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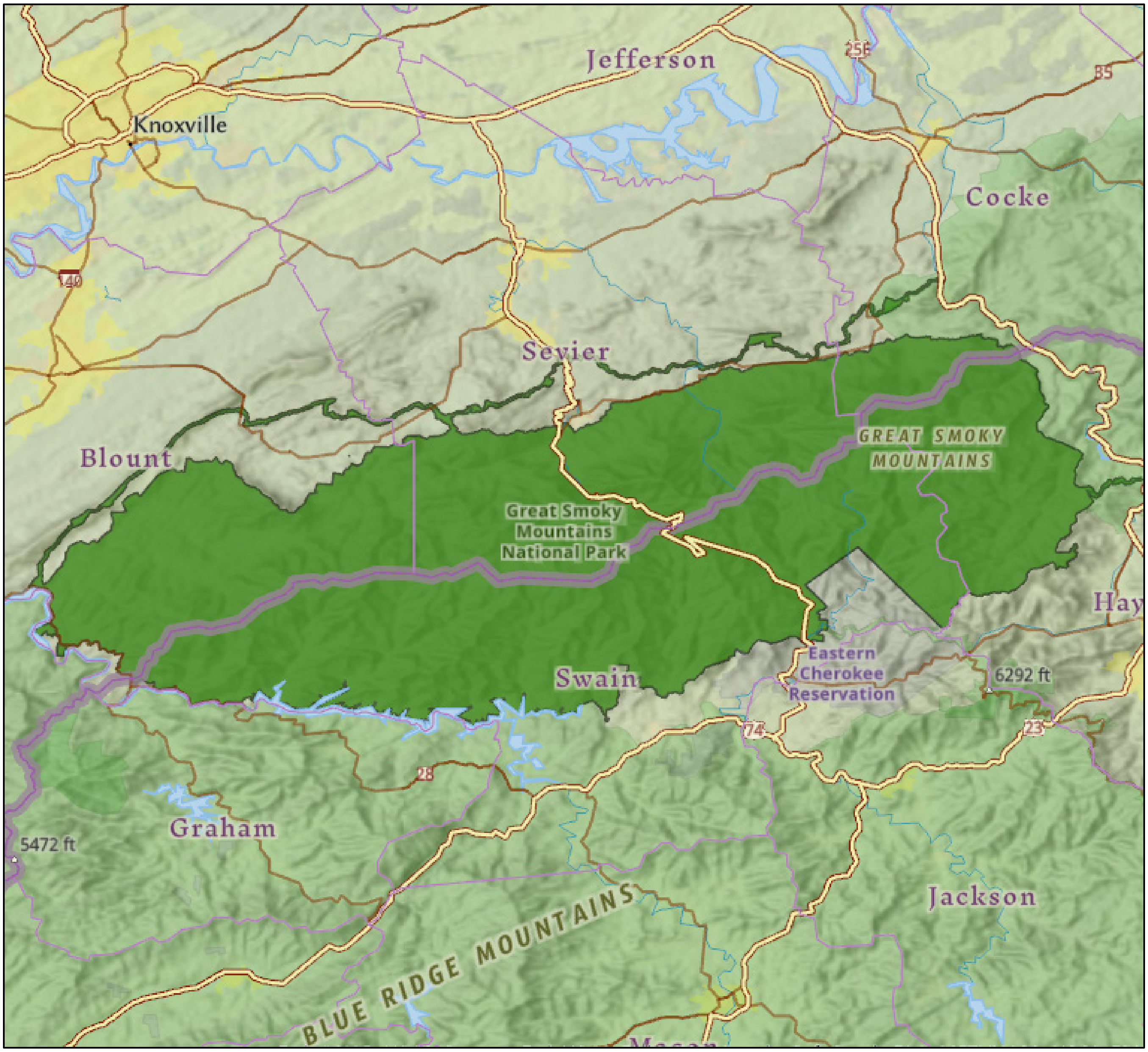
# Exploring spatial patterns of overflights at Great Smoky Mountains National Park

Natural Resource Report NPS/GRSM/NRR—2023/2518



**ON THE COVER**
Map of Great Smoky Mountains National Park
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# Exploring spatial patterns of overflights at Great Smoky Mountains National Park

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May 2023

U.S. Department of the Interior
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Please cite this publication as:

Peterson, B. A., Hutchinson, J. M. Shawn, Gurung, B., Beeco, J. A., Anderson, S. J., & Joyce, D. 2023. Exploring spatial patterns of overflights at Great Smoky Mountains National Park. Natural Resource Report NPS/GRSM/NRR—2023/2518. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2299255

NPS 133/188435, May 2023

# Contents

Page

# Figures

# Figures (continued)

# Tables

## Acknowledgements

The authors would like to thank the National Park Service Natural Sounds and Night Skies Division for funding and supporting this project, and specifically Vicki Ward and Warren Deeds. The authors would also like to thank Ethan McClure and Jim Renfro from Great Smoky Mountains National Park for their tireless support of maintaining the collection units and downloading the data.

## Abstract

This study explored spatial patterns of overflights at Great Smoky Mountains National Park (GRSM). Overflights were analyzed from September 25th, 2019 to June 1st, 2022 using Automatic Dependent Surveillance-Broadcast (ADS-B) data. The first phase of analysis focused on all overflights and found a high concentration of overflights above GRSM. The second phase of analysis focused on low-level overflights that fly below 10,000ft mean sea level (MSL) and fly within 10-miles of the GRSM boundary. Phase 2 figures display yearly overflights (2019, 2020, 2021, 2022) and show a concentration of flights beneath 4,000ft MSL near the northcentral and northwest boundary of GRSM. Additionally, for Phase 2, a figure was produced to show overflight travel patterns of rotorcraft that flew below 10,000ft MSL. The third phase of analysis removed all overflights known to not be air tours. Kernel density analysis was conducted using waypoints segmented into 500ft above ground level (AGL) altitude intervals. The altitude intervals with the highest density of overflights were ‘500-1,000ft AGL’ and ‘1,001-1,500ft 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

**GRSM:** Great Smoky Mountains National Park

**MSL**: Mean sea level

**NPS**: National Park Service

**NPATMA**: National Parks Air Tour Management Act

# Introduction

Great Smoky Mountains National Park (GRSM) was established in 1934 and since then has been designated as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site and an International Biosphere Reserve (National Park Service, 2021a). GRSM is located at the border of North Carolina and Tennessee, is comprised of 522,427 acres with elevations ranging between 875ft at Abrams Creek to 6,643ft on top of Clingmans Dome, and receives the highest visitation of any of the 59 national parks (National Park Service, 2017). Furthermore, the park preserves a vast expanse of the southern Appalachian Mountains ecosystem including acoustic resources. Past research found that the level of non-natural sounds is low at GRSM, but long-term projected increases in ground-based and aircraft traffic suggest a diminishing trend of the natural acoustic quality (Bates et al., 2018).

In 2019, commercial air tour operators reported conducting a total of 983 air tours at GRSM (National Park Service, 2021b), which was the fourth highest frequency of air tours in the national park system. The National Parks Air Tour Management Act of 2000 (NPATMA) (Public law 106-81) requires the National Park Service (NPS) and Federal Aviation Administration (FAA) to develop an air tour management plan for those parks and tribal lands where operators have applied to conduct commercial air tours, with the exception of Grand Canyon National Park and all national parks in the State of Alaska (Beeco & Joyce, 2019). NPATMA only applies to air tours within a half-mile of a park boundary. However, it is beneficial to understand overflight travel patterns beyond half-mile of park boundaries to gain a stronger sense of flight objective. The purpose of this report is to provide examination of the spatial patterns of all overflights at GRSM, which may assist in the management of the Air Tour Management Plan for air tours at GRSM.

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) (FAA, 2020). However, at GRSM, no airspace requires ADS-B technology. The nearest designated airspace to the park, is Class C to the northwest for Knoxville McGhee Tyson Airport. Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States. The Gatlinburg Pigeon Forge Airport is also north of the park, but does not include designated airspace; however, air tours do depart from the Sevierville area including private helipads.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (FAA, 2018). This study analyzed overflights using ADS-B technology that flew above GRSM. The data discussed in this report span from September 25th, 2019 to June 1st, 2022 and include 837 days of data and 144 days of missing data.

After the data were screened of flights known not to be air tours, the dataset was comprised of 13,931 flights. A total of 983 air tour flights were reported at GRSM for 2019. This discrepancy was expected because the data were collected for 981 days and there are likely still many flights that were captured that were not air tours.

# Methods

### Data Collection

Data were collected by two ADS-B terrestrial data loggers, which were located at Cove Mountain (35.69667, -83.6097 decimal degrees; 4,150 feet elevation) and Elkmont (35.66444, -83.5903 decimal degrees; 2,120 feet elevation) (Figure 1). The Elkmont data logger was necessary to collect flight data for aircraft that flew at a lower elevation than Cove Mountain. Both loggers were positioned with an unimpeded and expansive skyward exposure, though Cove Mountain was located at a mountain summit and Elkmont was located in a valley. The loggers recorded ADS-B signals as text files.

### 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, removed repeated occurrences of waypoints collected by both data loggers, created waypoint and flightline feature classes (spatial reference = North American Datum 1983 Universal Transverse Mercator Zone 17N), merged daily waypoints and flightlines, screened for suspected flights known to not 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).

To explore spatial patterns of overflights at GRSM, analysis was conducted in three phases. Phase 1 and Phase 2 report 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 undulate over the terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, and NPS; and all data were projected to North American Datum 1983 Universal Transverse Mercator Zone 17N.

## Phase 1 methods

The purpose of the first phase was to explore all overflight paths above GRSM regardless of flight type or altitude. Thus, the flightline feature class was not cleaned of any flight types nor was an altitude threshold implemented. To understand how flightpaths extended beyond the park boundary, a 10-mile buffer around the GRSM boundary was used. Four maps were produced. The first map shows overflights from September 25th, 2019 to December 31st, 2019 (all data collected for 2019). The second map shows overflights from January 1st, 2020 to December 31st, 2020 (all data collected for 2020). The third map shows overflight from January 1st, 2021 to December 31st, 2021 (all data collected for 2021). The fourth map shows overflights from January 1st, 2022 to June 1st, 2022 (all data collected for 2022).

### Phase 2 methods

The purpose of the second phase was to understand low-level overflights above GRSM 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 10,000ft MSL. This altitude was chosen because the highest point at GRSM is 6,643ft on top of Clingmans Dome (National Park Service, 2022), and approximately 3,000ft above the highest point in the park 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. Four maps were produced using the same dates as the maps produced in Phase 1. Because the park has an express interest in air tours, and all air tours at GRSM are conduct by helicopters, a fifth map was produced that includes only rotorcraft data from the entire period of collection.

### Phase 3 methods

The purpose of the third phase was to focus on flights that were likely air tours. The toolbox also 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 to not be air tours by: 1) cleaning the data of civil patrol flights, 2) major airlines, 3) straight-line flights, 4) flights with a flightpath less than a mile in length, and 5) survey flights. Civil patrol flights were identified as government aircraft (FAA Releasable Database type registrant = 5). Major airlines were identified using a list of major airlines (e.g., American Airlines, Delta Airlines, Southwest Airlines) inputted into the Python-based tool. 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 0.80 were visually inspected to validate straight-line paths were flown and these were subsequently removed from analysis. 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 likely to be air tours, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are air tours is not possible.

Because NPTMA applies to flights within 0.5-mile of the park boundary, a 0.5-mile buffer was used for Phase 3. Using a 500ft AGL altitude interval, waypoint data were segmented (0-500ft AGL; 501-1,000ft AGL; 1,001-1,500ft AGL; 1,501-2,000ft AGL; 2,001-2,500ft AGL; 2,501-3,000ft AGL; 3,001-3,500ft AGL; 3,501-4,000ft AGL; 4,001-4,500ft AGL; 4,501-5,000ft AGL) and kernel density analysis was conducted for each altitude interval. Because each altitude interval had different amounts of waypoints, density classifications were normalized across altitude intervals. To do this, the altitude interval with the highest maximum density of waypoints (1,001-1,500ft AGL) was used to normalize density classification, which required two steps. First, the 1,001-1,500ft AGL altitude density was classified using equal interval percentage breaks with five intervals of 20%. These percentage breaks were determined using the maximum waypoints per square kilometer as the '100%' value. Second, the maximum number of waypoints per each 20% interval were then applied to density classifications for the other altitude intervals. These steps are necessary to ensure density was calculated the same across altitude intervals regardless of the number of waypoints.

The kernel density analysis produced three figures. The first figure shows density analysis across sequential altitude intervals (beginning with the lowest altitude interval) until an altitude interval showed no density hot spots (1,501-2,000ft AGL). The next two figures show zoomed in maps of the density hot spots for 501 - 1,000ft and 1,001 - 1,500ft AGL altitude intervals. After these steps were accomplished, kernel density outputs were statistically compared for relatedness using the 'Band Collection Statistics' tool which conducted a correlation test.

Next, four more figures were produced to spatially compare AGL and MSL waypoint trends. The first figure displays waypoint altitudes between 0 - 2,500ft AGL using a 500ft AGL interval. The second figure displays waypoint altitudes between 2,501 - 5,000ft AGL using a 500ft AGL interval. The third figure displays waypoint altitudes between 0 - 5,000ft MSL using a 1,000ft MSL interval. The fourth figure displays waypoint altitudes between 5,001 - 10,000ft MSL using a 1,000ft MSL interval.

Next, descriptive analyses were conducted to understand waypoint frequencies across AGL and MSL altitudes; number of flights across months, day of the week, and hour of the day; and number of flights across aircraft types. To gain insight into overflight travel patterns across aircraft types, three more figures were produced for fixed-wing single engine aircraft, fixed-wing multi engine aircraft, and rotorcraft aircraft. Lastly, four figures were produced that display the rotorcraft that conducted the most flights.

# Results

## Results – Phase 1

Data were collected by two data loggers located at Cove Mountain and Elkmont (Figure 1). The research team mapped overflights for all flights (*n*=249,114). Figure 2 shows overflights from September 25th, 2019 to December 31st, 2019. Figure 3 shows overflights from January 1st, 2020 to December 31st, 2020. Figure 4 shows overflights from January 1st, 2021 to December 31st, 2021. Figure 5 shows overflights from January 1st, 2022 to June 1st, 2022.

