



Exploring Spatial Patterns of Overflights at Hawai‘i Volcanoes National Park



Map of Hawai'i Volcanoes National Park (boundary layer dated 2017).

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Exploring spatial patterns of overflights at Hawai‘i Volcanoes National Park

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Brian A. Peterson¹, J. M. Shawn Hutchinson¹, Bijan Gurung¹, J. Adam Beeco², Damon Joyce²

¹ Kansas State University
Manhattan, Kansas

² National Park Service
Natural Resource Stewardship and Science
Natural Sounds and Night Skies Division
Fort Collins, Colorado

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Abstract

This study explored spatial patterns of overflights at Hawai‘i Volcanoes National Park (HAVO). Overflights were analyzed from: 1) December 28th, 2020–May 20th, 2021; 2) August 30th, 2021–September 8th, 2021; and 3) January 7th, 2022–April 14th, 2023 (617 total days; 50 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. Phase 1 of analysis focused on all overflights and found a high concentration of overflights above HAVO and definitive travel patterns across the east side of the park. Phase 2 of analysis focused on low-level overflights that fly below 15,000ft mean sea level (MSL) and fly within 10 miles of the HAVO boundary and found that above 6,000ft MSL, the number of waypoints decreases as altitude increases. Also, as altitude increases, the directionality of waypoints trends toward the northeast. Phase 3 of analysis removed all overflights that were civil patrol flights, major airlines, and survey flights. The remaining flights were low-level overflights, including air tours. Kernel density analysis was conducted using waypoints segmented into 500ft above ground level (AGL) altitude intervals. The altitude interval with the highest density of overflights was ‘1,501–2,000ft 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

HAVO: Hawai'i Volcanoes National Park

MSL: Mean sea level

NPS: National Park Service

Introduction

Hawai‘i Volcanoes National Park (HAVO) was designated as a national park in 1916 (National Park Service, 2022) and is designated as a World Heritage Site and a Biosphere Reserve deemed by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to possess outstanding universal value to humanity (UNESCO, 2023). The entirety of HAVO is an important cultural place to Native Hawaiians due to the diversity of cultural resources found within the park boundary that expand across the entire park landscape, the Native Hawaiian Traditional Cultural Properties found within the park, and the many sacred areas that continue to be actively used by cultural practitioners (Peterson et al., 2023).

HAVO is located on the Island of Hawai‘i and is comprised of 354,461 acres featuring over 155 miles of hiking trails, campgrounds, cabins, wilderness areas, expansive vistas, volcanic craters, lava flows, lava shields, rift zones, and two active volcanoes (Mauna Loa and Kīlauea) (Lawson et al., 2007). Mauna Loa rises 13,681 feet above mean sea level (MSL), which is the highest elevation in the park, and is the largest active volcano on the planet (United States Geological Survey, 2023). Kīlauea, located on the southeastern flank of Mauna Loa, appears as a slight bulge at an elevation of 4,091 feet MSL (National Park Service, 2023). From 1983 to 2018, the eruptive activity of Kīlauea was nearly continuous along the volcano’s East Rift Zone (McMurtry et al., 2019). The lowest elevation in the park is at sea level. The combination of adjacent volcanoes and the recent decades-long activity of Kīlauea makes HAVO a popular destination for air tours.

The purpose of this report is to provide examination of the spatial patterns of all overflights at HAVO, which may assist in the management and communication between air tour operators, other airspace users, and the park. In 2019, HAVO received 9,276 reported air tours which was the most of any national park (Lignell, 2020) that is subject to the requirements of the National Parks Air Tour Management Act. In 2020, the latest available report, air tour operators reported a substantial drop in air tours at HAVO (down to 1,252) due to the COVID 19 pandemic (Ward & Shields, 2023).

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, 2023a). However, at HAVO, no airspace requires ADS-B technology. 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). Most HAVO air tour operators are known to be equipped and operate with ADS-B technology.

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency (FAA, 2023b). This study analyzed overflights using ADS-B technology that flew above HAVO. The data discussed in this report span from: 1) December 28th, 2020–May 20th, 2021; 2) August 30th, 2021–September 8th, 2021; and 3) January 7th, 2022–April 14th, 2023 (617 total days; 50 days of missing data).

Methods

Data Collection

Data were collected by an ADS-B data logger positioned at three different locations around the Jaggar Museum (Figure 1). It was deployed on top of the Annex building (19.420044, -155.28831), to the north of the museum (19.42072, -155.287872), and to the south of the museum (19.41951, -155.288469) (Figure 1). It was deployed on top of the Annex building from 1) December 28th, 2020–May 20th, 2021; 2) August 30th, 2021–September 8th, 2021; and 3) January 8th, 2022–April 14th, 2023. It was deployed to the north of the museum from September 7th, 2022 to October 14th, 2022 and from December 21st, 2022–January 5th, 2023. It was deployed to the south of the museum from January 5th, 2023–February 13th, 2023. The data logger was positioned with an unimpeded and expansive skyward exposure. The logger recorded ADS-B signals as text files. The repositioning of the data logger was due to the anticipated removal of the building where the ADS-B unit was originally placed.



Figure 1. ADS-B data logger locations around the Jaggar Museum and other buildings.

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 multiple data loggers, created waypoint and flightline feature classes (spatial reference = North American Datum 1983 Universal Transverse Mercator Zone 5N), 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 for any 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 some error. Negative AGL values are reported in the analysis. Finally, in some data sets MSL altitudes in the data are also negative. This is likely a system error. These data generally represent less than 0.1% of the data and are discarded from data analysis.

To explore spatial patterns of overflights at HAVO, 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 undulating terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer

credits for: Esri, USGS, HERE, Garmin, SafeGraph, FAO, METI/NASA, and EPA; and all data were projected to North American Datum 1983 Universal Transverse Mercator Zone 5N.

The research team used a HAVO boundary file that was accurate until December of 2017. Since then, HAVO has expanded by about 20,000 acres. The research team did not have access to the new boundary shapefile at the time of analysis. However, it is unlikely that this small boundary change would have a large effect on this study's findings because the routes and altitudes of overflights are apparent and mapped 10 miles beyond the boundary, and the detailed analysis of data was a minimum of 0.5 mile beyond the park boundary.

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above HAVO regardless of flight type. Thus, the flightline feature class was not cleaned of any flight types. To understand how flightpaths extended beyond the park boundary, a 10-mile buffer around the HAVO boundary was used. One map was produced that showed all of the data.

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above HAVO 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 15,000ft MSL. This altitude was chosen because the highest point at HAVO is 13,681ft on top of Mauna Loa Volcano (National Park Service, 2023), and approximately 1,300ft 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. Five maps were produced which show low-level overflight waypoints across the following MSL altitudes: 1) 0–3,000ft MSL; 2) 3,001–6,000ft MSL; 3) 6,001–9,000ft MSL; 4) 9,001–12,000ft MSL; and 5) 12,001–15,000ft MSL.

Phase 3 Methods

The purpose of the third phase was to remove flights known not to be 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 not to 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, which was used to identify any major airlines that were not listed in the prior step. 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. 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 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.

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 HAVO's acoustic environment. Using a 500ft AGL altitude interval, waypoint data were segmented (<0ft; 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 density results, density classifications were normalized across altitude intervals. To do this, the altitude interval with the highest maximum density of waypoints (1,501–2,000ft AGL) was used to normalize density classification, which required two steps. First, the 1,501–2,000ft 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 five 20% equal interval classifications. The resulting density classifications were then 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.

Kernel density analysis revealed dense low-level overflights between 501–3,000ft AGL. Dense low-level overflights were not found for the following altitude intervals: 0–500ft AGL; 3,001–3,500ft AGL; 3,501ft AGL–4,000ft AGL; 4,001–4,500ft AGL; and 4,501–5,000ft AGL. This analysis produced two figures. The first figure shows all altitude interval densities merged together for altitude intervals between 501–3,000ft AGL to serve as a reference for where dense overflights occurred above HAVO. The second figure shows density analysis across sequential altitude intervals ranging from 501–3,000ft AGL. 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 classification. The second figure displays waypoint altitudes between 2,501–5,000ft AGL using a 500ft AGL interval classification. Because the elevation of Mauna Loa is 13,681ft MSL (National Park Service, 2022), that elevation was used to design the next two figures. The third figure displays

waypoint altitudes between 0–7,500ft MSL and the fourth figure displays waypoint altitudes between 7,501–15,000ft MSL. 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. Lastly, 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.

Results

Results — Phase 1

The research team mapped overflights for all flights ($n=11,713$). Figure 2 shows the east side of HAVO receives more overflights than the west side and that there is a distinctive travel corridor, which is the most common travel pattern for known air tours. Areas with opaque lines indicate where there is greater flight density.

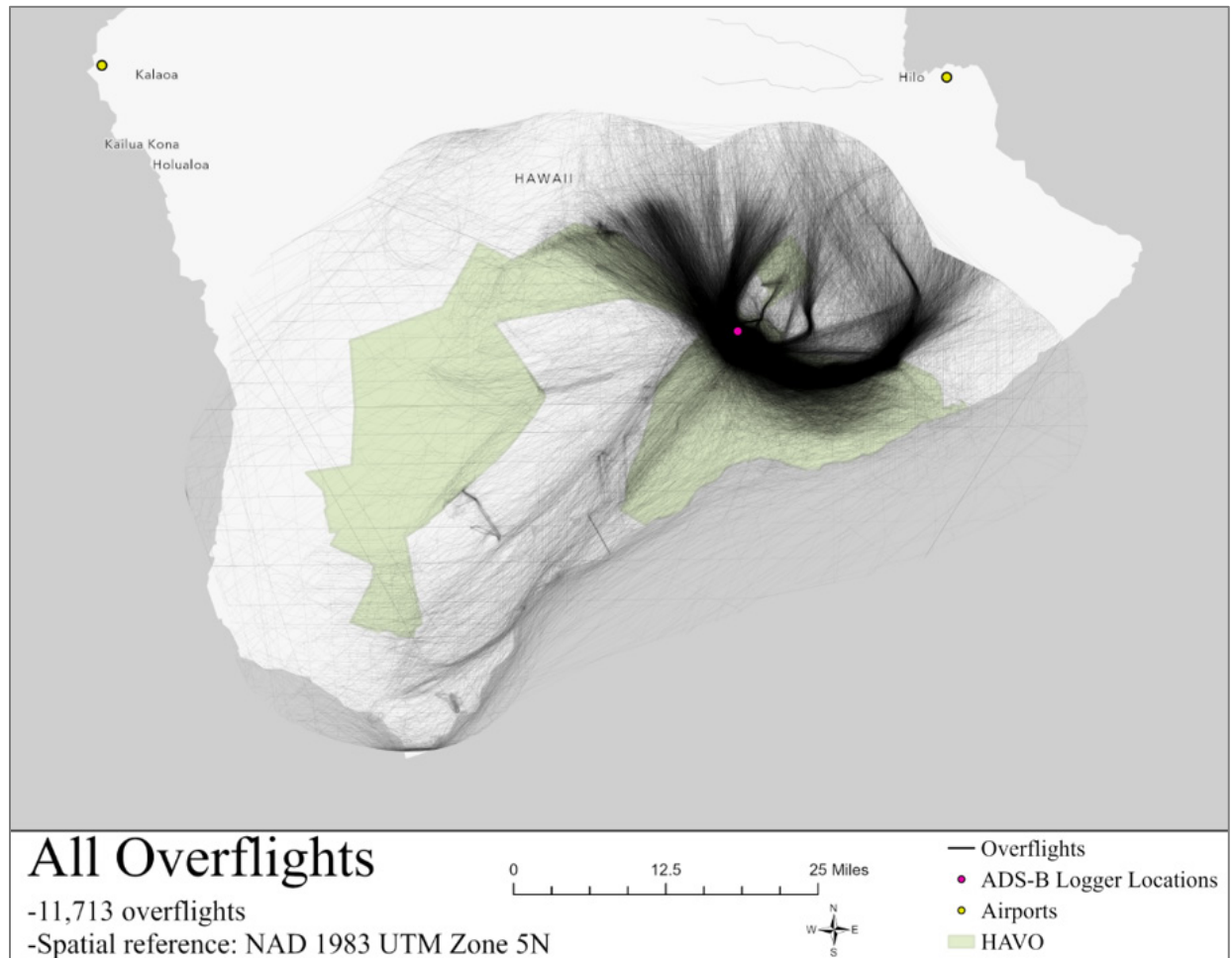


Figure 2. All overflights.

