A Quantitative Model to Support Automated Approval Processes of Small Unmanned Aircraft Systems Operations

Jason Lu

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Small Unmanned Aircraft Systems (sUAS) are operating in the National Airspace (NAS) in increasing numbers. The Federal Aviation Administration (FAA) Part 107 Rule allows sUAS to fly at low altitude, in controlled airspace, near airports; and more than 20,000 requests for authorizations have been made over the first year of the rule. FAA typically review each request manually, approving within 60 days of request date. The approval time period has served as a safety buffer, but many sUAS operations are more time-sensitive.

FAA has developed facility maps (UASFMs) to depict airspaces around many airports. The Volpe Center has developed a quantitative model to support automated approval processes by examining the altitude of manned aircraft in UASFMs. This report describes assumptions and methods of the model, altitude results for Class B airspaces, and repeatability and scalability to all airspaces around airports. The model provides a quantifiable, consistent, and repeatable method to examine altitudes of manned aircraft. The results can complement Air Traffic Control and subject matter expert assessment of airspaces to inform future periodic revisions of UASFMs. The model can be improved upon in future work, and its methods can be incorporated into the overall UASFM analysis process.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Acronyms and Abbreviations

Common Abbreviations	Term
AGL	Altitude Above Ground Level
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment, Model X
ATC	Air Traffic Control
CSV	Comma-Separated Value (file format)
FAA	Federal Aviation Administration
KML	Keyhole Markup Language (file format)
LAANC	Low Altitude Authorization and Notification Capability
MSL	Altitude Mean Sea Level
NAS	National Airspace System
NM	Nautical Mile
PDARS	Performance Data Analysis and Reporting System
sUAS	Small Unmanned Aircraft System
TRACON	Terminal Radar Approach Control Facility
UASFM	UAS Facility Map
UTC	Coordinated Universal Time
VLOS	Visual Line-of-Sight
VMC	Visual Meteorological Conditions

NAS Facility and PDARS-related Abbreviations	May refer to: Airport or Associated Airspace
ANC	Anchorage Ted Stevens International Airport (Class C)
BOS	Boston Logan International Airport (Class B)
BWI	Baltimore-Washington Thurgood Marshall International Airport (Class B)
CLT	Charlotte International Airport (Class B)
CVG	Cincinnati/Northern Kentucky International Airport (Class B)
EWR	Newark Liberty International Airport (Class B)
IAH	Houston-Bush Intercontinental Airport (Class B)
JFK	New York-John F. Kennedy International Airport (Class B)
LHD	Lake Hood Seaplane Base (Class D)
MCO	Orlando International Airport (Class B)
MIA	Miami International Airport (Class B)
PDARS A11	PDARS Dataset: Anchorage TRACON
PDARS BOS+ASDEX	PDARS Dataset: Boston Tower and ASDE-X
PDARS CLT	PDARS Dataset: Charlotte TRACON
PDARS CLT+ASDEX	PDARS Dataset: Charlotte Tower and ASDE-X
PDARS I90	PDARS Dataset: Houston TRACON
PDARS IAH+ASDEX	PDARS Dataset: Houston-Bush Tower and ASDE-X
PDARS MCO	PDARS Dataset: Orlando Tower and ASDE-C
PDARS MIA	PDARS Dataset: Miami TRACON
PDARS MIA+ASDEX	PDARS Dataset: Miami Tower and ASDE-X
PDARS N90	PDARS Dataset: New York TRACON
PDARS NCT	PDARS Dataset: Northern California TRACON
PDARS PHX+ASDEX	PDARS Dataset: Phoenix Tower and ASDE-X
PDARS SCT	PDARS Dataset: Southern California TRACON
PDARS TPA	PDARS Dataset: Tampa Tower and TRACON
PDARS ZMA	PDARS Dataset: Miami ARTCC
PHX	Phoenix Sky Harbor International Airport (Class B)
SAN	San Diego International Airport (Class B)
SJC	San Jose International Airport (Class C)
ZAN	Anchorage ARTCC
ZHN	Honolulu ARTCC

Preface

This report was prepared by the Air Navigation and Surveillance Division (V-341), and Aviation Human Factors Division (V-315) at the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center. It was completed with funding from the Federal Aviation Administration (FAA) Emerging Technologies Office (AJV-0). We are thankful for the support from our sponsor Bill Davis.

Many individuals helped to complete this project. Thanks to Brandon Lint (Volpe V-341, FAA AJV-7) for providing project management and providing essential guidance on sponsor needs; Dr. Thomas Sheridan (V-315) for providing great mentorship and technical guidance in developing our model; Dr. Kim Cardosi and Dr. Tracy Lennertz for their continued support and feedback during the writing of this report. Thanks to Maura Lohrenz, Alan Yost, Andrew Kendra, Andrea Sparko, Megan France, and Aaron Hoffman for their insightful discussion on UAS safety analyses at the Volpe Center.

For questions or comments, please e-mail Jason Lu at jason.lu@dot.gov

Executive Summary

This report describes a quantitative model to support the Federal Aviation Administration's (FAA) effort to integrate small Unmanned Aircraft Systems (sUAS) into the National Airspace System (NAS). Input data, methods and assumptions, sources of error, sample results, and recommendations to improve the model are discussed.

The model uses Performance Data Analysis and Reporting System (PDARS) manned aircraft track data to estimate an altitude Above Ground Level, below which sUAS are unlikely to encounter manned aircraft. That altitude is called the "Risk Adjusted Altitude" in this report, defined as 200 feet (abbreviated to "ft") below routine operations in a given airspace. The 200-ft vertical safety buffer is a conservative estimate based on uncertainty in input data and error sources of the model; routine operations are defined statistically. Risk Adjusted Altitude can be compared to UAS Facility Map pre-approved altitudes determined by ATC and subject matter expert qualitative airspace assessments.

Analysis was done for all 37 Class B airspaces, as well as a number of Class C and D airspaces participating in initial implementation of the FAA Low Altitude Authorization and Notification Capability (LAANC)—a system to support faster approval of Part 107 sUAS operations, and facilitate communication and data sharing among the FAA, Air Traffic Control (ATC), and sUAS operators. Results are generally conservative in the busiest airspaces, but show consistency among airspaces of the same type. In comparison, pre-approved altitudes show a wide range of risk acceptance and in contrast, risk aversion, from one airspace to another.

Results also capture vulnerable areas in the NAS such as medical and police helipads, seaplane bases, etc., where sUAS can encounter manned aircraft at low altitudes. This further reinforces a need for quantitative analysis using real-world manned aircraft track data. ATC and subject matter expert assessments, along with quantitative model outputs, can be considered together in future revisions of pre-approved altitudes. Future work may improve the model and continue to support sUAS integration into the NAS.

1. Introduction

Small Unmanned Aircraft Systems (sUAS), also referred to as "drones", are entering the National Airspace (NAS), and flying closer to manned aircraft and population centers. The Federal Aviation Administration (FAA) defines UAS as "an aircraft without a human pilot onboard… controlled from an operator on the ground" and small UAS as those weighing less than 55 lbs (FAA, 2016). The FAA projects an increase from 1.1 million hobbyist drones in 2016 to 3.5 million in 2021 (FAA, 2017); and an increase from 42,000 non-hobbyist (commercial) drones in 2016 to 420,000 in 2021.

The FAA Part 107 Rule—effective August 29, 2016—has allowed sUAS to operate at low altitude, in controlled airspace, near airports. The rule has defined safety provisions common to the entire, diverse population of sUAS. sUAS operators (from this point forward referred to as "operators") are responsible for registering their drones, obtaining remote pilot certification, inspecting the aircraft, among others before flight. Additionally, they must maintain visual line-of-sight (VLOS), avoid flying over people, and operate only during daytime in visual meteorological conditions (VMC)—unless allowed by an additional waiver. Operators may fly without contacting Air Traffic Control (ATC) in Class G airspace, but are required to obtain FAA and ATC approval in Class B, C, D, and E airspace. Finally, flight altitudes are restricted to below 400 ft above ground level (AGL) or within 400 feet (ft) laterally from and vertically above a structure. Apart from nominal Part 107 operations, waivers have allowed sUAS to operate within airport grounds and over large crowds of people (Michel & Gettinger, 2018).

The approval process is critical to safe, efficient, and secure operation of sUAS in controlled airspace (Classes B, C, D, and surface Class E airspaces). To request approval, operators visit the FAA website and submit a waiver or authorization request with the details of their flight. More than 20,000 requests have been made over the past year; FAA staff have manually reviewed each request, issuing approvals within 60 days of the request date. The approval time period allows FAA staff to identify potential hazards in the airspace, serving as a safety buffer up to this point; however, but many sUAS operations are more time-sensitive.

The FAA is developing automated systems to increase approvals and decrease approval waiting time, while maintaining an acceptable level of operational risk. The Low Altitude Authorization and Notification Capability (LAANC) system uses facility maps depicting Class B, C, D, and E airspaces around airports. Currently, each facility map shows 1-minute by 1-minute latitude-longitude grids around each airport, with a pre-approved altitude between zero and 400 feet above ground level (AGL) in each grid. UAS operators requesting to fly below the pre-approved altitude in the corresponding grid volume may receive faster approval in LAANC, than in the manual review process.

The LAANC approval process requires accurate facility maps periodically updated to account for manned aircraft traffic patterns. The Volpe Center has developed a prototype quantitative model to meet those needs. This model takes in Performance Data Analysis and Reporting System (PDARS) data as input, and calculates a new quantity referred to as Risk Adjusted Altitude in each grid, for each applicable facility map. This report describes the assumptions and methods of the model, Risk Adjusted Altitude results for Class B airports, repeatability and scalability to Class C, D, and E airports, and applicability to other safety risk analyses for sUAS operations at low altitude near airports in controlled airspace.

The model provides a consistent method to identify manned aircraft traffic patterns near airports in support of development of FAA automated approval systems. Risk Adjusted Altitudes may be shown as an additional data layer in an automated approval system such as LAANC, and accessed by operators as well as ATC—informing the decision-making of both parties concerning sUAS operations.

The model's scope is limited to well-informed, well-intentioned, and well-controlled sUAS operations in Class B, C, D, and E airspace. The main result is Risk Adjusted Altitude—an estimated AGL altitude below which sUAS may avoid manned aircraft traffic patterns near airports, according to the current model and input data. The results can change with any change in input data, as well. Section 2 describes the FAA data considered for the model. Section 3 describes assumptions and methods of the model. Section 4 discusses Risk Adjusted Altitude results for Class B airports. Section 5 discusses ways to improve the model, and its applicability to other ongoing FAA safety analyses. Finally, conclusions and main takeaways from the analysis are presented.

2. Description of Input Data

The model takes in several types of data available to the FAA and partnering organizations. Section 2 describes UAS Facility Map (UASFM) data, pre-approved altitude data, and PDARS data.

2.1 UAS Facility Map Data

The FAA provides satellite imagery of each UASFM airspace in Portable Document Format (PDF), Figure 1 shows the UASFM for Boston Class B airspace.

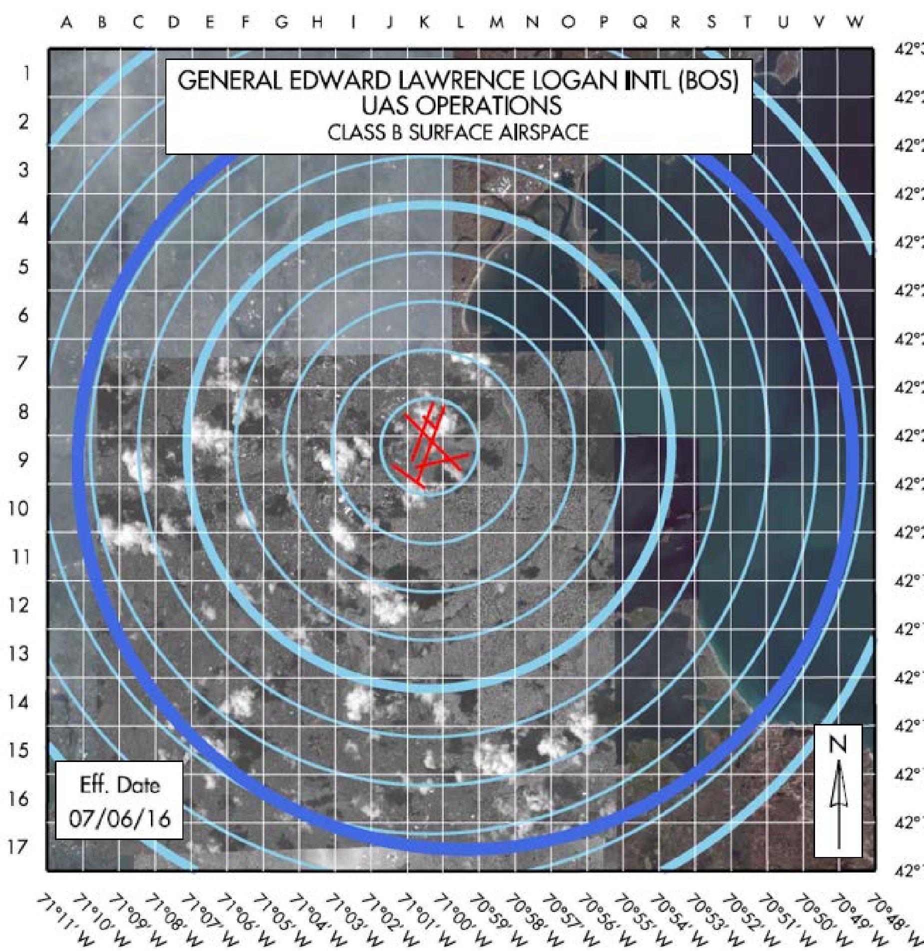


Figure 1. UASFM for Boston Class B (BOS)

Each facility map image shows the name of the airport, airspace class, and effective date. The map's left vertical axis contains row numbers starting with 1, and the right vertical axis contains latitudes in 1-minute increments. The top horizontal axis contains column letters starting with A, and the bottom horizontal axis contains longitudes in 1-minute increments. The axes form rectangular grid, with the corner of each grid at a 1-minute increment in latitude and longitude.

Airport runways are shown in red, concentric 1-Nautical Mile rings are shown in light blue, the boundary of the surface airspace (that is, the volume of airspace extending down to ground level) are shown in dark blue. The surface airspace, as it relates to Part 107 sUAS operations, extends from the ground up to 400 ft AGL. Thus, each grid is 1-minute latitude by 1-minute longitude by 400 ft (from this point on referred to as a "grid volume"). The satellite imagery may be improved and updated periodically.

The geospatial structures described above (airport information, airspace boundaries, runway locations, etc.) are available in Keyhole Markup Language (KML) format, and are read into MATLAB for use in the model. Airport information is verified with online sources[1].

2.2 Pre-approved Altitude Data

Each UASFM has designated pre-approved AGL altitude ceilings for sUAS operations, for each grid volume up to 400 ft AGL. Figure 2 shows BOS pre-approved altitudes, and all pre-approved altitude data are available online[2]. In this report, altitudes are color-coded from red (zero) to green (400), with warmer colors representing lower pre-approved altitudes—however, this does not represent the way FAA will show the pre-approved altitudes at any point in the future, color selections are arbitrary and simply used as a visual aid in this report.

During the development of LAANC, the FAA requested ATC facilities to perform qualitative assessments of their airspaces; Boston pre-approved altitudes are zero closest to the airport (within 2-3 NM), increasing with distance from the airport. BOS runways occupy grid volumes J9, K8-10, and L9, indicated by red patterned grid volumes.

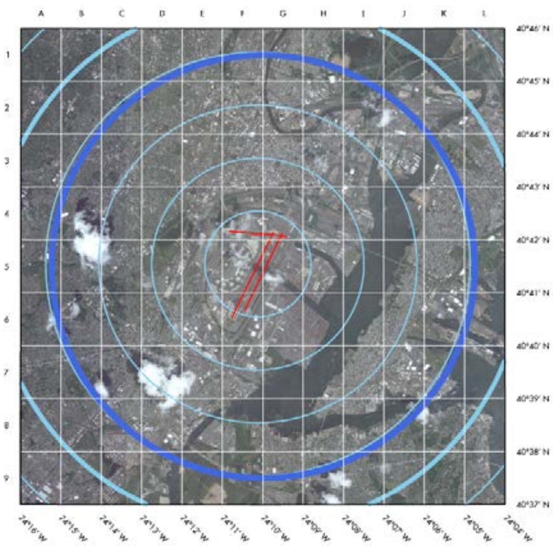
[1]AirNav, LLC. http://www.airnav.com
[2]Federal Aviation Administration, UAS Data Delivery System http://uas-faa.opendata.arcgis.com

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1									300	300	300	300	300	300	300	300							
2						300	300	300	300	300	300	300	300	300	300	300	300	300					
3				300	300	300	300	250	250	250	250	250	250	250	300	300	300	300	400	400			
4			300	300	300	300	250	200	200	150	150	100	100	150	200	250	300	400	400	400	400		
5		300	300	300	300	250	200	150	150	100	100	50	50	100	150	250	250	300	300	400	400	400	
6		300	300	300	250	200	150	100	100	50	0	0	50	100	150	150	200	250	300	300	400	400	
7		300	300	250	200	150	100	0	0	0	0	0	50	50	100	100	150	200	200	250	300	400	400
8	300	300	250	200	150	100	0	0	0	0		0	0	50	50	50	100	150	200	200	250	300	400
9	300	300	250	200	150	100	0	0	0				0	0	50	50	100	150	150	200	250	300	400
10	300	300	250	200	150	100	0	0	0	0		0	0	0	50	50	100	150	150	200	250	300	400
11		300	250	250	200	150	100	50	0	0	0	0	50	50	50	50	100	150	200	250	300	400	400
12		300	300	250	200	150	150	100	50	50	50	50	100	100	100	150	150	200	250	250	300	400	
13		300	300	300	250	200	150	150	100	100	100	100	150	150	150	200	200	250	250	300	400	400	
14			300	300	300	250	200	200	150	150	150	150	200	200	200	200	250	250	300	300	300		
15				300	300	300	250	250	250	250	250	250	250	250	250	300	300	300	300	300			
16						300	300	300	300	300	300	300	300	300	300	300	300	300	300				
17								300	300	300	300	300	300	300	300	300							

Figure 2. Pre-approved Altitude for BOS, Effective August 11, 2017

Pre-approved altitudes produced by qualitative assessment reflect the varying amount of risk tolerance for each ATC facility. Figure 3 and Figure 4 show pre-approved altitudes for Newark Class B (EWR) and San Diego Class B (SAN), respectively. EWR pre-approved altitudes are all set to zero, while SAN pre-approved altitudes are 0 or 50 ft in all grid volumes.

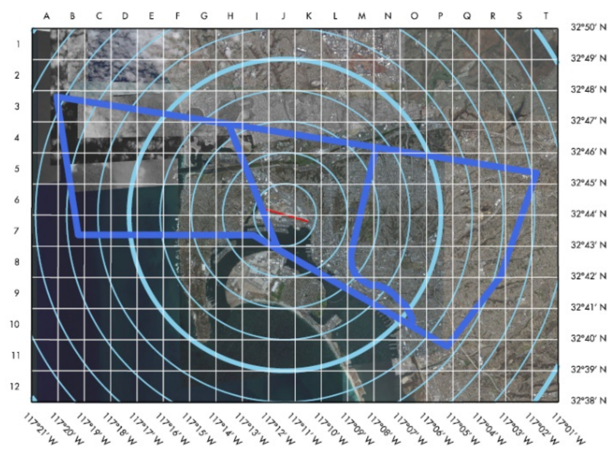
In contrast, Figure 5 and Figure 6 show pre-approved altitudes for Baltimore-Washington Class B (BWI) and Houston-Bush Intercontinental Class B (IAH), respectively. All altitudes are 400 ft except close to the airport. These figures show a wide range of qualitative assessments, as well as risk tolerance and aversion in developing the initial set of pre-approved altitudes.



	A	B	C	D	E	F	G	H	I	J	K	L
1				0	0	0	0	0	0			
2		0	0	0	0	0	0	0	0	0	0	
3		0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0			0	0	0	0	0
5	0	0	0	0	0			0	0	0	0	0
6	0	0	0	0	0		0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0	0	
8		0	0	0	0	0	0	0	0	0	0	
9				0	0	0	0	0	0			

Figure 3a. UASFM for Newark Class B (EWR)

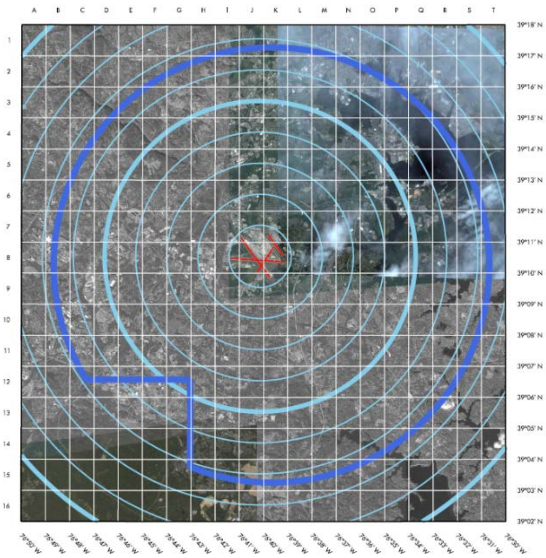
Figure 3b. Pre-approved Altitude for EWR, Effective August 11, 2017



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1																				
2																				
3	50	50	50	50	50	0	0													
4		50	50	50	50	0	0	0	0	0	0	0	0	50	50					
5		50	50	50	50	0	0	0	0	0	0	0	0	50	50	50	50	50	50	50
6		50	50	50	50	0	0	0			0	0	0	50	50	50	50	50	50	50
7		50	50	50	50	0	0	0	0			0	0	50	50	50	50	50	50	
8										0	0	0	0	50	50	50	50	50	50	
9												0	0	0	50	50	50	50		
10														0	0	0	50			
11																0				
12																				

Figure 4a. UASFM for San Diego Class B (SAN)

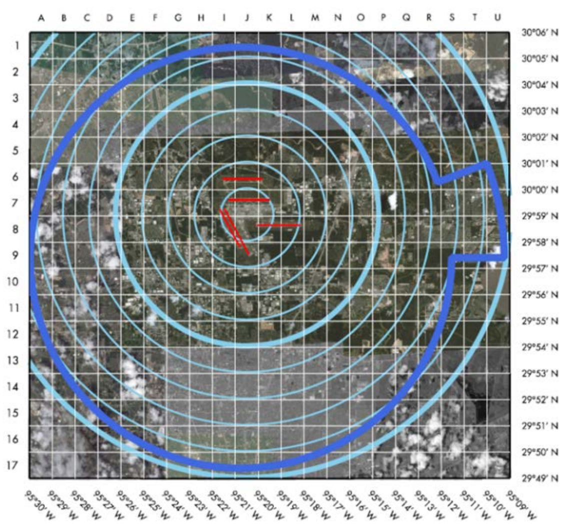
Figure 4b. Pre-approved Altitude for SAN, Effective December 7, 2017



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1								400	400	400	400	400	400							
2						400	400	400	400	400	400	400	400	400	400	400				
3				400	400	400	400	400	400	400	400	400	400	400	400	400	400			
4			400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400		
5			400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
6		400	400	400	400	400	400	0	0	0	0	0	0	400	400	400	400	400	400	400
7		400	400	400	400	400	400	0	0			0	0	400	400	400	400	400	400	400
8		400	400	400	400	400	400	0				0	0	400	400	400	400	400	400	400
9		400	400	400	400	400	400	0	0			0	0	400	400	400	400	400	400	400
10		400	400	400	400	400	400	0	0	0	0	0	0	400	400	400	400	400	400	400
11		400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
12			400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
13							400	400	400	400	400	400	400	400	400	400	400	400		
14							400	400	400	400	400	400	400	400	400	400	400			
15							400	400	400	400	400	400	400	400	400					
16																				

Figure 5a. UASFM for Baltimore-Washington Class B (BWI)

Figure 5b. Pre-approved Altitude for BWI, Effective October 12, 2017



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1							400	400	400	400	400	400	400								
2				400	400	400	400	400	400	400	400	400	400	400	400						
3			400	400	400	400	400	400	400	400	400	400	400	400	400	400					
4		400	400	400	400	400	300	300	300	300	300	300	300	400	400	400	400				
5		400	400	400	400	300	150	100	100	100	100	100	200	300	400	400	400	400			400
6	400	400	400	400	300	200	100	0				0	100	150	200	300	400	400	400	400	400
7	400	400	400	400	300	200	100	0				0	100	150	200	300	400	400	400	400	400
8	400	400	400	400	300	250	150	50					0	50	100	150	300	400	400	400	400
9	400	400	400	400	400	400	300	100			0	50	100	200	300	400	400	400	400	400	400
10	400	400	400	400	400	400	300	200	50	50	50	100	200	200	300	400	400	400	400		
11	400	400	400	400	400	400	400	300	200	100	100	200	300	400	400	400	400	400	400		
12	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400		
13	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400			
14		400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400				
15			400	400	400	400	400	400	400	400	400	400	400	400	400	400	400				
16				400	400	400	400	400	400	400	400	400	400	400	400						
17						400	400	400	400	400	400	400	400								

Figure 6a. UASFM for Houston-Bush Class B (IAH)

Figure 6b. Pre-approved Altitude for IAH, Effective August 11, 2017

2.3 PDARS Data

FAA Performance Data and Reporting System (PDARS) datasets are collected at various aviation facilities in the NAS, including airport towers, Terminal Radar Approach Control facilities (TRACONs), and Air Route Traffic Control Centers (ARTCCs or "centers"). Airport tower datasets can also include terminal, gate, runway, and taxiway traffic from Airport Surface Detection Equipment, Model X systems (ASDE-X). Tower and ASDE-X (i.e. "Tower+ASDEX") datasets are available at the majority of Class B airports in the NAS, and relied upon heavily in the analysis.

PDARS data are obtained in comma-separated value (CSV) format, Figure 7 shows a sample from the Miami Tower+ASDEX (PDARS MIA+ASDEX) dataset. Column A contains the "record type" and the Volpe model currently examines record types 2, 3, and 4. Entries with record type 2 are "header records" that describe the manned aircraft itself. Header records (among other data) contain the track start time in seconds from midnight, January 1, 1970 Coordinated Universal Time (UTC, column B); PDARS unique flight ID (column C); call sign (column H); make and model (column J); and estimated origin or navigation fix, and estimated destination or navigation fix (columns K and L).

Entries with record type 3 are "track point records" that describe the aircraft track. Track point records (among other data) contain time in seconds from midnight, January 1, 1970 (column B); latitude and longitude in degrees (columns J and K); altitude in hundreds of feet Mean Sea Level (MSL) for radar-based data, or in decimal feet for ASDE-X data; and groundspeed, heading, and climb rate (not shown in figure). Entries with record type 4 are "flight plan records" that describe routing and timing information. These data are read into MATLAB using built-in data input/output functions such as "csvread." The data sample shows a commercial airliner departing MIA.

A	B	C	D	E	F	G	H	I	J	K	L
1	BFF	2.13									
5	ATAC Corporation	BirdWatch Analysis Module	4.8.8.19								
0	==										
2	1464756884	90113	3504		0/ASR9		AAL931	1	B77W	MIA	?
4	1464756884	90113	3504		0/MODE_SADSB	0xE02	AAL931	1	B77W	?	?
4	1464756895	90113	3504		0/SMRMODE_SADSB	0xE02	AAL931	1	B77W	?	?
4	1464757483	90113	3504		0/MIA	0xE02	AAL931	1	B77W	?	?
3	1464757374	90113	3504		0/SMRMODE_SADSB	0xE02	AAL931	1	25.80171	-80.27524	0.06
3	1464757375	90113	3504		0/SMRMODE_SADSB	0xE02	AAL931	1	25.80181	-80.27434	0.06
3	1464757380	90113	3504		0/SMRMODE_S	0xE02	AAL931	1	25.8021	-80.26938	1.88
3	1464757381	90113	3504		0/SMRMODE_SADSB	0xE02	AAL931	1	25.80213	-80.2684	2.38
3	1464757383	90113	3504		0/MODE_SADSB	0xE02	AAL931	1	25.8022	-80.26647	3.75
3	1464757384	90113	3504		0/MODE_S	0xE02	AAL931	1	25.80223	-80.26553	4.25

Figure 7. PDARS Data Sample

PDARS data are available at 28 Tower+ASDEX sites, 28 TRACONs or co-located tower and TRACONs, and 20 ARTCCs. PDARS coverage is not available for Cape Cod, MA (K90); Meridian, MS (NMM); Pensacola, FL (P31); Omaha, NE (R90); Tucson, AZ (U90); and Windsor Locks, CT (Y90) TRACONs[3]. Certain airports with co-located tower and TRACONs may, however, have

[3] Federal Aviation Administration, Air Traffic Organization (ATO), Air Traffic Services, List of TRACONs

PDARS coverage—such as Cleveland, Miami, and Pittsburgh. PDARS coverage is not available for Anchorage (ZAN) and Honolulu (ZHN) centers[4]. A full list of PDARS data sources is available in Appendix A.

It is possible to obtain multiple datasets for the same area in the NAS; for example, air traffic in Miami Class B (MIA) may be found in the Miami Tower (PDARS MIA+ASDEX), Miami TRACON (PDARS MIA), and Miami Center (PDARS ZMA). Figure 8 shows the UASFM for Miami Class B, and Figure 9a-c show the three datasets described above. In each figure with PDARS data, the state boundary of Florida is plotted on a latitude-longitude scale in black, boundary of the surface airspace is plotted in blue (from KML data), and PDARS data are plotted in red. Data from June 1, 2016 are plotted in each figure.

