Developing Tools for Overflight Analysis in National Parks Using GIS

Using ADS-B data to detect ATMP violations and analyze data logger effectiveness

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Abstract: This project utilized Automatic Dependent Surveillance-Broadcast (ADS-B) data collected by the National Park Service (NPS) in order to monitor operator adherence to air tour management agreements and policies. Geospatial software (ArcGIS Pro) was used to create models that identify flights that violate no-fly zones within a national park, as well as flights that violate minimum altitude restrictions. Additionally, viewshed analysis was conducted for the ADS-B data loggers deployed by the NPS in order to determine 'blind spots' due to loss of line-of-sight connection to air tour aircraft. The methods introduced in this project addressed how ADS-B flight data was pre-processed, how flight violations were identified (for both point and line data), and the execution of skyline analysis for the data logger locations in order to model the data logger viewshed. While the methods were developed using ADS-B data, they can be modified to accept operator provided data and provide the same results. The methods developed in this project will serve as tools the NPS can implement to monitor overflight compliance over national parks that allow air tours.

Keywords: National parks, acoustics, overflights, ADS-B, onboard GPS, GIS

Table of Contents

Table of Figures

Introduction

Natural soundscapes are an important feature of US national parks, serving as both a prominent component of the park's ecosystem and an enriching experience for visitors, that has been increasingly threatened by anthropogenic noise (Francis et al., 2017). Over the past several decades, soundscapes have been labeled as a valuable natural resource worthy of conservation and protection (Dumyahn & Pijanowski, 2011). The preservation of natural soundscapes is a legal responsibility of the National Park Service (NPS), who monitors acoustic soundscapes and informs policies and practices that aim to mitigate the impacts of noise. A recent review of acoustic data from US national parks identified the biggest challenge facing natural soundscapes to be noise pollution caused by aircraft (Buxton et al., 2019). These study results and legal requirements for managing air tours have prompted new efforts to monitor national park overflights. With the federal requirement for aircraft to utilize ADS-B, the NPS is now able to collect ADS-B flight data for any aircraft flying over national parks. In addition, the development of Air Tour Management Plans (ATMP) with air tour operators will provide the NPS with onboard GPS flight data for air tour overflights. With the acquisition of these two datasets, monitoring overflights is feasible with the appropriate development of methods and tools that allow for data verification, comparison, and analysis. This project aims to provide the NPS with methods that will allow them to monitor national park overflights and ensure compliance with established rules and regulations.

Importance of Sound and the Impact of Noise

Soundscapes are considered "the collection of sounds perceived in an environment, including those from biological sources (e.g., bird vocalizations), geophysical sounds (e.g., wind and rain), and anthropogenic sounds" (e.g. road and air traffic) (Buxton et al., 2021). Natural soundscapes usually refer to the sounds from biological and geophysical sources, while anthropogenic sounds are often referred to as 'noise', especially once it becomes louder than natural sounds. The quality of these natural soundscapes has broad implications for the health of their respective ecosystems. There are several aspects of noise that can impact wildlife - from intensity, amount of exposure, to how much noise disrupts or mimics natural sounds - all of which serve to disrupt natural behaviors (Francis & Barber, 2013). Many species rely on the ability to detect sounds for identifying prey or predators, communication and mating signals, and determining their spatial movements (Francis et al., 2013). Introducing new sounds, especially from anthropogenic sources, into an ecosystem can disrupt these functions impacting wildlife, plant life, and the health of the ecosystem (Francis et al., 2013). These impacts of noise on specific species can have cascading effects on their ecosystems, leading to much larger ecological implications and the decline of biodiversity (Francis et al., 2017).

In addition to the impact on natural ecosystems, noise also impacts human health (Huynh et al., 2022). More specifically, the biological and geophysical sounds have been documented to be preferred over anthropogenic noise and have also been shown to help decrease stress and anxiety levels and increase perceived levels of tolerance and pleasure (Franco et al., 2017). Recent research not only documents the psychological benefits of experiencing natural sounds, it also addresses the negative impacts of degraded soundscapes due to anthropogenic noise such as decreases in cognitive function, memory, and mood (Francis et al., 2017). Combined with the health benefits of natural sounds and the negative impacts of noise, soundscapes have become increasingly recognized as a valuable resource in need of management and protection.

Soundscapes in National Parks

Despite limits on human activity, anthropogenic noise has doubled background sound levels in over 60% of protected areas in the US, including national parks, and a 10-fold increase or greater in about 20% of protected areas (Buxton et al., 2017). This abundance of noise affects the ability of national parks to preserve biodiversity and healthy ecosystems, but it also affects the experience of visitors (Francis et al., 2017). Natural soundscapes are an important element of national parks that some people expect to experience and the presence of anthropogenic sounds is often a source of disappointment for visitors (Miller et al., 2018). One survey conducted by the NPS showed that 67% of participants indicated that natural sounds were an important factor of their visit to a national park while another survey had visitors rating experiencing acoustic disturbances, like aircraft noise, more than once per 15 minutes as unacceptable (Betchkal et al., 2023). In addition to protecting natural environments and enjoyable visitor experiences, the NPS is responsible for the preservation of soundscapes for cultural and/or historical purposes which can be site specific or related to an event, such as native drumming or military reenactments (NPS, 2006). The importance of natural sounds is evident by the number of laws, regulations, and policies that guide the NPS in protecting soundscapes and pursuing noise reduction, from the Noise Control Act of 1972 to NPS Director's Order #47: Soundscape Preservation and Noise Management. NPS Director's Order #47, which was established in 2000, is the primary source of guidance for the NPS's acoustic responsibilities while additional management policies provide more detail and explicitly direct the Service to "take action to prevent or minimize all noise that…adversely affects the natural soundscape" (NPS, 2006).

In 2011 the NPS established the Natural Sounds and Night Skies Division (NSNSD) whose mission is to protect, maintain, and restore both natural soundscapes and night skies within US national parks. The NSNSD are the stewards of the natural soundscapes and night skies of US national parks, providing scientific leadership, technical assistance, and development of policies and solutions to prevent anthropogenic noise and light pollution in and around national parks (NPS, 2021). Any national park can request assistance from the NSNSD to conduct acoustic monitoring. These requests support a wide range of scientific interest and research, from establishing soundscape baselines to species identification to monitoring noise pollution, and the results of these efforts are published as Acoustic Monitoring Reports. In addition to being able to create geospatial models from their vast acoustic data collection, the NPS executed a comprehensive analysis of noise pollution across the national parks. After analyzing almost 1.5 million acoustic samples from national parks, the NPS found ten common noise sources and although these sources varied across the sites, aircraft noise was heard at every site and was predominant at most of them (Buxton et al., 2019). These results highlight overflight noise pollution as one of the most pressing issues for the NSNSD when it comes to preserving natural soundscapes and it is currently one of the most active efforts for the division.

Natural Sounds and Night Skies Division Overflight Program

The NPS monitors three primary sources of overflights: UAVs, military aircraft, and air tours. The first two, UAVs and military overflights, have relatively established management practices in effect. When the use of UAVs in national parks drastically increased due to the popularity of recreational drones, the June 2014 Policy Memorandum was created, prohibiting the use of UAVs in national parks unless authorized by the NPS via a permit (NPS, 2023). Military overflights are addressed through partnerships with Department of Defense agencies as needed to mitigate impacts at the local level (NPS, 2023). The most complex source of overflights to manage are the air tours operated over national parks.

The National Parks Air Tour Management Act of 2000 requires all operators wanting to conduct air tours above national parks to apply for Federal Aviation Administration (FAA) approval. In order to implement this Act, the NSNSD established the Overflight Program which works in conjunction with the FAA. For any park that receives applications, the FAA and NPS must cooperatively establish an Air Tour Management Plan (ATMP) that establishes the conditions and operational and reporting requirements for tours (NPS, 2023). An amendment to the Act allowed for voluntary agreements (VA) to be utilized in lieu of formal ATMPs, the primary difference being that agreements do not require compliance with the National Environmental Policy Act (NEPA) (FAA, 2024). These ATMPs and voluntary agreements are designed to allow the NPS to monitor and reduce the impact of low flying aircraft on the soundscapes in and around national parks. While the requirement for ATMPs has been long standing, recent legal activity in 2020 prompted the prioritization of completed ATMPs and VAs for eligible national parks. As a result, many national parks have only formalized ATMPs or VAs within the last four years. Table 1 shows which National Parks have ATMPs and VAs as of January 2024.

Table 1. List of National Parks with completed ATMPs and VAs*

Completed ATMPs	Arches National Park, Badlands National Park, Bryce Canyon National Park, Canyonlands National Park, Death Valley National Park, Glacier National Park, Golden Gate National Recreation Area/Muir Woods National Monument/Point Reyes National Seashore/San Francisco Maritime National Historical Park, Great Smoky Mountains National Park, Mount Rainier National Park, Mount Rushmore National Memorial, Natural Bridges National Monument, Olympic National Park, Hawai'i Volcanoes National Park, and Haleakala National Park
Completed VAs	Governors Island National Monument/ Statue of Liberty National Monument, Glen Canyon National Recreation Area, and Rainbow Bridge National Monument
In progress	Bandelier National Monument, Canyon de Chelly National Monument, and Lake Meade National Recreation Area

*Note: National parks with 50 or less air tours each year are exempt from the National Parks Air Tour Management Act, as are parks in Alaska, while the Grand Canyon National Park is subject to the National Park Overflights Act of 1987 (Beeco & Joyce, 2019).