Results — Phase 2

The research team mapped waypoints for all overflights that flew between 0–15,000 feet MSL (11,834,567 total waypoints), which is displayed across five figures. Figure 3 shows waypoints between 0–3,000 feet MSL (661,735 waypoints). Figure 4 shows waypoints between 3,001–6,000 feet MSL (7,315,624 waypoints). Figure 5 shows waypoints between 6,001–9,000 feet MSL (3,217,334 waypoints). Figure 6 shows waypoints between 9,001–12,000 feet MSL (481,797 waypoints). Figure 7 shows waypoints between 12,001–15,000 feet MSL (31,042 waypoints). These figures show that above 6,000ft MSL, the number of waypoints decreases as altitude increases. Also,

as altitude increases, the directionality of waypoints trends toward the northeast. Finally, as overflights move more inland, their MSL altitudes increase, which is likely due to the topography of the island.

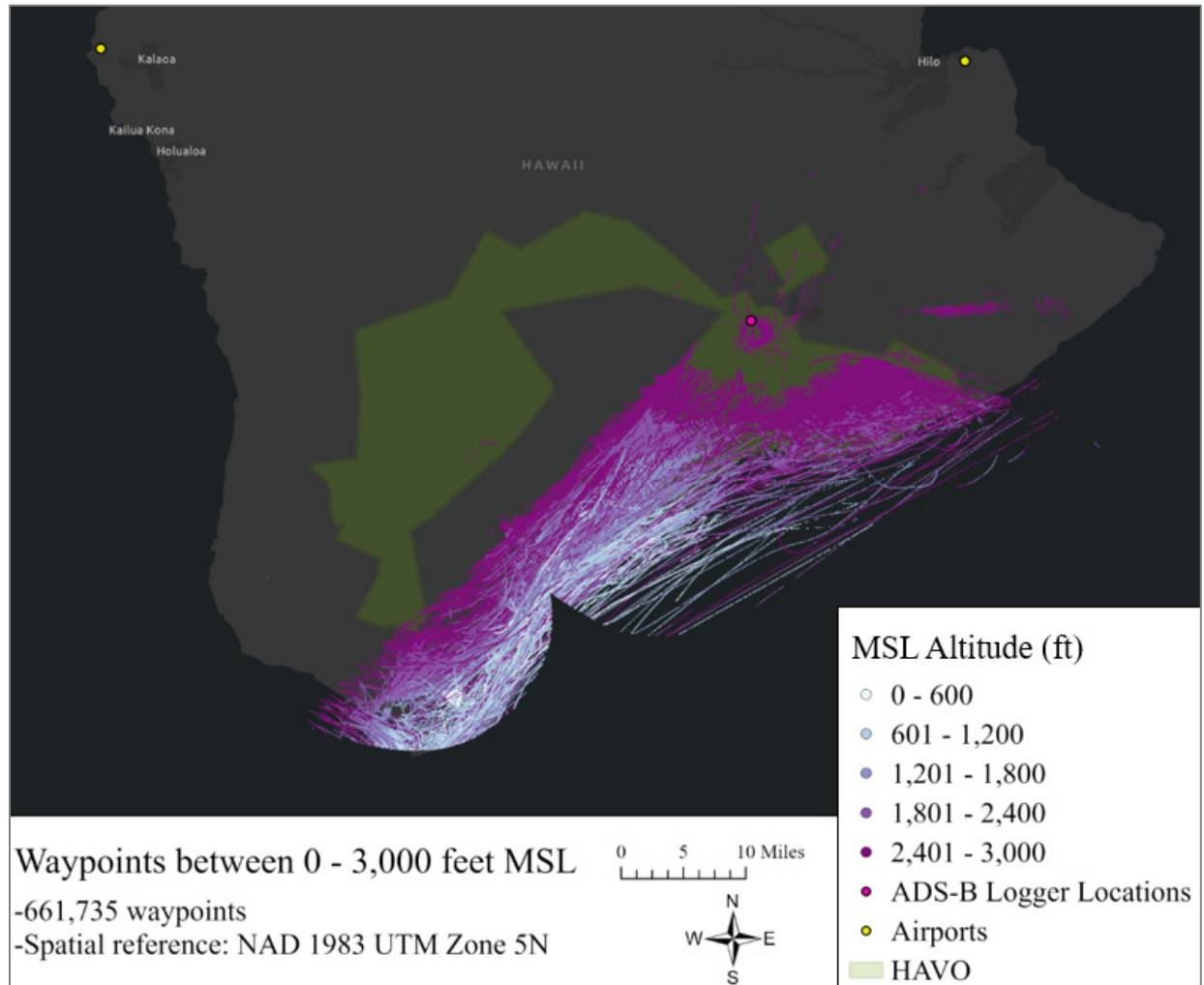


Figure 3. Waypoints between 0–3,000 feet MSL.

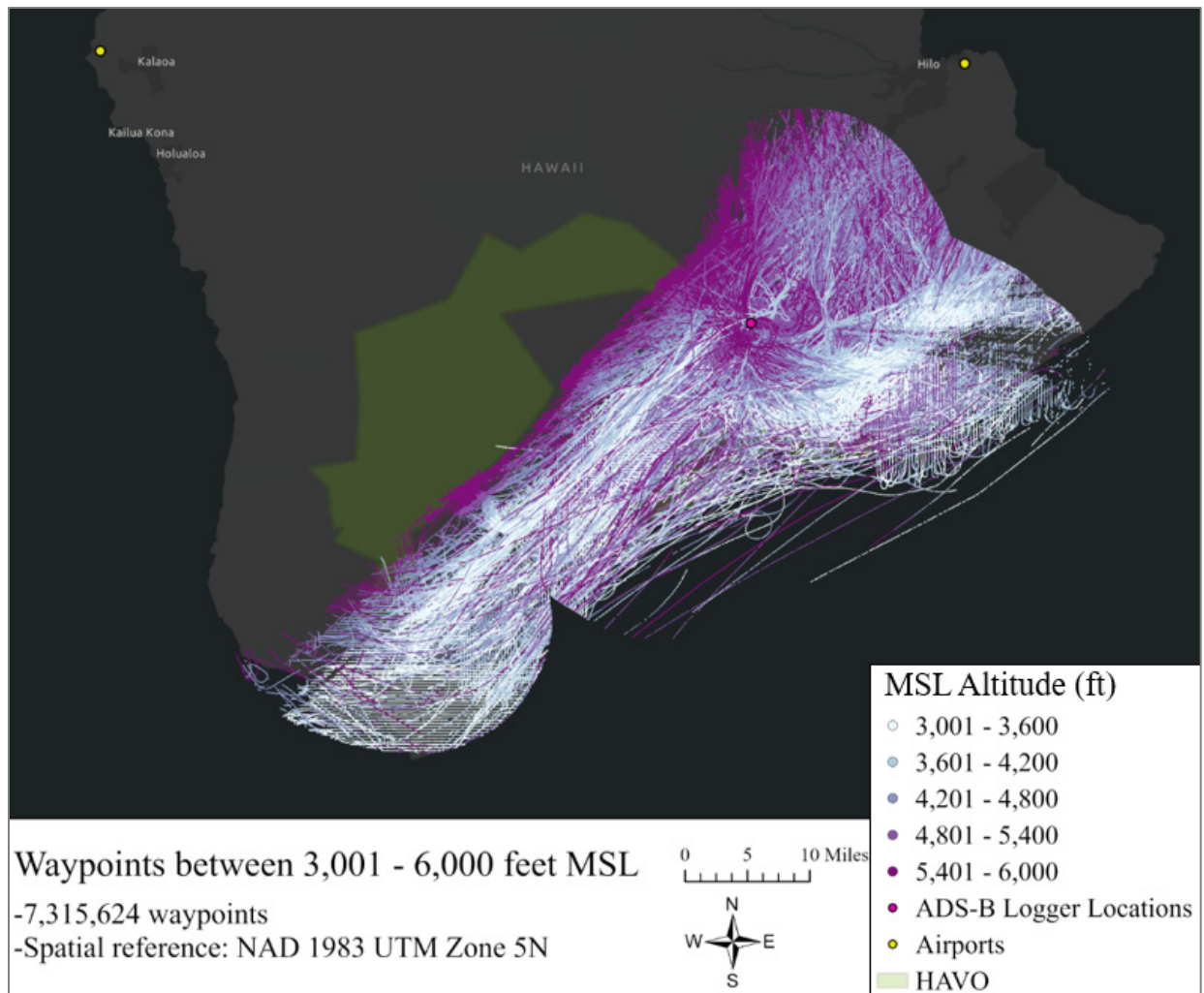


Figure 4. Waypoints between 3,001–6,000 feet MSL.