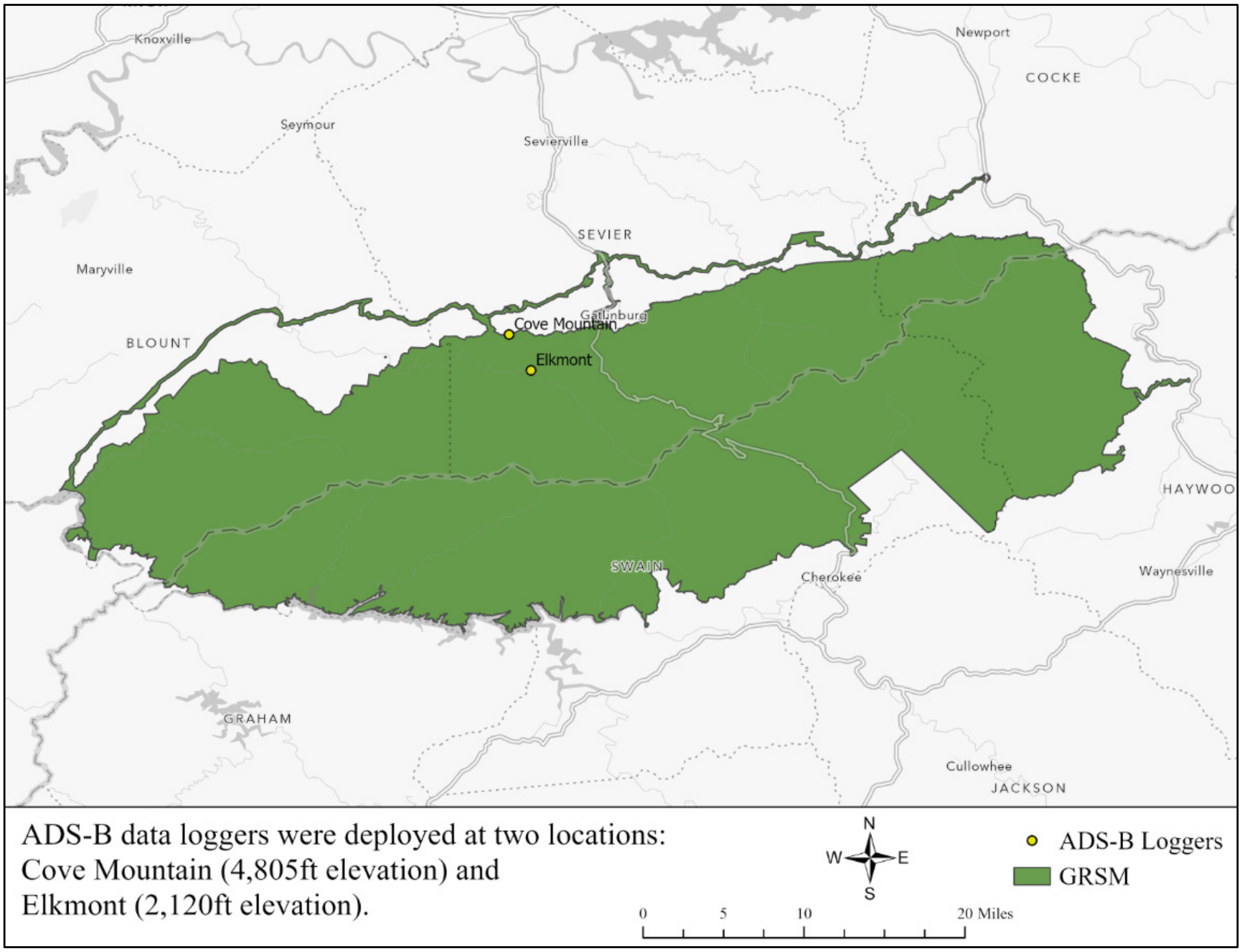

**Figure 1.** Locations of ADS-B data loggers.

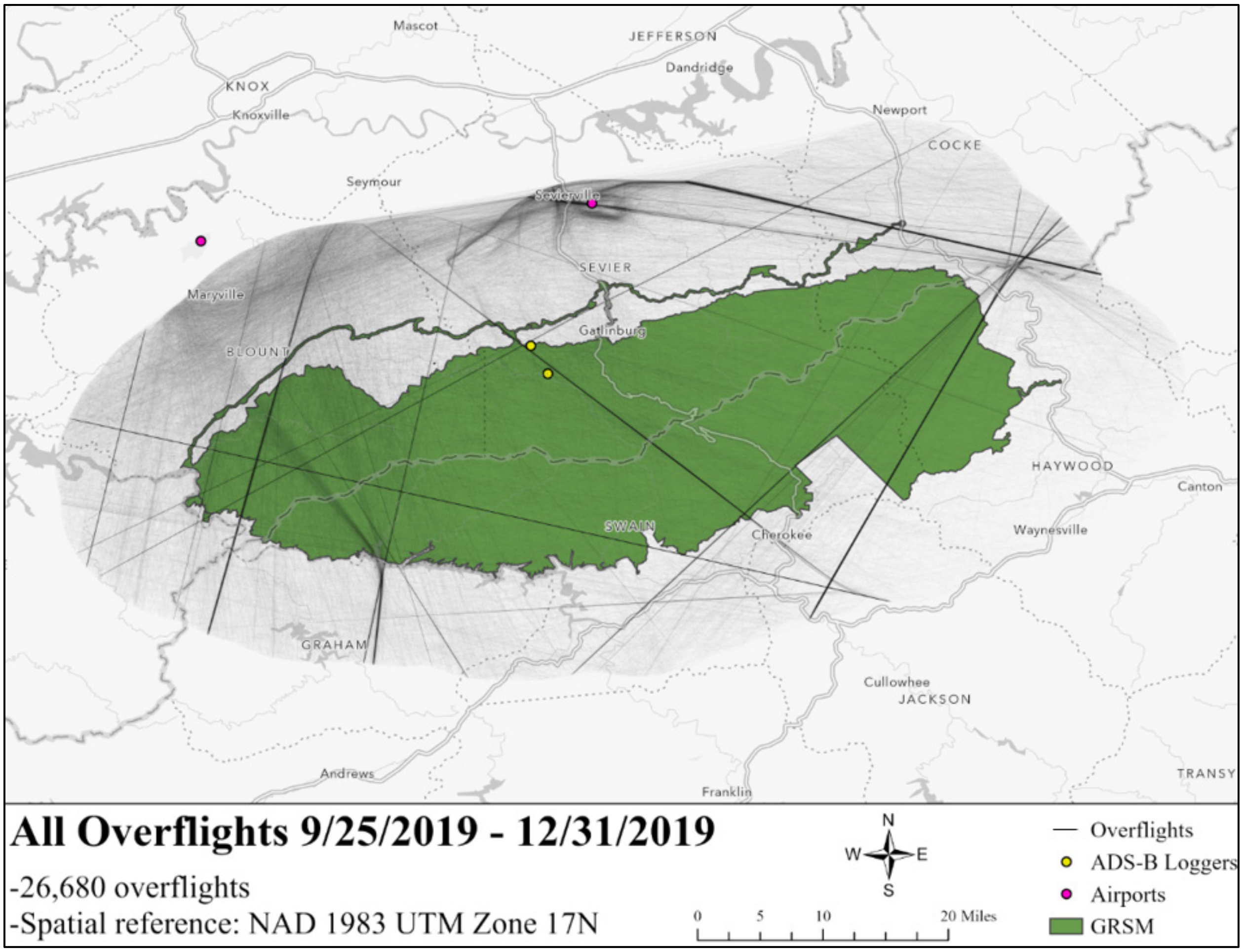

**Figure 2.** Overflights between September 25th, 2019 to December 31st, 2019.

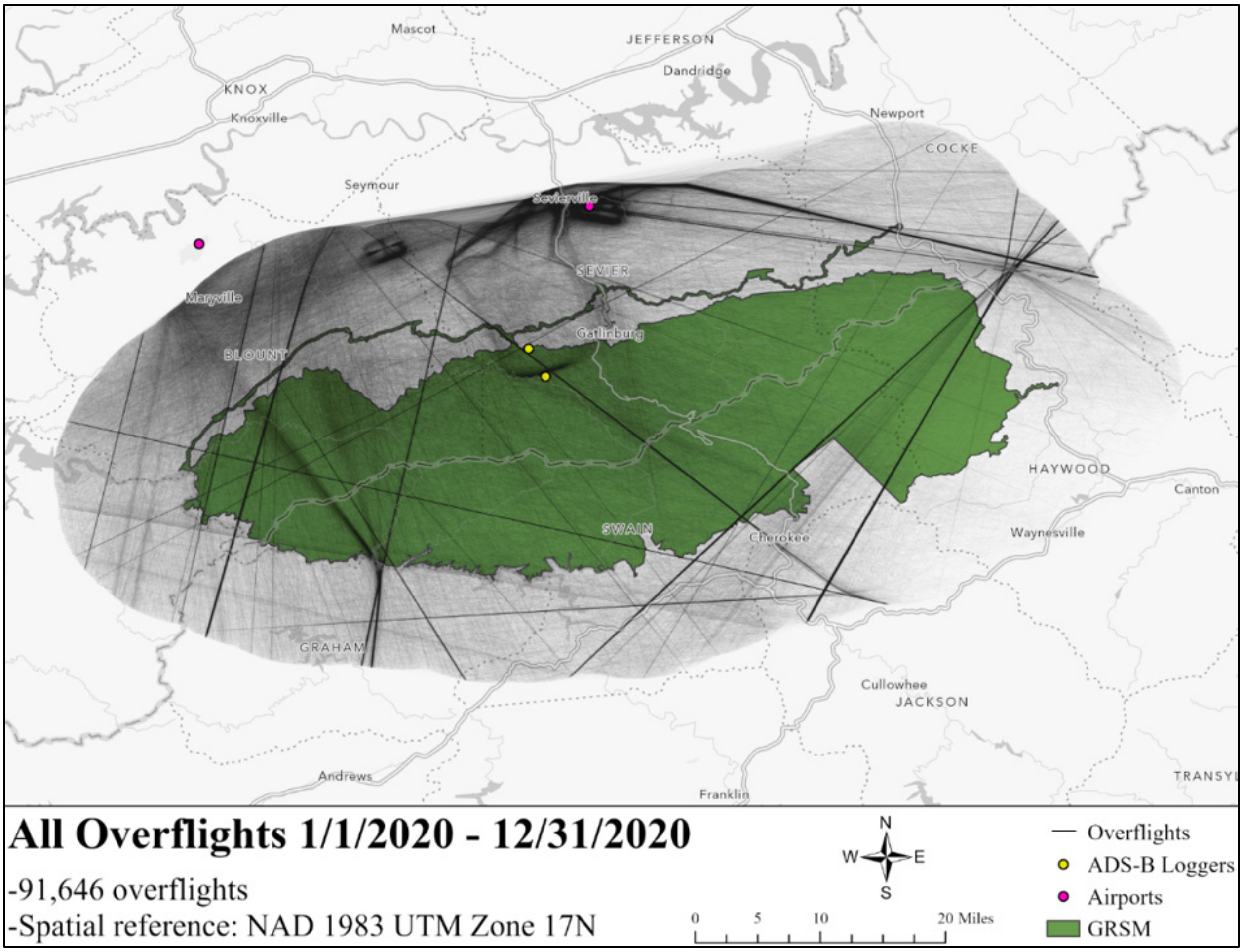

**Figure 3.** Overflights between January 1st, 2020 to December 31st, 2020.

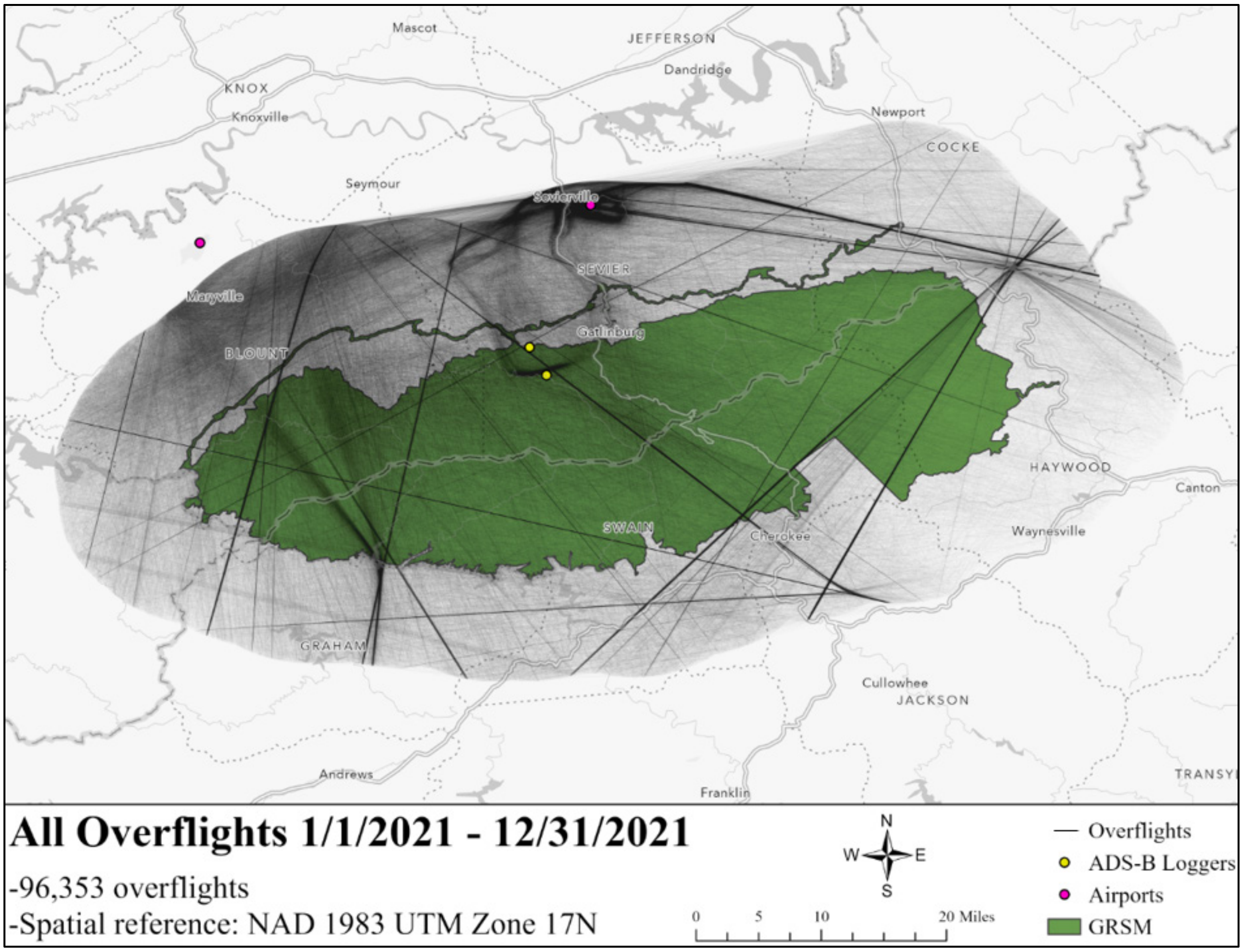

**Figure 4.** Overflights between January 31st, 2021 to December 31st, 2021.

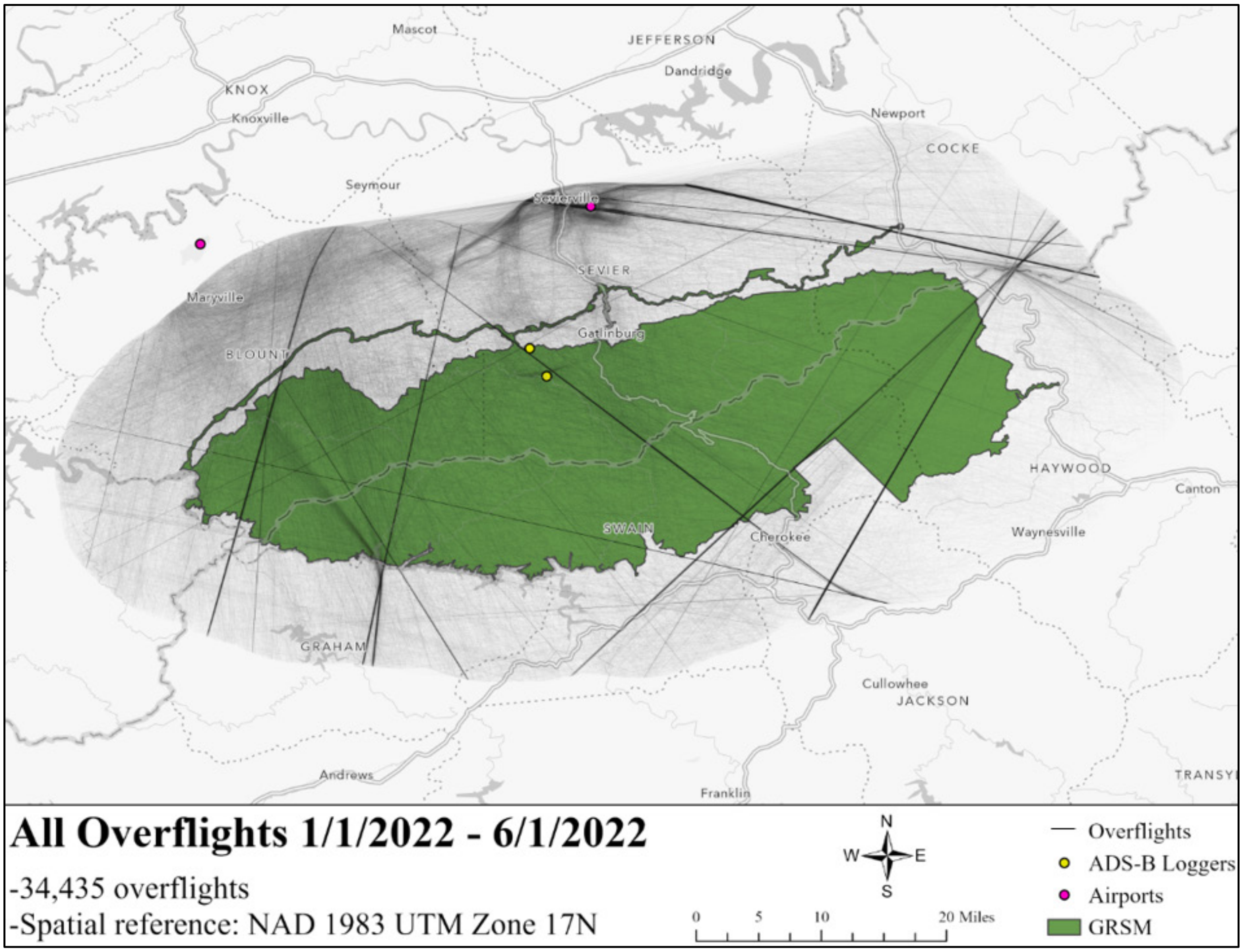

**Figure 5.** Overflights between January 1st, 2022 to June 1st, 2022.

## Results – Phase 2

The research team mapped low-level overflights that flew below 10,000ft MSL regardless of flight type. Four figures were produced. Figure 6 shows waypoint MSL altitudes for September 25th, 2019 to December 31st, 2019. Figure 7 shows waypoint MSL altitudes for January 1st, 2020 to December 31st, 2020. Figure 8 shows waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021. Figure 9 shows waypoint MSL altitudes for January 1st, 2022 to June 1st, 2022. Next, a fifth figure was produced that shows all rotorcraft waypoints that were equal to or below 10,000ft MSL for the entire data collection period of 9/25/2019 to 6/1/2022 (Figure 10).

