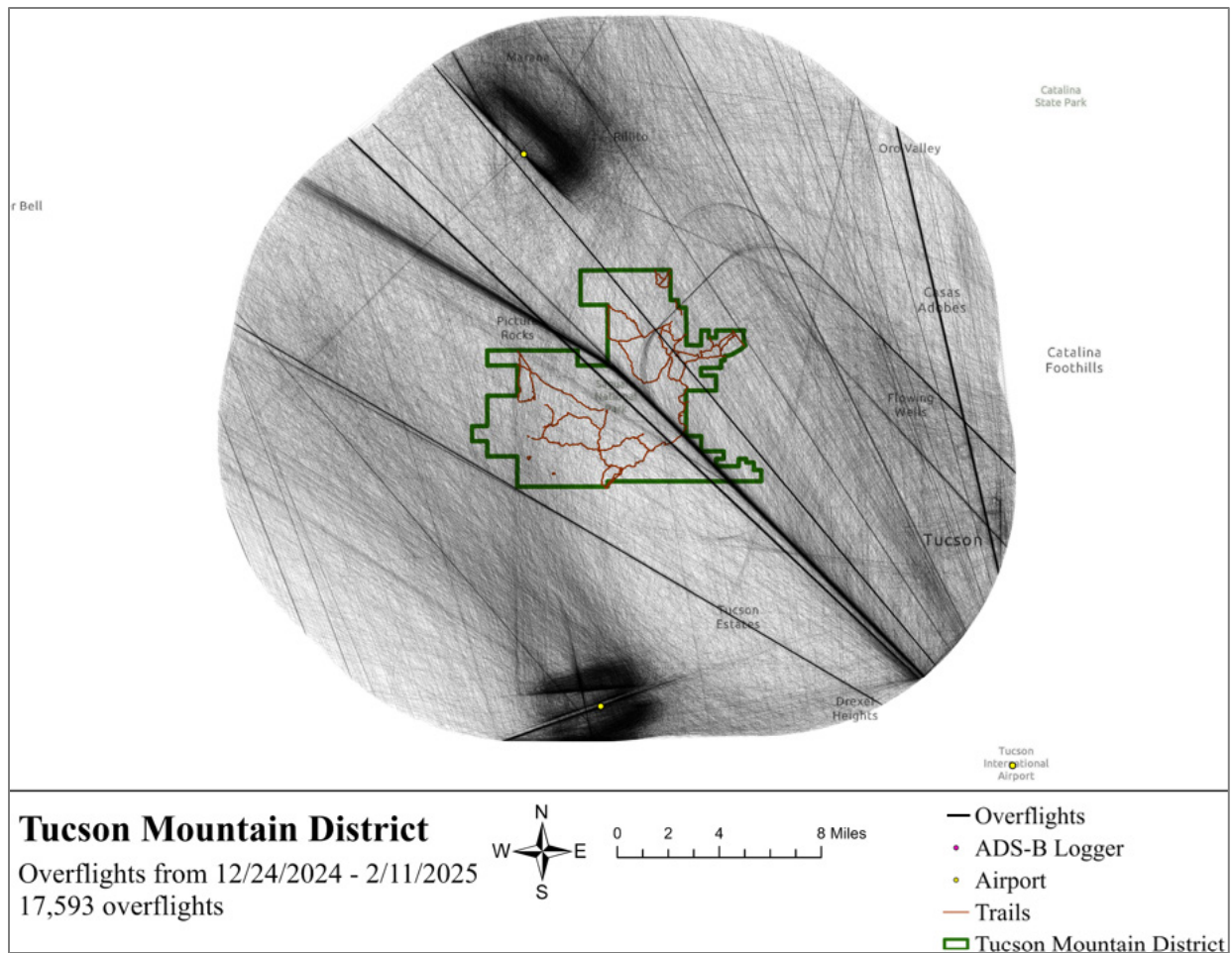


Figure 4. Tucson Mountain District overflights from December 24th, 2024 to February 11th, 2025 ($n = 17,593$).

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Results—Phase 2

The research team mapped waypoints for all overflights that flew between 2,000–10,000 feet MSL. Figure 5 displays the Rincon Mountain District (774,467 waypoints) and shows that most overflights occur outside the west boundary. Figure 6 displays the Tucson Mountain District (2,156,081 waypoints) and shows that the district receives more overflights than the Rincon Mountain District. Additionally, a distinct overflight corridor is visible that traverses northwest from the southeast boundary.

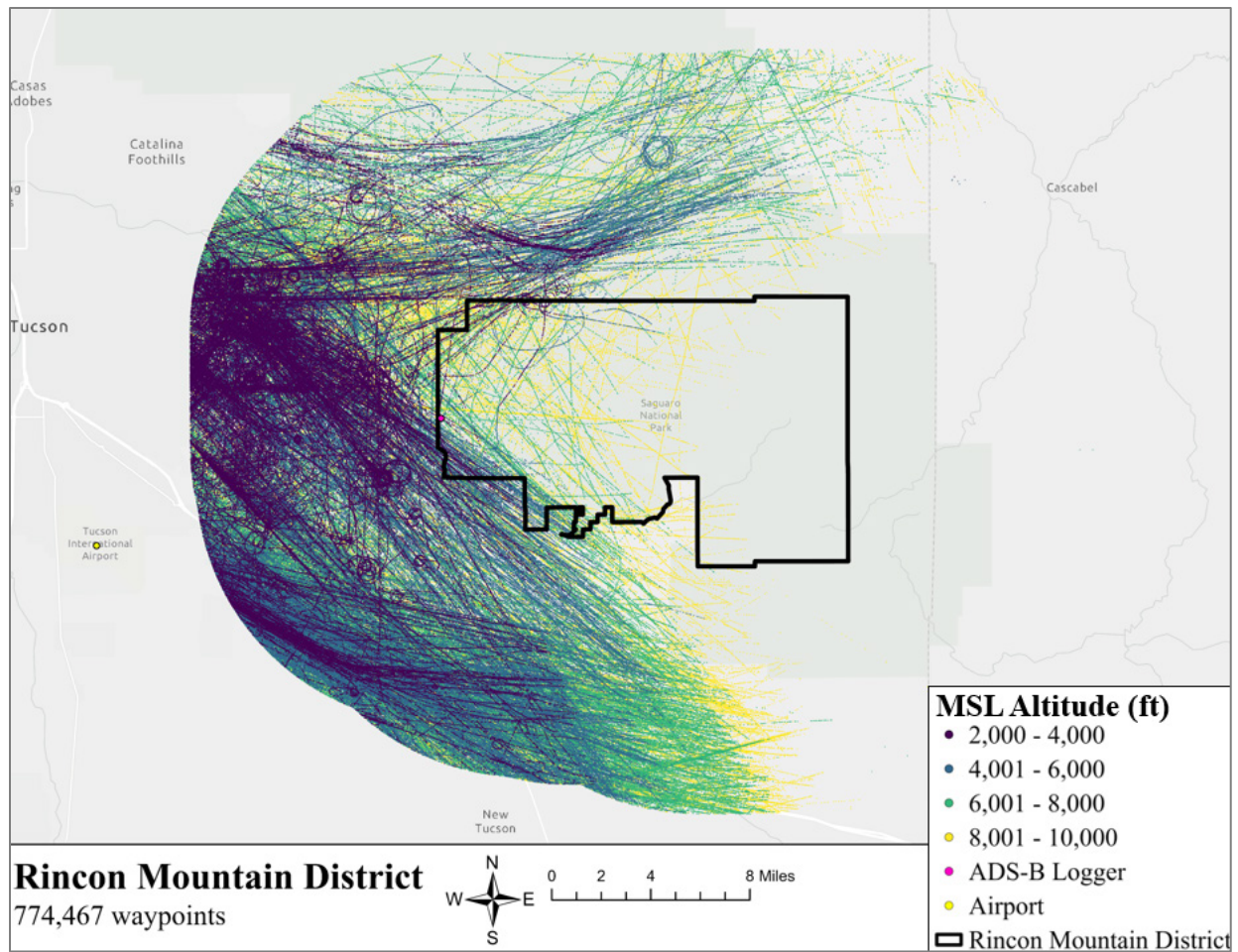


Figure 5. Waypoints between 2,000–10,000 feet MSL for the Rincon Mountain District.

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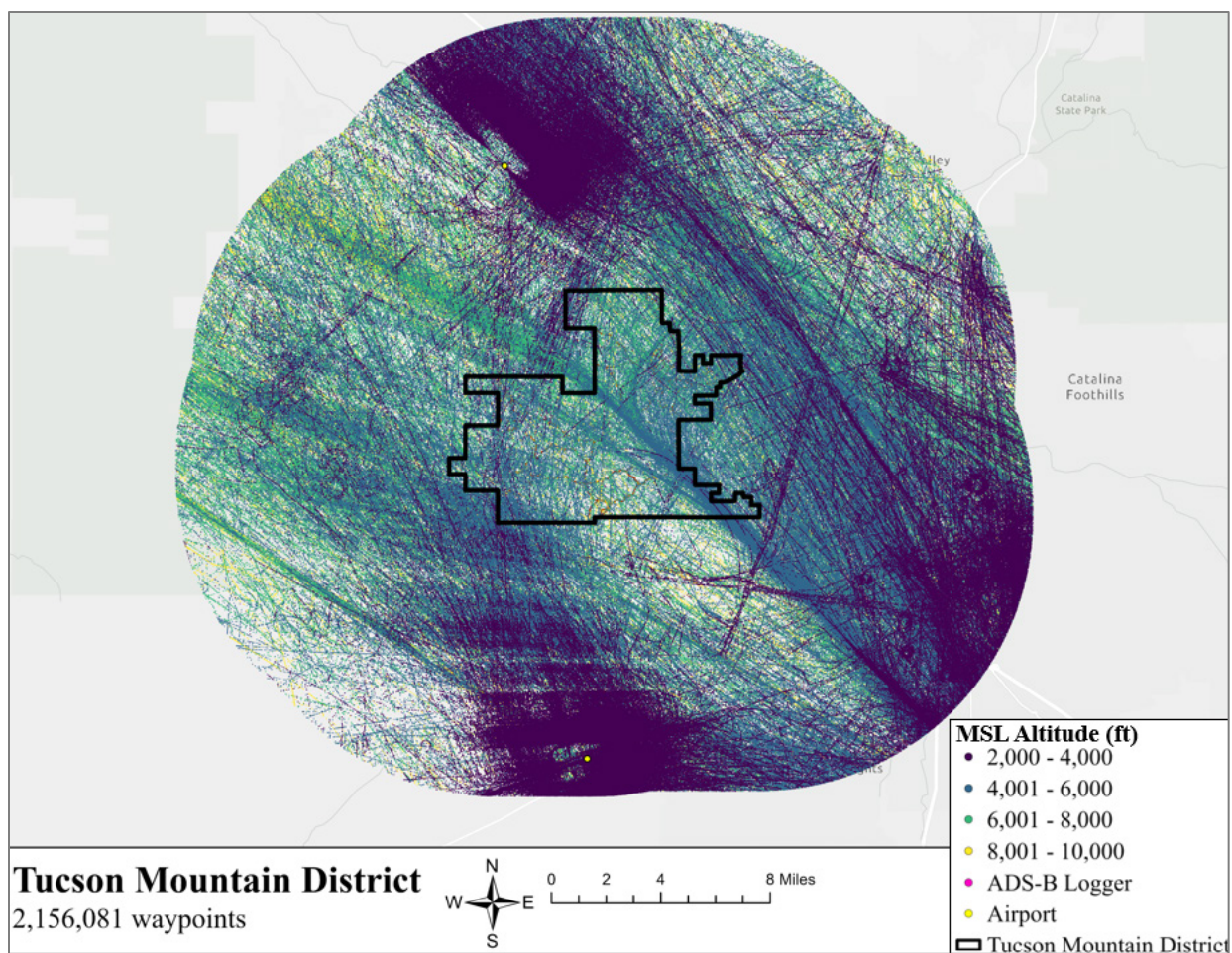


Figure 6. Waypoints between 2,000–10,000 feet MSL for the Tucson Mountain District.