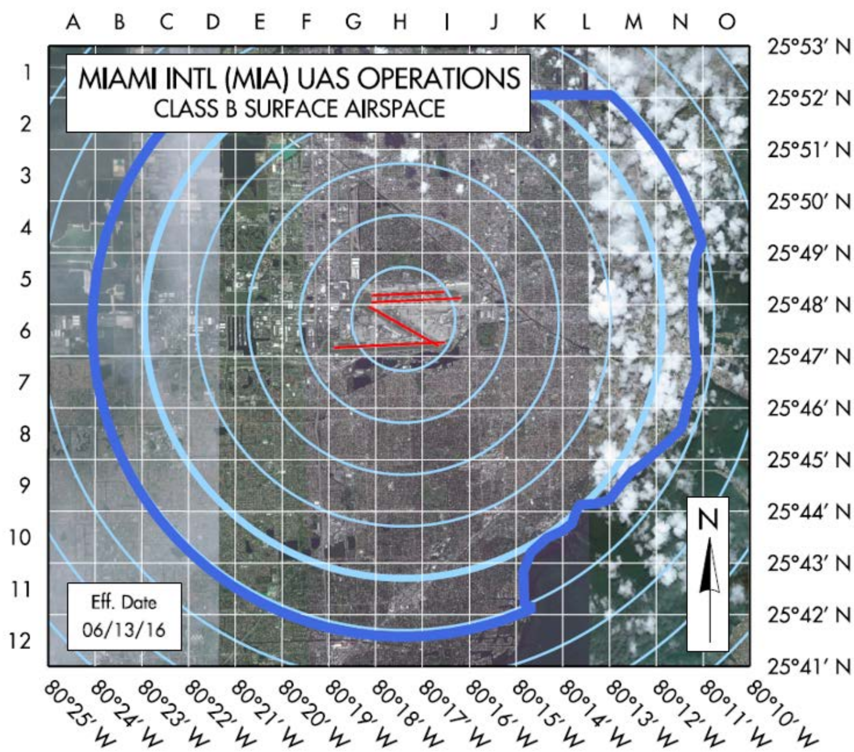


Figure 8. UASFM for Miami Class B (MIA)

https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/air_traffic_services/tracon/
[4] Federal Aviation Administration, Air Traffic Organization (ATO), Air Traffic Services, List of ARTCCs https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/air_traffic_services/artcc/

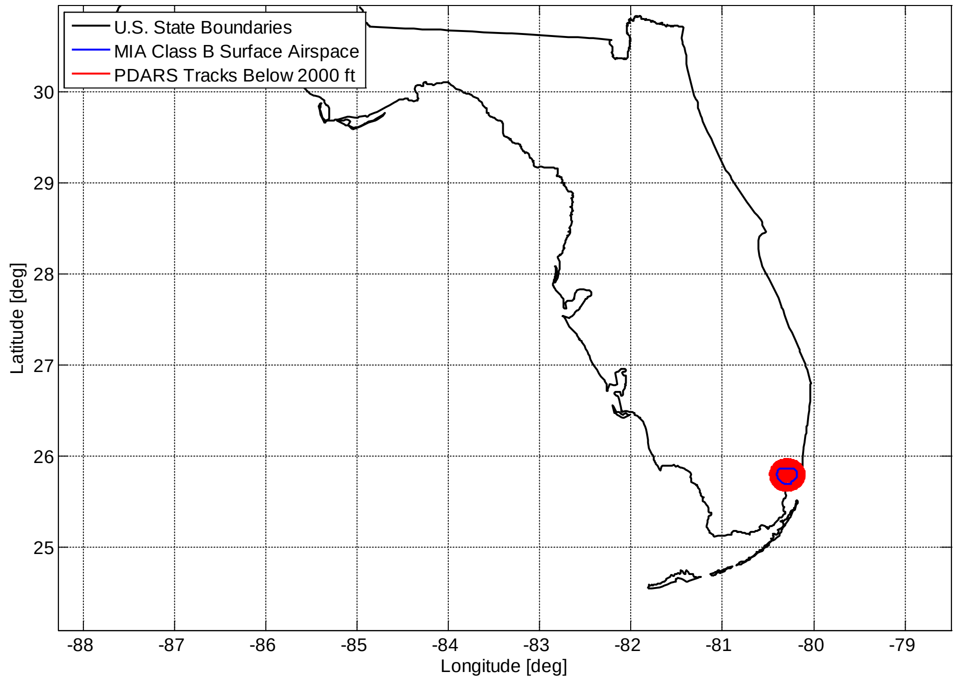


Figure 9a. PDARS MIA+ASDEX Dataset June 1, 2016 – Estimated AGL Altitude below 2,000 ft

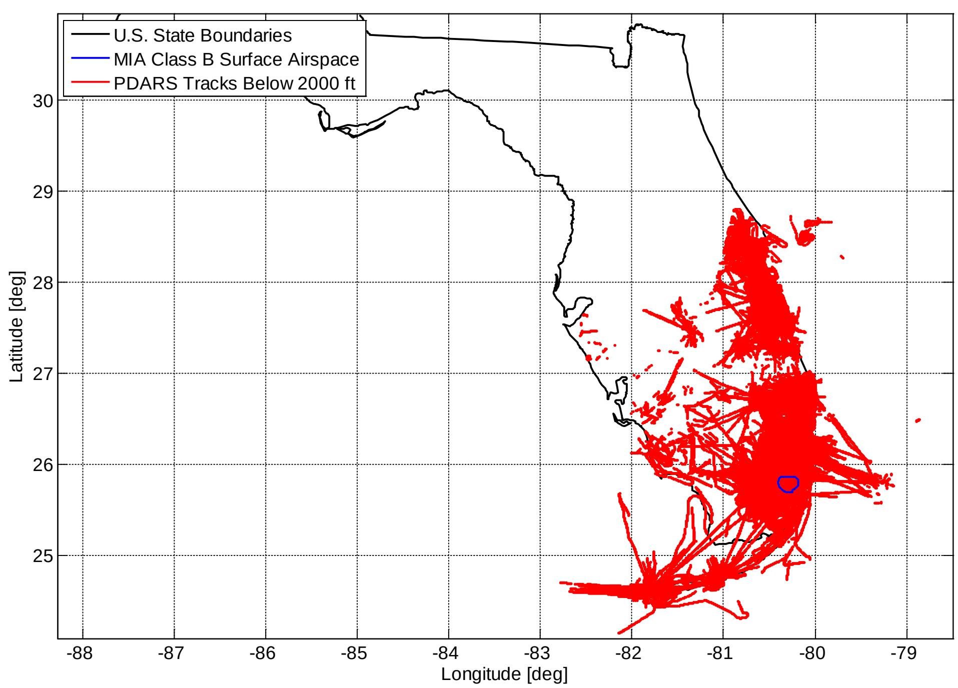


Figure 9b. PDARS MIA Dataset June 1, 2016 – Estimated AGL Altitude below 2,000 ft

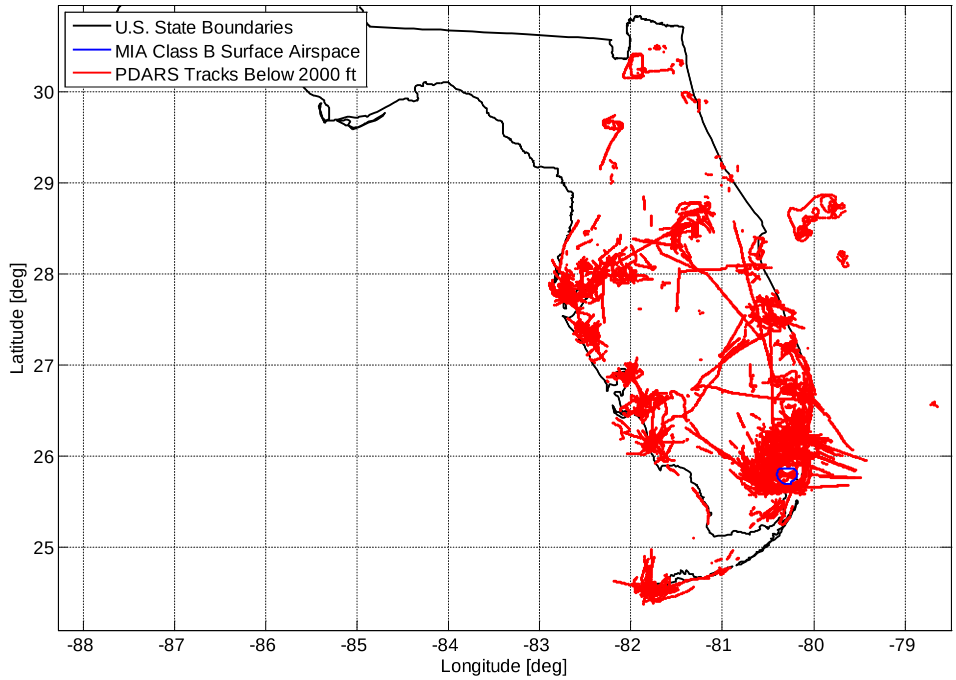


Figure 9c. PDARS ZMA Dataset June 1, 2016 – Estimated AGL Altitude below 2,000 ft

The above figures show track point records below an "estimated AGL" altitude of 2,000 ft. "Estimated AGL" is calculated by subtracting the terrain elevation of a central location from all MSL altitude entries. The estimation is appropriate for small areas like the UASFM surface airspaces, areas of which are on the order of less than 20 NM by 20 NM (east-to-west distance by north-to-south distance). The estimation is less accurate over large areas, however the above figures are only used to visualize differences between PDARS data sources for the same geographical area. A ceiling of 2,000 ft was chosen to depict where manned aircraft may take off, land, or maintain a sufficiently low altitude where sUAS may be operating concurrently.

The datasets are very different. Tower+ASDEX datasets have the smallest coverage areas, but provide the most coverage at low altitudes, close to the airport. These datasets provide altitudes up to 7,000 ft which is sufficient for the low-altitude scope of this analysis. TRACON datasets have large coverage areas, higher upper altitudes, and a lesser (albeit sufficient) coverage at low altitudes, close to the airport. Finally, ARTCC datasets also have large coverage areas and may provide data up to 40,000 ft, but potentially insufficient coverage at low altitudes.

Differences in coverage area between TRACON and ARTCC datasets can also be accommodated.

Figure 9c showing the ZMA dataset covers parts of the Tampa airspace, however, Figure 10 showing the Tampa Tower and TRACON (TPA) dataset has more coverage for that airspace.

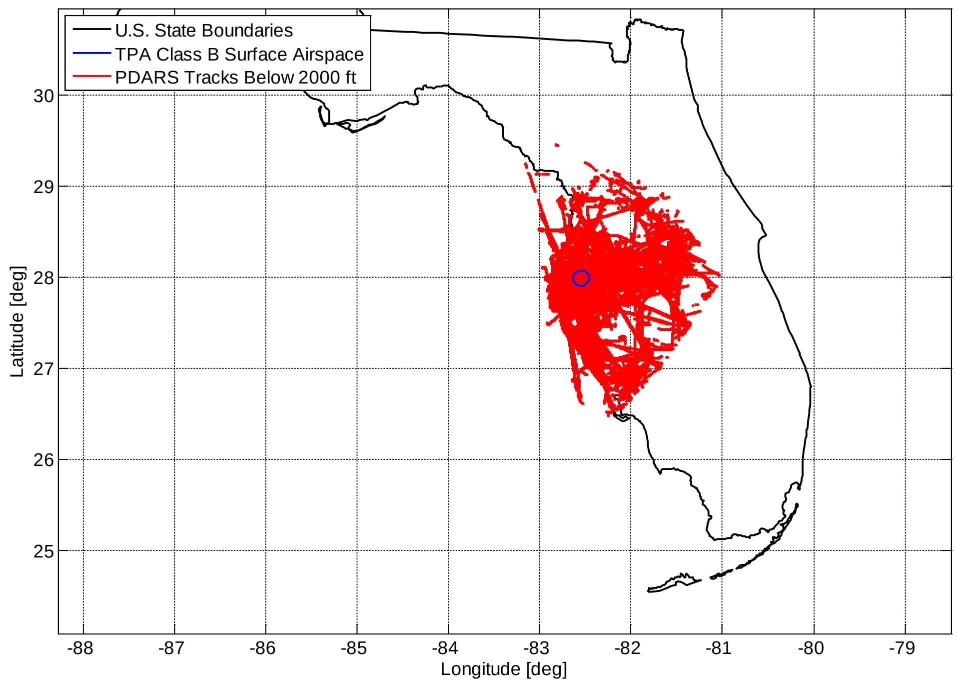


Figure 10. PDARS TPA Dataset June 1, 2016 – Estimated AGL Altitude below 2,000 ft

Based on this information, Tower+ASDEX datasets and TRACON datasets should be used to analyze as many UASFM airspaces as possible, with Tower+ASDEX being the preferred option. ARTCC datasets should only be considered if no other datasets are applicable. Section 3 provides further quantification of the amount of coverage available in Tower+ASDEX and TRACON datasets. Sections 4 and 5 discuss recommended PDARS datasets for each UASFM airspace, if applicable.

3. Model Assumptions and Methods

The model is still under development. Section 3 describes the assumptions and methods used, the assumptions are often conservative and can be improved upon in future analyses.

3.1 Assumptions on See-and-Avoid

Federal Aviation Regulation Part 91, Section 91.113 [FAA, 2004] defines “see-and-avoid” for manned aircraft operating in the same airspace. Manned aircraft pilots (i.e. “pilots”) shall maintain vigilance and a well clear separation from other aircraft, and give right-of-way to other aircraft when necessary. This basic assumption of safe operations cannot be expected to be reliably exercised with respect to sUAS due to limitations in human visual perception. Differences between sUAS and manned aircraft in terms of size, physical dimensions, contrast, controllability, and maneuverability make “see-and-avoid” between sUAS operators and manned aircraft pilots inconsistent at best.

Table 1 (Gettinger & Michel, 2017) shows the largest dimension in ft of the 30 most common, non-hobbyist drone make/models registered with the FAA, as of October 31, 2017. It is assumed these are the sUAS most likely to be flown at low altitude, in controlled airspace, near airports under Part 107. The left three columns with blue headers contain data directly quoted from Gettinger & Michel (2017), while the right two columns with red headers contain data from the respective manufacturers’ websites. The “Largest Dimension” column is rounded up to the nearest 0.1 feet.

Table 1. Common Non-Hobbyist sUAS Make/Models in FAA Registry (Gettinger & Michel, 2017)

	Manufacturer	Model	Quantity	Type	Largest Dimension [ft]
1	DJI	Phantom 4	26,189	Quadcopter	1.2
2	DJI	Phantom 3	16,944	Quadcopter	1.2
3	DJI	Mavic	13,902	Quadcopter	1.1
4	DJI	Inspire 1	7,787	Quadcopter	2.0
5	Intel	Shooting Star 2	4,800	Quadcopter	1.3
6	3DR	Solo	3,269	Quadcopter	1.5
7	DJI	Inspire 2	2,669	Quadcopter	2.0
8	DJI	Phantom 2	2,272	Quadcopter	1.2
9	Intel	Shooting Star	1,838	Quadcopter	1.3
10	Yuneec	Typhoon H	1,609	Hexacopter	1.8

	Manufacturer	Model	Quantity	Type	Largest Dimension [ft]
11	Yuneec	Typhoon Q500	1,505	Quadcopter	1.9
12	Autel Robotics	X-Star Premium	1,234	Quadcopter	1.2
13	Kespry	Kespry Drone 2.0	1,042	Quadcopter	
14	GoPro	Karma	938	Quadcopter	1.4
15	DJI	Matrice 600	883	Hexacopter	5.5
16	DJI	Matrice 100	801	Quadcopter	2.2
17	DJI	Spark	747	Quadcopter	0.5
18	senseFly	eBee	686	Fixed Wing	3.7
19	DJI	Phantom 1	676	Quadcopter	1.2
20	Parrot	AR Drone 2.0	540	Quadcopter	2.0
21	Parrot	Bebop 2	450	Quadcopter	1.1
22	3DR	Iris	439	Quadcopter	1.9
23	*Unknown*	Hamilton2	426		
24	Parrot	Bebop	401	Quadcopter	1.3
25	DJI	S1000	380	Octocopter	3.5
26	*Unknown*	R1	329		
27	Blade	Chroma	300	Quadcopter	0.8
28	Hitec	Q-*Cop*[5] 450	272	Quadcopter	1.5
29	Flyzone	FLZA-3000	215	Fixed Wing	6.1
30	DJI	F450	208	Quadcopter	1.5

The sUAS make/models in this list have largest dimension ranging from 0.5 to 6.1 ft, with the Kespry Drone 2.0, Hamilton2, and R1 models' technical specifications not readily available online. Among the model types: 23 of 28 are quadcopters, 2 fixed wing, 2 hexacopters, and 1 octocopter. In terms of total quantity, 89,223 of 93,996 individual aircraft in this list (95%) are quadcopters. 17 of 28 models, and 76,946 of 93,996 individual aircraft have largest dimension between 1 and 2 ft (82%). These observations may be used to constrain the most likely appearance of sUAS flown at low altitude, in controlled airspace, near airports under Part 107. A representative sUAS in the table above is a quadcopter with cross-sectional profile area of less than 4 square ft. The area threshold of 4 square ft is conservative; for example, a DJI Phantom 4 (most common make/model in Table 1), at most, has cross-sectional area of 1.5 square ft.

Woo (2017) has demonstrated that see-and-avoid cannot be consistently achieved by a manned aircraft pilot attempting to visually acquire sUAS of the sizes described above. Considering that 1 arc-minute of visual angle is the critical angle of visual detection for a human

[5] Gettinger and Michel 2017 lists the sUAS make/model "Hitec Q-*Box* 450" in row 28 – but no such make/model was found. The correct make/model may be "Hitec Q-*Cop* 450" – specifications available online: http://hitecrcd.com/files/Q-Cop450_ManualFinal_Web.pdf

with 20/20 vision, unaugmented (Woo, 2017; Howett, 1983)—a Phantom 4-sized sUAS would be first detectable at approximately 4,100 ft distance from the manned aircraft. If the manned aircraft approaching the sUAS head-on at 120 knots, then approximately 20 seconds are available for the manned aircraft to detect, discern, assess, and react to complete the see-and-avoid process.

The distance of 4,100 ft and available time of 20 seconds is a best-case scenario assuming optimal contrast, full attention of the pilot to search for sUAS, immediate visual focus and direct line-of-sight on the area where the sUAS is located, and many other factors (Boff and Lincoln, 1988). Optimal contrast is not consistently achievable due to visibility, atmospheric scattering, and potentially complex visual backgrounds (for example, urban landscapes in busy terminal airspaces). The pilot is also subject to a nominal workload of controlling the aircraft (or monitoring auto-pilot), communicating with ATC, searching for other manned aircraft ahead of searching for any UAS, among other tasks. The pilot can simply miss a small image while flying—"looking without seeing" (Mack and Rock, 1998).

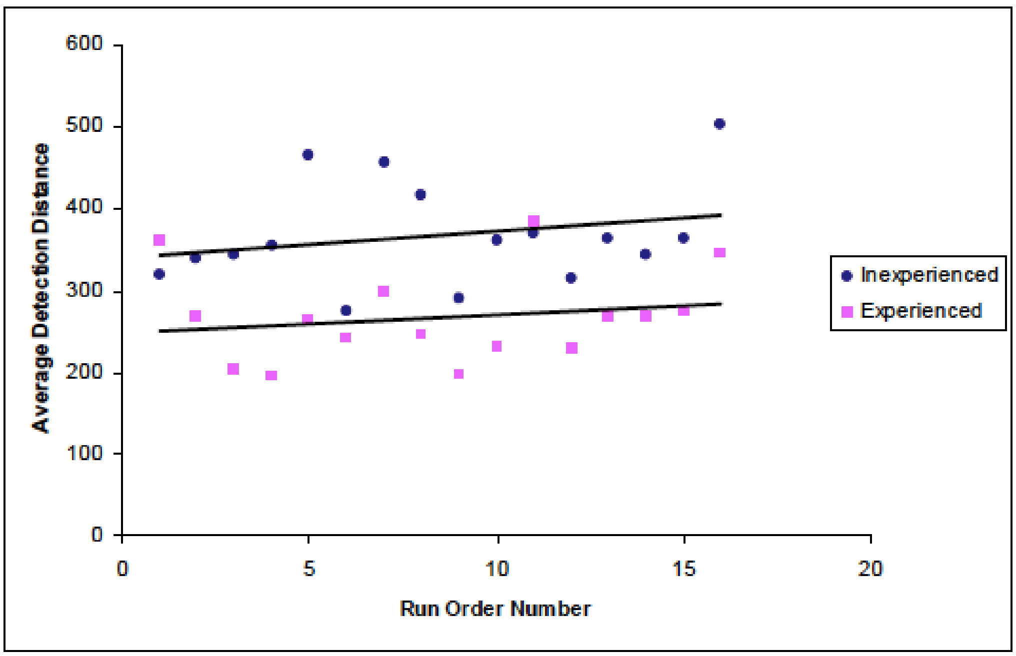


Figure 11. Average Detection Distance for a Boeing Scan Eagle (Crognale, 2009)

In fact, Crognale (2009) determined that a Boeing Scan Eagle (10.2-ft wingspan, 48.5 lbs takeoff weight, considered a sUAS[6]), was first detected by visual observers at 1073 ft on average when the observer did not know the direction of approach; and 4,186 ft when the observer knew the

[6] Boeing Insitu ScanEagle Unmanned Aircraft Systems Backgrounder, available online: http://www.boeing.com/farnborough2014/pdf/BDS/ScanEagle%20Backgrounder%200114.pdf

direction of approach (cf. Williams & Gildea, 2014). Visual observers were on the ground, and had no additional tasks besides searching for the sUAS. [Note these conditions represent the best case for detection; clearly an operator who was performing other tasks and did not expect to encounter a sUAS would not be able to detect the sUAS at the same distances.] The average distances of first detection are approximately 1 order of magnitude less than the theoretical threshold. Dolgov et al. (2012) also showed the visual observer's "performance in judging whether an intruder aircraft was on a collision course with (a sUAS)" was poor.

Much research in human visual detection of sUAS assert that see-and-avoid cannot be consistently achieved by manned aircraft pilots searching for sUAS. Consequently, the current model assumes for sUAS to safely operate at low altitude, in controlled airspace, near airports under Part 107—<u>sUAS should be flown below the altitudes at which manned aircraft routinely operate.</u> That appropriate altitude is, as alluded to earlier, the Risk Adjusted Altitude.

3.2 Assumptions on Safe Vertical Separation

The assumption on see-and-avoid is applied to each 1-minute by 1-minute by 400 ft grid volume in UASFM airspaces (described in Section 2.1). Manned aircraft tracks depicted in PDARS data (Section 2.3) travel through each grid volume, and the observed altitudes in each grid volume may be compared to that in the pre-approved altitude data (Section 2.2). Figure 12 shows the current definition of Risk Adjusted Altitude as "200 ft below routine operations" within each grid volume, again the color coding is used as a visual aid only. 200 ft is a conservative initial value for safe vertical separation (i.e. "safety buffer").

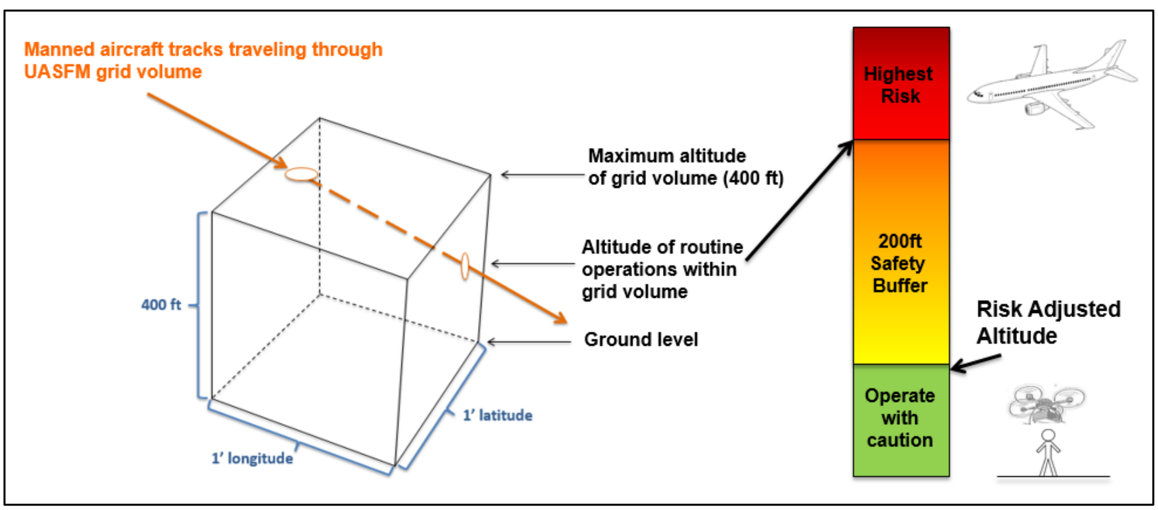


Figure 12. 200-ft Safety Buffer for Risk Adjusted Altitude

It is also assumed the Risk Adjusted Altitude is the threshold below which sUAS may operate with a negligible probability of collision. The probability of collision is non-negligible above the Risk Adjusted Altitude, and increases with altitude.

Figure 13 shows considerations for choosing a vertical safety buffer of 200 ft: 1) accuracy, precision, and uncertainty in manned aircraft altitude data; 2) accuracy, precision, and uncertainty in sUAS altitude data; and 3) lack of standard altitude reporting method onboard sUAS (NASA, 2017). The resolution of PDARS altitude data is 100 ft, therefore precision is ±50 ft with respect to rounding; accuracy of barometric altimeter data may also vary with pressure, temperature, and relative humidity. Displayed altitude in the cockpit may also differ from the altitude outgoing from the transponder (FAA-ANG-E61, 2017). Thus, the contribution to altitude uncertainty from the manned aircraft altitude is at least 50 ft.

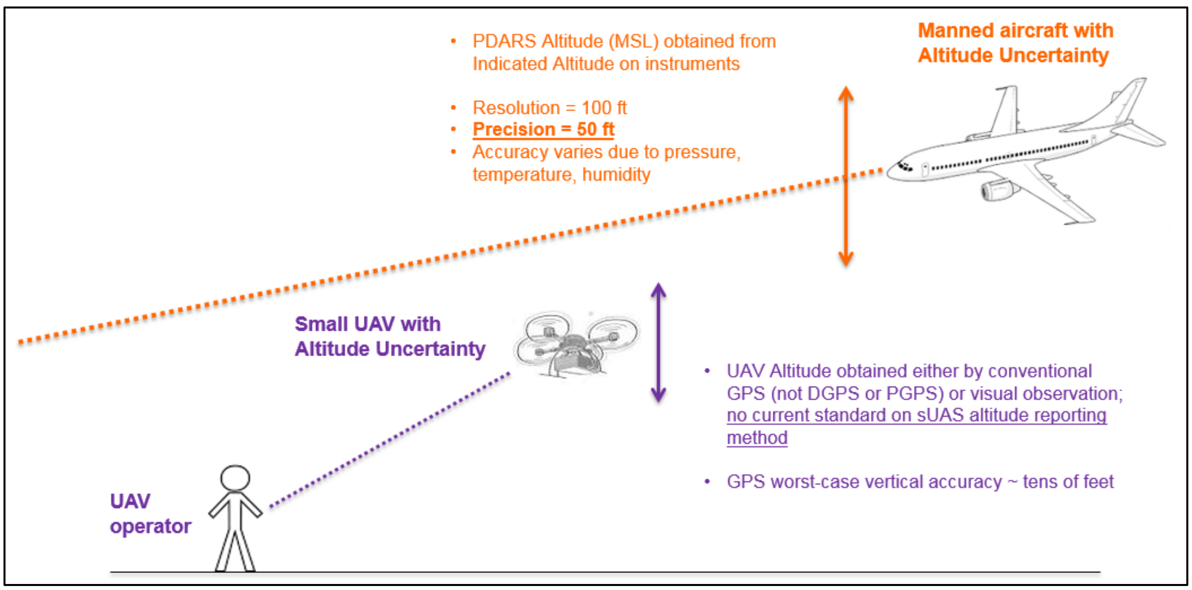


Figure 13. Considerations for Initial Use of 200-ft Safety Buffer

sUAS altitude is assumed to be determined either by operator's heads-up display—showing altitude from launch point for current drone models such as DJI Phantom 4 (DJI, 2016) or by operator's visual estimation. If the sUAS provides altimeter information in the heads-up display, then altimeter information is assumed to originate from standard GPS rather than differential GPS or precision GPS. The GPS performance standard worst-case vertical accuracy is 37 meters, while "well-designed" GPS receivers may achieve 5 meters vertical accuracy (Department of Defense, 2008). It may also be assumed visual observation of altitude is comparable or worse than GPS. Thus, the contribution to altitude uncertainty from the sUAS (entire system, including human operator) can be tens of ft.

Finally, uncertainty from estimating AGL altitude must be considered. The model uses a simplistic estimation, correcting every altitude in PDARS data (in MSL) by the terrain elevation at the airport of interest. Consider Figure 14 below which shows 1 hour of PDARS data in Miami Class B. The UASFM boundary is plotted in blue, PDARS tracks are plotted in orange and red, and grid volumes are plotted in gray. The PDARS data depict manned aircraft landing and departing MIA, as well as low-altitude helicopter traffic south of the airport. Altitude is reported in hundreds of ft, and each entry is corrected by 9 ft, the elevation of the airport[7]. Thus, the red data actually represent all PDARS tracks up to 400 ft above airport elevation.

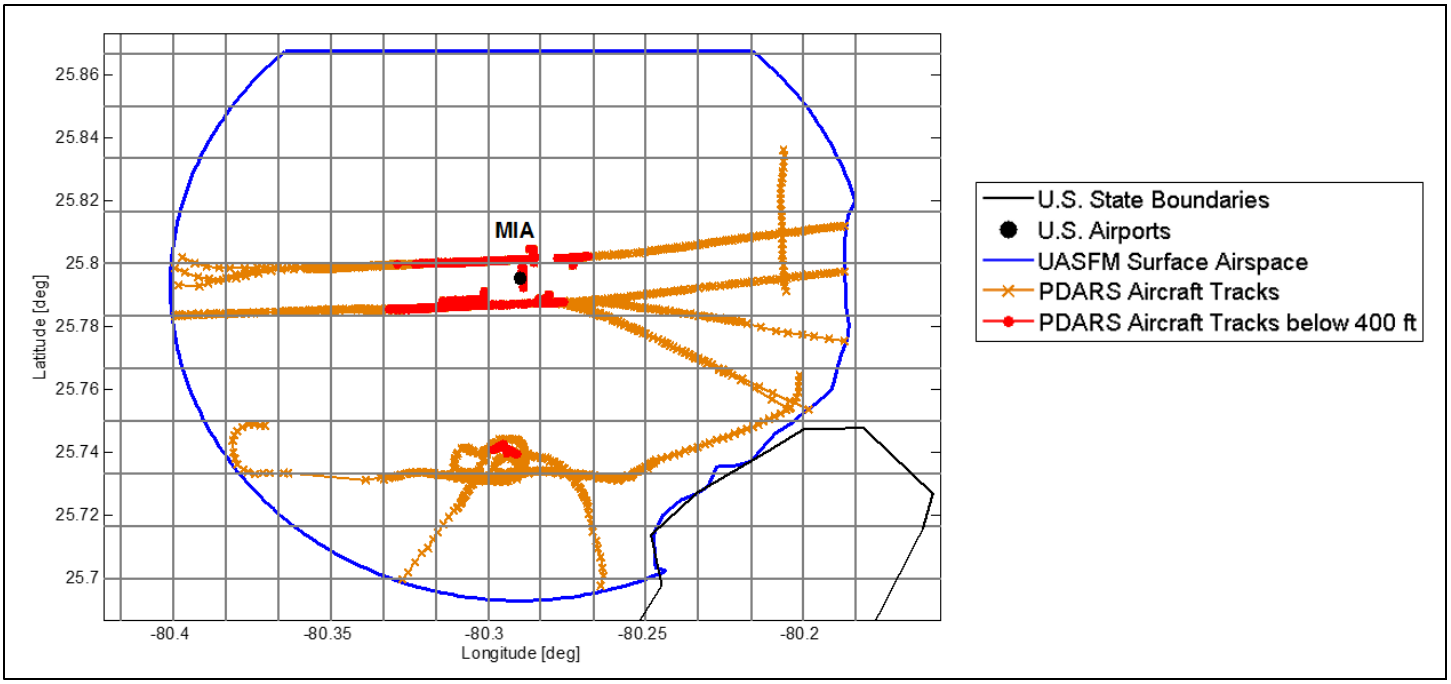


Figure 14. 1 Hour of PDARS Data in Miami Class B (MIA)

If elevation change within the airspace is small, then the estimation error from this method may be acceptable. Figure 15 shows topographic data near MIA[8], with the airport runways indicated in red. The highest elevation is approximately 30 ft near Virginia Key, while the lowest elevation is approximately 3 ft west of the airport. Maximum error associated with estimating the AGL altitude is 21 ft[9]. Elevation change in the MIA airspace is among the smallest of Class B airspaces. Other Class B airspaces with elevation change comparable to MIA include Houston-Hobby (HOU), Houston-Bush Intercontinental (IAH), Orlando (MCO), and

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[7] Airnav.com – Miami International Airport: http://www.airnav.com/airport/KMIA
[8] Topographic data for areas near Miami International Airport: http://en-us.topographic-map.com/places/Miami-International-Airport-3803137/
[9] Largest difference between terrain elevations and elevation of airport (30 ft - 9 ft)

Tampa (TPA).