Relevant ADS-B Research

ADS-B is a technology that has been designed to replace ground radar as a means to provide real-time aircraft location and status via satellite signal (FAA, 2023). ADS-B equipment is installed onboard participating aircraft and transmits flight data (such as the location, velocity, and heading) at least once a second (14 C.F.R. § 91.227, 2023). Since ADS-B data is transmitted real-time from aircraft, receivers can capture flight data if it is within range and has an unobstructed line-of-sight (LOS). Currently, the availability of published studies using ADS-B data in GIS platforms are limited. The FAA began implementing ADS-B in 2007 but it only became required for aircraft in class A, B, and C airspace in 2020 (AOPA, n.d.). With ADS-B data publicly available to anyone capable of receiving and capturing the broadcast, ADS-B has become a source of data in a few different types of geospatial and GIS studies. Most studies utilizing ADS-B data have been exploring different uses for the data around airports. Some studied the use of ADS-B with GIS tools for airport surveillance (Jing et al., 2014) and the development of 4D GIS tools for managing ADS-B data for air traffic control purposes (Deng et al., 2023). Others have researched the use for ADS-B in GIS platforms to study airflight crashes (Li et al., 2020), air route clustering (Duong et al., 2019), and a learning-based aircraft trajectory tool (Zhang et al., 2022). Other studies of ADS-B data in GIS platforms include identifying spatial patterns of remote UAS pilots (Lercel & Hupy, 2023) and developing a meteorological early warning system for air operations (Zuluaga et al., 2019).

The use of utilizing ADS-B data for studying flights over national parks is a new application lead by the NSNSD, who have published six studies that involve analyzing ADS-B data over national parks. However, none of these have yet combined or compared ADB-S data with onboard GPS data. This is primarily because the ATMPs and voluntary agreements requiring flight operators to submit onboard flight data have only been finalized in the past few years. Tracking aircraft flights over national parks first became feasible with the invention and deployment of ADS-B units on aircraft, allowing the NPS to collect and log overflight data. The first foray into tracking national park overflights consisted of a feasibility study that tested the build and functionality of ADS-B data loggers and data collection and processing (Beeco & Joyce, 2019). This study concluded that ADS-B technology and data was viable for the purposes of overflight monitoring and served to identify what issues needed to be addressed before it could be implemented successfully such as equipment modifications, data logger site selection, and additional data processing steps (Beeco & Joyce, 2019).

Most of the ADS-B analysis that has been conducted focused on Hawai'i Volcanoes National Park, resulting in a study of overflight altitude characteristics and hotspots (Peterson et al., 2023) and a study pairing flight data to acoustic data in an effort to determine actual overflight noise levels for both Hawai'i Volcanoes National Park and Denali National Park (Betchkal et al., 2023). An analysis of overflights for the Smoky Mountains was also conducted with a focus on identifying patterns in the altitude of aircraft (Peterson et al., 2023). One of the challenges faced in these studies was differentiating air tours from other low-level overflights, establishing the need for being able to identify which flights are relevant for reviewing ATMP and VA compliance (Peterson et al., 2022). Downsizing the amount of data required to process for overflight identification would serve to streamline the ability of the NSNSD to audit ATMP and VA operator data submittals for accuracy and completeness. Additionally, the ability to identify all air tours in the ADS-B data would also serve as verification that flight operators are submitting all air tour information as required. If the comparison shows that operators have submitted flight data that is not present in the ADS-B dataset, that is an indication that the ADS-B data logger might have blind spots due to mountainous terrain.

Project Background

This project aimed to provide the NSNSD with tools and methods for analyzing ADS-B and onboard GPS data air tour flights for compliance with ATMPs and to model the effectiveness of the ADS-B data loggers at collecting air tour flight data. This project utilized ArcGIS Pro as the software of choice due to the current use of ArcGIS Enterprise by the NSNSD.

Project Study Area

The NPS selected the primary area of interest for this project, the Great Smoky Mountains National Park, due to the high number of operator tours over the park and the recent establishment of the ATMP on December 3, 2022. The ATMP not only applies to all commercial air tours over the park but those within ½ mile outside of the park boundary as well. While this project was executed for GRSM, the methods developed in the project can easily be adapted for any park that has available ADS-B data.

Figure 1: Great Smoky Mountain National Park boundary line

Within GRSM, the NPS has built and placed ADS-B data loggers in open areas to capture and record flight data from aircraft overflights. A total of 3 units were deployed to Cades Cove, Elkmont, and Cove Mountain as shown in Figure 2. Figure 3 shows the approximate geospatial locations of each data logger. The lat/long coordinates were provided by the NSNSD and the elevation values were estimated based on the DEM being utilized for this analysis.

Figure 2: ADS-B data logger locations in GRSM

	A	B	C	D	E
1	id	location	lat	long	elev (m)
2	0	Cove Mountain	35.69667	-83.6097	1246
3	1	Elkmont	35.66444	-83.5903	639
4	2	Cades Cove	35.60402	-83.7829	567

Figure 3: ADS-B data logger locations

Project Objectives

The objectives for this project are as follows:

1. Develop methods for identifying operator air tour flights that violate the terms set forth in the GRSM ATMP.
2. Conduct viewshed analysis and compare ADS-B coverage for each data logger location within the Great Smoky Mountains National Park.

For the first objective, there are three primary flight rules in the GRSM ATMP that apply to air tour operators. First, operators must stay at least one mile from cultural districts and areas of interest within the park. Secondly, the operators must stay at least ½ mile from the Appalachian Trail (AT). Lasty, the operators must fly above 2,600 ft above ground level (AGL). In order to identify air tour overflights that violate these rules, models were created using ArcGIS Pro ModelBuilder. The models were built using ModelBuilder to ensure that the methods developed are repeatable and could be transformed into python code for future tool development. The models needed to identify NFZ and altitude violations and address data management required to produce usable data and results. These models were ultimately designed to be used on operator provided GPS flight data but since it was not yet available for this project, ADS-B data was also used for model development.

In regard to the second objective, over the past several years the NSNSD has deployed data loggers in GRSM in order to capture flight data with the intent of identifying and monitoring air tour overflights. The NSNSD has historically determined deployment locations based on trial and error, moving locations if enough data wasn't collected. Ultimately the locations selected were either valleys or mountain tops. This project served to model the effectiveness of each location, determine whether improvements were possible, and provide the NSNSD with methods to predict the effectiveness of other potential deployment locations within the park. The first step in gauging the effectiveness of each data logger location in collecting operator data was comparing the amount of operator data collected by each logger. While a data logger located in a valley might collect massive amounts of flight data due to the amount of sky is visible (primarily commercial flight data), operator routes are much closer to the ground and are harder to track when hidden by mountainous terrain. Second, a viewshed analysis was created for each data logger location based off the surrounding terrain using the 10m NED data to estimate how much of the surrounding airspace was within line-of-sight without obstructions. Lastly, the viewshed data made it possible to estimate how much of the operator routes would be visible to each logger. While not an original objective of this project, this provided the NSNSD with valuable information on which deployment locations were effective for capturing the most air tour flight data for the new routes set forth in the ATMP.

Data

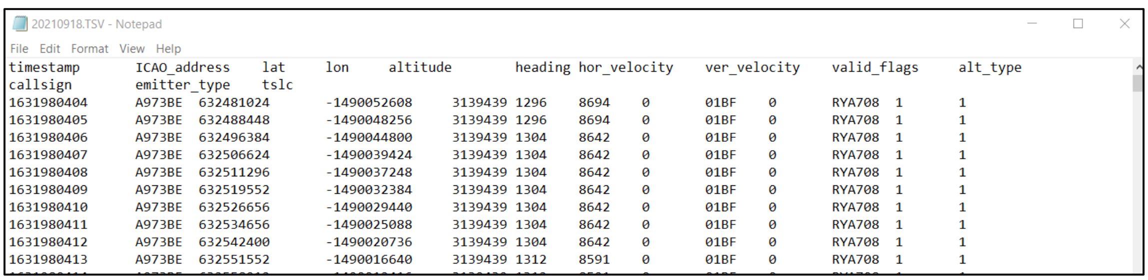
There were three data types used in this project: ADS-B data collected by the NPS, terrain data (10m NED), and vector data representing park features (points of interest, trails, and cultural districts). Table 2 provides a summary of the characteristics of the data types used in this project.

Table 2. Project Data Description

	Source	Format	File type	Attributes	Processing required	Limitations
ADS-B Data	Terrestrial data loggers built and placed by the NPS	Tabular data	.tsv	Identification (ICAO), location, altitude, velocity, timestamp	Extensive (ADS-B Overflight Analysis Toolbox: reformats and transform data into vector shapefile)	ADS-B data is only available for days where data loggers were active
Terrain Data	USGS National Elevation Dataset	Raster data (DEM)	.tif	Elevation values	Clip to relevant AOI	Resolution impacts processing time
Park Data	NPS	Vector data	.shp	Points of interest, trails, and protected districts	Buffered according to ATMP rules	n/a

ADS-B Data

The ADS-B data loggers records flight data and export .tsv files with the fields shown in Figure 4. The data provided by the NPS covered different time frames - the data from Cove Mountain was from 2022 while Cades Cove and Elkmont had data from 2023 into early 2024. These collection times (Cove Mountain especially) mostly fall before the implementation of the GRSM ATMP which is expected to result in a lack of ATMP compliance. All data used in this project was provided by the NSNSD.