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Results—Phase 3

Phase 3 focuses on low-level overflights. Data were cleaned of government flights, straight-line flights, flights less than a mile in length, and commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights), and survey flights. The following numbers of flights were removed from the Rincon Mountain District dataset: 119 government flights, 3,607 straight-line flights, 112 flights with a flightpath less than a mile in length, 804 commercial airline flights, and 2 survey flights. This left 1,783 flights within 10-miles of the Rincon Mountain District boundary (Figure 7). The following numbers of flights were removed from the Tucson Mountain District dataset: 159 government flights, 8,371 straight-line flights, 257 flights with a flightpath less than a mile in length, 1,040 commercial airline flights, and 1 survey flight. This left 7,765 flights within 10-miles of the Tucson Mountain District boundary (Figure 8).

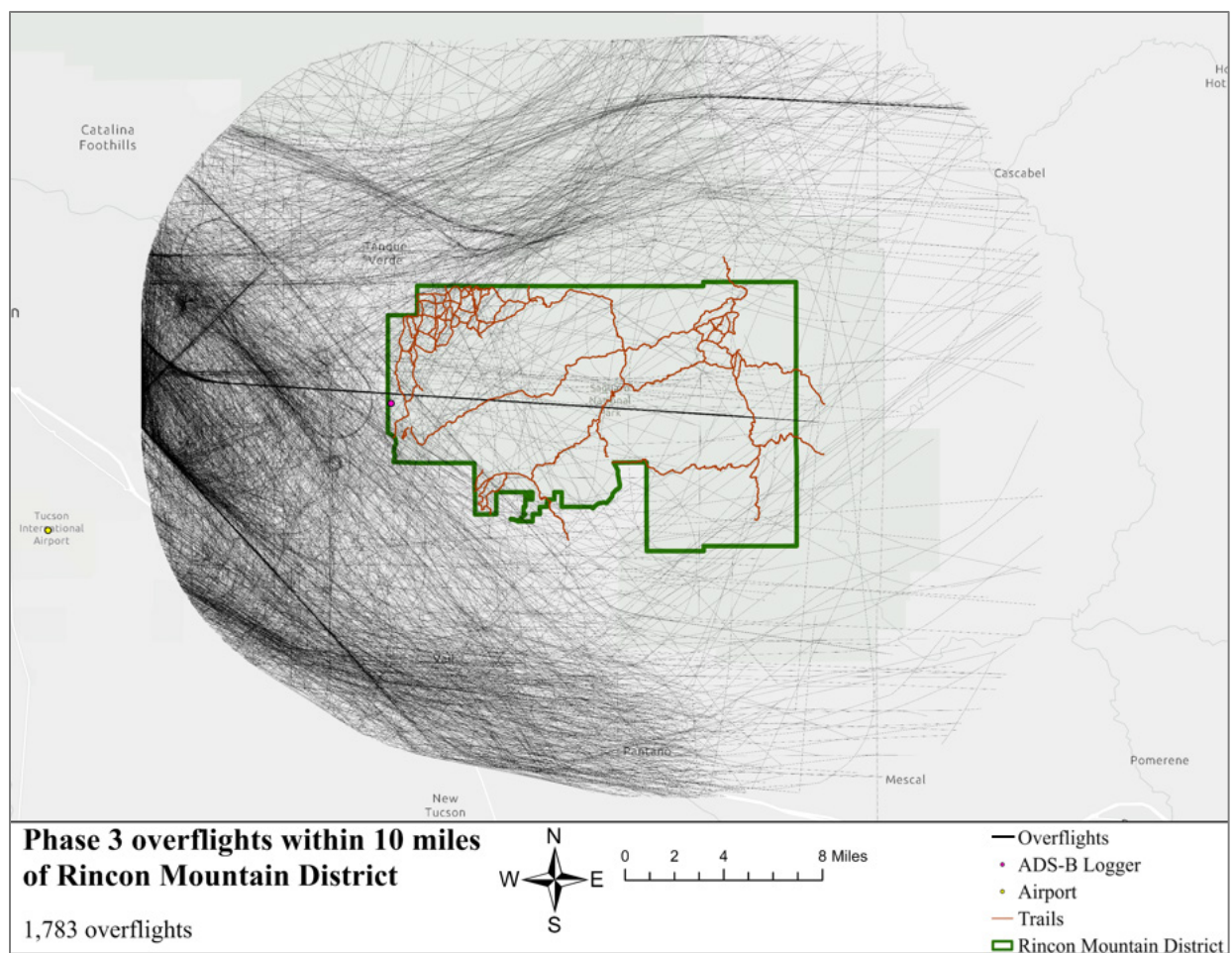


Figure 7. Phase 3 overflights within 10 miles of Rincon Mountain District.
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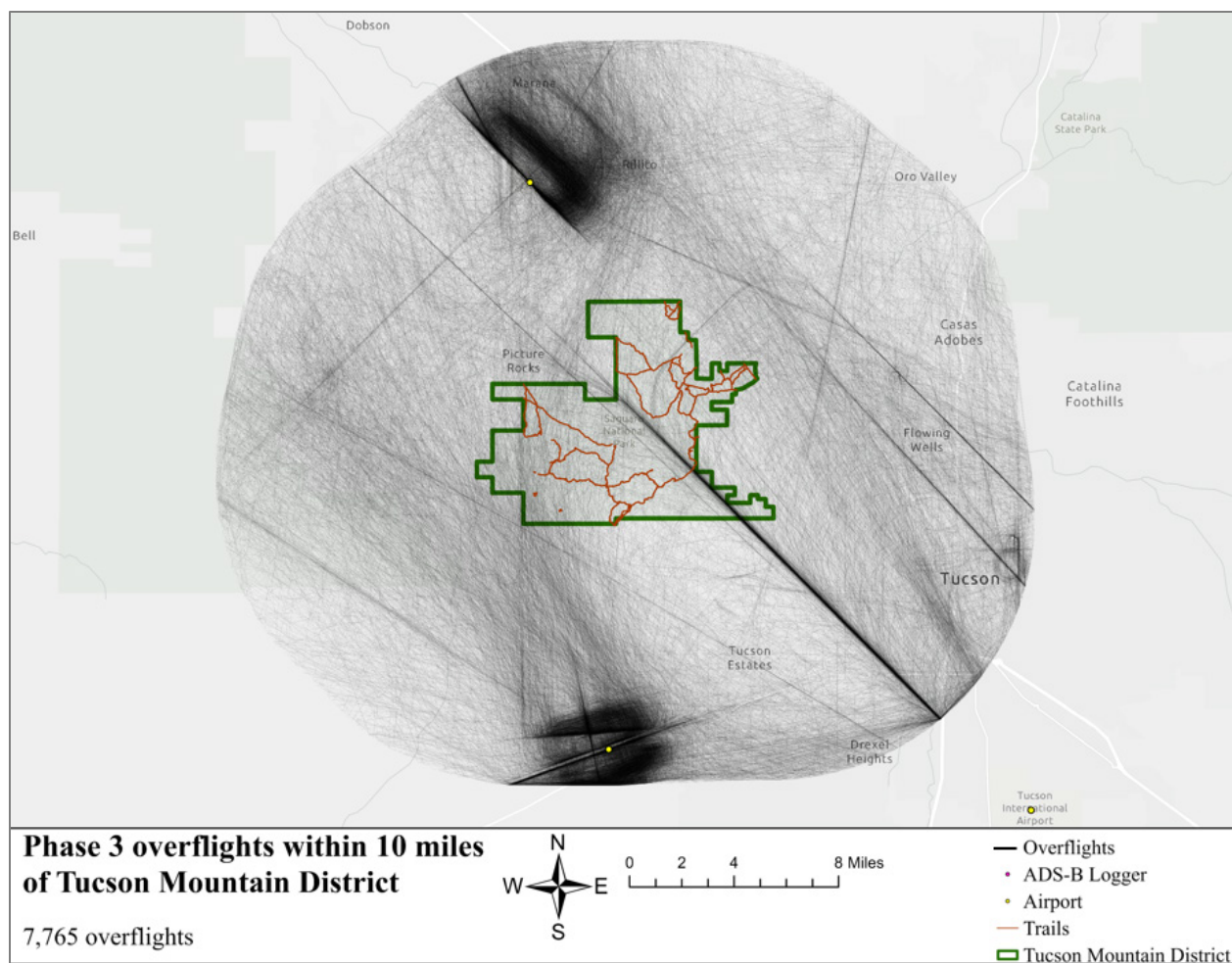


Figure 8. Phase 3 overflights within 10 miles of Tucson Mountain District.

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Next, these flights were clipped to a 0.5-mile boundary around each SAGU district, which left 238 flights for the Rincon Mountain District and 1,725 flights for the Tucson Mountain District. Using these datasets, kernel density analysis was conducted and the altitude interval that showed the highest density was used to normalize the other altitude ranges (as described in the Methods). For the Rincon Mountain District, the altitude interval with the highest density was 500–1,000 feet AGL. For the Tucson Mountain District, the altitude interval with the highest density was 2,501–3,000 feet AGL.

Figure 9 shows kernel density analysis for the Rincon Mountain District and Figure 10 shows kernel density analysis for the Tucson Mountain District. A distinct difference is that the Rincon Mountain District received less flights which resulted in less waypoints per square kilometer. Thus, the density classification of waypoints per square kilometer is different between the two districts. The maximum waypoints per square kilometer for the Rincon Mountain District was 110, while the maximum number of waypoints per square kilometer for the Tucson Mountain District was 4,013. The results for the Rincon Mountain District should be interpreted with caution because the results are normalized using lesser waypoints.

