# 911 Location Test Bed, LLC

# Report on Stage Z

**Certification Statement**

Further Enterprise Solutions, FES, as the Test Bed Administrator-Executor, certifies that all results in this report have been derived from independent testing that complies with the methodology specified by the Alliance for Telecommunications Industry Standards (ATIS) for indoor wireless testing, including as described in ATIS-0500030 Guidelines for Testing Barometric Pressure-Based Z-axis Solutions and ATIS-0500031.v002: Test Bed and Monitoring Regions Definitions and Methodology.

ATIS, the Program Manager for the 911 Location Technologies Test Bed, LLC, certifies that Stage Z testing has been performed independently under its oversight and in accordance with its test methodologies as described in ATIS-050030 and ATIS-0500031.v002.

# 1. EXECUTIVE SUMMARY

This Stage Z Test Report describes the independently administered and transparent test bed process established to develop and validate a proposed Z-axis (vertical) metric for indoor wireless 9-1-1 calls, as required by the Federal Communications Commission's (FCC's) 9-1-1 Location Accuracy Fourth Report & Order. The objective of the Z-axis test campaign described in this report, known as Stage Z, was to provide a rigorous, transparent process to evaluate the accuracy and overall assessment of Z-axis technology based on standard testing methodologies.

The Test Bed LLC publicly solicited technology vendors to participate in Stage Z, and two Z-axis technology vendors, NextNav and Polaris Wireless, volunteered, formally applied, and participated in Stage Z to test technologies that rely on barometric pressure sensor information from mobile wireless handsets to determine an estimated altitude of an indoor wireless 9-1-1 call.

The Stage Z testing was specifically conducted in accordance with ATIS standards and testing parameters, which account for unique factors beyond those that affect x/y (horizontal) technologies. Stage Z testing was also conducted among a wide variety of buildings types and environments, including high-rise residential and commercial buildings in dense urban, urban, suburban, and in some cases rural areas. For each selected building several test points were identified that represent different barometric pressure environments within a building, and generally span the different areas within a building from which a wireless 9-1-1 call might be initiated.

Stage Z testing was conducted in the Atlanta, Chicago and San Francisco regions. Stage Z testing in the Atlanta and San Francisco regions was consistent with testing of other horizontal solutions administered by the Test Bed LLC and based on ATIS standards. Consistent with ATIS's testing methodology for Z-axis, Chicago was specifically added as a third test region to explore the effects of broader and possibly more extreme weather conditions, including fluctuating indoor-outdoor temperature and pressure differences that may affect barometric-based technologies. While reasonably comprehensive, the number of regions, buildings, and test points used in this Stage Z testing did not capture every possible indoor environment. Further, while the weather conditions encountered in the Stage Z testing were reasonably diverse, the full range of extreme weather conditions that could impact the limits of performance of barometric pressure sensors in live 9-1-1 call environments were not encountered.

This Stage Z Test Report's results demonstrates the following.

Compensated barometric pressure-based altitude estimation is a complex process that must contend with several potential measurement error sources. The range and extent to which the error sources test the limits of pressure sensor altitude estimation should be tested further as technology continues to evolve and improve.

The technology assessment results contained herein varied significantly. Stage Z testing was not designed to establish a direct comparison between the tested vendors' solutions, but to assess the available technology performance to recommend a Z-axis (altitude) metric. In addition, variability in how the two vendors participated in the testing further rule out any side-by-side comparison of the solutions. For example, NextNav was unable to participate in every test location (rural areas and Chicago) due to lack of availability of their proprietary technology in those areas. Separately, Polaris Wireless' solution could not support iOS devices during the testing.

Based on the technologies submitted for test, active barometric sensor bias calibration unique to each individual mobile device is necessary to achieve reasonable Z-axis measurements with barometric pressure-based estimation systems for live 9-1-1 calls. For example, specific results documented in this report relied on the active calibration of the barometric sensor in mobile devices utilized for testing performed by NextNav's proprietary system. This calibration capability would need to be built into "live" production solutions and retested at scale to fully assess performance.

Further the test did not include assessment as to what degree existing standards support the signaling necessary to perform this function at scale nationally, thus expanded standardization or platform-specific implementations may also be required. Furthermore, it is not clear at this point what software changes to mobile device middleware and operating system may be needed to integrate the calibration functionality. These pieces of the z-axis technology puzzle don't yet exist, and the timelines and availability are at this point unknown and require further study.

Overall, the Stage Z test was intended to demonstrate the state of available Z-axis technology and solutions in order to develop a recommended metric consistent with the FCC's Fourth Report & Order on 9-1-1 Location Accuracy. This report demonstrates that the performance results of the technologies tested varied significantly depending on the specific approach to dealing with mobile device barometric pressure sensor biases and other error sources. For example, technology submitted for test by Polaris Wireless used a manual one-time calibration method at the beginning of testing, while NextNav used a background calibration method to track and account for individual mobile device barometric sensor biases. The contrast in the two technologies' performance in this report offers the single most important message of the testing:  Active calibration (continuous opportunistic / background calibration for each individual mobile device) is essential to achieve consistent and reasonable Z-axis estimation measurements for indoor wireless 9-1-1 calls due to mobile wireless handset biases that significantly affect the accuracy of barometric pressure-based estimation systems.

While the results of Stage Z testing provide helpful data and lessons learned, numerous key questions remain that could not be answered through Stage Z testing completed to date.  For example, questions remain about how a barometric pressure-based altitude estimation system would perform in a real-world production deployment and how such a system would scale to hundreds of millions of devices across the U.S.  Moreover, additional focus is needed to better understand the extent of mobile device barometric sensor biases, to then develop and test commercial Z-axis implementations, and to understand if Z-axis systems can make reliable and accurate floor level determinations in buildings – at scale.

The results of Stage Z demonstrate that it is challenging to identify a Z-axis metric that can be consistently replicated in a live 9-1-1 calling environment with only two technology vendors participating in this round of Z-axis testing, under somewhat artificial conditions.  Consistent with the FCC's *Fourth Report & Order* (para. 4 and 170), the proposed Z-Axis metric must be vendor-neutral and achievable across the entirety of carrier networks within the timeframe prescribed by Commission rules. Going forward, the Test Bed can be made available to administer additional rounds of Stage Z testing for Z-axis technology vendors interested in participating.

## 2. References

This document builds upon the relevant guidelines, recommendations and references from ATIS and leverages previously approved test plan documents in this and earlier stages of the Test Bed. The initial methodology and outline described herein will be based on these sources.

The following documents and standards have been used as sources in the Stage Z Test Plan and in this Report.

FCC 15-9, PS Docket No. 07-114, 4th Report and Order, *Fourth Report and Order in the Matter of Wireless E911 Location Accuracy Requirements*.

ATIS-0500030, *Guidelines for Testing Barometric Pressure-Based Z-axis Solutions*, May 2016.

ATIS-0500031.v002*, Test Bed Monitoring Regions Definition and Methodology*, February 2017.

# 3. Document Revision History

| Revision Number | Date | Description |
|---|---|---|
| 0 | 05/04/2018 | Initial Draft |
| 1.2 | 05/30/2018 | Revised draft reflecting comments from vendors and subsequent comments from TAC |
| 1.4 | 06/08/2018 | Draft including results and assessment sections |
| 2.0 | 06/27/2018 | Draft including update with full test results and review comments from TAC |
| 2.9 | 07/13/2018 | Final Draft from TAC with vendor results |
| 3.0 | 07/23/2018 | Final Z-axis Report including Vendor Statements and Z-axis WG inputs |

# 4. Table of Contents

# 5. Test Bed Participants and Stakeholders

The 9-1-1 Location Technologies Test Bed, LLC (Test Bed, LLC) is a non-profit entity established by CTIA to administer the testing operations as described in the FCC's 2015 9-1-1 Location Accuracy Fourth Report & Order (FCC Order) through a transparent test bed (Test Bed). The Test Bed evaluates both location technologies currently utilized by wireless providers and emerging technologies from various location technology vendors.

Test Bed operations are primarily funded by the nationwide wireless providers: AT&T, Sprint, T-Mobile USA, and Verizon. For testing emerging technologies, such as in the Stage Z testing described in this report, technology vendors contribute funding to support the execution of the test campaign.

## 5.1 Nationwide Wireless Providers

For Stage Z testing, wireless carriers were not the direct test participants under evaluation but served as indirect partners to the technology vendors in providing network access and data connections. The carrier networks that were employed in this test included:

**Table 5-1. Stage Z Wireless Carriers used**

| Wireless Operator | Website | RAT Technologies Used |
|---|---|---|
| Verizon Wireless | https://www.verizonwireless.com | LTE |
| AT&T | https://www.att.com | LTE, UMTS |

## 5.2 Z-axis Technology Vendors

In September 2017, the Test Bed publicly solicited applications from vendors of Z-axis technologies to volunteer and participate in Stage Z. Vendors were made aware that the results of Stage Z would be provided to the FCC by the nationwide wireless providers pursuant to the FCC Order.

Two vendors of Z-axis technologies applied to participate in Stage Z: NextNav LLC and Polaris Wireless, Inc. After evaluation and consultation with the Test Bed's Technical Advisory Committee (TAC), these two vendors' applications were accepted, and they were invited to participate in Stage Z. The Test Bed can be made available to administer additional rounds of Stage Z if additional Z-axis technology vendors would like to participate.

As described below, the systems from NextNav and Polaris Wireless are primarily based on barometric pressure observations but may include additional location sources or a form of vendor-specific processing customized by each Z-axis technology vendor. Descriptions about the solutions used by each technology vendor can be found at the links in Table 5-2. Additional details, including those that pertain to the configurations tested, are provided in Section 8.5 of this report.

**Table 5-2. Z-axis Technology Vendor Definition**

| Technology Vendor | Website | Solution Type |
|---|---|---|
| NextNav | http://www.nextnav.com | Barometric Pressure based-Z as part of a Metropolitan Beacon System (MBS) |
| Polaris Wireless | http://www.polariswireless.com | Barometric Pressure based Z, Hybrid XY (UE-based, UE-Assisted GPS, ECID, baro, WiFi) |

## 5.3 CTIA's Z-axis Working Group

In addition to the participation of the technology vendors during the actual testing, there are stakeholders and involved parties concerned with Z-axis technologies and performance. The CTIA Z-axis Working Group is a collaboration of industry leaders from across many related disciplines, including wireless carriers, technology OEMs, sensor and handset manufacturers, service providers related to E9-1-1, and public safety representatives.

The Z-axis Working Group met on multiple occasions to provide guidance to the Test Bed, LLC on the testing and evaluation of Z-axis technologies. For example, the Z-axis Working Group held an all-day meeting on September 8th, 2015 to discuss the performance of barometric pressure sensor devices, including accuracy, trends and the state of technology. Although this document is a work product of Test Bed, LLC, the Z-axis Working Group has reviewed and provided input that has been incorporated throughout.

# 6. BACKGROUND

## 6.1 Purpose of 911 Location Test Bed

Test Bed, LLC was established by CTIA to independently administer the Test Bed to evaluate wireless 9-1-1 location information technologies consistent with the FCC Order. As will be noted throughout this report, the Stage Z test is not designed to establish any comparison between the tested vendor's solutions.

The Test Bed is administered consistent with the recommendations of the FCC's fourth Communications, Security, Reliability & Interoperability Council (CSRIC IV). It follows the testing guidelines developed by the Alliance for Telecommunications Industry Solutions' (ATIS) Emergency Services Interconnection Forum (ESIF), including ESIF's Emergency Services and Methodologies (ESM) subcommittee.

The Test Bed provides independent indoor performance results of deployed and emerging wireless 9-1-1 location information technologies. Test Bed, LLC has selected FES as the independent "Administrator-Executor" of the Test Bed. It also selected ATIS as the Test Bed's independent Program manager. ATIS provided guidelines on test building and test point selection and oversaw implementation of the Test Bed by the Administrator-Executor. In addition, Test Bed, LLC receives guidance from the TAC, which includes representatives of the nationwide wireless service providers, as well as the Association of Public-Safety Communications Officials International (APCO) and the National Emergency Number Association (NENA).

As explained further below, ATIS ESIF ESM recommended that, for Z-axis testing, in addition to Atlanta, GA, and San Francisco, CA, portions of urban and dense urban Chicago, IL be tested to provide a cold climate test environment. This was intended to assess the effects of large temperature differences between indoor and outdoor environments on the performance of barometric pressure sensor-based z-axis systems.

## 6.2 Z-axis and the FCC Order

Historically, FCC location accuracy requirements for 9-1-1 calls focused on horizontal location (i.e., x/y coordinates) and did not distinguish between indoor and outdoor 9-1-1 calls. With the increased reliance of wireless calls placed from within buildings, the FCC examined new approaches to improve wireless location accuracy, including from indoor locations. In January 2015, the FCC adopted the FCC Order, establishing new indoor location accuracy rules and indoor location accuracy benchmarks for x/y and z. While the FCC particularly focused on the development of dispatchable location solutions, it also adopted requirements and timeframes for the provision of z-axis information (and more precise x/y). To this end, the FCC Order required the wireless industry to develop and validate a proposed z-axis accuracy metric, and to report to the FCC the results of its development and testing. This report describes the independently administered and transparent test bed process to develop a proposed z-axis metric pursuant to this FCC requirement.

## 6.3 Z-axis Testing Objectives

The objective of the Z-axis test campaign in the Test Bed is to provide a rigorous, transparent framework in which emerging Z-axis technology solutions are evaluated and their accuracy performance assessed – in accordance with a well-established, consensus-driven test methodology – as provided in ATIS-0500030. The Z-axis test campaign was intended to demonstrate the state of available Z-axis technology in order to develop a recommended metric consistent with the FCC's *Fourth Report & Order on 9-1-1 Location Accuracy*. Stage Z testing was not designed to establish a direct comparison between the tested vendors' solutions. In addition, variables in how the two vendors participated in the testing further rule out any side-by-side comparison of the solutions.

## 6.4 Test Bed Framework

### 6.4.1 Organizational Structure

The Test Bed utilizes a tiered organizational structure as shown in Figure 6.1.

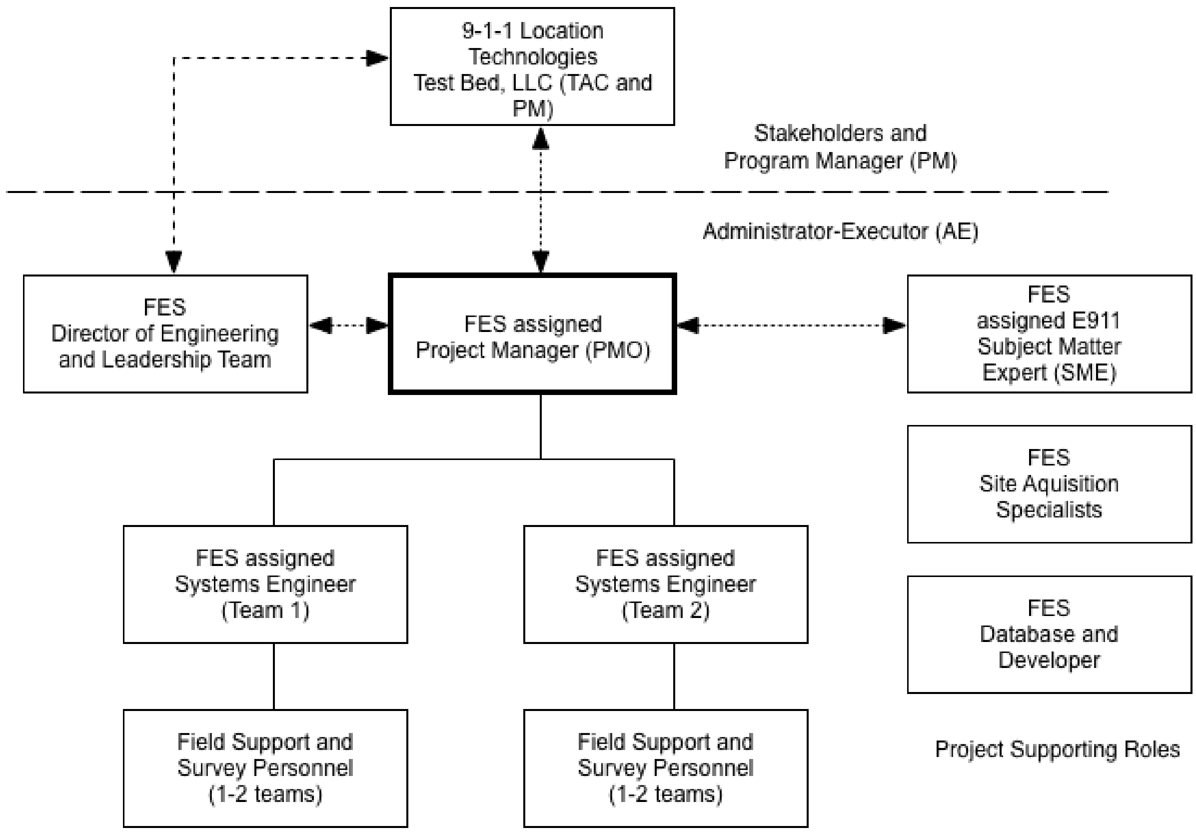



**Figure 6.1 Project Organizational Structure**

As outlined in this Figure 6.1, there were multiple stakeholders involved with the Test Bed, LLC's organization and process, consistent with the CSRIC IV recommendations. The Test Bed, LLC's Steering Committee and TAC provided guidance on operational and technical issues, respectively. Both committees included representatives of the nationwide wireless providers, as well as APCO and NENA. The Test Bed, LLC oversaw the efforts of the Administrator/Executor, ATIS, and the test service provider, FES, who performed the actual testing. ATIS' committees developed the test methodologies utilized by the test service provider.

In addition, a variety of stakeholders throughout the mobile wireless ecosystem have participated directly or indirectly in the Test Bed. For example, location technology vendors and handset manufacturers have participated in testing, either directly when their technologies or handsets are under test, or indirectly through the nationwide wireless carriers when carrier networks are under test. Infrastructure vendors have been indirectly involved in supporting their carrier clients either in preparing for testing or in assessing testing results related to their products in carrier networks.

### 6.4.2 Test Bed Stages

For administrative purposes, the Test Bed has operated several Stages and Test Cycles. Initial stages of testing (Stages 1, 1A and 1B, collectively Stage 1) focused on location technologies currently deployed and operationally used by wireless carriers for E9-1-1. The results from these Stage 1 cycles are used by the national wireless carriers to support compliance with the FCC's rules and obligations.

Other stages of testing (Stage 2, 2A, collectively Stage 2) focus on emerging location technologies as well as parallel initiatives such as Z-axis and Dispatchable Location (DL) testing. These results enable wireless carriers to determine the extent to which such emerging technologies can be used to improve public safety and enhance compliance with the FCC's rules.

The Test Bed, LLC has established the following milestone dates to coincide with each Test Stage.

**Table 6.1 General Project Stages and Milestone Dates**

| Milestone | Date |
|---|---|
| Test Bed Dry Run | Prior to each test stage |
| Stage 1 Testing | Completed 2016 |
| Stage 2 Testing | Completed 2016 |
| Stage 1A Testing | Completed 2017 |
| Stage 1B Testing | Completed Q1 2018 |
| Stage 2A Testing | Completed Q1 2018 |
| Stage Z Testing | Q1-Q2 2018 |
| Stage DL Testing | Q3-Q4 2018 |
| Stage 1C, etc. | As needed, late 2018 into Q1 2019 and beyond |
| Stage 2B, etc. | As needed, late 2018 into Q1 2019 and beyond |
| Stage 3 Testing (limited deployment technologies) | As needed, not scheduled at this time |
| Stage Za, etc. | As needed, not scheduled at this time |

## 6.5 ATIS Testing Methodology

ATIS' Standard ATIS-0500031.v002[1], "*Test Bed and Monitoring Regions Definition and Methodology,"* details guidelines regarding test regions, morphologies, building types and construction materials, and suggested range of test points.

- The four morphologies are defined as Dense Urban, Urban, Suburban, and Rural.
- Within each morphology there are Setting/Use types, Commercial or Residential.
- Within Commercial or Residential use type there are building categories, such as : Single Family Home, Multi Family Home, Small Office, Large Commercial, or Arena.
- Within each building category, there are different building and construction types, such as: – low rise, high rise, glass exterior, brick, stucco, etc.
- Emerging Z-axis location technologies under test currently rely heavily on barometric pressure-based readings from sensors in the handset and employ compensation algorithms (for weather and other factors) implemented in software on the devices and servers within the technology vendors' networks. Accordingly, the criteria for test building and environment selection have been expanded in accordance with the guidelines in ATIS-0500030.
- As further explained below in 7.1, ATIS ESIF ESM recommended that a third test region be included in Z-axis testing to explore the effects of colder weather, including larger indoor-outdoor temperature differential on the barometric-based technologies under test.
- Building and test point selection has been further refined in ATIS-0500030 to include "sealed" and "unsealed" building types where indoor pressure may or may not be affected differently.

[1] Test Bed Monitoring Regions Definition and Methodology (ATIS-0500031.v002), February 2017. © 2010 Alliance for Telecommunications Industry Solutions (ATIS). A copy may be obtained via https://atis.org/docstore/product.aspx?id=28279

The intention of the morphology and building type breakdown is to provide a good representation of the range of indoor operational environments in real world wireless 9-1-1 caller scenarios.

Multiple test points were identified for each of these building types. This included points on multiple floors and/or varying parts of the building to ensure objectivity and a broad, unbiased statistical representation.

The indoor testing framework is described in Figure 6.2., which was reproduced from ATIS-0500013[2] with permission from the ATIS.

The framework is applicable to each of the morphologies.

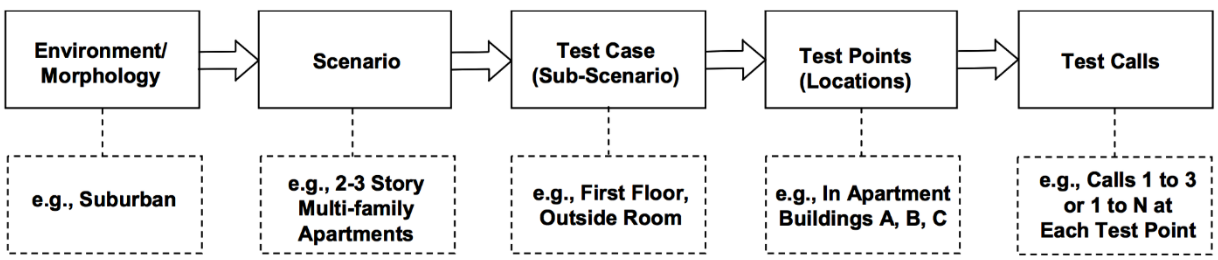



**Figure 6.2 Indoor Testing Framework and Flow (from ATIS-0500013)**

[2] Approaches to Wireless E9-1-1 Indoor Location Performance Testing (ATIS-0500013). © 2010 Alliance for Telecommunications Industry Solutions (ATIS). A copy may be obtained via https://www.atis.org/docstore/product.aspx?id=25009.