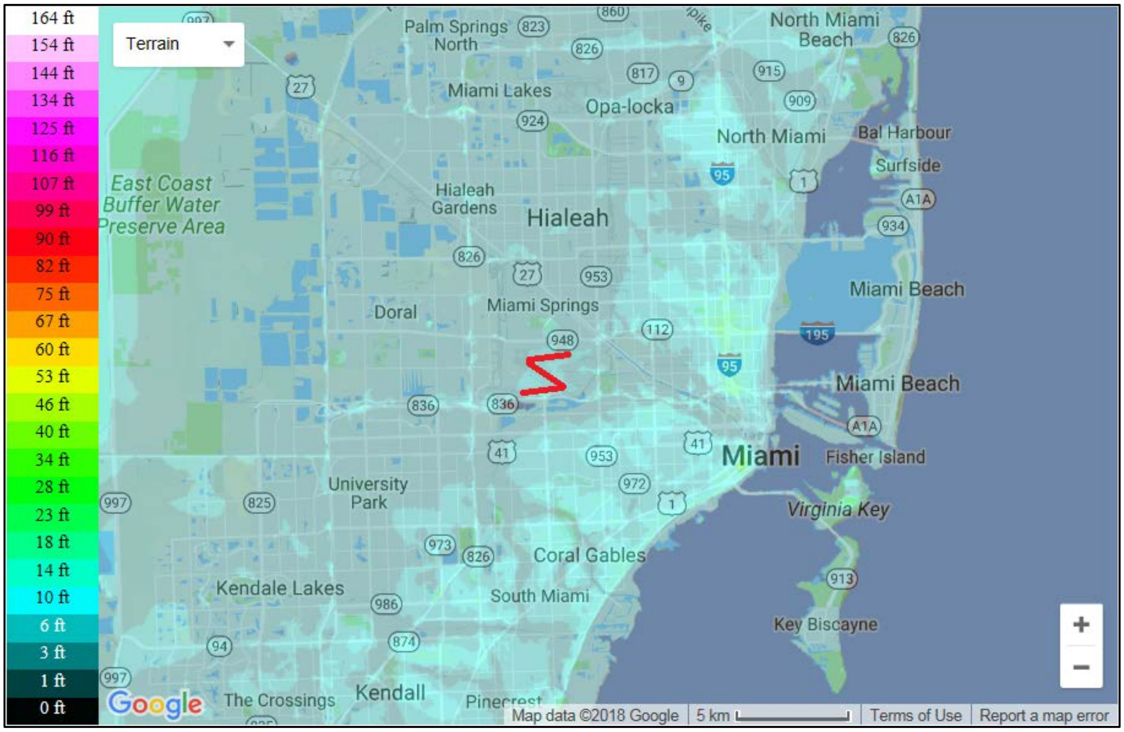

Figure 15. Elevation Change in Areas near MIA

Conversely, elevation change in Salt Lake City (SLC), Las Vegas (LAS), Honolulu (HNL), and San Francisco (SFO) are among the largest of Class B airports. Figure 16 shows 1 hour of PDARS data in SLC, with the AGL altitude estimated with the elevation of the airport (4,227 ft)[10]. Figure 17 shows topographic data near SLC[11], with the airport runways indicated in red. Elevation in most of the airspace varies from 4,200 to 4,300 ft, with areas along National Highway 89 reaching over 5,000 ft. Thus, error associated with estimating the AGL altitude is less than 73 ft[12] for most of the airspace, with few outlier errors of several hundred ft. All topography maps are compiled in Appendix B. With current sUAS models measuring altitude from launch point (which changes within UASFM grid volumes), extra care should be taken when operating close to the pre-approved altitude in that grid volume. Thus, elevation changes within the airspace presenting a challenge for developing accurate pre-approved altitudes. <u>The remainder of the uncertainty budget making up the total 200-ft safety buffer, is attributed to AGL altitude estimation error.</u>

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[10] Airnav.com – Salt Lake City International Airport: http://www.airnav.com/airport/KSLC

[11] Topographic data for areas near Salt Lake City International Airport: http://en-us.topographic-map.com/places/Salt-Lake-City-International-Airport-2034737/

[12] Largest difference between terrain elevations and elevation of airport (4300 ft - 4227 ft)

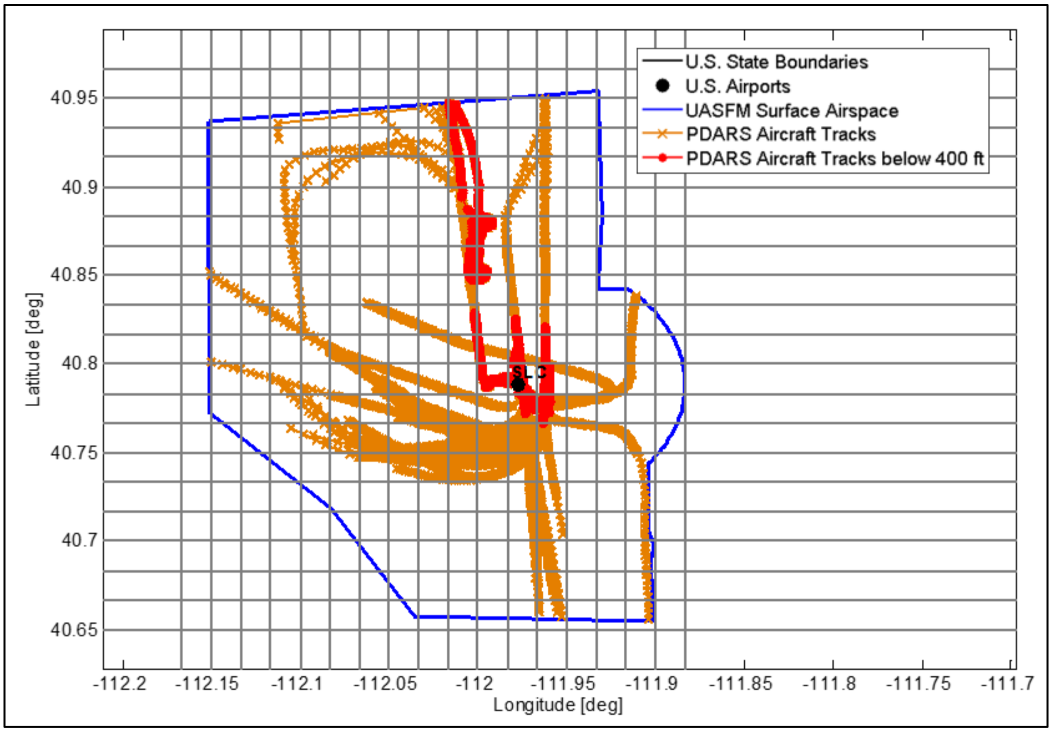

Figure 16. 1 Hour of PDARS Data in Salt Lake City Class B (SLC)

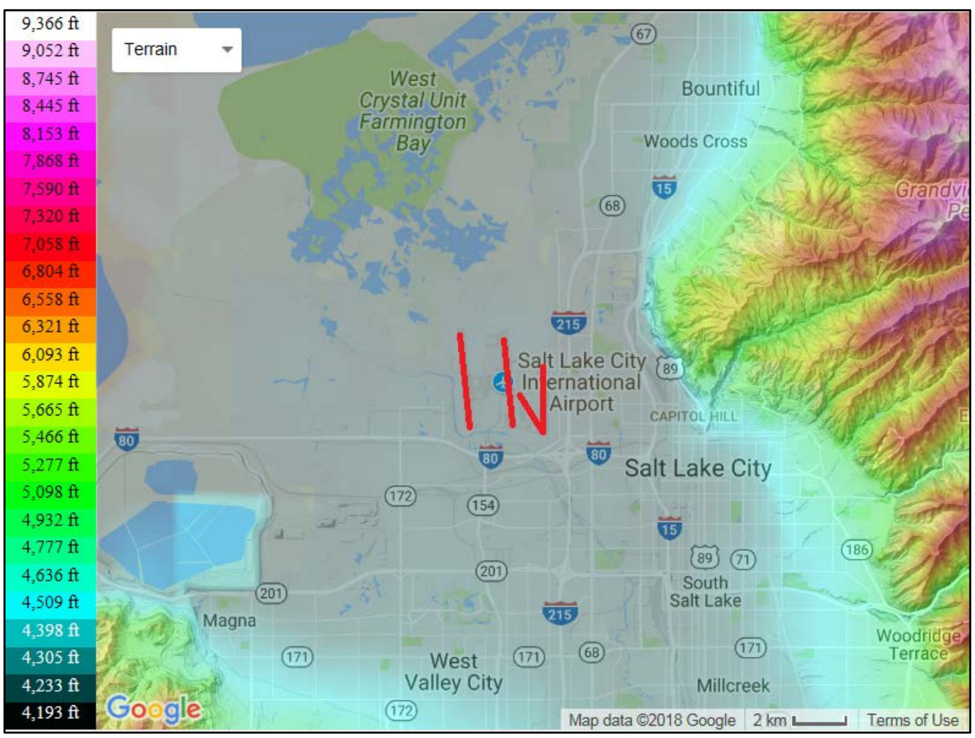

Figure 17. Elevation Change in Areas near SLC

In summary, error from estimating AGL altitude may vary depending on elevation changes in the airspace. This error, along with uncertainties in manned aircraft and sUAS altitudes, led to initial consideration of a 200-ft vertical safety buffer. Sections 3.1 and 3.2 have described why it is recommended for sUAS 1) to operate below manned aircraft (due to lack of see-and-avoid); and 2) operate at least 200 ft below manned aircraft due to current model uncertainties and errors.

3.3 Assumptions on Initial Departure and Final Approach Operations

As described in Section 2.3, PDARS datasets have different coverage at low altitudes. Manned aircraft tracks—starting or ending within 2 nautical miles (NM) of the airport with altitude, speed, and climb rate profiles consistent with initial departure or final approach—are linearly extrapolated to and from the center of the airport. Figure 18a-b show a sample manned aircraft track in PDARS at an arbitrary location. Grids in gray indicate 1-minute increments in latitude and longitude, same as previous figures.

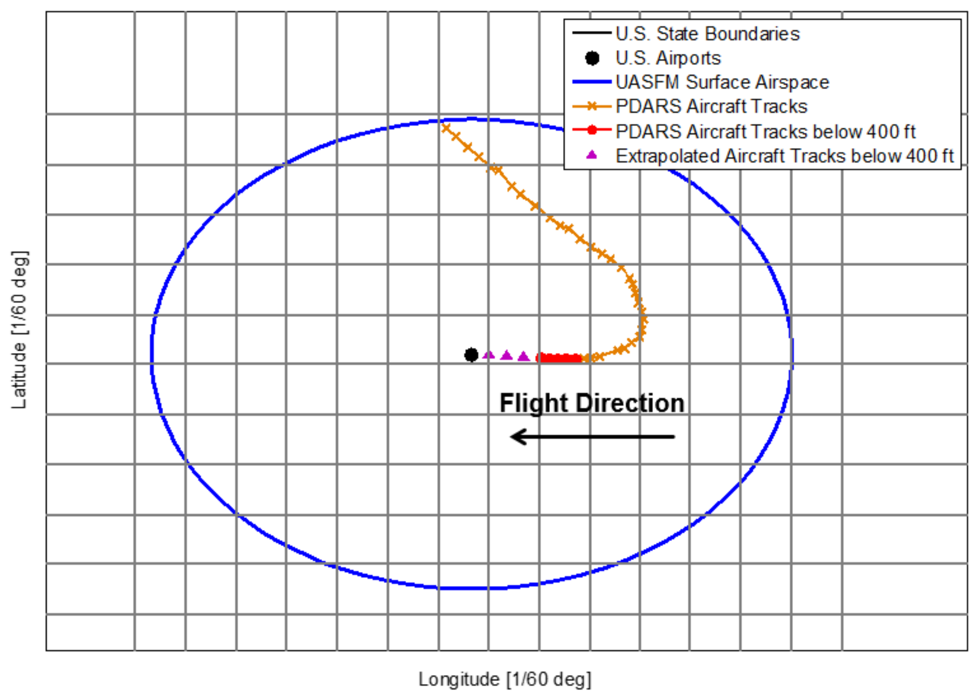

Figure 18a. Sample PDARS Track Position for a Final Approach

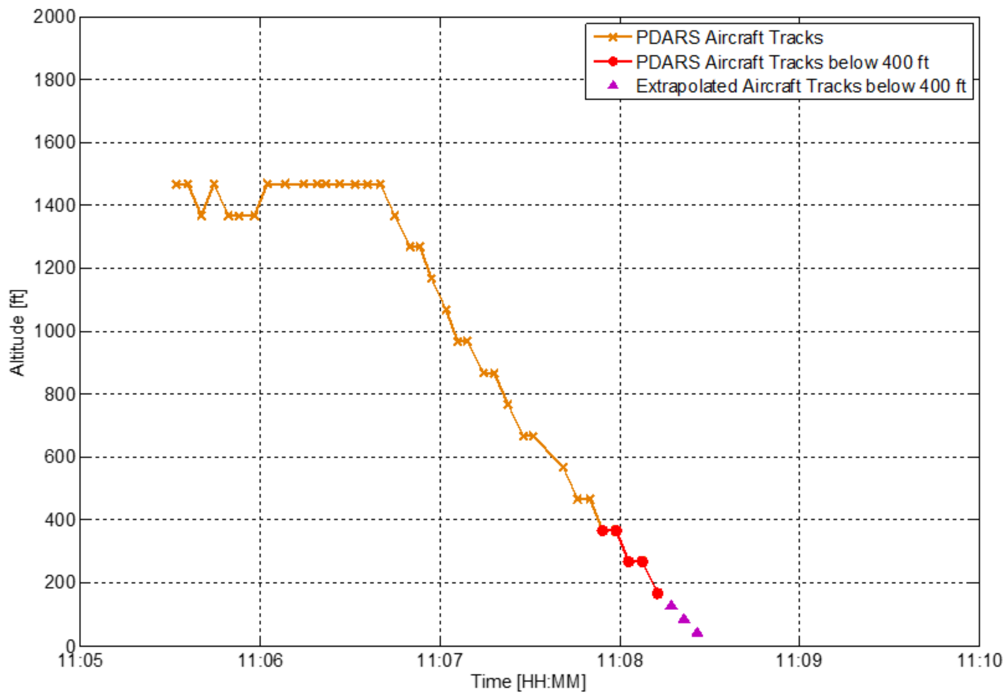

Figure 18b. Sample PDARS Track Altitude for a Final Approach

The aircraft enters the airspace from the north, heading southeast; then turns counterclockwise and lands at the airport. Table 2 shows sample data for the track; note altitude is shown in estimated AGL, corrected from MSL using the airport elevation of 132 ft. Rows of the table are color-coded in the same way as Figure 18a-b. A final approach is identified by 1) altitude and speed are either constant or decreasing over the entire track, and 2) climb rate either zero or negative over the entire track. The model uses these data to find the number of updates to extrapolate, and finds the extrapolated latitude, longitude, and altitude.

Table 2. Sample PDARS Track Data for a Final Approach

Relative Time [s]	Estimated AGL Altitude [ft]	Ground Speed [kts]	Climb Rate [ft/s]
0.0	1168	164	-22.0
4.8	1068	164	-15.4
8.7	968	164	-21.2
11.8	968	161	-12.8
17.6	868	152	-13.1
21.0	868	143	-12.4
25.6	768	136	-12.4
30.7	668	125	-9.9
34.0	668	115	-16.8
43.9	568	105	-9.9

Relative Time [s]	Estimated AGL Altitude [ft]	Ground Speed [kts]	Climb Rate [ft/s]
48.7	468	104	-10.3
52.8	468	104	-10.3
56.9	368	105	-14.9
61.7	368	104	-7.9
65.9	268	104	-14.4
70.3	268	102	0.0
75.4	168	95	-19.4

Number of extrapolated updates is based on average update interval and extrapolation time period. Average update interval is the mean of differences in Table 2, column 1 – approximately 4.4 seconds. Extrapolated time period is equal last reported AGL altitude[13], divided by average climb rate. The track ends at 168 ft estimated AGL and average climb rate is estimated at -14.2 ft/s from the last 5 updates[14] – which yields 11.8 seconds. Finally, the number of updates is the extrapolation time period divided by average update interval, rounded up to the nearest integer – which yields 3 updates. Due to rounding, climb rate is adjusted in order for altitude to reach zero. The adjusted climb rate is -11.9 ft/s.

Table 3 shows the same data as Table 2, with 3 extrapolated updates appended (rows are purple, same color as data plotted in Figure 18a-b). <u>All data in the added rows are outputs from the model, and a discrepancy is noted between estimated AGL altitude (output from model, column 2) and expected altitude based on adjusted climb rate (calculated from columns 1 and 3).</u> As described by the method in this section, correct values for column 2 are 112, 56, and 0 ft. Similar discrepancies exist in all results presented in this report, however, overall results from the model are not expected to change noticeably as extrapolations were only made close to the airport, at altitudes below 400 ft AGL[15]. In comparison, pre-approved altitudes in the area of

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[13] Last reported AGL altitude is used for final approaches (current example). In contrast, first reported AGL altitude is used for initial departures.

[14] If the track is an initial departure or final approach, then the last 5 updates are used to find mean climb rate. If fewer than 5 updates are available for a departure or approach, then all updates are used. Tracks with 1 update are not extrapolated, but may be used to determine Risk Adjusted Altitude if located at sufficiently low altitude.

[15] A discrepancy is noted between estimated AGL altitude (output from model) and expected altitude based on constant climb rate.

- Expected altitude based on constant climb rate – Track ends at 168 ft estimated AGL with estimated climb rate of -14.2 ft/s, time to land is 11.8 seconds, which is rounded to 3 update intervals of 4.7 seconds each. The model then assumes exactly n=3 updates are required for altitude to reach zero, climb rate is adjusted to -11.9 ft/s
    - Altitude of first extrapolated update = 168ft + 1update*(4.7s/update)*(-11.9ft/s) = 112ft
    - Second extrapolated update = 168ft + 2updates*(4.7s/update)*(-11.9ft/s) = 56ft
    - Third extrapolated update = 168ft + 3updates*(4.7s/update)*(-11.9ft/s) = 0ft
- Output from model – assumed n+1=4 updates are required for altitude to reach zero

extrapolation are also expected to be zero.

Table 3. Sample PDARS Track Data for a Final Approach (Extrapolated)

Relative Time [s]	Estimated AGL Altitude [ft]	Ground Speed [kts]	Climb Rate [ft/s]
0.0	1168	164	-22.0
4.8	1068	164	-15.4
8.7	968	164	-21.2
11.8	968	161	-12.8
17.6	868	152	-13.1
21.0	868	143	-12.4
25.6	768	136	-12.4
30.7	668	125	-9.9
34.0	668	115	-16.8
43.9	568	105	-9.9
48.7	468	104	-10.3
52.8	468	104	-10.3
56.9	368	105	-14.9
61.7	368	104	-7.9
65.9	268	104	-14.4
70.3	268	102	0.0
75.4	168	95	-19.4
80.1	**126**[16]	**Not Calculated**	**-11.9**[17]
84.8	**84**	**Not Calculated**	**-11.9**
89.5	**42**	**Not Calculated**	**-11.9**

The linear extrapolation algorithm assumes the following for initial departures and final approaches:

- 2 NM is a sufficiently close distance to apply the extrapolation
- Constant climb rate to and from ground level (0 ft AGL)
- Constant heading to and from geographical center of airport (found on airnav.com), and
- Geographical center of airport is sufficiently close to runways

As a result – extrapolated latitude and longitude propagate to the geographical center of the airport, and extrapolated altitude decrease linearly to ground level. Ground speed is not extrapolated, but may be considered in future versions of the model. The extrapolation method may be improved in multiple ways in future iterations.

[16] See previous footnote.

[17] Average climb rate of -14.2 ft/s adjusted to -11.9 ft/s due to rounding, see previous footnotes.

In summary, initial departures and final approaches are linearly extrapolated within 2 NM of the airport, both the existing PDARS tracks and extrapolated tracks are then considered in the Risk Adjusted Altitude. It is important to know how much additional data is contributed by the extrapolation, and how the extrapolation affects results. Two Class B UASFM airspaces – IAH and CLT – were selected due to coverage by both Tower+ASDEX and TRACON data sources. All airspaces are recommended to be examined in future analyses.

The following tables contain sample sizes for available PDARS data and extrapolated data. The number of extrapolated data per 100 available PDARS data was calculated on a per-day basis over a 2-month period, and may be calculated over the entire airspace or within 2 NM of the airport (2 NM was selected as the distance threshold for extrapolation). Tables 4-5 show the contribution of extrapolated data in IAH Class B, considering both the Tower+ASDEX and TRACON datasets. For the IAH+ASDEX (Tower+ASDEX) dataset – over a 2-month period in the entire airspace, the 5th percentile, median, and 95th percentile of extrapolated data contribution are 4.0, 4.5, and 5.3 respectively. For the I90 (TRACON) dataset – over a 2-month period in the entire airspace, the 5th percentile, median, and 95th percentile of extrapolated data contribution are 7.4, 8.0, and 8.9 respectively. Extrapolated data contribution over time is plotted in Figure 19.

Table 4. Extrapolated Data in IAH Class B, PDARS IAH+ASDEX Dataset

Analysis Time Period	PDARS Data 0-1 NM from Airport	PDARS Data 1-2 NM from Airport	PDARS Data >2 NM from Airport	Extrapolated Data 0-1 NM from Airport	Extrapolated Data 1-2 NM from Airport
June 1-30, 2016	195,662	774,893	3,452,234	148,316	58,228
July 1-31, 2016	204,004	767,593	3,632,913	148,020	61,184

Table 5. Extrapolated Data in IAH Class B, PDARS I90 Dataset

Analysis Time Period	PDARS Data 0-1 NM from Airport	PDARS Data 1-2 NM from Airport	PDARS Data >2 NM from Airport	Extrapolated Data 0-1 NM from Airport	Extrapolated Data 1-2 NM from Airport
June 1-30, 2016	5,394	144,971	1,417,446	102,370	24,891
July 1-31, 2016	5,405	141,237	1,460,196	99,172	27,869

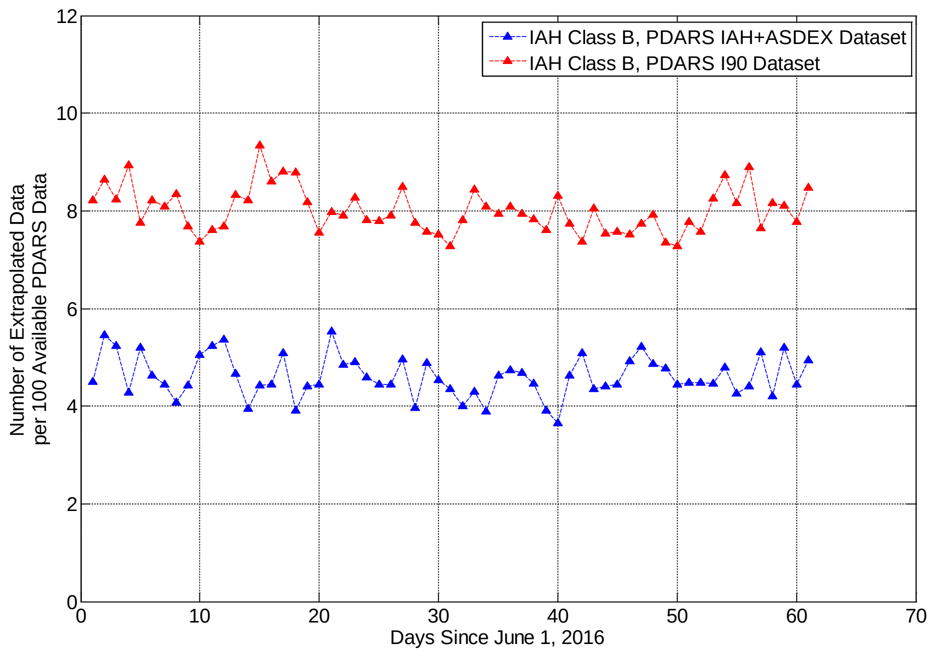

Figure 19. Contribution of Extrapolated Data in IAH Class B

Tables 6-7 show the contribution of extrapolated data in CLT Class B, considering both the Tower+ASDEX and TRACON datasets. For the CLT+ASDEX (Tower+ASDEX) dataset – over a 2-month period in the entire airspace, the 5th percentile, median, and 95th percentile of extrapolated data contribution are 3.1, 4.0, and 4.9 respectively. For the CLT (TRACON) dataset – over a 2-month period in the entire airspace, the 5th percentile, median, and 95th percentile of extrapolated data contribution are 7.3, 8.9, and 9.7 respectively. Extrapolated data contribution over time is plotted in Figure 20.

Table 6. Extrapolated Data in CLT Class B, PDARS CLT+ASDEX Dataset

Analysis Time Period	PDARS Data 0-1 NM from Airport	PDARS Data 1-2 NM from Airport	PDARS Data >2 NM from Airport	Extrapolated Data 0-1 NM from Airport	Extrapolated Data 1-2 NM from Airport
June 1-30, 2016	407,592	1,285,636	2,949,077	169,932	13,823
July 1-31, 2016	404,608	1,336,975	3,092,159	178,390	16,013

Table 7. Extrapolated Data in CLT Class B, PDARS CLT Dataset

Analysis Time Period	PDARS Data 0-1 NM from Airport	PDARS Data 1-2 NM from Airport	PDARS Data >2 NM from Airport	Extrapolated Data 0-1 NM from Airport	Extrapolated Data 1-2 NM from Airport
June 1-30, 2016	24,104	287,772	1,334,446	131,940	3,620
July 1-31, 2016	22,350	280,594	1,283,812	135,203	3,763

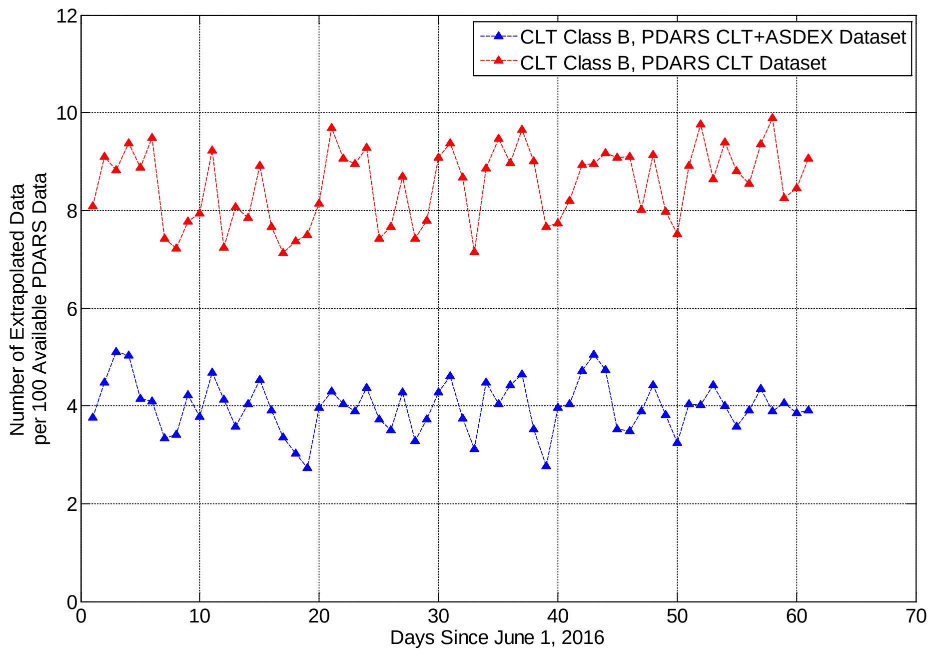

Figure 20. Contribution of Extrapolated Data in CLT Class B

Similar takeaways may be drawn from the both sets of results. As expected, Tower+ASDEX provide significantly more coverage within 2 NM of the airport. Number of extrapolated data is higher for Tower+ASDEX due a higher number of tracks depicted, but the ratio to total data is about 50% lower, compared to TRACON datasets. These results further support Tower+ASDEX as the preferred dataset for this analysis. In general, extrapolated data constitutes approximately 10% of the total dataset.

All model assumptions have been described to this point, the next section describes how the Risk Adjusted Altitude is calculated and presented.

3.4 Method

Risk Adjusted Altitude is defined as “200 ft below routine operations” within each grid volume. Consider an analysis time period where manned aircraft travel through UASFM airspaces, and where each data point may lie within a grid volume. The model collects all data points in a grid volume, determine the altitude of “routine operations,” and subtract the 200-ft vertical safety buffer to find the Risk Adjusted Altitude.

Two representations of Risk Adjusted Altitude were implemented based on two ways to define routine operations. The first is “Worst-case,” where the altitude of routine operations is the lowest altitude reached, among all data points in a grid volume. The second is “5th Percentile below analysis ceiling” (from this point forward referred to as “5th percentile”), where the lowest 5 percent of data points is not considered. An analysis ceiling of 1,200 ft was chosen initially to consider sufficiently low altitudes where both manned aircraft and sUAS operations may be well-informed, but may still come into conflict.

Figure 21a-b show worst-case and 5th percentile (below 1,200 ft) results for BOS Class B, using the PDARS BOS+ASDEX dataset. Time period of analysis is June 1-July 31, 2016. BOS runways occupy grid volumes J9, K8-10, and L9. Altitudes are color-coded from red (zero) to green (400), with warmer colors representing lower values used for visual aid only. Grid volumes E10 and M5 are highlighted in purple, and are examined in further detail after the figures. Figure 22 shows topographic data for areas near BOS[18], with approximate locations for E10 and M5 also indicated in purple. The airport elevation used to estimate AGL altitude is 19 ft[19].

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[18] Topographic data for areas near Boston Logan International Airport: http://en-us.topographic-map.com/places/Boston-Logan-International-Airport-2057425/

[19] Airnav.com – Boston Logan international Airport: http://www.airnav.com/airport/KBOS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1									100	100	100	400	300	400	150	400							
2						400	50	50	50	0	0	0	200	0	150	350	350	150					
3				400	100	50	250	0	100	0	250	0	0	0	0	0	0	0	50	50			
4			350	300	50	0	150	0	250	0	0	0	0	0	0	50	0	0	50	50	400		
5		400	300	300	0	100	0	0	0	0	200	0	0	0	0	50	0	50	50	50	50	50	
6		0	150	150	0	0	0	0	0	0	0	0	0	0	100	200	0	50	50	50	0	50	
7		0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	400
8	400	350	0	100	0	0	0	0	0	0		0	0	0	0	200	0	50	0	0	150	200	400
9	300	100	150	0	0	0	0	0	0				0	0	100	0	0	0	0	0	200	400	400
10	400	250	250	200	0	0	0	0	0	0		0	0	0	0	0	50	0	0	50	0	0	400
11		300	300	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
12		400	400	100	100	100	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13		400	200	0	50	100	50	0	0	0	0	0	0	0	0	50	0	50	0	0	0	50	
14			400	0	200	200	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
15				250	150	250	200	0	0	0	100	100	50	150	50	0	0	0	50	200			
16						250	200	0	0	0	50	400	150	100	250	100	250	400	400				
17								0	50	50	100	400	350	0	0	400							

Figure 21a. Worst-Case Risk Adjusted Altitude in BOS Class B, PDARS BOS+ASDEX Dataset, June 1-July 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1									150	150	350	400	300	400	200	400							
2						400	350	400	150	250	350	50	350	200	400	400	400	350					
3				400	350	400	350	200	400	300	350	200	200	0	50	50	200	50	200	50			
4			350	400	300	300	200	350	400	300	150	100	400	50	50	100	100	200	200	50	400		
5		400	300	350	300	400	350	400	350	350	400	400	400	400	350	250	50	150	100	50	50	50	
6		100	300	300	300	300	400	400	350	400	400	300	400	400	400	400	200	250	150	50	50	50	
7		200	150	100	400	300	250	250	150	0	0	50	0	150	400	400	0	150	100	50	50	50	400
8	400	400	250	350	300	250	200	200	0	0		0	0	250	300	400	400	400	100	100	250	400	400
9	400	400	400	400	400	350	150	300	0				0	100	300	400	50	50	0	100	250	400	400
10	400	400	350	350	100	350	300	150	0	0		0	0	300	400	400	200	0	0	250	250	50	400
11		400	400	350	350	350	150	0	50	200	0	0	250	350	400	400	150	0	250	50	0	0	400
12		400	400	350	400	400	300	0	400	400	0	0	0	400	400	300	200	300	400	0	0	0	
13		400	400	350	400	350	200	300	400	50	50	0	0	0	50	150	200	250	300	200	150	400	
14			400	250	250	250	300	0	0	200	100	100	50	100	0	0	50	50	50	50	0		
15				350	350	350	300	250	50	350	400	250	250	300	200	150	150	150	250	250			
16						300	200	50	50	200	350	400	350	250	400	250	250	400	400				
17								0	150	300	250	400	400	50	0	400							

Figure 21b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in BOS Class B, PDARS BOS+ASDEX Dataset, June 1-July 31, 2016

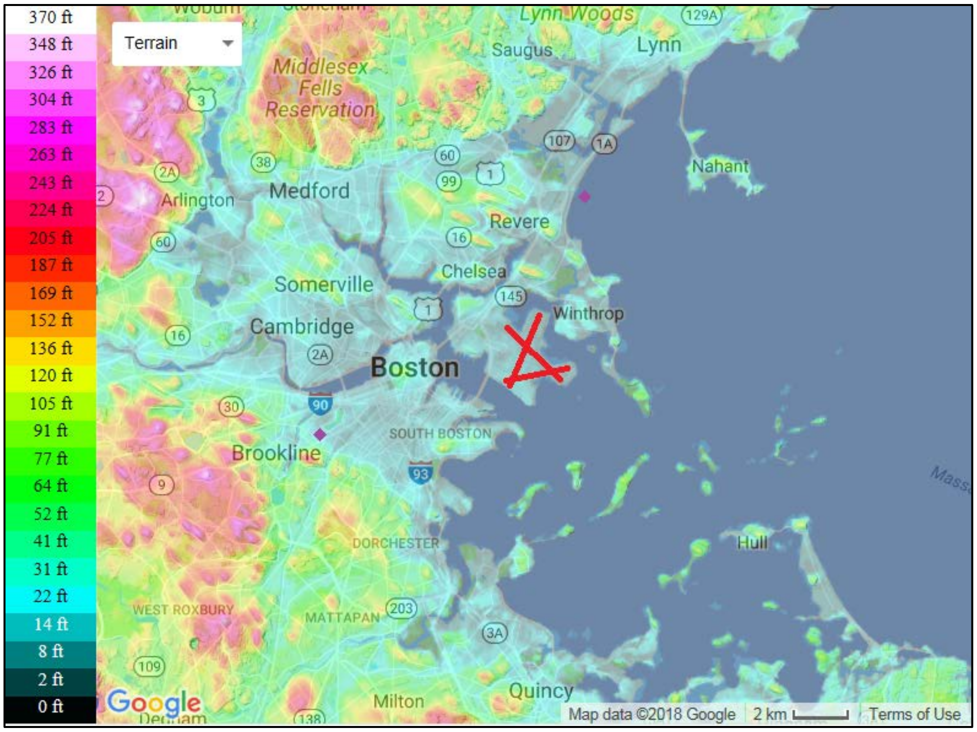
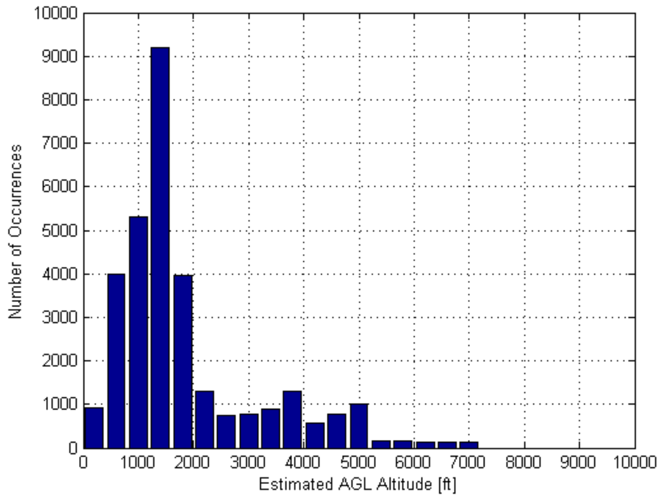


Figure 22. Elevation Change in Areas near BOS (with E10 and M5 indicated)

For BOS E10, the worst-case Risk Adjusted Altitude was 0 ft while the 5th percentile Risk Adjusted Altitude was 100 ft. E10 is indicated in purple (◆) near Brookline, MA. Local elevation is approximately 50 ft, resulting in estimation error of 31 ft. For BOS M5, the worst-case Risk Adjusted Altitude was 0 ft while the 5th percentile Risk Adjusted Altitude was 400 ft. M5 is indicated in purple (◆) near Revere, MA. Local elevation is 0 ft, resulting in estimation error of 19 ft.

Figure 23 shows the histogram of estimated AGL altitude in BOS E10, using the PDARS BOS+ASDEX dataset, in analysis time period June 1-July 31, 2016. Histogram bins are 0-10,000 ft with 400-ft bins (first bin is 0-400 ft, second bin is 400-800 ft, and so on). 31,412 data points were collected over the 2-month analysis period. The minimum altitude is 11 ft – which results in a worst-case Risk Adjusted Altitude of 0 ft after subtracting the 200-ft safety buffer. Additional statistics are shown in Table 8.

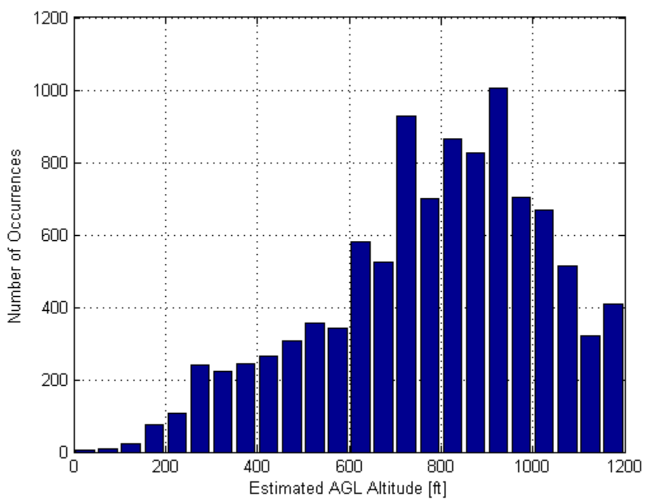
Figure 24 shows the same data, filtered to 0-1,200 ft (the left-most 3 bars in Figure 23). Histogram bins are 0-1,200 ft with 50-ft bins. 10,241 data points (32% of total) have estimated AGL altitude below 1,200 ft. The 5th percentile altitude in this dataset is 319 ft – which results in a 5th percentile Risk Adjusted Altitude of 100 ft after subtracting the 200-ft safety buffer, and rounding down to the nearest 50 ft. Additional statistics are shown in Table 9.