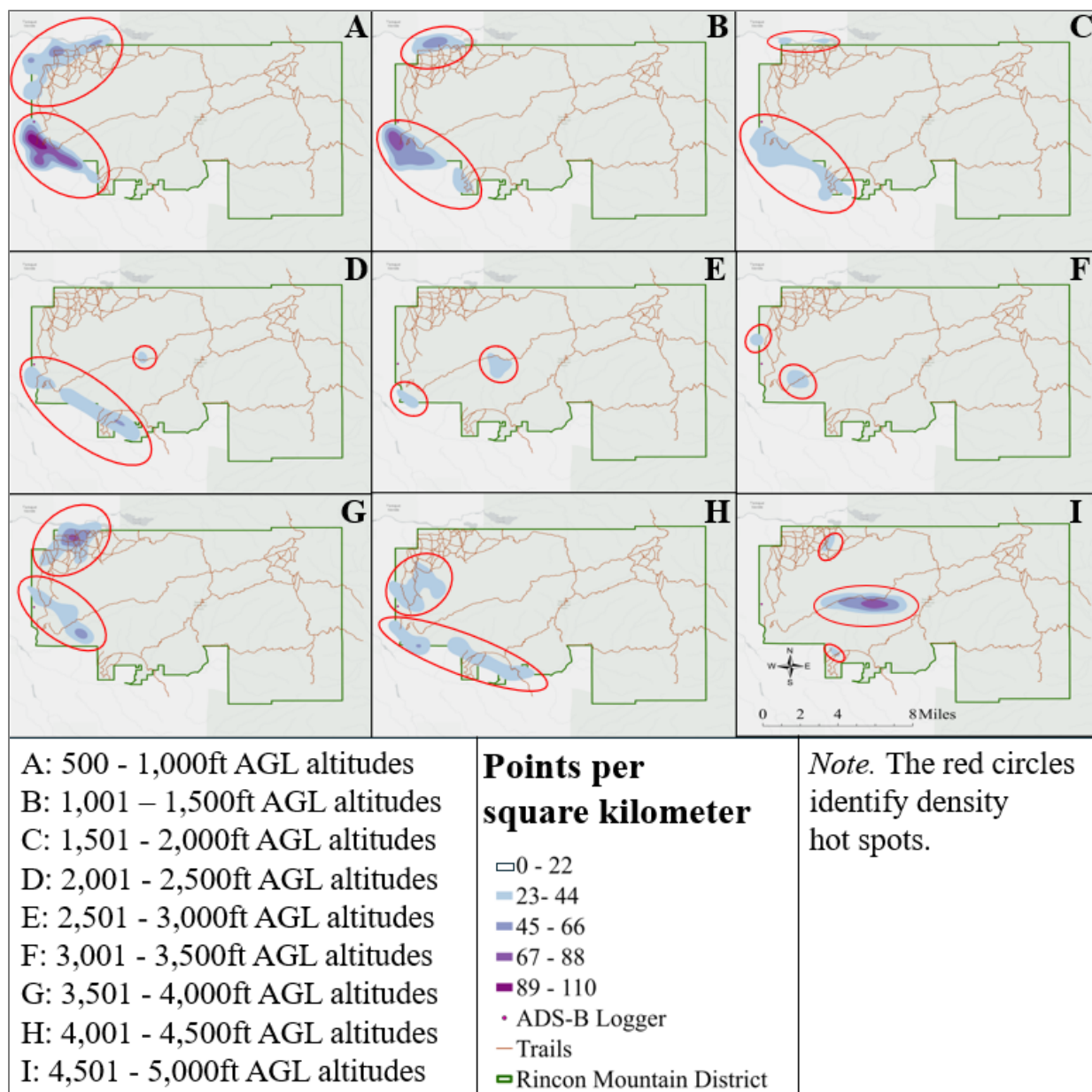


Figure 9. Overview of kernel density analysis for Rincon Mountain District showing AGL altitudes ranging from 500–5,000 feet.

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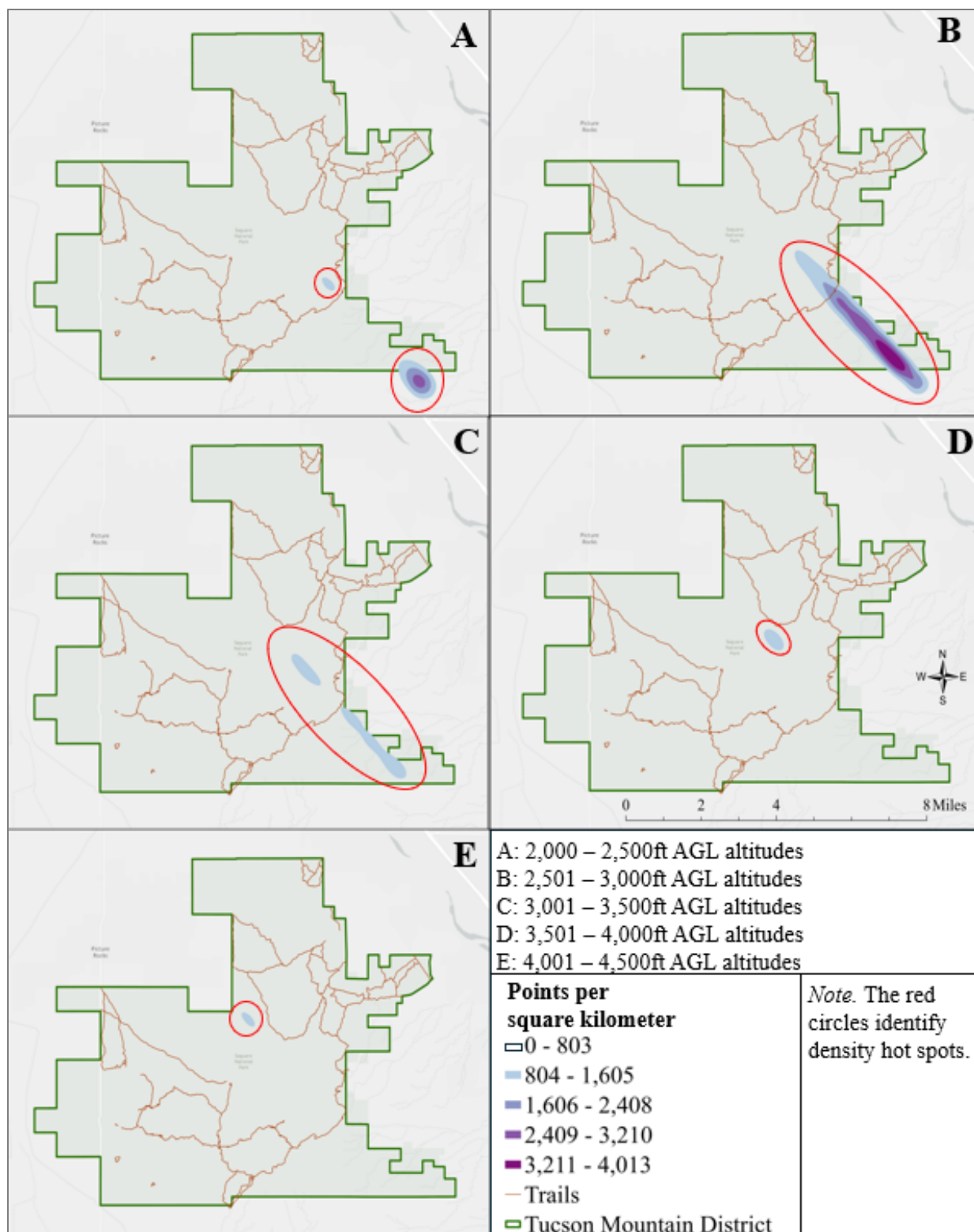


Figure 10. Overview of kernel density analysis for Tucson Mountain District showing AGL altitudes ranging from 2,000–4,500 feet.

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The density outputs were statistically compared using a spatial correlation test which was conducted for altitude intervals that showed density hot spots. A correlation threshold value of 0.70 was used to identify altitude intervals that had flights concentrating in the same areas. Table 1 shows the results of the spatial correlation test for the Rincon Mountain District and it shows that the following altitude intervals had flights concentrating in similar areas: 501–1,000 feet AGL and 1,001–1,500 feet AGL; 501–1,000 feet AGL and 1,501–2,000 feet AGL; 1,001–1,500 feet AGL and 1,501–2,000 feet AGL; and 1,501 feet AGL and 2,001–2,500 feet AGL.

Table 1. Spatial correlation matrix of Above Ground Level (AGL) altitude point densities for Rincon Mountain District. Correlation values closer to 1 indicate a stronger relationship. Correlation values greater and or equal to 0.70 are in bold.

AGL Altitude Interval	1.	2.	3.	4.	5.	6.	7.	8.
1. 501–1,000ft AGL	–	–	–	–	–	–	–	–
2. 1,001–1,500ft AGL	0.84	–	–	–	–	–	–	–
3. 1,501–2,000ft AGL	0.71	0.86	–	–	–	–	–	–
4. 2,001–2,500ft AGL	0.57	0.57	0.71	–	–	–	–	–
5. 2,501–3,000ft AGL	0.50	0.49	0.46	0.49	–	–	–	–
6. 3,001–3,500ft AGL	0.41	0.27	0.29	0.39	0.54	–	–	–
7. 3,501–4,000ft AGL	0.49	0.41	0.35	0.39	0.48	0.69	–	–
8. 4,001–4,500ft AGL	0.48	0.46	0.51	0.61	0.56	0.54	0.54	–
9. 4,501–5,000ft AGL	0.13	0.13	0.18	0.33	0.51	0.31	0.28	0.45

Table 2 shows the results of the spatial correlation test for the Tucson Mountain District and it shows that the following altitude intervals had flights concentrating in similar areas: 2,501–3,000 feet AGL and 3,001–3,500 feet AGL; 3,001–3,500 feet AGL and 3,501–4,000 feet AGL; and 3,501–4,000 feet AGL and 4,001–4,500 feet AGL. The altitude interval for 0–500 feet AGL did not show any density hot spots and subsequently was not included in the correlation analysis.

Table 2. Spatial correlation matrix of Above Ground Level (AGL) altitude point densities for Tucson Mountain District. Correlation values closer to 1 indicate a stronger relationship. Correlation values greater and or equal to 0.70 are in bold.

AGL Altitude Interval	1.	2.	3.	4.
1. 2,001–2,500ft AGL	–	–	–	–
2. 2,501–3,000ft AGL	0.69	–	–	–
3. 3,001–3,500ft AGL	0.57	0.79	–	–
4. 3,501–4,000ft AGL	0.42	0.49	0.80	–
5. 4,001–4,500ft AGL	0.24	0.22	0.54	0.70

It is important to examine waypoints with altitudes less than 0 feet AGL for reasons of data quality and to serve as an additional examination of possible low-level flights. Any tracking point with a negative AGL is due to error, although identifying the exact error can be difficult. 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. The Rincon Mountain District dataset did not have any waypoints with altitudes less than 0 feet AGL and the Tucson Mountain District dataset had four waypoints with altitudes less than 0 feet AGL which were all from the same aircraft. Because there were so few waypoints with negative values, no maps were produced.