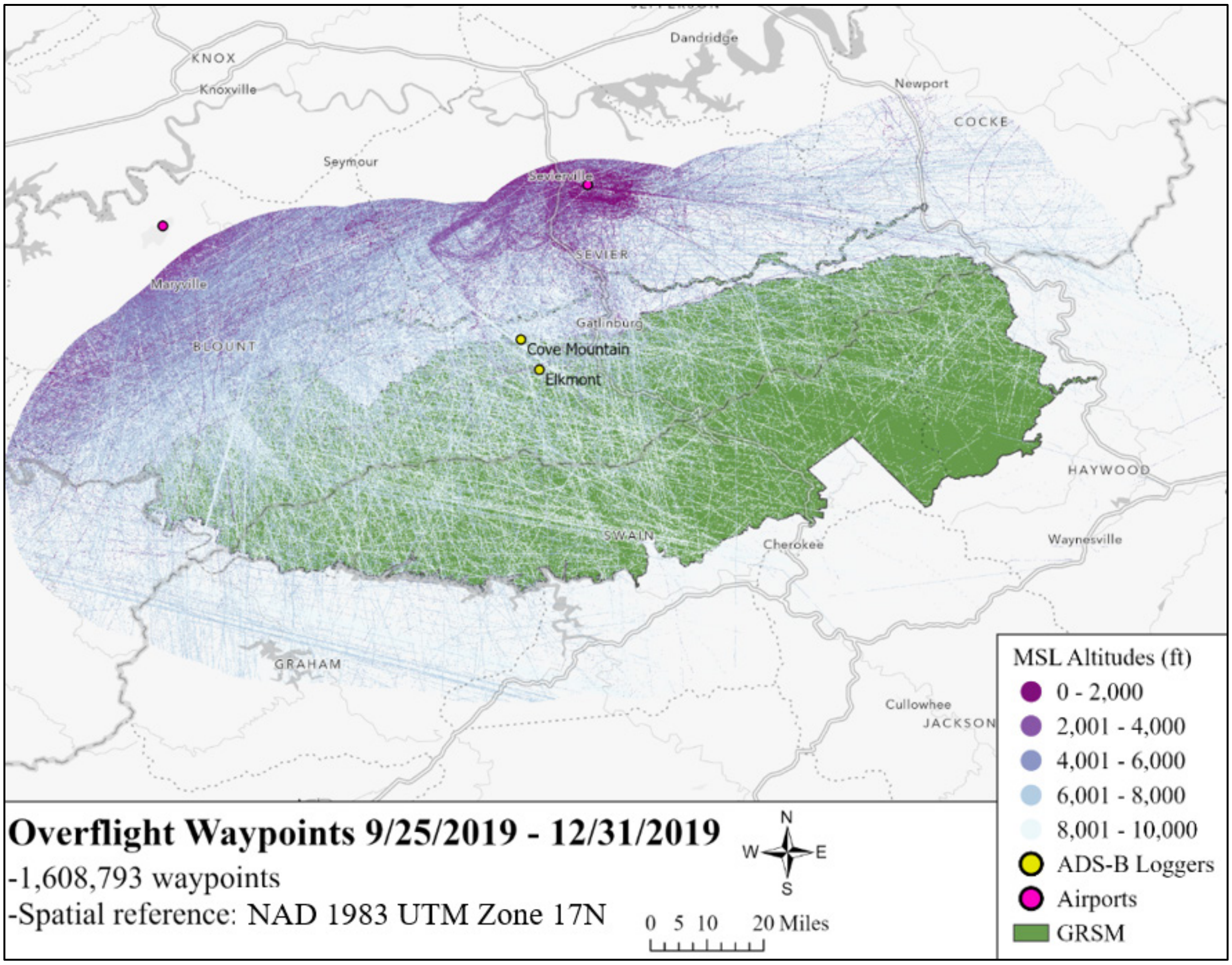

**Figure 6**. Waypoint MSL altitudes for September 25th, 2019 to December 31st, 2019.

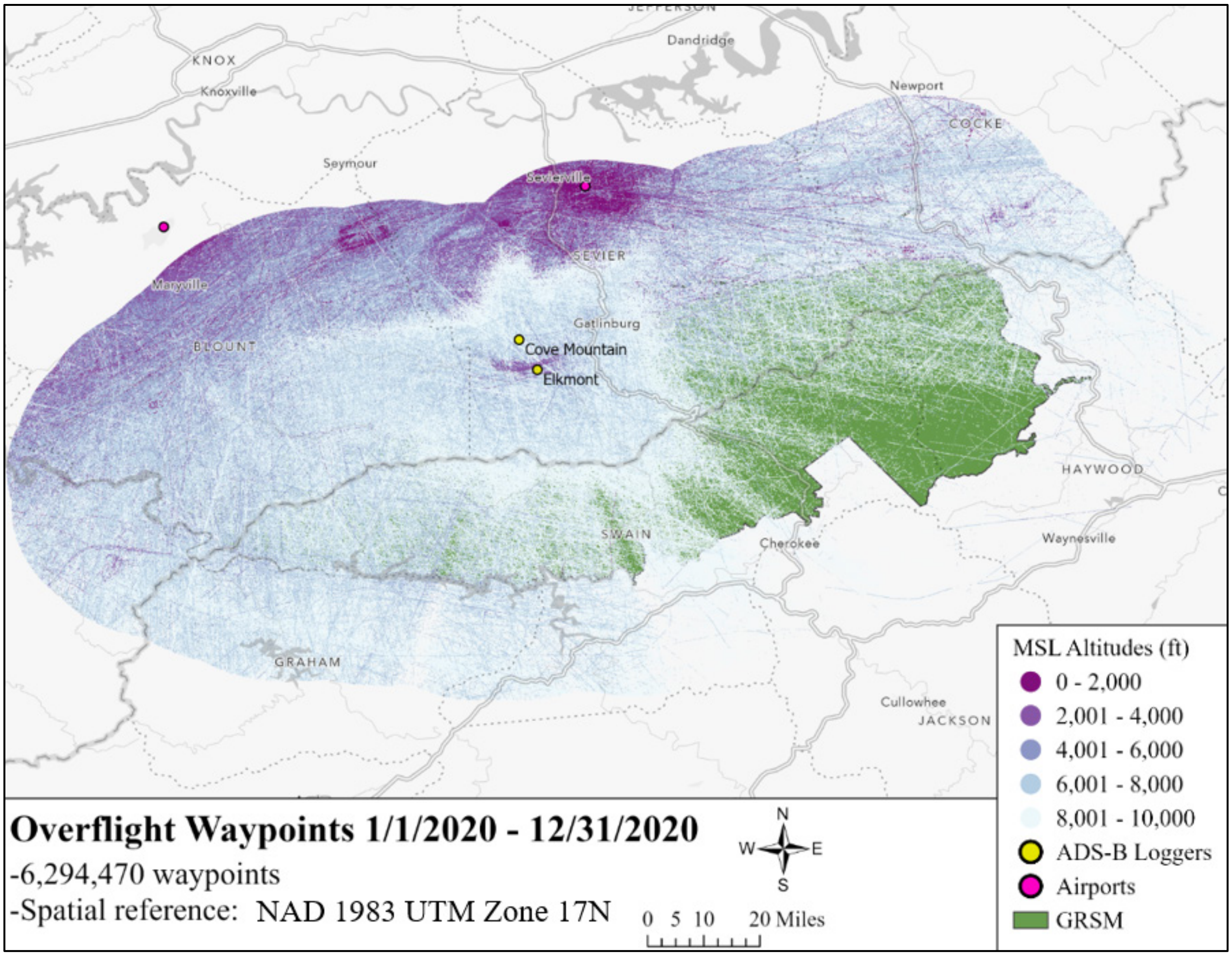

**Figure 7.** Waypoint MSL altitudes for January 1st, 2020 to December 31st, 2020.

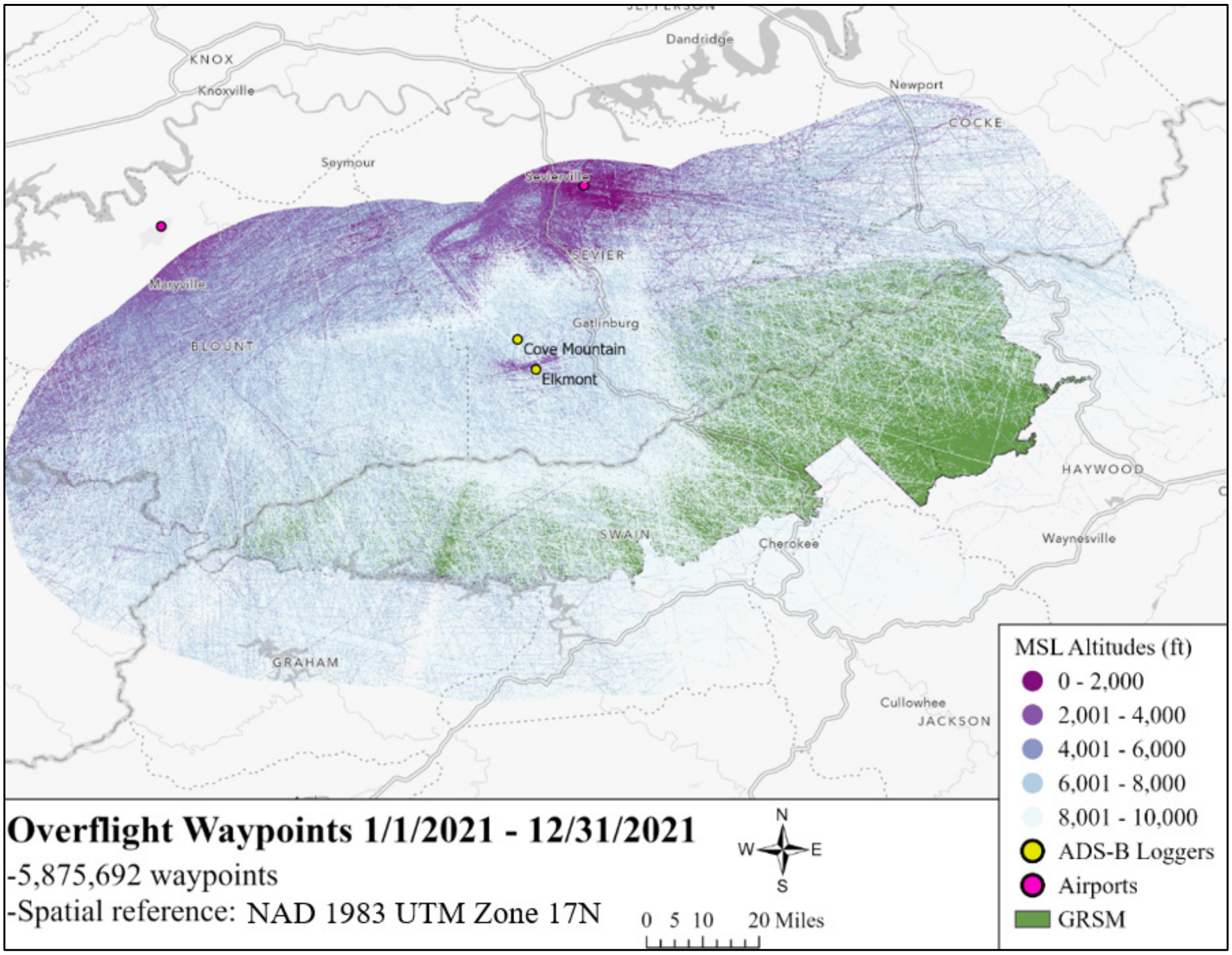

**Figure 8**. Waypoint MSL altitudes for January 1st, 2021 to December 31st, 2021.

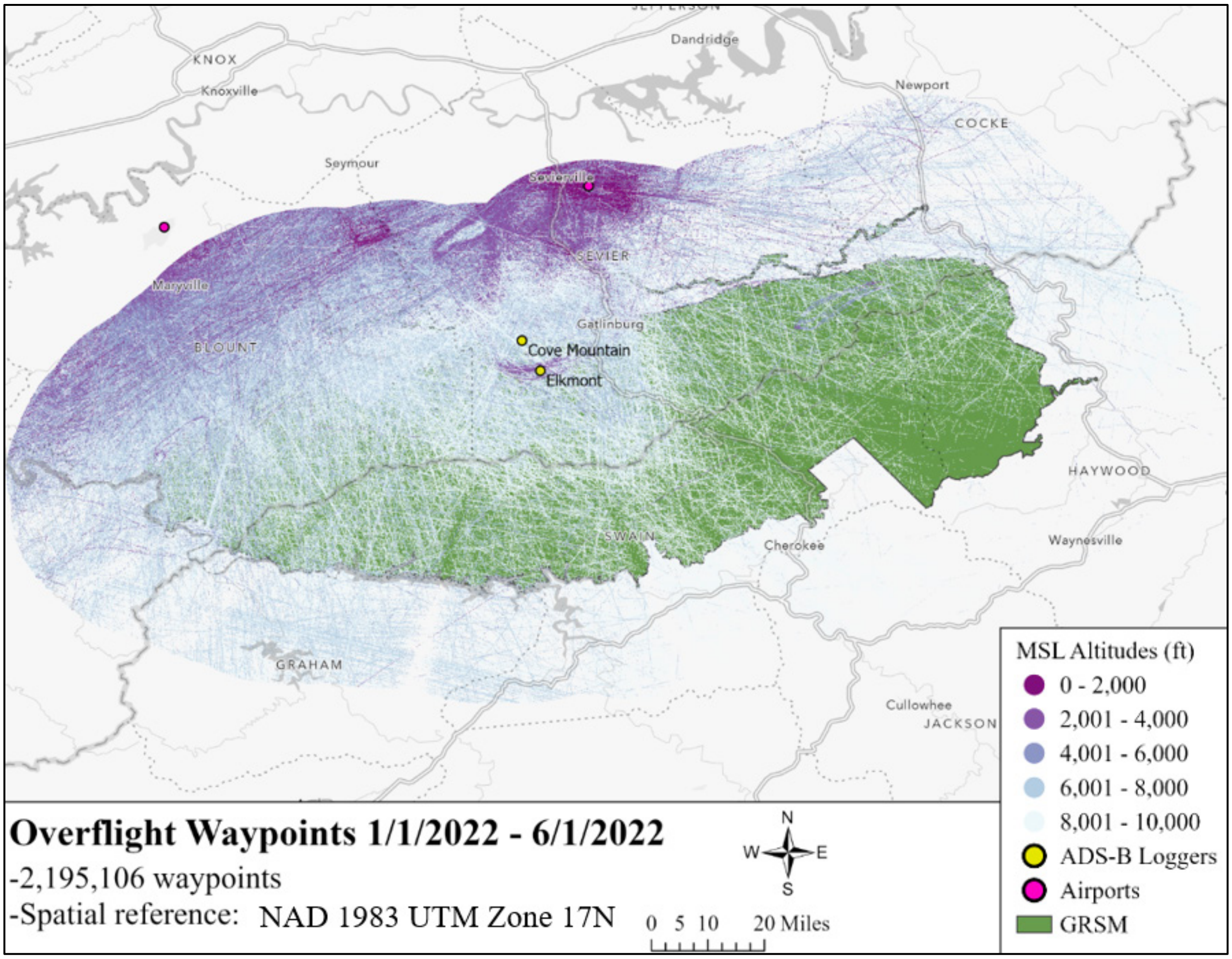

**Figure 9**. Waypoint MSL altitudes for January 1st, 2022 to June 1st, 2022.

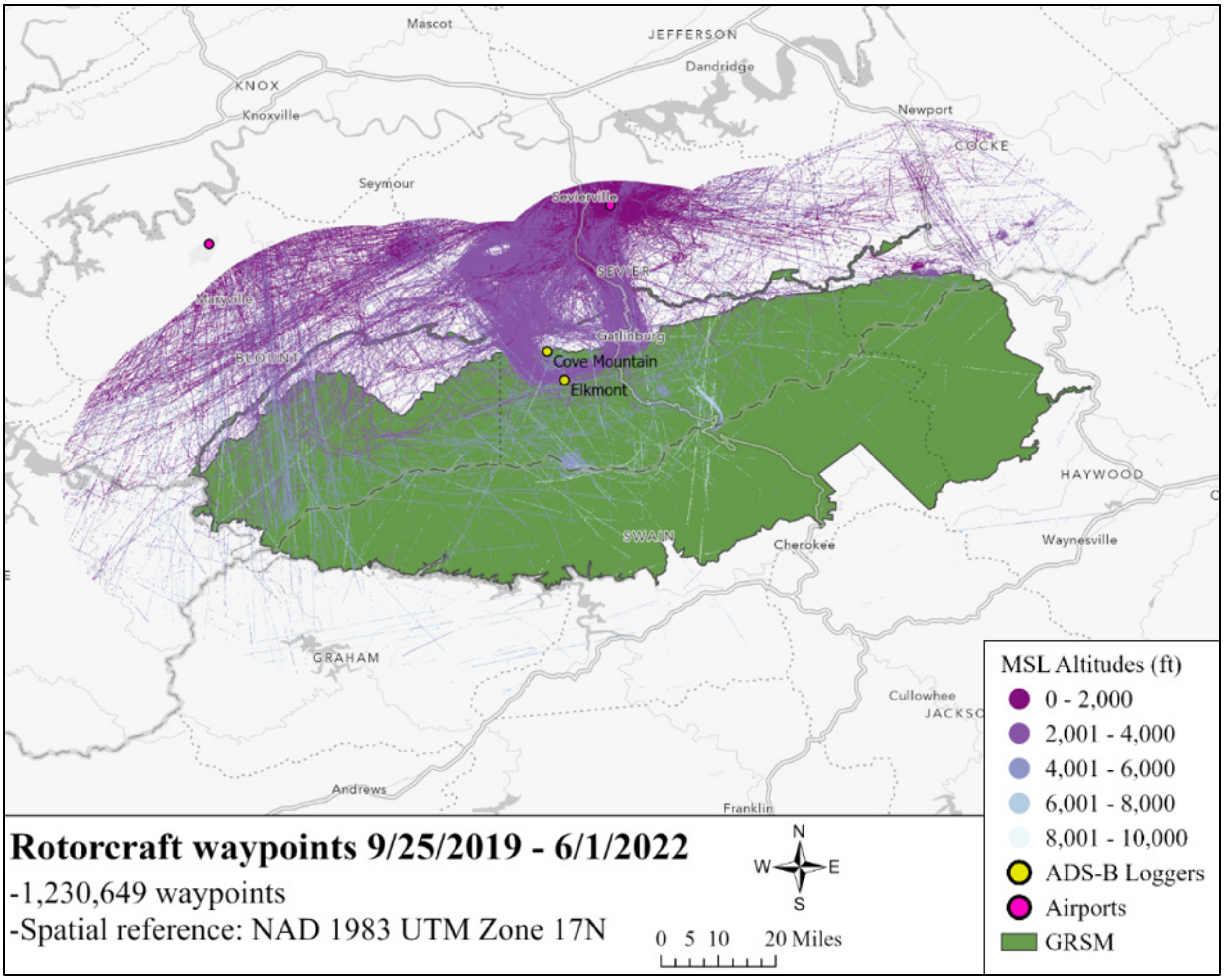

**Figure 10**. Rotorcraft waypoints below 10,000ft MSL for the entire collection period

## Results – Phase 3

Data were cleaned of all flights known to not be air tours, which resulted in the following numbers of flights removed: 1,407 civil patrol flights, 57,799 major airlines flights, 161,763 straight-line flights, 9,546 flights with a flightpath less than a mile in length, and 5 survey flights. This left 13,931 flights. Next, kernel density analysis was conducted across AGL altitude intervals up to 1,501 - 2,000ft AGL. The AGL altitude interval that showed the most density was 1,001 - 1,500ft. Figure 11 shows density hot spots for 501 - 1,000ft and 1,001 - 1,500ft AGL, but no density hot spots for 0 - 500ft and 1,501 - 2,000ft AGL. Figure 12 is zoomed in to show the density hot spot for 501 - 1,000ft AGL. Figure 13 is zoomed in to show the density hot spot for 1,001 - 1,500ft AGL. Data for Phase 3 analysis were not segmented by year.