Statistic for All Altitudes in Class B Airspace	Estimated AGL Altitude [ft]
Minimum	11
5th Percentile	511
25th Percentile	969
Median	1,500
75th Percentile	2,044
Maximum	7,000

Figure 23. Histogram of Estimated AGL Altitudes in BOS E10, below 10,000 ft

Table 8. Statistics for Estimated AGL Altitudes in BOS E10, below 10,000 ft



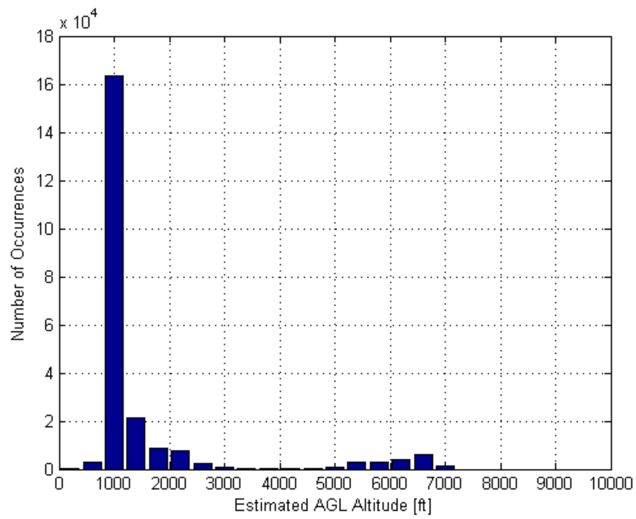
Statistic for All Altitudes below 1,200 ft	Estimated AGL Altitude [ft]
Minimum	11
5th Percentile	319
25th Percentile	631
Median	819
75th Percentile	956
Maximum	1,200

Figure 24. Histogram of Estimated AGL Altitudes in BOS E10, below 1,200 ft

Table 9. Statistics for Estimated AGL Altitudes in BOS E10, below 1,200 ft

Figure 25 shows the histogram of estimated AGL altitude in BOS M5. 226,173 data points were collected over the 2-month analysis period. The minimum altitude is 81 ft – which results in a worst-case Risk Adjusted Altitude of 0 ft after subtracting the 200-ft safety buffer. More statistics are shown in Table 10.

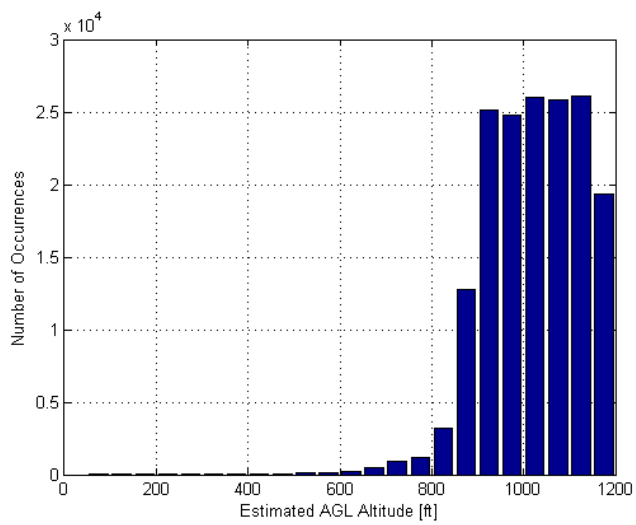
Figure 26 shows the same data, filtered to 0-1,200 ft. 166,492 data points (73% of total) have estimated AGL altitude below 1,200 ft. The 5th percentile altitude in this dataset is 862 ft – which results in a 5th percentile Risk Adjusted Altitude of 400 ft (upper limit for allowable sUAS altitude). Additional statistics are shown in Table 11.



Statistic for All Altitudes in Class B Airspace	Estimated AGL Altitude [ft]
Minimum	81
5th Percentile	875
25th Percentile	981
Median	1,087
75th Percentile	1,212
Maximum	7,000

Figure 25. Histogram of Estimated AGL Altitudes in BOS M5, below 10,000 ft

Table 10. Statistics for Estimated AGL Altitudes in BOS M5, below 10,000 ft



Statistic for All Altitudes below 1,200 ft	Estimated AGL Altitude [ft]
Minimum	81
5th Percentile	862
25th Percentile	950
Median	1,031
75th Percentile	1,112
Maximum	1,200

Figure 26. Histogram of Estimated AGL Altitudes in BOS M5, below 1,200 ft

Table 11. Statistics for Estimated AGL Altitudes in BOS M5, below 1,200 ft

The worst-case and 5th percentile results are both used to determine recommendations for facility maps. The worst-case result is most appropriate for small sample sizes or short analysis time periods. Meanwhile, the 5th percentile result represents a recommendation based on an acceptable level of risk; and by definition, the 5th percentile approaches the worst-case for small sample sizes.

Finally, Risk Adjusted Altitudes are reviewed for "areas of interest" where manned aircraft traffic patterns are lower than expected, where there is a large difference from the pre-approved altitude, and where any additional safety considerations should be taken when operating sUAS.

One area of interest is BOS E10: 42 degrees, 20-21 minutes north; 71 degrees, 6-7 degrees west. Figure 27a-b shows satellite imagery over the approximate location of the grid volume. The grid volume area includes Beth Israel Deaconess Medical Center which receives emergency patients via helicopter[20]. Given the type of manned aircraft operation, manned aircraft vulnerability in event of collision with sUAS, and pilot workload in emergency situations – operators should not be recommended to fly sUAS in E10, and should take significant caution in adjacent grid volumes.

Section 3 has described assumptions on 1) inability to consistently achieve see-and-avoid, 2) a 200-ft safety buffer between routine manned aircraft operations and pre-approved altitude for sUAS, and 3) linear extrapolation of initial departure and final approach. In addition, the worst-case and 5th percentile (below 1,200 ft) Risk Adjusted Altitudes have been defined.

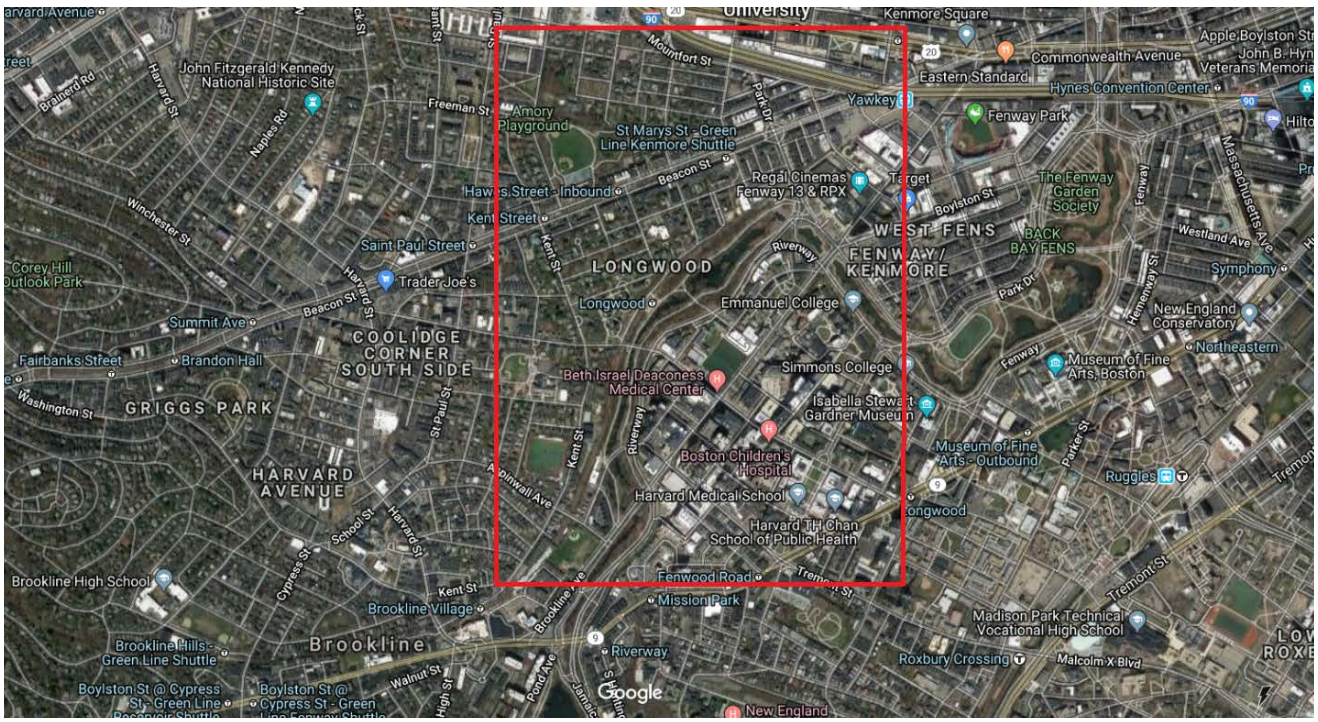


Figure 27a. Google Maps Image of BOS E10

[20] Beth Israel Deaconess Medical Center, Boston, MA – Emergency Services: http://www.bidmc.org/Centers-and-Departments/Departments/Emergency-Medicine/Emergency-Services.aspx

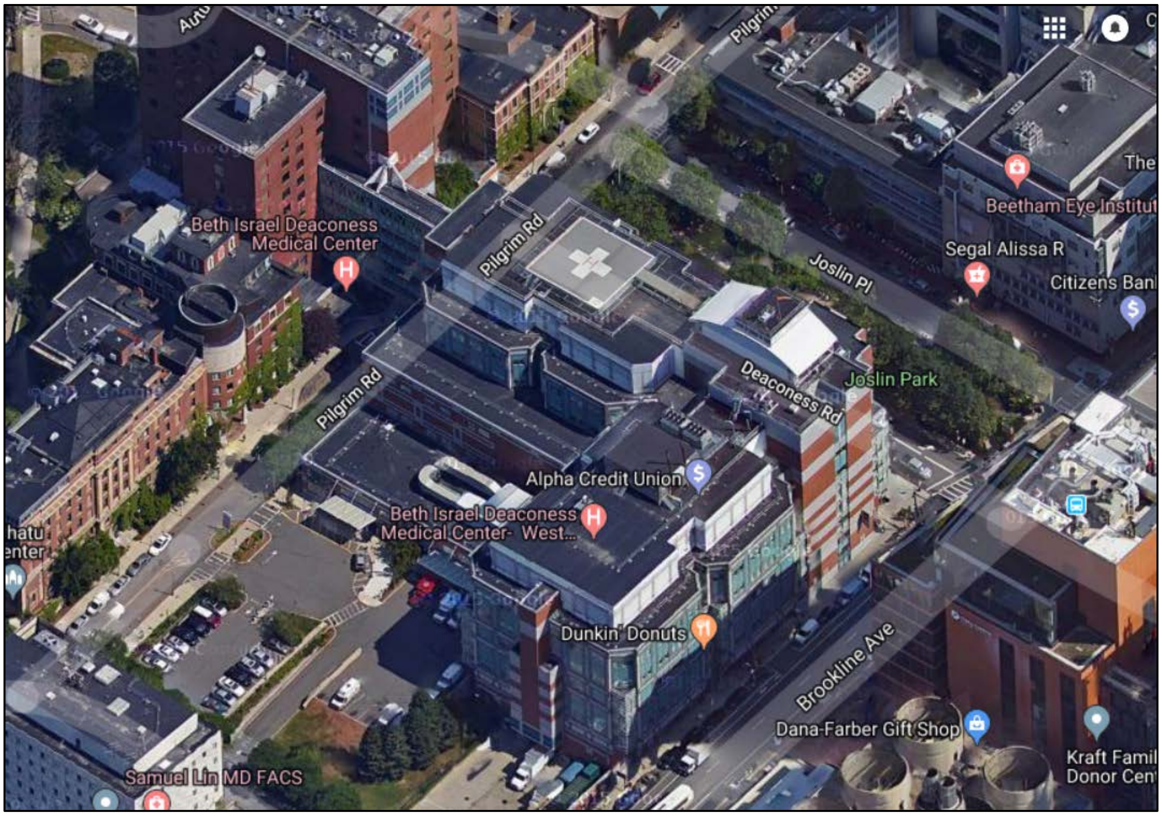


Figure 27b. Close-up View of Beth Israel Deaconess Medical Center

4. Risk Adjusted Altitude Results

Risk Adjusted Altitudes were calculated for 3 Class B facilities participating in LAANC initial implementation[21], all other Class B facilities (total of 37), and additional airports also participating in LAANC initial prototype evaluation.

Section 4 shows Risk Adjusted Altitude results for:

- Class B facilities participating in LAANC
  - Cincinnati/Northern Kentucky International Airport (CVG)
  - Miami International Airport (MIA)
  - Phoenix Sky Harbor International Airport (PHX)
- Class C facilities participating in LAANC
  - Anchorage International Airport (ANC) and nearby airports
  - San Jose International Airport (SJC)
- Various airports where areas of interest were found

One year of PDARS data from May 1, 2016 to April 30, 2017 was analyzed for CVG, MIA, and PHX. Worst-case and 5th percentile results are presented for the annual timeframe in this Section, as well as all two-month timeframes in the year (six total) in Appendix C. Two months of PDARS data from June 1 to July 31, 2016 were analyzed for all other airports considered, with Worst-case and 5th percentile results presented. The altitude ceiling for 5th percentile results is 1,200 ft in all cases. All Risk Adjusted Altitudes are in estimated AGL, subject to all error sources described in Section 3, including elevation changes within the airspaces. Risk Adjusted Altitudes are rounded down to the nearest 50 ft, all results range from 0 to 400 ft.

4.1 CVG Class B

Cincinnati/Northern Kentucky International Airport (CVG) averaged 376 operations per day over a 12-month period ending on March 31, 2017[22]; with 65% commercial, 30% air taxi, 5% general aviation, and <1% military traffic mix. CVG is one of three Class B airports participating in LAANC initial implementation. According to Gettinger and Michel (2017), Kentucky has 390 Part 107 Remote Pilot Certifications per 100,000 people, with 1.58 non-hobbyist drones per operator. Ohio has 978 per 100,000 people, and 1.57 drones per operator.

[21] FAA facilities participating in LAANC initial prototype evaluation: https://www.faa.gov/uas/programs_partnerships/uas_data_exchange/airports_participating_in_laanc/

[22] Airnav.com – Cincinnati/Northern Kentucky International Airport: http://www.airnav.com/airport/KCVG

Figure 28 shows the UASFM for CVG Class B, and Figure 29 shows topographic data for areas near the airport. The airport occupies 10 grid volumes (F4, F5-I6, and I7). Airport elevation used to estimate AGL altitude is 896 ft. Highest elevation in the airspace is approximately 961 ft, south of the airport. Lowest elevation over land is approximately 776 ft, and lowest elevation over the Ohio River is approximately 500 ft. Based on the elevation change in the airspace, maximum error associated with estimating AGL altitude is 120 ft for all grid volumes (compared to 200-ft safety buffer), except those over the Ohio River (10 of 116 non-airport grid volumes). Average grid volume width (east-to-west dimension, estimated with airport latitude) is 0.78 NM.

Figure 30 shows pre-approved altitude for CVG. Grid volumes with 0 pre-approved altitude are within 2 NM of all runways. All other pre-approved altitudes are 400 ft AGL. Figure 31a-b show worst-case and 5th percentile Risk Adjusted Altitudes using 1 year of PDARS MIA+ASDEX data. Areas where manned aircraft traffic patterns are lower than expected include Burlington, KY (southwest of airport) and Florence, KY (southeast of airport). 5th percentile results east of the airport, over the Ohio River and Cincinnati metropolitan area, are less accurate due to much lower terrain. Appendix C shows all 2-month results over the 1-year dataset, few seasonal changes are observed among the 2-month periods.

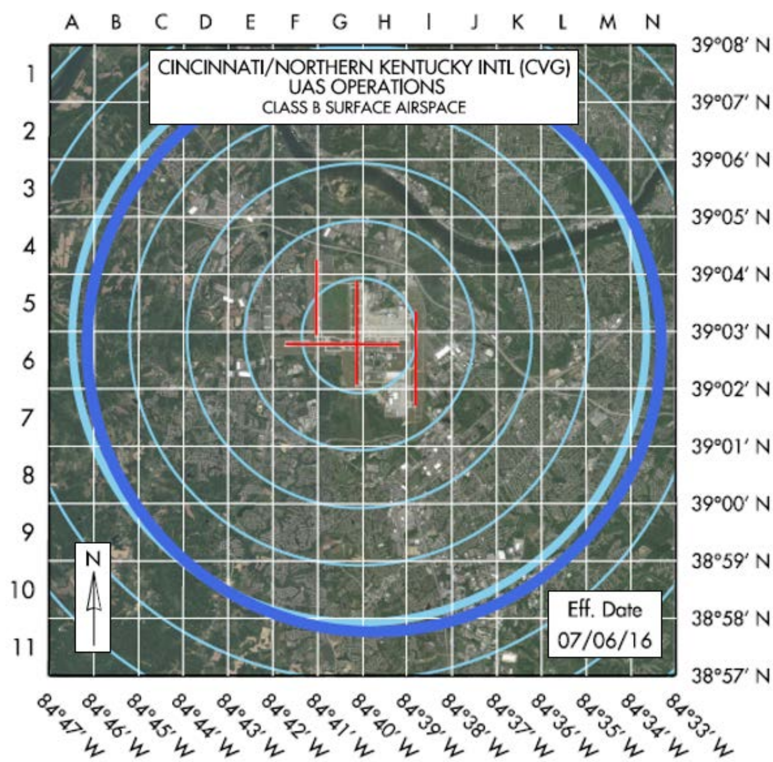


Figure 28. UASFM for Cincinnati/Northern Kentucky Class B (CVG)

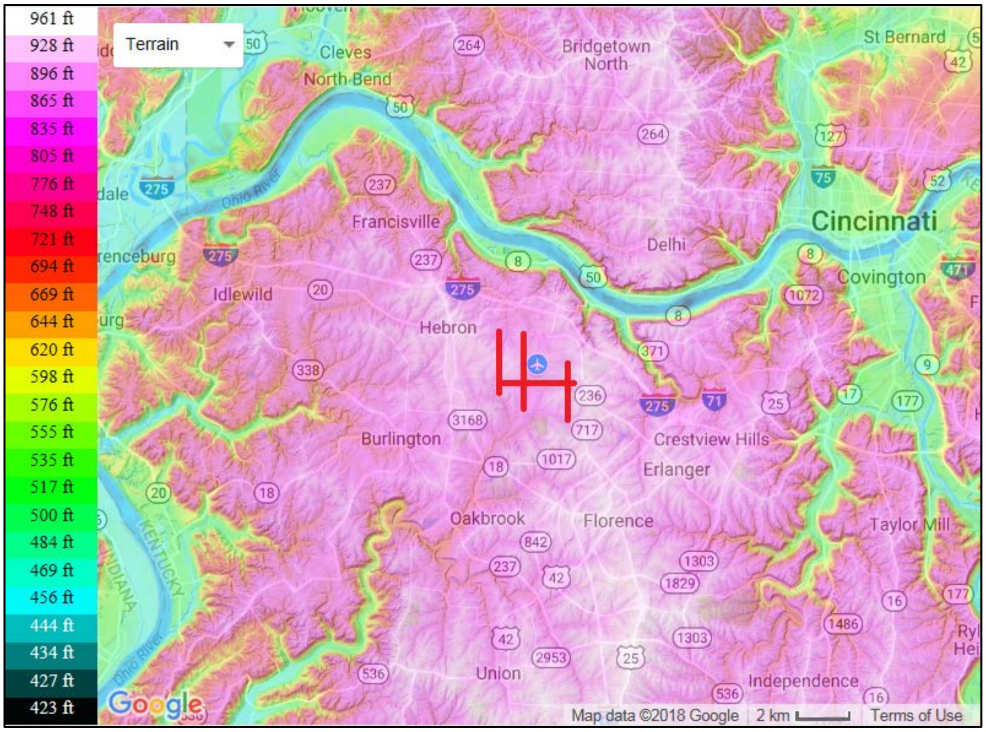


Figure 29. Elevation Change in Areas near CVG

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	400	400	400	400	400	400	400			
2			400	400	400	0	0	400	400	400	400	400	400	
3		400	400	400	400	0	0	0	0	400	400	400	400	400
4		400	400	400	400		0	0	0	400	400	400	400	400
5	400	400	400	0	0					0	0	400	400	400
6	400	400	400	0	0					0	0	400	400	400
7	400	400	400	400	400	0	0	0		400	400	400	400	400
8		400	400	400	400	0	0	0	0	400	400	400	400	400
9		400	400	400	400	400	400	0	0	400	400	400	400	
10				400	400	400	400	400	400	400	400	400		
11						400	400	400	400	400				

Figure 30. Pre-approved Altitude for CVG, Effective May 8, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	0	0	0	0	0	0	0			
2			0	0	0	0	0	0	0	0	0	100	400	
3		100	0	0	0	0	0	0	0	100	100	200	0	400
4		100	0	0	0		0	0	0	0	0	0	0	0
5	400	300	0	100	0					0	0	0	0	0
6	400	300	0	0	0					0	0	0	0	0
7	400	0	0	0	0	0	0	0		0	0	0	0	0
8		0	0	0	0	0	0	0	0	0	200	0	0	100
9		400	200	0	0	0	0	0	0	0	0	0	100	
10				0	0	0	0	0	0	0	0	0		
11						300	0	300	0	400				

Figure 31a. Worst-Case Risk Adjusted Altitude in CVG Class B, PDARS CVG Dataset, May 1, 2016-April 30, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	0	400	400	300	400	0	0			
2			50	200	0	200	400	300	400	300	200	200	400	
3		100	0	0	0	100	200	0	400	300	200	200	200	400
4		100	200	300	300		0	50	100	200	200	100	100	0
5	400	300	0	200	300					200	200	0	0	250
6	400	400	400	200	300					100	400	400	400	100
7	400	0	0	0	200	0	0	0		0	300	300	200	0
8		0	0	0	200	200	200	0	100	200	300	300	150	100
9		400	200	0	200	100	400	0	400	100	0	0	200	
10				0	200	300	400	0	400	100	0	0		
11						300	0	300	100	400				

Figure 31b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG Class B, PDARS CVG Dataset, May 1, 2016-April 30, 2017

4.2 MIA Class B

Miami International Airport averaged 1,134 operations per day over a 12-month period ending on December 31, 2016[23]; with 86% commercial, 9% air taxi, 4% general aviation, and <1% military traffic mix. MIA is one of 3 Class B airports participating in LAANC initial implementation. Florida has 2,752 Part 107 Remote Pilot Certifications per 100,000 people, with 1.88 non-hobbyist drones per operator.

Figure 32 shows the UASFM for MIA Class B, and Figure 33 shows topographic data for areas near the airport. The airport occupies 6 grid volumes – G5-I6. Airport elevation used to estimate AGL altitude is 9 ft. Highest elevation in the airspace is approximately 30 ft near Virginia Key. Lowest elevation is approximately 3 ft west of the airport. Based on the elevation change in the airspace, maximum error associated with estimating AGL altitude is 21 ft for all grid volumes (compared to 200-ft safety buffer). Average grid volume width (east-to-west dimension) is 0.90 NM.

Figure 34 shows pre-approved altitude for MIA. Grid volumes with 0 pre-approved altitude are within 1 NM east, west, and south of all runways. In addition, grid volumes E8, H9, M6, and M9 have 0 pre-approved altitude. Other than these grid volumes, pre-approved altitudes increase gradually off the runways, and are 400 ft north and south of the airport. Figure 35a-b show worst-case and 5th percentile Risk Adjusted Altitudes using 1 year of PDARS MIA+ASDEX data. The 5th percentile result is generally lower than the pre-approved altitude over the entire airspace. Appendix C shows all 2-month results over the 1-year dataset, few seasonal changes are observed among the 2-month periods.

[23] Airnav.com – Miami International Airport: http://www.airnav.com/airport/KMIA

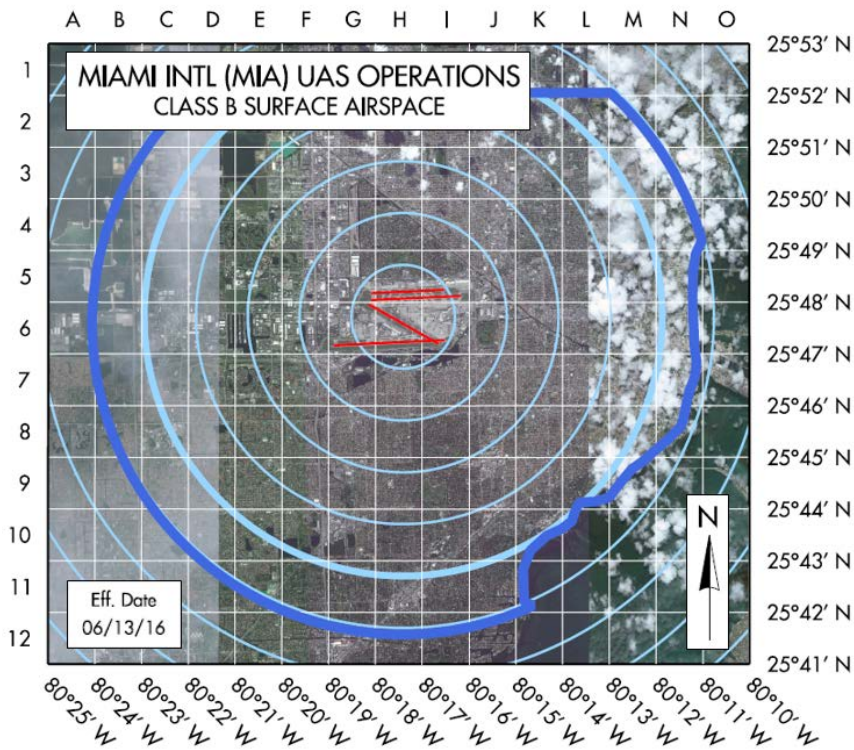


Figure 32. UASFM for Miami Class B (MIA)

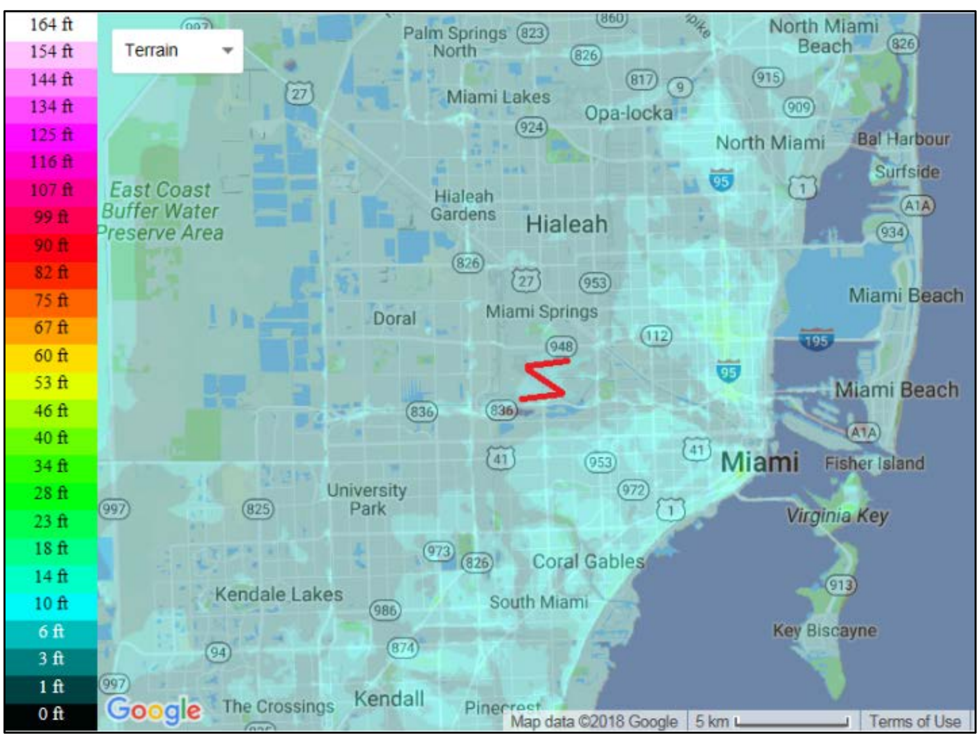


Figure 33. Elevation Changes in Areas near MIA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	400	200	200	200	200	200	200	400	400	
2			400	400	400	400	400	400	400	400	400	400	400	400
3		400	400	200	200	400	400	400	400	400	400	400	400	400
4		400	400	200	100	100	100	100	100	200	200	400	400	400
5	400	400	300	200	100	0				0	100	200	300	400
6	400	400	300	200	100	0				0	100	200	0	400
7	400	400	300	200	100	0	0	0	0	0	100	200	300	400
8		400	400	400	0	100	100	100	100	100	100	200	300	400
9		400	400	400	400	400	400	0	400	400	200	300	0	
10			400	400	400	400	400	400	400	400	400	400		
11				400	400	400	400	400	400	400	400			
12						400	400	400	400	400	400			

Figure 34. Pre-approved Altitude for MIA, Effective August 11, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				0	0	0	0	0	50	50	50	50	100	
2			0	0	0	0	0	0	0	0	0	0	0	200
3		0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0
5	100	0	0	0	0	0				0	0	0	0	0
6	0	0	0	0	0	0				0	0	0	0	0
7	100	0	0	0	0	0	0	0	0	0	0	0	0	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0
9		0	0	0	0	0	0	0	0	0	0	0	0	
10			0	0	0	0	0	0	0	0	0	0		
11				0	0	0	0	0	0	0	0			
12						100	0	0	0	0	300			

Figure 35a. Worst-Case Risk Adjusted Altitude in MIA Class B, PDARS MIA+ASDEX Dataset, May 1, 2016-April 30, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				100	150	150	150	150	150	150	150	150	100	
2			100	150	200	100	100	150	150	150	150	100	100	200
3		100	100	150	150	150	150	150	150	150	150	150	100	100
4		100	100	400	400	100	0	0	0	0	150	100	100	100
5	100	50	150	400	350	0				0	200	250	150	100
6	100	50	400	400	200	0				0	200	150	0	100
7	100	50	100	100	0	0	0	0	0	0	300	150	150	150
8		150	200	200	100	100	0	0	0	100	250	350	100	250
9		150	150	200	150	200	100	0	150	150	150	100	150	
10			150	150	200	150	200	100	150	150	150	100		
11				100	150	200	0	200	200	150	50			
12						150	150	200	100	150	300			

Figure 35b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA Class B, PDARS MIA+ASDEX Dataset, May 1, 2016-April 30, 2017

4.3 PHX Class B

Phoenix Sky Harbor International Airport (PHX) averaged 1,199 operations per day over a 12-month period ending on February 28, 2017[24]; with 83% commercial, 12% air taxi, 5% general aviation, and <1% military traffic mix. PHX is one of 3 Class B airports participating in LAANC initial implementation. Arizona has 855 Part 107 Remote Pilot Certifications per 100,000 people, with 1.41 non-hobbyist drones per operator.

Figure 36 shows the UASFM for MIA Class B, and Figure 37 shows topographic data for areas near the airport. The airport occupies 6 grid volumes (J5-L6). Airport elevation used to estimate AGL altitude is 1,135 ft. Highest elevation in the airspace is approximately 1,565 ft in the Arizona Desert Botanical Garden (halfway between Scottsdale and Tempe, AZ), and 1,200 ft among all other grid volumes. Lowest elevation is approximately 1,050 ft west of the airport. Mountains higher than 2,000 ft in South Mountain Park are apparently not included in the airspace. Based on the elevation change in the airspace, maximum error associated with estimating AGL altitude is 85 ft for all grid volumes (compared to 200-ft safety buffer), except over the botanical garden (N3, N4, O4, and O5; 4 of 144 non-airport grid volumes). Average

[24] Airnav.com – Phoenix International Airport: http://www.airnav.com/airport/KPHX

grid volume width (east-to-west dimension) is 0.84 NM.

Figure 38 shows pre-approved altitude for PHX. Grid volumes with 0 pre-approved altitude are within 2 NM of all runways. A large part of the airspace has 100 ft pre-approved altitude, and the only grid volumes with 400 ft pre-approved altitude are on the edge of the airspace. Figure 39a-b show worst-case and 5th percentile Risk Adjusted Altitudes. Manned aircraft traffic patterns were lower than expected in S8, where the Banner Desert Medical Center in Mesa, AZ is located[25] (the hospital uses 2 helipads). 5th percentile results were either 0 or 50 ft for all 2-month periods in addition to the annual results. Risk Adjusted Altitudes of 0 were also found at the western edge of the airspace, which corresponds with the lowest terrain in the airspace. These results may be less accurate due to lower terrain. Appendix C shows all 2-month results over the 1-year dataset, few seasonal changes are observed among the 2-month periods.