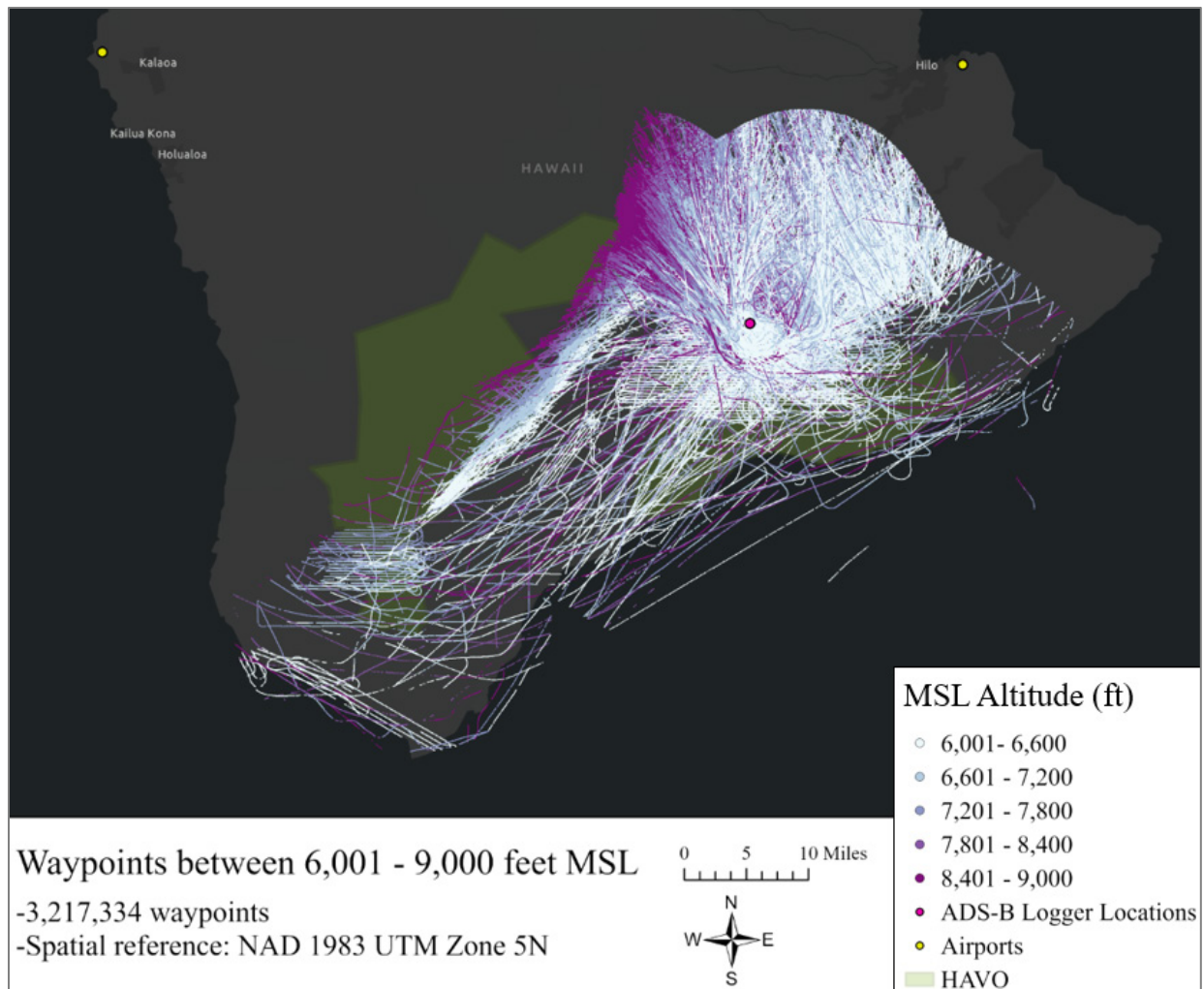


Figure 5. Waypoints between 6,001–9,000 feet MSL.

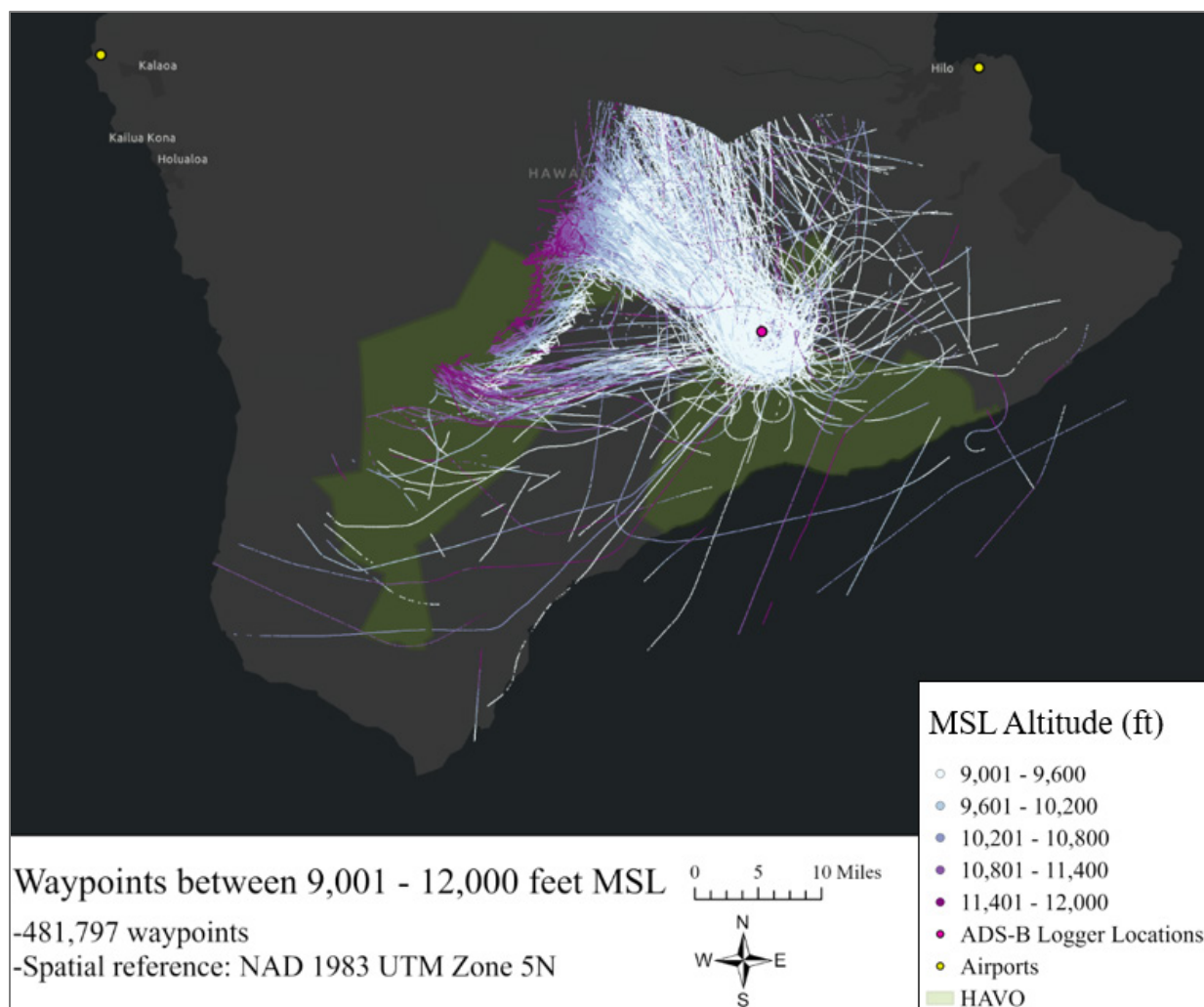


Figure 6. Waypoints between 9,001–12,000 feet MSL.

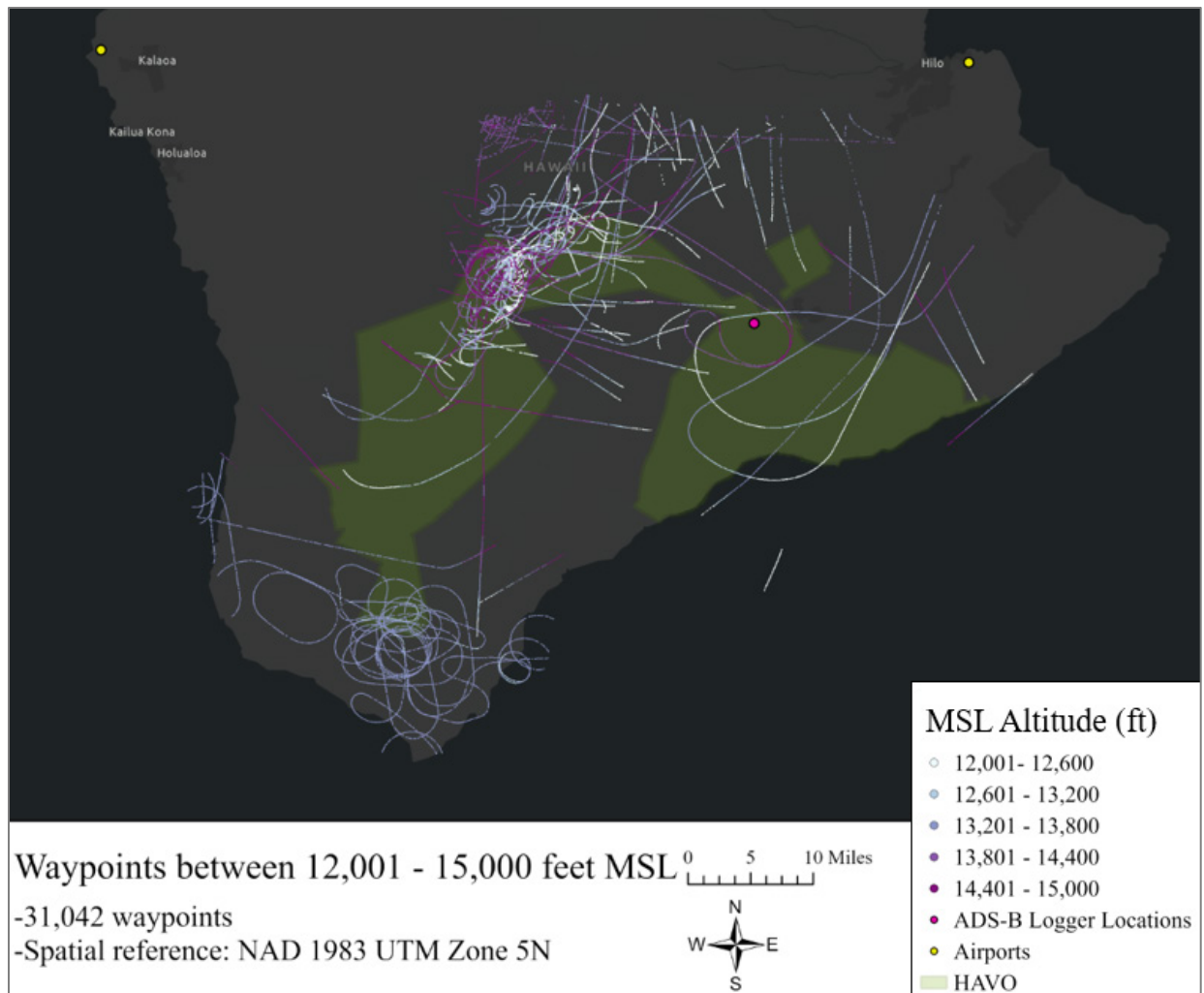


Figure 7. Waypoints between 12,001–15,000 feet MSL.

Results — Phase 3

Data were cleaned of all flights known not to be air tours, which resulted in the following numbers of flights removed: 93 civil patrol flights, 407 straight-line flights, 26 flights with a flightpath less than a mile in length, 116 survey flights, and 3 commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights). This left 11,068 flights within 10-miles of the HAVO boundary (Figure 8). Next, these flights were clipped to a 0.5-mile boundary of HAVO, which left 10,556 flights. Using this dataset, kernel density analysis was conducted across AGL altitude intervals up to 2,501–3,000ft AGL. The AGL altitude interval that showed the most density was 1,501–2,000ft. As described in the Methods, this density altitude was then used as the baseline to normalize the other altitude ranges. Figure 9 shows a density overview map, which displays waypoint densities from 501–3,000ft AGL. There were no density hot spots for 0–500ft AGL, 3,001–3,500ft AGL, 3,501–4,000ft AGL, 4,001–4,500ft AGL, and 4,501–5,000ft AGL. Figure 10 is zoomed in to show density hot spots for 501–3,000ft AGL across 500ft AGL altitude intervals. All density hotspots were located near the Kīlauea Crater.