To further understand altitude trends of waypoints, four visualizations were produced that focus on waypoints within 0.5-mile of each SAGU district boundary. Figure 11 displays waypoint altitudes ranging from 0–5,000 feet AGL for the Rincon Mountain District. Figure 12 displays waypoint altitudes ranging from 0–5,000 feet AGL for the Tucson Mountain District. Figures 13 and 14 display waypoints expressed in MSL. The maximum altitude used was 10,000 feet MSL because the highest point in SAGU is on the summit of Mica Mountain at 8,666 feet. The lowest altitude used was 2,000 feet MSL because the lowest point in SAGU is 2,180 feet. Figure 13 displays MSL altitude trends for the Rincon Mountain District and Figure 14 displays altitude trends for the Tucson Mountain District.

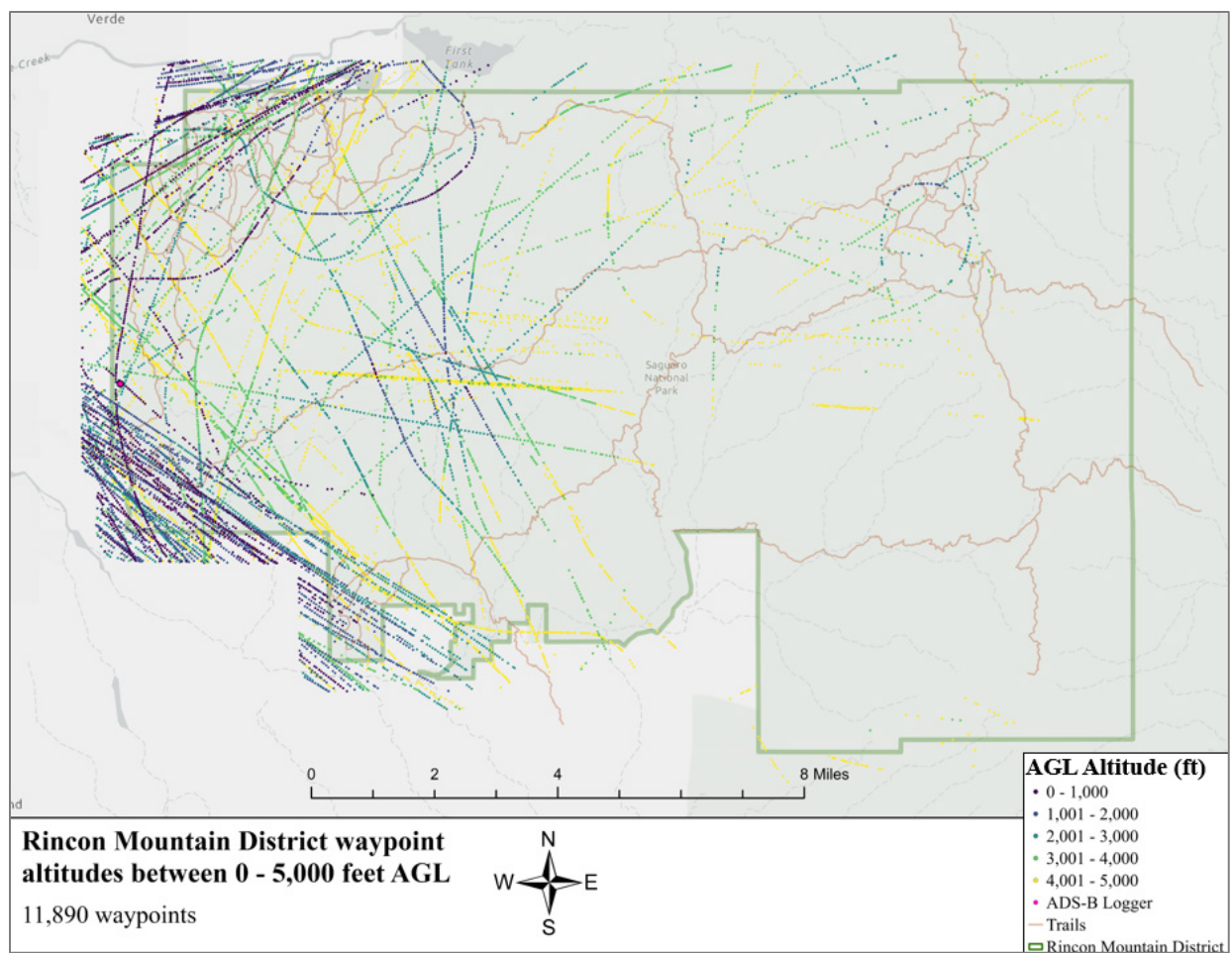


Figure 11. AGL altitude trends of altitudes ranging from 0–5,000 feet AGL for waypoints within 0.5-mile of the Rincon Mountain District boundary ($n = 11,890$ waypoints).

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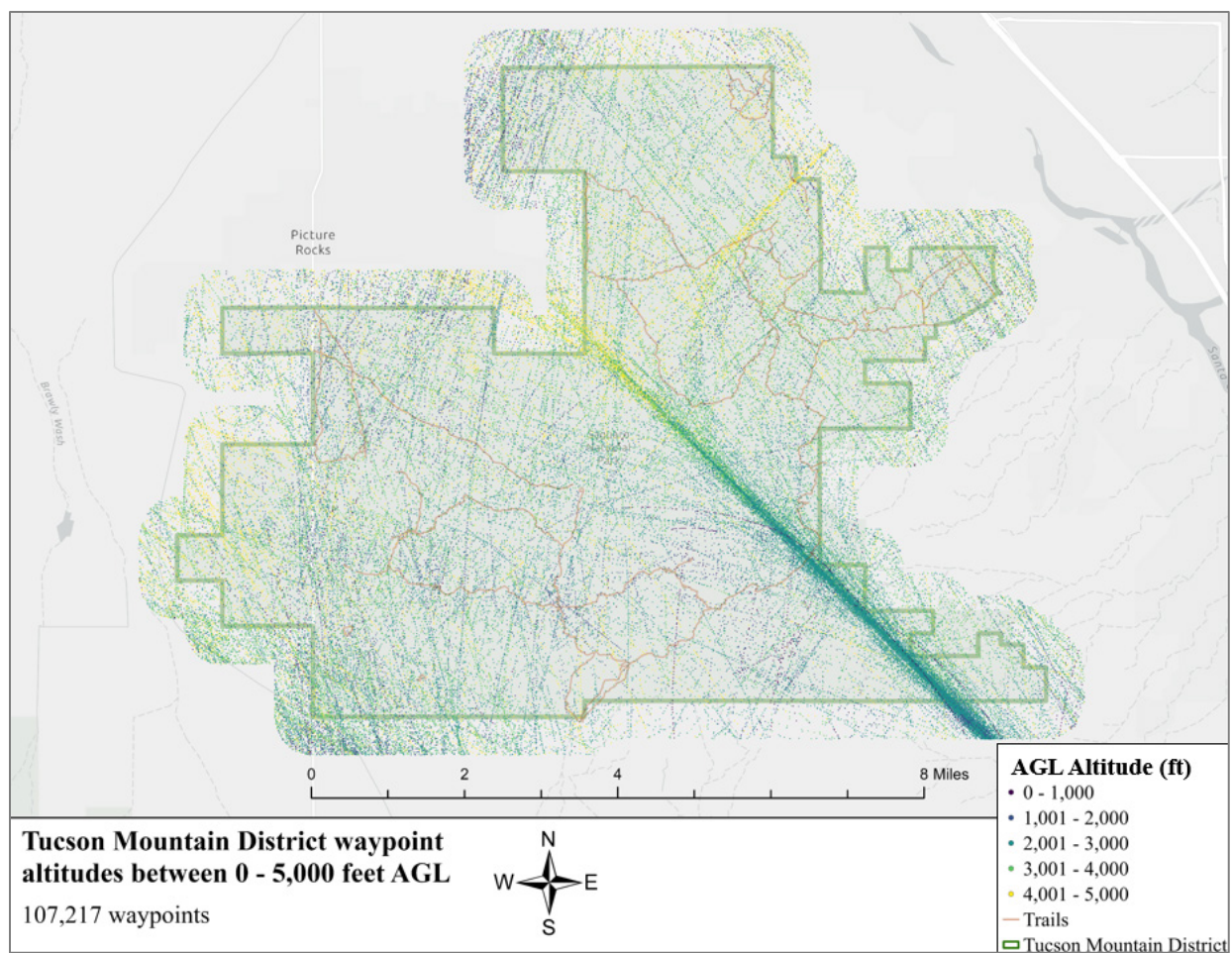


Figure 12. AGL altitude trends of altitudes ranging from 0–5,000 feet AGL for waypoints within 0.5-mile of the Tucson Mountain District boundary ($n = 107,217$ waypoints).

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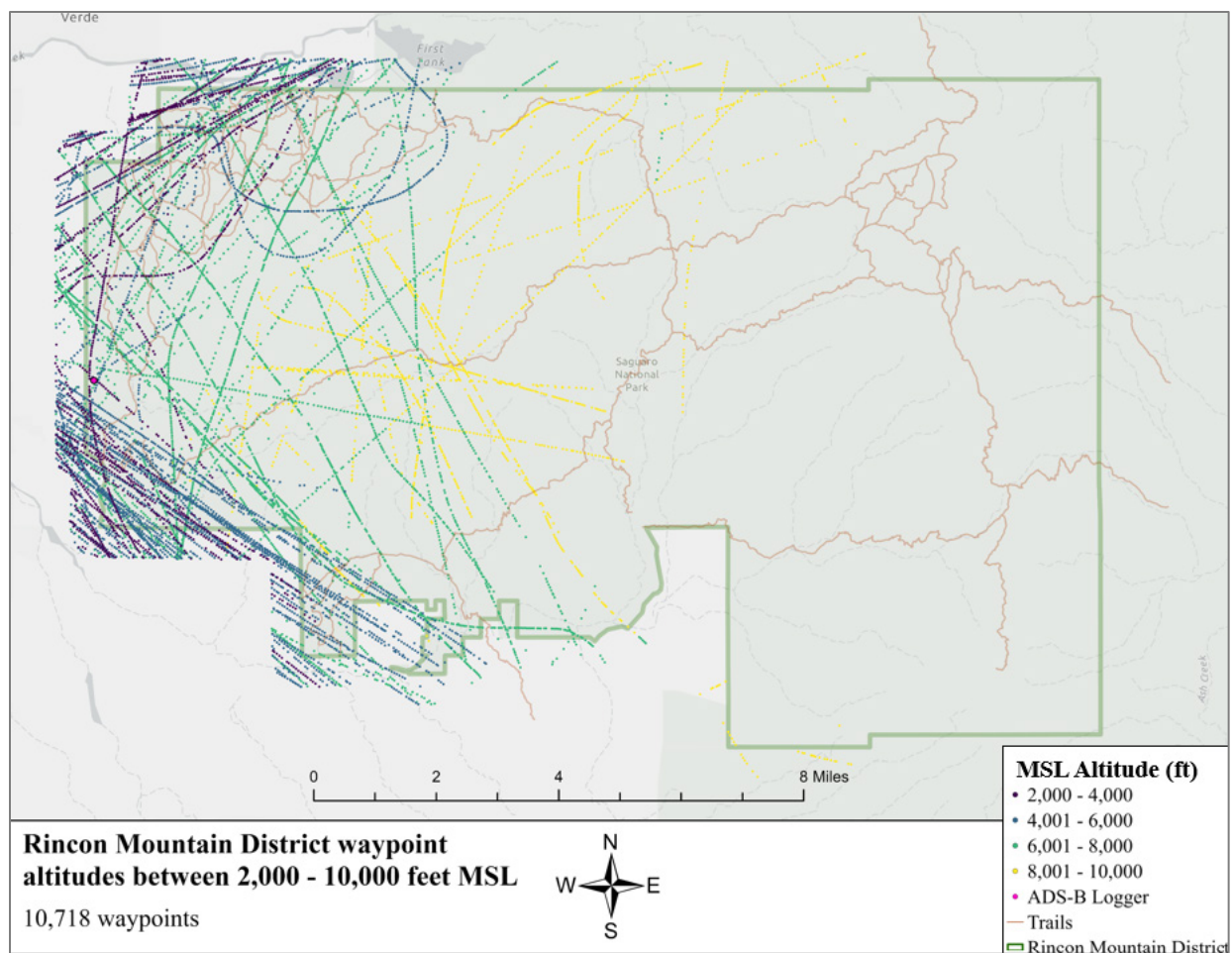


Figure 13. MSL altitude trends of altitudes ranging from 2,000–10,000 feet MSL for waypoints within 0.5-mile of the Rincon Mountain District boundary ($n = 10,718$ waypoints).