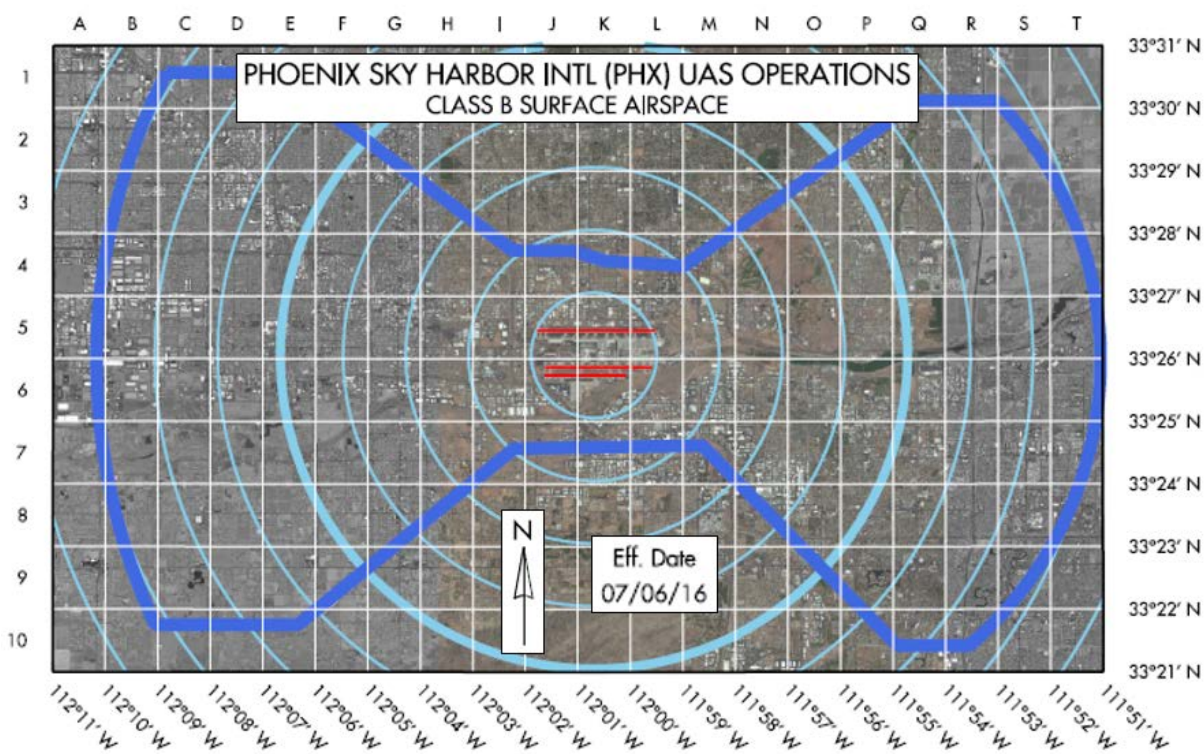


Figure 36. UASFM for Phoenix Class B (PHX)

[25] Airnav.com – Banner Desert Medical Center Heliport: http://www.airnav.com/airport/66AZ

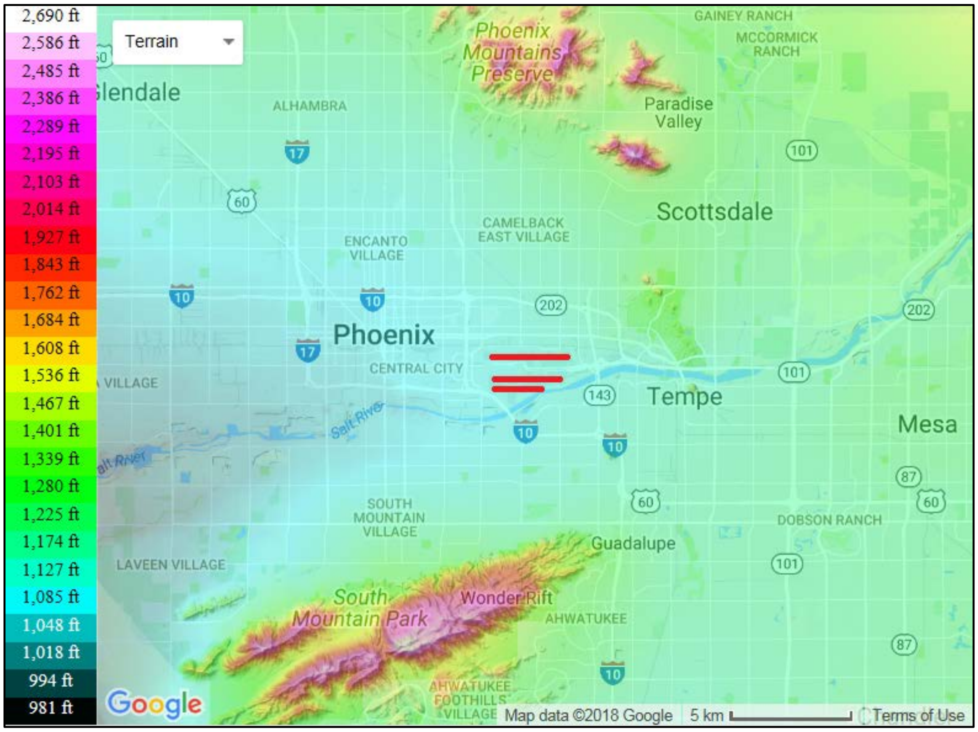


Figure 37. Elevation Changes in Areas near PHX

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		300	300	300	300	300											400	400	400	
2		300	300	300	300	300	300								300	300	300	300	300	
3		300	300	300	300	300	200	100	100				100	100	200	300	300	300	300	300
4	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
5	200	200	200	200	100	100	100	0	0				0	0	100	100	100	100	100	100
6	200	200	200	200	100	100	100	0	0				0	0	100	100	100	100	100	100
7	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
8		200	200	200	100	100	100	100						100	100	100	100	100	100	100
9		400	400	400	400	400	400								400	400	400	400	400	400
10		400	400	400	400	400										400	400	400	400	

Figure 38. Pre-approved Altitude for PHX, Effective December 7, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		100	0	0	0	50											200	100	250	
2		0	0	0	0	0	0								100	0	0	0	150	
3		0	0	0	0	0	0	0	0				0	0	0	0	0	0	100	100
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0
8		0	0	0	0	0	0	0						50	0	50	0	0	0	0
9		0	0	0	0	0	100								0	0	0	0	100	400
10		200	0	100	150	400										50	0	0	300	

Figure 39a. Worst-Case Risk Adjusted Altitude in PHX Class B, PDARS PHX+ASDEX Dataset, May 1, 2016-April 30, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		250	150	150	200	250											350	250	300	
2		150	150	150	150	200	0								400	150	250	250	300	
3		150	200	200	200	200	0	0	100				250	0	350	300	300	250	300	350
4	150	100	100	150	150	150	100	0	0	0	0	0	0	100	300	250	250	200	250	200
5	0	0	50	50	200	400	400	150	0				0	150	400	400	250	100	50	150
6	0	0	0	0	200	400	400	150	0				0	250	400	250	200	150	200	250
7	150	0	50	50	50	100	50	150	0	0	50	0	150	150	150	100	150	200	250	250
8		0	50	100	150	150	200	200						200	50	250	250	200	0	250
9		50	100	150	200	150	200								150	200	200	200	300	400
10		200	100	200	200	400										200	250	200	400	

Figure 39b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX Class B, PDARS PHX+ASDEX Dataset, May 1, 2016-April 30, 2017

4.4 ANC Class C and LHD Class D

Anchorage International Airport (ANC) averaged 717 operations per day over a 12-month period ending on December 1, 2016[26]; with 38% commercial, 29% air taxi, 32% general aviation, and <1% military traffic mix. ANC is one of 2 Class C airports participating in LAANC initial implementation. Alaska has 239 Part 107 Remote Pilot Certifications per 100,000 people, with 1.13 non-hobbyist drones per operator. Lake Hood Seaplane Base (LHD) shares the airspace and is also participating in LAANC.

Figure 40 shows the UASFM for ANC; LHD is also indicated on the graphic in purple, northeast of ANC. and Figure 41 shows topographic data for areas near the airports. ANC occupies 8 grid volumes (J5, H6-N6); while LHD occupies 4 grid volumes (M4-N5). Airport elevation used to estimate AGL altitude is 152 ft. Highest elevation in the airspace is approximately 295 ft over Kincaid Park. Lowest elevation is approximately 65 ft southeast of ANC. Based on the elevation change in the airspace, maximum error associated with estimating AGL altitude is 87 ft for all grid volumes (compared to 200-ft safety buffer), except those over Kincaid Park (11 of 116 non-airport grid volumes. Average grid volume width (east-to-west dimension) is 0.49 NM.

Figure 42 shows pre-approved altitude for ANC/LHD. Pre-approved altitude is 0, 50, or 100 ft for all grid volumes. Figure 43a-b show worst-case and 5th percentile Risk Adjusted Altitudes using 2 months of PDARS Anchorage TRACON (A11) data. The 5th percentile result is generally higher than the pre-approved altitude over the entire airspace, although results over Kincaid Park may be less accurate due to local elevation.

[26] Airnav.com – Anchorage International Airport: http://www.airnav.com/airport/PANC

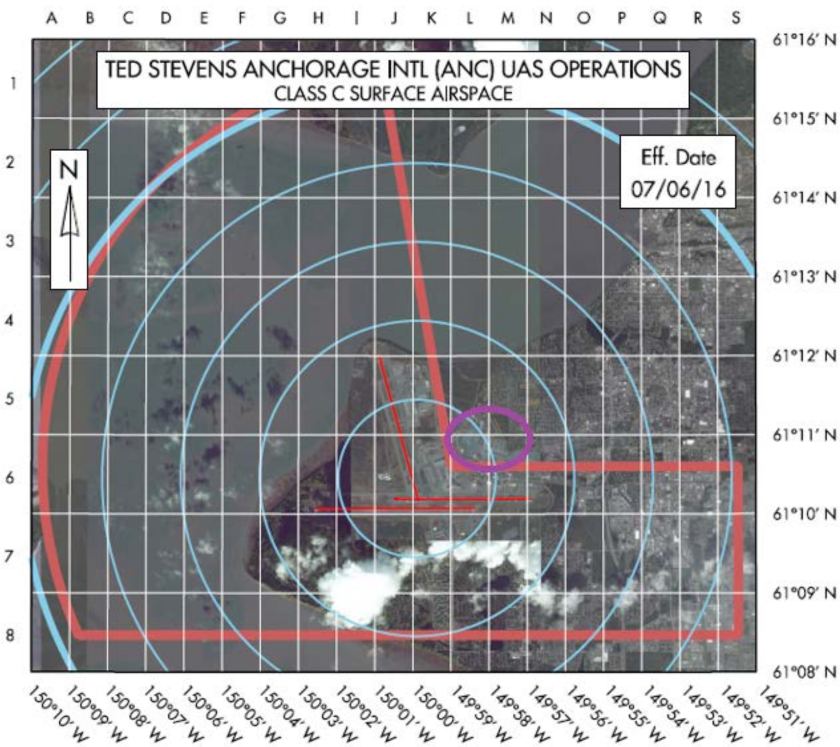


Figure 40. UASFM for Anchorage Class C (ANC), with Lake Hood Seaplane Base (LHD) also indicated

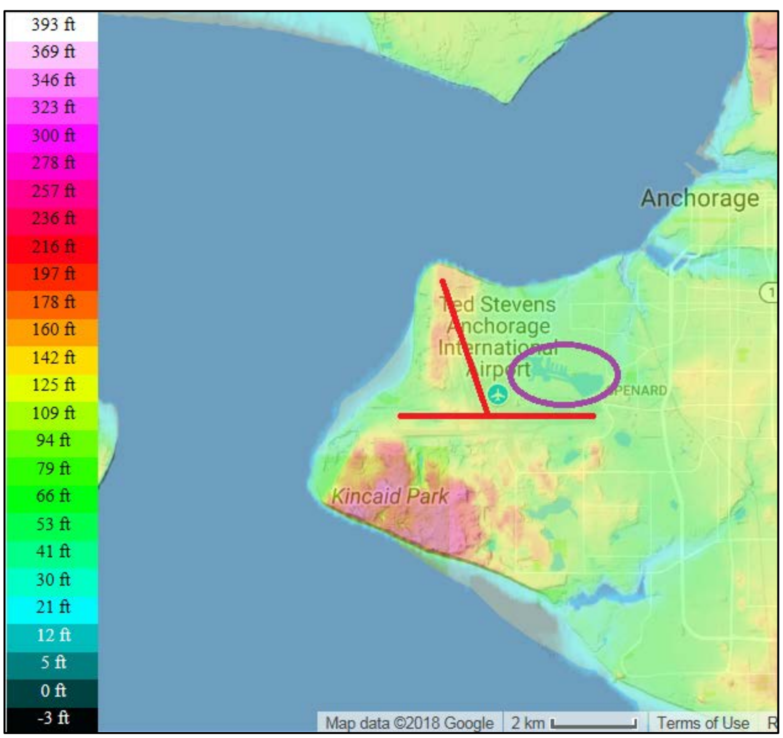


Figure 41. Elevation Changes in Areas near ANC

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1										100	50	50	50						
2							100	100	50	50	50	50	50	50					
3						100	100	100	100	50	50	0	0	0	0	50			
4				50	50	50	50	100	100	100	50	0			0	0	0	50	50
5	0	0	0	0	0	0	50	50	50		50	0			0	0	0	0	0
6	0	0	0	0	0	0	0								0	0	0	0	0
7		0	0	0	0	0	0	100	100	100	100	0	0	0	0	0	0	0	0
8		100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	0	100

Figure 42. Pre-approved Altitude for ANC/LHD, Effective August 14, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1						0	0	0	0	0	0	0	0						
2				150	0	0	0	0	0	0	0	0	0	0					
3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
4	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0
5	0	0	0	0	0	0	0	0	0		0	0			0	0	0	0	0
6	0	0	0	0	0	0	0								0	0	50	50	50
7	0	0	0	50	50	0	0	0	0	0	0	0	0	0	0	0	0	50	50
8	50	0	0	150	250	150	150	0	250	150	0	0	0	0	0	50	50	50	50

Figure 43a. Worst-Case Risk Adjusted Altitude in ANC/LHD, PDARS A11 Dataset, June 1-July 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1						50	50	250	150	150	200	300	200						
2				150	0	0	50	400	50	150	200	200	300	200					
3		0	50	50	50	0	150	350	250	150	150	0	0	0	0	200			
4	0	50	50	50	50	50	50	150	0	0	0	0			0	100	300	300	200
5	0	50	50	50	50	50	50	50	0		0	0			0	0	200	300	300
6	400	400	400	350	250	50	0								50	150	250	350	350
7	0	400	400	400	350	250	250	250	0	0	0	0	0	50	250	250	250	150	150
8	50	300	350	400	400	400	250	150	350	350	0	0	50	150	250	350	400	350	150

Figure 43b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in ANC/LHD, PDARS A11 Dataset, June 1-July 31, 2016

4.5 SJC Class C

San Jose International Airport (SJC) averaged 449 operations per day over a 12-month period ending on February 28, 2017[27]; with 63% commercial, 15% air taxi, 21% general aviation, and <1% military traffic mix. SJC is one of 2 Class C airports participating in LAANC initial implementation. California has 3,687 Part 107 Remote Pilot Certifications per 100,000 people, with 4.01 non-hobbyist drones per operator.

Figure 44 shows the UASFM for SJC Class C, and Figure 45 shows topographic data for areas near the airport. The airport occupies 5 grid volumes – G5-H6, I6. Airport elevation used to estimate AGL altitude is 62 ft. Highest elevation in the airspace is approximately 200 ft northeast and southwest of the airport. Lowest elevation is approximately 0 ft near San Francisco Bay. Based on the elevation change in the airspace, maximum error associated with estimating AGL altitude is 138 ft for all grid volumes (compared to 200-ft safety buffer). Average grid volume width (east-to-west dimension) is 0.80 NM.

Figure 46 shows pre-approved altitude for ANC/LHD. Pre-approved altitude is 0, 50, or 100 ft for all grid volumes. Figure 47a-b show worst-case and 5th percentile Risk Adjusted Altitudes using 2 months of PDARS Northern California TRACON (NCT) data. The 5th percentile result agrees well with the pre-approved altitude.

[27] Airnav.com – Anchorage International Airport: http://www.airnav.com/airport/PANC

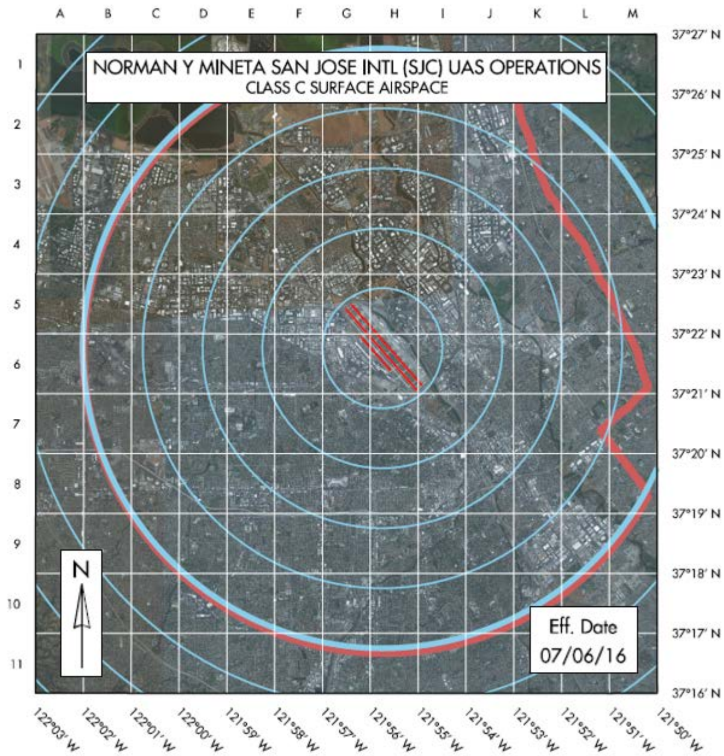


Figure 44. UASFM for San Jose Class C (SJC)

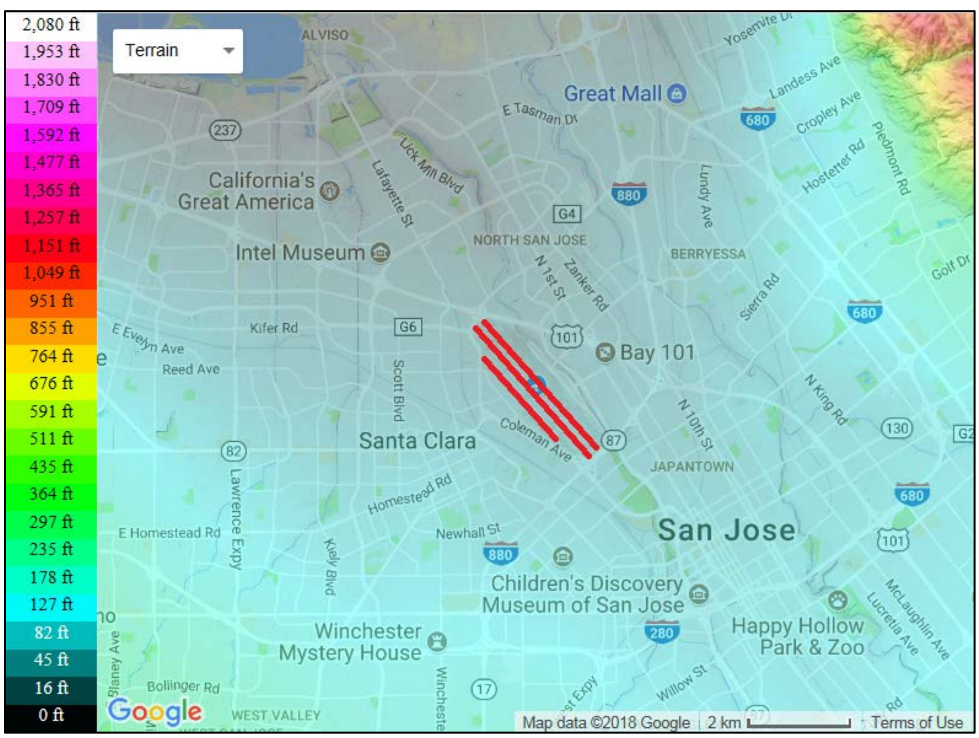


Figure 45. Elevation Changes in Areas near SJC

	A	B	C	D	E	F	G	H	I	J	K	L	M
1					400	400	400	400	400	400			
2			400	300	300	300	400	400	400	400	400		
3		400	300	0	0	0	200	300	400	400	400		
4		400	300	200	0	0	0	0	200	300	400	400	
5		400	400	300	0	0			0	200	300	400	400
6		400	400	400	300	200				0	200	400	0
7		400	400	400	400	300	200	0	0	0	0	200	0
8		400	400	400	400	400	300	200	0	0	0	0	0
9			400	400	400	400	400	300	200	0	0	0	0
10				400	400	400	400	400	300	300	300	400	
11						400	400	400	400	400			

Figure 46. Pre-approved Altitude for SJC, Effective August 14, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M
1					100	100	100	100	0	200			
2			300	300	100	0	0	0	0	0	200		
3		200	100	100	0	0	0	0	0	0	100		
4		0	0	0	0	0	0	0	0	0	0	100	
5		0	300	100	0	0			0	50	0	100	300
6		100	200	100	100	0				0	0	0	0
7		400	200	0	100	150	0	0	0	0	100	0	100
8		400	400	300	100	0	0	0	0	100	0	0	0
9			400	300	400	200	0	0	100	100	200	0	200
10				300	400	300	200	100	300	200	300	200	
11						400	300	300	400	400			

Figure 47a. Worst-Case Risk Adjusted Altitude in SJC, PDARS NCT Dataset, June 1-July 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M
1					100	200	300	300	200	300			
2			300	400	100	200	300	300	300	300	200		
3		300	300	300	300	300	200	400	300	0	200		
4		200	300	300	300	100	0	0	0	300	200	350	
5		300	400	400	200	0			0	50	400	200	300
6		400	400	400	300	0				0	400	200	0
7		400	400	400	300	150	0	0	0	300	300	400	300
8		400	400	400	200	400	0	0	300	400	400	300	400
9			400	400	400	300	0	200	400	300	400	200	400
10				300	400	400	400	400	400	400	400	250	
11						400	400	400	400	400			

Figure 47b. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in SJC, PDARS NCT Dataset, June 1-July 31, 2016

4.6 Other Areas of Interest

Accounting for areas of interest will be critical to continual improvement of the model. Figure 48-50 show 5th percentile results from 3 Class B airports where frequent low-altitude manned aircraft traffic was found. Figure 48 shows Floyd Bennett Field southwest of John F. Kennedy International Airport, grid volumes F18-H20. The NYPD dispatches helicopters from the airfield[28]. Figure 49 shows Lake Conway South and North Seaplane Bases[29] northwest of Orlando, grid volume D2; and low-altitude helicopter training areas over columns K-M indicated on sectional charts[30]. Figure 50 shows various tourist, navy, and coast guard helicopter routes over the Sunset Cliffs scenic area west of San Diego. These areas have been reflected in manned aircraft often enough to be considered in developing UASFM pre-approved altitudes. The FAA maintains a list of balloon ports, glider ports, helipads, seaplane bases, and ultralight aircraft operating areas – which may serve as helpful data to include in the UASFM development process[31].

[28] Airnav.com – NYPD Air Operations Heliport (Floyd Bennett Field): http://www.airnav.com/airport/ny22
[29] Airnav.com – Lake Conway South Seaplane Base: http://www.airnav.com/airport/0FL5
[30] Retrieved from: http://vfrmap.com/?type=vfrc&lat=28.459&lon=-81.350&zoom=10
[31] Federal Aviation Administration, Airport Safety, Airport Data & Contact Information database: https://www.faa.gov/airports/airport_safety/airportdata_5010/menu/

	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
9	350	400	250	0	50	350	50	250	400	150	150	250	250	350	250	350						
10	250	250	350	250	150	400	400	400	400	400	150	250	350	350	250	250	150	150				
11	250	400	400	50	250	400	400	350	250	350	250	250	150	150	150	150	150	150	150			
12	250	250	150	250	250	250	250	250	150	150	150	150	150	50	250	150	200	150	150	150		
13	150	250	250	250	250	250	150	150	150	150	150	250	400	400	400	150	250	150	150	150	200	
14	250	250	250	250	150	250	350	250	150	0	0	0	250	400	150	150	250	150	150	150	250	
15	150	150	150	150	150	400	350	150	0				0	150	150	50	150	150	250	150	150	150
16	150	150	50	50	400	150	0	50					0	250	250	50	150	50	150	150	150	250
17	150	150	50	50	150	0	50	50	0				150	350	400	250	150	150	50	50	0	250
18	150	150	50	50	50	50	50	0	0	0	0	0	400	400	400	400	150	50				
19	50	50	50	0	0	0	0	0	150	350	0	0	50	0	0	150	150					
20	350	0	0	50	0	0	50	0	50	400	400	400	400	0	0	0	0					
21		0	0	0	0	0																

Figure 48. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in JFK, PDARS N90 Dataset, June 1-July 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				350	150	400	300	400	400	350			
2			200	0	0	400	200	400	400	300	300		
3		250	250	100	300	150	300	400	250	300	250	300	
4	200	250	350	250	0	0	100	0	0	350	250	200	
5	250	250	250	250	0					150	200	250	300
6	250	250	300	300	0					0	250	250	250
7	300	250	250	250	0					0	300	0	0
8		300	200	300	250	150	150	250	200	150	200	350	
9		200	250	200	100	400	400	250	400	100	250	400	
10			300	300	200	400	300	400	400	250	250		
11					400	0	0	250	350				

Figure 49. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MCO, PDARS MCO+ASDEX Dataset, June 1-July 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
3	0	0	0	0	0	0	250													
4		0	0	0	0	0	150	150	250	400	400	400	400	400	400					
5		0	0	0	0	0	150	0	0	0	0	100	400	400	400	400	400	400	400	400
6		0	0	0	0	0	350	0			0	0	400	400	400	400	400	400	400	
7		0	0	0	0	0	350	0	0			0	400	400	400	400	400	400	400	
8										0	0	0	250	400	400	350	400	400	400	
9												150	250	400	400	350	350	400		
10														350	350	400	350			
11																350				

Figure 50. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in SAN, PDARS SCT Dataset, June 1-July 31, 2016

5. Model Improvement

Several ways to improve the model have been noted throughout the report, and are summarized in this section.

5.1 Estimation of AGL Altitude

AGL altitude was estimated by subtracting airport elevation from terrain elevation at the latitude-longitude location of all manned aircraft track data in the airspace of interest. Estimation error is equal to the difference between airport elevation and terrain elevation at each data point. Among Class B airspaces, the best-case error is approximately 20 ft in flat airspaces such as MIA; and the worst-case error may be larger than the 200-ft safety buffer, in mountainous areas (such as South Mountain Park near Phoenix, AZ) or over rivers (such as the Ohio River near Cincinnati, OH) – affecting a small number of grid volumes in certain airspaces. Data describing average terrain elevation in each grid volume, or more precise datasets (such as 1 second-by-1 second terrain data) will be a key input to the model.

5.2 Linear Extrapolation of Track Data

Linear extrapolation of initial departures and final approaches can be improved. Recommendations include the following, however the list is not exhaustive: 1) improve justification for 2 NM (distance from airport) as the threshold of extrapolation, 2) improve methods to determine average climb rate and speed, 3) extrapolate along airport runways instead of center, and 4) gain capability to extrapolate helicopter tracks maintaining altitude. Contribution of extrapolated data to the overall dataset should also be tracked for all airspaces, that contribution should not exceed a to-be-determined percentage threshold.

5.3 Definition of Risk Adjusted Altitude

Risk Adjusted Altitude is defined as "200 ft below routine operations." The 200-ft vertical safety buffer may change based on input data, methods and assumptions, and uncertainties therein. Current representations of routine operations are worst-case, and 5th percentile below 1,200 ft. The worst-case is considered appropriate for short analysis time periods (2 months was assumed to be a sufficient time period), however other definitions may be more suitable. Both the 5th percentile threshold and the 1,200-ft altitude ceiling for analysis may be revised to meet any future needs of the FAA, as well.

5.4 PDARS Coverage

PDARS data are available at 28 Tower+ASDEX sites, 28 TRACONs or co-located tower and TRACONs, and 20 ARTCCs. Tower+ASDEX datasets provide the most coverage at low altitudes, over a small area close to the airport; while TRACON datasets provide sufficient coverage at low altitudes, over larger areas. Table 12 shows 35 of 37 Class B UASFM airspaces may be analyzed to a high degree of confidence with Tower+ASDEX or TRACON datasets. Kansas City (MCI) and New Orleans (MSY) have no corresponding Tower+ASDEX or TRACON dataset. ARTCC datasets may be applied, though low-altitude coverage may be insufficient.

Table 12. Recommended PDARS Datasets for Class B UASFM Airspaces

Class B Airspace	PDARS Dataset
ADW	PCT
ATL	ATL+ASDEX
BOS	BOS+ASDEX
BWI	PCT
CLE	CLE
CLT	CLT+ASDEX
CVG	CVG
DCA	DCA+ASDEX
DEN	DEN+ASDEX
DFW	DFW+ASDEX
DTW	DTW+ASDEX
EWR	EWR+ASDEX
HNL	HNL+ASDEX
HOU	I90
IAD	IAD+ASDEX
IAH	IAH+ASDEX
JFK	JFK+ASDEX
LAS	LAS+ASDEX
LAX	LAX+ASDEX
LGA	LGA+ASDEX
MCI	ZKC*
MCO	MCO+ASDEX
MEM	M03
MIA	MIA+ASDEX
MSP	MSP+ASDEX
MSY	ZHU*
NKX	SCT
ORD	ORD+ASDEX
PHL	PHL+ASDEX
PHX	PHX+ASDEX
PIT	PIT
SAN	SAN+ASDEX
SEA	SEA+ASDEX
SFO	SFO+ASDEX
SLC	SLC+ASDEX
STL	STL+ASDEX
TPA	TPA

Table 13 shows that about 50% of all UASFM airspaces may be analyzed with Tower+ASDEX and TRACON datasets. The full list of Class B/C/D/E UASFM airspaces are available online (see footnote). In all, PDARS data have provided a helpful starting point and baseline for this analysis – though future analyses may incorporate other datasets or change to a different dataset altogether.

Table 13. Estimated Coverage of PDARS Datasets for UASFM Airspaces

Airspace Class	Number of Airports[32]	Airspaces Covered by Tower+ASDEX and TRACON Datasets	Airspaces Covered by Tower+ASDEX, TRACON, and ARTCC Datasets
B	37	35	35
C	61	30	40
D	153	102	124
E	237	54	64
Total	488	221 (45%)	263 (54%)

5.5 Airport Operations and FAA Sites of Interest

Airport operations, such as approach paths, glide slopes, and other special areas indicated on sectional charts may be included in the UASFM development process. FAA sites of interest – balloon ports, glider ports, helipads, seaplane bases, and ultralight aircraft operating areas – may be included as well.

[32] UASFM list, updated August 17, 2017: https://www.faa.gov/uas/request_waiver/uas_facility_maps/

6. Conclusions

This report describes a quantitative model to support the Federal Aviation Administration (FAA) to integrate small Unmanned Aircraft Systems (sUAS) into the National Airspace System (NAS). Input data, methods and assumptions, sources of error, sample results, and recommendations to improve the model are presented.

Current research has shown human pilots are unable to consistently see-and-avoid sUAS; because of this, the model limits sUAS operations to altitudes below manned aircraft traffic patterns, in general. More specifically to the model, a safe vertical separation of 200 ft is assumed based on uncertainty in input data and terrain elevation changes within the airspace. Elevation changes, in particular, present a challenge to developing accurate quantitative models.

Due to the above assumptions, results are generally conservative in areas where much PDARS coverage is available at low altitudes (such as in airspaces covered by Tower+ASDEX and TRACON datasets). Low-altitude manned aircraft traffic over medical helipads, police helipads, seaplane bases, etc. have been found, further reinforcing a need for quantitative analysis using real-world manned aircraft track data. The model also provides a consistent analysis method for widely differing airspaces. In comparison, pre-approved altitudes based on qualitative assessments of the airspace show a wide range of risk tolerance site-to-site.

ATC and subject matter expert assessments, along with quantitative Risk Adjusted Altitudes, may be considered together in continual revisions of pre-approved altitudes. Future work may improve the model and continue to support sUAS integration into the NAS.

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Appendix A: List of PDARS Data Sources

Appendix A contains a list of PDARS datasets organized by source – Tower+ASDEX, co-located Tower and TRACON, (standalone) TRACON, and ARTCC.