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1631980413      A973BE  632551552       -1490016640     3139439 1312    8591    0       01BF    0       RYA708  1       1
```

Figure 4: Raw ADS-B attributes

Data Preprocessing

Given that the ADS-B data provided by the NPS was raw data collected by the data logger, some preprocessing was required before it was in a usable format that could be used for geospatial analysis. The ADS-B data was first processed into geospatial vector data using the ADS-B Overflight Analysis Toolbox created by the Applied Park Science Laboratory and Geographic Information Systems Spatial Analysis Laboratory at Kansas State University, which is in active development for the NPS. The toolbox is designed for ArcGIS Pro and utilizes Python-based geoprocessing scripts to process raw ADS-B data files into vector data, both point and line as seen in Figure 5 (Hutchison & Peterson, 2023). Tool #1 served to process the raw .tsv files into .csv files that can be imported into ArcGIS Pro. This tool also provided unique flight IDs based on attributes selected in the tool. Tool #2 was then used to further process the data into waypoints with the option of also producing flight lines. For this project, point data was the data type chosen for a majority of the analysis and therefore the tool was not utilized to convert the waypoints into flight lines.

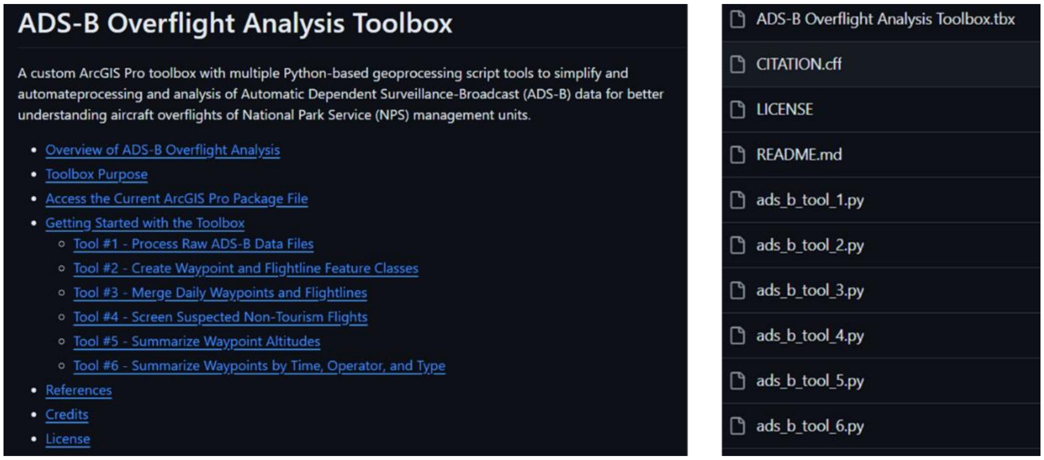


Figure 5: [ADS-B Overflight Analysis Toolbox]

The last step in preprocessing the flight data was to filter the entire dataset for aircraft that are registered to the operators conducting air tours over the GRSM. The ATMP lists two primary operators: Whirl’d Helicopters, Inc. and Great Smoky Mountain Helicopter Inc. However, a review of the FAA Masters file revealed that the businesses with aircraft conducting air tours over GRSM were Whirl’d Helicopters, Inc. and RotorPro LLC. Table 3 shows the ICAO addresses and N-numbers registered to both of these operators. The ADS-B data was filtered for flight data only belonging to these ICAO addresses. This significantly reduced the amount of ADS-B data to a more manageable size (from millions of waypoints to less than 250,000) and limited the dataset to the flights in question. The ADS-B toolbox is designed to identify operator flights through other methods but filtering the data directly was more efficient for this project since the ICAO addresses were known.

Table 3. Aircraft Registered to GRSM Operators

WHIRLD HELICOPTERS INC		ROTORPRO LLC	
ICAO / N-NUMBER		ICAO / N-NUMBER	
A10977	166RH	A1DC89	219SH
A1A96E	206MP	A4E838	415RP
A480B0	39CP	A71289	555FP
A54798	4395D	A7525B	571CJ
A54EA4	441DE		
AA48A1	7617W		
AB4F00	828EJ		

In addition to the flight data, the park data required some minor preprocessing. Each of the shapefiles were buffered by the appropriate distance set forth in the ATMP rules (one mile from points and areas of interest, ½ mile from the AT). Figure 6 shows the no-fly zones (NFZ) within the GRSM that were used in this project.

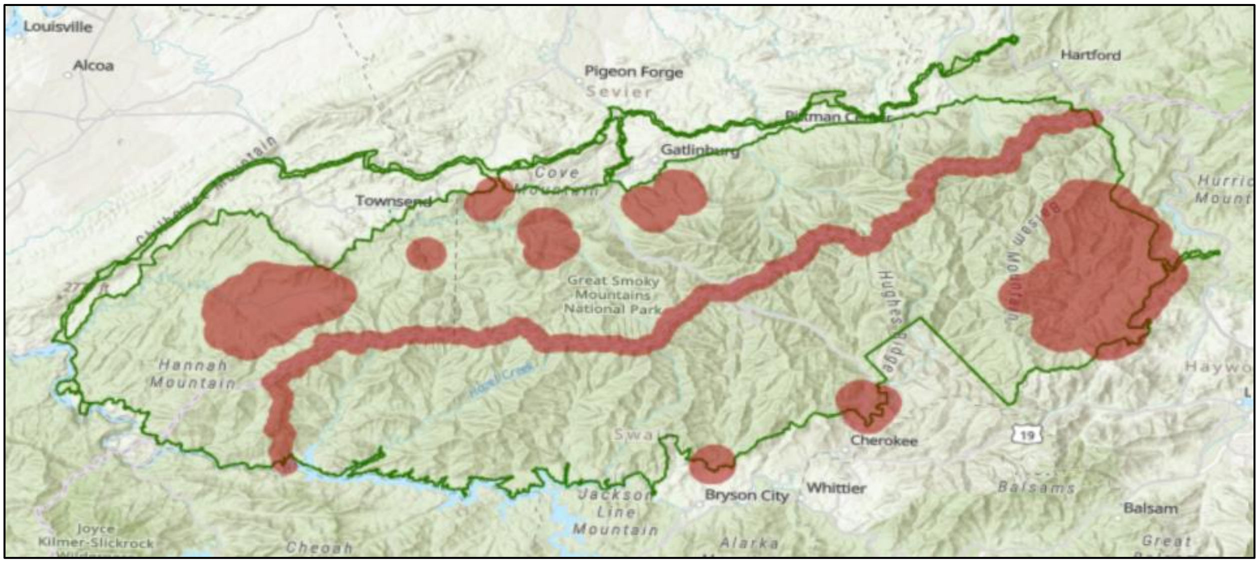


Figure 6: No-fly zones within GRSM based on the ATMP

Methods

This project developed methods for processing, comparing, and analyzing ADS-B flight data collected from a data logger to identify flights that violate the terms of the GRSM ATMP and to analyze the effectiveness of the data loggers in capturing air tour flight information.

ATMP Violation Models