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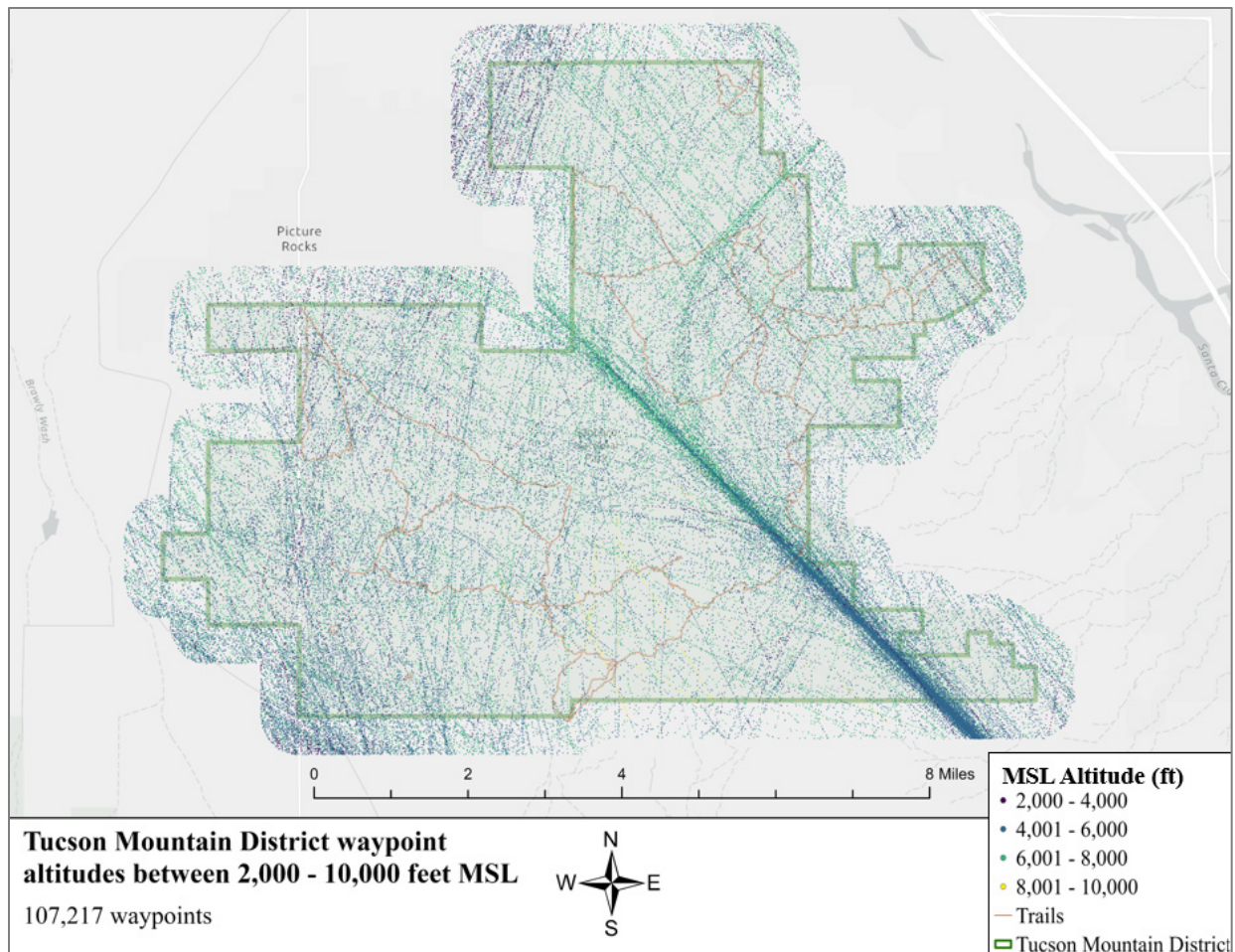


Figure 14. MSL altitude trends of altitudes ranging from 2,000–10,000 feet MSL for waypoints within 0.5-mile of the Tucson Mountain District boundary ($n = 107,217$ waypoints).

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The information displayed in Figures 11–14 were inputted into tables to quantitatively understand which altitude intervals had the highest percentage of observed waypoints. Table 3 shows analysis across AGL altitude intervals for the Rincon Mountain District and the Tucson Mountain District. For the Rincon Mountain District, 11,890 waypoints were analyzed and the AGL altitude interval that received the highest percentage of waypoints was 4,001–4,500 feet AGL, but the following altitude intervals had a significant number of waypoints: 501–1,000 feet AGL; 1,001–1,500 feet AGL; 3,501–4,000 feet AGL; and 4,501–5,000 feet AGL (Table 3). For the Tucson Mountain District, 107,217 waypoints were analyzed and the AGL altitude interval that received the highest percentage of waypoints was 2,501–3,000 feet AGL, but the following altitude intervals had a significant number of waypoints: 2,001–2,500 feet AGL; 3,001–3,500 feet AGL; 3,501–4,000 feet AGL; and 4,001–4,500 feet AGL.

Table 3. Number and percentage of waypoints across AGL altitude intervals for the Rincon Mountain District ($n = 11,890$) and the Tucson Mountain District ($n = 107,217$).

AGL Altitude	Rincon Mountain District		Tucson Mountain District	
	Number of Waypoints	Percentage of Waypoints	Number of Waypoints	Percentage of Waypoints
<0ft	0	0.0	4 ^A	0.004
0–500ft	201	1.7	356	0.3
501–1,000ft	1,544	13.0	1,573	1.5
1,001–1,500ft	1,191	10.0	3,361	3.1
1,501–2,000ft	877	7.4	7,875	7.3
2,001–2,500ft	1,123	9.4	14,571	13.6
2,501–3,000ft	961	8.1	24,044	22.4
3,001–3,500ft	1,034	8.7	20,096	18.7
3,501–4,000ft	1,638	13.8	17,044	15.9
4,001–4,500ft	1,954	16.4	12,991	12.1
4,501–5,000ft	1,367	11.5	5,302	4.9

^A 100% of these data were accounted for by one aircraft.

Table 4 shows analysis across MSL altitude intervals for the Rincon Mountain District and the Tucson Mountain District. For the Rincon Mountain District, 13,731 waypoints were analyzed and the MSL altitude interval that received the highest percentage of waypoints was 7,001–8,000 feet MSL, but the other altitude intervals received high percentages of waypoints except for 2,000–3,000 feet MSL (the lowest point in the Rincon Mountain District is 2,670 feet) and 5,001–6,000 feet MSL (Table 4). For the Tucson Mountain District, 114,286 waypoints were analyzed and the AGL altitude interval that received the highest percentage of waypoints was 5,001–6,000 feet MSL, but the 6,001–7,000 feet MSL altitude interval also received a high percentage of waypoints.

Table 4. Number and percentage of waypoints across MSL altitude intervals for the Rincon Mountain District ($n = 13,731$) and the Tucson Mountain District ($n = 114,286$).

MSL Altitude	Rincon Mountain District		Tucson Mountain District	
	Number of Waypoints	Percentage of Waypoints	Number of Waypoints	Percentage of Waypoints
2,000–3,000ft	0	0.0	326	0.3
3,001–4,000ft	1,742	12.7	4,909	4.3
4,001–5,000ft	1,932	14.1	14,300	12.5
5,001–6,000ft	1,344	9.8	46,068	40.3
6,001–7,000ft	1,696	12.4	35,954	31.5
7,001–8,000ft	2,479	18.1	7,496	6.6
8,001–9,000ft	2,320	16.9	3,967	3.5
9,001–10,000ft	2,218	16.2	1,266	1.1

Next, overflights were analyzed across months, days of the week, and hours of the day. For the Rincon Mountain District, 238 flights were analyzed. For the Tucson Mountain District, 1,725 flights were analyzed. Table 5 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 December 24th, 2024–February 11th, 2025. The Rincon Mountain District averaged 6.43 overflights per day, while the Tucson Mountain District averaged 46.62 overflights per day.

Table 5. Number and percentage of overflights across months for the Rincon Mountain District ($n = 238$) and for the Tucson Mountain District ($n = 1,725$).

Month	Rincon Mountain District			Tucson Mountain District		
	Number of Data Collection Days ^A	Number of Overflights	Average Number of Overflights Per Day	Number of Data Collection Days ^A	Number of Overflights	Average Number of Overflights Per Day
December 2024	7	33	4.71	7	228	32.57
January 2025	21	135	6.43	21	1052	50.10
February 2025	9	70	7.78	9	445	49.44
Total	37	238	6.43	37	1,725	46.62

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

Table 6 shows the percentage of flights across days of the week. The day of the week with the highest percentage of flights was Fridays (19.3% for Rincon Mountain District and 22.4% for Tucson Mountain District). Table 7 shows the percentage of overflights across hour of the day. Most overflights occur from 10:00 am to 5:00 pm. Table 8 shows percentage of overflights across aircraft type. Fixed wing single engine is the aircraft type most common among low-level overflights at SAGU.

Table 6. Percentage of overflights across days of the week.

Day of the Week	Rincon District Percent of Overflights	Tucson District Percent of Overflights
Monday	13.9	10.1
Tuesday	11.8	15.0
Wednesday	19.3	15.4
Thursday	9.2	8.1
Friday	19.3	22.4
Saturday	18.9	18.5
Sunday	7.6	10.6

Table 7. Percentage of overflights across hours of the day. Percentage of overflights does not add up to 100% because some flights occurred beyond the hours reported.