# 7. TEST METHODOLOGY

## 7.1 Test Bed Regions - Atlanta, Chicago and San Francisco

"Representative testing" is the cornerstone of the test methodology that governs testing in the Test Bed. After extensive study and deliberation with ATIS ESIF ESM, consensus was achieved in adopting the San Francisco and Atlanta regions as providing sufficient test representation of the broad conditions prevailing in both the Western and Eastern United States. In both of these regions test boundaries, or polygons, that contain samples of the four distinct morphologies, dense urban, urban, suburban, and rural, which are described concisely in Section 7.3, were defined and included in ATIS-0500031.v002. (Note that these polygons are reproduced later in this report in Section 8.3 in figures that describe the buildings used in testing within those polygons.)

ATIS-0500030, which provides the guidelines for testing barometric-based z-axis technologies, explains some of the unique factors, beyond those that affect horizontal technologies, that should be examined in a rigorous Z-axis test campaign. These effects, which are explained further in Section 7.4., include weather effects (outside temperature versus inside, barometric pressure variation with weather fronts, strong winds, etc.) and in-building effects (e.g., various pressure zones within a building due to HVAC, air stack effects, open vs closed window effects, etc.). These factors could pose challenges to pressure compensation algorithms critical to producing accurate z-axis readings. ATIS-0500030 observed that these effects may be particularly noticeable in taller buildings as found in urban and dense urban settings and that an additional testing environment, namely Chicago in winter, would provide a prime example to assess these factors.

Test Bed, LLC, in consultation with the TAC and ATIS ESIF ESM, therefore decided to include Chicago in the Z-axis test campaign prior to the start of testing in any of the cities. However, to maintain a reasonable test campaign scope and provide the results sought without extreme additional costs to be borne by the participants (due to new test building acquisition and test point surveying) testing in Chicago was limited to its urban and dense urban morphologies only in order to better examine the environmental and building design effects on barometric sensors.

## 7.2 General Ruleset for Z-axis Testing

The following guidelines (recommended by ATIS ESIF ESM and found in ATIS-0500031.v002, ATIS-0500030) were required for executing Stage Z test scenarios and methodology:

1. Three (3) test regions: San Francisco, CA (SFO); Atlanta, GA (ATL); and Chicago, IL (CHI)
2. SFO and ATL: Up to twenty (20) candidate buildings selected and surveyed per test region across all 4 morphologies, according to the requirements in ATIS-0500031.v002.
3. CHI: Up to ten (10) candidate buildings selected and surveyed across only dense urban and urban morphologies, per the guidance in ATIS-0500030 for inclusion of a colder climate in z-axis testing of barometric pressure-based technologies. (Selected within 5 miles of downtown Chicago, see Figure 8.1).
4. A range of test points in each of the test buildings, including in two high-rise buildings per region (sealed and unsealed if possible) where additional test points are selected as much as possible evenly distributed throughout the vertical axis of the building.
5. A total of approximately 120 test points in each of the San Francisco and Atlanta test regions and 75 test points in Chicago.
6. Up to six (6) test devices per testing participant. Thirty (30) test calls from each of the six (6) test devices divided into five (5) groups of six (6) test calls at each visit to a test point. Total rounds of testing per building were five, executed occasionally in a round-robin manner and frequently in a more random fashion.
7. Test handsets included a variety of models and manufacturing dates. The intent was to ensure variability between on-device barometric sensor manufacturers and unit age which would more closely represent the general public handset make up. However, only relatively new handsets, released more recently than mid-2016, were tested because older devices' limitations could not support the vendors' test apps. (Accordingly, performance on older or less capable handsets cannot be inferred from the current testing.)
8. A scientific grade barometric pressure sensor unit was used alongside the test handsets for informational purpose to capture changes in ambient pressure due to activities in test surroundings and to serve as a cross check in test point ID logging. Measurements were recorded in 1-minute intervals and provided as hectopascal (i.e., millibar).
9. When possible, testing was scheduled with variability in weather conditions and randomization of atmospheric conditions. Daily atmospheric conditions were recorded from nearby weather stations using National Wireless Service standard data. Three geographically dispersed locations surrounding the test building were selected for each test region.
10. In at least one building, test devices were left with the barometric reference unit on-site to perform an extended 24-hour observation test.

11. Exterior doors and windows were normally closed at test point locations, except for certain predefined test points where testing was performed with the windows both closed and open. Room doors were closed to hallways when possible.
12. GPS was enabled on test-handsets.
13. Test handsets did not need to be power cycled at end of each 6-call test cycle and prior to moving to each subsequent test point for Stage Z. This is because the barometric pressure reading is not likely to be interdependent as was the case with x/y readings from device-based hybrid in other stages of testing.
14. No placement of pre-test configuration verification calls prior to actual testing at any of the test points was allowed. Such calls, when needed, were placed as separate as possible (horizontally and/or vertically) from the test points.

FES procured access rights from property managers and completed testing of the Z-axis location technologies in various building types in the test bed regions and morphologies specified.

## 7.3 Morphology Selections and Polygons

As mentioned above, the ATIS-0500031.v002 defines the detailed test polygons across all four morphologies in the Atlanta and San Francisco test regions. For Chicago the test polygon was defined as a semicircular region of radius 5 miles centered around downtown Chicago and includes both urban and dense urban morphologies, as shown in Section 8.3.

Representative buildings were carefully selected per the requirements in ATIS-0500031.v002 and ATIS-0500030 to support Stage Z testing within each of the four morphologies in San Francisco and Atlanta and the two morphologies in Chicago. Description of the test areas is further expanded in Section 8.3 along with characteristics of the test buildings. The four distinct morphologies can be described as follows.

### 7.3.1 Dense Urban Morphology

The dense urban (DU) morphology is the densest scenario for testing, consisting of a large population and/or building density within a small area. The dense urban morphology is reserved for city centers, comprising of many high-rise buildings which tend to create urban canyons. The dense urban environment is typically a business district, with a mix of residential properties as well.

### 7.3.2 Urban Morphology

The urban (U) morphology is a relatively dense scenario for testing, containing a wide selection of large buildings but with less high-rises and a general absence of urban canyons. Its population density is less than the dense urban morphology. The urban environment is typically the area surrounding city centers or dense urban areas and contains a larger mix of commercial and residential buildings.

### 7.3.3 Suburban Morphology

The suburban (S) morphology is a largely residential area, with some distribution of commercial buildings. The suburban landscape consists often of 2-3 story buildings, occasional mid-rises, and single-family dwellings. It has more trees and green space than urban or dense urban environments.

### 7.3.4 Rural Morphology

The rural (R) morphology is the sparsest environment overall. It is mostly residential but also contains commercial structures depending on the rural area. The vast majority of rural structures are between 1 and 2 stories. The distances between buildings is typically significantly larger than in the suburban environment.

## 7.4 Elevation Technology (Z-axis), Error Sources and Stage Considerations

ATIS 05-00030 provides background on potential error sources that should be considered during the definition of the Z-axis test and during its data review process. These include handset sensor bias, indoor building HVAC and stack effects, weather and other outdoor-to-indoor pressure variations. These can all have an impact on vertical height accuracy and were measured / carefully noted as part of the overall data collection process.

### 7.4.1 Handset Barometric Pressure Device Bias and Drift Attributes

Handset barometric pressure sensor accuracy refers to the potential for measurement bias, noise, and/or drift over time. Additionally, the temperature and age of the handset may affect overall function. Handsets were carefully selected to ensure variety between sensor manufacturers, the age of handsets (within limits) and their overall use characteristics. All data related to handsets was recorded and included for consideration in the final results. The testing included a 24-hour data collection event at one indoor test point in each region to assess observable drift over that period.

### 7.4.2 Weather Effects

Temperature differences, wind speeds, storm fronts and system changes (high and low pressure) all can affect barometric sensor performance. FES field teams notated test area conditions using observations from local weather stations. Observations from a minimum of three weather stations in each region per test day are included. Max-Min variation in barometric pressure in the area in excess of 10 mbar and/or high gusty winds during the testing period generally indicate unsettled weather.

ATIS-0500030 recommended that testing be performed during the winter months to capture as much variable and extreme weather conditions in the test regions, especially in Chicago. Due to overriding logistical and scheduling factors, Z-axis testing in the field was not possible to start sooner than late February. This likely reduced the prevalence of very cold weather during the test campaign.

### 7.4.3 In-Building Effects

HVAC systems operating in test areas as well as sealed or unsealed building test environments can cause differences or uneven readings. Effort was made to not over-emphasize test points that may be easy to acquire (e.g., in elevator lobbies, emergency stairwells, and large public spaces with doors or windows open to the outside). Because the test locations are mostly in occupied spaces, not every test location could be tightly controlled by FES testers. Some movement in and out of test spaces could occur. Any significant changes outside of the control of the tester were noted and additional barometric pressure readings using the reference barometer provide an added input to detect unusual events.

### 7.4.4 Other Effects

A host of other factors may affect Z-axis system performance. Not all of these effects apply to all systems, or can be measured directly, but they may be discernable in detailed data analysis:

- Mobile to weather reference station distance
- Reference measurements frequency and time delays
- Quality and resolution of the terrain altitude database
- Impact of mobile position estimates and inaccuracies on terrain database lookup

Discernible effects, when possible to identify and attribute, are included in the findings of this report.

### 7.4.5 Commercial Grade Handsets

The handsets used in testing were the same production-ready handsets sold by wireless carriers and available to the general public. The handsets did not contain any hardware modification that would favor these handsets over any commercially available handsets. By agreement between the Test Bed, LLC and the Z-axis technology vendors only relatively new handsets, released more recently than mid-2016, were tested. Test results, therefore, cannot be extrapolated to older, less capable handsets.

The handsets required test applications from each technology vendor participant to be installed to utilize their platforms. These applications performed, among other functions, the critical function of handset sensor bias calibration, which was mostly performed in the background using nonstandard vendor-specific methods. (More details provided in Section 8.5.)

Handset configurations were specified by each test participant (network preference, location accuracy settings, device timeouts and privacy controls). Test handsets were purchased from commercial sources by the test administrator and were a mix of new and somewhat older units. (More details provided in Section 8.5.) No handling of the test handset by a technology vendor was permitted.

### 7.4.6 Rural Testing Consideration and FCC Requirements for the Top 50 CMAs

The FCC Order requires that wireless providers' 9-1-1 location solutions meet the vertical requirements in the Top 50 CMAs. For Z-axis, as opposed to DL, the FCC Order requires wireless provider's Z-axis solutions to cover 80% of the population on a per CMA basis. Stage Z testing included rural morphologies, per ATIS standards, even though the FCC's vertical location accuracy requirements are exclusive to the Top 50 CMAs.

# 8. TESTING PERFORMED AND DATA COLLECTION

The primary purpose of this Stage Z is to assess the accuracy of systems that use barometric pressure sensors in the handset for determining altitude in support of E9-1-1. The following sections outline the details regarding general rules for Stage Z, test point definitions, ground truth determination and an overview of each participant's solution as well as particular test configuration and procedures.

## 8.1 Data Collection Requirements

The overall test process consisted of testing at locations in all test regions in parallel. Below are some common parameters related to placing simulated test calls (location transactions) at each test point:

- Testing in buildings that have been selected by FES per ATIS guidelines and pre-approved by the ATIS Program Manager.
- **Simulated 9-1-1 test calls per test point:** Six (6) independent simulated test calls per test device per each visit to a test point, using up to six (6) test devices per participant. The location transactions or simulated calls were placed in five cycles, totaling 30 test calls from each device at each test point. The test handset did not need to be power cycled before moving to the next test point. This process was followed for all building locations.
- In some test cycles the test points were taken in a round robin strategy and in other cycles a more random ordering of the test points was followed.
- **Simulated Test Call Duration**: Fixed to 30 seconds (although the NextNav application defaulted to 25 seconds and the location fixes for Polaris Wireless were also received at approximately 25 seconds).
- **Down Time (between transactions)**: Fixed to 10 seconds (with the NextNav application defaulting to 5 sec.) It should be noted that Barometric pressure measurements tend to be independent between fixes and do not require long down times. As such, the exact duration between location transactions is not critical.

**Test Cart** – Used for power and managing test equipment. Kept powered on between points.

**Handset Base Configuration -** The test handsets were configured with the following general ruleset prior to commencing testing. Six test handsets were used for each technology vendor in each region during the Z-axis testing.

- SIM provisioned with AT&T or Verizon network access for voice and data services. SIM did not need to be whitelisted for live 911 dialing. Voice and Data Services provisioned for LTE.
- Operating Systems and essential applications fully updated
- Operating System Network Selection configured to LTE/WCDMA/Auto
- WiFi ENABLED (No AP's joined and WiFi 'Auto-Connect' or similar features were DISABLED)
- WiFi calling DISABLED
- Bluetooth and NFC ENABLED
- UE Location Services set to HIGH accuracy
- Low Power and Battery Saving Mode DISABLED
- Date and Time correctly configured (AUTO)
- Screen Display Timeout DISABLED or ALWAYS ON (Note: Handset configuration for battery saving and screen always-on are not typical handset operational modes but are requirements of the vendor for their software application to operate properly. They are expected to have no effect on the accuracy of Z measurements.
- Full Compliance with Android and iOS specific settings per participant instructions.

## 8.2 Candidate Building and Test Point Selection Process

Nineteen (19) buildings were selected in each of San Francisco and Atlanta and ten (10) buildings in Chicago. Test buildings selected were consistent with the types outlined by ATIS in ATIS-0500031.v002. The building types used in Stage Z testing and their general characteristics are described in Section 8.3.

For each selected building, several test points were identified that represent different barometric pressure environments within a building, and generally span the different areas within the building from which an individual might initiate a wireless 9-1-1 call.

The general guideline for Stage Z testing is an average of five to six test points in most of the selected test buildings. Some taller buildings had additional test points along the vertical axis for a target total of one hundred twenty (120) test points per region in San Francisco and Atlanta and seventy-five (75) test points in Chicago.

### 8.2.1 Requirements and Guidelines for Test Point Selection

#### 8.2.1.1 Test Point Base Guidelines

- Distribution of test points needs to support determination of the elevation level across a wide selection of interior environments and floors.
- Test Points should be placed in a variety of use cases, including common spaces, occupied office spaces and where possible tenant spaces in residential buildings.
- Do not over represent typically easier to acquire test points in interior hallways, emergency stairwells, elevator areas.
- Target equal distribution across floors. In taller buildings, target points on low, mid and high floors.
- Points should be >5 Meters or greater from exterior doors and major entrance ways.
- Ideal points would have an interior or exterior door to stabilize ambient atmosphere in test environment. Open windows should be closed except in certain predefined test cases.
- Ensure adequate RF coverage for any wireless network required to support the test.

#### 8.2.1.2 Points in different HVAC zones

Test points were selected in a variety of building interior and exterior locations to capture different HVAC zones and their possible impact on barometric pressure-based altitude measurements. For example, in a hotel building, four or more distinct HVAC zones may have been recognized: interior hallways, hotel rooms (guest, conference, etc.), a multi-floor plenum, and emergency stairwells. Testing encompassed a selection of these somewhat distinct environments.

#### 8.2.1.3 Distribution along building height

The goal was to have a wide distribution of test points along building height. For taller buildings low floor, middle floor, and upper floor points were selected. Interior and exterior points were not necessarily on the same floor.

For larger footprint buildings, the horizontal and vertical spacing of the points was taken into account to ensure a wide distribution in the building. Vertical points were placed every few floors to have an approximately even distribution while keeping the total number of points manageable.

#### 8.2.1.4 RF Coverage

FES field technicians ensured there was adequate wireless RF coverage at the interior (and exterior) test points in order to reliably run the required test(s).

### 8.2.2 Approval

After identifying a building candidate and test points, the test point scouting and summary data was reviewed and approved by the ATIS PM. The actual test points remained anonymous to the TAC and Test Bed participants. Once a building and its set of test points were approved, the ground truth survey was performed.

## 8.3 Stage Z Buildings and Test Points

For the final building mix, nineteen (19) buildings were selected in San Francisco, nineteen in Atlanta, and ten (10) in Chicago. Their salient characteristics are summarized below.

### 8.3.1 Atlanta

Table 8.1 shows the distribution of test buildings among the morphologies. Table 8.2 lists the morphology and characteristics for each building.

**Table 8.1 Atlanta building morphology distribution for Stage Z**

| Market ID | Morphology | Building Count |
|---|---|---|
| **Atlanta** | Dense Urban | 4 |
| **Atlanta** | Urban | 8 |
| **Atlanta** | Suburban | 5 |
| **Atlanta** | Rural | 2 |

**Table 8.2 Atlanta building morphology and characteristics for Stage Z**

| Region | Building ID | Morphology | Use Category | Building Characteristics |
|---|---|---|---|---|
| Atlanta | ATLDBC29 | Dense Urban | Commercial/ Residential (Hotel) | 20+ story steel/concrete frame stone/plaster finish w Glass; sealed bldg. |
| Atlanta | ATLDBC36 | Dense Urban | Commercial | 20+ story steel with glass exterior; sealed building |
| Atlanta | ATLDBC48 | Dense Urban | Residential | 5-10 story steel/concrete frame w stone/plaster finish |
| Atlanta | ATLDBC50 | Dense Urban | Commercial | 4-6 story mixed use commercial center surrounded by high rises |
| Atlanta | ATLUBC03 | Urban | Commercial | Large multi-purpose event venue, no seating area, two-level with open space; sealed building |
| Atlanta | ATLUBC10 | Urban | Commercial | 20+ story commercial high-rise glass exterior; sealed building |
| Atlanta | ATLUBC21 | Urban | Commercial/ Residential (Hotel) | 7-15 story brick or concrete/plaster finish; sealed building |
| Atlanta | ATLUBC37 | Urban | Commercial | 5-10 story sealed office building |
| Atlanta | ATLUBC64 | Urban | Residential | 5-10 story brick or concrete/plaster finish |
| Atlanta | ATLUBC72 | Urban | Residential | 20+ story steel/concrete frame w/wood with glass or other exterior materials |
| Atlanta | ATLUBC73 | Urban | Commercial | Large multiple purpose event venue with multi-level amphitheater seating |
| Atlanta | ATLUBC78 | Urban | Commercial | 20+ story commercial high-rise stone/concrete/plaster; sealed building |
| Atlanta | ATLSBC04 | Suburban | Residential | 3-4 story brick or other prevailing construction materials |
| Atlanta | ATLSBC08 | Suburban | Commercial | 2 story commercial center; sealed |
| Atlanta | ATLSBC25 | Suburban | Residential | 2-3 story brick or other prevailing construction materials |
| Atlanta | ATLSBC33 | Suburban | Residential | 15-20 story brick and/or brick veneer |
| Atlanta | ATLSBC99 | Suburban | Residential | 2-story house with prevailing construction materials |
| Atlanta | ATLRBC22 | Rural | Public | 1-2 story Church |
| Atlanta | ATLRBC26 | Rural | Public | 2-story brick with metal roof church annex building |

Figures 8.1 through 8.4 show the placement of the test buildings within the boundaries of each morphology polygon in the Atlanta region. The Test Bed polygons are reproduced from ATIS-

0500031.v002 with permission from the Alliance for Telecommunications Industry Solutions (ATIS)[3].

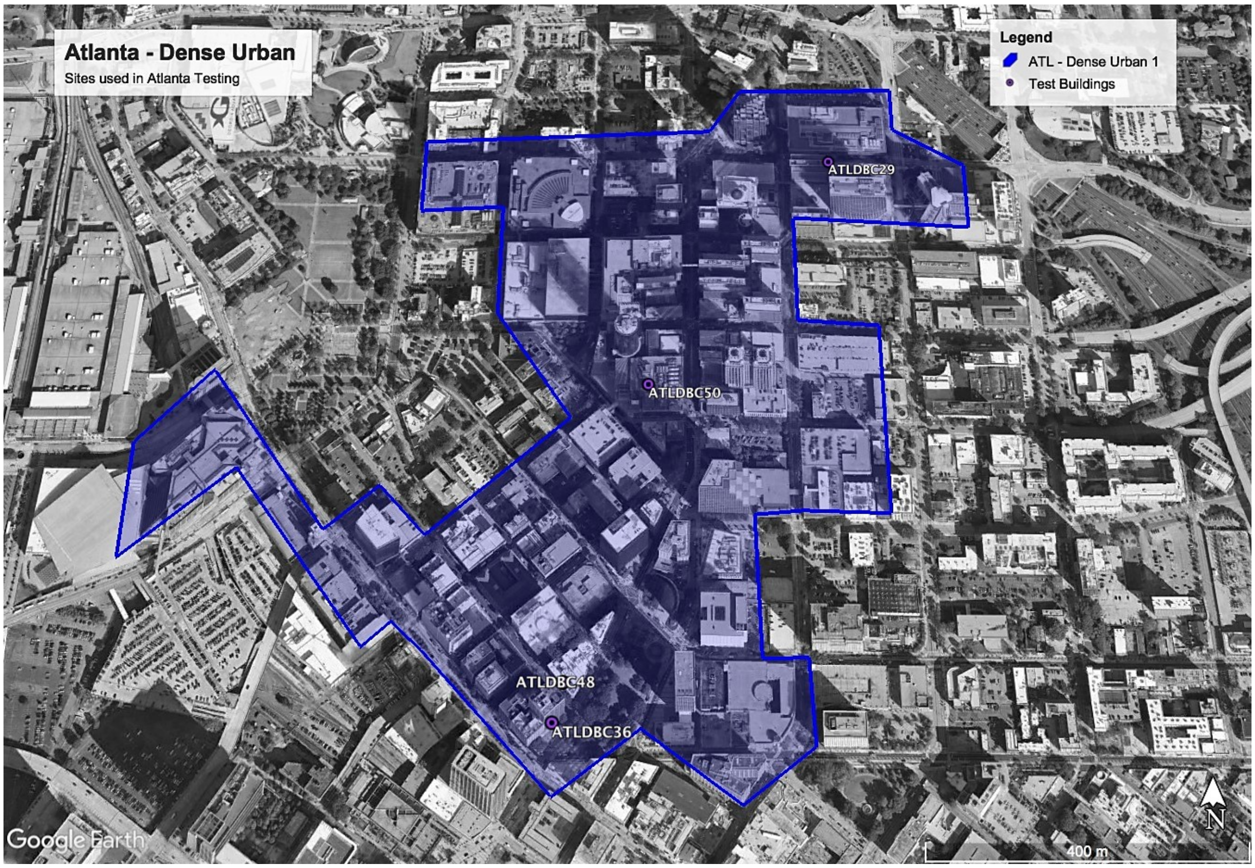



**Figure 8.1 Dense Urban Atlanta building locations**

[3] Test Bed and Monitoring Regions Definition and Methodology (ATIS-0500031.v002). © 2016 Alliance for Telecommunications Industry Solutions (ATIS). A copy may be obtained via https://www.atis.org/docstore/product.aspx?id=28279.