In order to identify air tour overflights that violate the GRSM ATMP, a total of 5 primary models and 1 auxiliary model were created using ArcGIS Pro ModelBuilder. The first two models identify NFZ and altitude violations while the last three are data management oriented by identifying the flight IDs that contain a violation, creating a corresponding attribute and populating it appropriately. The last model serves as an optional step to adding the violation attribute to the original ADS-B dataset. The auxiliary model was created in order to find NFZ violations using line data instead of point data. This mitigates the risk that a gap in point data might result in an NFZ violation being missed.

Model 1: NFZ Violations (point data)

The first model was developed to identify flights that violate the no-fly zones within GRSM and is shown in Figure 7. The model used the **Pairwise Intersect** tool to identify all waypoints that are located over an NFZ. **Statistics** were used to identify all flights that have a point within the NFZ and the attribute was modified for distinction that the violations are for the NFZs.

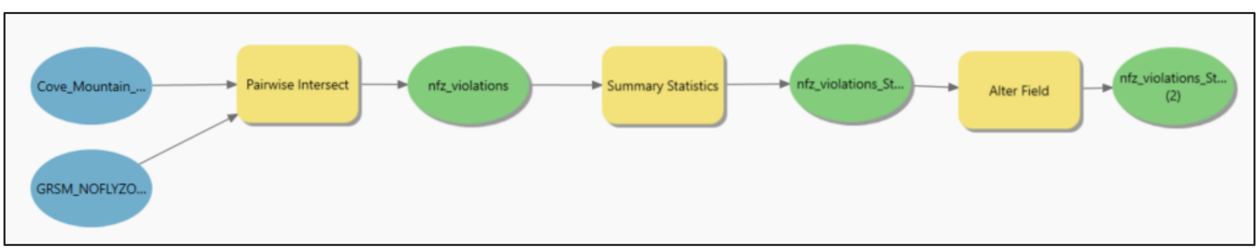


Figure 7: NFZ Violation Model

Model 2: ALT Violations

The second model was developed to identify flights that violate the minimum altitude requirement of 2,600ft AGL within GRSM and is shown in Figure 8. The model used the **Pairwise Intersect** tool to identify all waypoints that were located over the GRSM and the **Select** tool was used to capture all waypoints violating the minimum altitude requirement using the 'altitude' attribute within the data. **Statistics** were used to identify all flights that have a point violating the minimum altitude and the attribute was modified for distinction that they are altitude violations.

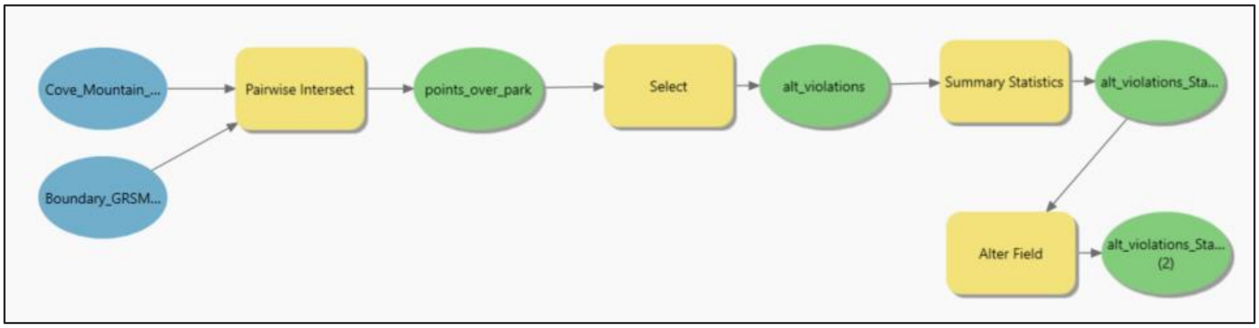


Figure 8: Altitude Violation Model

Model 3: Flight Table

The third model (Figure 9) created a new flight table that listed all of the unique flight IDs found within the ADS-B point data set by using the **Statistics** tool. This table was then used to add the flights that contain a NFZ or altitude violation using the attributes modified within the first two models by use of the **Join Field** tool. A new field for 'violations' was added to the table using the **Add Field** tool. Once all attributes were added, the table was exported (using **Export Table**) so that it can be used as a standalone product.

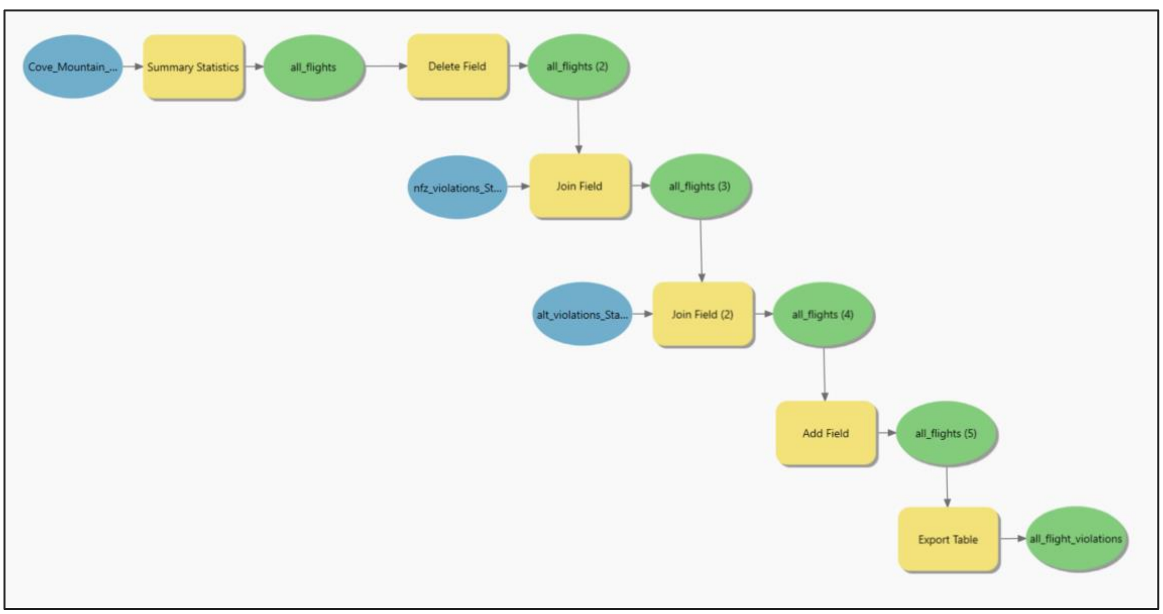


Figure 9: Creating the all flights table

Model 4: Violation Attribute

The fourth model (Figure 10) served to populate the 'violation' attribute within the all flights table created by Model 3. This was accomplished by using the **Select Layer by Attribute** to identify flights within the 'flight_id_nfz' and 'flight_id_alt' columns. Based on which column was populated (meaning that the flight carried the respective violation), the attribute was populated with one of four values shown in Table 4. Figure 11 shows the table after the model was run and demonstrated that the violation attribute was calculated appropriately.

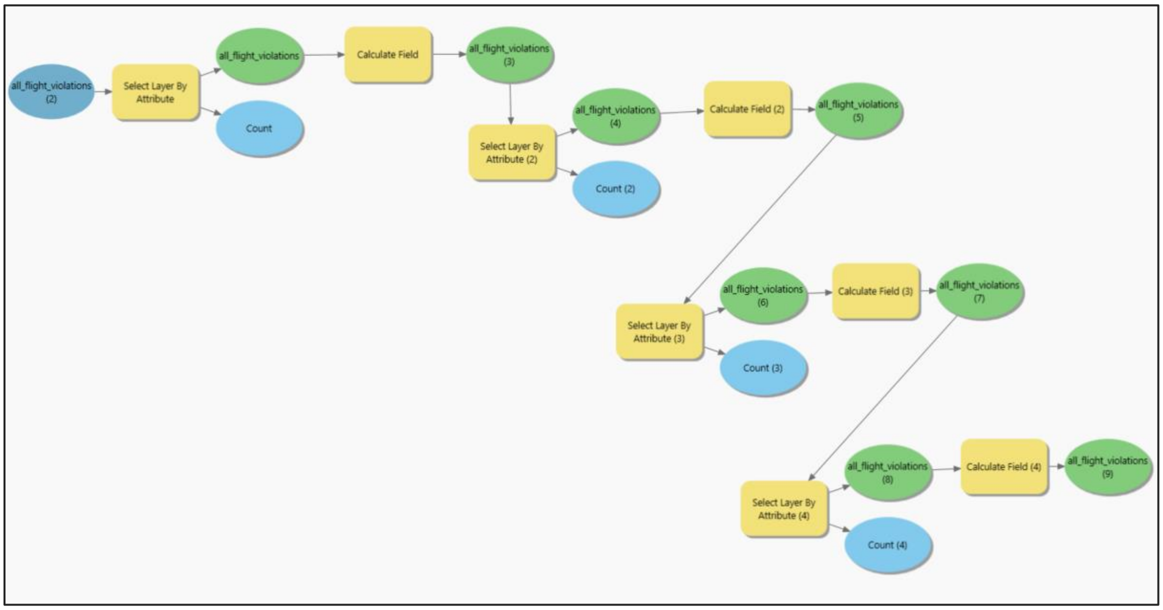


Figure 10: Populating the violation attribute

Table 4. Violation attribute values

Violation	Attribute Value
No Violations	0
ALT Violation	1
NFZ Violation	2
Both Violations	3

	OBJECTID *	flight_id *	flight_id_nfz	flight_id_alt	violation
1	1	A10977_0_20220415	<Null>	<Null>	0
2	2	A10977_0_20220416	<Null>	<Null>	0
3	3	A10977_0_20220419	<Null>	<Null>	0
4	4	A10977_0_20220420	A10977_0_20220420	A10977_0_20220420	3
5	5	A10977_0_20220423	A10977_0_20220423	A10977_0_20220423	3
6	6	A10977_0_20220424	<Null>	<Null>	0
7	7	A10977_0_20220427	<Null>	<Null>	0
8	8	A10977_0_20220508	<Null>	<Null>	0
9	9	A10977_0_20220509	<Null>	<Null>	0
10	10	A10977_0_20220511	<Null>	<Null>	0
11	11	A10977_0_20220517	A10977_0_20220517	A10977_0_20220517	3