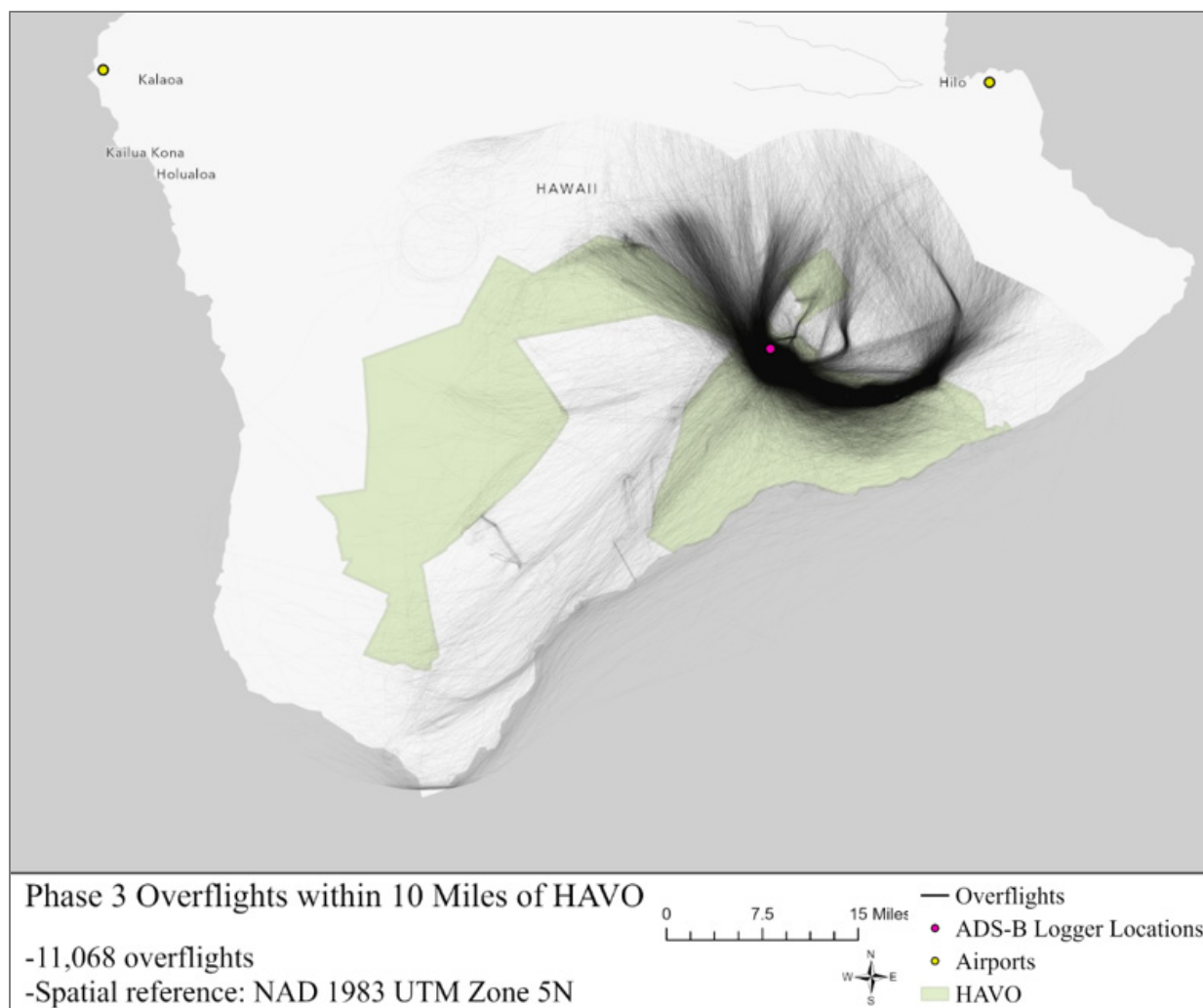


Figure 8. Overview of Phase 3 flights.

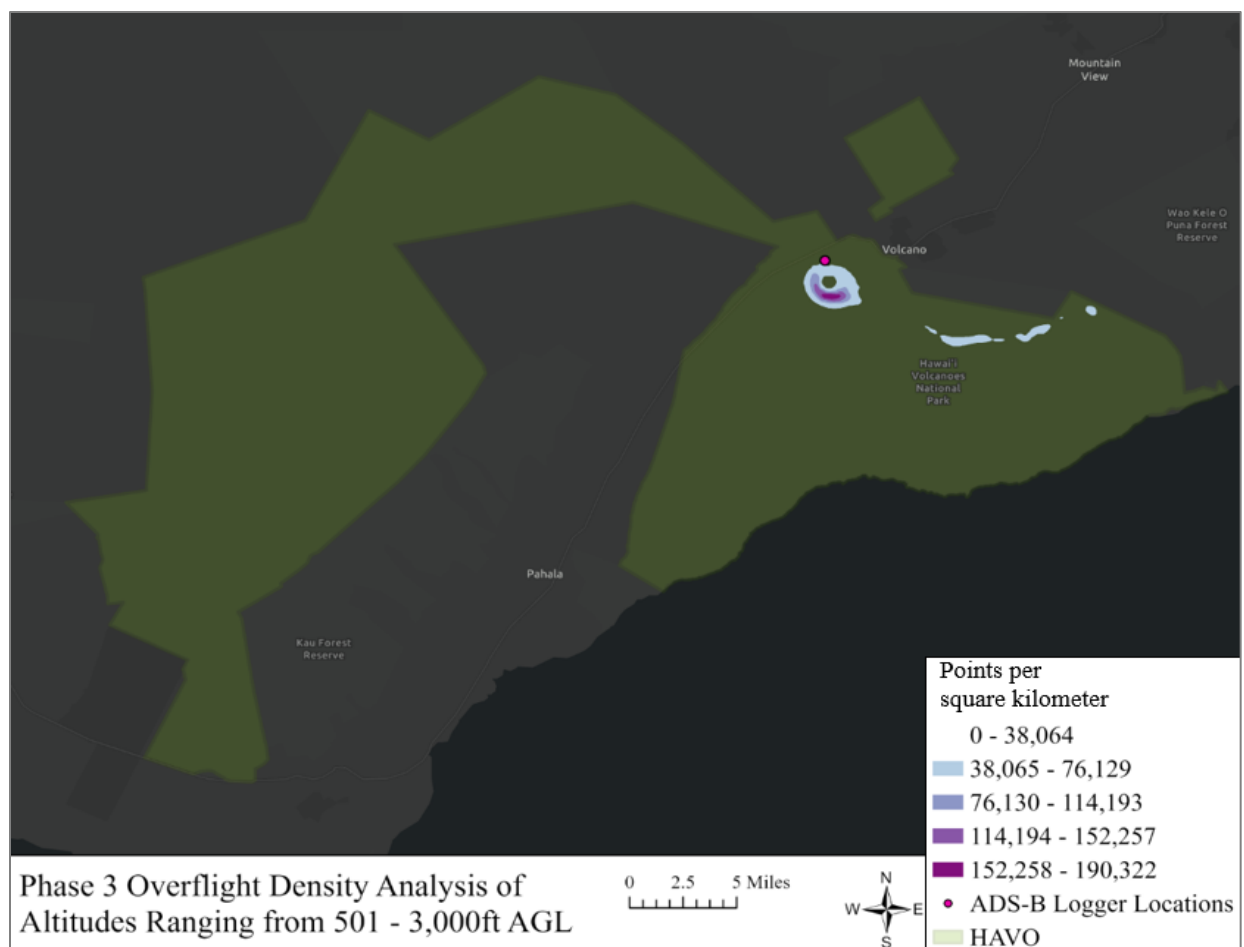


Figure 9. Overview of kernel density analysis showing AGL altitudes ranging from 501–3,000 feet.

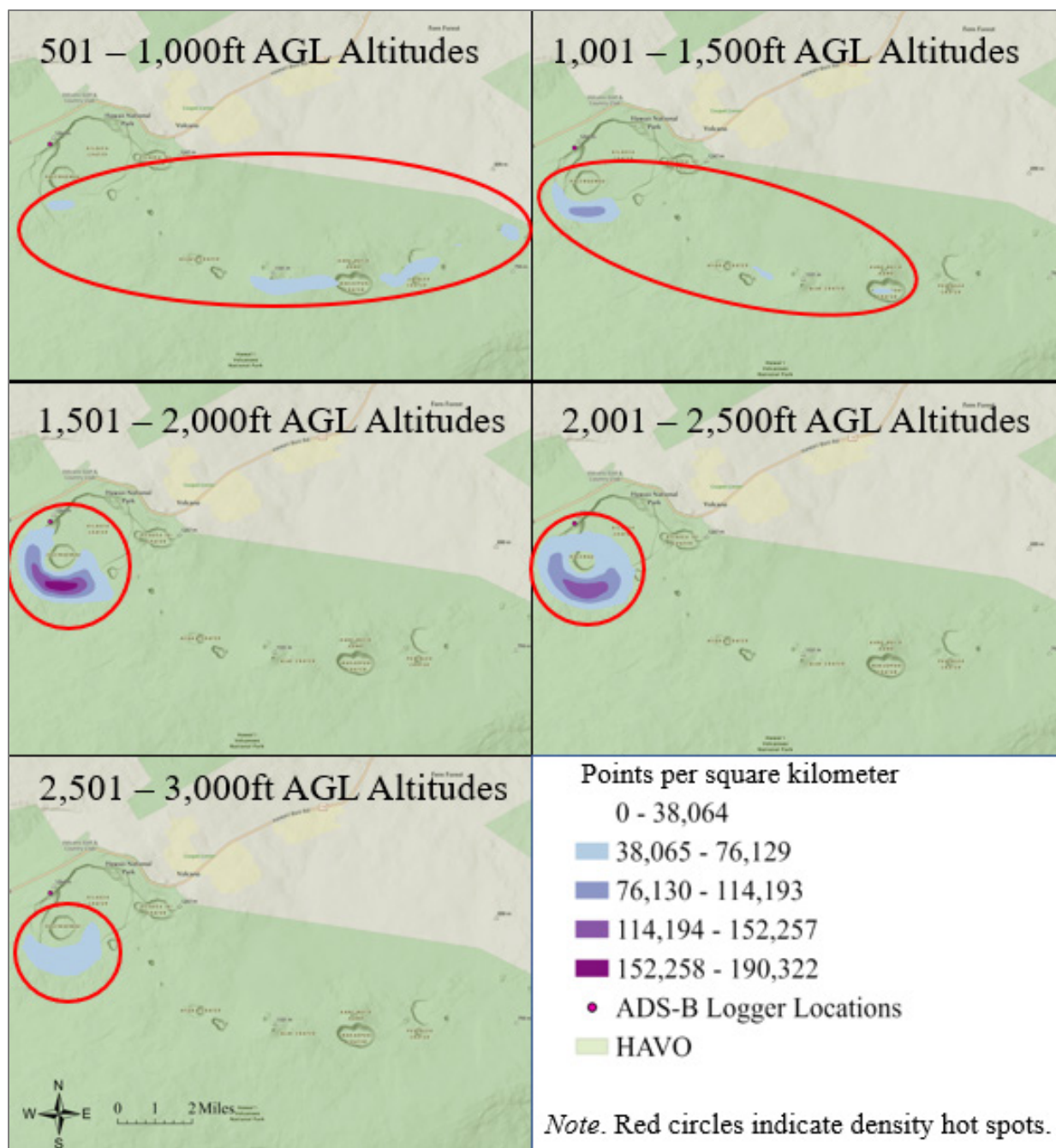


Figure 10. Kernel density analysis of 501–3,000ft AGL altitudes.