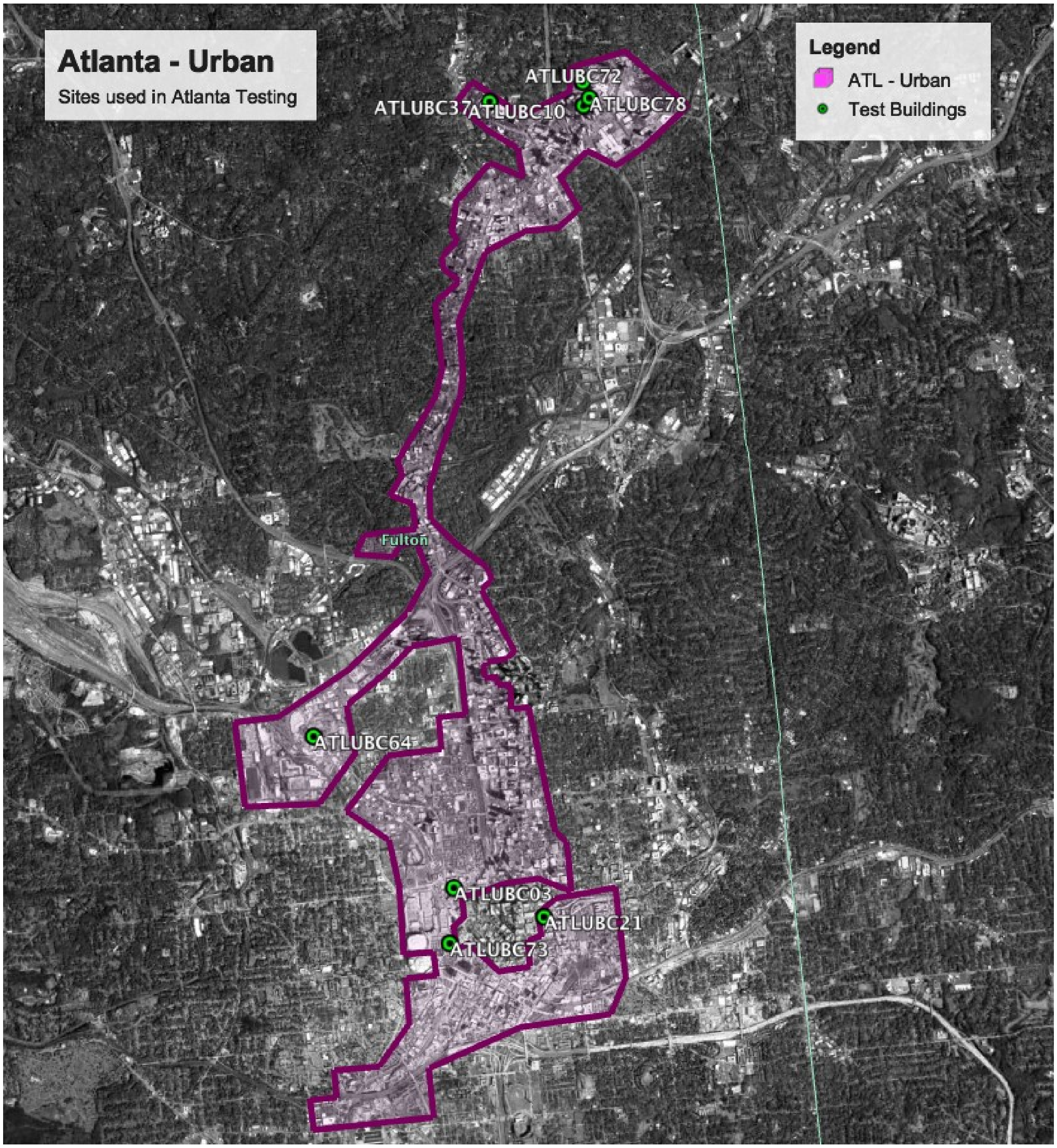



**Figure 8.2 Urban Atlanta building locations**

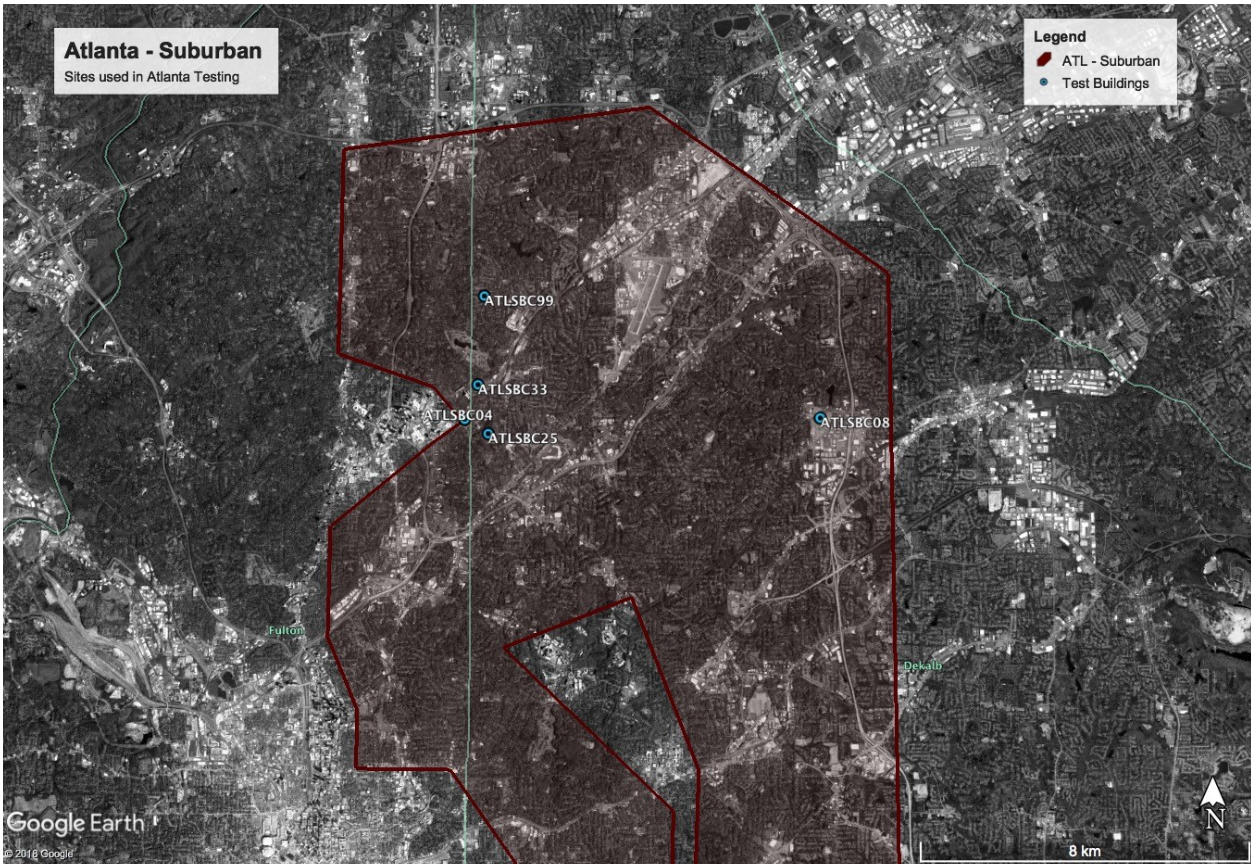



**Figure 8.3 Suburban Atlanta building locations**

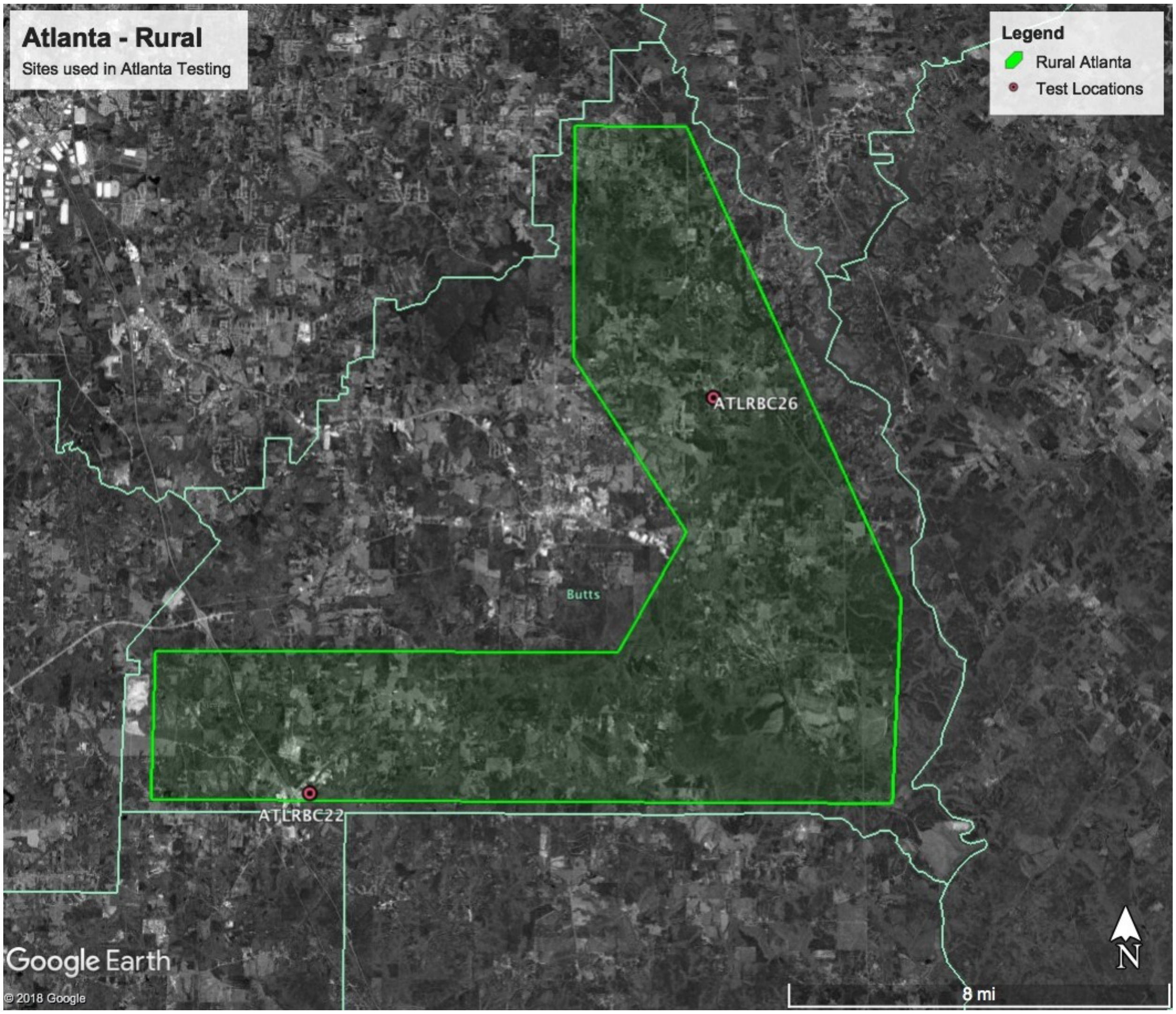



**Figure 8.4 Rural Atlanta building locations**

### 8.3.2 Chicago

Table 8.3 shows the distribution of buildings in Chicago, while Table 8.4 lists the morphology and characteristics for each building. Figures 8.5 shows the testing radius for the Chicago area. Figures 8.6 and 8.7 show the placement of the test buildings within the boundaries of each morphology polygon in the Chicago region.

**Table 8.3 Chicago building morphology distribution for Stage Z**

| Market ID | Morphology | Building Count |
|---|---|---|
| **Chicago** | Dense Urban | 5 |
| **Chicago** | Urban | 5 |

**Table 8.4 Chicago building morphology and characteristics for Stage Z**

| Region | Building ID | Morphology | Use Category | Building Characteristics |
|---|---|---|---|---|
| Chicago | CHIDBC01 | Dense Urban | Residential | 20+ story steel/concrete frame stone/plaster finish w Glass |
| Chicago | CHIDBC02 | Dense Urban | Residential | 20+ story steel/concrete frame stone/plaster finish w Glass |
| Chicago | CHIDBC03 | Dense Urban | Commercial | 20+ story steel/concrete frame stone/plaster finish w Glass; sealed building |
| Chicago | CHIDBC04 | Dense Urban | Commercial | 20+ story steel/concrete frame w stone/plaster finish; sealed building |
| Chicago | CHIDBC05 | Dense Urban | Commercial/ Residential (Hotel) | 20+ story steel/concrete frame stone/plaster finish w Glass; sealed building |
| Chicago | CHIUBC06 | Urban | Residential | 5-10 story steel/concrete frame brick or stone/plaster finish |
| Chicago | CHIUBC07 | Urban | Residential | 20+ story steel/concrete frame stone/plaster finish w Glass |
| Chicago | CHIUBC08 | Urban | Commercial | 5 - 10 story steel/concrete frame w brick and glass exterior; sealed building |
| Chicago | CHIUBC09 | Urban | Residential | 20+ story steel/concrete frame w stone/plaster finish w glass |
| Chicago | CHIUBC10 | Urban | Commercial | 8 story brick building |


**Figure 8.5 Chicago Test Area Overview (5-mile radius of downtown)**


**Figure 8.6 Chicago Dense Urban Test Locations**

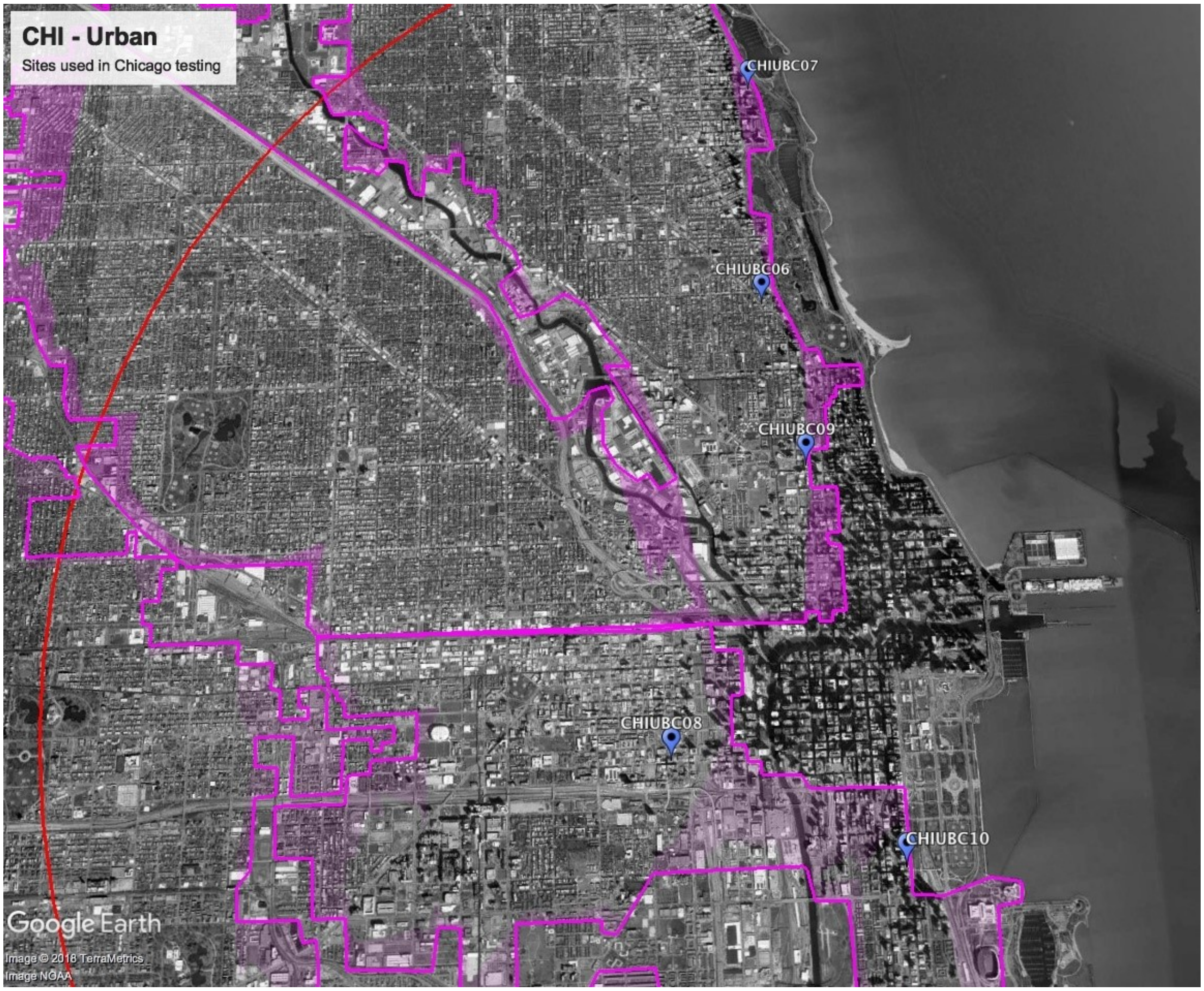



**Figure 8.7 Chicago Urban Test Locations**

(Note: urban Chicago polygons are denoted by the magenta boundaries)

### 8.3.3 San Francisco

Table 8.5 shows the distribution of building morphologies. Table 8.6 lists the morphology and characteristics for each building. Figures 8.8 through 8.12 show the placement of the test buildings within the boundaries of each morphology polygon in the San Francisco region.

**Table 8.5 SF building morphology distribution for Stage Z**

| Market ID | Morphology | Building Count |
|---|---|---|
| **San Francisco** | Dense Urban | 5 |
| **San Francisco** | Urban | 6 |
| **San Francisco** | Suburban | 6 |
| **San Francisco** | Rural | 2 |

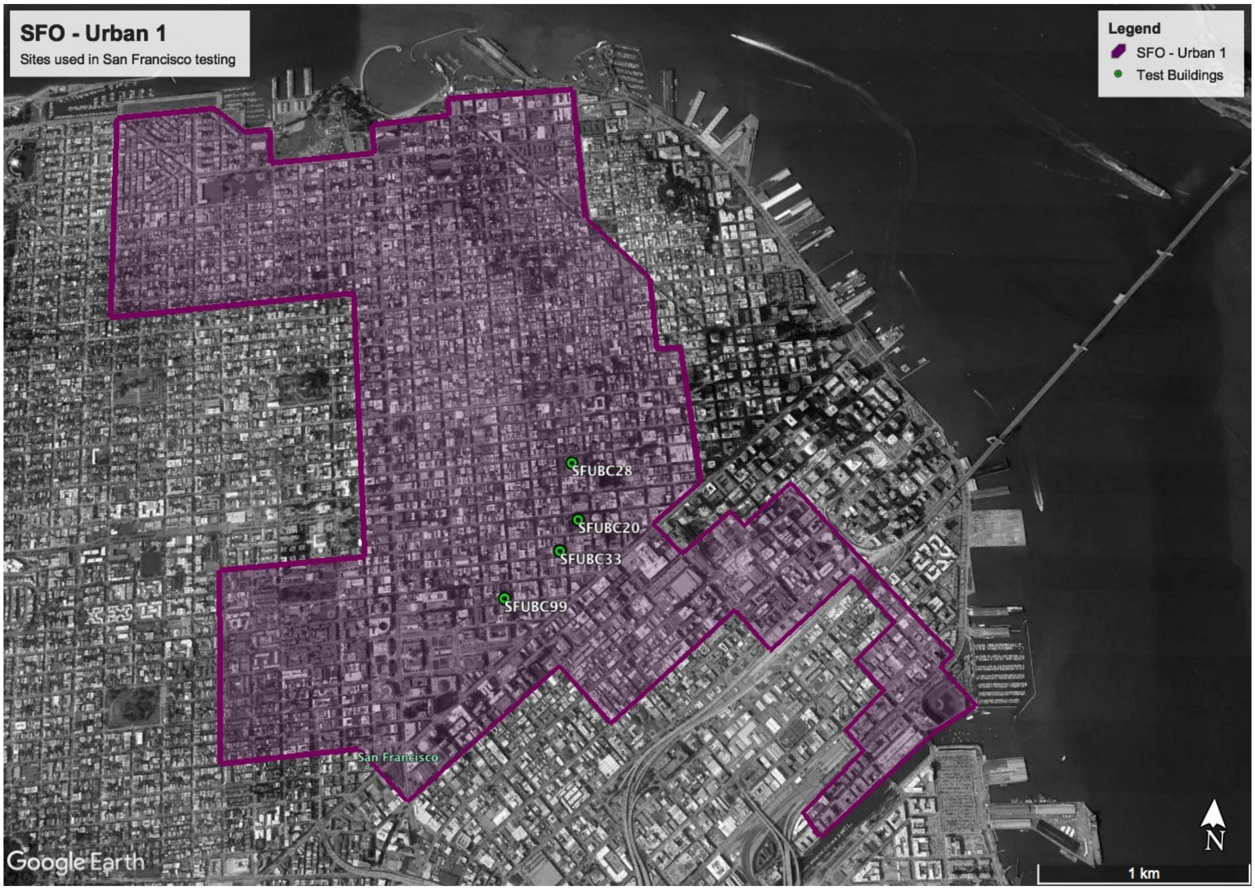
**Table 8.6 SF building morphology and characteristics for Stage Z**

| Region | Building ID | Morphology | Use Category | Building Characteristics |
|---|---|---|---|---|
| San Francisco | SFDBC08 | Dense Urban | Commercial | 20+ story steel/concrete frame w stone/plaster finish |
| San Francisco | SFDBC12 | Dense Urban | Commercial | 5-12 story steel/concrete frame brick veneer or stone/plaster finish |
| San Francisco | SFDBC16 | Dense Urban | Commercial | 20+ story steel with predominantly glass exterior; sealed building |
| San Francisco | SFDBC21 | Dense Urban | Commercial/ Residential (Hotel) | 20+ story steel/concrete frame stone/plaster finish w glass |
| San Francisco | SFDBC25 | Dense Urban | Commercial | 4-6 story mixed use commercial center surrounded by high rises |
| San Francisco | SFDBC73 | Dense Urban | Commercial | 20+ story steel/concrete frame w stone/plaster finish; sealed building |
| San Francisco | SFUBC02 | Urban | Commercial | 7-15 story concrete/plaster or similar finish |
| San Francisco | SFUBC14 | Urban | Commercial/ Residential (Hotel) | 20+ story steel/concrete frame w/wood, glass or other exterior materials; sealed |
| San Francisco | SFUBC20 | Urban | Commercial/ Residential (Hotel) | 20+ story commercial high-rise concrete/plaster w glass; sealed building |
| San Francisco | SFUBC28 | Urban | Commercial | 5-10 Story older building; sealed |
| San Francisco | SFUBC33 | Urban | Residential | 3-5 story plaster and brick veneer exterior apartment building |
| San Francisco | SFUBC99 | Urban | Commercial | 7-15 story concrete/plaster or similar finish |
| San Francisco | SFSBC24 | Suburban | Residential | 2-3 story wood framing condo complex |
| San Francisco | SFSBC46 | Suburban | Public | 2 Story larger newer building; sealed building |