Table A-1. PDARS Data Sources, Tower+ASDEX

PDARS Source Abbreviation (Tower+ASDEX)	Airport / NAS Facility
ATL+ASDEX	Atlanta Hartsfield-Jackson International Airport (Class B)
BOS+ASDEX	Boston Logan International Airport (Class B)
CLT+ASDEX	Charlotte Douglas International Airport (Class B)
DCA+ASDEX	Washington-Reagan National Airport (Class B)
DEN+ASDEX	Denver International Airport (Class B)
DFW+ASDEX	Dallas/Fort Worth International Airport (Class B)
DTW+ASDEX	Detroit Metropolitan/Wayne County International Airport (Class B)
EWR+ASDEX	Newark Liberty International Airport (Class B)
FLL+ASDEX	Fort Lauderdale/Hollywood International Airport (Class C)
HNL+ASDEX	Honolulu International Airport (Class B)
IAD+ASDEX	Washington-Dulles International Airport (Class B)
IAH+ASDEX	Houston-Bush Intercontinental Airport (Class B)
JFK+ASDEX	New York-John F. Kennedy International Airport (Class B)
LAS+ASDEX	Las Vegas McCarran International Airport (Class B)
LAX+ASDEX	Las Angeles International Airport (Class B)
LGA+ASDEX	New York-LaGuardia International Airport (Class B)
MCO+ASDEX	Orlando International Airport (Class B)
MDW+ASDEX	Chicago-Midway International Airport (Class C)
MIA+ASDEX	Miami International Airport (Class B)
MSP+ASDEX	Minneapolis/St. Paul International Airport (Class B)
ORD+ASDEX	Chicago-O'Hare International Airport (Class B)
PHL+ASDEX	Philadelphia International Airport (Class B)
PHX+ASDEX	Phoenix Sky Harbor International Airport (Class B)
SAN+ASDEX	San Diego International Airport (Class B)
SEA+ASDEX	Seattle/Tacoma International Airport (Class B)
SFO+ASDEX	San Francisco International Airport (Class B)
SLC+ASDEX	Salt Lake City International Airport (Class B)
STL+ASDEX	St. Louis Lambert International Airport (Class B)

Table A-2. PDARS Data Sources, Co-located Tower and TRACON

PDARS Source Abbreviation (Co-located Tower and TRACON)	Airport / NAS Facility
CLE	Cleveland Tower and TRACON
CLT	Charlotte Tower and TRACON
CVG	Cincinnati Tower and TRACON
MIA	Miami Tower and TRACON
PHL	Philadelphia Tower and TRACON
PIT	Pittsburgh Tower and TRACON
TPA	Tampa Tower and TRACON

Table A-3. PDARS Data Sources, TRACON

PDARS Source Abbreviation (TRACON)	Airport / NAS Facility
A11	Anchorage TRACON, Anchorage, AK
A80	Atlanta TRACON, Peachtree City, GA
A90	Boston TRACON, Merrimack, NH
C90	Chicago TRACON, Elgin, IL
D01	Denver TRACON, Denver, CO
D10	Dallas-Fort Worth TRACON, Dallas-Fort Worth, TX
D21	Detroit TRACON, Detroit, MI
F11	Central Florida TRACON, Orlando, FL
I90	Houston TRACON, Houston, TX
L30	Las Vegas TRACON, Las Vegas, NV
M03	Memphis TRACON, Memphis, TN
M98	Minneapolis TRACON, Minneapolis, MN
N90	New York TRACON, Westbury, NY
NCT	Northern California TRACON, Mather, CA
P50	Phoenix TRACON, Phoenix, AZ
P80	Portland TRACON, Portland, OR
PCT	Potomac TRACON, Warrenton, VA
S46	Seattle TRACON, Burien, WA
S56	Salt Lake City TRACON, Salt Lake City, UT
SCT	Southern California TRACON, San Diego, CA
T75	St. Louis TRACON, St. Charles, MO

Table A-4. PDARS Data Sources, ARTCC

PDARS Source Abbreviation (ARTCC)	Airport / NAS Facility
ZAB	Albuquerque Center
ZAU	Chicago Center
ZBW	Boston Center
ZDC	Washington, D.C. Center
ZDV	Denver Center
ZFW	Dallas-Fort Worth Center
ZHU	Houston Center
ZID	Indianapolis Center
ZJX	Jacksonville Center
ZKC	Kansas City Center
ZLA	Los Angeles Center
ZLC	Salt Lake City Center
ZMA	Miami Center
ZME	Memphis Center
ZMP	Minneapolis Center
ZNY	New York Center
ZOA	Oakland Center
ZOB	Cleveland Center
ZSE	Seattle Center
ZTL	Atlanta Center

Appendix B: Elevation Change in Class B Airspaces affecting AGL Altitude Estimations

Appendix B contains topographic maps for all 37 Class B airports. 35 maps are included because 2 UASFM airspaces cover 2 airports each (ADW and DCA; JFK and LGA). Elevation change in the airspace (and further, error from estimating AGL altitude) may be quantified in part, by examining the lowest and highest elevations on the maps. Table B-1 contains a list of topographic maps. All airspaces are shown in the subsequent figures.

As mentioned in the main body of the report, AGL altitude may be estimated more accurately by correcting every PDARS altitude (in MSL) by terrain elevation at the corresponding latitude and longitude. Due to the accuracy and precision requirements for UASFM pre-approved altitudes to safely, efficiently, and securely integrate sUAS into the NAS, future analysis on this subject is highly recommended.

Table B-1. List of Topographic Maps in Appendix B

Topographic Map / Class B UASFM Airspace	Airport	Lowest Altitude Tier [ft]	Highest Altitude Tier [ft]	Difference [ft]
ADW/DCA	Andrews AFB and Washington-Reagan	0	462	462
ATL	Atlanta	675	1,177	502
BOS	Boston	0	370	370
BWI	Baltimore/Washington	0	416	416
CLE	Cleveland	564	1,279	715
CLT	Charlotte	525	1,240	715
CVG	Cincinnati/Northern Kentucky	423	961	538
DEN	Denver	4,757	6,095	1338
DFW	Dallas/Ft. Worth	390	784	394
DTW	Detroit Metropolitan/Wayne County	567	757	190
EWR	Newark	0	636	636
HNL	Honolulu	-15	2,742	2,757
HOU	Houston-Hobby	0	164	164
IAD	Washington-Dulles	49	941	892
IAH	Houston-Bush Intercontinental	3	167	164
JFK/LGA	New York-John F. Kennedy and New York-LaGuardia	0	360	360
LAS	Las Vegas	1,201	3,973	2,772
LAX	Los Angeles	0	489	489

Topographic Map / Class B UASFM Airspace	Airport	Lowest Altitude Tier [ft]	Highest Altitude Tier [ft]	Difference [ft]
MCI	Kansas City	708	1,079	371
MCO	Orlando	55	219	164
MEM	Memphis	183	419	236
MIA	Miami	0	164	164
MSP	Minneapolis/St. Paul	662	1,217	555
MSY	New Orleans	0	413	413
NKX	Miramar AFB	16	1,551	1,535
ORD	Chicago-O'Hare	574	846	272
PHL	Philadelphia	0	482	482
PHX	Phoenix	981	2,690	1,709
PIT	Pittsburgh	679	1,351	672
SAN	San Diego	0	692	692
SEA	Seattle/Tacoma	0	1,751	1,751
SFO	San Francisco	0	1,909	1,909
SLC	Salt Lake City	4,193	9,366	5,173
STL	St. Louis	390	731	341
TPA	Tampa	0	164	164