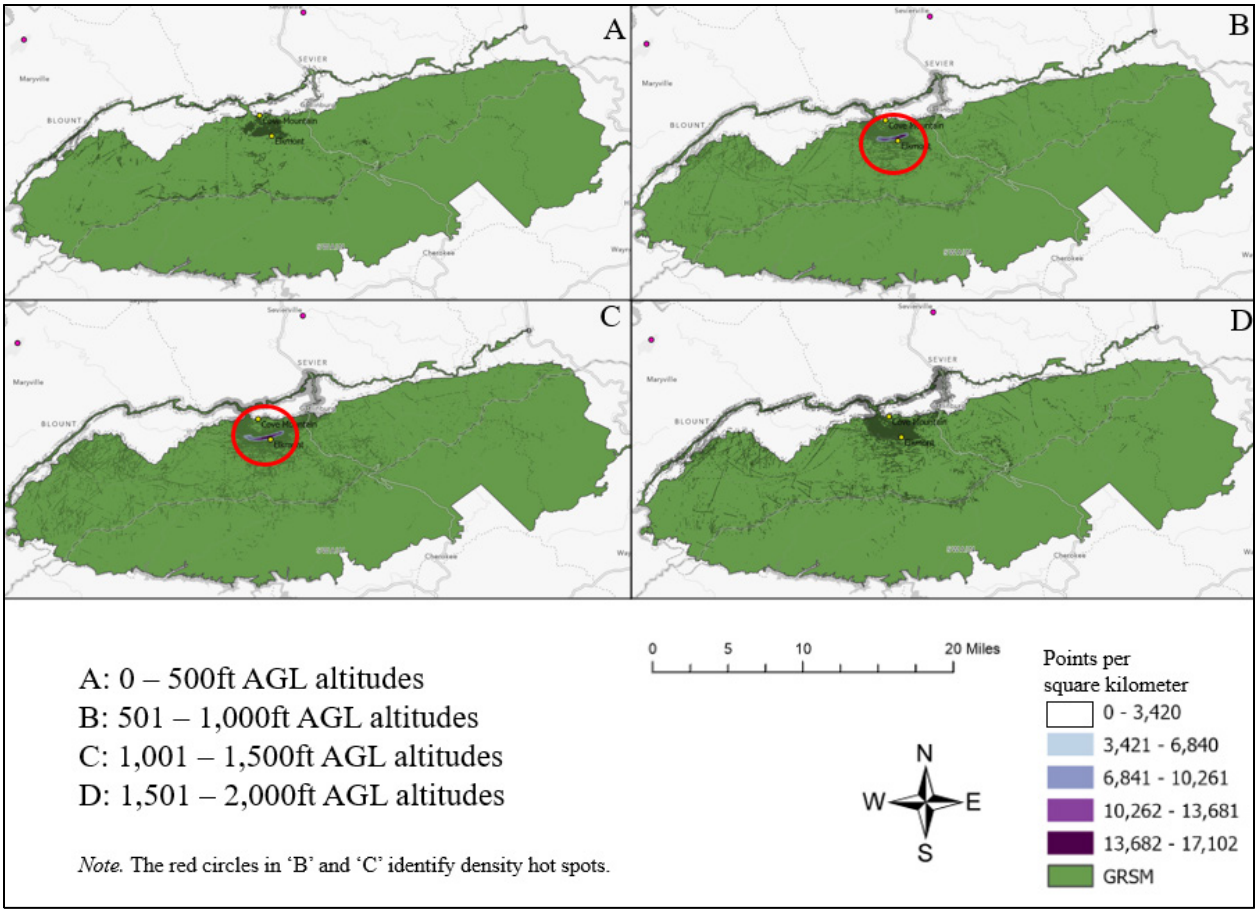

**Figure 11**. Kernel density analysis across AGL altitude intervals ranging from 0-2,000ft AGL.

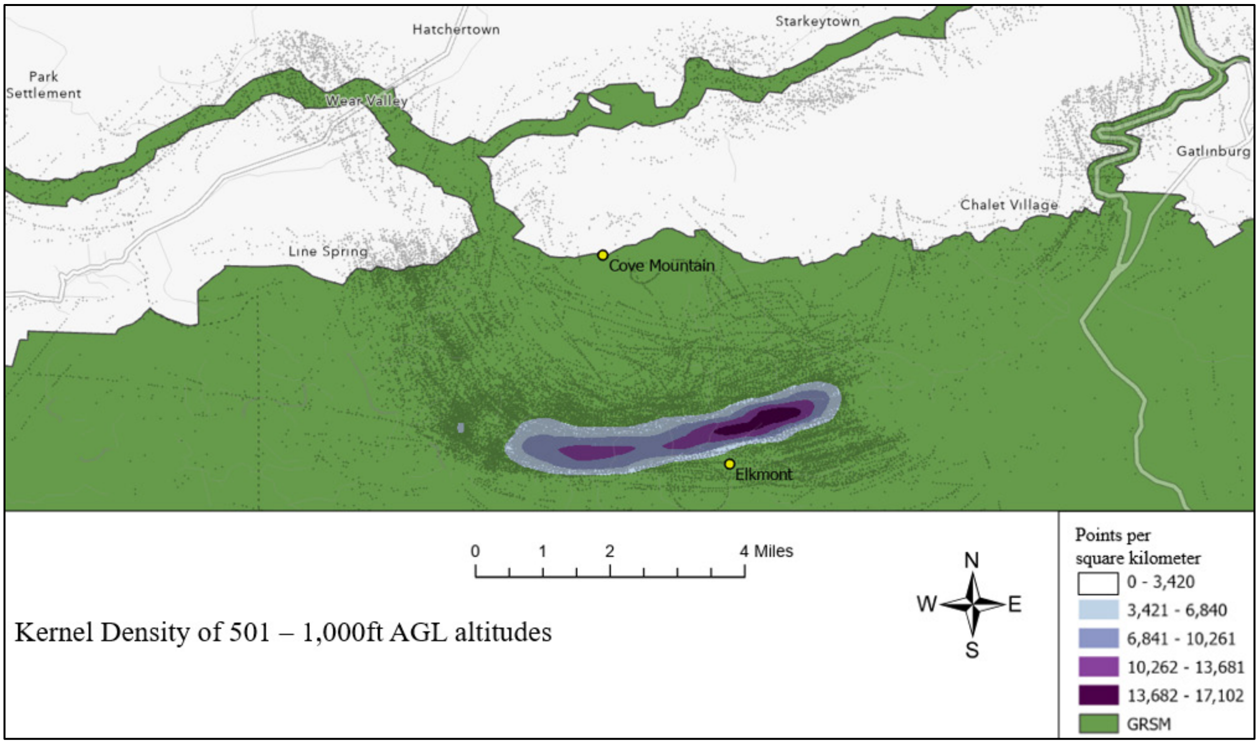

**Figure 12**. Kernel density analysis of 501 – 1,000ft AGL altitudes.

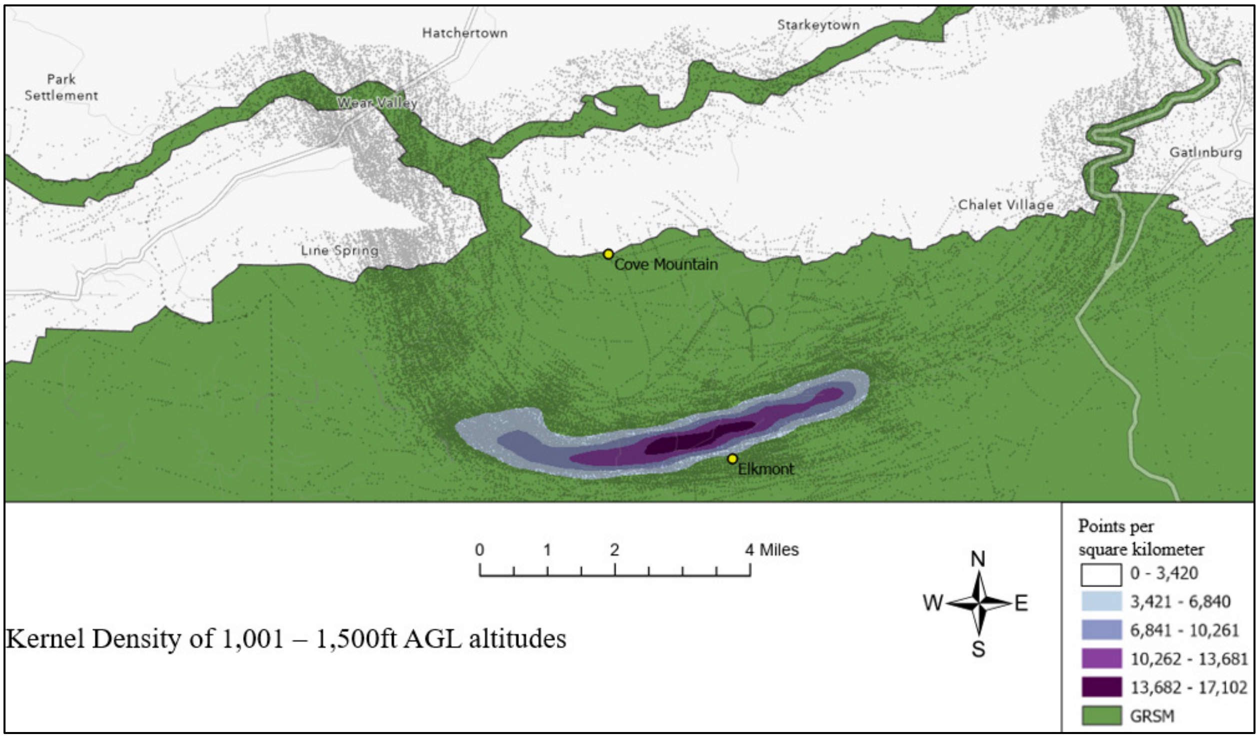

**Figure 13**. Kernel density analysis of 1,001 – 1,500ft AGL altitudes.

The density outputs were statistically compared using a correlation test. The altitude intervals with the highest correlation were 501 - 1,000ft AGL and 1,001 - 1,500ft AGL (Table 1). Also, Table 1 reveals that spatial patterns vary across different altitude levels.

**Table 1.** Spatial correlation matrix of Above Ground Level (AGL) altitude point densities.

| AGL Altitude Interval | 1. | 2. | 3. |
|---|---|---|---|
| 1. 0 – 500ft AGL | – | – | – |
| 2. 501 – 1,000ft AGL | 0.79 | – | – |
| 3. 1,001 – 1,500ft AGL | 0.60 | 0.89 | – |
| 4. 1,501 – 2,000ft AGL | 0.54 | 0.69 | 0.85 |

To further understand altitude trends of waypoints, four visualizations were produced. Figures 14 (altitudes ranging from 0 - 2,500ft AGL) and 15 (altitudes ranging from 2,501 - 5,000ft AGL) display AGL altitude trends directly above GRSM and show variability in flight altitudes. Figures 16 (altitudes ranging from 0 – 5,000ft MSL) and 17 (altitudes ranging from 5,001 – 10,000ft MSL) displays MSL altitude trends directly above GRSM and shows waypoint altitudes trended between 4,001 – 7,000ft MSL.

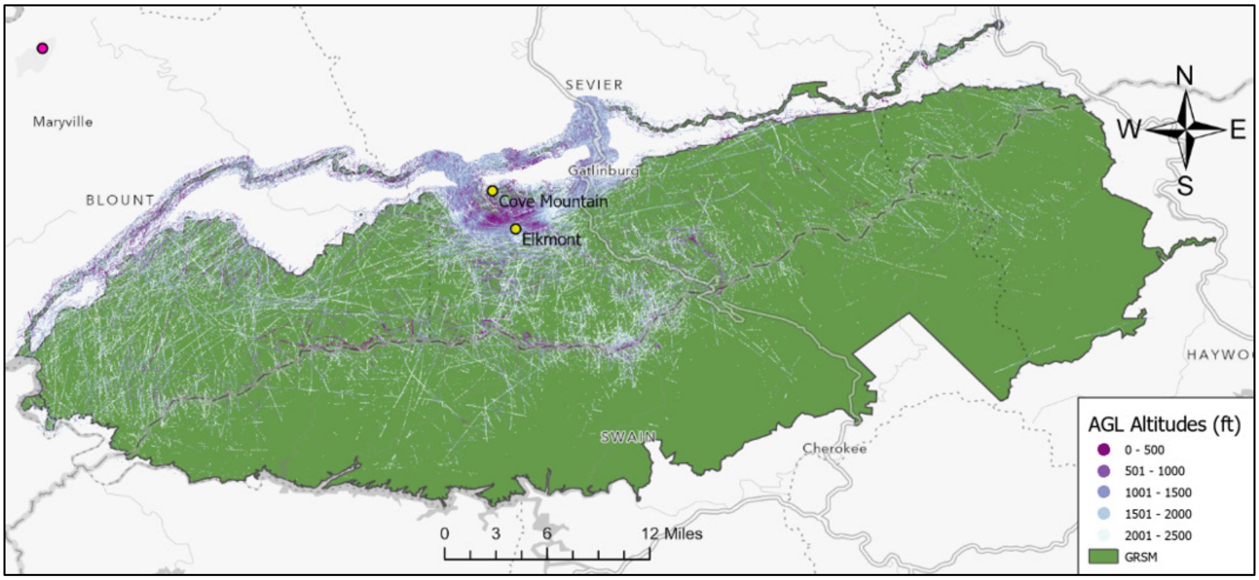

**Figure 14.** AGL altitude trends of altitudes ranging from 0 - 2,500ft AGL for waypoints within 0.5-mile of the GRSM boundary (*n*=344,067 waypoints).

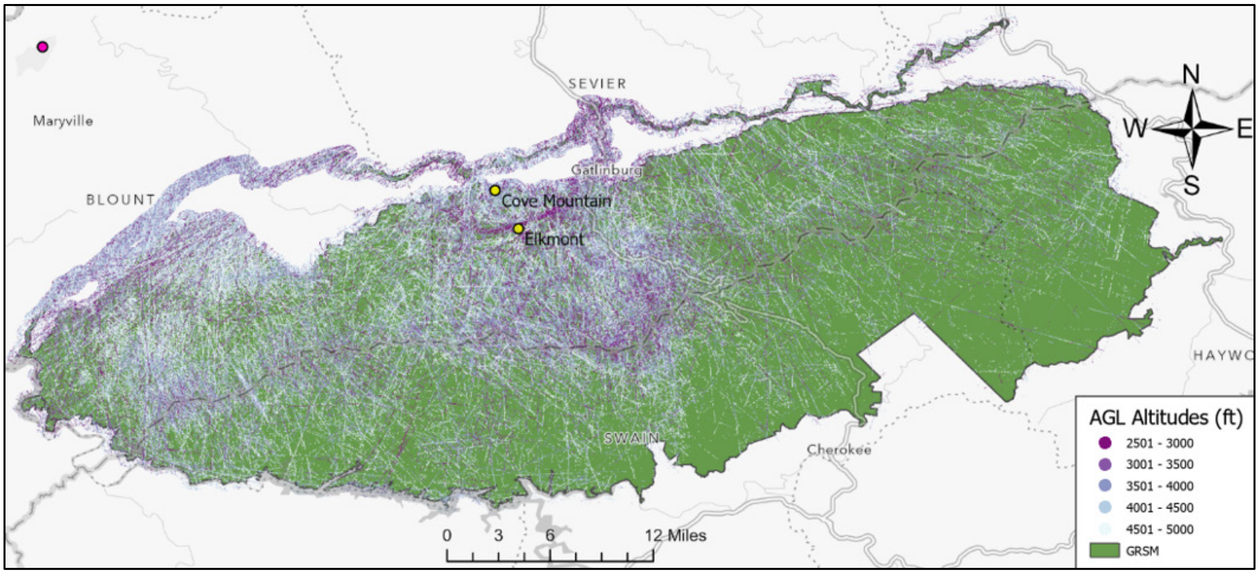

**Figure 15.** AGL altitude trends of altitudes ranging from 2,501 - 5,000ft AGL for waypoints within 0.5-mile of the GRSM boundary (*n*=455,767 waypoints).