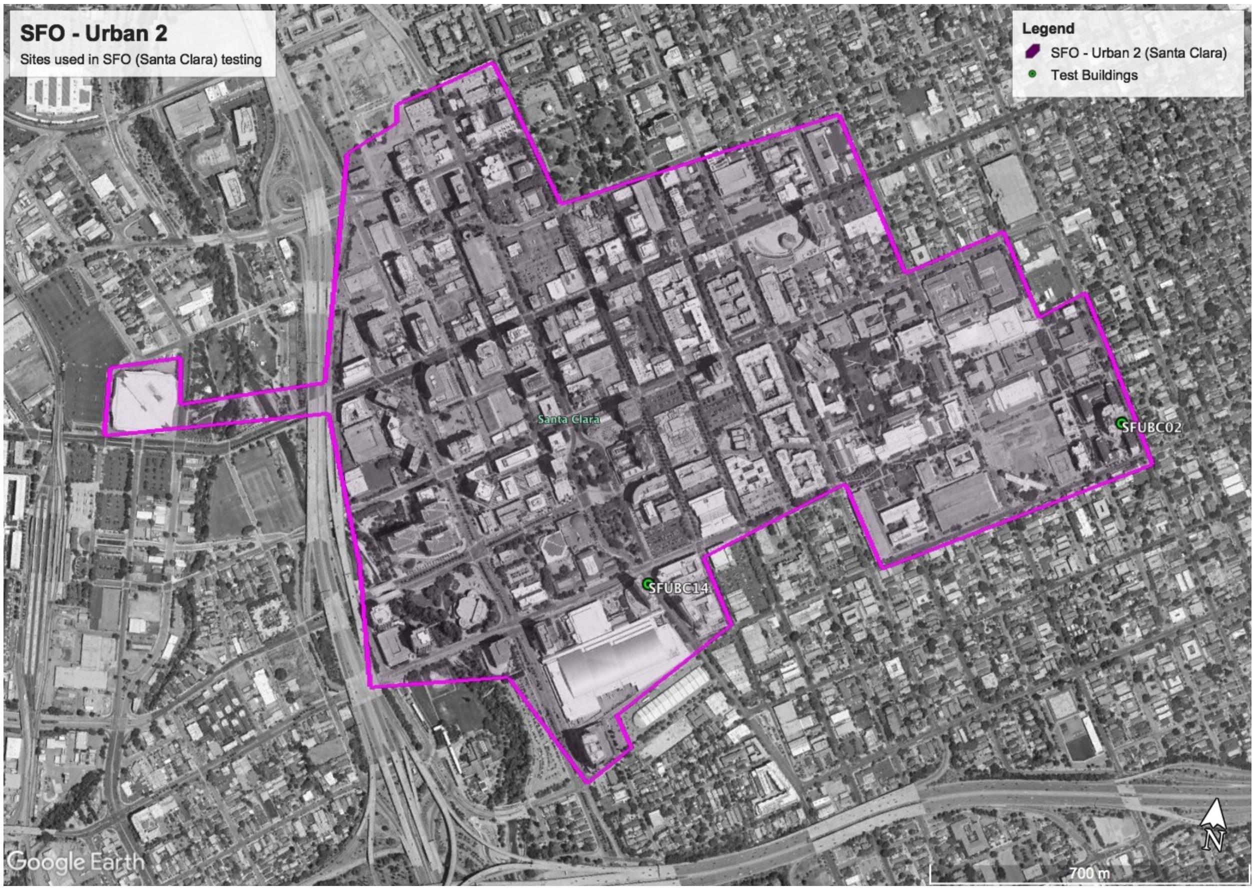
| | | | | |
|---|---|---|---|---|
| San Francisco | SFSBC47 | Suburban | Public | 2-story single structure-plaster or stucco |
| San Francisco | SFSBC72 | Suburban | Commercial | 5-10 story newer office building; sealed building |
| San Francisco | SFSBC91 | Suburban | Residential | 7-15 story concrete/plaster or similar finish |
| San Francisco | SFSBC94 | Suburban | Commercial/ Residential (Hotel) | 7-15 story newer building |
| San Francisco | SFRBC29 | Rural | Residential | 2-3 story cabin or chalet in foothill area |
| San Francisco | SFRBC50 | Rural | Commercial | 2 story (or equivalent height) retail/office/bank building in tourist oriented small town |

The following figures show the building locations within the test bed polygons. The polygons in these figures, Figures 8.8 through 8.12, are reproduced from ATIS-0500031.v002 with permission from the Alliance for Telecommunications Industry Solutions (ATIS). No buildings were identified within the Rural #1, Flat Agricultural test bed polygon from ATIS-0500031.v002.

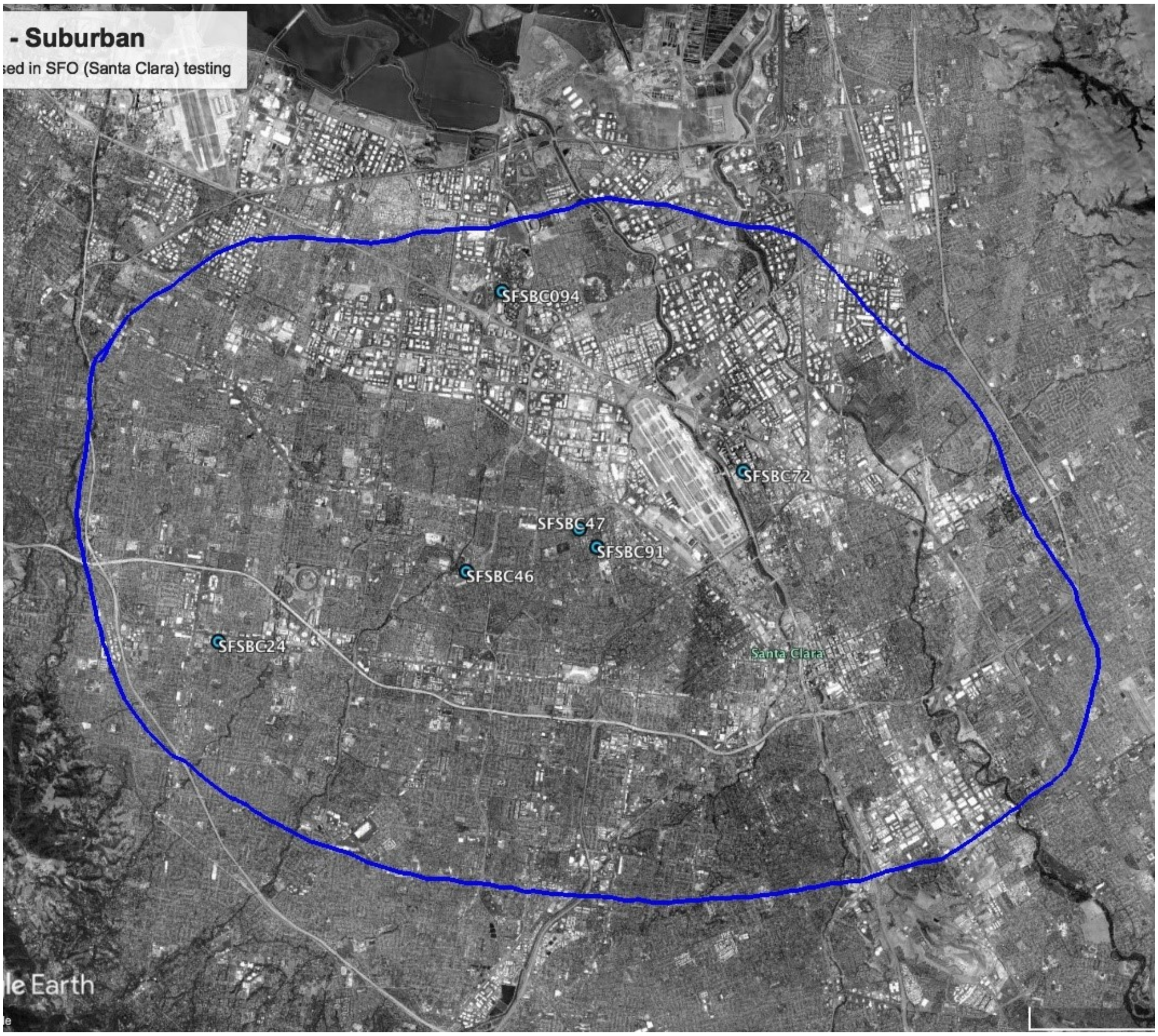

**8.8 San Francisco Dense Urban Test Locations**



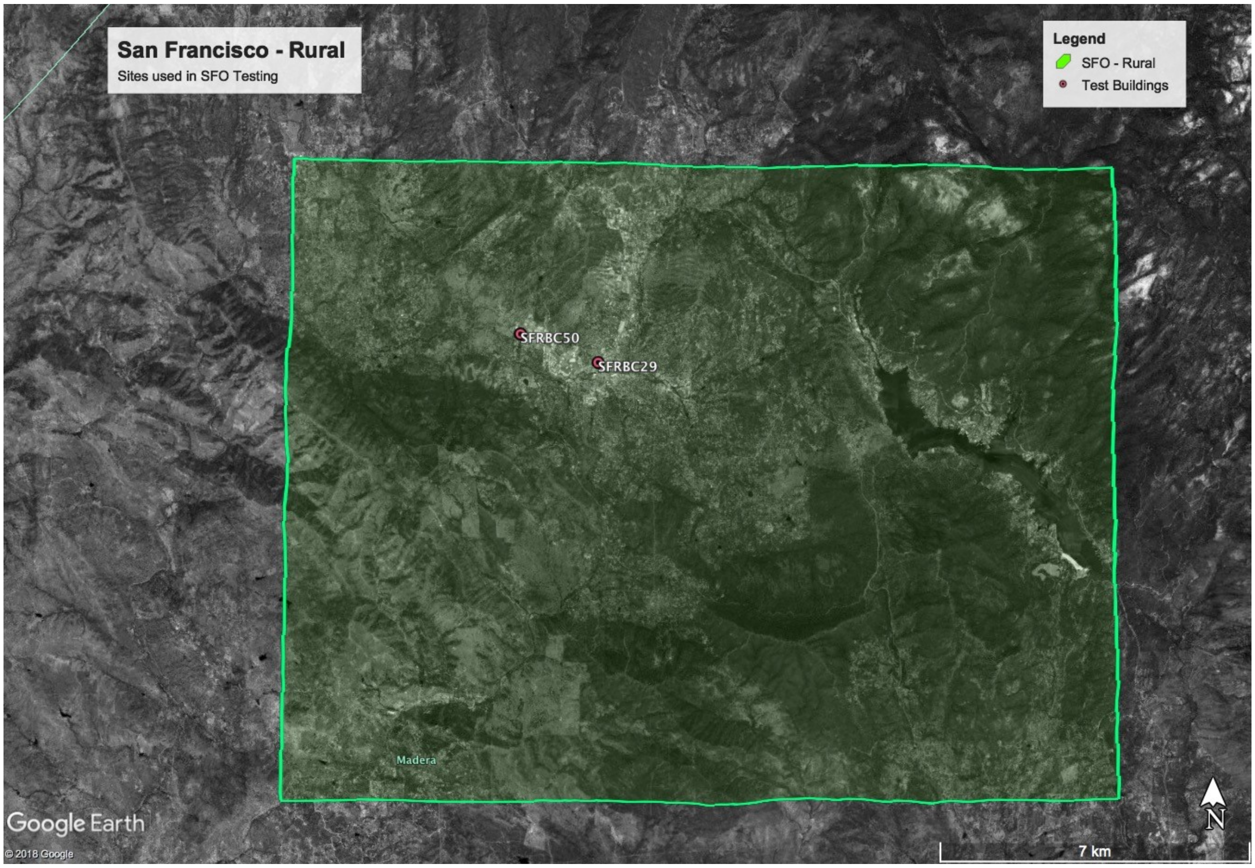

**8.9 San Francisco Urban Test Locations (Urban 1 – SFO)**




**8.10 San Francisco Urban Test Locations (Urban 2 – San Jose)**




**8.11 San Francisco Suburban Test Locations**




**8.12 San Francisco Rural Test Locations**

## 8.4 Ground Truth Determination Process

The test buildings were approved by the TAC and test points were selected by FES and approved by the ATIS Program Manager. Subsequently, FES performed ground truth surveys for measuring reference location ground truth. These measurements were done based on Section 7 of ATIS-0500013, which contains a detailed description on how to determine the ground truth for indoor test points.

FES contracted professional land survey companies with experience in indoor surveying and local knowledge to perform precise ground truth surveys of indoor test points. The surveyors used 3D laser survey/land survey techniques coupled with current industry technologies to collect highly accurate survey X, Y, Z (Latitude, Longitude, Elevation) coordinate data to within (+/- 2cm) of the designated test points inside the building locations.

Table 8.7 contains a sample of final survey data for a single test point.

**Table 8.7 Sample of ground truth survey data for test point**

| | |
|---|---|
| **Building** | ATLSB88 'XYZ Manufacturing' Suburban Atlanta |
| **Test Point** | 1 (ATLSBC8801) |
| **Description** | Interior test point located on the 1st Floor down Management Office hallway |
| **LAT, LONG** | 33.8XXXXX, -84.2XXXXX |
| **Elevation** | 1029.74' (313.8650 Meters) per Geoid 12b<br>WGS84 ellipsoid height = 932.86' (284.335 Meters) |

## 8.5 Location Technologies Under Test

Section 8.5 provides a brief overview of each participant in this stage of Z-axis testing and the required configurations for set up.

### 8.5.1 NextNav LLC

NextNav's location technology solution relies on its MBS managed network and infrastructure. MBS is a standards-based technology supported in 3GPP (Release 13 onwards), and in Open Mobile Alliance's (OMA) SUPL 2.0.3 specification. NextNav operates its MBS network using Part 90 Multilateration Location and Monitoring Service licenses held by a NextNav affiliate (Progeny LMS, LLC). NextNav Beacons, where deployed, broadcast a variety of information required for the device to compute its location accurately including: location, time, and other measurements useful for the computation of barometric-based altitude to mobile devices. Certain Beacon information and device measurements are also sent back to the NextNav location server. NextNav combines these sources of information to generate a Z-location estimate.

The NextNav solution currently is not available on consumer handsets, and therefore required a software application, which was installed on the test handsets by FES field technicians and configured for testing using NextNav specifications.

All interaction between the mobile device and the NextNav location server to produce Z-axis positions occurred in test transactions (simulated test calls) using proprietary data messages via the NextNav application. No actual call was placed to produce a Z-axis fix in this testing and standardized 9-1-1 signaling was not used.

NextNav's solution was tested in areas where its network has been deployed. For this reason, NextNav's solution was excluded from testing in the Chicago test region and the rural morphologies of Atlanta and San Francisco test regions. (See Section 8.8 for actual test point breakdown.)

#### 8.5.1.1 Test Hardware - NextNav

The test plan specified which types of handsets would be used and the various configurations for testing. A mix of new and somewhat older (used) commercially available handsets were used to simulate a mix of handset population, barometric sensor OEMs, as well as explore possible aging effects on performance.

**Table 8.8 Stage Z Test handsets used by NextNav**

| Handset Model | Handset Age | Barometric Sensor OEM | Carrier |
|---|---|---|---|
| Samsung Galaxy S8 | New | ST | AT&T |
| Samsung Galaxy S8 Plus | New | ST | Verizon |
| iPhone 7 | Used | Bosch | Verizon |
| iPhone 7 Plus | Used | Bosch | AT&T |
| iPhone 8 | New | Bosch | AT&T |
| iPhone 8 Plus | New | Bosch | Verizon |

Table 8.9 shows handset OS version and radio technology configuration preferences based on the information provided by NextNav. The table reflects configuration for a single test region and assumes configurations are mirrored in the other regions.

**Table 8.9 Stage Z Handset Model and Test Mode for NextNav**

| Model Name | Operating System | Technology Locking/Provisioning |
|---|---|---|
| Samsung Galaxy S8 | Android | LTE/WCDMA/Auto |
| Samsung Galaxy S8 Plus | Android | LTE/WCDMA/Auto |
| iPhone 7 | iOS | LTE/WCDMA/Auto |
| iPhone 7 Plus | iOS | LTE/WCDMA/Auto |
| iPhone 8 | iOS | LTE/WCDMA/Auto |
| iPhone 8 Plus | iOS | LTE/WCDMA/Auto |

Note: NextNav System application required LTE but per NextNav, Phone was kept in Auto mode

#### 8.5.1.2 Test Software - NextNav

Although the test handsets were consumer grade models with no hardware modifications, the NextNav solution is not commercially available on consumer handsets and required a software application to be installed for testing. The NextNav client software consists of two applications: NextNav Client Software Application (NNClientSW) and NextNav Client Test Application (NNAltitudeTest). Both applications were provided separately to FES by NextNav engineers and installed on the test devices by FES. FES configured the test devices per NextNav instructions and performed a small amount of user familiarization calls within the test area to ensure end-to-end functionality prior to formal testing.

In addition to the software applications on the device, the following general requirements were specified by NextNav for configuring the test handsets to work with their altitude location system and were completed by FES.

- Android Devices - Operating System software version 7.0 or higher.
  Operating System upgraded to last commercially available version as provided by carrier at time of stage start.
- Handsets configured with a Google Play Store account.
- Google Play Services updated to most currently available version. (v 11.9.51 or newer).
- Android settings configured per NextNav instructions with Developer Mode enabled for additional functionality.
- iOS Devices - Operating System software version 11.0 or higher.
- iOS UDID (Universal Device ID) and ADID (Advertising Identifier) shared with NextNav for tracking and matching to device IMEI.
- iOS settings configured per NextNav instructions with special attention to Location Services ENABLED and Limit Ad Tracking DISABLED.
- NNClientSW installed and all permission requests allowed.
- NNAltitudeTest installed, all permission requests allowed, and app configured for testing.

It should be noted that some of these configuration settings were intended to enable testing of the NextNav system and were not typical of what would be expected of a consumer new “out of the box” set up and experience.

#### 8.5.1.3 Special Test Set Up Notes - NextNav

NextNav requested the following special provisions prior to and during testing in market.

1. Five (5) test calls at the FES office in Blue Bell, PA. Calls were a combination of indoors and outdoors.
2. Once in test regions, handsets were used for an additional ten (10) simulated test calls (location transactions) in a variety of locations (indoors, outdoors, ground level or at altitude) over a two-day period. Test calls were not made at formal test buildings or points.
3. Handsets were kept powered on the entire time (as much as possible) while in market and during the stage. FES field technicians were requested to carry the handsets with them in the course of personal movement around the test regions (off time, dinner, overnight lodging, travel within region, etc.).
4. During formal testing, NextNav would monitor test calls daily to ensure delivery of calls and test results.

One purpose of the initial five test calls at FES offices and the ten test calls in-market was to ensure system functionality, including end-to-end data collection. They also enabled the FES test technicians to become familiar with the NextNav application.

The initial test calls, as well as the two-day “soak-in” period of the test handsets while in-market, are also understood to support the function of calibrating the biases in the barometer sensors of the test handsets. Maintaining the handsets powered on 24/7 with the NextNav application running in the background was also to enable performing on-going background calibration of the barometric sensor bias in each handset.

The rationale provided by NextNav for such operational requirements is that their technology would eventually be embedded in both hardware and middleware in the handset, and would operate in the background. Maintaining the handsets powered-on continuously is also considered a normal way of operating handsets for many real users today.

Situations where a handset would be turned off and subsequently powered back on were outside the scope of the testing.

### 8.5.2 Polaris Wireless

The Polaris Wireless Hybrid Location Engine (HLE) Z-axis hybrid is a software-based solution that utilizes data from the handset including handset GPS, raw GPS, Barometer, ECID, and WiFi. These measurements are collected in the Polaris Wireless location Server where these sources are combined, and proprietary algorithms are applied to generate a hybrid Z-location estimate.

Polaris Wireless originally proposed that its complete hybrid solution be put under test. It also intended to collect test and calibration data within test buildings in each Test Region in advance of the Z-axis test bed campaign. The TAC asked Polaris Wireless not to enter potential test buildings in advance of the test since doing so would not be representative of the process that can be scaled to the remainder of the country and therefore would not render a fair assessment of the technology. Given this restriction, Polaris Wireless opted not to include the 3D WiFi component of their hybrid location solution and tested only the barometric component.

Polaris Wireless asserts that its barometric-based Z-axis capability was initially commercially available in the market through an over-the-top application for iOS and Android devices and was demonstrated to the FCC in 2014. Nevertheless, the Polaris Wireless solution under Stage Z testing currently is not available on consumer handsets and therefore required a software application, which was installed on the test handsets by FES field technicians and configured for testing using Polaris Wireless specifications.