12	12	A10977_0_20220518	A10977_0_20220518	A10977_0_20220518	3
13	13	A10977_0_20220522	<Null>	<Null>	0
14	14	A10977_0_20220524	<Null>	<Null>	0
15	15	A10977_0_20220525	A10977_0_20220525	A10977_0_20220525	3
16	16	A10977_0_20220527	<Null>	<Null>	0
17	17	A10977_0_20220528	<Null>	A10977_0_20220528	1
18	18	A10977_0_20220529	A10977_0_20220529	A10977_0_20220529	3
19	19	A10977_0_20220530	<Null>	A10977_0_20220530	1
20	20	A10977_0_20220604	A10977_0_20220604	A10977_0_20220604	3

Figure 11: All flights table with violation attribute

Model 5: Join Attribute to Dataset

The fifth model serves as an optional tool. If it would be helpful to have the violation attribute in the original ADS-B point dataset, this model uses the **Join Field** tool to do so. It is important to note that the violation attribute is joined using the flight ID and therefore applies the same violation attribute to every point within a flight. Figure 13 shows the final result.

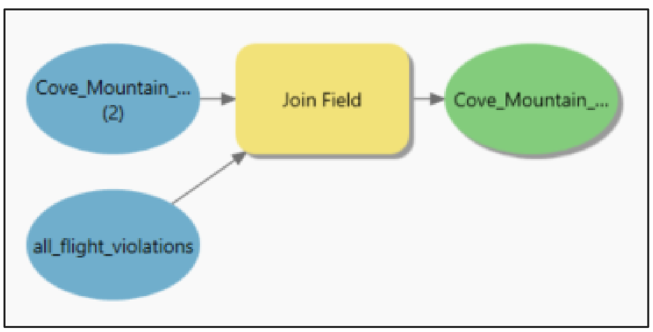


Figure 12: Join field model

DATE	flight_id	alt_msl	alt_agl	N_NUMBER	TYPE_AIRCR	TYPE_ENGIN	TYPE_REGIS	NAME	MFR_MDL_CO	MODEL	violation
20221125	A10977_0_20221125	3650	838	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3650	792	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3650	756	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3600	456	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	484	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	484	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	484	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	484	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	527	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	543	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	441	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3575	340	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3550	246	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3550	849	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3550	958	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3525	897	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3525	769	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3525	736	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3525	775	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3
20221125	A10977_0_20221125	3525	920	166RH	6	3	3	WHIRLD HELICOPTERS...	7640130	R66	3

Figure 13: Violation attribute joined to ADS-B data

Aux Model: NFZ Violations (line data)

The auxiliary model (Figure 14) is virtually identical to Model 1, except that it used line data for an input instead of point data. Given that this is an auxiliary model, the results were not included as inputs for Model 3 but that can be modified if using line data for NFZ violations instead of point data.

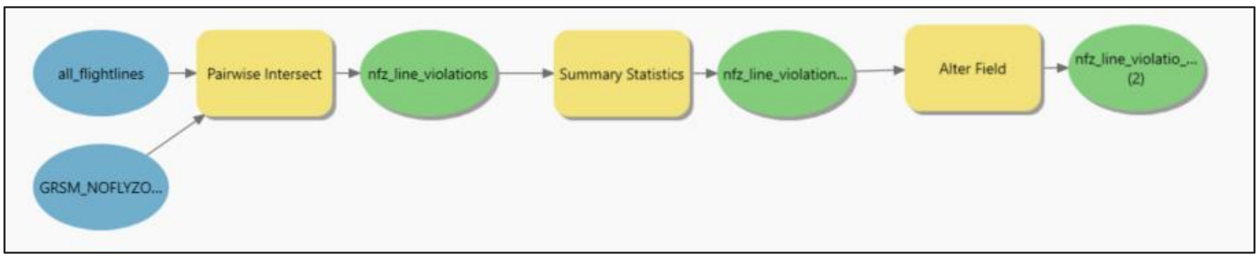


Figure 14: Auxiliary NFZ Violation Model

ADS-B Data Logger Viewshed Analysis

In order to model the effectiveness of the data loggers in collecting ADS-B data for operator flights over GRSM, three elements of analysis were pursued. The first was a comparison of how much data each logger collected. The second was modeling the skyward viewshed for each data logger location and the third was modeling how much of the operator route was visible from each location.

ADS-B Data Collection Comparison

This comparison was completed through visual examination of the data from each in addition to a calculation of how many points were contained within each dataset. Figures 15, 16, and 17 show the ADS-B data collected from each data logger while Table 5 shows the number of points from each location. With the sparse collection from Elkmont and Cades Cove, the ADS-B data from Cove Mountain was selected for the development of models and analysis in this project.