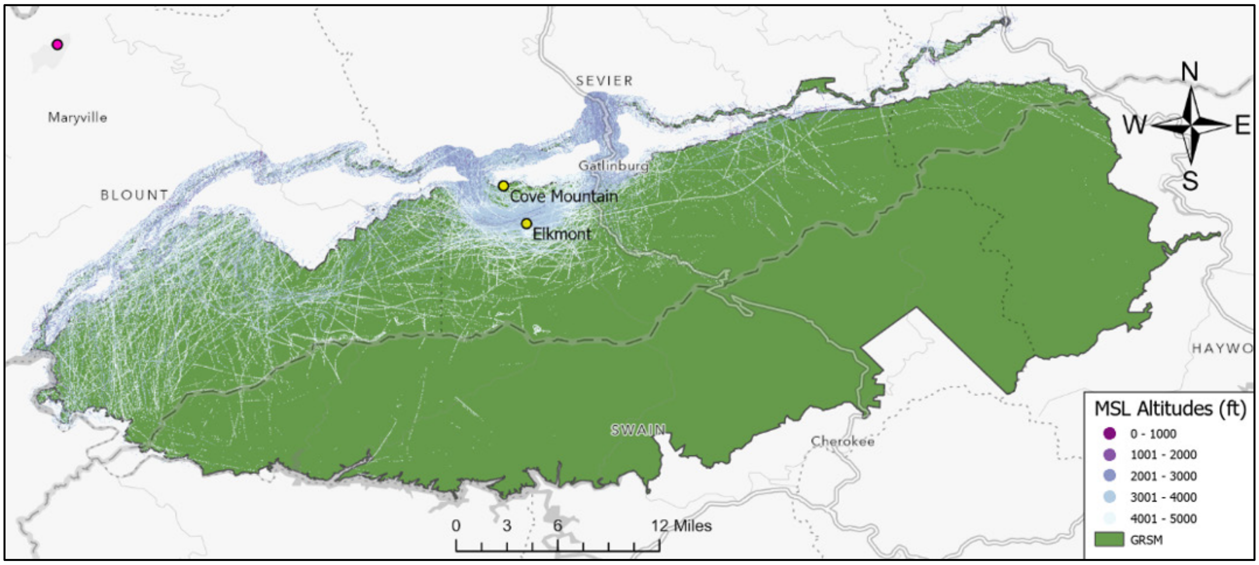

**Figure 16.** MSL altitude trends of altitudes ranging from 0 – 5,000ft MSL for waypoints within 0.5-mile of the GRSM boundary (*n*=348,760 waypoints).

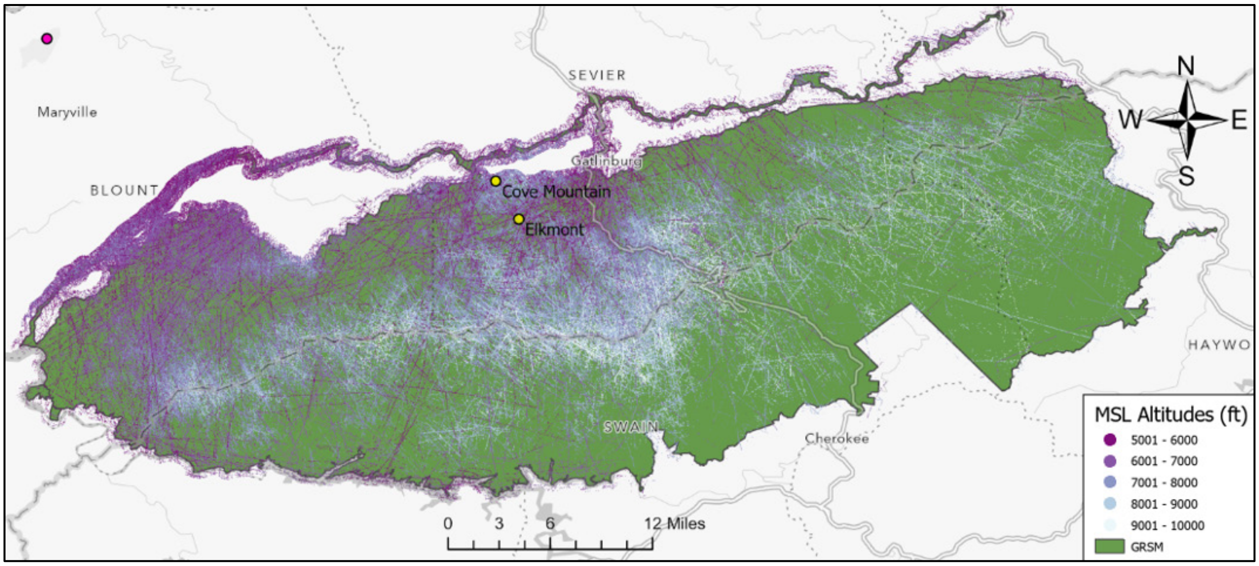

**Figure 17.** MSL altitude trends of altitudes ranging from 5,001 - 10,000ft MSL for waypoints within 0.5-mile of the GRSM boundary (*n*=450,993 waypoints).

The information displayed in Figures 14, 15, 16, and 17 were inputted into tables to quantitatively understand which altitude intervals had the highest percentage of waypoints. Table 2 shows analysis of 799,834 waypoints across AGL altitudes and Table 3 shows analysis of 799,753 waypoints across MSL altitudes. The AGL altitude interval that received the highest percentage of waypoints was 4,501-5,000ft (Table 2), but note how the 1,001-1,500ft category also stands out. The MSL altitude interval that received the high percentage of waypoints was 3,001-4,000ft (Table 3), with again the 1,001-1,500ft category standing out.

**Table 2.** Number and percentage of waypoints across AGL altitude intervals (*n*=799,834).

| AGL altitude | Number of waypoints | Percentage of waypoints |
|---|---:|---:|
| 0-500ft | 23,657 | 2.96 |
| 501-1,000ft | 73,105 | 9.14 |
| 1,001-1,500ft | 104,253 | 13.03 |
| 1,501-2,000ft | 78,495 | 9.81 |
| 2,001-2,500ft | 64,557 | 8.07 |
| 2,501-3,000ft | 66,084 | 8.26 |
| 3,001-3,500ft | 72,418 | 9.05 |
| 3,501-4,000ft | 84,970 | 10.62 |
| 4,001-4,500ft | 103,131 | 12.89 |
| 4,501-5,000ft | 129,164 | 16.15 |

**Table 3.** Number and percentage of waypoints across MSL altitude intervals (*n*=799,753).

| MSL altitude | Number of waypoints | Percentage of waypoints |
|---|---:|---:|
| 0-1,000ft | 4 | 0.00 |
| 1,001-2,000ft | 3,468 | 0.43 |
| 2,001-3,000ft | 79,259 | 9.91 |
| 3,001-4,000ft | 170,962 | 21.38 |
| 4,001-5,000ft | 95,067 | 11.89 |
| 5,001-6,000ft | 97,644 | 12.21 |
| 6,001-7,000ft | 146,046 | 18.26 |
| 7,001-8,000ft | 113,496 | 14.19 |
| 8,001-9,000ft | 72,637 | 9.08 |
| 9,001-10,000ft | 21,170 | 2.65 |

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 13,931). Table 4 shows number of days air tour data were collected, overflights per month, and average number of flights per day for the data collection duration, which occurred from September 25th, 2019 to June 1st, 2022. GRSM received the most overflights during June of 2021 (30.40 average number of flights per day).

**Table 4.** Number and percentage of overflights across months (*n*=13,931).

| Month | Number of data collection days* | Number of overflights | Average Number of overflights per day |
|---|---:|---:|---:|
| September 2019 | 6 | 16 | 2.67 |
| October 2019 | 18 | 362 | 20.11 |
| November 2019 | 30 | 769 | 25.63 |
| December 2019 | 31 | 455 | 14.68 |
| January 2020 | 31 | 375 | 12.10 |
| February 2020 | 29 | 381 | 13.14 |
| March 2020 | 25 | 288 | 11.52 |
| April 2020 | 23 | 152 | 6.61 |
| May 2020 | 31 | 456 | 14.71 |
| June 2020 | 30 | 425 | 14.17 |
| July 2020 | 31 | 669 | 21.58 |
| August 2020 | 31 | 631 | 20.35 |
| September 2020 | 30 | 179 | 5.97 |

* For some months, data collection did not occur everyday because technological failure.

**Table 4.** Number and percentage of overflights across months (*n*=13,931).

| Month | Number of data collection days* | Number of overflights | Average Number of overflights per day |
|---|---|---|---|
| October 2020 | 31 | 817 | 26.35 |
| November 2020 | 30 | 436 | 14.53 |
| December 2020 | 30 | 123 | 4.10 |
| January 2021 | 31 | 65 | 2.10 |
| February 2021 | 28 | 219 | 7.82 |
| March 2021 | 31 | 561 | 18.10 |
| April 2021 | 30 | 472 | 15.73 |
| May 2021 | 31 | 743 | 23.97 |
| June 2021 | 30 | 912 | 30.40 |
| July 2021 | 1 | 6 | 6.00 |
| August 2021 | 13 | 185 | 14.23 |
| September 2021 | 30 | 500 | 16.67 |
| October 2021 | 31 | 830 | 26.77 |
| November 2021 | 30 | 870 | 29.00 |
| December 2021 | 31 | 301 | 9.71 |
| January 2022 | 13 | 148 | 11.38 |
| February 2022 | – | – | – |
| March 2022 | 15 | 299 | 19.93 |
| April 2022 | 23 | 592 | 25.74 |
| May 2022 | 31 | 677 | 21.84 |
| June 2022 | 1 | 17 | 17.00 |
| Total | 837 | 13,931 | 16.64 |

* For some months, data collection did not occur everyday because technological failure.

Table 5 shows percentage of flights across days of the week. The day of the week with the highest percentage of flights was Saturdays (18.20%). Table 6 shows percentage of overflights across hour of the day for when air tours are permitted. Most overflights occur from 12:00pm to 4:00pm. Table 7 shows percentage of overflights across aircraft type. Fixed wing single engine is the aircraft type most common among overflights at GRSM.

**Table 5.** Percentage of overflights across days of the week.

| Day of the week | Percentage of overflights |
|---|---:|
| Monday | 12.10 |
| Tuesday | 12.20 |
| Wednesday | 13.00 |
| Thursday | 12.70 |
| Friday | 14.80 |
| Saturday | 18.20 |
| Sunday | 17.00 |

**Table 6.** Number and percentage of overflights across hours of the day for weekdays (*n*=7,379) and weekends (*n*=3,336).

| Hour | Percentage of overflights |
|---|---:|
| 6:00am-7:00am | 0.42 |
| 7:00am-8:00am | 0.79 |
| 8:00am-9:00am | 1.56 |
| 9:00am-10:00am | 3.45 |
| 10:00am-11:00am | 7.01 |
| 11:00am-12:00pm | 9.97 |
| 12:00pm-1:00pm | 11.11 |
| 1:00pm-2:00pm | 12.00 |
| 2:00pm-3:00pm | 11.04 |
| 3:00pm-4:00pm | 10.68 |
| 4:00pm-5:00pm | 9.86 |
| 5:00pm-6:00pm | 9.03 |
| 6:00pm-7:00pm | 7.45 |
| 7:00-8:00pm | 5.62 |

**Table 7.** Percentage of overflights across aircraft type.

| Aircraft type | Percentage |
|---|---|
| Fixed-wing single engine | 53.82 |
| Fixed-wing multi engine | 13.15 |
| Rotorcraft | 33.03 |

Using the cleaned dataset comprised of all four years of data, three more figures were produced to show overflight travel patterns across aircraft type. Figure 18 displays overflight travel patterns for fixed wing single engine aircraft. Figure 19 displays overflight travel patterns for fixed wing multi engine aircraft. Figure 20 displays overflight travel patterns for rotorcraft.