The Polaris Wireless z-axis solution includes the ability for an application to run in the background of the device with the purpose of measuring device and barometric sensor bias over time – continuous opportunistic (background) calibration. Device and sensor bias are key sources of location error, and the Polaris Wireless software includes proprietary algorithms to calibrate and compensate for these sensor biases, which may improve accuracy performance. Polaris Wireless chose to disable this feature for Stage Z testing based on their interpretation of available procedures and guidance from the Test Bed's TAC and Program Manager. (The Test Bed provided the same procedure to both NextNav and Polaris). As such, Polaris Wireless results in the current test campaign may underestimate the performance results that might be achieved using an effective continuous (background) calibration algorithm for each individual mobile device.

#### 8.5.2.1 Test Hardware – Polaris Wireless

The test plan specified which types of handsets would be used and the various configurations for testing. A mix of older used and new commercially available handsets were used to simulate the general population mix, handset and barometric sensor OEMs as well as explore aging effects on performance.

**Table 8.10 Stage Z Test handsets used by Polaris Wireless**

| Handset Model | Handset Age | Barometric Sensor OEM | Carrier |
|---|---|---|---|
| Sony Xperia XZ1 Compact | New | Alps Electric | AT&T |
| Huawei Mate 9 | New | ST | AT&T |
| Samsung Galaxy Note 8 | Used | ST | Verizon |
| Samsung Galaxy S8 | Used | ST | Verizon |
| Motorola Z2 Force | New | Bosch | AT&T |
| Essential PH-1 | New | Bosch | Verizon |

Table 8.11 shows handset OS version and radio technology configuration preferences based on the information provided by Polaris Wireless. The table reflects configuration for a single test region and assumes configurations are mirrored in the other regions.

**Table 8.11 Stage Z Handset Model and Test Mode for Polaris Wireless**

| Model Name | Operating System | Technology Locking/Provisioning |
|---|---|---|
| Sony Xperia XZ1 Compact | Android | LTE/WCDMA/Auto |
| Huawei Mate 9 | Android | LTE/WCDMA/Auto |
| Samsung Galaxy Note 8 | Android | LTE/WCDMA/Auto |
| Samsung Galaxy S8 | Android | LTE/WCDMA/Auto |
| Motorola Z2 Force | Android | LTE/WCDMA/Auto |
| Essential PH-1 | Android | LTE/WCDMA/Auto |

Note 1: The Polaris Wireless system application requires LTE but per Polaris, Phone may be kept in Auto mode
Note 2: The Polaris Wireless application was not available for Apple iOS.

It is worth noting that the Polaris Wireless technology was not tested on iOS devices and that the Polaris Wireless test application was not available for iOS handsets. Polaris Wireless reports that its test application was designed for the complete Polaris Wireless HLE Z-axis hybrid solution that includes WiFi. Raw measurements required for this solution are restricted on iOS handsets, so the test application was written specifically for Android devices. If the WiFi component of the z-axis hybrid was not proposed for testing by Polaris Wireless or was removed earlier in the proposal evaluation process, Polaris asserts that its test application could have been written to support both Android and iOS devices for z-axis location.

#### 8.5.2.2 Test Software – Polaris Wireless

Although the test handsets were consumer grade models with no hardware modifications or needs, the Polaris Wireless solution under test is not commercially available on consumer handsets and required a software application to be installed for testing. The Polaris Wireless client software consisted of one application: Polaris Wireless Data Logger App (.apk). This test application collects and streams handset location and barometric measurements, together with optional measurements of raw GNSS, WiFi, and ECID, back to the Polaris Wireless location server in order to combine the various sources of information to generate a Z-axis location estimate.

The Polaris Wireless solution is server-based and relies on standard interfaces. Its test application sends measurements from the handset to the server for calibration of the barometric sensor in the mobile device in the same way as the test calls are made.

The test application was provided separately to FES by Polaris Wireless engineers and installed on the test devices by FES. FES configured the test devices per Polaris Wireless' instructions and performed a small amount of user familiarization and initialization calls at FES' location in Pennsylvania. Additionally, in each test region a minimum of 10 calls from each handset were placed at various locations within the test areas. This was to ensure end-to-end functionality and allow the test application to perform whatever initial functions are needed prior to formal testing.

While the solution under test did not require in-market calibration, the Polaris Wireless proposal did include a request for in-building (setup) calibration through their test application. The TAC, however, determined that such in-market building (setup) calibration, which involved placing tens of initial indoor test calls in the test regions, did not reflect real world usage conditions. Therefore, the Polaris Wireless solution did not use any in-market calibration procedure between initial setup and any location test request, and the continuous opportunistic (background) calibration feature was also disabled by Polaris Wireless for all testing. Continuous opportunistic (background) calibration procedures could potentially improve location accuracy performance, and therefore their absence may have had an impact on the performance results of the Polaris Wireless solution under test.

All interaction between the mobile device and the Polaris Wireless location server to produce Z-axis positions occurred in test transactions (simulated test calls) using vendor specific data messages via the Polaris Wireless test app. No actual call was placed to produce a Z-axis fix in this testing and standardized 9-1-1 signaling was not used.

In addition to the software applications on the device, the following general requirements were specified by Polaris Wireless for configuring the test handsets to work with their altitude location system and were completed by FES.

- Android Operating System - software version 4.4.4 or higher
  Operating System upgraded to last commercially available version as provided by carrier.
- Handsets configured with a Google Play Store account.
- Google Play Services updated to most currently available version.
- Android settings configured per Polaris Wireless specifications with Developer Mode enabled.
- Polaris Wireless Datalogger App (.apk) installed and configured for testing.

#### 8.5.2.3 Special Test Set Up Notes – Polaris Wireless

In addition to the handset configuration, Polaris Wireless engineers requested the following special provisions prior to and during testing in market.

1. Five (5) test calls at the FES office in Blue Bell, PA. Calls were a combination of indoors and outdoors.
2. Once in test regions, handsets were used for an additional ten (10) simulated test calls (location transactions) in a variety of locations (indoors, outdoors, ground level or at altitude) over a two-day period. Test calls were not made at formal test buildings or points.
3. During formal testing, Polaris Wireless would monitor test calls daily to ensure delivery of calls and test results.
4. Polaris Wireless did not require two days of handset operation in-market prior to starting the formal stage.

5. Polaris Wireless did not request the handsets remain powered on the entire time while in market and during the stage. The handsets were left powered on in general.

These provisions are believed to be necessary for the Polaris Wireless test application to facilitate background calibration of the barometer sensor biases in the test handsets.

## 8.6 Performance Attributes Tested and Results Reported

Testing and reporting requirements for Stage Z testing differ from previous geodetic test stages. The intent of this initial Z-axis testing is to assess altitude measurements of solutions using a compensated barometric pressure system. Other solutions that may or may not use barometric pressure sensors may be tested in future Z-axis campaigns (when such solutions are ready to be tested).

### 8.6.1 Z-axis Technology Accuracy Statistics

Vertical Location Accuracy is defined as the error between the reported altitude location of the device, as provided by the Stage Z vendor's location system under test, and the surveyed ground truth position of the test location (determined through a precise land survey). For both participants in this stage, the delivered altitude (Z) and computed vertical distance error in meters are reported.

The detailed results provided to each test participant include the following for each test handset, at a test point, in a test building, and aggregated per morphology:

- Average (arithmetic mean) altitude error (can be positive or negative in meters)
- Standard deviation of altitude error (in meters)
- Average (arithmetic mean) vertical distance error (absolute value of altitude error; always positive)
- $67^{th}$, $80^{th}$ and $90^{th}$ percentiles of vertical distance error (in meters)

Cumulative Distribution Functions (CDF) for the vertical distance error are also provided per building and morphology.

The summary results also include these statistics but aggregated in a table per building and per morphology along with CDFs for each morphology and all morphologies combined.

### 8.6.2 X/Y Accuracy Statistics

Strictly for informational purposes, the results for the error in the horizontal location computed by the handset's OS or by the vendor's server are also included, along with the error's 67$^{th}$, 80$^{th}$, and 90$^{th}$ percentiles in meters. The horizontal error CDF is also included for each building in the detailed results provided to the participants.

### 8.6.3 Reported Uncertainty

The vertical uncertainty reported by both participants has been included in the detailed per-building logs and in the results summary. The vertical uncertainty metric reported by the technology vendors represents the altitude uncertainty with 90% confidence.

### 8.6.4 Successful Test Yield

The number of initiated, completed and successfully correlated test transactions (simulated calls) are reported. Overall successful test yield is determined as the percentage of tests with delivered locations. Given the artificial nature of the test where location transactions are directed to the servers of the test participants, yield is often 100% and not meaningful in representing a true operational location system in a wireless carrier's network.

### 8.6.5 Time to Fix (Latency)

This is the time to obtain the first computed caller location as calculated by establishing the precise time for call initiation (an equivalent initiation event since the technology vendor's test configuration did not support the placement of an actual test call) and the reported location time stamp. For both technology vendors this number is essentially constant by design at around 25 seconds. It is informative but not a meaningful representation of how an operational location system in a wireless carrier's network will behave.

### 8.6.6 Weather Conditions

The detailed result for each test building include a tabulation of the prevailing weather conditions from three reference weather stations in the test area. This includes temperature, atmospheric pressure, wind speed and wind gusts. Min-Max results are also provided for each of these quantities.

### 8.6.7 Reference Barometric Trend

The detailed results for most test buildings include also a barometric pressure trend plot from the reference barometer on the test cart. It is used as a cross check for various aspects of data collection and test results.

## 8.7 Data Collection Method

Testing was closely monitored by FES engineers, ensuring that all testing was completed per the specifications enclosed within the Participant Test Plan(s). Location log files were emailed from participants to FES engineers. FES engineers analyzed all field test data and verified that the test data met acceptance criteria.

FES field testers kept daily logs that included observed conditions and any issues encountered. FES field testers also recorded the test order, location and timestamps to aid with record matching and post processing.

Upon validation of the test call logs from a given test point, if all test points were not yet complete, the FES tester was moved to another available test point at that test building. When all test points were complete for a test building and all data verified, the tester was moved to the next test building ready for testing.

During both testing and post processing, FES engineers performed audits for each test point ensuring data accuracy and completeness. If it was discovered that data collected at a particular point did not meet all data collection requirements and a re-test was required, the tester was redeployed to the location for re-testing.

Logs from the participant test applications provided all location transaction data sent back to the participant's servers for collating reported location information. All test data is summarized in a reporting workbook of raw results, correlated with FES time and ground truth records, providing an overview of system performance. Test results are supplemented by a list of handset types (matched by IMEI) and building information matched by test point ID.

## 8.8 Distribution of Actual Test points

The target number of total test points in each test region has been provided in Section 7.2 as 120 in each of San Francisco and Atlanta, and 75 in Chicago. Acquisition of actual test points is a very challenging and costly endeavor impacted by willingness of building owners, managers and tenants to cooperate in the process.

As shown in Table 8.12, the actual test point totals were 121 in San Francisco, 117 in Atlanta and 84 in Chicago for a total of 312 test points, very close to the desired target of 315 test points.

**Table 8.12 Distribution of Actual Test Points in the Z-axis Test Campaign**

| Region | Morphology | # of buildings | # of test points | Polaris Wireless Tested | NextNav Tested |
|---|---|---|---|---|---|
| Atlanta | Rural | 2 | 8 | Y | N |
| Atlanta | Suburban | 5 | 22 | Y | Y |
| Atlanta | Urban | 8 | 55 | Y | Y |
| Atlanta | Dense Urban | 4 | 32 | Y | Y |
| San Francisco | Rural | 2 | 8 | Y | N |
| San Francisco | Suburban | 6 | 30 | Y | Y |
| San Francisco | Urban | 6 | 37 | Y | Y |
| San Francisco | Dense Urban | 5 | 46 | Y | Y |
| Chicago | Urban | 5 | 33 | Y | N |
| Chicago | Dense Urban | 5 | 41 | Y | N |
| | Total | 48 | 312 | | |

## 8.9 Data Handling and Confidentiality

Log files and results were segregated by test participant and processed by FES. Participants only received their own results.

Ground truth data was embargoed from participants as well as other project stakeholders, and only shared with the ATIS Program Manager.

# 9. Stage Z Testing – Summary of Results and Technical Analysis

This section contains a summary and details of the Z-axis accuracy results as well as quantitative assessment of Z-axis performance characteristics relative to a number of factors that affect its accuracy performance.

It is critical to note that the objective of this testing was to assess vertical location technologies under standard testing methodology; the objective was not to conduct a direct comparison of the performance of the vendor solutions. For the technologies under test, the devices were tested under similar standard testing methodology. It is, however, important to note that the two vertical location technologies tested are different in their approach to addressing various error sources encountered in estimating altitude, and, of necessity, in some aspects of the actual testing performed. The two solutions included different set-up and calibration capabilities. In addition, NextNav technology requires an overlay terrestrial beacon network to provide localized atmospheric pressure weather assistance data, and was not tested in the rural morphology and not tested in Chicago. Polaris utilized existing sources of localized atmospheric pressure weather data, and was not tested on iOS devices. As such, no conclusions regarding relative performance should be drawn by directly comparing the results of each participant.

The results are first summarized by morphology, by test region and overall. A host of corresponding CDFs are provided. Performance by individual handsets and a detailed analysis of residual handset biases are also presented due to their criticality. A technical assessment of the other factors that can impact Z-axis performance, including weather, in-building HVAC effects and longer term indoor variation, is also included, enabling an overall assessment of what is technically achievable with the technologies under test.

It should be noted that the app-based solutions used in this Stage Z testing would need to be turned into working, production solutions for all handsets before these technologies could be used for 9-1-1 calling. For 9-1-1, one cannot presume an app will exist on all phones. Instead, a standards-based approach, or handset platform-specific production implementations, needs to be deployed under the control of a real, production Location Server (E-SMLC), suitably augmented with Z-axis capabilities.

Additionally, the results documented in this report relied on calibration of the barometric sensor in the mobile devices, which had been performed by the applications provided by NextNav and Polaris Wireless. Thus, the calibration function also will need to be built into production solutions to achieve results equivalent to this testing. It is unclear to what degree existing standards support the signaling necessary to perform this function at scale nationally, thus expanded standardization or platform-specific implementations may also be required.

Furthermore, it is not clear at this point what software changes to the handset middleware and operating system may be needed to integrate the calibration functionality.

These pieces of the z-axis technology puzzle don't yet exist, and the timelines are at this point unknown.

## 9.1 Z-axis Location Accuracy Summary

This section includes the top-level summary results for both technology vendors (NextNav and Polaris Wireless) combined and broken out by morphology,