Figure 15: Elkmont ADS-B data

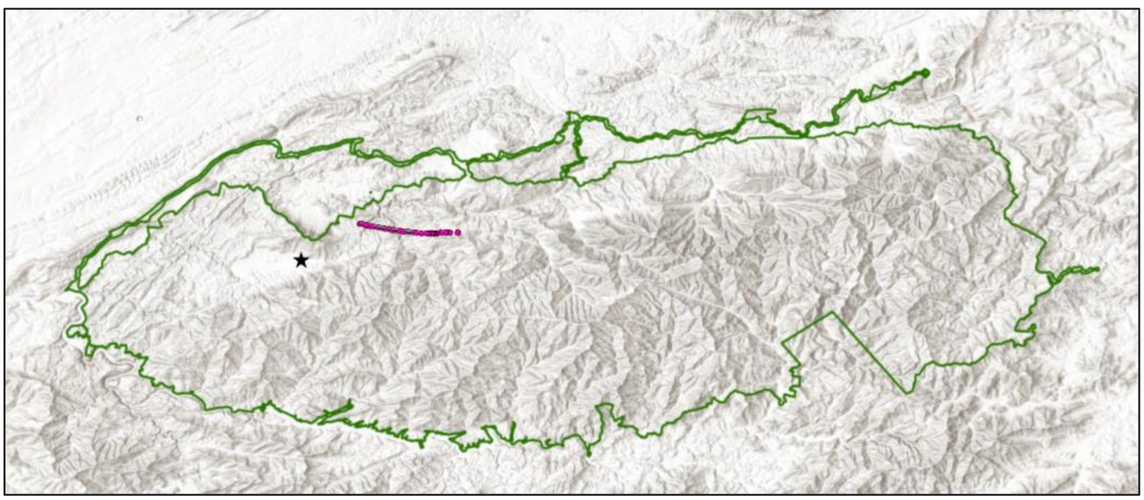


Figure 16: Cades Cove ADS-B data

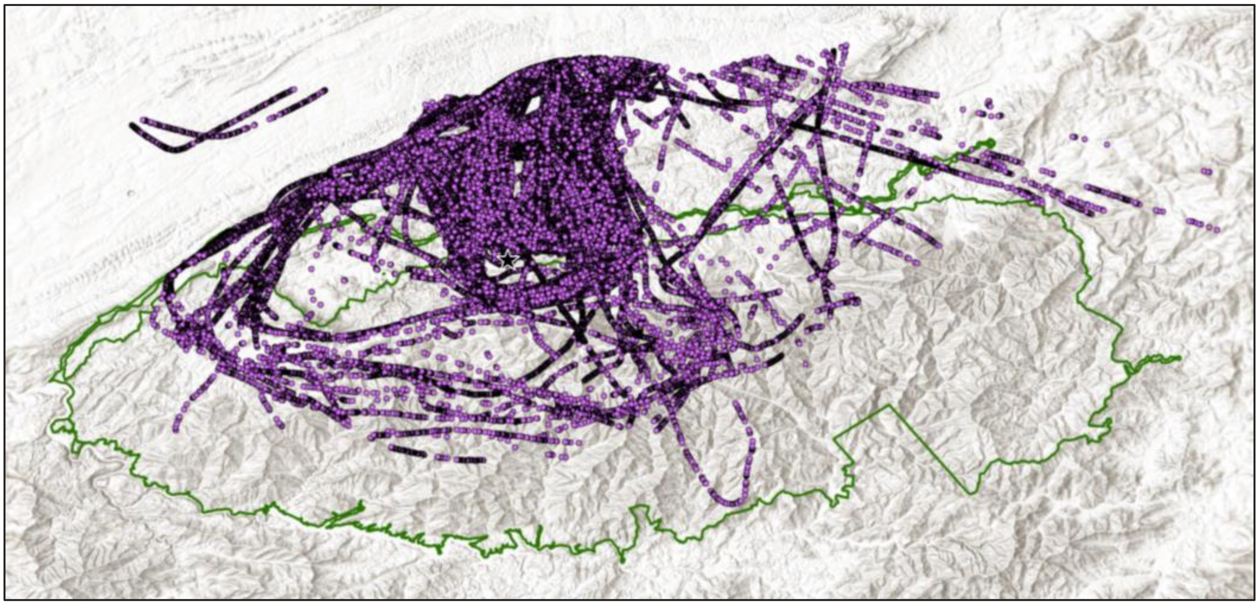


Figure 17: Cove Mountain ADS-B data

Table 5. Number of ADS-B points for each data logger

Location	Number of Points
Elkmont	974
Cades Cove	69
Cove Mountain	220,847

Viewshed Analysis

There are several tools within ArcGIS Pro that are designed for line-of-sight analysis but most of them focus on the visibility between two points instead of the viewshed of a single point. In addition, the viewshed tools focus on the viewshed of the terrain surrounding a point observer, not the sky above it. However, there were two tools that achieved the result of producing an output that could be used to both visualize the data logger viewshed but also predict the effectiveness of each location: the **Skyline** tool and the **Skyline Barrier** tool.

The **Skyline** tool was first used to model the skyline as seen from the data logger in each location. The inputs were the 3D location of the data logger and the DEM and the result, as shown in Figure 18, was a 3D feature that aligned with the obstructing terrain. While helpful in terms of visualizing areas of concern, this output was limited to the immediate area surrounding the data logger. The **Skyline Barrier** tool was then used to extend the skyline to a minimum radius and create a 3D multipatch that represented the space where the ADS-B data logger had no visibility (Figure 19). The minimum radius was selected in order to push the results to cover the entire park. The multipatches for each location were then used to predict how many ADS-B data points were visible from each location.

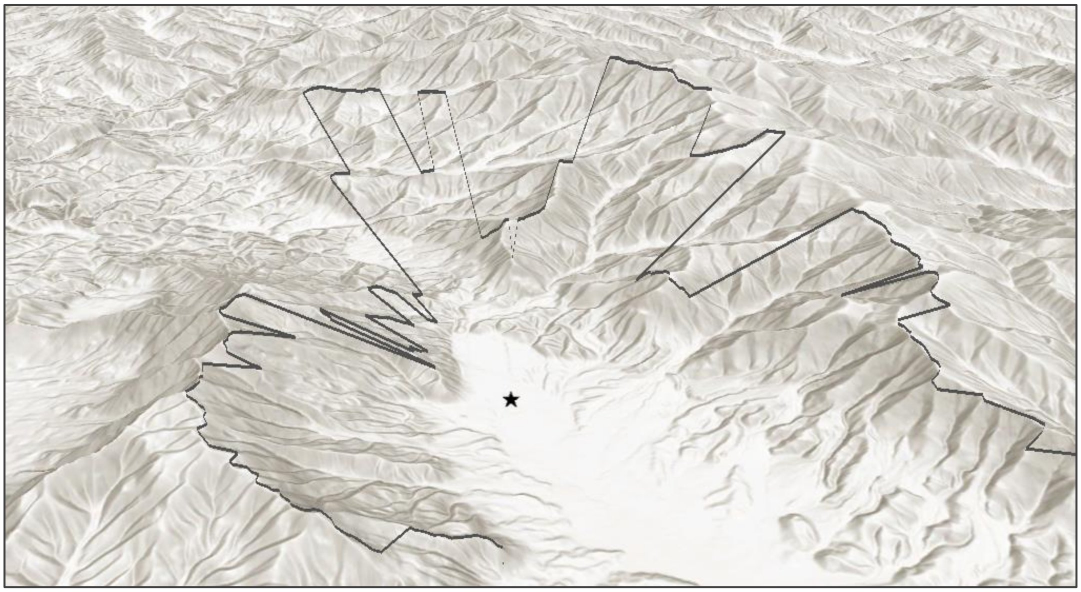


Figure 18: Skyline output for Cades Cove

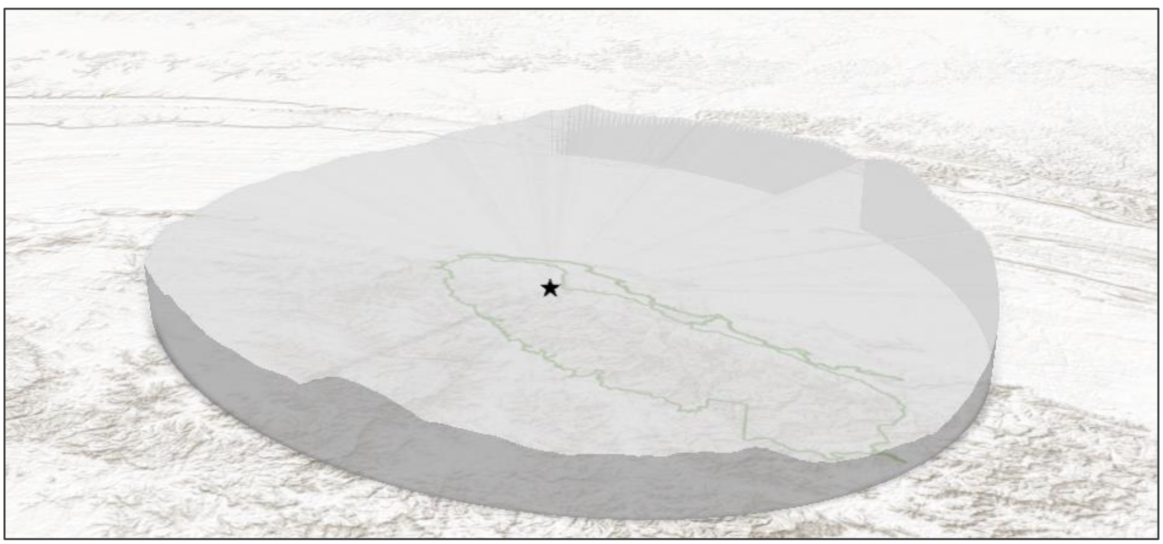


Figure 19: Skyline Barrier output for Cades Cove

Operator Route Visibility

In order to run this 3D analysis, the routes (Figure 20) were transformed into 3D routes. Without an example altitude profile for the flights, and with the intent to identify blind spots for the data logger, each route was given an altitude profile that followed the terrain profile. This was accomplished by first using the **Raster Calculator** to create a new DEM that added 2,600ft (the minimum altitude for overflights) to the terrain values. Then, the **Interpolate Shape** tool was used to give the routes the Z-values of the new, elevated DEM as shown in Figure 21.

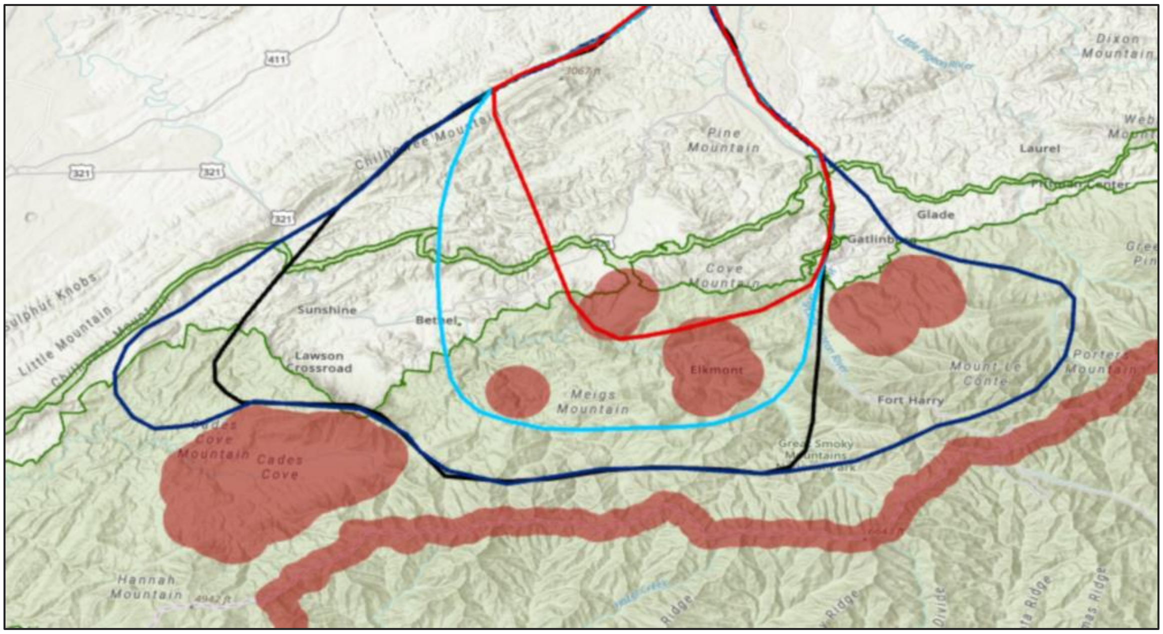


Figure 20: New operator routes for GRSM

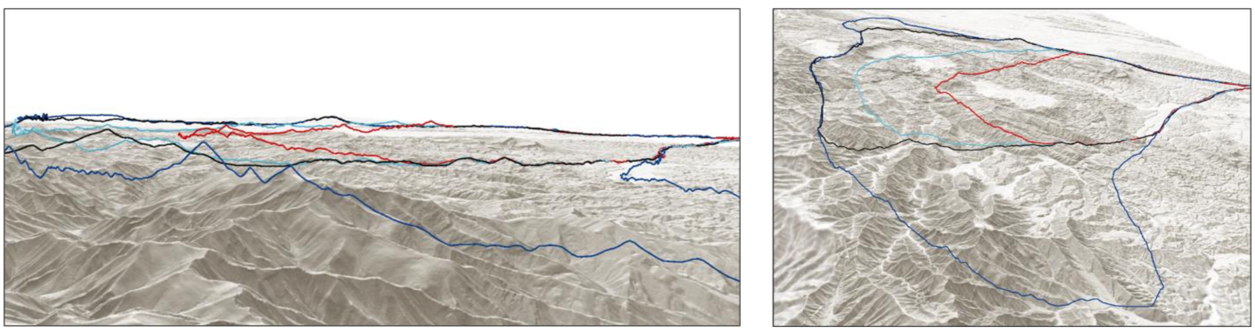


Figure 21: 3D operator routes for GRSM

Once the routes had the appropriate altitude values, they were compared across the skyline barrier multipatches to visualize the route for predicted visibility. Figures 22, 23, and 24 show the routes for each location compared to the multipatch representing the space that is not visible to the ADS-B data logger. In order to calculate the actual length of the route segments that were and were not visible, the **Intersect 3D Line With Multipatch** tool was used to create line and point outputs representing each individual segment that intersected with the multipatch with points at each intersection as shown in Figure 25 and 26. Two new attributes were added to the line segments for visibility and length in miles. The visibility attribute was manually updated while the **Measure** tool was used to measure the length of each segment. This allowed for the calculation of the percentage of the entire route that was visible to each data logger.