Hour	Rincon District Percentage of Overflights	Tucson District Percentage of Overflights
6:00am–7:00am	0.8	0.9
7:00am–8:00am	1.3	1.0
8:00am–9:00am	1.7	3.2
9:00am–10:00am	2.1	6.4
10:00am–11:00am	5.0	9.2
11:00am–12:00pm	7.1	10.3
12:00pm–1:00pm	8.0	10.3
1:00pm–2:00pm	8.0	10.6
2:00pm–3:00pm	9.7	7.3
3:00pm–4:00pm	7.1	6.5
4:00pm–5:00pm	10.9	5.6
5:00pm–6:00pm	4.6	5.5
6:00pm–7:00pm	3.4	4.1
7:00pm–8:00pm	4.2	2.3
8:00pm–9:00pm	6.3	4.8
9:00pm–10:00pm	4.2	5.2

Table 8. Percentage of overflights across aircraft type. Percentage of overflights does not add up to 100% because some aircraft types had a null value retrieved from the FAA Releasable Database.

Aircraft Type	Rincon District Percentage	Tucson District Percentage
Fixed-wing single engine	23.9	67.8
Fixed-wing multi engine	26.9	19.1
Rotorcraft	23.9	2.5

Using the cleaned Phase 3 dataset, six more figures were produced to show overflight travel patterns across aircraft type. Figures 15, 16, and 17 are for the Rincon Mountain District and display overflight travel patterns for fixed-wing single engine (Figure 15), fixed-wing multi engine (Figure 16), and rotorcraft aircraft (Figure 17). Figures 18, 19, and 20 are for the Tucson Mountain District and display overflight travel patterns for fixed-wing single engine (Figure 18), fixed-wing multi engine (Figure 19), and rotorcraft aircraft (Figure 20).

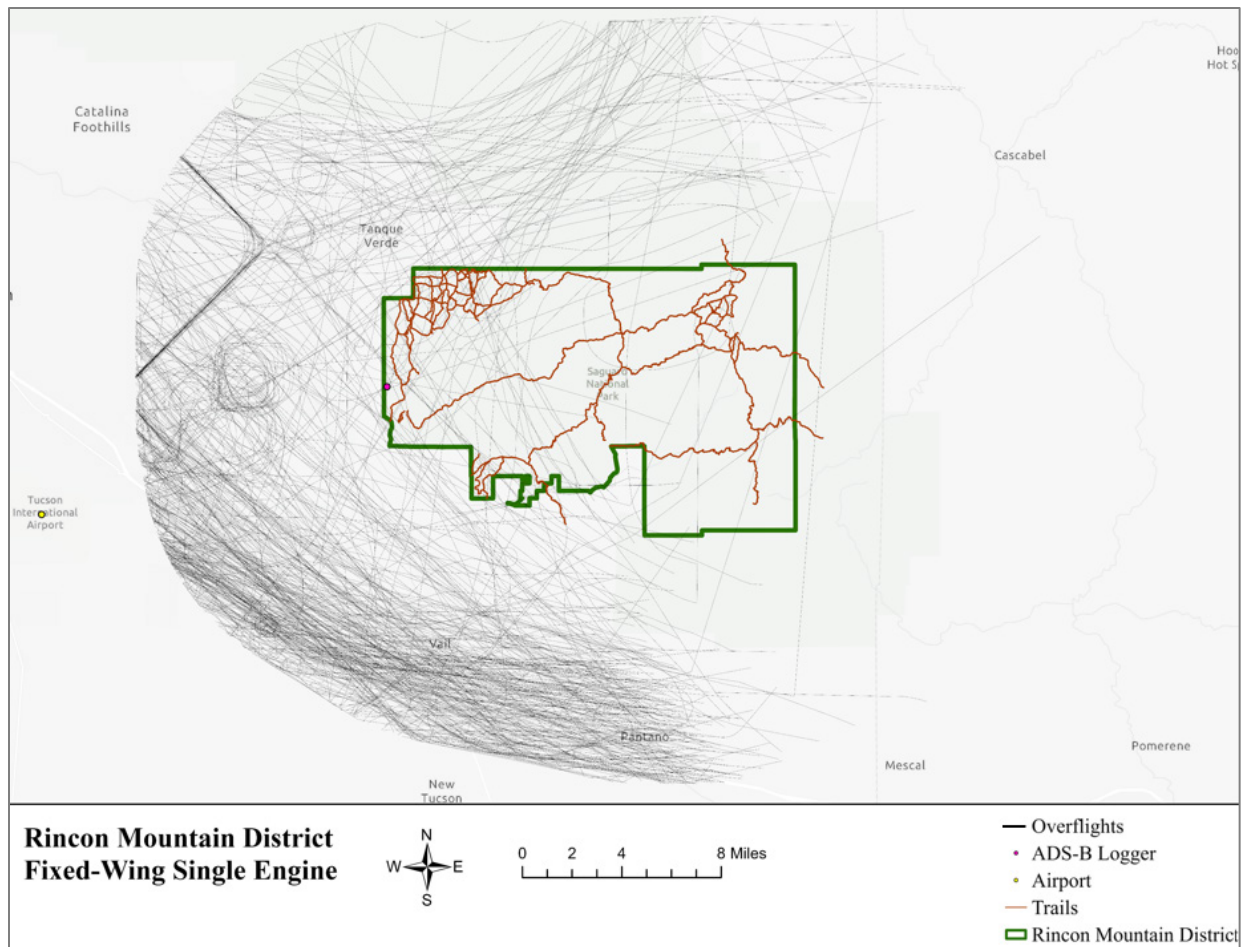


Figure 15. Rincon Mountain District fixed-wing single engine overflight travel patterns.
NPS / BRIAN PETERSON

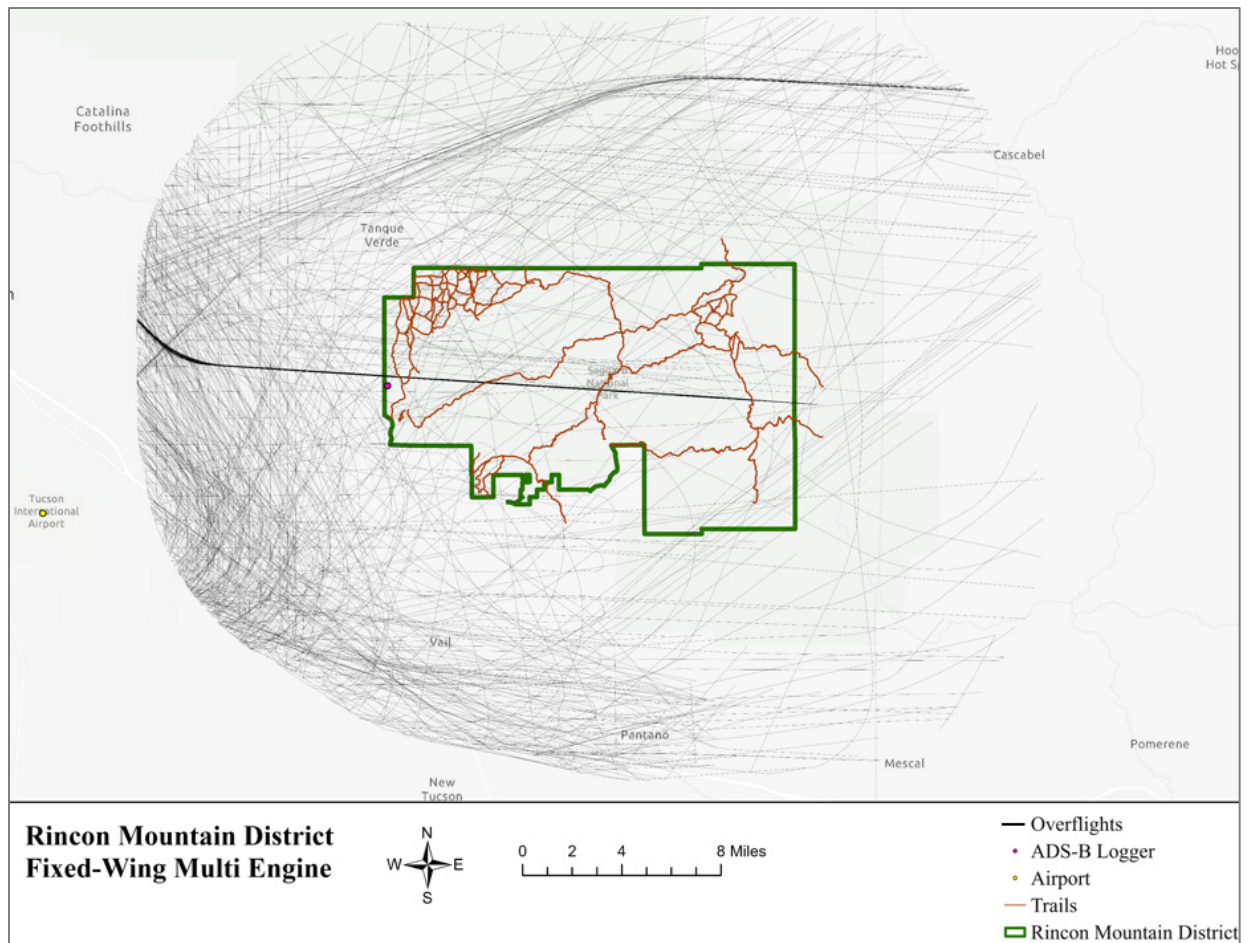


Figure 16. Rincon Mountain District fixed-wing multi engine overflight travel patterns.
NPS / BRIAN PETERSON