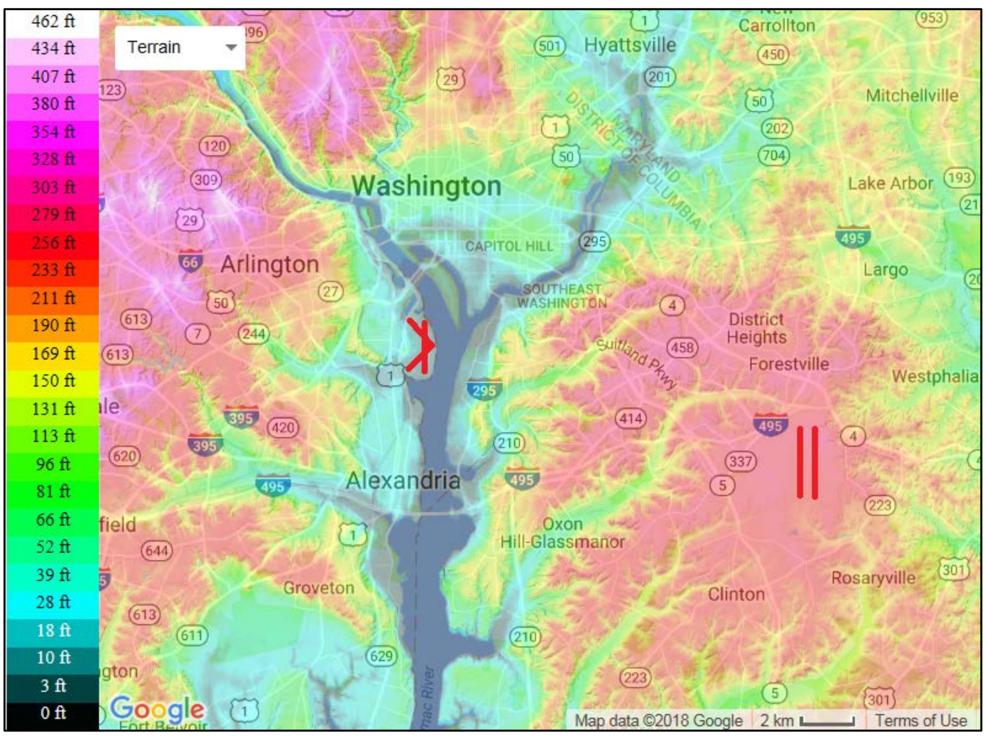

Figure B-1. Elevation Change in Areas near ADW and DCA

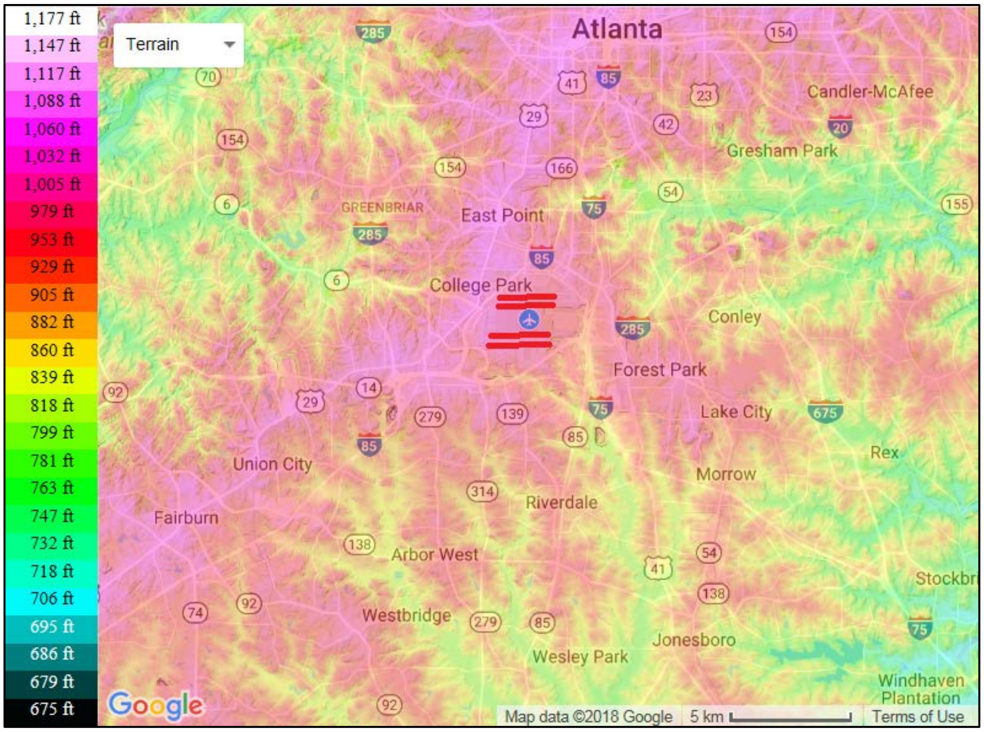

Figure B-2. Elevation Change in Areas near ATL

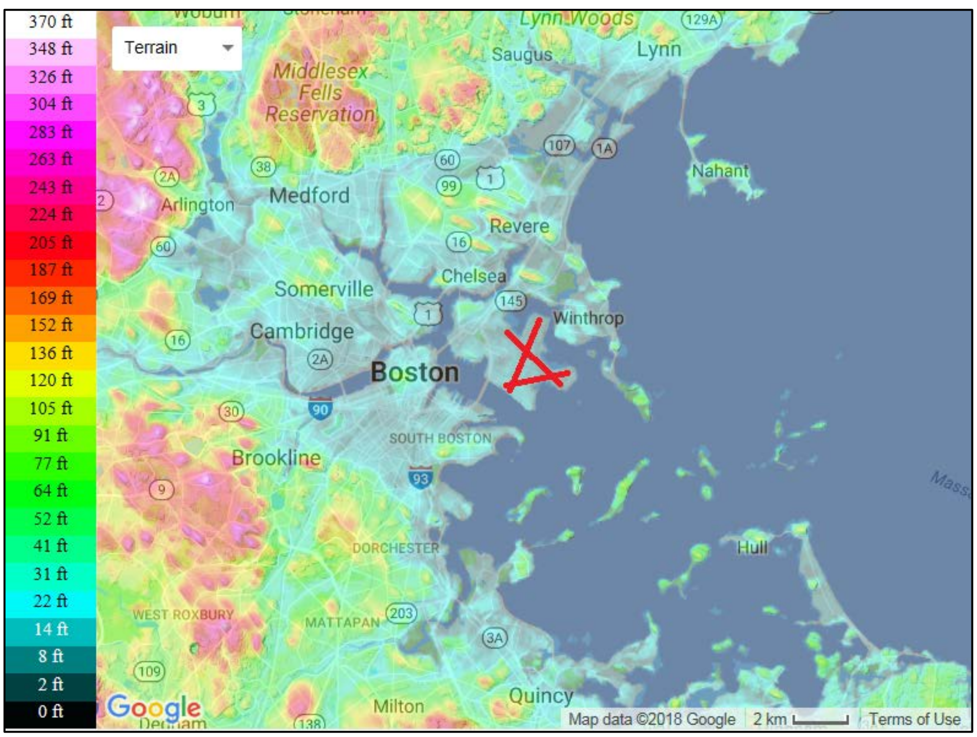

Figure B-3. Elevation Change in Areas near BOS

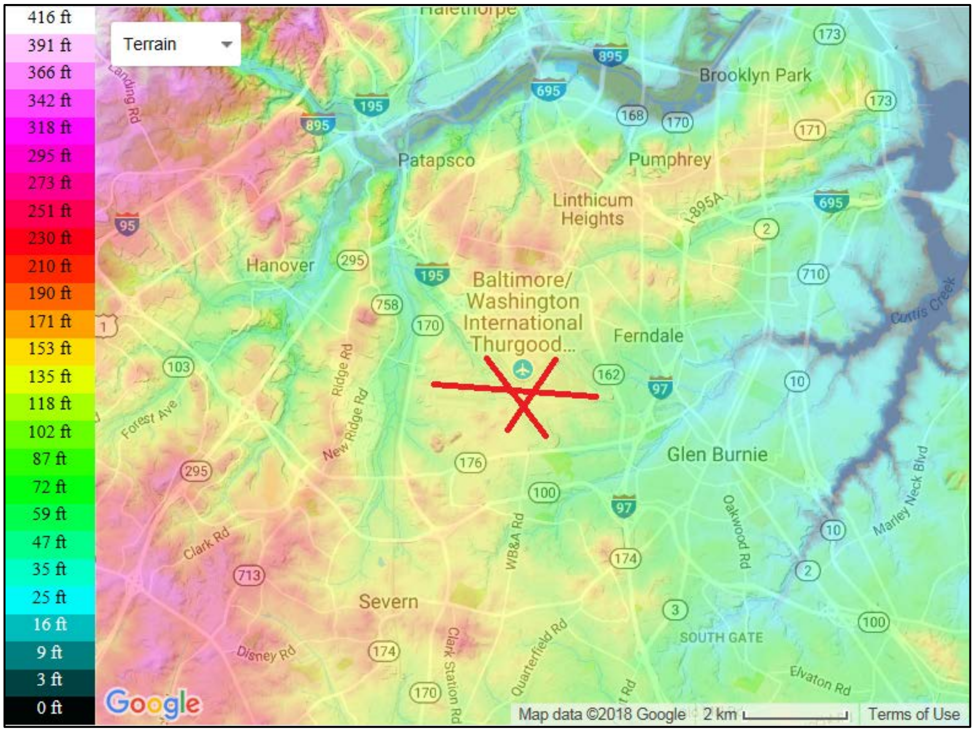

Figure B-4. Elevation Change in Areas near BWI

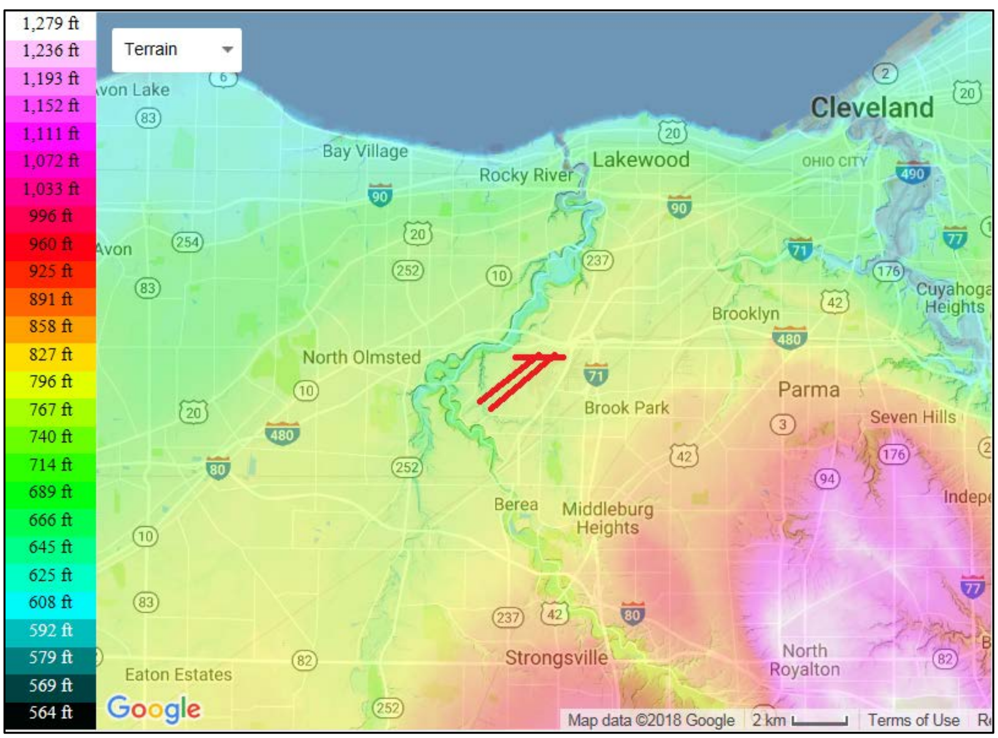

Figure B-5. Elevation Change in Areas near CLE

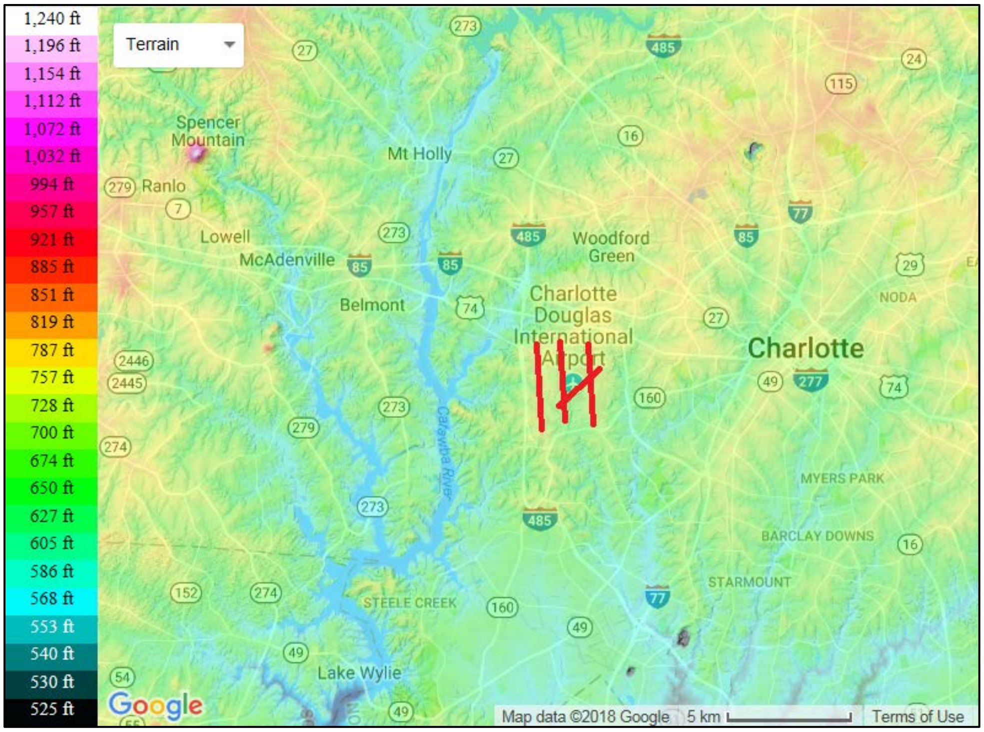

Figure B-6. Elevation Change in Areas near CLT

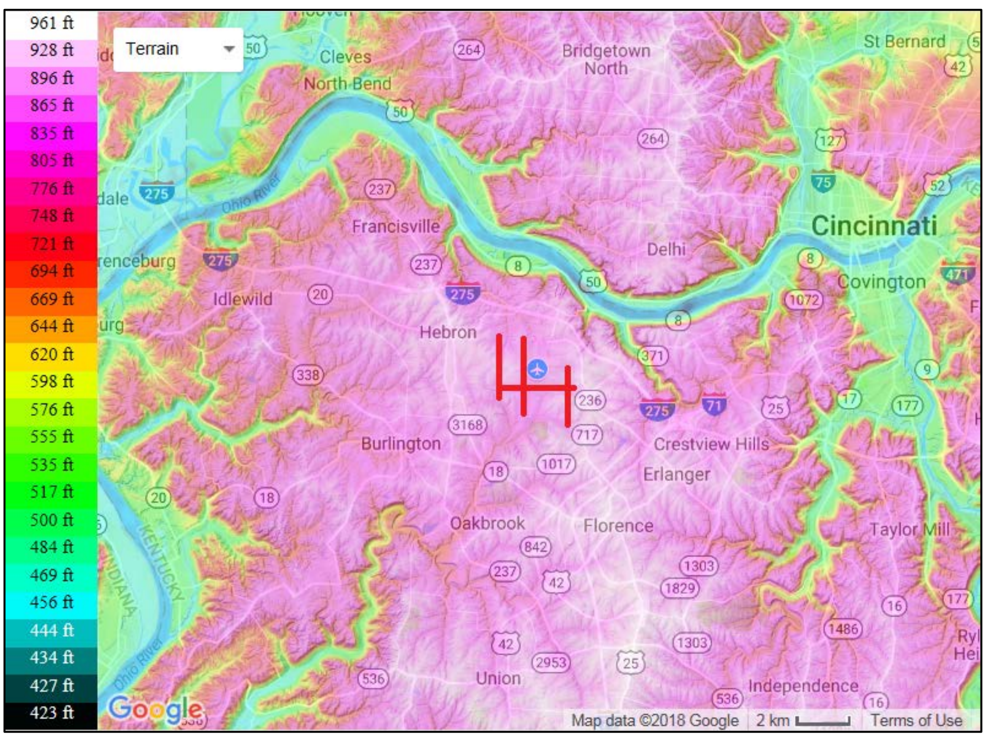

Figure B-7. Elevation Change in Areas near CVG

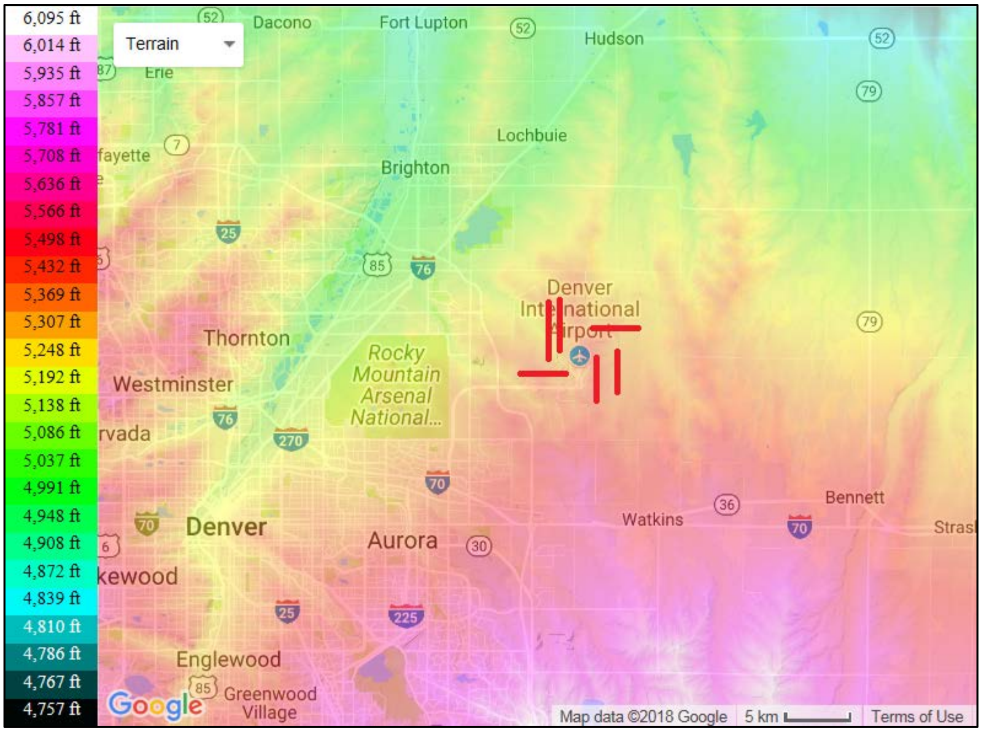

Figure B-8. Elevation Change in Areas near DEN

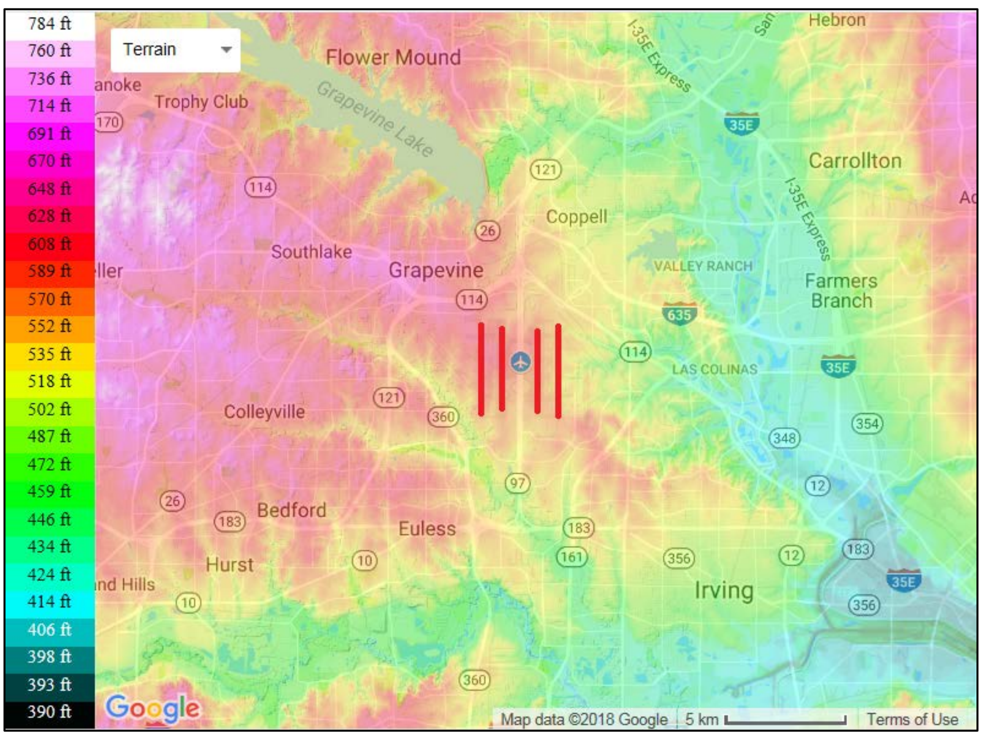

Figure B-9. Elevation Change in Areas near DFW

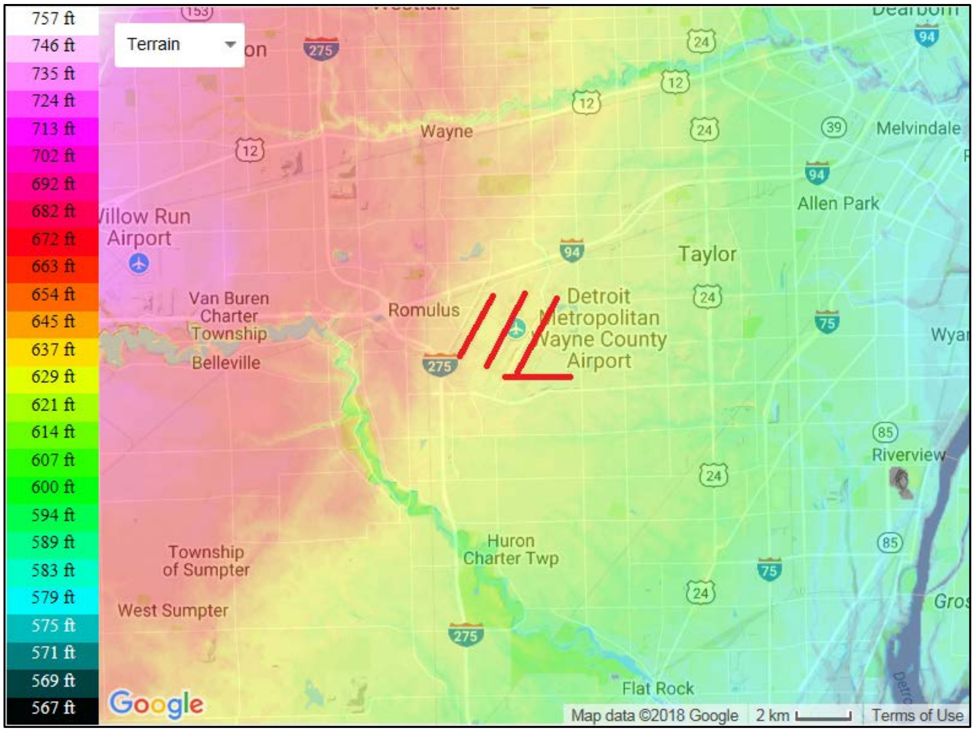

Figure B-10. Elevation Change in Areas near DTW

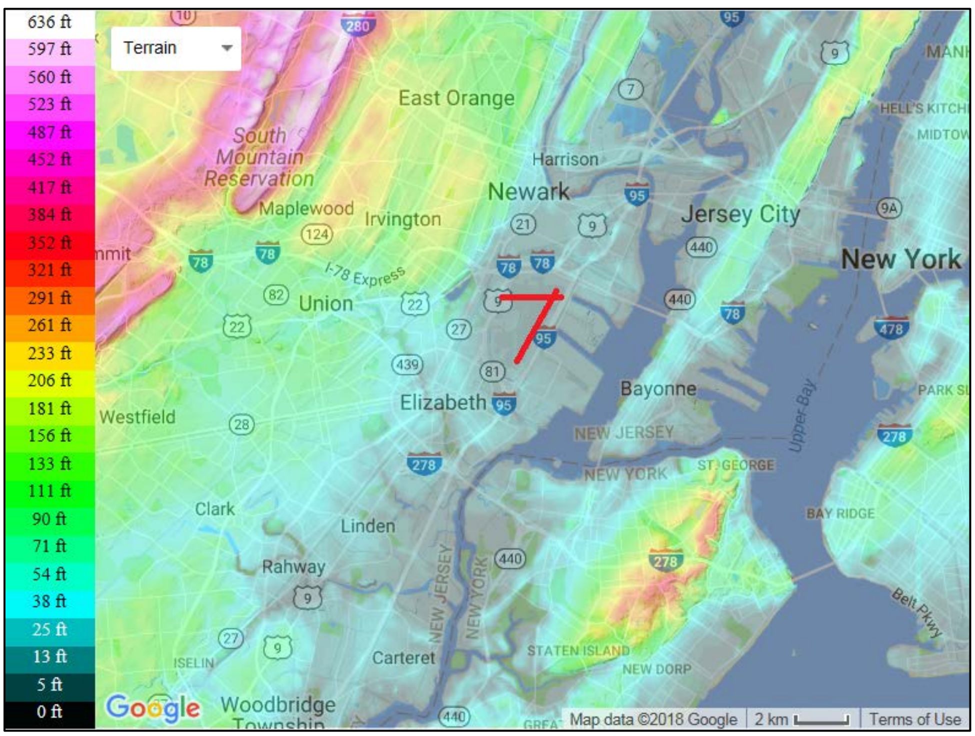

Figure B-11. Elevation Change in Areas near EWR

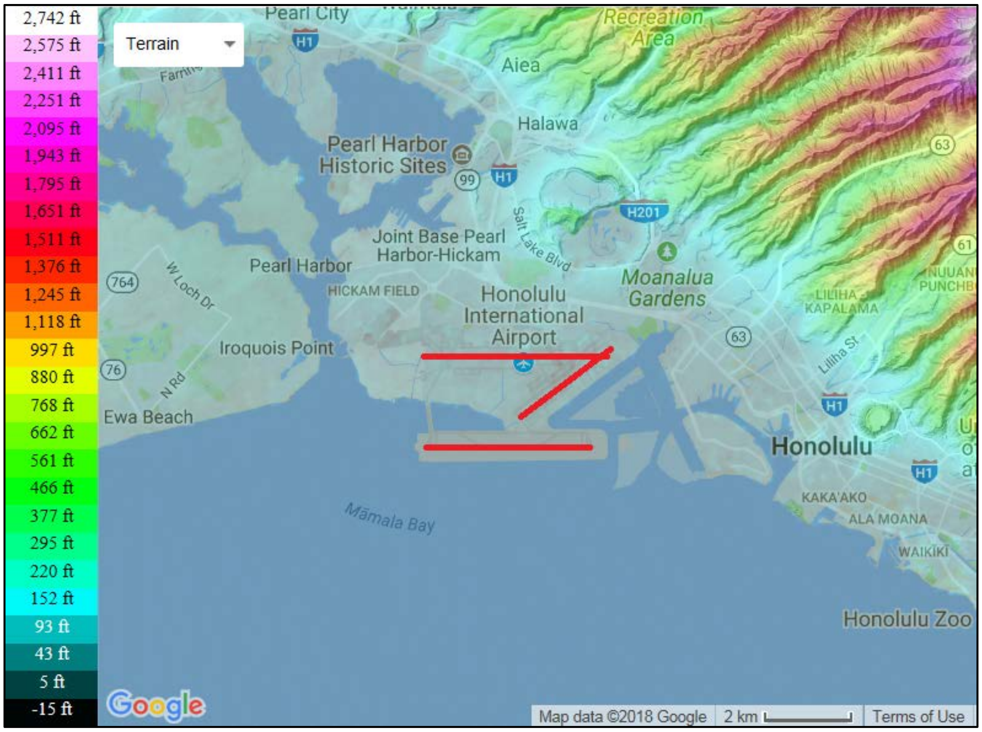

Figure B-12. Elevation Change in Areas near HNL

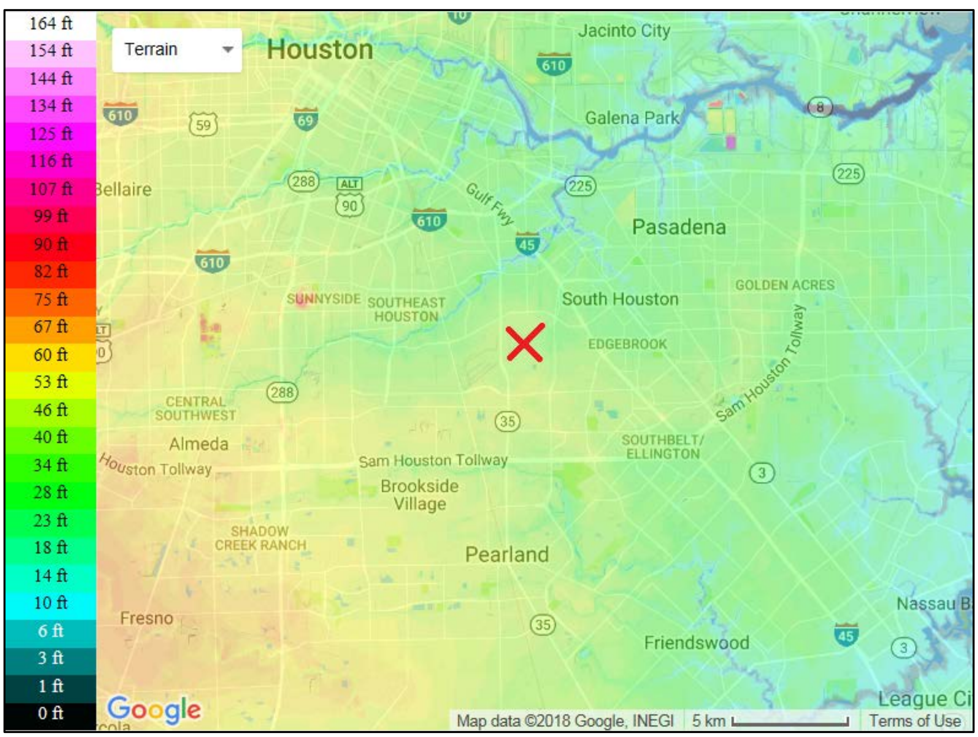

Figure B-13. Elevation Change in Areas near HOU

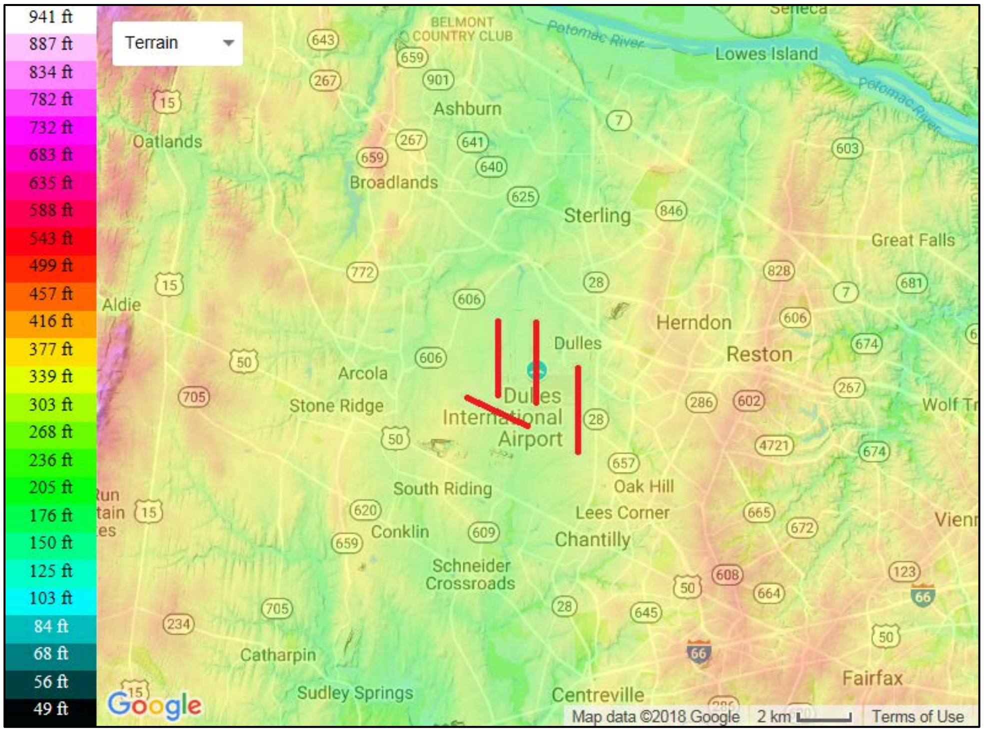

Figure B-14. Elevation Change in Areas near IAD

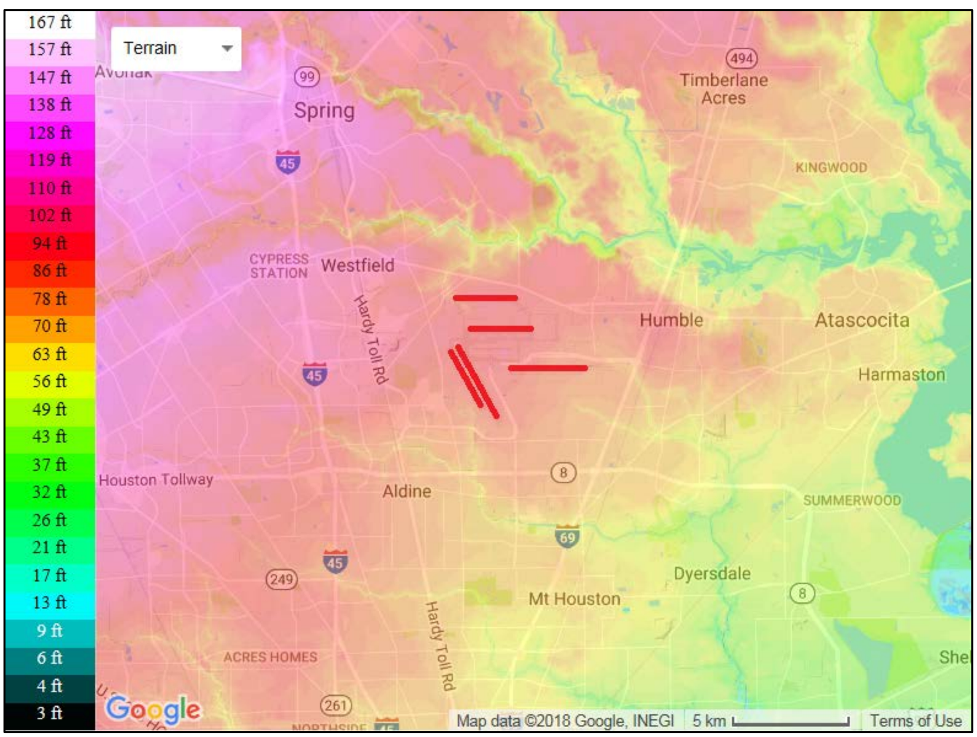

Figure B-15. Elevation Change in Areas near IAH

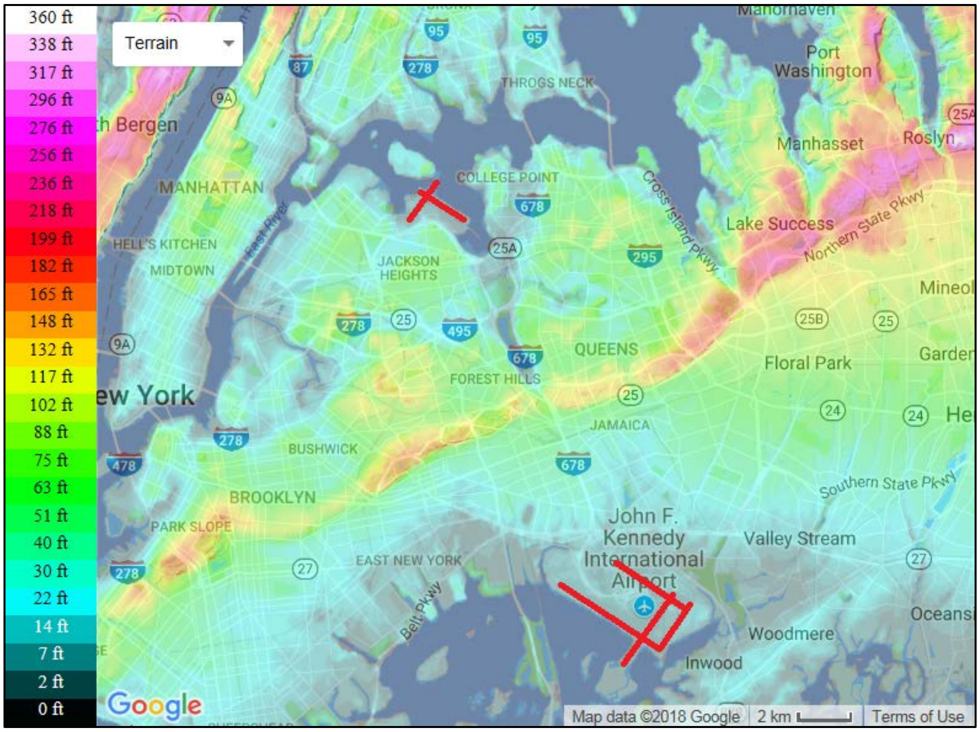

Figure B-16. Elevation Change in Areas near JFK and LGA

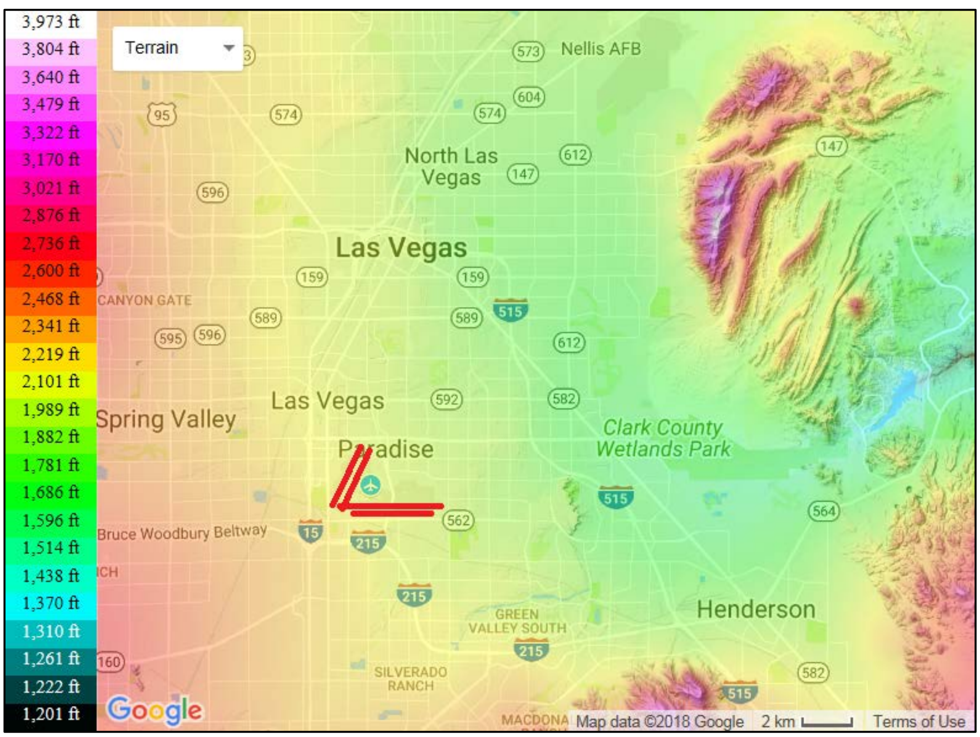

Figure B-17. Elevation Change in Areas near LAS

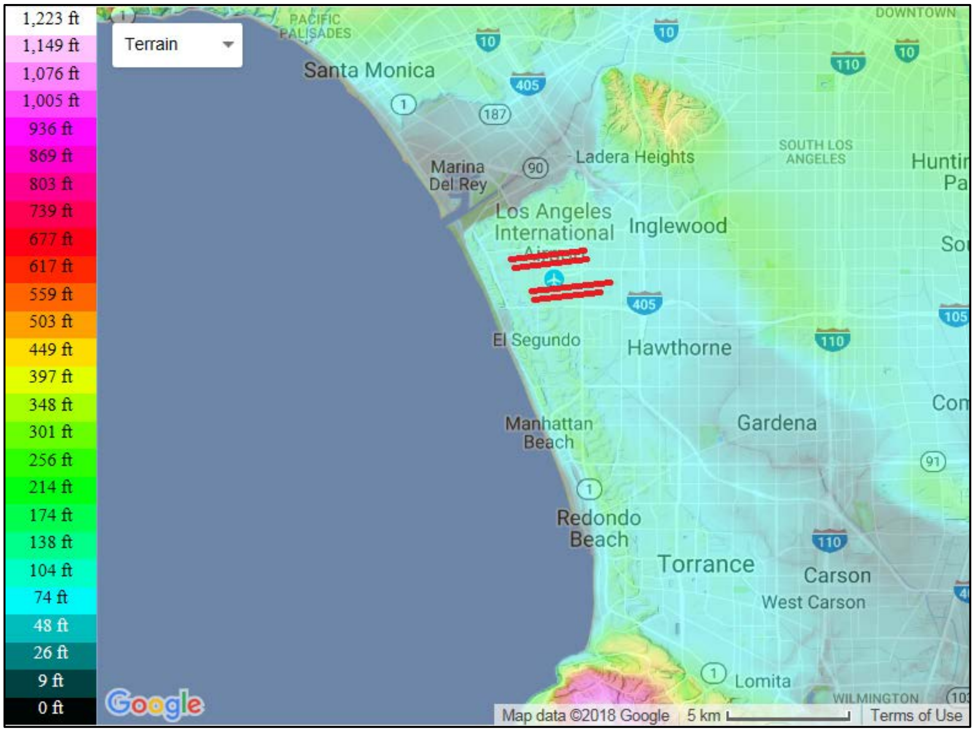

Figure B-18. Elevation Change in Areas near LAX

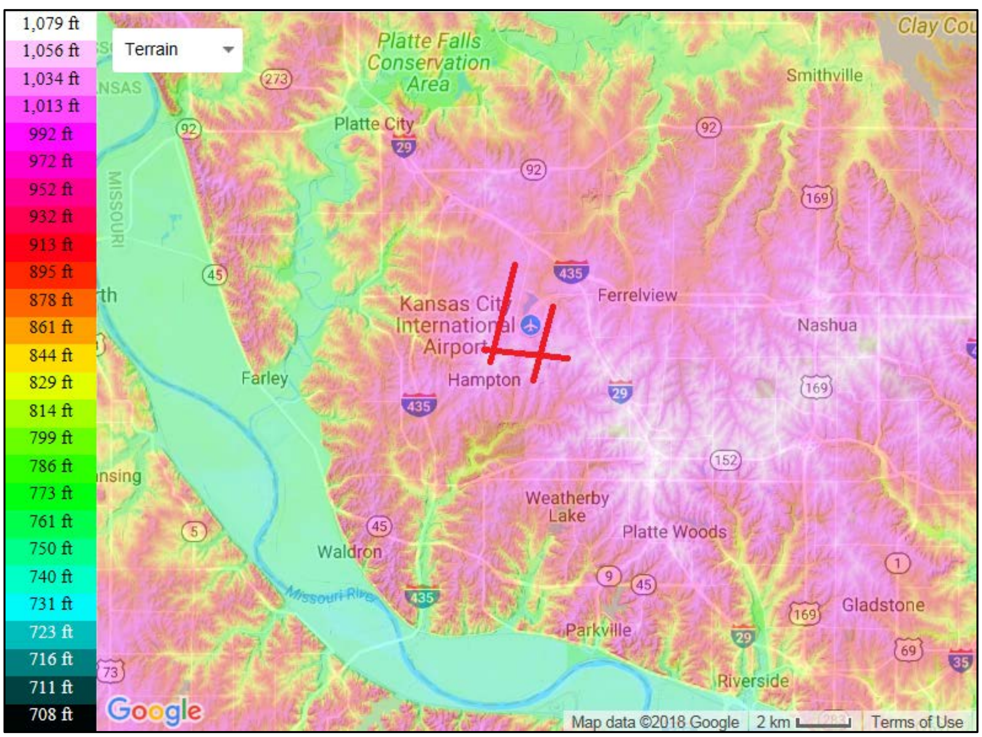

Figure B-19. Elevation Change in Areas near MCI

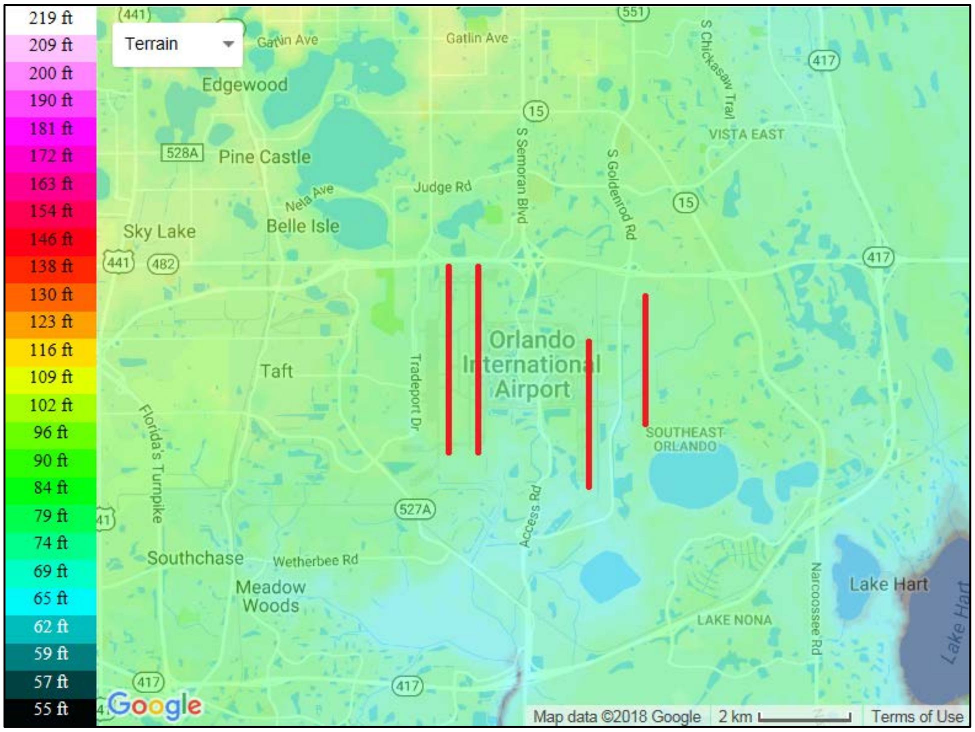

Figure B-20. Elevation Change in Areas near MCO

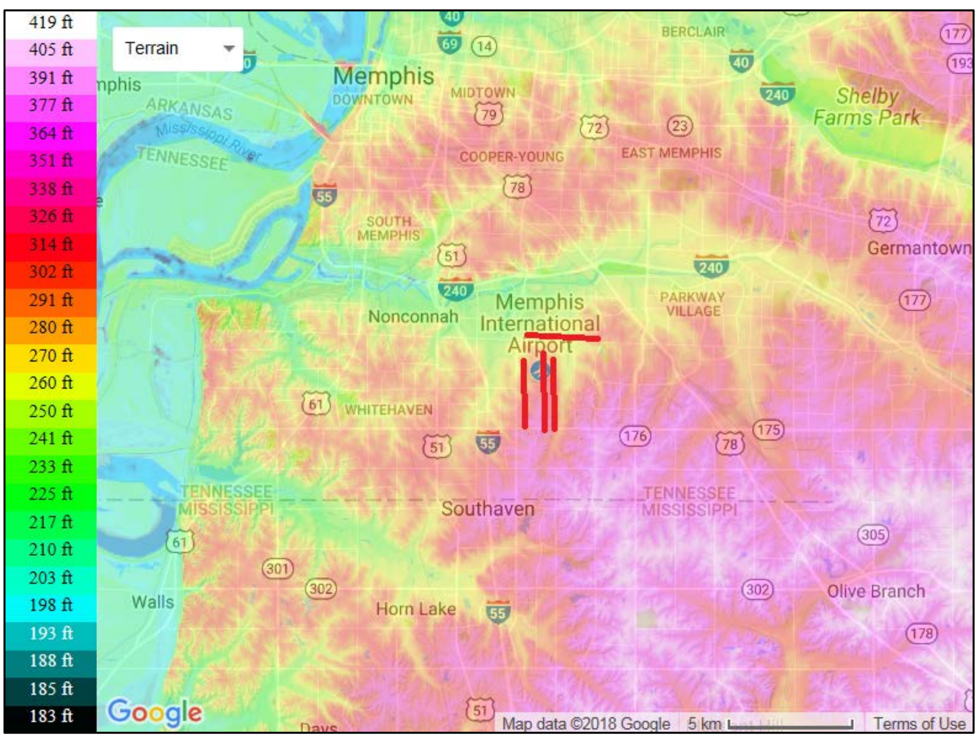

Figure B-21. Elevation Change in Areas near MEM

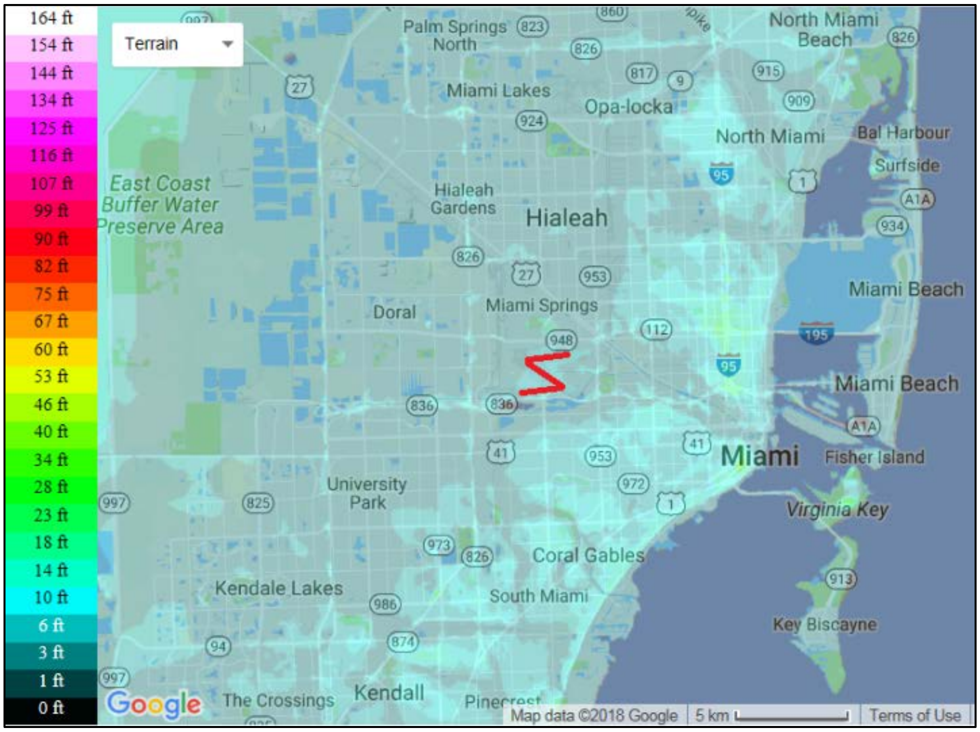

Figure B-22. Elevation Change in Areas near MIA

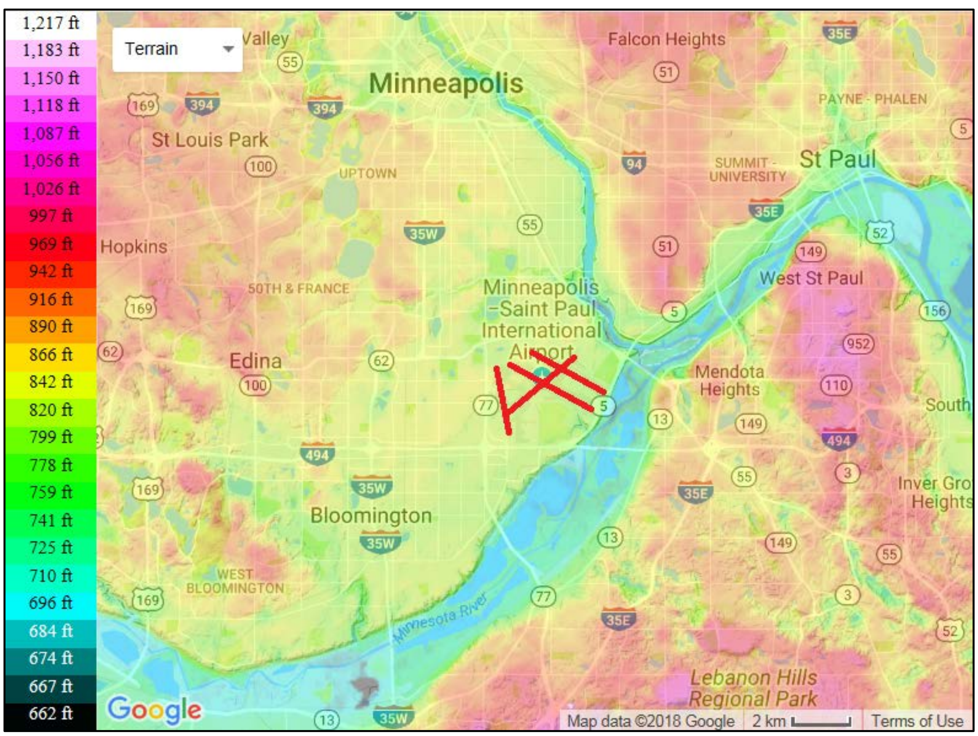

Figure B-23. Elevation Change in Areas near MSP

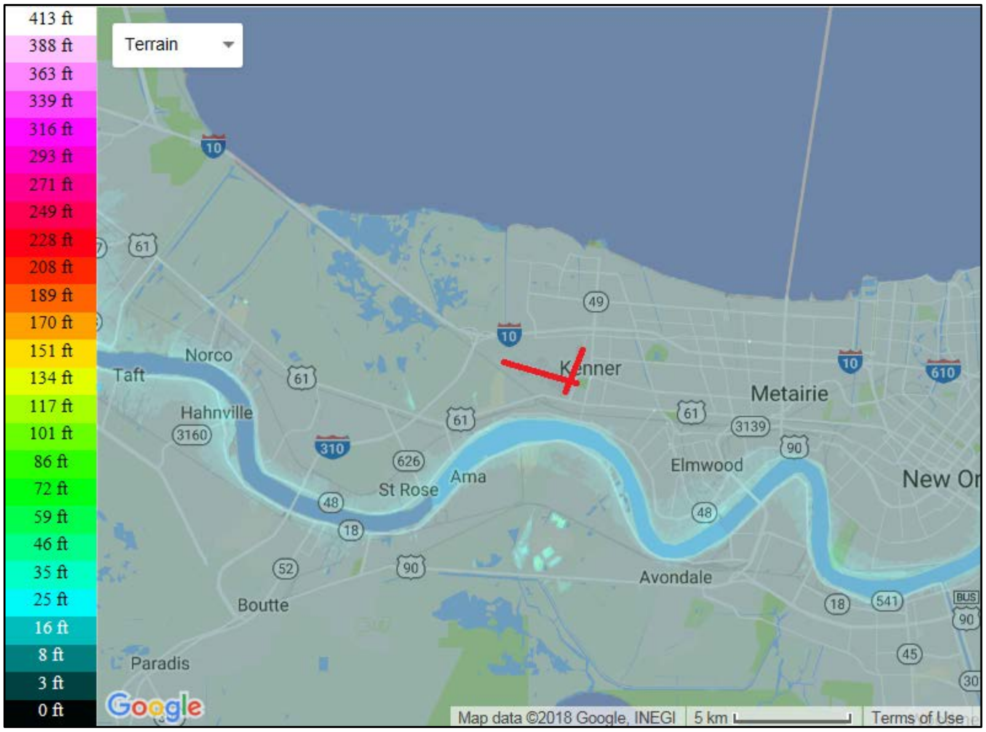

Figure B-24. Elevation Change in Areas near MSY

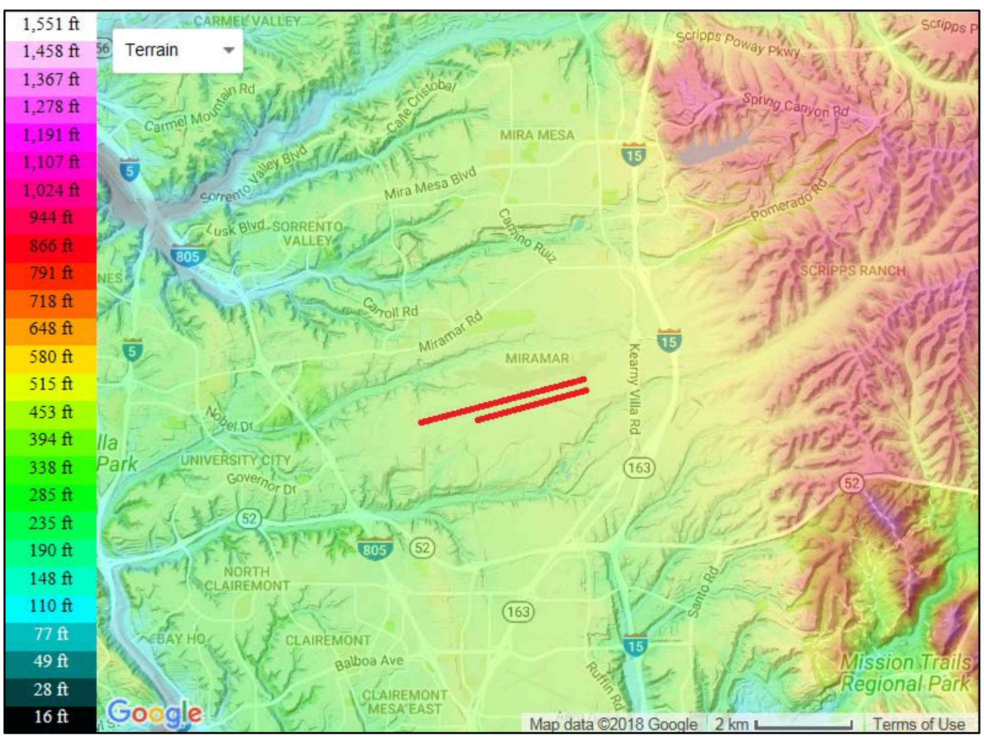

Figure B-25. Elevation Change in Areas near NKX

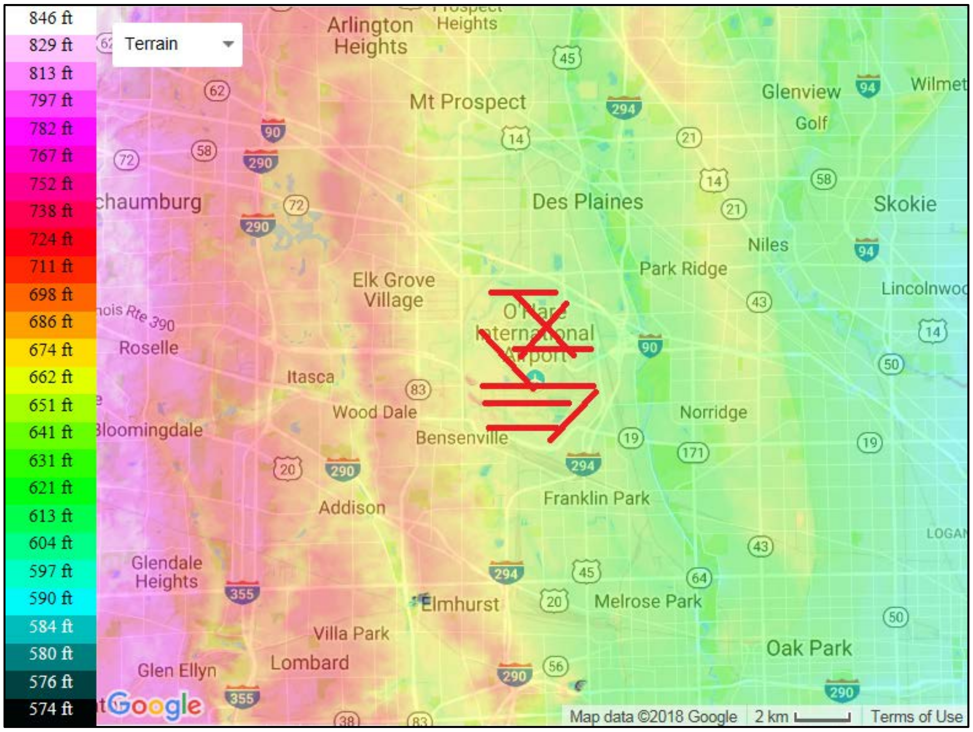

Figure B-26. Elevation Change in Areas near ORD

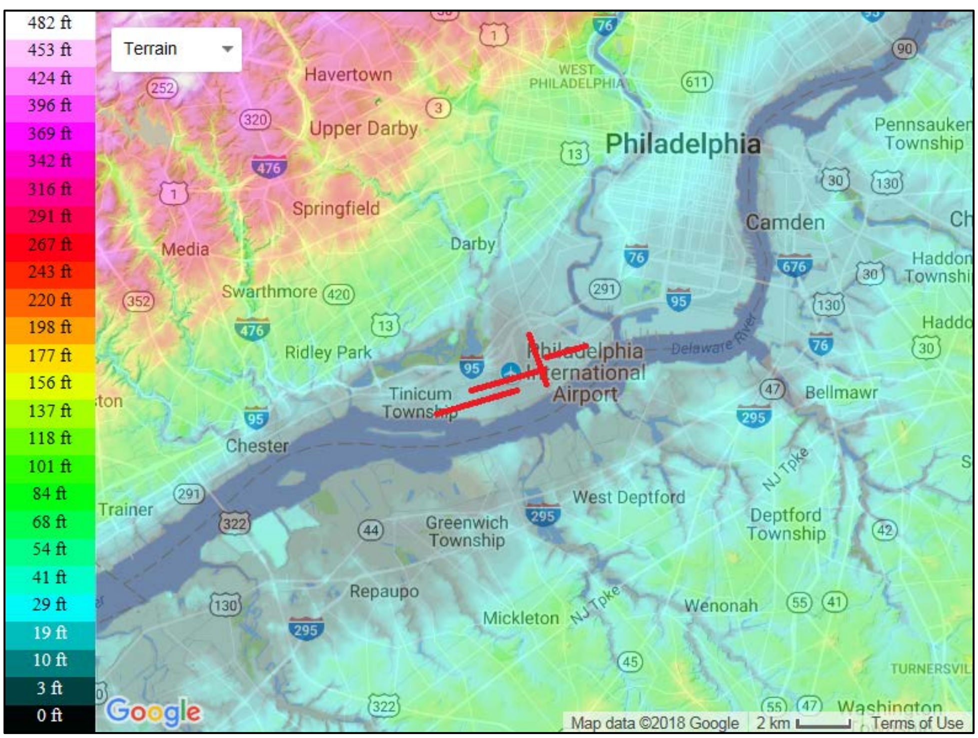

Figure B-27. Elevation Change in Areas near PHL

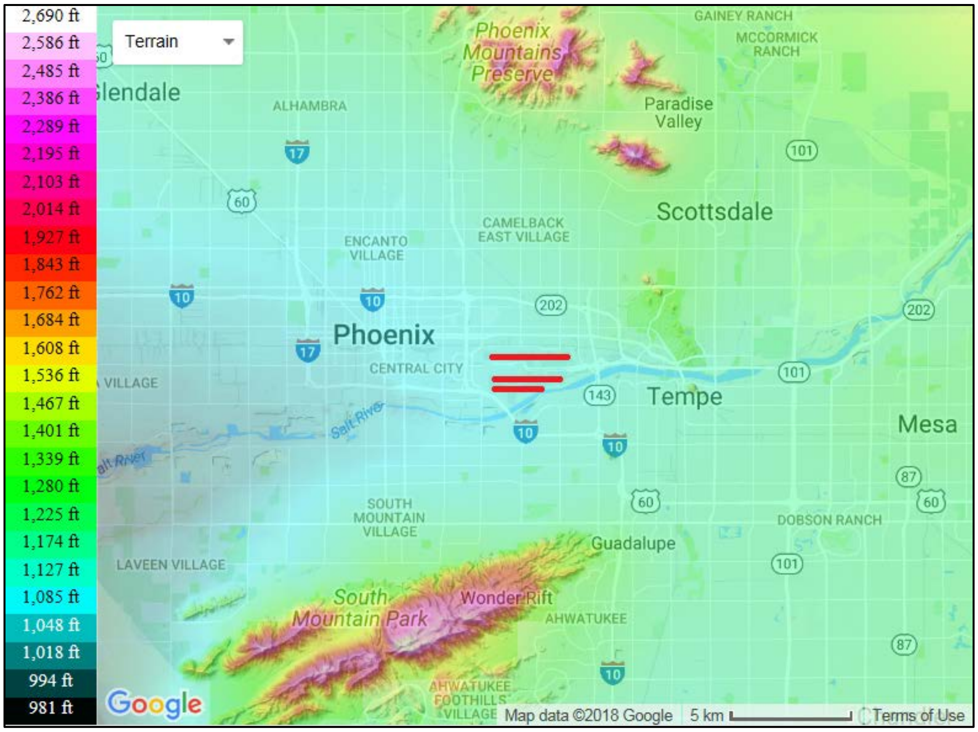

Figure B-28. Elevation Change in Areas near PHX

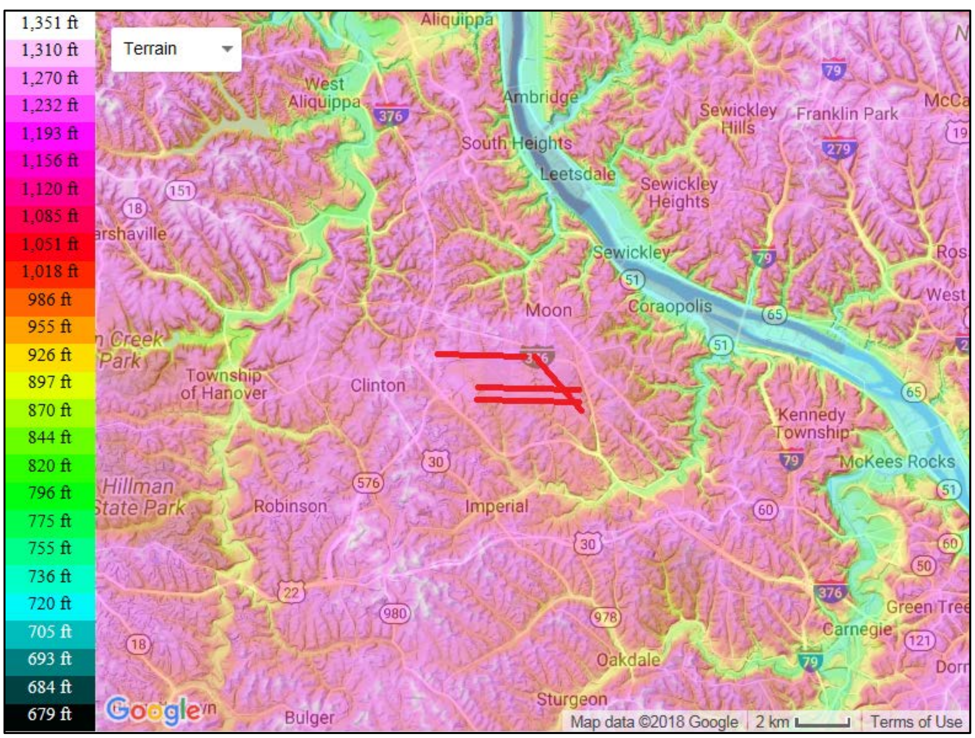

Figure B-29. Elevation Change in Areas near PIT

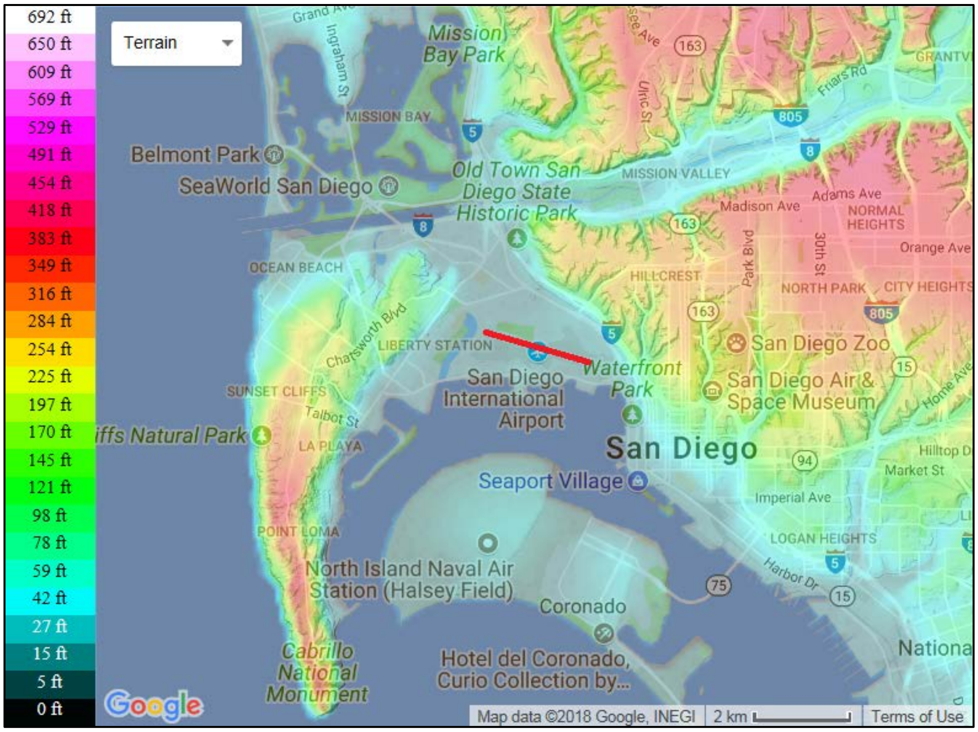

Figure B-30. Elevation Change in Areas near SAN

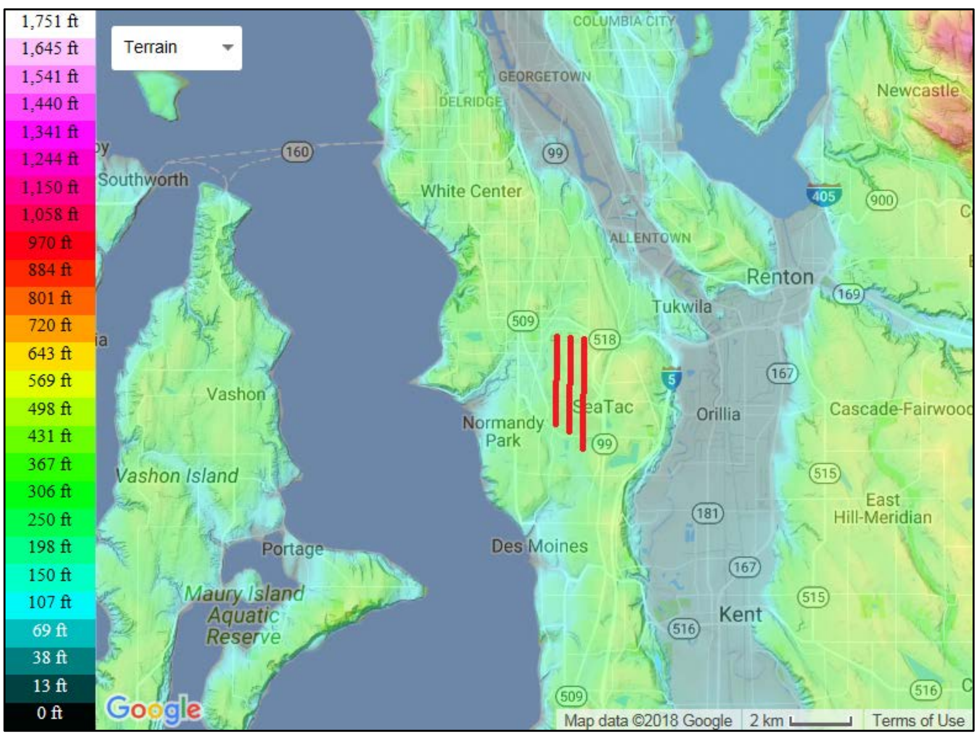

Figure B-31. Elevation Change in Areas near SEA

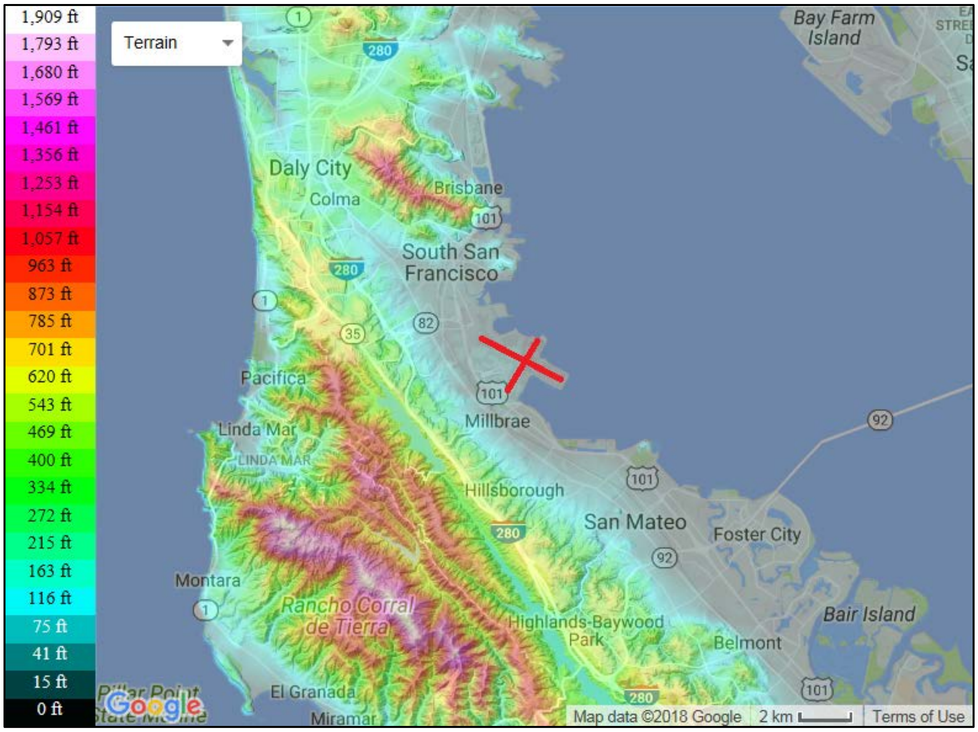

Figure B-32. Elevation Change in Areas near SFO

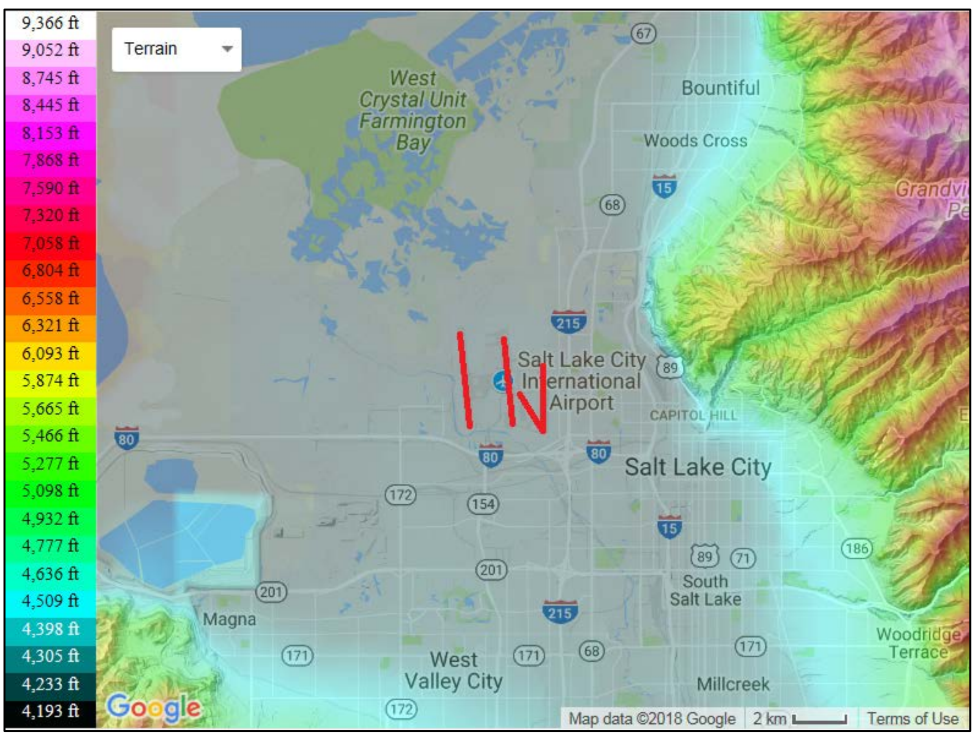

Figure B-33. Elevation Change in Areas near SLC

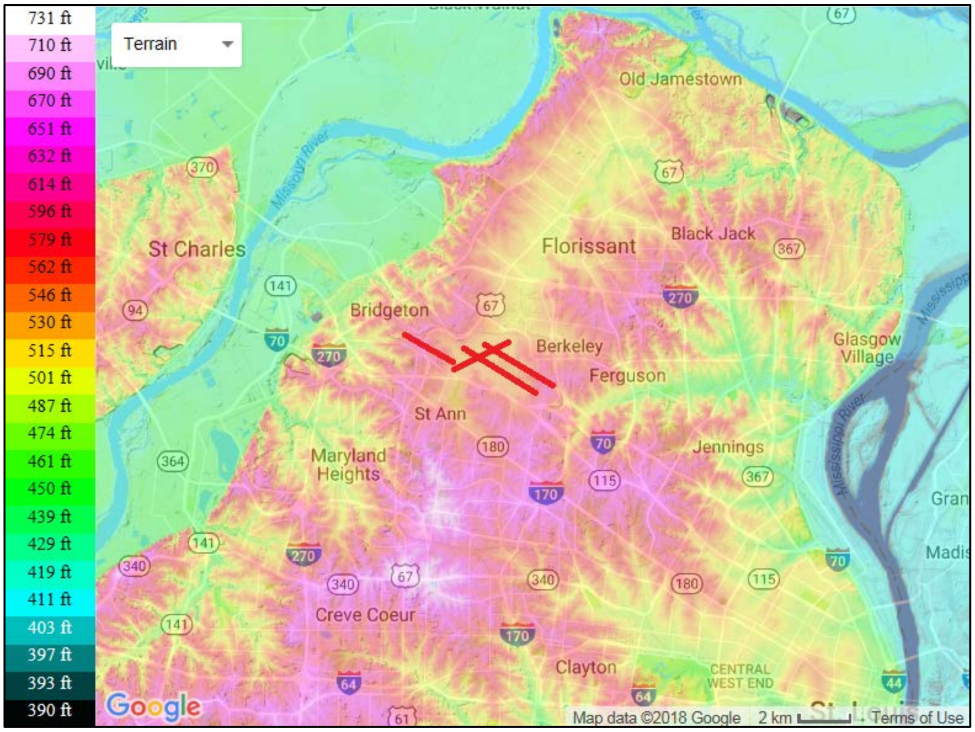

Figure B-34. Elevation Change in Areas near STL

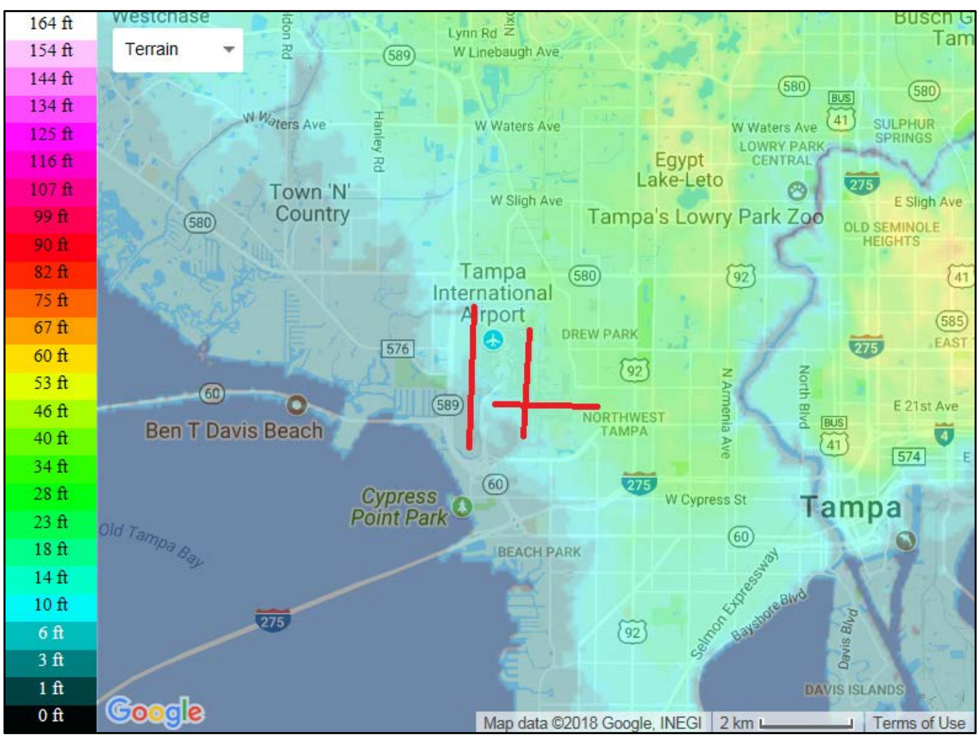

Figure B-35. Elevation Change in Areas near TPA

Appendix C: Additional Risk Adjusted Altitude Results for CVG, MIA, and PHX

Appendix C contains additional Risk Adjusted Altitude results for CVG, MIA, and PHX. One year of data was analyzed for each airspace, this appendix contains figures for 5th percentile results in each 2-month period in the year, for each airspace. In general, areas where manned aircraft traffic patterns are lower than expected, are repeated in each 2-month period. Few seasonal changes are observed.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	0	400	400	400	400	0	0			
2			400	300	0	0	400	100	400	400	400	400	400	
3		400	0	0	0	0	200	0	400	400	400	400	250	400
4		400	350	300	400		0	0	100	200	200	100	0	0
5	400	400	400	250	400					100	0	0	0	300
6	400	400	400	200	200					100	300	400	400	200
7	400	0	400	0	200	0	0	0		0	250	400	300	200
8		0	0	400	200	100	100	100	100	200	300	300	300	200
9		400	400	400	200	100	400	0	400	0	200	300	300	
10				400	200	250	400	0	400	100	0	0		
11						300	0	400	50	400				

Figure C-1. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, May 1-June 30, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	0	400	400	100	400	0	0			
2			300	200	100	200	400	0	400	300	200	250	400	
3		100	200	0	400	100	200	0	400	200	200	200	100	400
4		200	100	0	200		0	50	50	300	200	200	200	300
5	400	300	0	200	100					300	300	0	200	300
6	400	400	400	200	200					100	300	400	400	400
7	400	0	400	200	200	0	0	0		100	400	200	200	200
8		0	0	0	0	300	100	0	100	200	250	300	100	400
9		400	200	200	0	200	400	0	400	200	150	0	100	
10				250	100	100	400	0	400	0	0	0		
11						400	300	400	300	400				

Figure C-2. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, July 1-August 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	200	400	400	300	400	350	300			
2			300	300	300	300	400	200	400	200	300	300	400	
3		400	400	300	300	100	200	0	400	150	200	200	100	400
4		400	400	400	400		0	50	100	0	200	50	0	200
5	400	300	0	300	400					200	300	300	50	400
6	400	400	400	300	300					100	400	400	350	300
7	400	400	0	0	100	200	0	0		200	400	400	150	300
8		300	0	300	200	200	100	0	100	100	300	300	300	100
9		400	300	0	200	350	400	350	400	400	300	0	200	
10				0	50	200	400	300	400	300	400	400		
11						400	0	300	400	400				

Figure C-3. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, September 1-October 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	400	400	400	400	400	400	200			
2			400	400	400	400	400	400	400	400	200	400	400	
3		100	0	0	0	200	200	400	400	400	250	200	400	400
4		100	200	400	0		0	50	100	300	250	150	100	0
5	400	400	200	200	400					200	50	0	0	300
6	400	400	400	200	300					100	400	400	200	100
7	400	0	200	300	350	0	0	0		0	400	0	0	0
8		0	0	0	300	0	200	200	100	100	400	0	400	400
9		400	400	400	200	0	400	100	400	100	0	0	400	
10				400	200	400	400	0	400	100	0	0		
11						400	400	300	0	400				

Figure C-4. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, November 1-December 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	200	400	300	100	100	400	400			
2			400	400	200	300	100	400	100	400	400	400	400	
3		400	400	0	400	100	100	300	0	400	400	300	300	400
4		400	0	0	400		0	0	0	200	300	300	300	400
5	400	400	0	400	400					200	400	400	400	400
6	400	300	0	100	0					0	300	400	400	400
7	400	400	0	400	400	200	0	0		0	400	400	400	400
8		0	0	0	200	400	100	200	0	200	400	400	400	400
9		400	300	0	100	300	400	400	0	300	400	400	400	
10				0	200	0	0	400	0	300	400	400		
11						300	0	400	300	400				

Figure C-5. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, January 1-February 28, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				400	0	400	400	0	400	400	300			
2			0	0	400	0	400	300	400	300	100	100	400	
3		300	0	0	0	100	200	0	400	150	100	200	200	400
4		400	400	300	300		0	50	100	0	100	100	100	0
5	400	400	300	300	300					0	0	0	0	0
6	400	400	400	200	300					100	400	400	400	0
7	400	400	400	400	400	200	0	0		0	300	0	300	0
8		400	400	400	200	250	200	400	100	100	400	300	0	100
9		400	400	400	200	300	400	0	400	0	0	400	400	
10				0	200	400	400	0	400	100	0	0		
11						300	400	400	0	400				

Figure C-6. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in CVG, PDARS CVG Dataset, March 1-April 30, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				0	100	150	200	250	300	100	200	150	250	
2			150	150	150	100	150	250	200	150	100	200	100	400
3		100	150	100	150	150	100	200	150	200	150	150	150	150
4		150	150	400	400	100	0	0	0	0	150	150	100	150
5	400	100	150	400	400	0				0	250	400	150	150
6	0	100	400	400	200	0				0	200	200	0	100
7	400	150	150	50	0	0	0	0	0	0	400	200	150	200
8		150	200	200	150	150	0	0	0	150	400	400	150	250
9		150	200	250	150	200	150	0	150	150	150	100	100	
10			200	150	200	100	200	150	150	200	100	50		
11				100	200	250	250	200	200	100	0			
12						250	150	200	100	200	300			