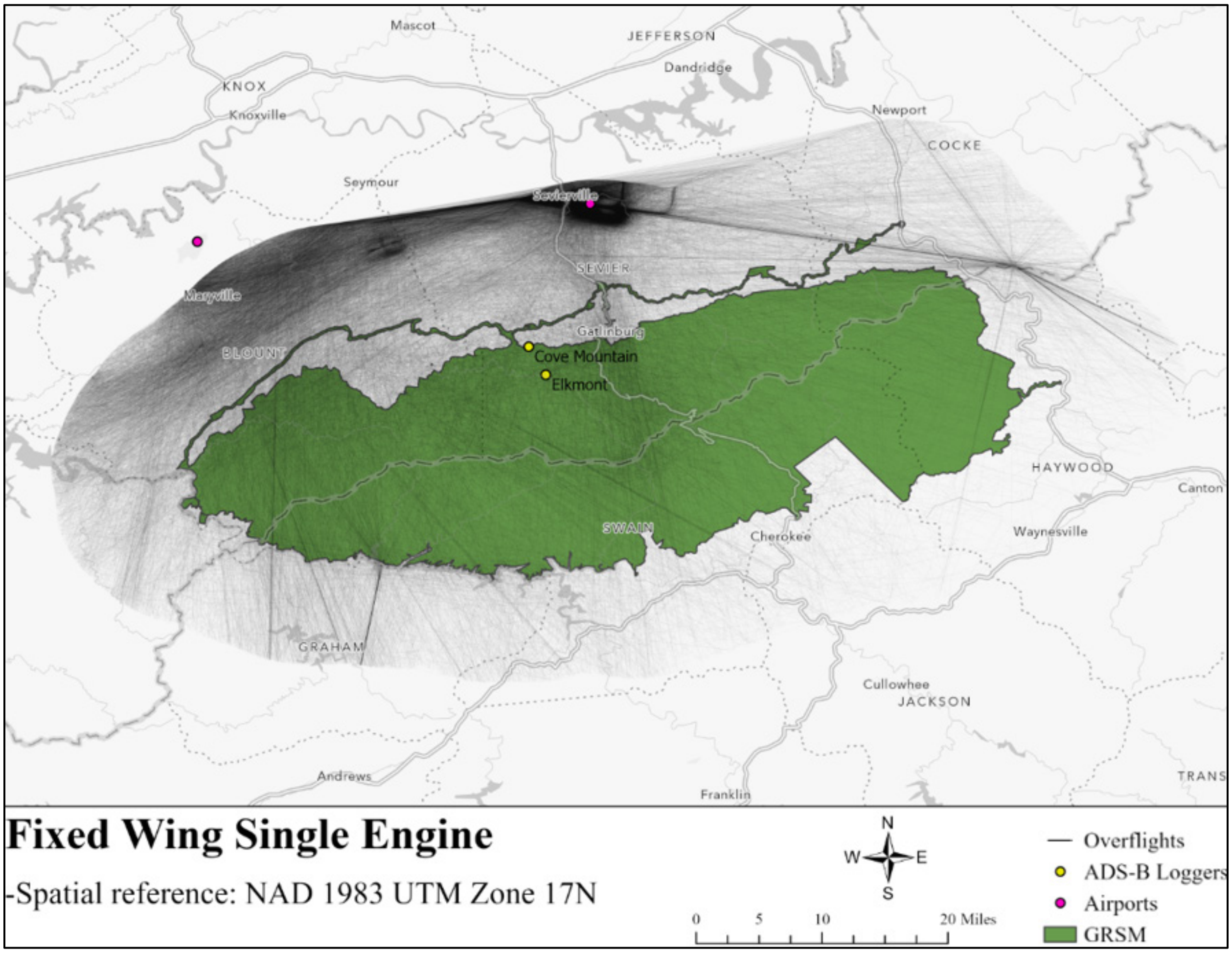

**Figure 18.** Phase 3 fixed wing single engine overflight travel patterns.

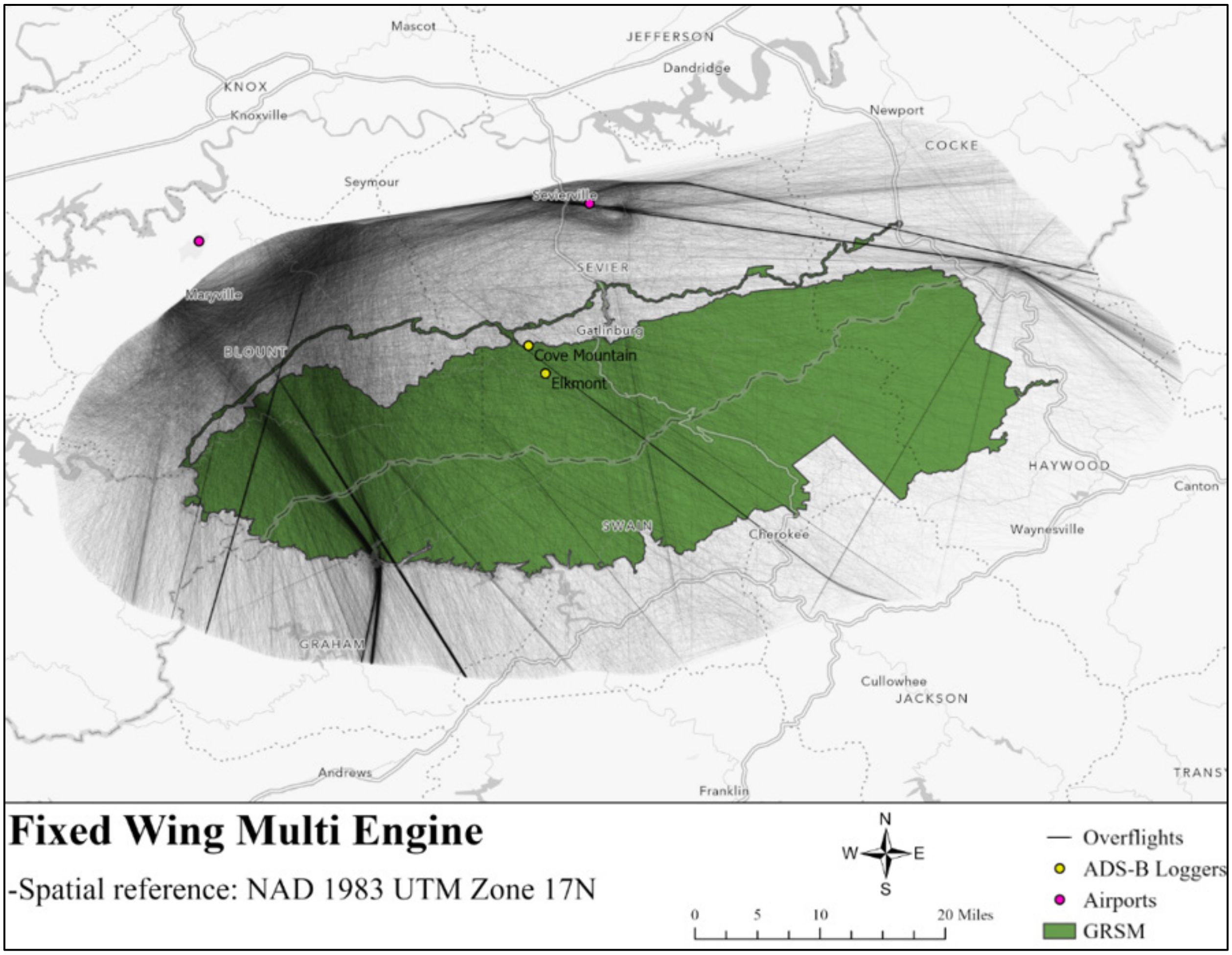

**Figure 19.** Phase 3 fixed wing multi engine overflight travel patterns.

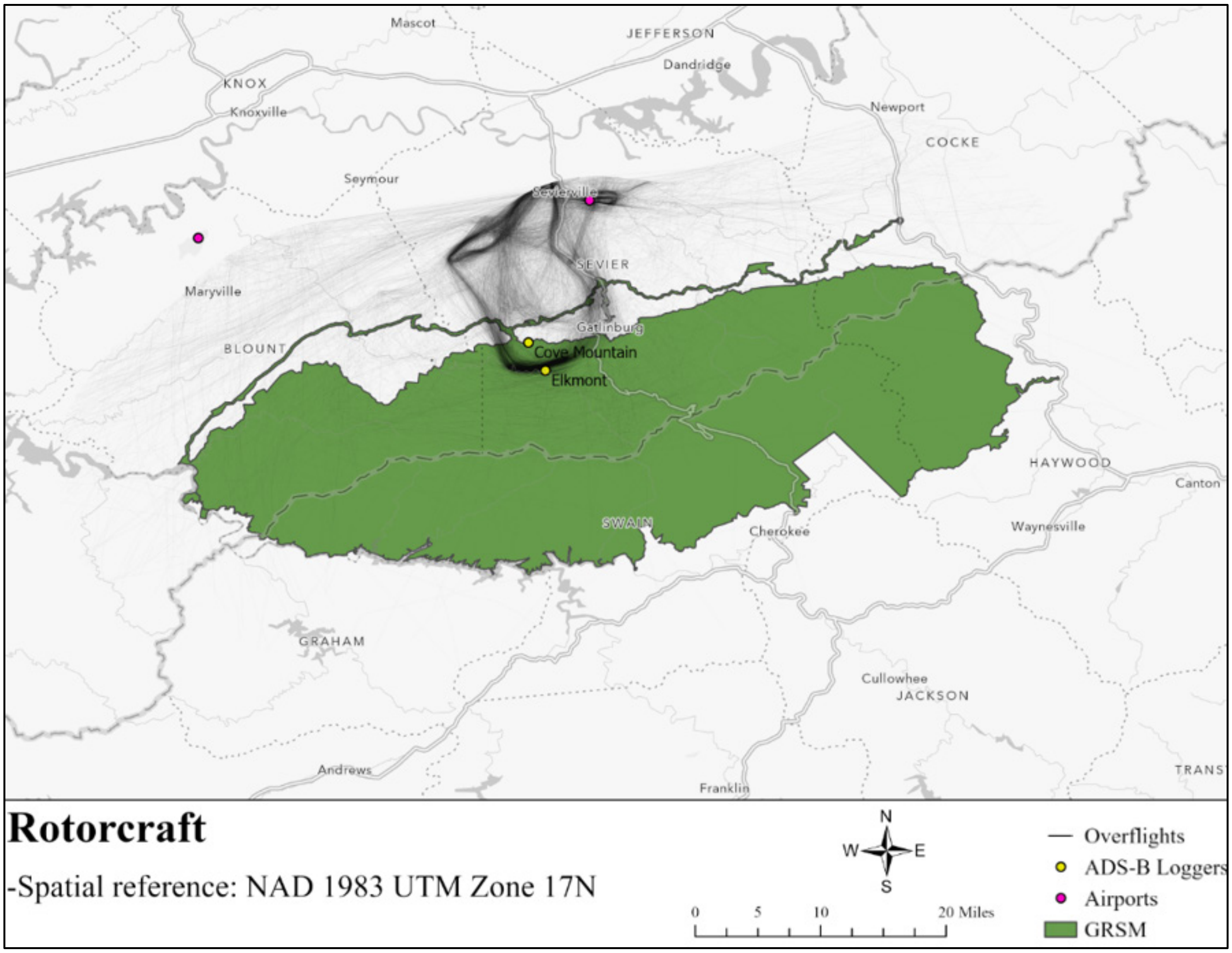

**Figure 20.** Phase 3 rotorcraft overflight travel patterns.

Lastly, figures were produced for rotorcraft that conducted the most overflights (Figures 21-24). A 10-mile buffer around the GRSM perimeter was applied to gain a better understanding of flight routes. The following four aircraft conducted the most rotorcraft flights: Figure 21 displays N415RP (Robinson Helicopter Company), Figure 22 displays N555FP (Robinson Helicopter Company), Figure 23 displays N571CJ (Bell Helicopter Textron), and Figure 24 displays N219SH (Bell Helicopter Textron).