### 9.1.1 Overall Results

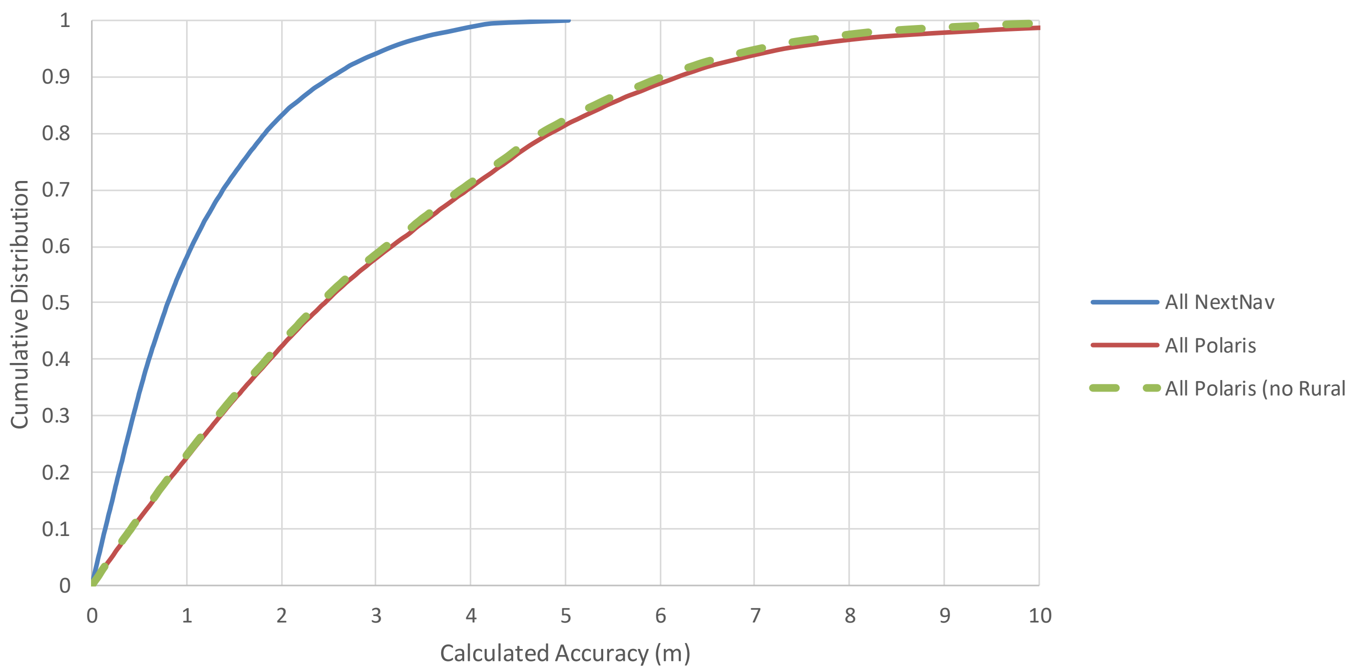



**Figure 9.1 Aggregated Vertical Accuracy CDF across all test data**

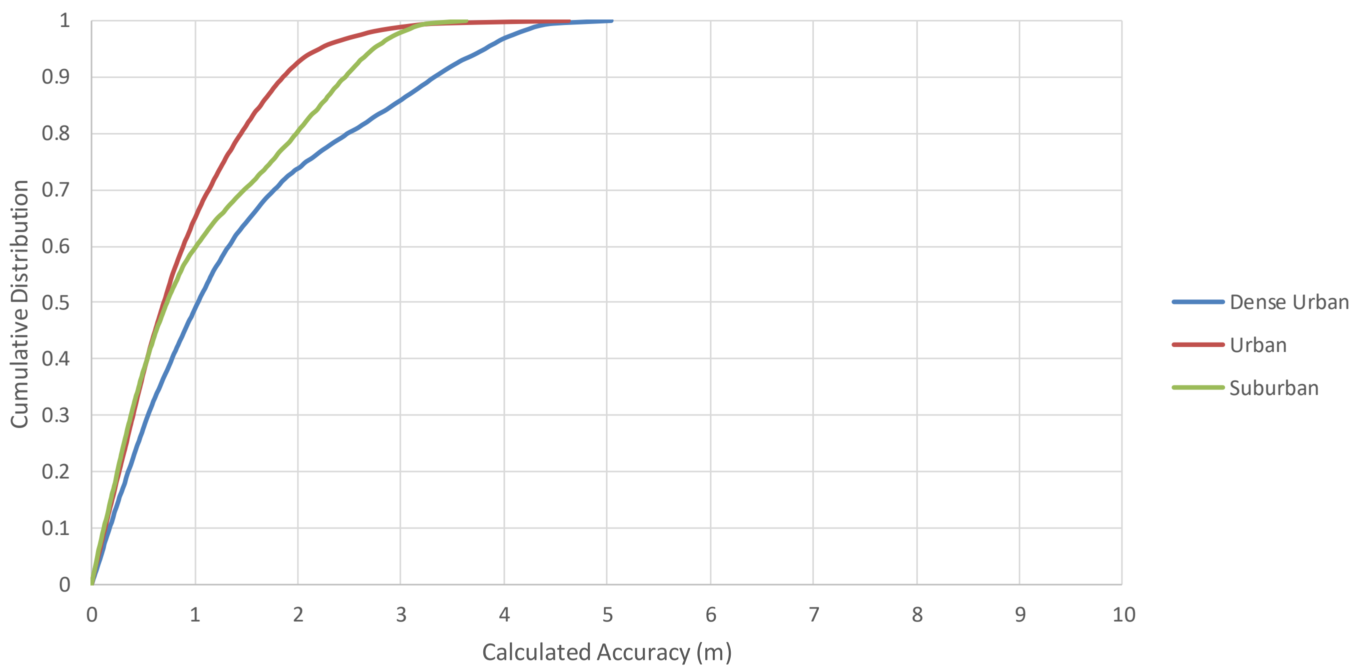



**Figure 9.2 NextNav Vertical Accuracy CDF per Morphology**

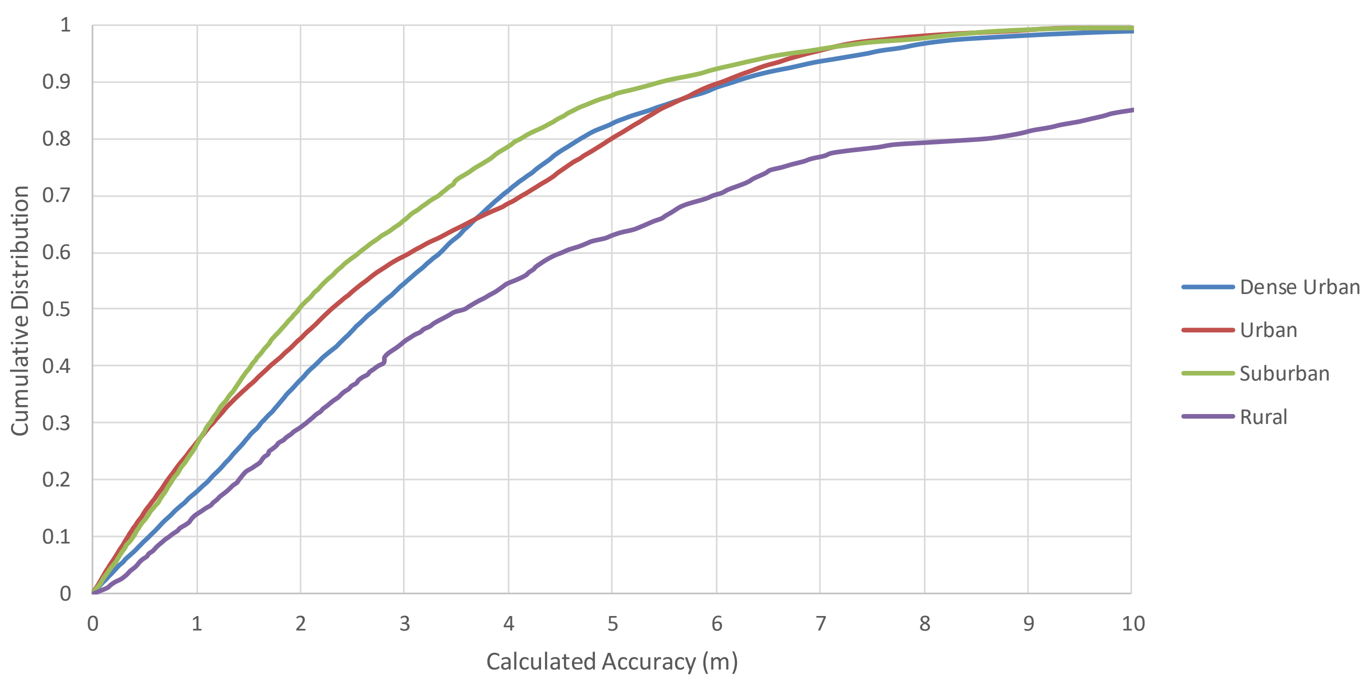



**Figure 9.3 Polaris Wireless Vertical Accuracy CDF per Morphology**

### 9.1.2 Dense Urban Morphology

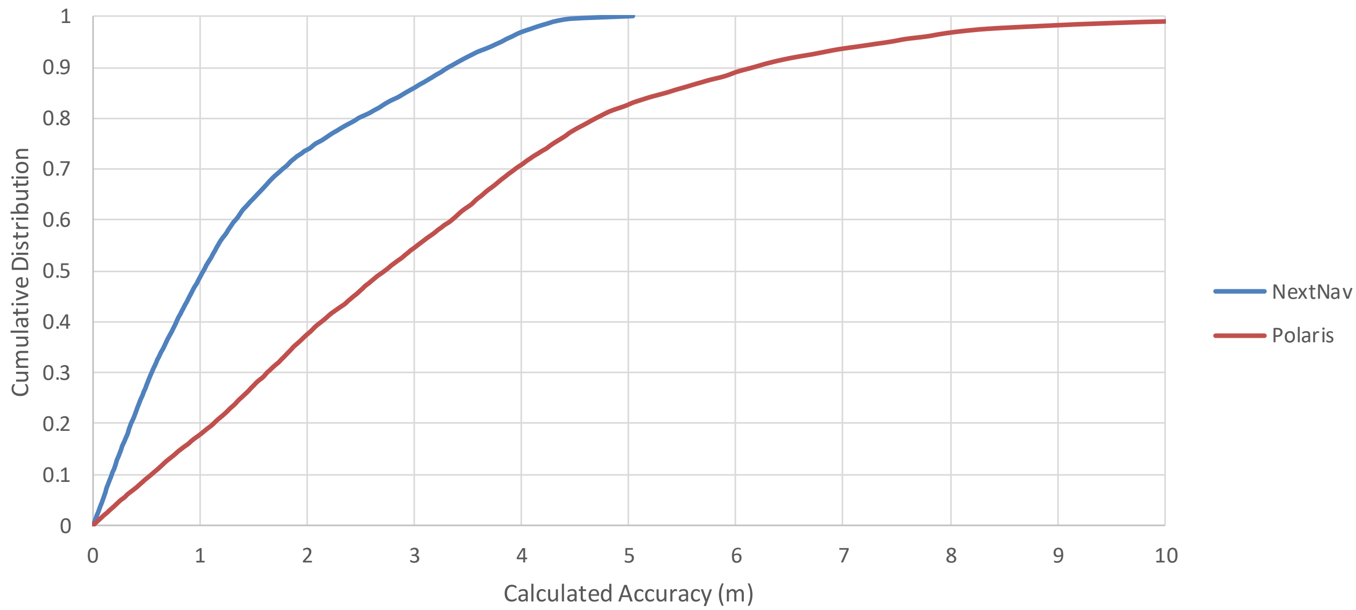



**Figure 9.4 Dense Urban Vertical Accuracy CDF by Technology Vendor**

### 9.1.3 Urban Morphology

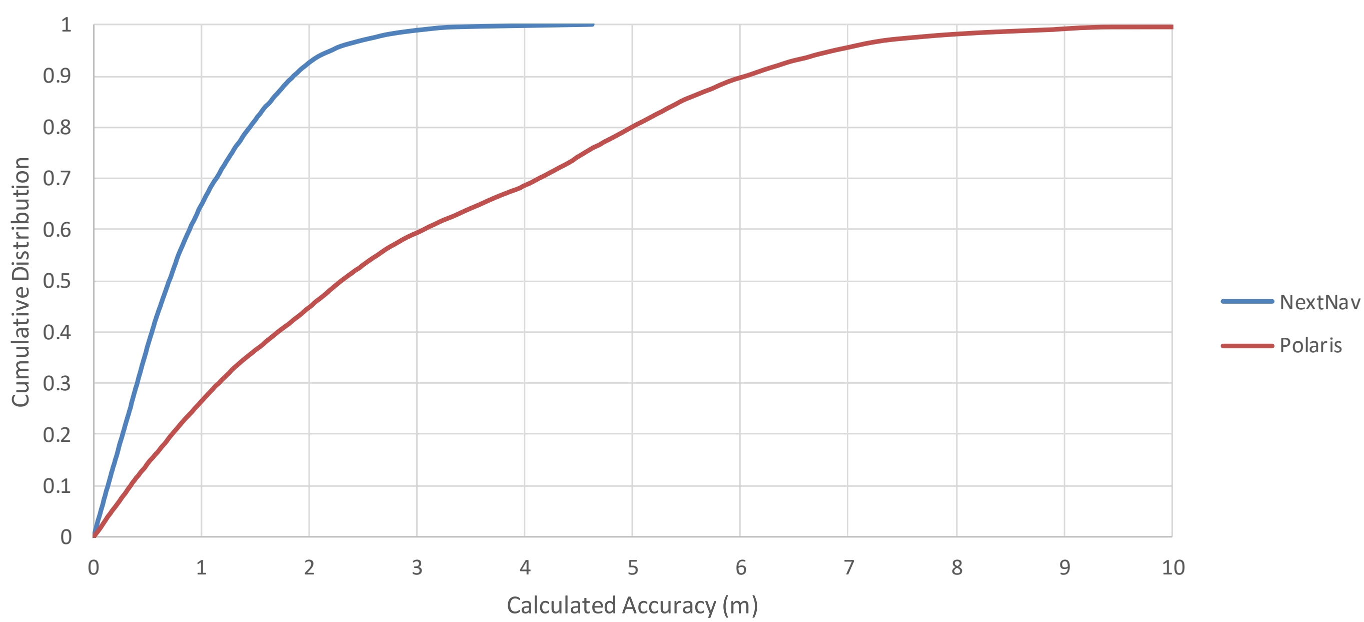



**Figure 9.5 Urban Vertical Accuracy CDF by Technology Vendor**

### 9.1.4 Suburban Morphology

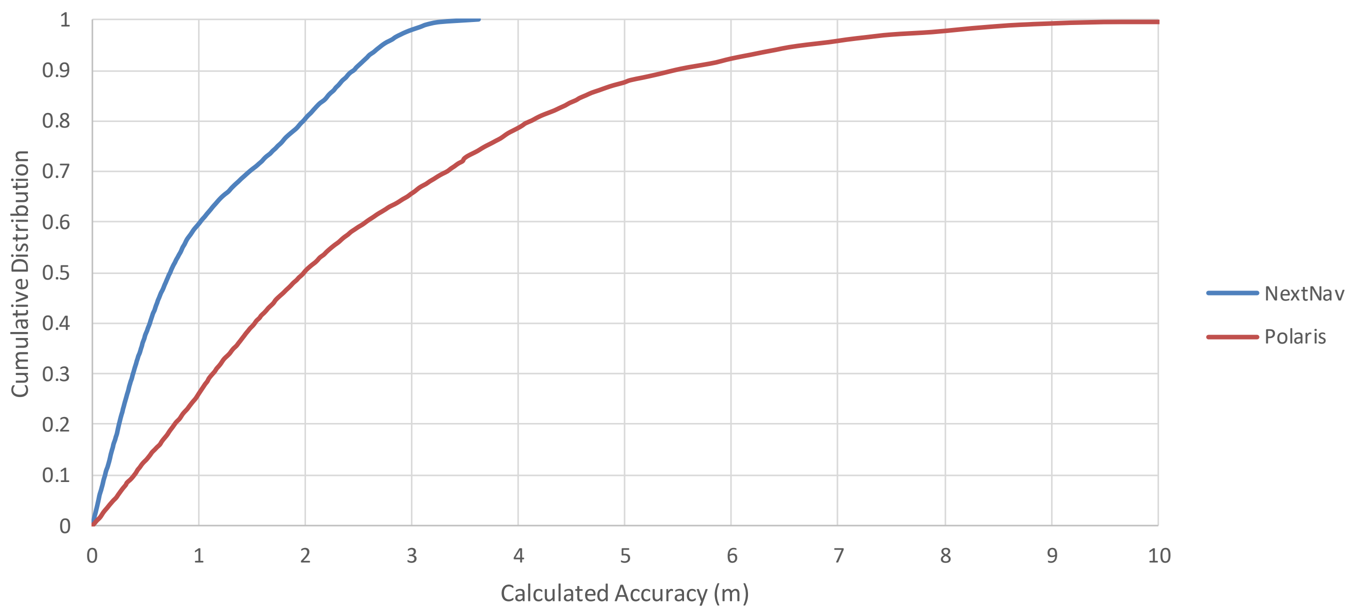



**Figure 9.6 Suburban Vertical Accuracy CDF by Technology Vendor**

### 9.1.5 Rural Morphology

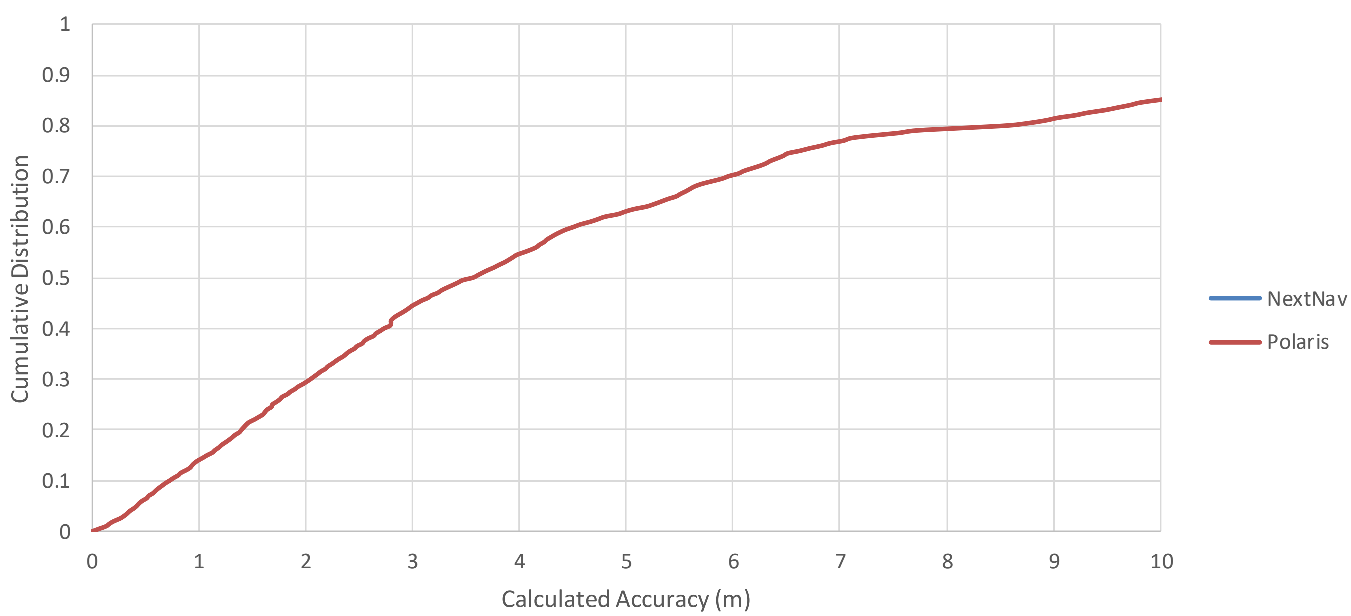



**Figure 9.7 Rural Vertical Accuracy CDF by Technology Vendor**

(Note: The NextNav system is not deployed in rural areas and was therefore not tested in Rural morphologies)

## 9.2 NextNav Z-Axis Location Accuracy

This section includes the summary results for NextNav broken out by morphology, city and handset. Handset-related effects are addressed in detail in section 9.4.

## 9.2.1 Overall Results Summary

**Table 9.1 NextNav Vertical Accuracy Results**

| | | | | | | Horizontal | | | | | Vertical | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tests Initiated | Tests Completed | Successful Test Yield (%) | Average Time to First Fix (sec) | Average Barometric Pressure (mbar) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) | Average Altitude Error (m) | Std. Dev. Altitude Error (m) | Average Distance Error (m) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) |
| **Test Bed Regions** | | | | | | | | | | | | | | | | | | |
| **All** | 38485 | 38485 | 100.0% | 25.0 | 996.9 | 29.2 | 40.4 | 59.1 | 57.1 | 75.7% | -0.4 | 1.0 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 96.5% |
| **Atlanta** | 19419 | 19419 | 100.0% | 25.0 | 980.0 | 29.9 | 42.3 | 60.5 | 62.9 | 75.8% | -0.6 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 95.9% |
| **San Francisco** | 19066 | 19066 | 100.0% | 25.0 | 1012.1 | 28.7 | 38.8 | 57.7 | 51.2 | 75.6% | -0.1 | 0.9 | 1.0 | 1.1 | 1.6 | 2.3 | 3.4 | 97.0% |
| **Per Carrier** | | | | | | | | | | | | | | | | | | |
| **AT&T** | 18829 | 18829 | 100.0% | 25.0 | 996.7 | 29.9 | 41.5 | 59.9 | 64.3 | 78.9% | -0.4 | 1.0 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 96.2% |
| **Verizon** | 19656 | 19656 | 100.0% | 25.0 | 997.1 | 28.6 | 39.5 | 58.5 | 50.2 | 72.6% | -0.3 | 0.9 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 96.7% |
| **Morphology** | | | | | | | | | | | | | | | | | | |
| **Dense Urban** | 13413 | 13413 | 100.0% | 25.0 | 995.8 | 40.5 | 57.4 | 82.7 | 74.8 | 69.3% | -1.0 | 1.2 | 1.4 | 1.6 | 2.5 | 3.3 | 3.4 | 90.6% |
| **Urban** | 15920 | 15920 | 100.0% | 25.0 | 995.8 | 25.7 | 34.8 | 48.7 | 51.7 | 79.5% | -0.2 | 0.7 | 0.9 | 1.1 | 1.5 | 1.9 | 3.4 | 99.5% |
| **Suburban** | 9152 | 9152 | 100.0% | 25.0 | 1002.5 | 21.1 | 28.4 | 39.1 | 40.5 | 78.3% | 0.3 | 0.9 | 1.0 | 1.3 | 2.0 | 2.5 | 3.4 | 99.7% |
| **Test Bed Regions by Morphology** | | | | | | | | | | | | | | | | | | |
| **Atlanta - Dense Urban** | 5753 | 5753 | 100.0% | 25.0 | 977.0 | 39.2 | 57.2 | 86.9 | 101.5 | 74.7% | -1.5 | 1.2 | 1.7 | 2.3 | 3.0 | 3.5 | 3.4 | 87.4% |
| **Atlanta - Urban** | 9913 | 9913 | 100.0% | 25.0 | 983.5 | 27.7 | 39.2 | 52.1 | 50.6 | 78.0% | -0.2 | 0.7 | 0.9 | 1.1 | 1.5 | 1.9 | 3.4 | 99.3% |
| **Atlanta - Suburban** | 3753 | 3753 | 100.0% | 25.0 | 976.3 | 21.4 | 31.4 | 45.6 | 36.1 | 71.5% | -0.2 | 0.9 | 1.2 | 1.7 | 2.1 | 2.5 | 3.4 | 99.9% |
| **San Francisco - Dense Urban** | 7660 | 7660 | 100.0% | 25.0 | 1011.0 | 41.0 | 57.5 | 80.9 | 54.7 | 65.2% | -0.6 | 1.1 | 1.2 | 1.2 | 1.8 | 3.0 | 3.4 | 93.0% |
| **San Francisco - Urban** | 6007 | 6007 | 100.0% | 25.0 | 1014.2 | 22.9 | 29.2 | 38.4 | 53.6 | 82.0% | -0.2 | 0.7 | 0.9 | 1.0 | 1.4 | 1.8 | 3.4 | 99.9% |
| **San Francisco - Suburban** | 5399 | 5399 | 100.0% | 25.0 | 1012.0 | 20.5 | 27.1 | 35.0 | 43.5 | 83.1% | 0.6 | 0.9 | 1.0 | 1.1 | 1.7 | 2.5 | 3.4 | 99.6% |

## Table 9.2 NextNav Vertical Accuracy Results by Handset

| | | | | | | Horizontal | | | | | Vertical | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tests Initiated | Tests Completed | Successful Test Yield (%) | Average Time to First Fix (sec) | Average Barometric Pressure (mbar) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) | Average Altitude Error (m) | Std. Dev. Altitude Error (m) | Average Distance Error (m) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) |
| **Test Bed Regions** | | | | | | | | | | | | | | | | | | |
| **All** | 38485 | 38485 | 100.0% | 25.0 | 996.9 | 29.2 | 40.4 | 59.1 | 57.1 | 75.7% | -0.4 | 1.0 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 96.5% |
| **Atlanta** | 19419 | 19419 | 100.0% | 25.0 | 980.0 | 29.9 | 42.3 | 60.5 | 62.9 | 75.8% | -0.6 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 95.9% |
| **San Francisco** | 19066 | 19066 | 100.0% | 25.0 | 1012.1 | 28.7 | 38.8 | 57.7 | 51.2 | 75.6% | -0.1 | 0.9 | 1.0 | 1.1 | 1.6 | 2.3 | 3.4 | 97.0% |
| **Handset** | | | | | | | | | | | | | | | | | | |
| **Each individual handset model** | | | | | | | | | | | | | | | | | | |
| **Samsung Galaxy S8** | 5986 | 5986 | 100.0% | 25.0 | 996.2 | 22.4 | 32.7 | 49.0 | 27.0 | 60.6% | -0.2 | 1.0 | 1.1 | 1.3 | 1.9 | 2.7 | 3.4 | 95.7% |
| **Samsung Galaxy S8 plus** | 6536 | 6536 | 100.0% | 25.0 | 997.1 | 24.8 | 36.3 | 55.2 | 24.7 | 53.6% | -0.3 | 1.0 | 1.0 | 1.1 | 1.7 | 2.4 | 3.4 | 96.2% |
| **iPhone 7** | 6562 | 6562 | 100.0% | 25.0 | 997.1 | 29.8 | 39.8 | 61.1 | 62.1 | 82.0% | -0.4 | 0.9 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 97.1% |
| **iPhone 7 plus** | 6299 | 6299 | 100.0% | 25.0 | 996.9 | 32.3 | 43.8 | 62.8 | 93.7 | 89.6% | -0.3 | 1.0 | 1.1 | 1.2 | 1.8 | 2.5 | 3.4 | 96.1% |
| **iPhone 8** | 6544 | 6544 | 100.0% | 25.0 | 997.1 | 33.2 | 44.3 | 64.5 | 70.0 | 85.4% | -0.5 | 0.9 | 1.1 | 1.3 | 1.8 | 2.5 | 3.4 | 96.8% |
| **iPhone 8 Plus** | 6558 | 6558 | 100.0% | 25.0 | 997.1 | 30.2 | 41.9 | 59.8 | 63.7 | 82.0% | -0.4 | 1.0 | 1.2 | 1.4 | 1.9 | 2.6 | 3.4 | 96.8% |
| **Atlanta individual handsets** | | | | | | | | | | | | | | | | | | |
| **Samsung Galaxy S8** | 3088 | 3088 | 100.0% | 25.0 | 980.2 | 21.4 | 30.9 | 50.0 | 32.9 | 66.1% | -0.6 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 94.5% |
| **Samsung Galaxy S8 plus** | 3248 | 3248 | 100.0% | 25.0 | 980.1 | 25.9 | 40.5 | 59.5 | 28.2 | 53.5% | -0.5 | 1.0 | 1.2 | 1.4 | 1.9 | 2.7 | 3.4 | 94.7% |
| **iPhone 7** | 3274 | 3274 | 100.0% | 25.0 | 980.0 | 30.0 | 40.7 | 58.3 | 64.9 | 80.4% | -0.4 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 97.1% |
| **iPhone 7 plus** | 3265 | 3265 | 100.0% | 25.0 | 980.0 | 32.0 | 43.2 | 59.0 | 111.4 | 91.5% | -0.6 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 95.6% |
| **iPhone 8** | 3270 | 3270 | 100.0% | 25.0 | 980.0 | 35.3 | 48.9 | 70.0 | 70.5 | 82.3% | -0.6 | 1.0 | 1.2 | 1.5 | 2.0 | 2.7 | 3.4 | 96.9% |
| **iPhone 8 Plus** | 3274 | 3274 | 100.0% | 25.0 | 980.0 | 32.1 | 45.4 | 61.7 | 67.8 | 80.2% | -0.7 | 1.0 | 1.2 | 1.5 | 2.1 | 2.7 | 3.4 | 96.4% |
| **San Francisco individual handsets** | | | | | | | | | | | | | | | | | | |
| **Samsung Galaxy S8** | 2898 | 2898 | 100.0% | 25.0 | 1011.7 | 24.6 | 35.2 | 48.7 | 20.8 | 54.7% | 0.2 | 1.0 | 1.1 | 1.2 | 1.8 | 2.7 | 3.4 | 96.9% |
| **Samsung Galaxy S8 plus** | 3288 | 3288 | 100.0% | 25.0 | 1012.2 | 23.4 | 33.1 | 50.4 | 21.2 | 53.7% | -0.1 | 0.9 | 0.9 | 0.9 | 1.3 | 2.1 | 3.4 | 97.7% |
| **iPhone 7** | 3288 | 3288 | 100.0% | 25.0 | 1012.2 | 29.2 | 39.3 | 65.5 | 59.4 | 83.5% | -0.4 | 0.9 | 1.0 | 1.1 | 1.5 | 2.3 | 3.4 | 97.0% |
| **iPhone 7 plus** | 3034 | 3034 | 100.0% | 25.0 | 1012.3 | 32.7 | 45.2 | 67.4 | 74.7 | 87.6% | 0.0 | 0.9 | 1.0 | 1.0 | 1.5 | 2.3 | 3.4 | 96.7% |
| **iPhone 8** | 3274 | 3274 | 100.0% | 25.0 | 1012.2 | 31.0 | 40.9 | 57.4 | 69.6 | 88.6% | -0.4 | 0.9 | 1.0 | 1.2 | 1.7 | 2.2 | 3.4 | 96.7% |
| **iPhone 8 Plus** | 3284 | 3284 | 100.0% | 25.0 | 1012.2 | 28.8 | 37.9 | 56.7 | 59.6 | 83.8% | -0.1 | 0.9 | 1.1 | 1.3 | 1.7 | 2.4 | 3.4 | 97.2% |