Figure C-7. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, May 1-June 30, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				250	250	150	250	250	250	300	150	150	100	
2			0	150	150	100	200	200	150	100	200	150	100	350
3		100	100	150	150	150	150	150	100	200	200	150	100	100
4		100	100	400	400	0	0	0	0	0	200	100	100	100
5	150	100	200	400	350	100				0	200	100	100	100
6	100	50	400	400	200	0				0	50	50	0	100
7	400	50	150	150	0	0	0	0	0	0	200	150	100	150
8		150	200	200	100	150	0	0	0	150	200	250	100	200
9		100	200	250	150	200	150	0	200	150	150	100	50	
10			150	150	150	200	200	200	150	150	150	150		
11				300	200	150	250	200	200	200	100			
12						150	150	200	200	200	300			

Figure C-8. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, July 1-August 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				250	50	200	150	150	150	250	250	150	250	
2			150	150	200	150	50	150	150	150	200	150	150	350
3		100	100	150	150	150	200	200	0	150	150	100	100	0
4		100	150	400	400	50	0	0	0	0	150	100	0	50
5	100	100	200	400	350	0				0	200	250	150	100
6	100	50	400	400	200	0				0	150	100	50	100
7	100	50	100	100	0	0	0	0	0	0	250	150	100	150
8		150	200	150	100	150	0	0	0	100	150	250	100	250
9		150	150	250	150	250	150	0	100	150	100	50	100	
10			150	250	250	250	250	250	150	100	100	50		
11				350	200	200	200	200	200	150	100			
12						250	200	200	150	150	400			

Figure C-9. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, September 1-October 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				200	0	150	0	350	100	200	150	200	200	
2			150	150	200	100	100	150	150	200	100	100	150	250
3		100	100	150	100	150	150	150	150	150	150	150	150	100
4		100	50	400	400	100	0	0	0	0	200	50	100	150
5	200	100	150	400	400	50				0	200	250	100	150
6	50	0	400	400	200	0				0	100	50	50	150
7	400	50	100	100	0	0	0	0	0	0	200	150	150	150
8		100	100	150	200	150	0	0	0	50	200	250	150	250
9		100	150	200	250	200	100	0	150	150	150	100	150	
10			200	150	200	200	250	50	200	150	150	100		
11				300	200	200	0	250	250	150	100			
12						200	200	200	150	200	400			

Figure C-10. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, November 1-December 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				100	200	100	150	200	150	100	100	100	200	
2			150	150	150	150	50	100	200	200	150	150	100	350
3		50	100	150	100	100	150	100	150	150	200	150	100	100
4		50	50	400	400	100	0	0	0	0	150	200	100	150
5	300	50	50	400	400	0				0	200	400	150	100
6	100	0	400	400	200	0				0	300	250	50	150
7	400	50	100	100	0	0	0	0	0	0	400	100	150	250
8		150	150	150	50	100	0	0	0	100	400	400	150	250
9		150	100	150	150	200	100	0	150	150	150	150	150	
10			50	50	200	150	100	100	100	150	150	150		
11				150	150	150	200	200	150	150	50			
12						250	200	150	150	150	400			

Figure C-11. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, January 1-February 28, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				250	250	150	0	100	150	200	200	150	350	
2			150	200	250	150	50	100	100	150	200	200	150	200
3		100	150	150	150	150	100	200	200	200	200	150	100	150
4		100	150	400	400	150	0	0	0	0	200	100	100	200
5	250	50	200	400	400	0				0	250	50	150	150
6	150	50	400	400	200	0				0	250	150	0	150
7	400	50	100	100	0	0	0	0	0	0	300	150	150	250
8		150	250	200	50	50	0	0	0	150	250	150	100	400
9		150	200	200	150	200	150	0	50	150	200	150	150	
10			200	0	300	200	250	150	150	150	150	100		
11				0	100	200	0	200	150	150	50			
12						150	150	200	50	100	400			

Figure C-12. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in MIA, PDARS MIA+ASDEX Dataset, March 1-April 30, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		200	150	150	150	200											350	250	300	
2		100	50	150	150	150	0								400	150	200	200	300	
3		150	150	150	150	200	0	0	50				200	0	350	300	250	200	300	300
4	200	150	150	150	150	150	100	0	0	0	50	0	0	150	300	250	250	150	250	250
5	50	0	50	100	200	400	400	150	0				0	150	400	400	300	100	150	200
6	50	150	0	0	200	400	400	150	0				0	250	400	300	200	150	250	250
7	0	0	0	0	0	50	0	50	0	0	0	0	100	100	100	0	100	200	300	250
8		50	100	150	150	100	150	100						250	250	250	250	200	50	300
9		50	50	200	200	150	250								250	250	250	200	300	400
10		200	100	100	250	400										200	250	200	400	

Figure C-13. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, May 1-June 30, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		200	150	100	150	200											300	200	350	
2		150	150	150	100	150	0								300	50	250	200	250	
3		0	150	150	150	150	0	0	50				250	50	300	200	250	200	300	300
4	150	50	50	100	100	100	50	0	0	0	0	0	0	150	250	250	200	100	150	250
5	0	0	50	0	250	400	350	100	0				0	150	400	400	400	50	50	100
6	0	0	0	100	200	400	350	100	0				0	250	400	250	150	150	150	200
7	200	0	0	0	50	100	100	150	0	0	50	0	150	150	150	100	150	150	250	250
8		0	0	0	100	100	200	150						250	250	200	200	150	0	200
9		100	200	200	0	200	200								0	150	200	150	250	400
10		300	350	200	200	400										250	200	150	400	

Figure C-14. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, July 1-August 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		200	200	50	200	150											300	250	350	
2		150	200	150	200	200	0								400	100	200	200	350	
3		150	150	150	200	200	0	0	100				400	0	250	250	300	250	300	350
4	50	100	100	150	150	150	150	0	0	0	0	0	0	150	300	250	250	200	250	150
5	0	0	50	100	200	350	400	150	0				0	150	400	400	200	150	100	150
6	0	0	50	50	400	400	400	150	0				0	250	400	250	200	200	200	250
7	150	0	50	100	100	100	0	150	0	0	100	0	100	150	100	150	250	250	250	250
8		0	50	100	200	200	200	200						250	100	250	250	250	0	250
9		250	150	150	200	250	250								200	200	200	250	350	400
10		300	150	250	200	400										200	300	250	350	

Figure C-15. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, September 1-October 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		300	250	200	200	250											400	300	400	
2		250	250	200	200	200	0								400	250	300	250	350	
3		200	200	200	200	200	0	0	100				400	0	350	300	350	250	350	350
4	150	100	150	150	150	150	150	0	0	0	0	0	0	100	250	250	250	150	250	300
5	0	0	100	150	200	400	400	150	0				0	200	400	400	100	100	100	100
6	50	50	50	100	250	400	400	150	0				0	300	400	150	200	150	250	250
7	150	50	150	50	100	100	0	100	0	50	100	0	250	200	250	150	200	150	250	250
8		0	50	0	100	150	150	150						150	0	250	200	250	0	250
9		150	100	150	200	200	200								300	200	150	250	350	400
10		400	100	250	250	400										150	200	150	400	

Figure C-16. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, November 1-December 31, 2016

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		350	200	200	200	300											400	300	250	
2		250	200	200	150	200	0								400	200	300	250	300	
3		200	200	250	150	200	0	50	150				350	0	400	300	300	250	350	300
4	150	100	150	150	150	150	150	0	0	0	50	0	0	100	300	250	250	250	150	150
5	200	0	100	50	250	350	400	150	0				0	200	400	400	150	100	0	200
6	100	0	0	0	200	400	400	150	0				0	300	400	200	200	200	250	250
7	250	0	100	0	50	100	150	150	0	0	50	0	200	200	200	150	100	200	300	250
8		100	100	150	150	150	200	200						200	200	200	250	200	50	300
9		100	100	50	200	200	100								300	200	250	200	300	400
10		400	300	250	300	400										250	200	200	300	

Figure C-17. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, January 1-February 28, 2017

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		300	250	250	150	250											400	300	300	
2		250	200	150	200	200	0								400	200	300	300	350	
3		200	200	250	200	200	0	0	100				300	0	350	350	350	300	350	400
4	200	100	100	150	150	150	150	0	0	0	0	0	0	50	300	300	250	250	300	300
5	0	0	100	100	150	400	400	150	0				0	200	400	400	200	150	200	200
6	0	0	0	0	150	250	400	150	0				0	250	400	250	150	200	200	200
7	300	0	50	50	100	100	100	100	0	0	0	0	150	200	200	200	200	200	200	250
8		50	100	150	200	150	200	200						200	200	200	200	200	0	250
9		100	50	150	200	200	250								250	250	200	250	250	400
10		250	200	200	400	400										300	200	200	400	

Figure C-18. 5th Percentile (below 1,200 ft) Risk Adjusted Altitude in PHX, PDARS PHX+ASDEX Dataset, March 1-April 30, 2017

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