Figure 22: Route visibility for Elkmont

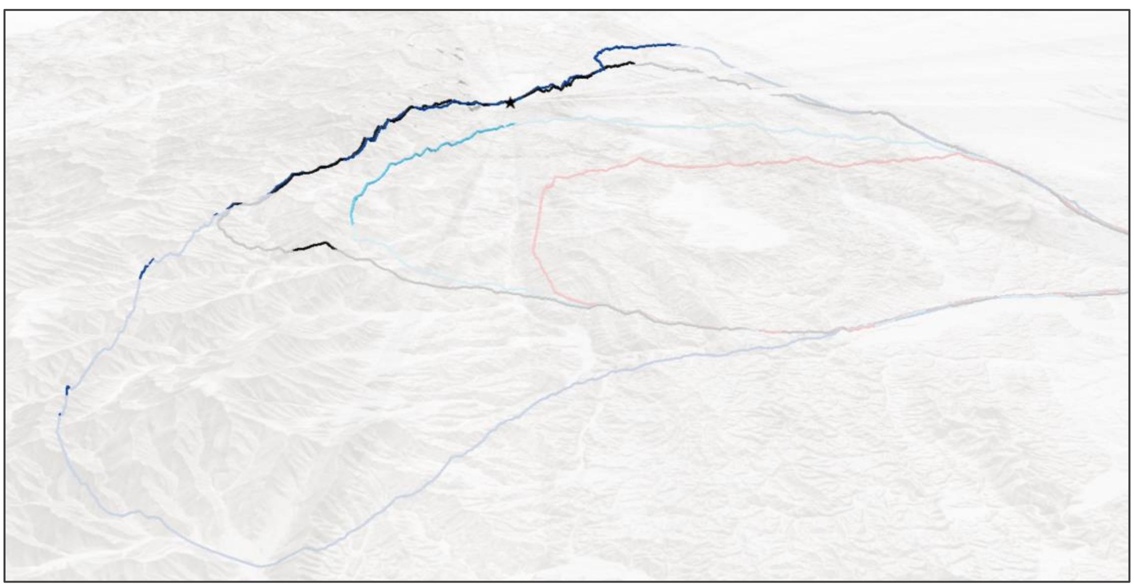


Figure 23: Route visibility for Cades Cove

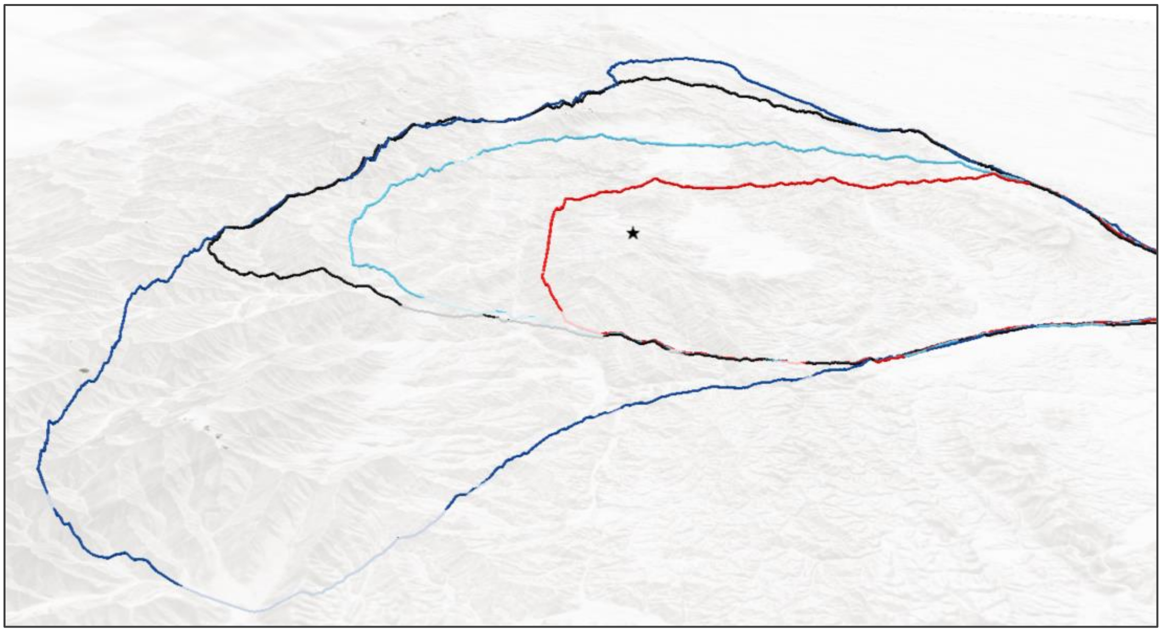


Figure 24: Route visibility for Cove Mountain

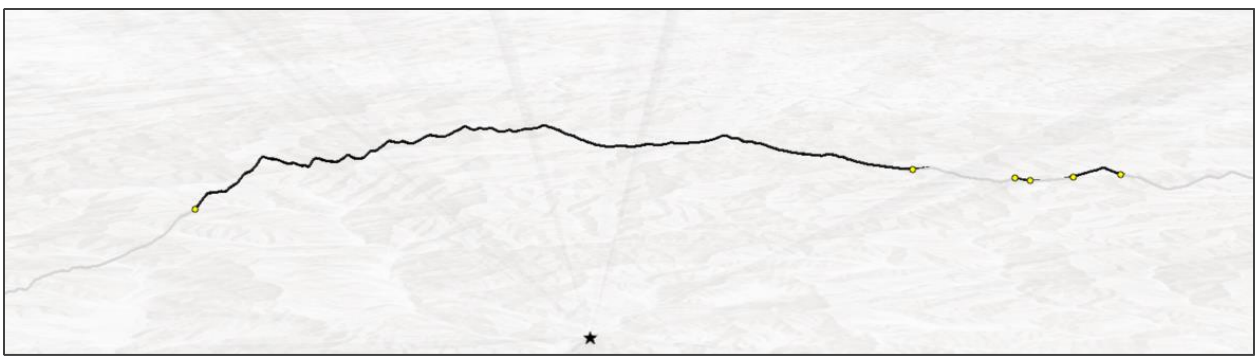


Figure 25: Route segments and intersecting points

Black_intersect_covemt_lines

Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy

	OID *	Shape *	LINE_OID	FROM_MP_ID	TO_MP_ID	DIST_3D	LENGTH_3D	Shape_Length	visible	seglength_mi
1	1	Polyline Z	2	-1	1	0	2400.948167	0.180625	yes	11.94
2	2	Polyline Z	2	1	1	2400.948167	129.484449	0.006438	no	0.44
3	3	Polyline Z	2	1	1	2530.432616	440.72504	0.019187	yes	1.32
4	4	Polyline Z	2	1	1	2971.157656	66.020792	0.004709	no	0.32
5	5	Polyline Z	2	1	1	3037.178448	552.828781	0.015852	yes	1.08
6	6	Polyline Z	2	1	1	3590.007229	587.593373	0.027261	no	1.88
7	7	Polyline Z	2	1	1	4177.600602	44.52823	0.002639	yes	0.18
8	8	Polyline Z	2	1	1	4222.128833	335.009259	0.021689	no	1.49
9	9	Polyline Z	2	1	1	4557.138092	8016.763587	0.271059	yes	16.14
10	10	Polyline Z	2	1	1	12573.901679	42.642598	0.002821	no	0.18
11	11	Polyline Z	2	1	-1	12616.544276	10346.395369	0.490153	yes	30.05

Figure 26: Segment table with new attributes

Results

ATMP Violation Models

Of the two project objectives, the first objective for building models to identify ATMP violations does not produce significantly relevant results for the NSNSD. Figure 27 shows the number of waypoints that violated the NFZ and Figure 28 shows the number of waypoints violating the minimum altitude restriction. These results were expected due to the ADS-B data being collected before the implementation of the GRSM ATMP.

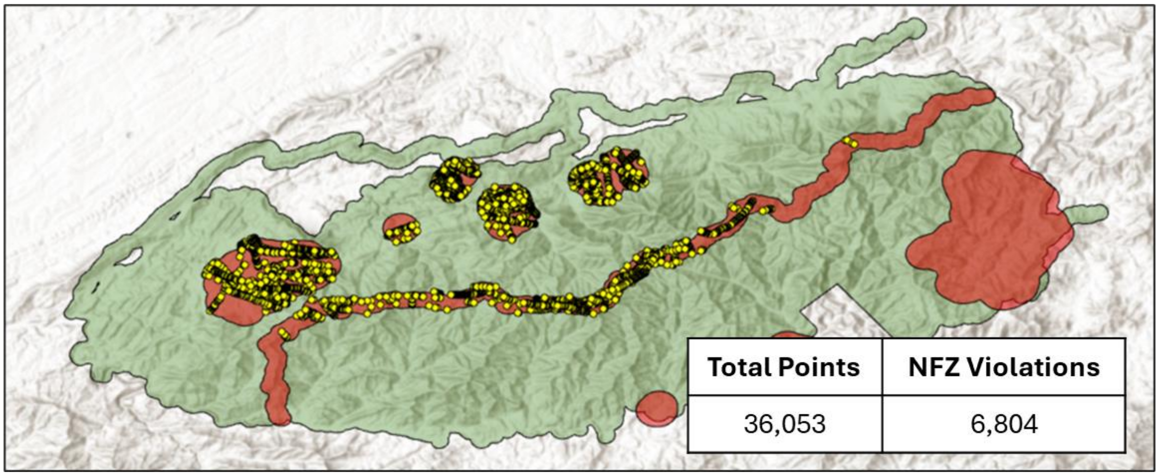


Figure 27: NFZ Violation Results

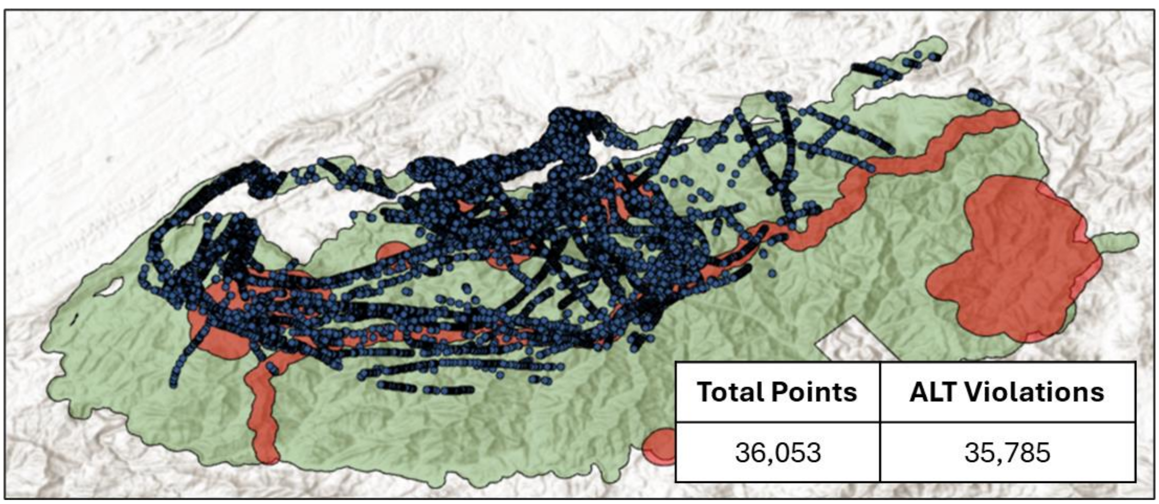
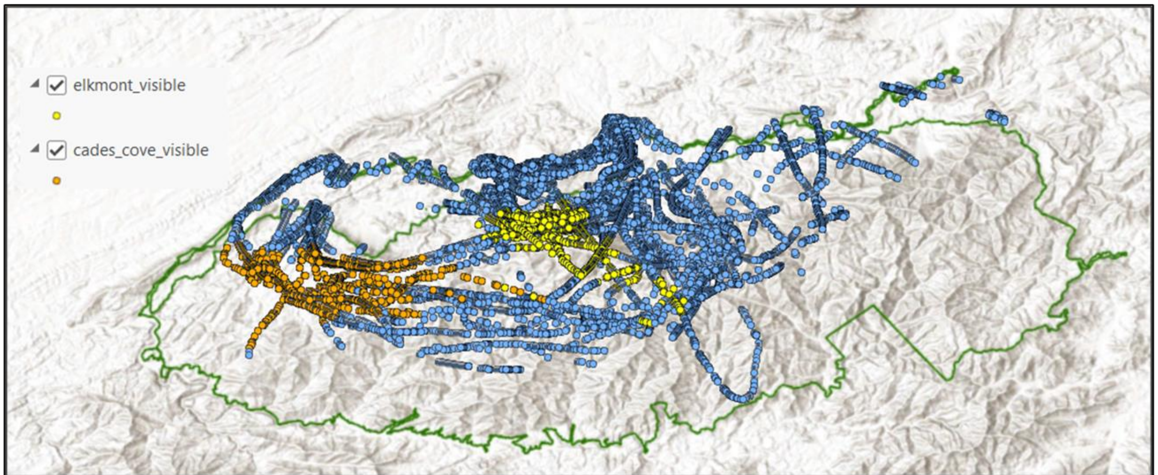


Figure 28: Altitude Violation Results

Data Logger Viewshed Analysis

The second objective was comparing the viewsheds for each data logger location. Figure 29 shows the predicted amount of ADS-B data that should be received by the Elkmont and Cades Cove data loggers in comparison to the Cove Mountain dataset, which was used as the baseline due to lack of operator provided data. According to this analysis, Cades Cove can only receive roughly 4% of the same data while Elkmont receives approximately 10%.



Total Points	Cades Cove	Elkmont	Cove Mountain
36,053	1,408 (4%)	3,521 (10%)	36,053 (100%)

Figure 29: ADS-B viewshed prediction

The second part of the viewshed analysis was comparing the viewsheds to the new operator routes established by the GRSM ATMP. Table 6 shows the results of the total percentage of each route that is visible to each of the three data logger locations. The results align with the ADS-B data results in that both the Cades Cove and Elkmont locations can detect far less of the operator route than the data logger at Cove Mountain.

Table 6. Operator route visibility results

Route	Total Length	Cades Cove	Elkmont	Cove Mountain
Red	42.58 mi	0 mi (**0%**)	6.35 mi (**15%**)	40.38 mi (**95%**)
Light Blue	50.89 mi	8.75 mi (**17%**)	8.98 mi (**18%**)	45.54 mi (**89%**)
Blue	80.94 mi	22.54 mi (**28%**)	9.15 mi (**11%**)	75.88 mi (**94%**)
Black	65.03 mi	18.1 mi (**28%**)	8.96 mi (**14%**)	60.71 mi (**93%**)

Discussion

The ATMP violation models were built using ADS-B data collected before the ATMP was put into effect and during a time that operator routes took them over areas of interest with an average flight altitude between 1,000ft and 1,500ft AGL. Due to these data limitations the results for the model only serve to validate its functionality. When operator provided GPS flight data becomes available, the results of the model will be much more valuable to the NSNSD than the results produced by this project which serve to show that the models work as intended.