The density outputs were statistically compared using a correlation test. Altitude intervals that had density hot spots were analyzed (Table 1). The altitude intervals with the highest correlations (correlation coefficient > 0.90) were: 1,501–2,000ft AGL; 2,001–2,500ft AGL; and 2,501–3,000ft AGL. For these altitude intervals, Figure 10 shows similarly shaped density hot spots. This means that across altitude levels, flights are concentrating in similar areas.

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

AGL Altitude Interval	1.	2.	3.	4.
1. 501–1,000ft AGL	–	–	–	–
2. 1,001–1,500ft AGL	0.68	–	–	–
3. 1,501–2,000ft AGL	0.36	0.85	–	–
4. 2,001–2,500ft AGL	0.30	0.74	0.96	–
5. 2,501–3,000ft AGL	0.27	0.68	0.91	0.98

To further understand altitude trends of waypoints, five visualizations were produced that focus on waypoints within 0.5-mile of the HAVO boundary. Figure 11 examines altitudes less than 0ft 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 a single aircraft accounted for 81.7% of negative AGL values. Because many of the data revealed substantial errors, the aircraft likely has a system error in its ADS-B system. More broadly, other error sources could be aircraft flying exceptionally low (including for landings or drop-offs) combined with DEM generalization errors and errors between barometric altitude estimates and actual altitude.

Figure 12 (altitudes ranging from 0–2,500ft AGL) and Figure 13 (altitudes ranging from 2,501–5,000ft AGL) display AGL altitude trends above the east side of HAVO. The majority of waypoints are below 2,500ft AGL. Figures 14 and 15 display waypoints expressed in MSL. The maximum altitude used was 15,000ft because Mauna Loa is at 13,681ft (National Park Service, 2022). Figure 14 (altitudes ranging from 0–7,500ft MSL) and 15 (altitudes ranging from 7,501–15,000ft MSL) display MSL altitude trends directly above HAVO and show waypoint altitudes trended between 3,000–7,500ft MSL.

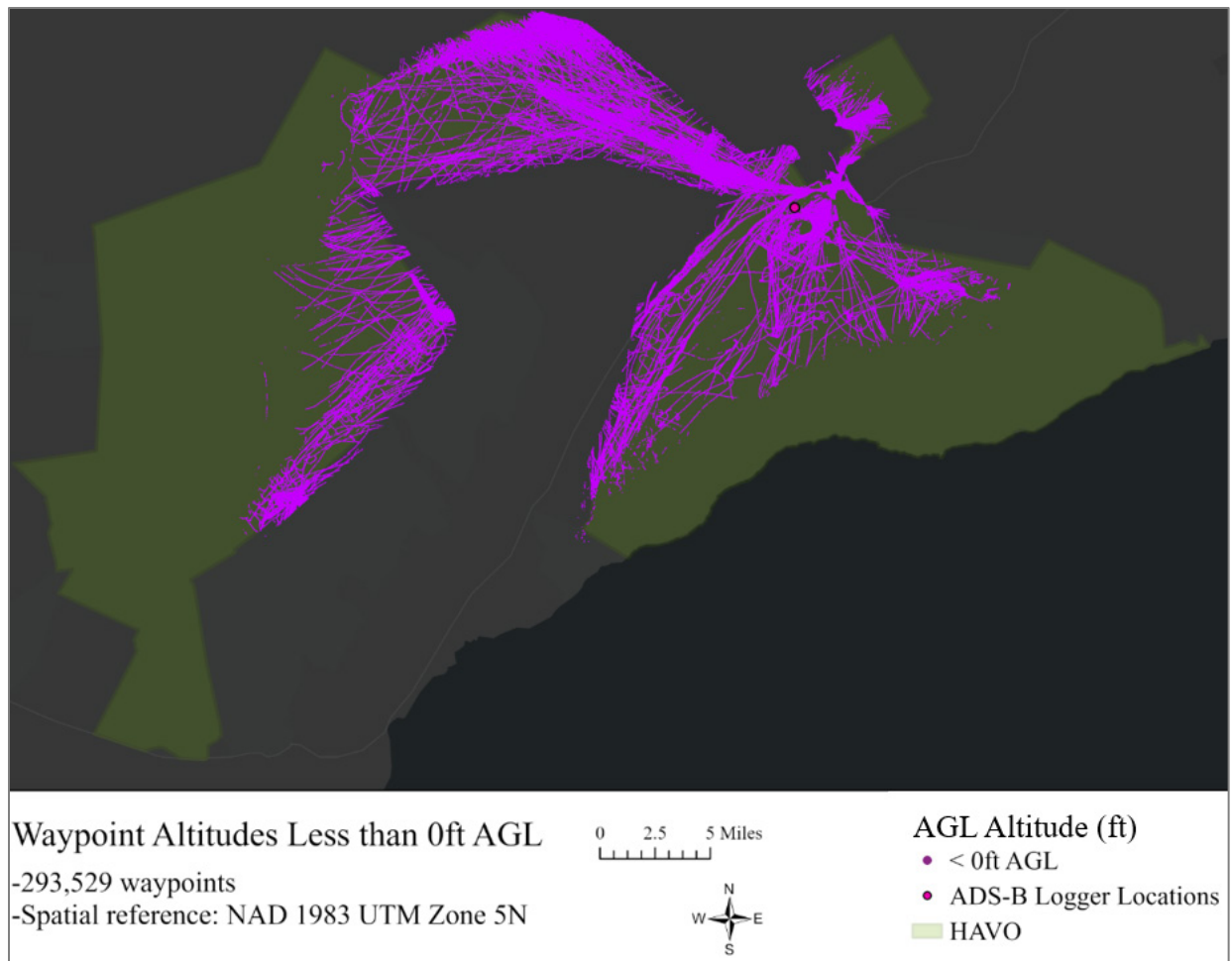


Figure 11. AGL altitude trends of altitudes less than 0ft AGL for waypoints within 0.5-mile of the HAVO boundary ($n=293,529$ waypoints).

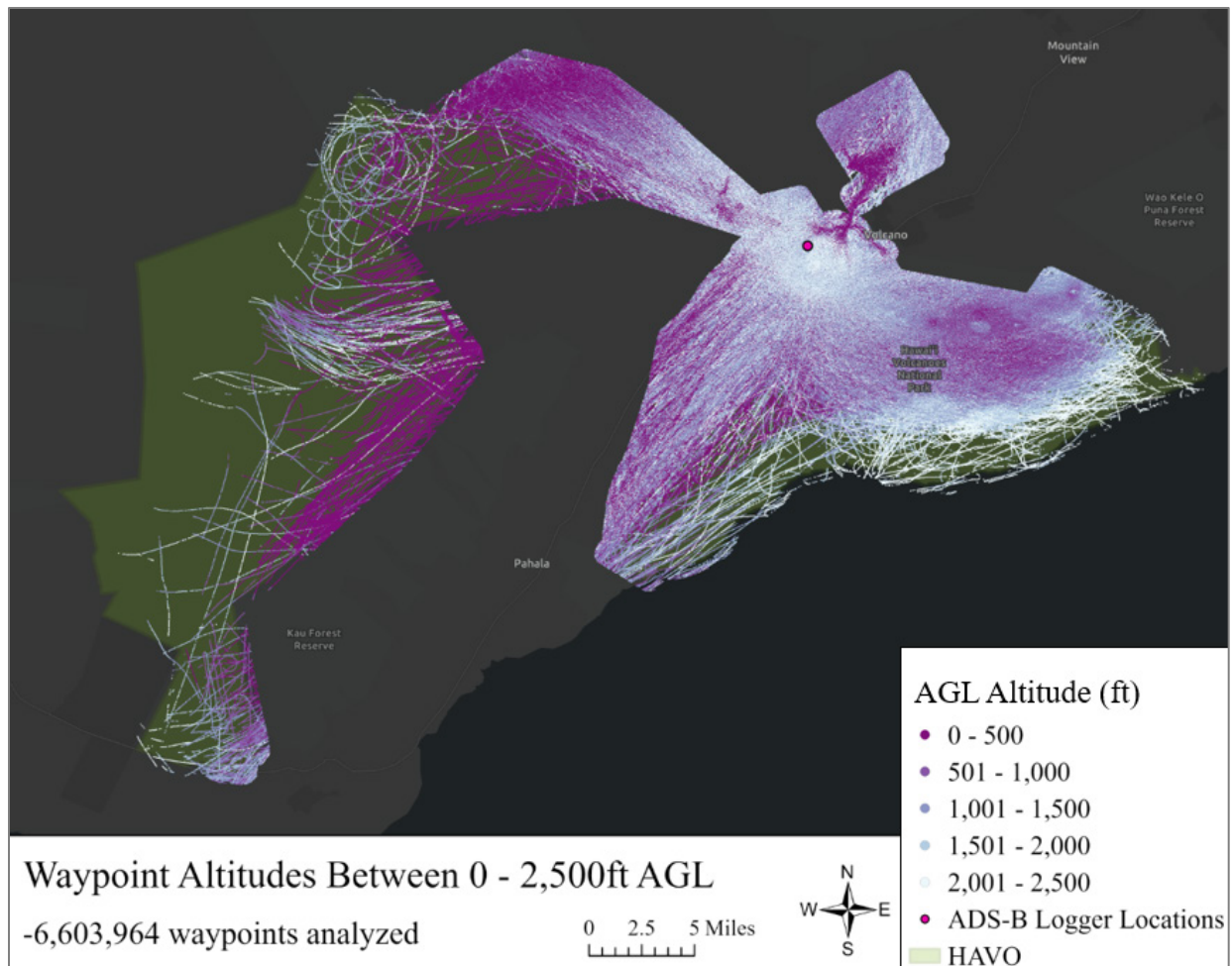


Figure 12. AGL altitude trends of altitudes ranging from 0–2,500ft AGL for waypoints within 0.5-mile of the HAVO boundary ($n=6,603,964$ waypoints).