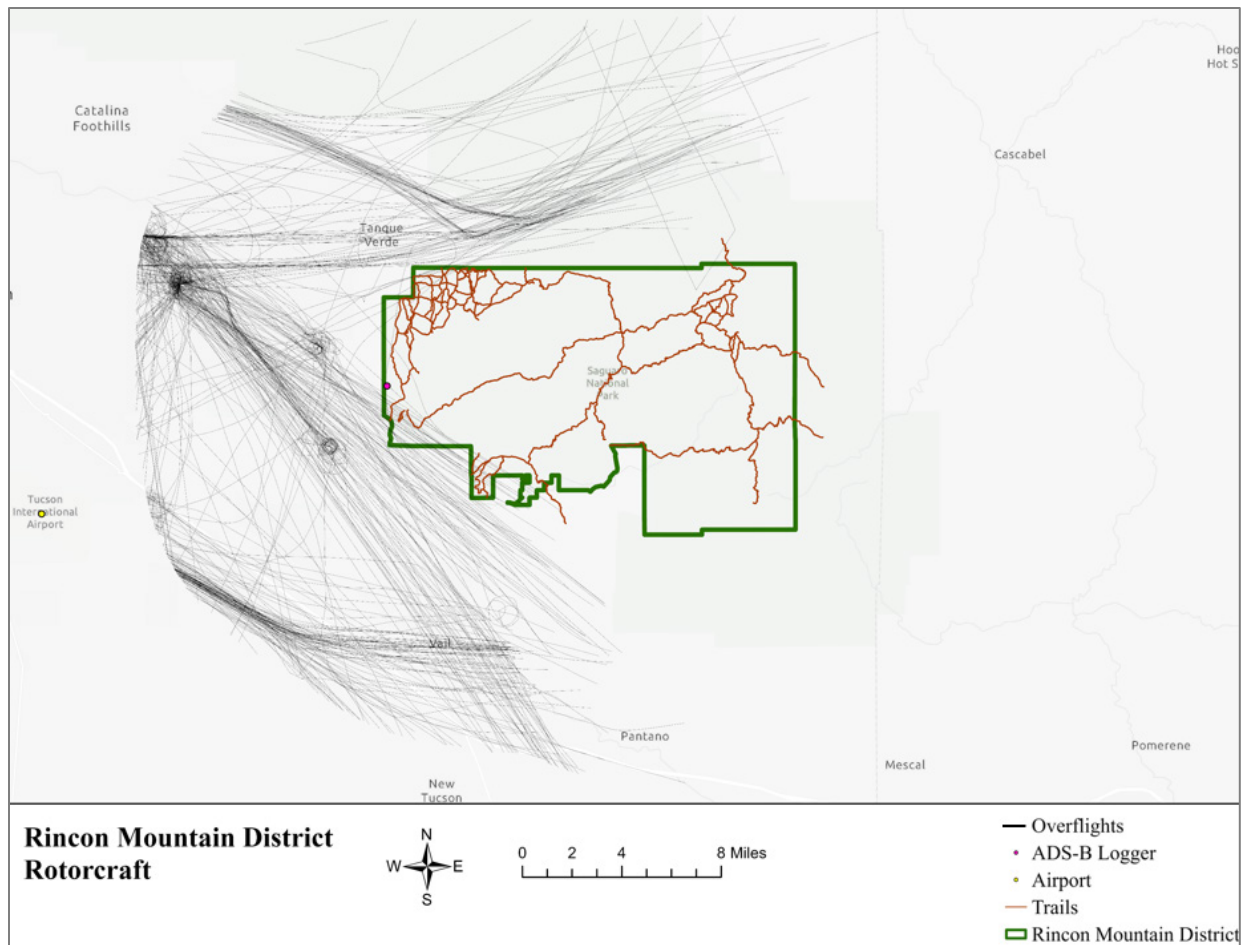


Figure 17. Rincon Mountain District rotorcraft overflight travel patterns.
NPS / BRIAN PETERSON

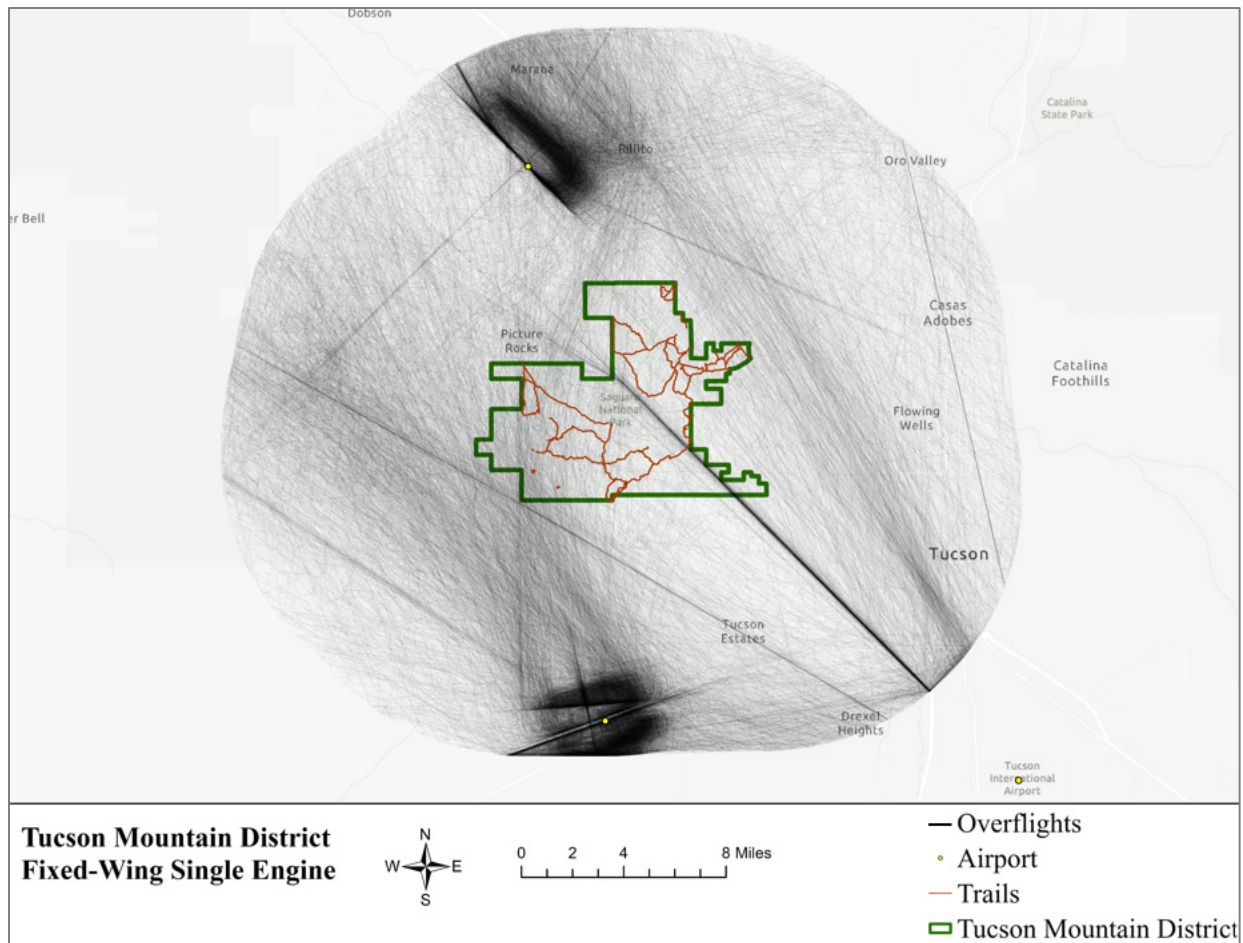


Figure 18. Tucson Mountain District fixed-wing single engine overflight travel patterns.
NPS / BRIAN PETERSON

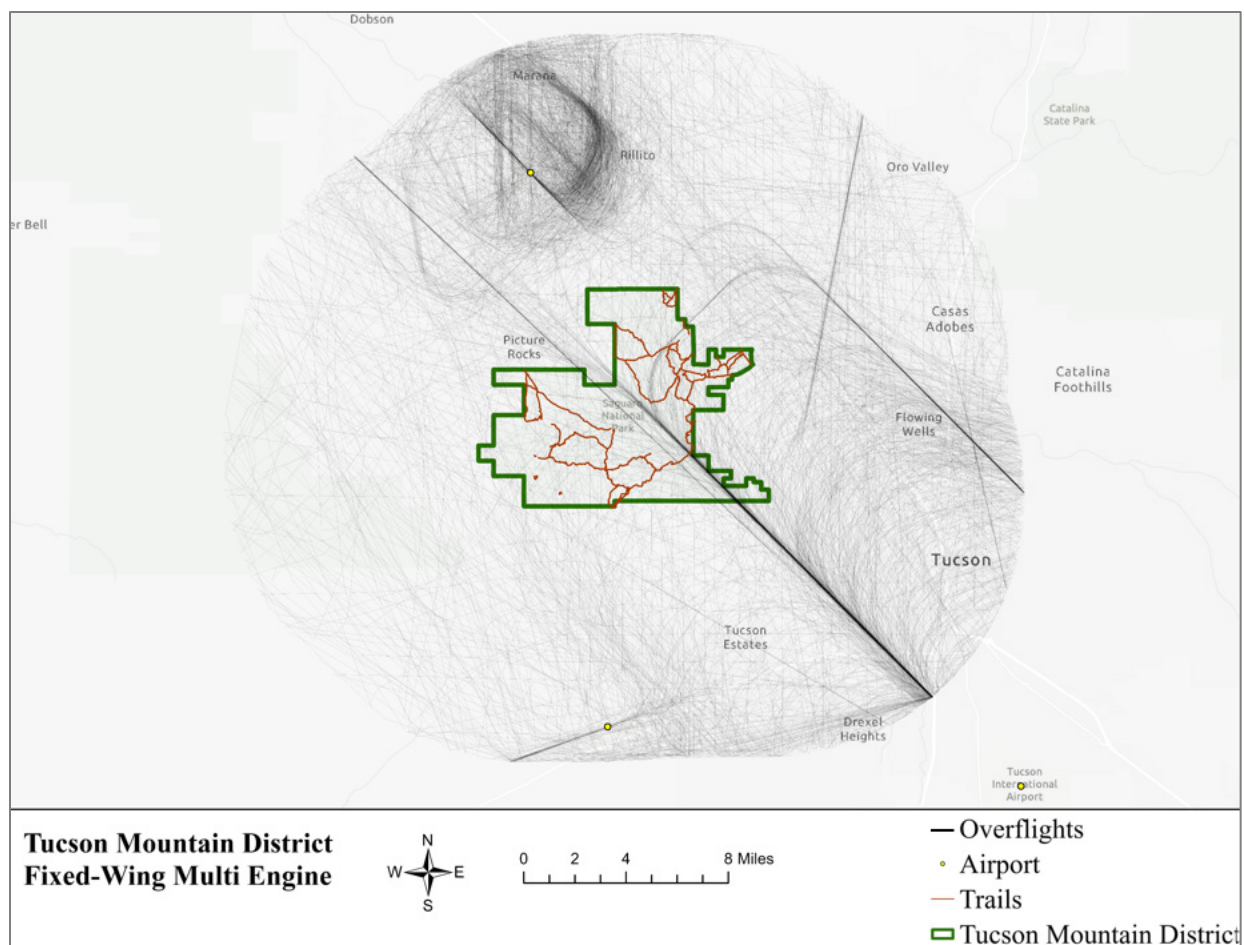


Figure 19. Tucson Mountain District fixed-wing multi engine overflight travel patterns.