The results for the data logger viewshed analysis were the most relevant to the NSNSD. According to the results, Cades Cove can only receive 4% of the same data received at Cove Mountain, while Elkmont receives 10%. These estimates are higher than the actual values (Table 5) but indicate that Cades Cove and Elkmont provide minimal value for collecting operator ADS-B data. These percentages might improve as operators begin to fly at higher altitudes but the viewshed from Cove Mountain still completely encompasses the viewsheds from Cades Cove and Elkmont. This was confirmed by operator route visibility results, making the Cades Cove and Elkmont locations arguably redundant. Furthermore, these results for the operator routes can provide insight into which locations the other data loggers can be deployed to cover the existing blind spots and providing full route coverage.

Limitations

Currently, the ADS-B data logger is only deployed for small windows of time, and only flights during that timeframe were recorded. This limits the ability of the NPS to monitor all of the overflights with the data logger, meaning that not every air tour overflight can be verified through the collection of ADS-B data. Many aircraft utilize a barometer to gauge altitude which is less accurate than using GPS so additional processing might be required in order to adjust ADS-B altitude values. Secondly, the skyline analysis to determine the viewshed for each data logger has many factors that can influence the accuracy of the results. For example, radio transmissions are electromagnetic and might still be received even if the direct line-of-sight is blocked. It is best if the results are treated as a general measure of effectiveness than a definitive predictive model.

Future Work

The tools and methods developed in this project only utilized ADS-B data collected by the NPS. The value of these products will increase once there is operator provided data ADS-B data available for analysis. One of the most important next steps in this effort to monitor overflights will be comparing the operator provided data to the ADS-B data. This will verify where the data loggers have the most difficulty receiving transmitted flight data and whether the operators are providing all of the required flight data. This data comparison will also validate how accurate the ADS-B altitude measurements are in relation to the GPS measurements. The second aspect of this project that could be improved is using a higher resolution DEM for the skyline analysis. 10m was appropriate for this project since it was an initial look and higher resolution could lengthen processing time. Using a higher resolution will result in more accurate results. The third item for potential future work also serves to increase the fidelity of the skyline analysis for the data logger viewshed. The skyline tool in ArcGIS allows for inputs in addition to a terrain DEM. This allows the option to include other obstacles such as buildings or vegetation. Since these data loggers are being placed in a national park, high tree lines on mountain ridges could further limit a data logger’s viewshed. The NPS and USGS have several datasets that can be used to this effect such as vegetation height data from LANDFIRE (Figure 31). Using a DEM that includes vegetation height will provide more accurate results, especially for spring and summer seasons when most air tours take place.

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