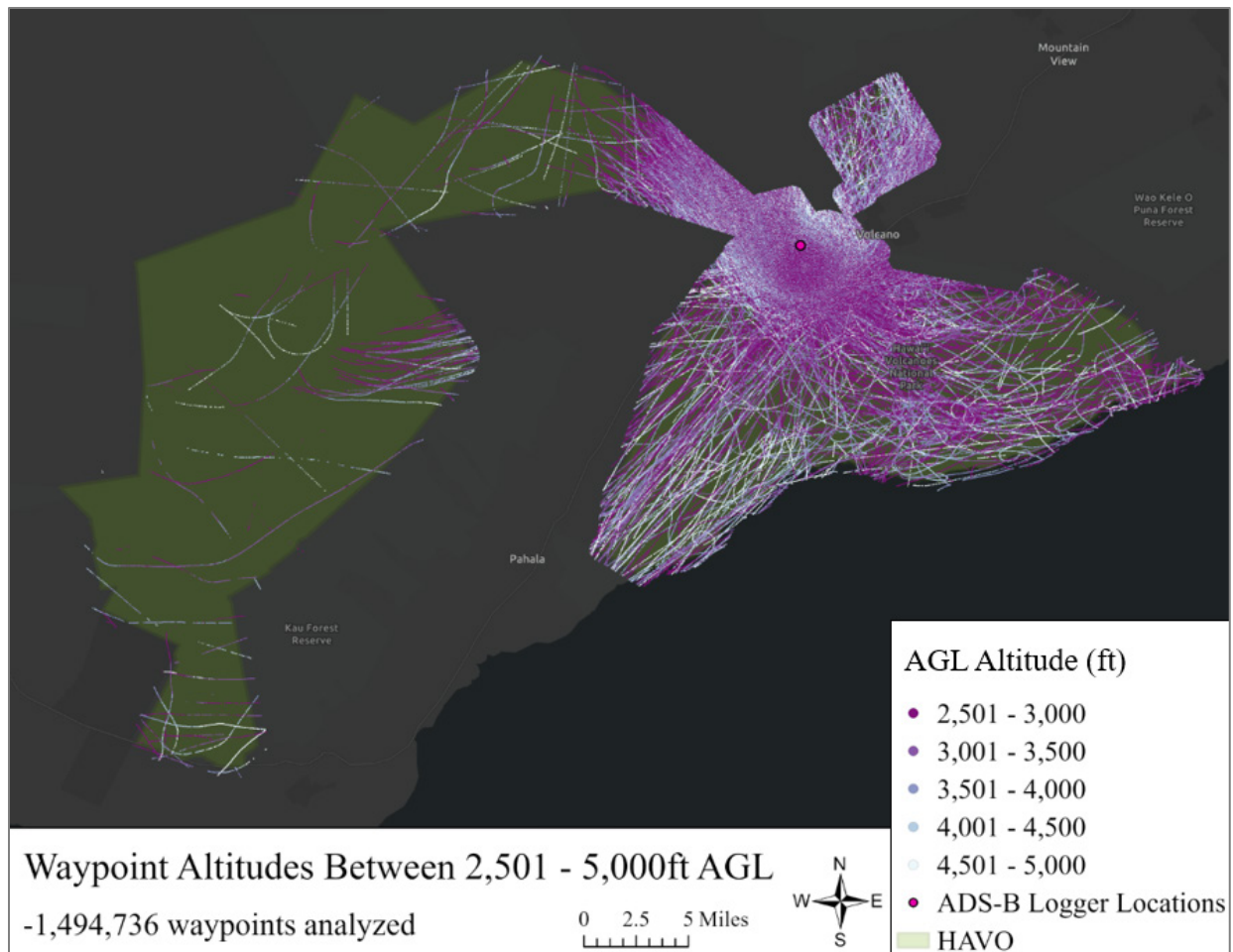


Figure 13. AGL altitude trends of altitudes ranging from 2,501–5,000ft AGL for waypoints within 0.5-mile of the HAVO boundary ($n=1,494,736$ waypoints).

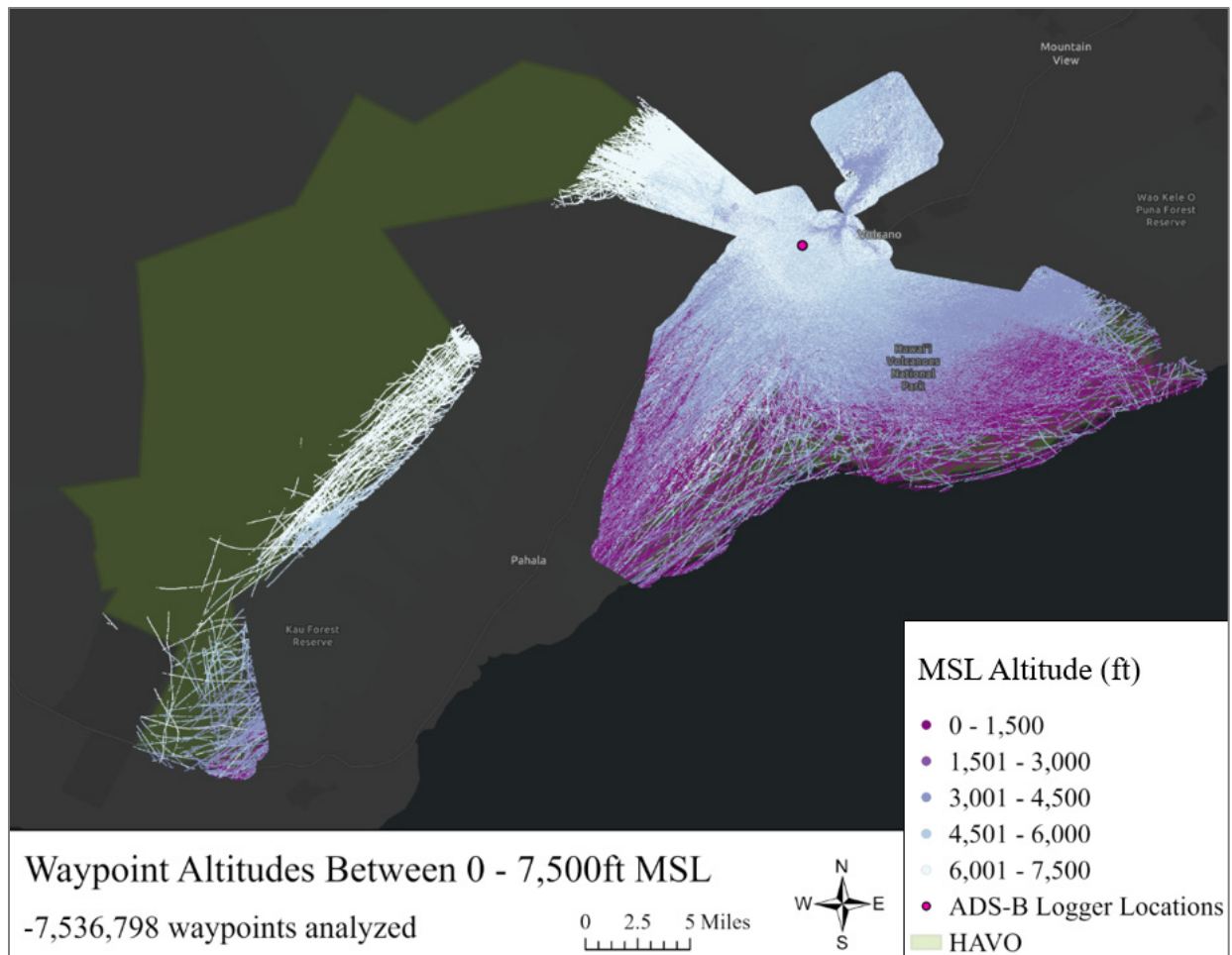


Figure 14. MSL altitude trends of altitudes ranging from 0–7,500ft MSL for waypoints within 0.5-mile of the HAVO boundary ($n=7,536,798$ waypoints).

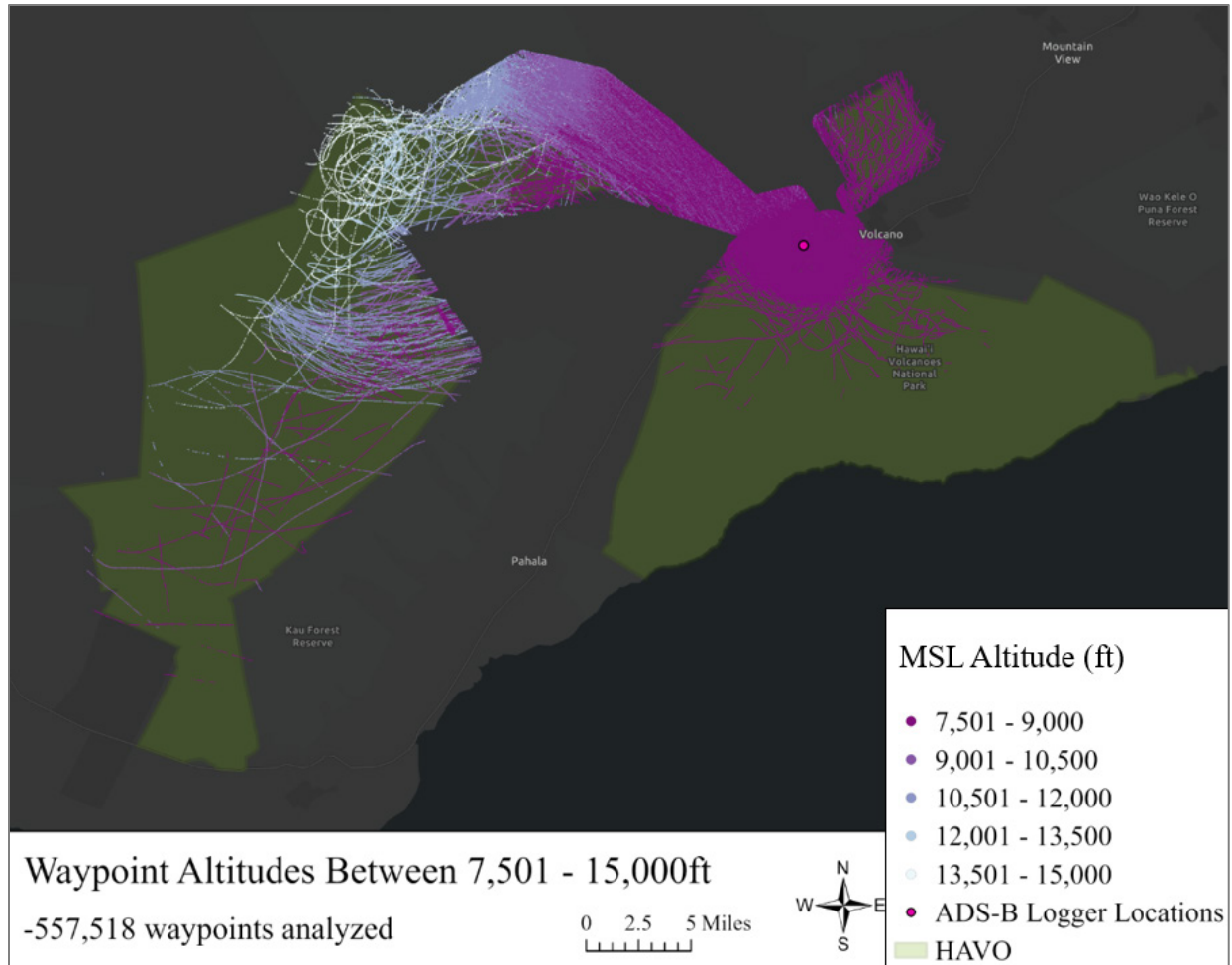


Figure 15. MSL altitude trends of altitudes ranging from 7,501–15,000ft MSL for waypoints within 0.5-mile of the HAVO boundary ($n=557,518$ waypoints).

The information displayed in Figures 11, 12, 13, 14, and 15 were inputted into tables to quantitatively understand which altitude intervals had the highest percentage of waypoints. Table 2 shows analysis of 8,098,700 waypoints across AGL altitudes and Table 3 shows analysis of 8,289,885 waypoints across MSL altitudes. The AGL altitude interval that received the highest percentage of waypoints was 1,501–2,000ft (Table 2), but note that the following altitude intervals had a significant number of waypoints: 501–1,000ft AGL; 1,001–1,500ft AGL; and 2,001–2,500ft AGL. The MSL altitude interval that received the high percentage of waypoints was 4,501–6,000ft (Table 3), but note that the following altitude intervals had a significant number of waypoints: 3,001–4,500ft MSL and 6,001–7,500ft MSL.

Table 2. Number and percentage of waypoints across AGL altitude intervals ($n=8,098,700$).