NPS / BRIAN PETERSON

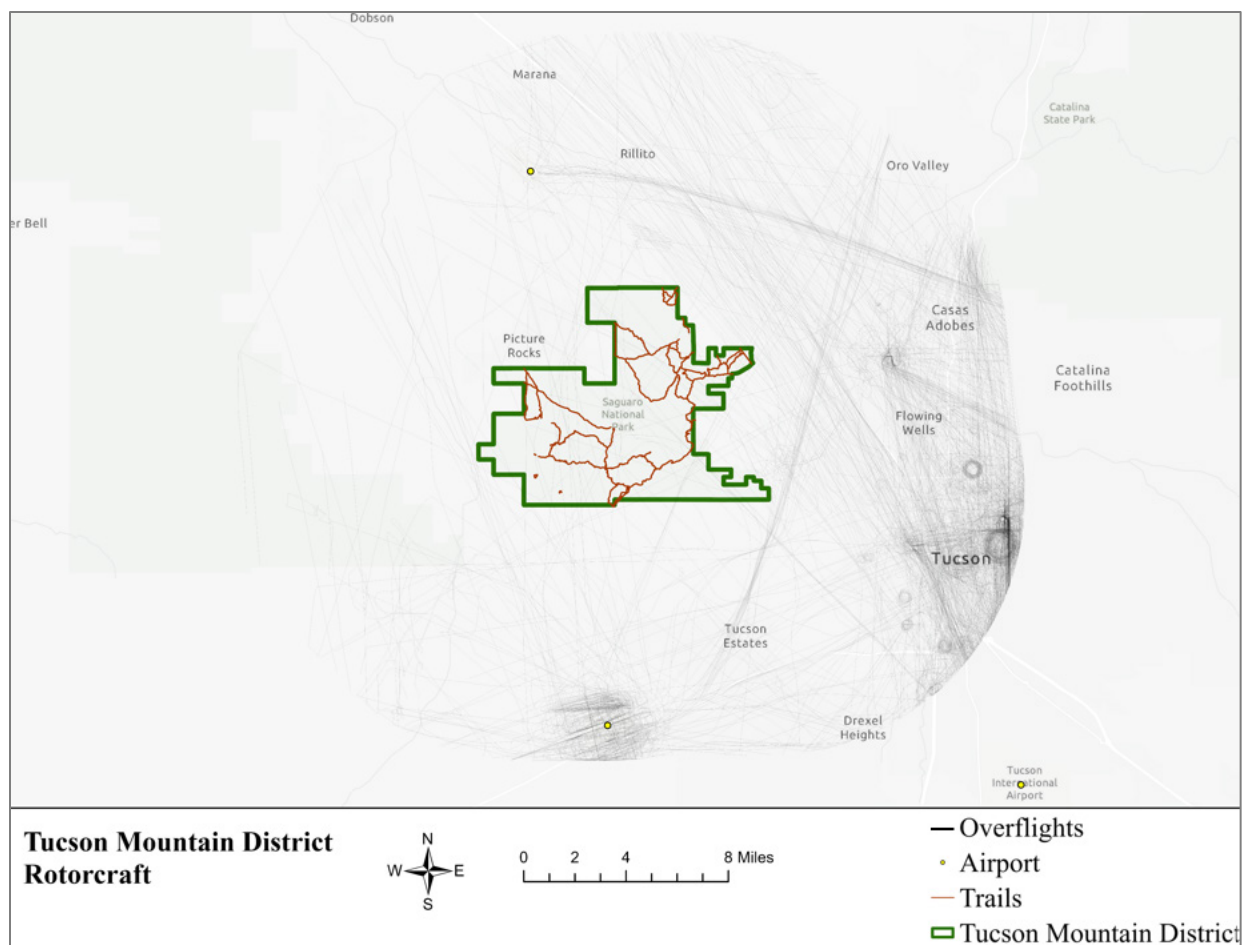


Figure 20. Tucson Mountain District rotorcraft overflight travel patterns.
NPS / BRIAN PETERSON

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at SAGU. Flight tracking data were analyzed from December 24th, 2024–February 11th, 2025 (50 total days; 13 days of missing data). Analysis consisted of three phases. SAGU’s two districts, Rincon Mountain District and Tucson Mountain District, were analyzed independently because they are geographically disparate with the Tucson International Airport and Davis-Monthan Air Force Base in between the two districts, creating distinct patterns of overflights for each.

The first phase focused on all overflights within 10 miles of each district’s boundary. The Rincon Mountain District has a distinct corridor that traverses laterally across it and most overflights are outside of the boundary to the west (Figure 3). The Tucson Mountain District receives more overflights and shows a concentrated trend of overflights and distinct corridors (Figure 4). The majority of flights for both districts seem to be arriving or departing at Tucson International Airport. Within 10 miles of the Tucson Mountain District are Ryan Airfield (to the south) and Marana Regional Airport (to the north) which both show similar overflight patterns around these smaller airports. These airports, along with Tucson International Airport, influence levels of overflights at the Tucson Mountain District.

The second phase focused on low-level overflights (defined as flights up to 10,000 feet MSL) that were not cleaned of any flight type (i.e., major airlines, government flights, and survey flights) or aircraft type (e.g., rotorcraft). The Rincon Mountain District shows low-level overflights across its west boundary but no low-level overflights across its east boundary (Figure 5). It is possible this could be due to terrain shielding, as this District has multiple peaks over 8,000 feet, or this could reflect actual travel patterns of aircraft avoiding these higher mountains. The Tucson Mountain District shows low-level overflights across most areas of the district and a distinct corridor is visible that extends northwest from the southeast boundary (Figure 6). This corridor has overflight waypoint altitudes mostly between 4,000 to 6,000 feet MSL (which corresponds to between 2,000 to 4,000 AGL; Figure 12).

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 flightpath less than a mile in length, and survey flights. The Rincon Mountain District dataset was cleaned of 119 government flights, 3,607 straight-line flights, 804 commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights), 112 flights with a flightpath less than a mile in length, and 2 survey flights. This left 1,783 flights (Figure 7), which is 27.74% of all the flights in Phase 1. The Tucson Mountain District dataset was cleaned of 159 government flights, 8,371 straight-line flights, 1,040 commercial airline flights, 257 flights with a flightpath less than a mile in length, and 1 survey flight. This left 7,765 flights (Figure 8), which is 44.14% of all the flights in Phase 1.

The Phase 3 dataset for the Rincon Mountain District (Figure 7) shows that most overflights are occurring outside of the district to the west of the boundary. The Phase 3 dataset for the Tucson

Mountain District (Figure 8) shows that same distinct corridor is present that traverses northwest from the southeast boundary. Despite that commercial airlines and straight-line flights were cleaned of the dataset the corridor remained. Although the corridor appears that it has straight-line flights, this is not the case; overflights veer away from the corridor in a variety of directions.

Phase 3 kernel density analysis was conducted independently for each district which resulted in the density classification being normalized differently. Waypoints per square kilometer are much less for the Rincon Mountain District (Figure 9) than for the Tucson Mountain District (Figure 10). For the Rincon Mountain District, the altitude interval with the highest density was 500 to 1,000 feet AGL which was shown to be correlated with the 1,001 to 1,500 feet AGL and 1,501 to 2,000 feet AGL altitude intervals. For the Tucson Mountain District, the altitude interval with the highest density was 2,500 to 3,000 feet AGL which was shown to be correlated with the 3,001 to 3,500 feet AGL altitude interval. For the Tucson Mountain District, all of the altitude intervals that showed flight density are from overflights likely using the corridor that traverses northwest from the southeast boundary. Further, the lack of correlation between all altitude intervals at both districts suggests that flights are relatively dispersed across altitudes (Table 1 and Table 2).

Figures 11 and 12 are represented tabularly in Table 3, which displays number of waypoints within specific AGL altitude intervals. This table shows that the Rincon Mountain District dataset has the highest percentage of waypoints in the 4,001 to 4,500 feet AGL altitude interval (16.4%), while the following altitude intervals received the second and third highest number of waypoints: 3,501 to 4,000 feet AGL (13.8%) and 501 to 1,000 feet AGL (13.0%). Table 3 shows that for the Tucson Mountain District dataset, the highest percentage of waypoints was in the 2,501 to 3,000 feet AGL altitude interval (22.4%), while the following altitude intervals received the second and third highest number of waypoints: 3,001 to 3,500 feet AGL (18.7%) and 3,501 to 4,000 feet AGL (15.9%). 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). The Rincon Mountain District did not have any waypoints with negative AGL altitude values. The Tucson Mountain District had four waypoints with negative AGL altitude values which represent 0.004% of that dataset.

Figures 13 and 14 are represented tabularly in Table 4, which displays number of waypoints within specific MSL altitude intervals. This table shows that the Rincon Mountain District dataset has the highest percentage of waypoints in the 7,001 to 8,000 feet MSL altitude interval and all of the MSL altitude intervals showed high percentages of waypoints except for the 2,000 to 3,000 feet MSL (the lowest point in the Rincon Mountain District is 2,670 feet) and the 5,001 to 6,000 feet MSL altitude interval. Table 4 shows that for the Tucson Mountain District dataset, the highest percentage of waypoints was in the 5,001 to 6,000 feet MSL altitude interval. Also, the 4,001 to 5,000 feet MSL and the 6,001 to 7,000 feet MSL altitude intervals showed high percentages of waypoints.

Temporal patterns of flights were also examined. Table 5 shows that January 2025 was the month that each district received the most overflights. Table 6 shows that the Rincon Mountain District receives a high percentage of overflights during most days of the week except for Thursdays and Sundays. The Tucson Mountain District receives a high percentage of overflights during most days of the week except for Thursdays. Table 7 displays percentage of overflights across hours of the day. This table shows that the Rincon Mountain District receives a significant number of overflights from 11:00 am to 5:00 pm and the Tucson Mountain District receives a significant number of overflights from 10:00 am to 3:00 pm.

Figures 15 to 20 show overflight travel patterns for fixed-wing single engine, fixed-wing multi engine, and rotorcraft. Table 8 shows that the Rincon Mountain District receives a high percentage of overflights from each aircraft type, while the Tucson Mountain District receives a high percentage of overflights from fixed-wing single engine aircraft.

This analysis did not specifically focus on military overflights associated with Davis-Monthan Air Force Base which is located between the Rincon District and Tucson International. It is possible that military aircraft fly in anonymous mode which could prevent collection of flight metadata so they intentionally cannot be identified (Gurung et al., 2024) or that military aircraft are not projecting ADS-B. Either way, there are no discernable patterns departing or arriving at the Air Force Base.

There was a total of 3,286 flights identified in the Phase 1 data set that were flying in anonymous mode over Tucson District (2,462) and Rincon District (824)—meaning that we could not identify aircraft type and other metadata information. However, these aircraft showed no distinct or systematic travel patterns, and therefore were not mapped. Like most of the flights mapped in this report, the majority of the anonymous flights seem to be arriving and departing from Tucson International Airport.

In conclusion, this study produced results to further understand overflights at SAGU at a fine spatial scale. The analysis revealed very similar patterns across all three phases of analysis. The Rincon Mountain District receives very few overflights across all altitudes. The only clear pattern was fixed-wing, multi engine aircraft traversing the park laterally at above 5,000 AGL. When present most of the aircraft are located on the western side of this district. The acoustic environment in the Rincon Mountain District likely experiences low levels of noise from private and commercial aircraft. The Tucson Mountain District receives many more overflights—mostly associated with arrivals and departures from local airports, primarily Tucson International. Here, the primary corridor is from the northwest to southeast. This corridor has flights across numerous altitude bands, and likely represents a source of consistent noise in the park below. Further, flights peeling off this corridor are also evident, likely spreading noise across a larger spatial extent of this district. Neither district in the park displays any signs of consistent low-level sightseeing tours or similar aviation recreational activity. This information can be used to better understand how overflights are impacting natural sounds and the wilderness experience, and for planning and management purposes.

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