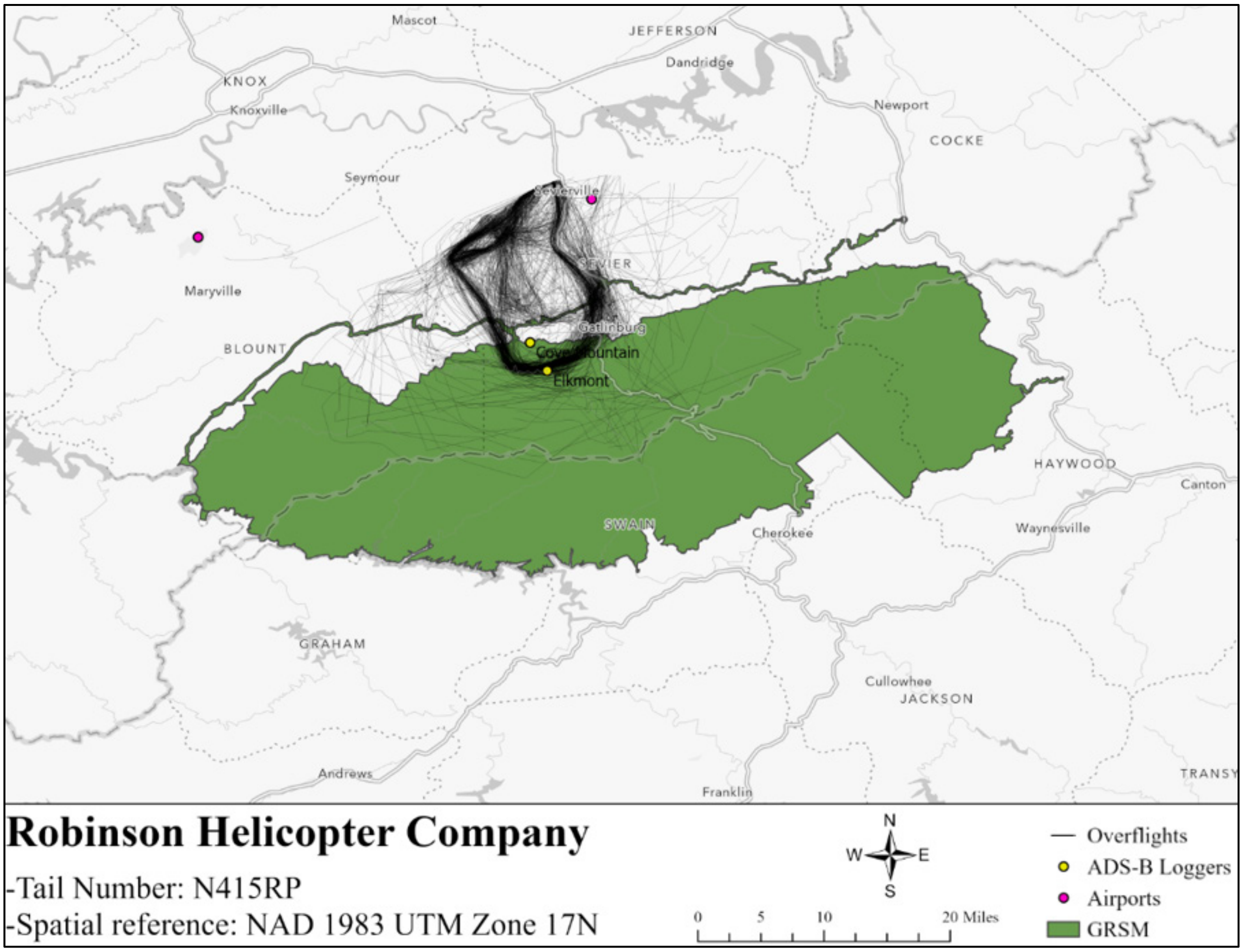

**Figure 21.** Overflight travel patterns for N415RP.

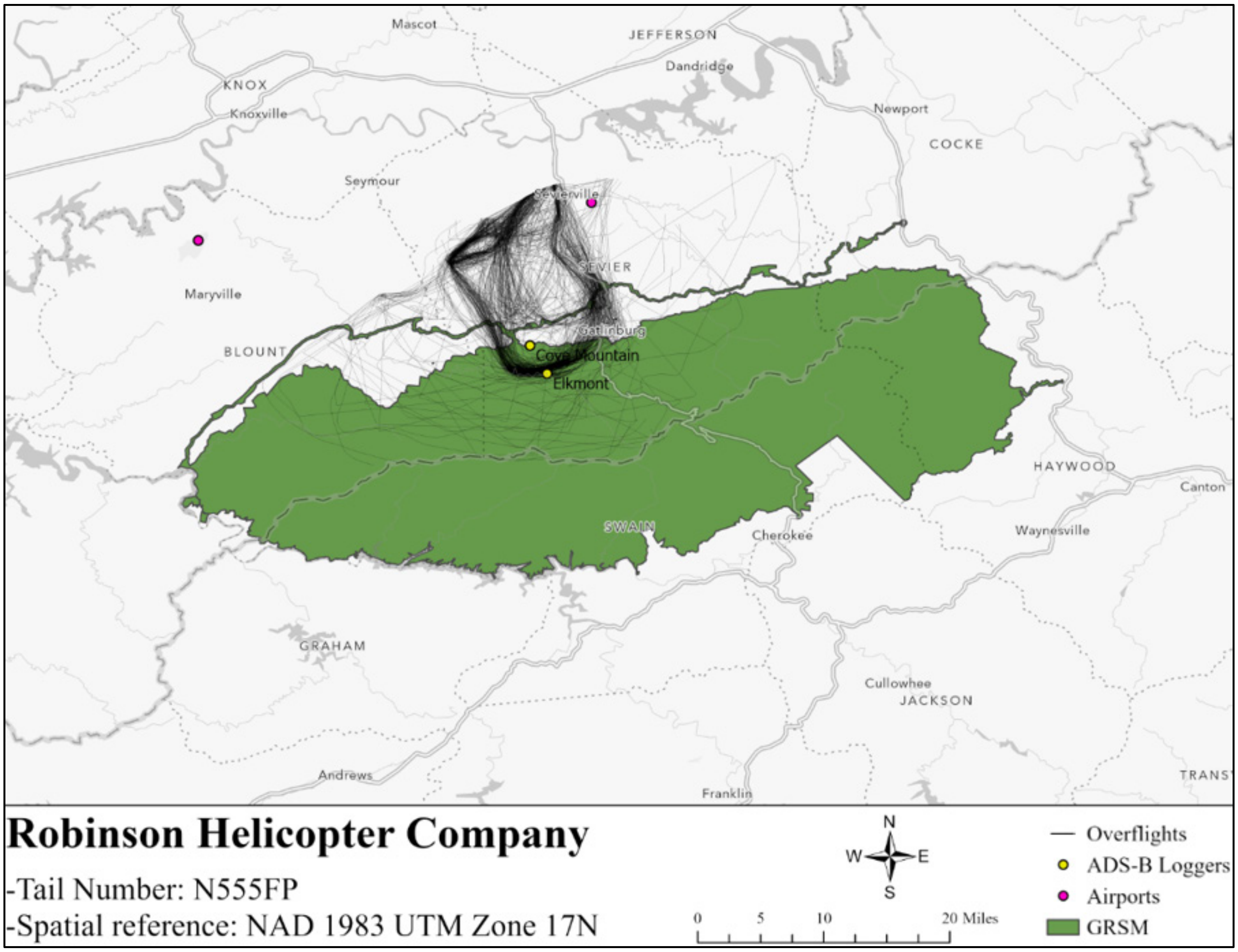

**Figure 22.** Overflight travel patterns for N555FP.

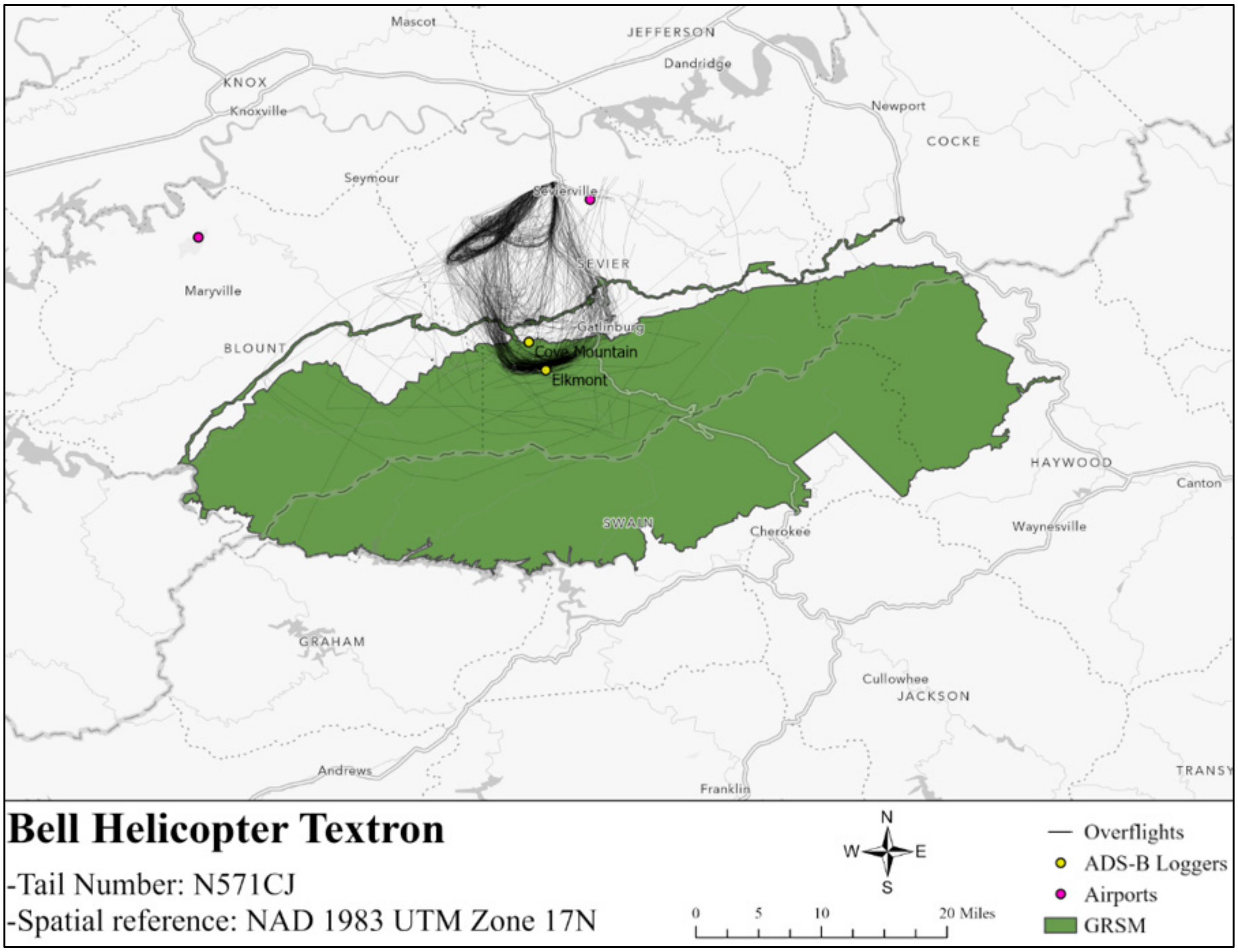

**Figure 23.** Overflight travel patterns for N571CJ.

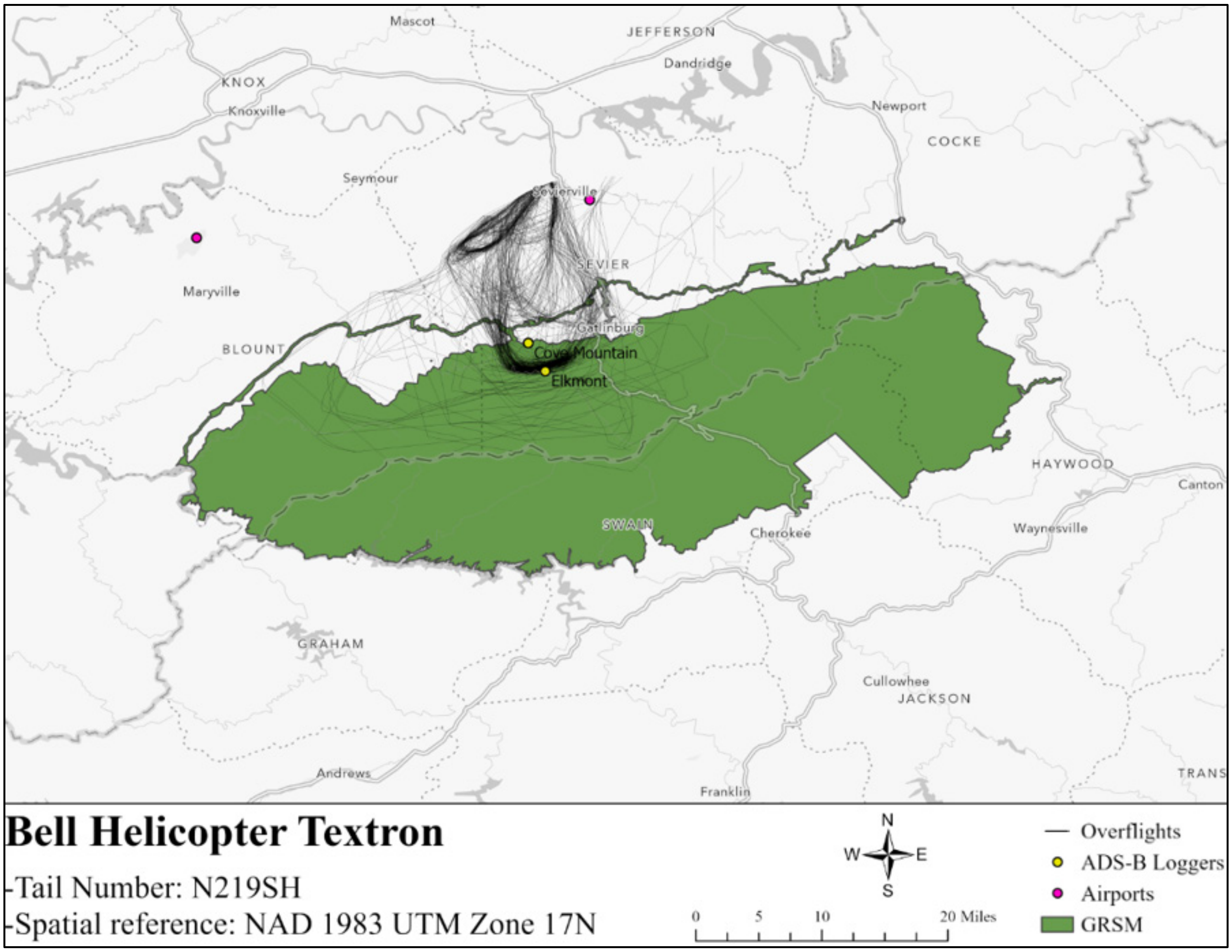

**Figure 24.** Overflight travel patterns for N219SH.

# Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at GRSM. Flight tracking data were analyzed from September 25th, 2019 to June 1st, 2022 and included 249,114 overflights. Analysis consisted of three phases.

The first phase focused on all overflights and showed a concentrated trend of overflights above GRSM. Visual analysis of these data suggests overflights are less concentrated above the southeast corner of the GRSM boundary. However, this may be due to terrain shielding that blocks the data loggers from receiving ADS-B signals. This phase also revealed very consistent route patterns over the park, including the most commonly reported air tour route. In a prior study, the acoustic environment under one these concentrated routes (near Parson Branch) revealed consistent noise disturbances from aircraft (Carpenter & Beeco, 2021). It is likely that each of these concentrated routes results in a consistent level of noise from aircraft. Further, visual analysis at that this phase reveals a diamond shape pattern in the north central area of the park. This diamond shaped pattern is an air tour route known as the Red Route (SNPF) (NPS, 2022b).

The second phase focused on low-level overflights and showed overflights fly at lower altitudes along the northern boundary of GRSM, which is where the Knoxville McGhee Tyson Airport is located, as well as the Sevierville area where most air tours are based. Additionally, this is the location where air tours are known to fly. At GRSM, all air tours are conducted by rotorcraft. This phase of analysis showed a rotorcraft travel trend in which flight patterns form a loop-formation (a diamond shape) that extends from the Sevierville area south to where the two data loggers were deployed. Further, figures 7, 8, and 9 reveal the low altitudes these air tours fly when over the park. These low-level overflights are known to transmit more intense noise than higher altitude flights for on the ground resources and visitors' experiences.

The third phase attempted to focus more specifically on air tours by removing flights known to not be air tours. The dataset was cleaned of 1,407 civil patrol flights, 57,799 major airlines flights, 161,763 straight-line flights, 9,546 flights with a flightpath less than a mile in length, and 5 survey flights. This left 13,931 flights. It is likely that the majority of these flights are not air tours, but the methods used in phase 3 are consistent with prior ADS-B cleaning practices. Based upon air tour reporting data, we would have expected a maximum of 4,000 air tours during the collection period. Further, it is known that all air tours at GRSM are helicopter tours. Most of the data remaining for phase 3 were fixed wing aircraft (Table 7).

Figures 10-12 display a density analysis, and reveal that density is highest along a known air tour travel pattern loop-formation that extends from the Sevierville area south to where the data loggers were deployed. It was found that overflight density was the highest for the altitude interval of 1,001 - 1,500ft AGL, followed by 501 – 1,000ft AGL, both common air tour elevation. Tables 2, which displays the number of waypoints within specific AGL altitude bands, also shows that the 1,001-1,500ft AGL pattern stands out, as does the corresponding 3,001-4,000ft MSL band (Table 3). The recently completed Air Tour Management Plan (ATMP; NPS, 2022b) does require air tours to fly no lower than 2,600ft AGL resulting in an increase in the air tour altitudes from 1,000-2,00ft. This requirement will begin in early 2023.

Figures 21-24 display the travel patterns of the most identified (by number of flights) individual rotorcraft. The patterns of these four figures show a clear air tour path (the Red Route) known and identified in the ATMP (NPS, 2022b) as well as less concentrated flights across other areas of the park.

The days of the week also show an interesting pattern for phase 3 data, with more flights on weekends rather than weekdays. Additionally, Table 6 displays the percentage of overflights across hours of the day, revealing that flights begin in earnest around 10:00am, peak between 1:00-2:00pm, and slowly decrease through the day. This suggests that the early morning hours of the park are the most free from low-level aircraft noise.

Much of the data from this study are located over the northern portions of the park. However, this is where the two ADS-B loggers were located. Therefore, it is not clear if these data represent a comprehensive understanding of overflights over the entire park.

In conclusion, this study produced results to further understand overflights at GRSM. 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.

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NPS 133/188435, May 2023

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