AGL altitude	Number of waypoints	Percentage of waypoints
< 0ft	293,529*	3.6
0–500ft	711,542	8.8
501–1,000ft	1,362,179	16.8
1,001–1,500ft	1,359,204	16.8
1,501–2,000ft	1,528,402	18.9
2,001–2,500ft	1,349,108	16.7
2,501–3,000ft	800,345	9.9
3,001–3,500ft	375,482	4.6
3,501–4,000ft	173,380	2.1
4,001–4,500ft	89,142	1.1
4,501–5,000ft	56,387	0.7

* 81.7% of these data were accounted for by a single rotorcraft.

Table 3. Number and percentage of waypoints across MSL altitude intervals ($n=8,289,885$).

MSL altitude	Number of waypoints	Percentage of waypoints
0–1,500ft	4,965	0.1
1,501–3,000ft	227,556	2.7
3,001–4,500ft	2,413,642	29.1
4,501–6,000ft	3,244,493	39.1
6,001–7,500ft	1,655,226	20
7,501–9,000ft	409,404	4.9
9,001–10,500ft	271,007	3.3
10,501–12,000ft	45,796	0.6
12,001–13,500ft	10,716	0.1
13,501–15,000ft	7,080	0.1

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 10,556). Table 4 shows 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 28th, 2020 to April 14th, 2023. HAVO received the most overflights during

January of 2023 (28.26 average number of flights per day) and received the highest average number of flights per day during December 2022. However, there were only 18 days of data collection for December 2022.

Table 4. Number and percentage of overflights across months ($n=10,556$).

Month	Number of data collection days *	Number of overflights	Average Number of overflights per day
December 2020	4	54	13.50
January 2021	31	225	7.26
February 2021	28	217	7.75
March 2021	31	293	9.45
April 2021	30	466	15.53
May 2021	20	331	16.55
August 2021	2	16	8.00
September 2021	8	114	14.25
January 2022	31	353	11.39
February 2022	28	614	21.93
March 2022	31	765	24.68
April 2022	30	525	17.50
May 2022	28	491	17.54
June 2022	30	691	23.03
July 2022	31	799	25.77
August 2022	25	670	26.80
September 2022	30	571	19.03
October 2022	31	614	19.81
November 2022	21	370	17.62
December 2022	18	560	31.11
January 2023	31	876	28.26
February 2023	14	112	8.00
March 2023	30	570	19.00
April 2023	14	259	18.50
Total	573	10,556	17.59

* For some months, data collection did not occur at all or every day because of ADS-B logger equipment issues.

Table 5 shows percentage of flights across days of the week. The day of the week with the highest percentage of flights was Tuesdays (16.50%). Table 6 shows percentage of overflights across hour of the day. Most overflights occur from 8:00am to 12:00pm. Table 7 shows percentage of overflights across aircraft type. Rotorcraft is the aircraft type most common among low-level overflights at HAVO.

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

Day of the week	Percent of overflights
Monday	15.4
Tuesday	16.5
Wednesday	16.3
Thursday	15.6
Friday	15.4
Saturday	11.4
Sunday	9.4

Table 6. Percentage of overflights across hours of the day.

Hour	Percentage of overflights
6:00am–7:00am	0.4
7:00am–8:00am	2.2
8:00am–9:00am	19.3
9:00am–10:00am	9.7
10:00am–11:00am	15.2
11:00am–12:00pm	20.0
12:00pm–1:00pm	4.3
1:00pm–2:00pm	8.5
2:00pm–3:00pm	8.3
3:00pm–4:00pm	5.4
4:00pm–5:00pm	2.7
5:00pm–6:00pm	0.8
6:00pm–7:00pm	0.3
7:00–8:00pm	0.5

Table 7. Percentage of overflights across aircraft type.

Aircraft type	Percentage
Fixed-wing single engine	2.2
Fixed-wing multi engine	1.0
Rotorcraft	95.8

Using the cleaned Phase 3 dataset, three more figures were produced to show overflight travel patterns across aircraft type. Figure 16 displays overflight travel patterns for fixed-wing single engine. Figure 17 displays overflight travel patterns for fixed-wing multi engine aircraft. Figure 18 displays overflight travel patterns for rotorcraft aircraft.

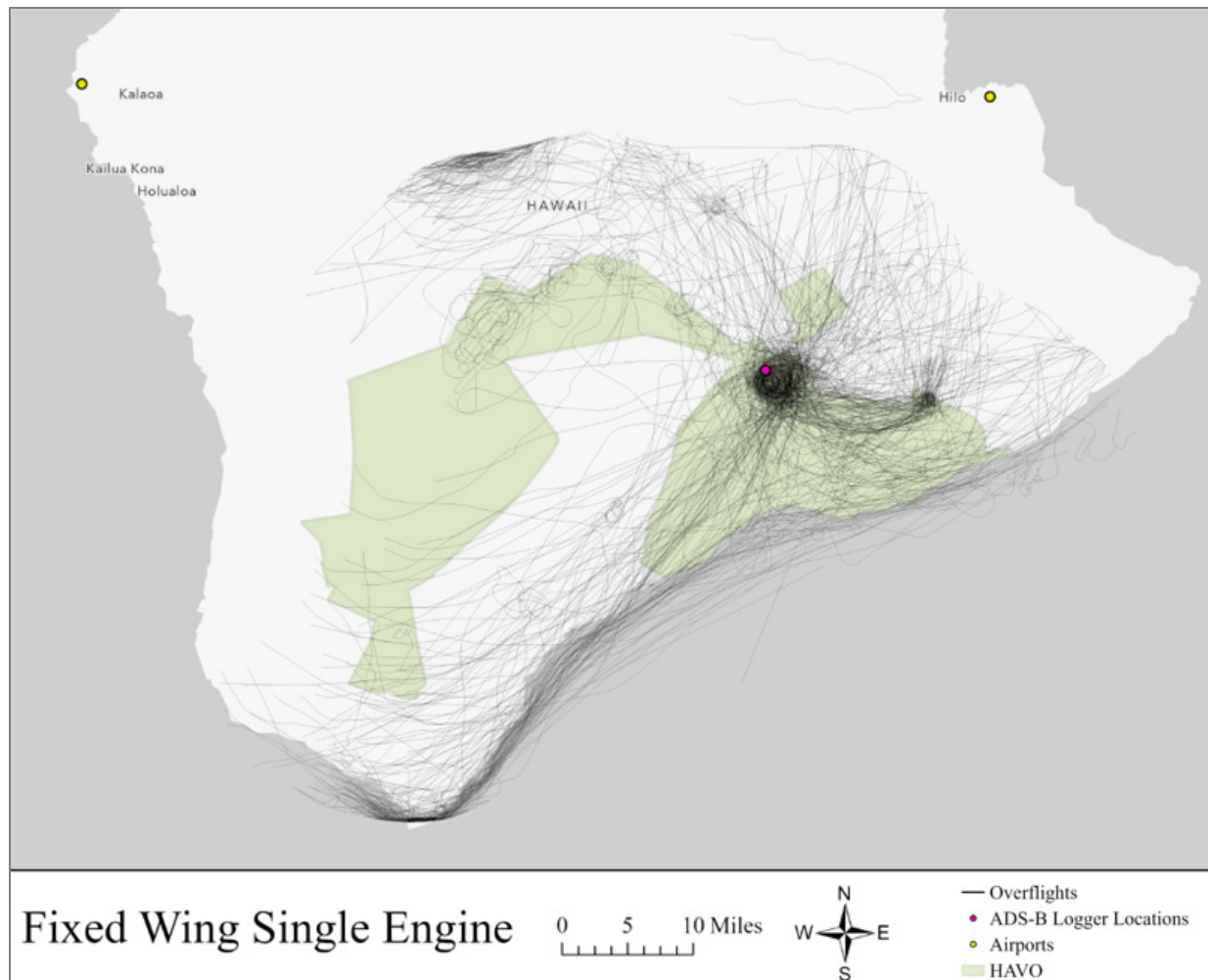


Figure 16. Phase 3 fixed-wing single engine overflight travel patterns.

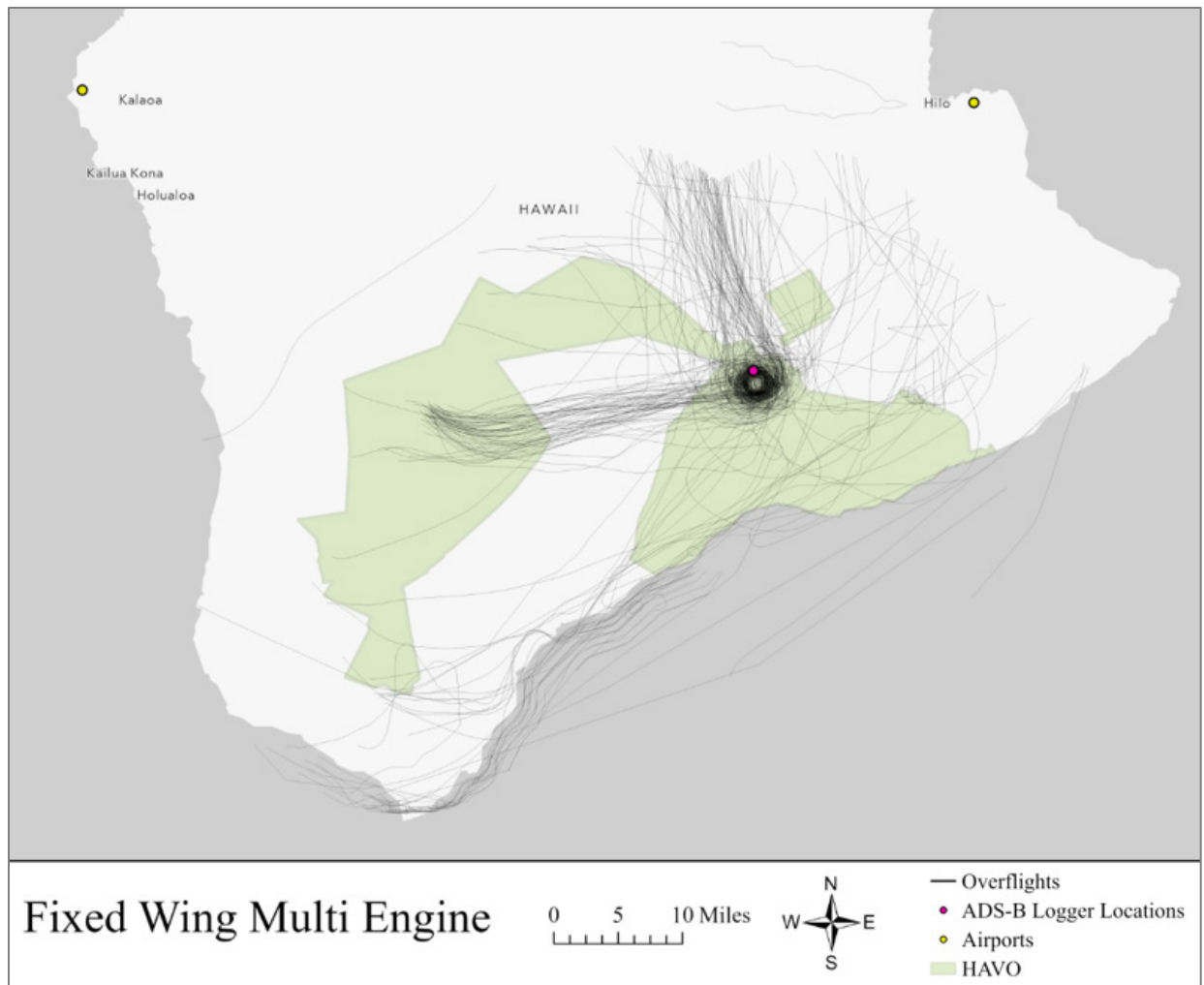


Figure 17. Phase 3 fixed-wing multi engine overflight travel patterns.