### 9.2.2 Dense Urban Morphology Distributions

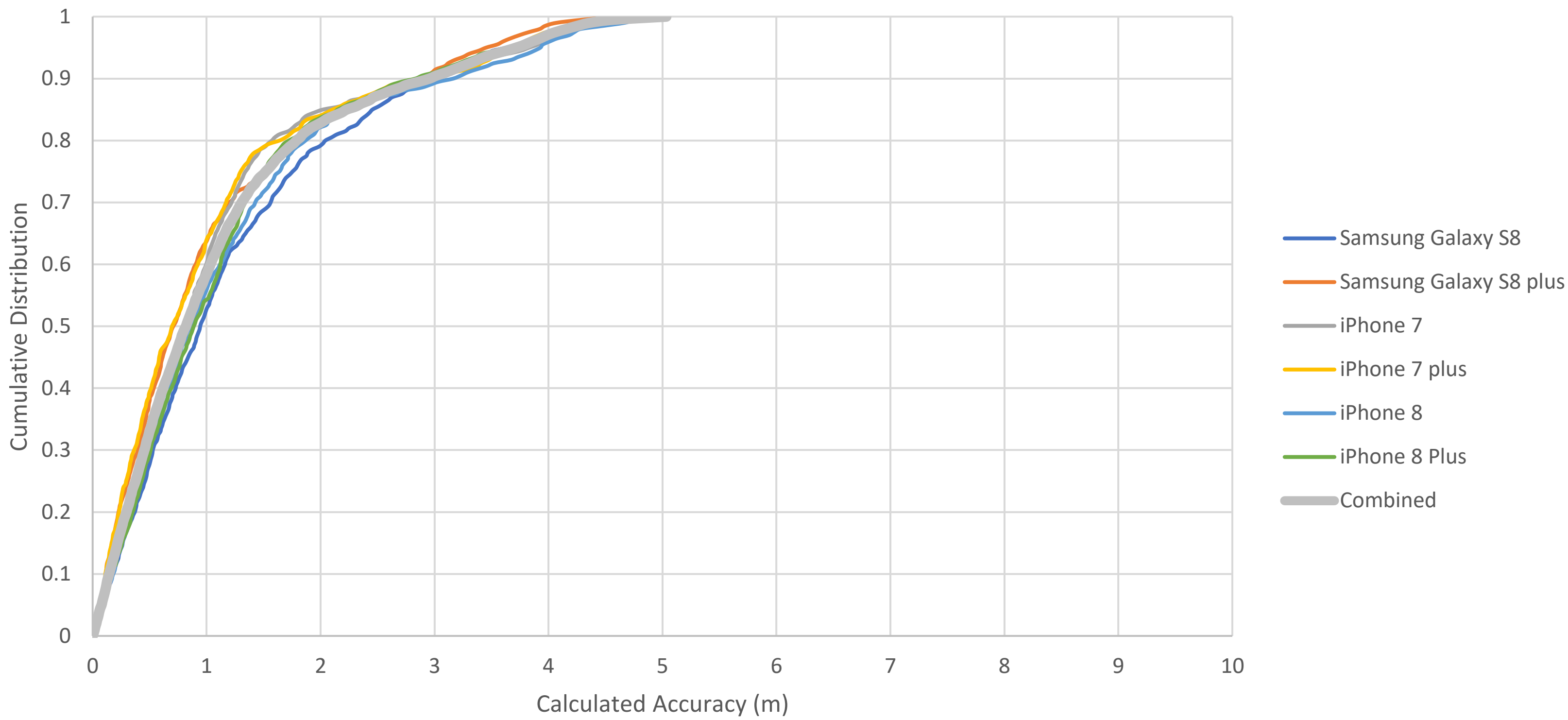



**Figure 9.8 NextNav SFO Dense Urban Aggregate and Per Handset Vertical Accuracy CDF**

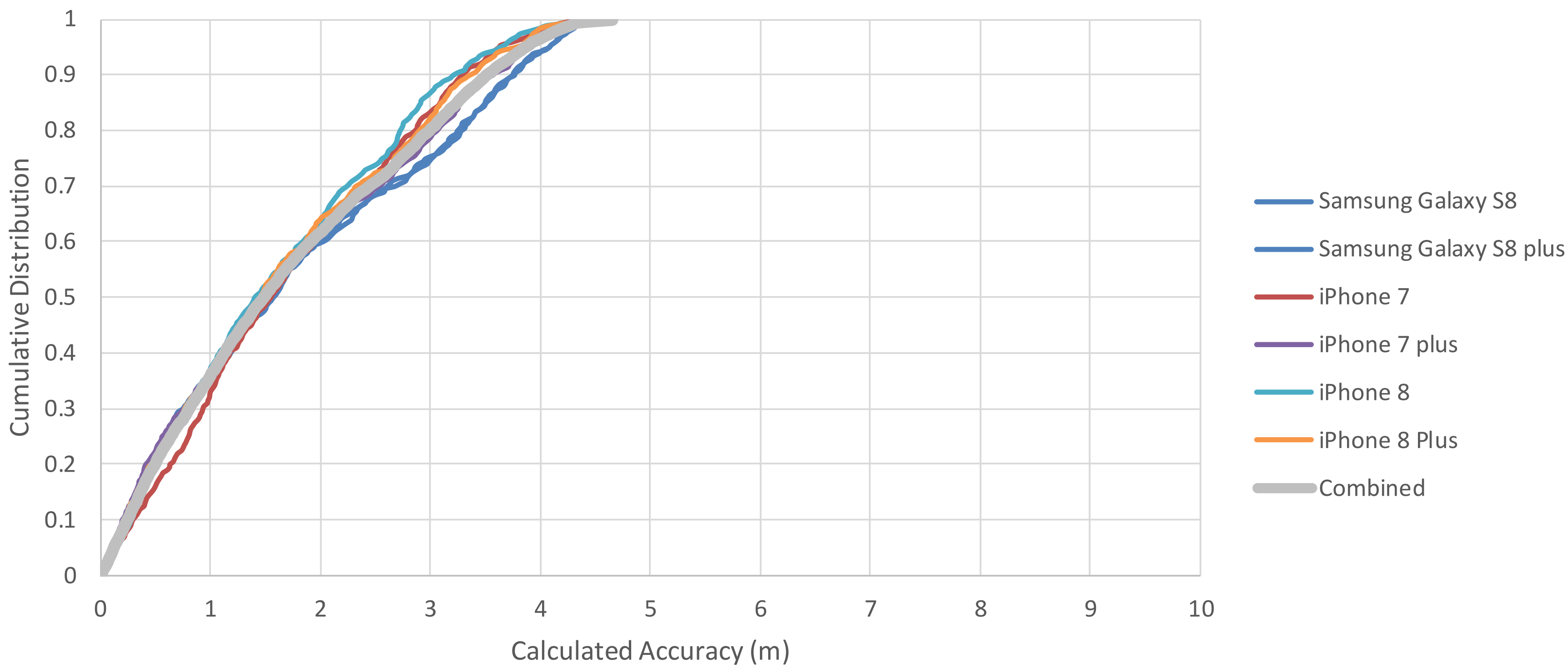



**Figure 9.9 NextNav ATL Dense Urban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.2.3 Urban Morphology Distributions

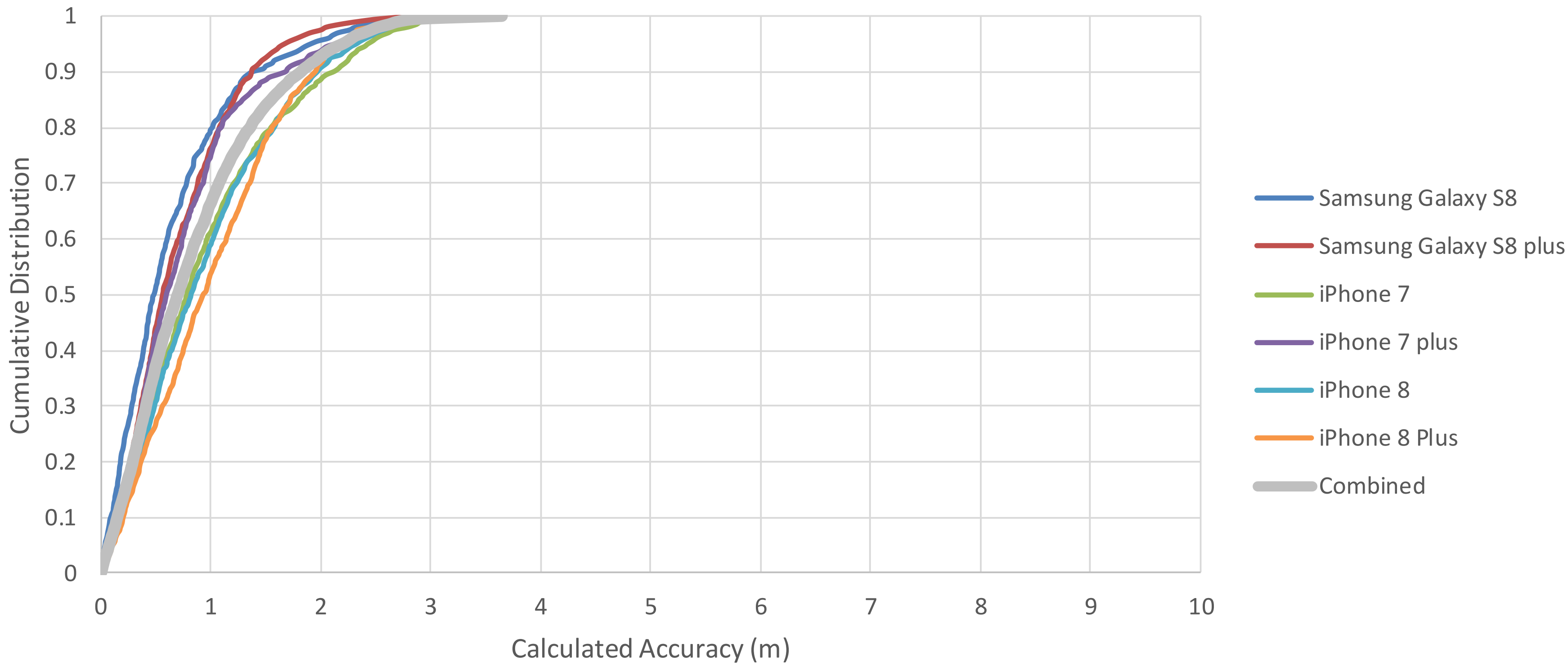



**Figure 9.10 NextNav SFO Urban Aggregate and Per Handset Vertical Accuracy CDF**

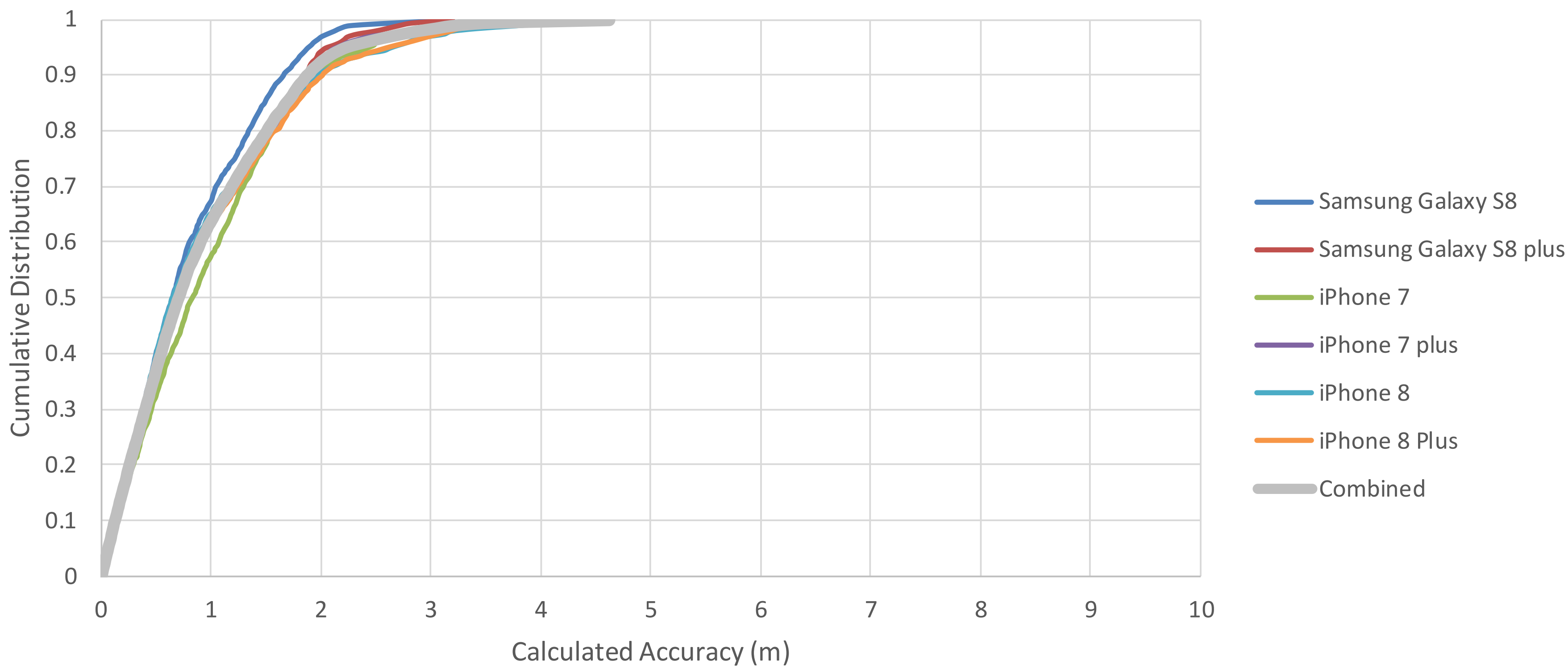



**Figure 9.11 NextNav ATL Urban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.2.4 Suburban Morphology Distributions

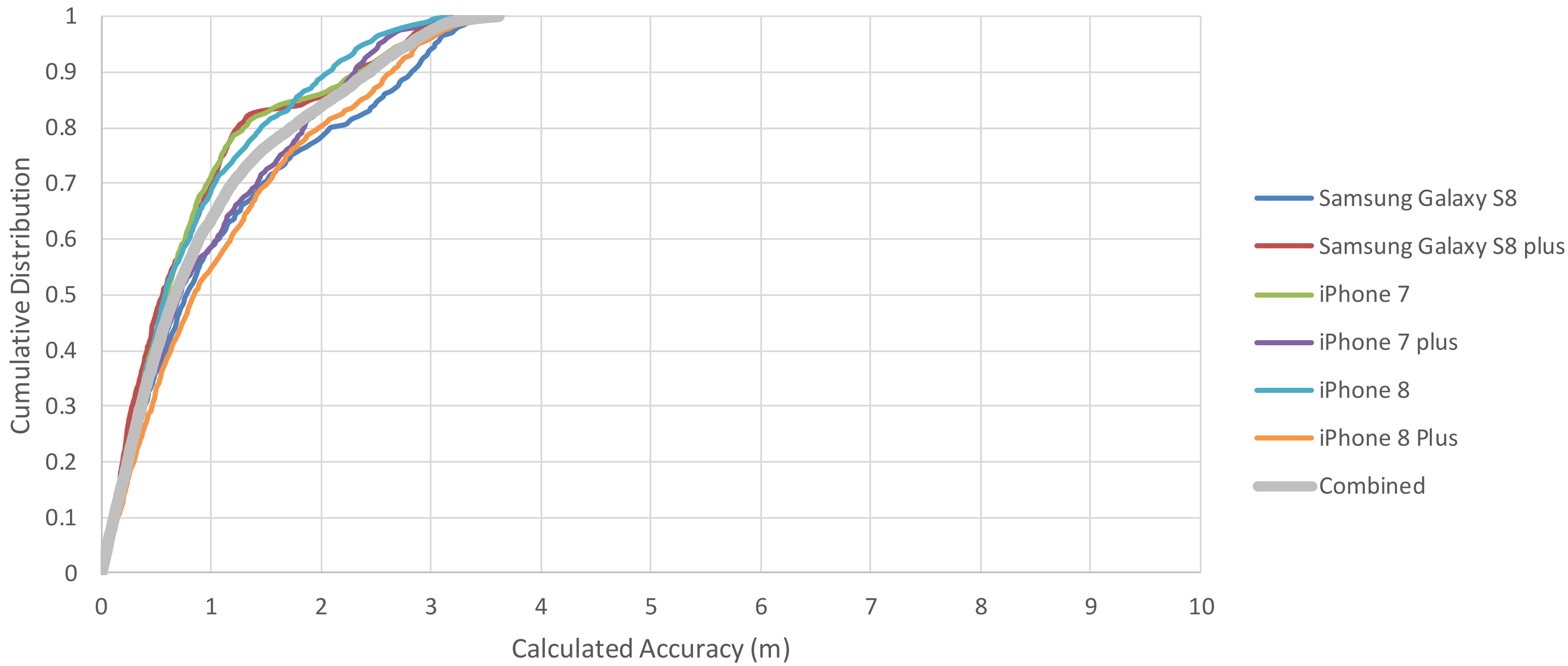



**Figure 9.12 NextNav SFO Suburban Aggregate and Per Handset Vertical Accuracy CDF**

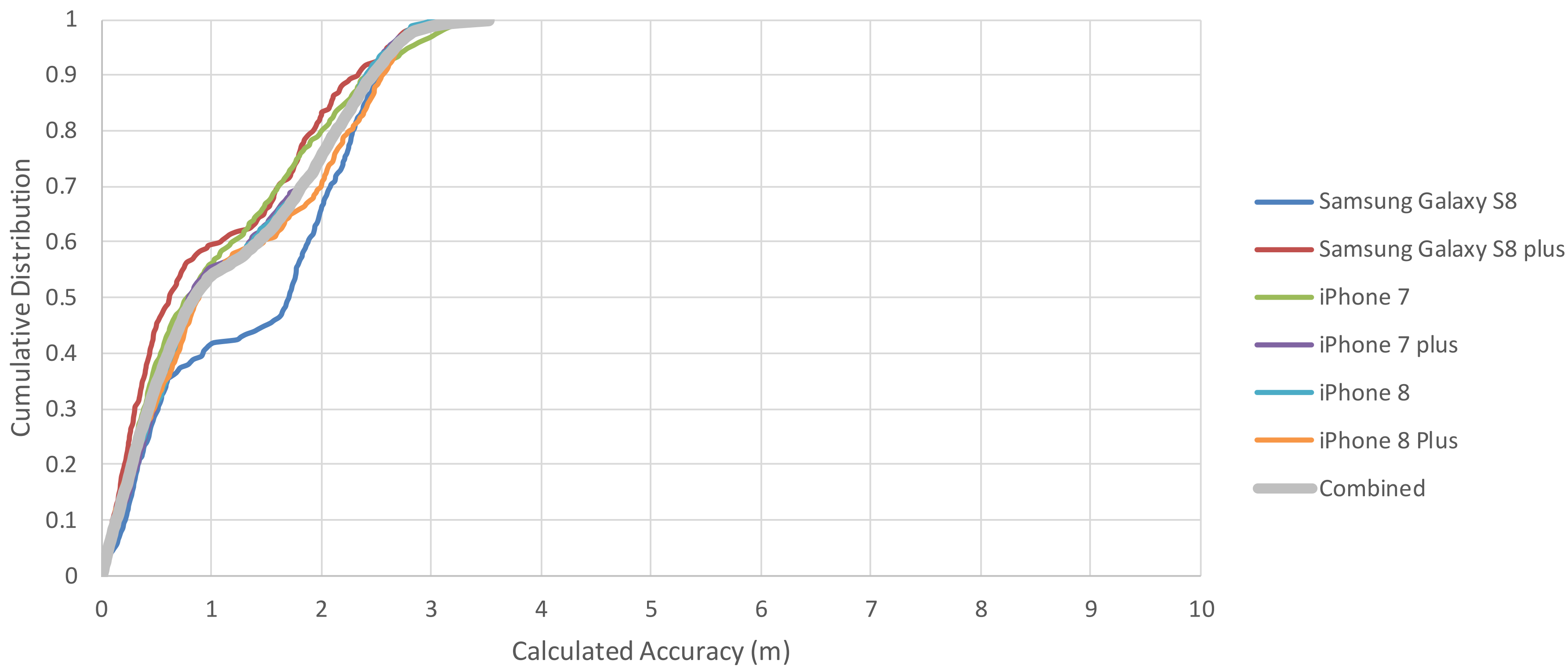



**Figure 9.13 NextNav ATL Suburban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.2.5 Rural Morphology

The NextNav system is not deployed in rural areas and therefore was not tested in Rural morphologies.

## 9.3 Polaris Wireless Z-Axis Location Accuracy

This section includes the summary results for Polaris Wireless broken out by morphology, City, and Handset Model. Handset-related effects are addressed in detail in section 9.4.