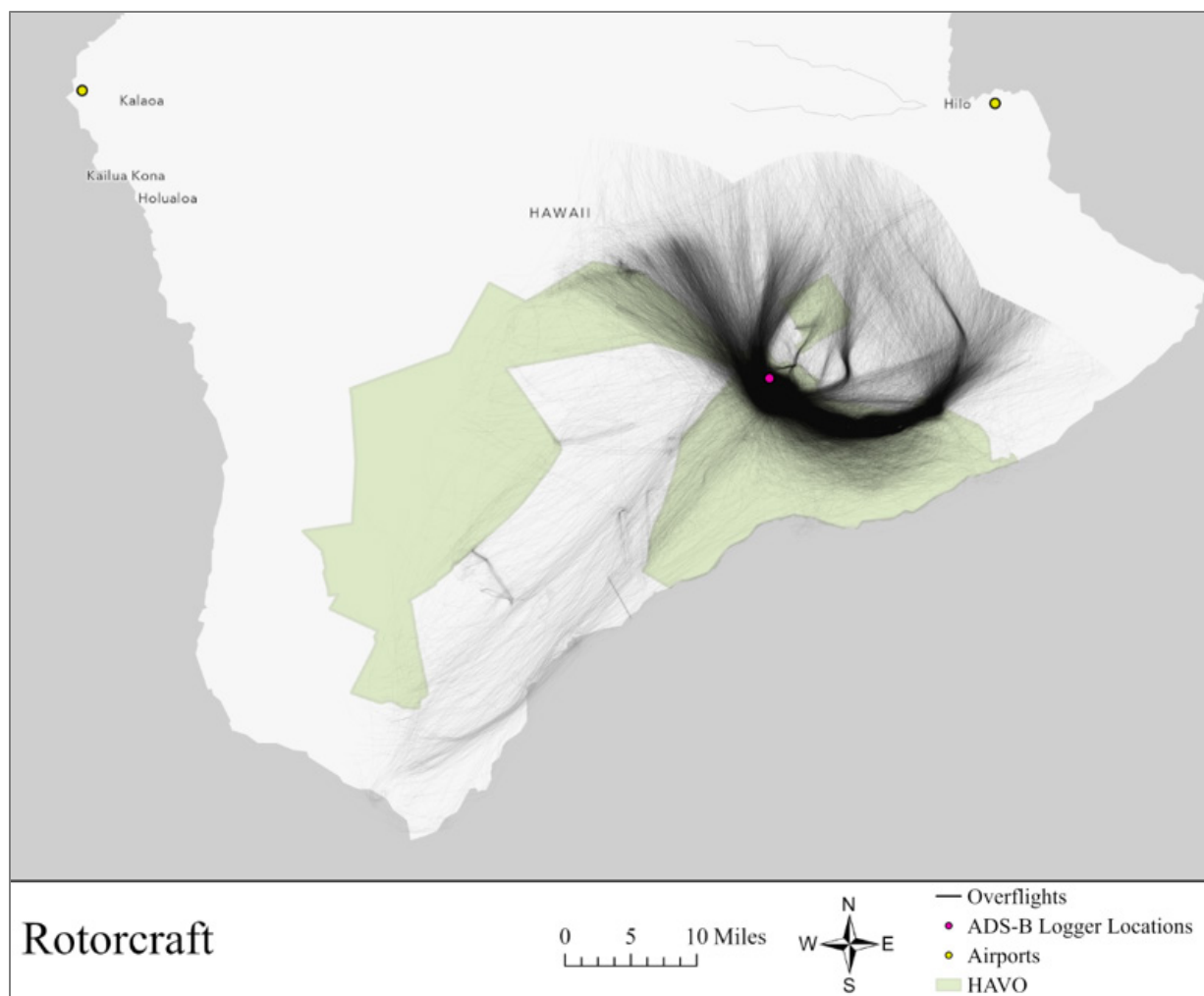


Figure 18. Phase 3 rotorcraft overflight travel patterns.

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at HAVO. Flight tracking data were analyzed from December 28th, 2020 to April 14th, 2023 (617 total days; 50 days of missing data). Analysis consisted of three phases.

The first phase focused on all overflights and showed a concentrated trend of overflights above the east side of HAVO. Visual analysis of these data suggest overflights are less concentrated above the western perimeter of the HAVO boundary. However, this may be due to terrain shielding from Mauna Loa that blocks the data logger from receiving ADS-B signals. Additionally, the east side of HAVO has many volcanic craters, including the Kīlauea Crater, which are popular for sightseeing air tours. Also, this phase revealed a primary flight corridor above the Kīlauea Crater, which likely results in substantial noise disturbances due to the number of flights at lower altitudes.

The second phase focused on low-level overflights (defined as less than 15,000ft MSL) and showed aircraft fly at lower altitudes along the southeast areas of HAVO. This trend likely occurs because of the topography differential between the coastline and Mauna Loa (13,681ft), which is located in the northern area of HAVO. Phase 2 displays five figures ranging from 0–15,000ft MSL that are segmented across waypoint altitude intervals that increase by 3,000ft MSL intervals. Two of the intervals had significantly more waypoints, which were the 3,001–6,000ft MSL and 6,001–9,000ft MSL altitude intervals.

The third phase attempted to focus more specifically on air tours by removing flights known not to be air tours. The dataset was cleaned of 93 civil patrol flights, 407 straight-line flights, 3 commercial airline flights, 26 flights with a flightpath less than a mile in length, and 116 survey flights. This left 11,068 flights. This is slightly less than the number of flights for Phase 1 (11,481), which suggests that most of the aircraft tracks captured in this sample are low-level flights. The 11,068 flights should not assumed to be all air tours; however, considering that 95.8% of the data are rotorcraft and the visual observation of the data is consistent with known air tour patterns, it is likely most of these 11,068 flights are air tours.

Figures 9 and 10 display density analysis, and reveal that density is highest near the Kīlauea Crater, which is consistent with the known air tour travel patterns (Peterson et al., 2022; Peterson et al., 2023). It was found that overflight density was the highest for the altitude interval of 1,501–2,000ft AGL. Further, the consistency of density of flights across multiple altitude bands likely increases disturbances for the terrestrial visitor experience, wildlife, and cultural sites.

A number of analyses in this report focus on altitude of aircraft above ground level. Table 2, which displays number of waypoints within specific AGL altitude bands, shows that the <0ft AGL, 0–500ft AGL, 501–1,000ft AGL, 1001–1,500ft AGL; 1,501–2,000ft AGL; and 2,001–2,500ft AGL; with the 1,501–2,000ft AGL interval receiving the most waypoints. Flights at altitudes lower than 1,000ft AGL, especially lower than 500ft AGL, present higher sound levels than flights at higher altitudes. Additionally, the FAA recommends pilots fly above 2,000ft 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 3.6% of the data. A single rotorcraft accounted for 87.1% of these negative AGL data — suggesting a system error on the aircraft’s ADS-B system. Further, Figure 3, which displays waypoint altitudes up to 3,000ft MSL, shows a circular flight pattern above the Kīlauea Crater, which has a summit of 4,000ft MSL. We display the data above the crater despite being unsure of the true altitude. When interpreting the data with respect to position, the latitude and longitude are accurate, but altitude error should be taken into consideration. Figure 11 displays the traffic patterns of the <0ft AGL tracks. These data below 0 AGL are the only data we know for certain are in error. Examination of these data revealed no discernable patterns as compared to the rest of the data — suggesting that the <0ft data are not spatially concentrated in any single region of the park.

Terrain shielding for ADS-B signals for flights near the coast may also be occurring. Figures 11 and 12 (both figures that focus on flights with low AGL) display very few tracks of data over the coastal area of the park. Both figures also display fairly clear areas where the data drop off occurs.

Temporal patterns of flights were also examined. Table 5 shows that the percentage of flights across days of the week are similar with the lowest percentage of flights occurring on Sundays (9.4%) and Saturdays (11.4%) and the highest percentage of flights occurring fairly evenly from Monday through Friday. Table 6 displays percentage of overflights across hours of the day, revealing that a significant number of flights begin at 8:00am and continue until 12:00pm. Table 6 shows that early evening (5:00pm–8:00pm) is the freest from low-level aircraft noise. This is likely due to a moisture inversion in which cloud build-up typically begins around noon and steadily increases throughout the day.

The ADS-B logger was deployed where HAVO managers know the majority of overflight data will be collected. The majority of data were collected over the eastern portion of the park and near locations that include series of craters with a focus on Kīlauea Crater. The northwestern area of HAVO is flown over less routinely, likely because there are no active volcano craters to view. Additionally, this area is higher in elevation which limits helicopter air tours from flying in this area.

In conclusion, this study produced results to further understand overflights, including air tours, at HAVO. 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.
- 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).
- FAA. 2023a. Equip ADS-B. Available at: https://www.faa.gov/air_traffic/technology/equipadsb
- FAA. 2023b. Automatic Dependent Surveillance-Broadcast (ADS-B). Available at: https://www.faa.gov/air_traffic/technology/adsb
- Lawson, S., K Hockett, B. Kiser, N. Reigner, A. Ingram, J. Howard, & S. Dymond. 2007. Social Science Research to Inform Soundscape Management in Hawai‘i Volcanoes National Park. Final Report. Department of Forestry, College of Natural Resources, Virginia Polytechnic Institute and State University.
- Lignell, B. W. 2020. Reporting information for commercial air tour operations over units of the national park system: 2019 annual report. Fort Collins, Colorado: National Park Service. Natural Resource Report NPS/NRSS/NSNSD/NRR— 2020/2193.
- McMurtry, G. M., Dasilveira, L. A., Horn, E. L., DeLuze, J. R., & Blessing, J. E. (2019). High $^3\text{He}/^4\text{He}$ ratios in lower East Rift Zone steaming vents precede a new phase of Kilauea 2018 eruption by 8 months. *Scientific Reports*, 9(1), 11860.
- National Park Service. 2022. Hawai‘i Volcanoes National Park. Available at: <https://www.nps.gov/havo/learn/nature/mauna-loa.htm>
- National Park Service. 2023. Hawai‘i Volcanoes National Park. Retrieved from: <https://www.nps.gov/havo/index.htm>
- 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.
- UNESCO. 2023. Hawai‘i Volcanoes National Park. Available at: <https://whc.unesco.org/en/list/409/>
- United States Geological Survey. 2021. The National Map – Data Delivery. Available at: <https://www.usgs.gov/core-science-systems/ngp/tnm-delivery>

United States Geological Survey. 2023. Kīlauea. Retrieved from:
<https://volcanoes.usgs.gov/volcanoes/kilauea>

Ward, V. L. and Shields, C. E. 2023. Reporting information for commercial air tour operations over units of the national park system: 2020 annual report. Natural Resource Report NPS/NRSS/NSNSD/NRR—2023/2548. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2299664>

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525