### 9.3.1 Overall Results Summary

## Table 9.3 Polaris Vertical Accuracy Results

| | | | | | | Horizontal | | | | | Vertical | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tests Initiated | Tests Completed | Successful Test Yield (%) | Average Time to First Fix (sec) | Average Barometric Pressure (mBar) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) | Average Altitude Error (m) | Std. Dev. Altitude Error (m) | Average Distance Error (m) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) |
| **Test Bed Regions** | | | | | | | | | | | | | | | | | | |
| **All** | 55592 | 55592 | 100.0% | 25.5 | 993.4 | 16.7 | 23.6 | 39.0 | 84.6 | 91.0% | -1.1 | 3.8 | 3.0 | 3.7 | 4.8 | 6.2 | 8.5 | 79.3% |
| **Atlanta** | 21029 | 21029 | 100.0% | 25.5 | 980.4 | 16.5 | 22.6 | 31.7 | 59.5 | 92.9% | -0.1 | 4.9 | 2.0 | 2.3 | 3.1 | 4.0 | 5.0 | 93.6% |
| **San Francisco** | 21115 | 21115 | 100.0% | 25.5 | 1005.4 | 15.5 | 21.6 | 30.9 | 44.8 | 93.0% | -1.6 | 2.7 | 3.6 | 4.4 | 5.6 | 7.0 | 9.7 | 73.9% |
| **Chicago** | 13448 | 13448 | 100.0% | 25.5 | 992.6 | 19.6 | 40.4 | 137.5 | 186.2 | 84.9% | -2.2 | 2.8 | 3.7 | 4.9 | 5.8 | 6.8 | 11.9 | 65.6% |
| **Per Carrier** | | | | | | | | | | | | | | | | | | |
| **AT&T** | 27826 | 27826 | 100.0% | 25.5 | 993.4 | 16.8 | 23.9 | 39.3 | 87.5 | 91.1% | -1.3 | 4.8 | 2.7 | 2.8 | 4.7 | 6.6 | 11.7 | 81.4% |
| **Verizon** | 27766 | 27766 | 100.0% | 25.5 | 993.4 | 16.5 | 23.4 | 38.8 | 81.6 | 90.9% | -1.0 | 2.3 | 3.4 | 4.1 | 4.9 | 5.9 | 5.2 | 77.2% |
| **Morphology** | | | | | | | | | | | | | | | | | | |
| **Dense Urban** | 20716 | 20716 | 100.0% | 25.5 | 994.5 | 22.7 | 36.8 | 115.3 | 149.2 | 85.5% | -1.5 | 2.6 | 3.1 | 3.8 | 4.7 | 6.2 | 9.3 | 79.0% |
| **Urban** | 22662 | 22662 | 100.0% | 25.5 | 995.1 | 13.8 | 19.2 | 27.7 | 54.5 | 95.1% | -1.2 | 2.3 | 2.9 | 3.8 | 5.0 | 6.1 | 4.6 | 75.7% |
| **Suburban** | 9336 | 9336 | 100.0% | 25.5 | 1001.7 | 11.5 | 15.8 | 20.2 | 30.4 | 96.5% | -1.5 | 7.1 | 2.7 | 3.1 | 4.1 | 5.5 | 15.5 | 86.8% |
| **Rural** | 2878 | 2878 | 100.0% | 25.4 | 953.8 | 24.4 | 28.9 | 36.9 | 31.8 | 80.5% | 2.5 | 4.2 | 4.9 | 5.6 | 8.6 | 11.4 | 10.6 | 86.4% |
| **Test Bed Regions by Morphology** | | | | | | | | | | | | | | | | | | |
| **Atlanta - Dense Urban** | 5735 | 5735 | 100.0% | 25.5 | 977.0 | 20.9 | 28.8 | 40.6 | 80.7 | 93.6% | -0.5 | 2.0 | 2.2 | 2.6 | 3.5 | 4.2 | 4.5 | 91.9% |
| **Atlanta - Urban** | 9917 | 9917 | 100.0% | 25.5 | 983.5 | 15.3 | 21.1 | 32.4 | 62.8 | 92.5% | 0.6 | 1.6 | 1.8 | 2.2 | 2.9 | 4.0 | 4.5 | 92.1% |
| **Atlanta - Suburban** | 3944 | 3944 | 100.0% | 25.5 | 976.5 | 12.0 | 16.5 | 21.5 | 30.1 | 94.1% | -0.5 | 10.6 | 2.0 | 2.0 | 2.5 | 3.3 | 5.3 | 98.2% |
| **Atlanta - Rural** | 1433 | 1433 | 100.0% | 25.4 | 985.7 | 20.9 | 24.5 | 28.5 | 32.6 | 89.3% | -1.7 | 1.6 | 2.4 | 3.0 | 3.8 | 4.5 | 10.1 | 98.5% |
| **San Francisco - Dense Urban** | 7638 | 7638 | 100.0% | 25.5 | 1011.0 | 20.3 | 27.1 | 48.1 | 50.0 | 89.9% | -2.1 | 2.3 | 3.4 | 4.1 | 5.3 | 6.8 | 4.5 | 73.6% |
| **San Francisco - Urban** | 6640 | 6640 | 100.0% | 25.5 | 1014.2 | 11.5 | 16.3 | 23.5 | 53.4 | 96.8% | -2.3 | 2.2 | 3.4 | 4.4 | 5.4 | 6.6 | 4.7 | 70.3% |
| **San Francisco - Suburban** | 5392 | 5392 | 100.0% | 25.5 | 1012.0 | 11.1 | 15.5 | 19.2 | 30.7 | 98.2% | -2.2 | 2.3 | 3.2 | 4.0 | 5.1 | 6.4 | 22.9 | 78.5% |
| **San Francisco - Rural** | 1445 | 1445 | 100.0% | 25.5 | 935.8 | 28.2 | 33.9 | 42.0 | 31.0 | 71.8% | 6.7 | 4.5 | 7.3 | 9.6 | 11.4 | 13.7 | 11.0 | 74.4% |
| **Chicago - Dense Urban** | 7343 | 7343 | 100.0% | 25.6 | 992.6 | 40.5 | 133.9 | 141.6 | 305.8 | 74.5% | -1.6 | 3.1 | 3.5 | 4.2 | 5.4 | 6.7 | 18.0 | 74.6% |
| **Chicago - Urban** | 6105 | 6105 | 100.0% | 25.5 | 992.5 | 14.0 | 19.2 | 24.9 | 42.3 | 97.4% | -2.9 | 2.5 | 4.0 | 5.4 | 6.1 | 6.9 | 4.7 | 54.9% |

**Table 9.4 Polaris Vertical Accuracy Results by Handset**

| | | | | | | Horizontal | | | | | Vertical | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tests Initiated | Tests Completed | Successful Test Yield (%) | Average Time to First Fix (sec) | Average Barometric Pressure (mBar) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) | Average Altitude Error (m) | Std. Dev. Altitude Error (m) | Average Distance Error (m) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) |
| **Test Bed Regions** | | | | | | | | | | | | | | | | | | |
| **All** | 55592 | 55592 | 100.0% | 25.5 | 993.4 | 16.7 | 23.6 | 39.0 | 84.6 | 91.0% | -1.1 | 3.8 | 3.0 | 3.7 | 4.8 | 6.2 | 8.5 | 79.3% |
| **Atlanta** | 21029 | 21029 | 100.0% | 25.5 | 980.4 | 16.5 | 22.6 | 31.7 | 59.5 | 92.9% | -0.1 | 4.9 | 2.0 | 2.3 | 3.1 | 4.0 | 5.0 | 93.6% |
| **San Francisco** | 21115 | 21115 | 100.0% | 25.5 | 1005.4 | 15.5 | 21.6 | 30.9 | 44.8 | 93.0% | -1.6 | 2.7 | 3.6 | 4.4 | 5.6 | 7.0 | 9.7 | 73.9% |
| **Chicago** | 13448 | 13448 | 100.0% | 25.5 | 992.6 | 19.6 | 40.4 | 137.5 | 186.2 | 84.9% | -2.2 | 2.8 | 3.7 | 4.9 | 5.8 | 6.8 | 11.9 | 65.6% |
| **Handset** | | | | | | | | | | | | | | | | | | |
| **Each individual handset models** | | | | | | | | | | | | | | | | | | |
| **Sony Xperia XZ1** | 9273 | 9273 | 100.0% | 25.5 | 993.4 | 17.6 | 25.2 | 44.5 | 96.4 | 91.0% | -1.3 | 2.4 | 2.2 | 2.3 | 3.3 | 4.7 | 19.7 | 91.3% |
| **Huawei Mate 9** | 9272 | 9272 | 100.0% | 25.5 | 993.4 | 16.3 | 23.2 | 38.2 | 69.2 | 91.5% | -3.2 | 6.9 | 4.2 | 5.8 | 6.8 | 7.8 | 5.5 | 58.7% |
| **Samsung Galaxy Note 8** | 9264 | 9264 | 100.0% | 25.5 | 993.4 | 17.2 | 24.1 | 41.1 | 85.7 | 90.2% | -3.0 | 2.0 | 3.4 | 4.4 | 5.1 | 5.8 | 5.2 | 76.1% |
| **Samsung Galaxy S8** | 9259 | 9259 | 100.0% | 25.5 | 993.5 | 16.2 | 22.9 | 37.4 | 76.9 | 91.2% | -2.9 | 2.2 | 3.4 | 3.9 | 5.0 | 6.1 | 5.3 | 78.3% |
| **Motorola Z2 Force** | 9281 | 9281 | 100.0% | 25.5 | 993.4 | 16.8 | 23.4 | 35.7 | 96.9 | 90.7% | 0.6 | 3.4 | 1.8 | 1.7 | 2.3 | 3.6 | 10.1 | 94.3% |
| **Essential** | 9243 | 9243 | 100.0% | 25.5 | 993.4 | 16.0 | 23.0 | 37.3 | 82.3 | 91.2% | 2.9 | 2.6 | 3.3 | 3.9 | 4.6 | 5.6 | 5.2 | 77.2% |

## Table 9.4 Polaris Vertical Accuracy Results by Handset—Cont.

| | | | | | | Horizontal | | | | | Vertical | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tests Initiated | Tests Completed | Successful Test Yield (%) | Average Time to First Fix (sec) | Average Barometric Pressure (mBar) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) | Average Altitude Error (m) | Std. Dev. Altitude Error (m) | Average Distance Error (m) | 67th Percen-tile (m) | 80th Percen-tile (m) | 90th Percen-tile (m) | Average Uncertainty | Within uncertainty (%) |
| **Atlanta individual handset** | | | | | | | | | | | | | | | | | | |
| **Sony Xperia XZ1** | 3509 | 3509 | 100.0% | 25.5 | 980.3 | 17.0 | 22.8 | 33.7 | 60.7 | 93.0% | -0.2 | 1.0 | 1.1 | 1.4 | 1.9 | 2.3 | 4.6 | 99.1% |
| **Huawei Mate 9** | 3515 | 3515 | 100.0% | 25.5 | 980.3 | 16.1 | 21.7 | 29.3 | 55.0 | 94.6% | -0.1 | 10.4 | 1.8 | 1.8 | 2.5 | 3.1 | 4.9 | 98.4% |
| **Samsung Galaxy Note 8** | 3506 | 3506 | 100.0% | 25.5 | 980.4 | 17.0 | 22.7 | 31.2 | 58.4 | 92.2% | -1.8 | 1.3 | 2.0 | 2.3 | 3.0 | 3.9 | 4.8 | 98.6% |
| **Samsung Galaxy S8** | 3495 | 3495 | 100.0% | 25.5 | 980.4 | 15.8 | 21.6 | 30.6 | 57.2 | 93.5% | -2.0 | 1.2 | 2.1 | 2.5 | 3.0 | 3.8 | 5.7 | 99.0% |
| **Motorola Z2 Force** | 3512 | 3512 | 100.0% | 25.5 | 980.4 | 16.9 | 23.5 | 33.3 | 63.8 | 92.1% | 0.2 | 4.5 | 1.4 | 1.6 | 2.0 | 2.5 | 5.1 | 99.7% |
| **Essential** | 3492 | 3492 | 100.0% | 25.5 | 980.4 | 16.4 | 23.3 | 32.6 | 61.8 | 91.9% | 3.5 | 2.4 | 3.6 | 4.4 | 4.9 | 5.4 | 5.0 | 66.7% |
| **San Francisco individual handset** | | | | | | | | | | | | | | | | | | |
| **Sony Xperia XZ1** | 3522 | 3522 | 100.0% | 25.5 | 1005.2 | 14.9 | 21.0 | 29.0 | 41.6 | 93.5% | -1.0 | 1.9 | 2.0 | 2.2 | 2.8 | 3.7 | 17.1 | 96.9% |
| **Huawei Mate 9** | 3515 | 3515 | 100.0% | 25.5 | 1005.4 | 15.9 | 23.3 | 33.4 | 47.9 | 92.2% | -6.2 | 1.7 | 6.6 | 7.3 | 7.9 | 8.6 | 6.4 | 16.0% |
| **Samsung Galaxy Note 8** | 3514 | 3514 | 100.0% | 25.5 | 1005.4 | 16.1 | 22.3 | 33.2 | 47.6 | 92.6% | -3.7 | 1.5 | 4.5 | 4.9 | 5.5 | 6.1 | 5.8 | 62.5% |
| **Samsung Galaxy S8** | 3529 | 3529 | 100.0% | 25.5 | 1005.4 | 15.1 | 20.9 | 29.7 | 43.8 | 93.1% | -2.8 | 1.7 | 3.7 | 4.1 | 4.7 | 5.3 | 5.3 | 81.9% |
| **Motorola Z2 Force** | 3520 | 3520 | 100.0% | 25.5 | 1005.4 | 16.7 | 22.4 | 32.2 | 45.1 | 91.8% | 0.9 | 2.5 | 1.7 | 1.5 | 2.0 | 3.3 | 18.2 | 97.9% |
| **Essential** | 3515 | 3515 | 100.0% | 25.5 | 1005.4 | 14.6 | 20.1 | 27.3 | 42.8 | 94.4% | 3.3 | 2.9 | 3.3 | 3.5 | 4.2 | 5.2 | 5.6 | 87.7% |
| **Chicago individual handset** | | | | | | | | | | | | | | | | | | |
| **Sony Xperia XZ1** | 2242 | 2242 | 100.0% | 25.6 | 992.6 | 26.7 | 74.3 | 140.5 | 238.1 | 84.1% | -3.4 | 3.4 | 4.0 | 4.7 | 5.4 | 6.3 | 47.3 | 70.4% |
| **Huawei Mate 9** | 2242 | 2242 | 100.0% | 25.5 | 992.6 | 17.7 | 38.0 | 136.2 | 124.9 | 85.7% | -3.6 | 2.4 | 4.1 | 5.0 | 5.6 | 6.6 | 5.0 | 63.4% |
| **Samsung Galaxy Note 8** | 2244 | 2244 | 100.0% | 25.6 | 992.6 | 20.4 | 44.8 | 137.2 | 187.9 | 83.4% | -3.6 | 2.4 | 4.1 | 5.1 | 5.8 | 6.6 | 4.8 | 62.2% |
| **Samsung Galaxy S8** | 2235 | 2235 | 100.0% | 25.5 | 992.6 | 19.3 | 40.4 | 134.3 | 160.0 | 84.4% | -4.7 | 2.8 | 4.9 | 6.1 | 6.8 | 7.6 | 4.8 | 40.4% |
| **Motorola Z2 Force** | 2249 | 2249 | 100.0% | 25.6 | 992.6 | 16.7 | 26.5 | 121.3 | 229.6 | 86.8% | 0.6 | 2.5 | 2.4 | 2.5 | 4.1 | 6.1 | 5.1 | 80.1% |
| **Essential** | 2236 | 2236 | 100.0% | 25.6 | 992.6 | 19.2 | 32.9 | 137.7 | 176.3 | 85.0% | 1.7 | 2.5 | 2.8 | 3.0 | 4.7 | 7.2 | 4.7 | 77.2% |

### 9.3.2 Dense Urban Morphology Distributions

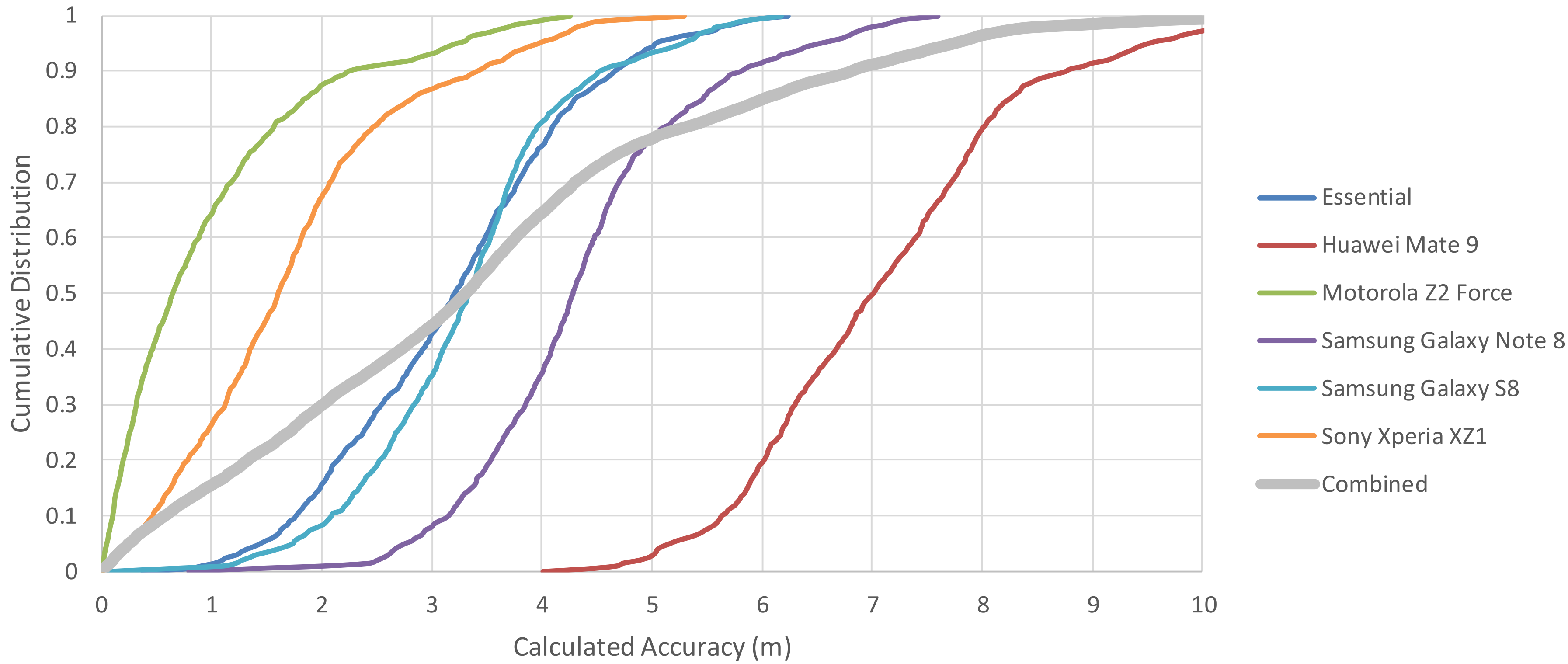



**Figure 9.14 Polaris Wireless SFO Dense Urban Aggregate and Per Handset Vertical Accuracy CDF**

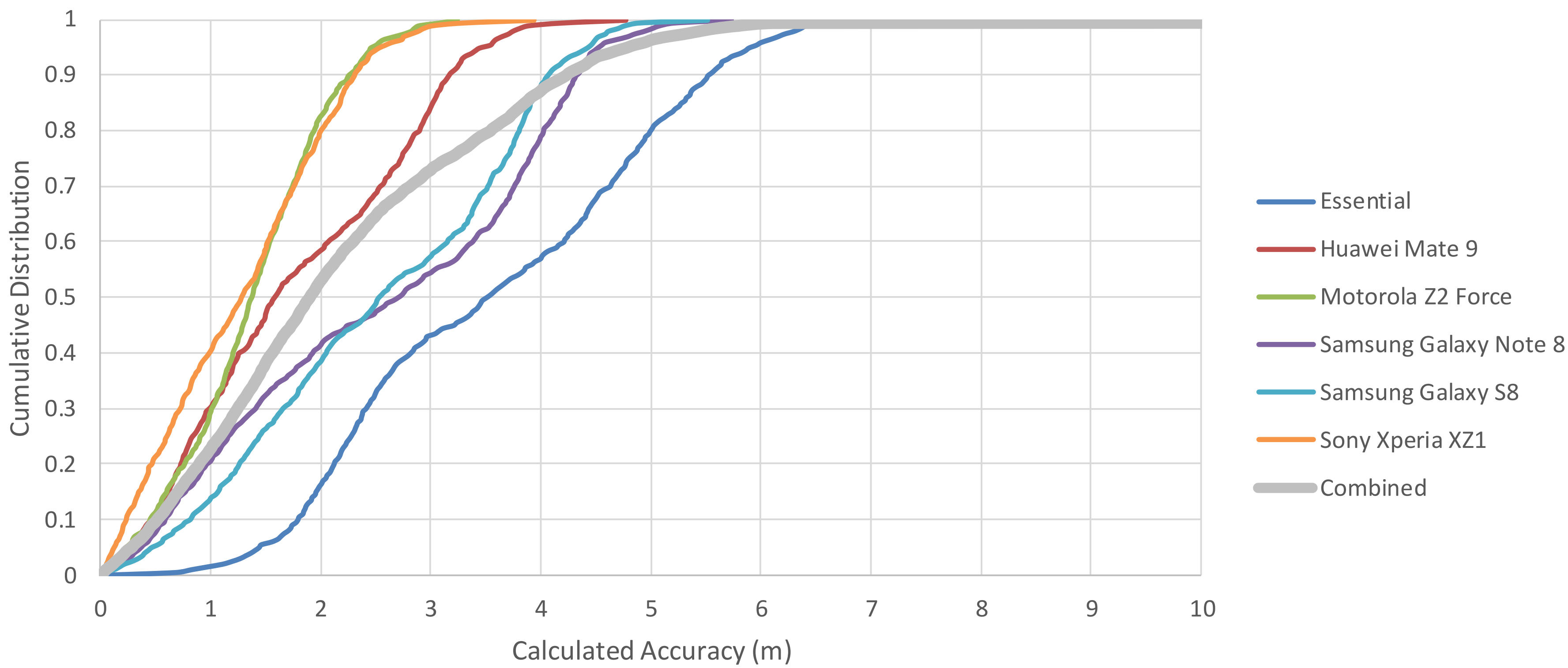



**Figure 9.15 Polaris Wireless ATL Dense Urban Aggregate and Per Handset Vertical Accuracy CDF**

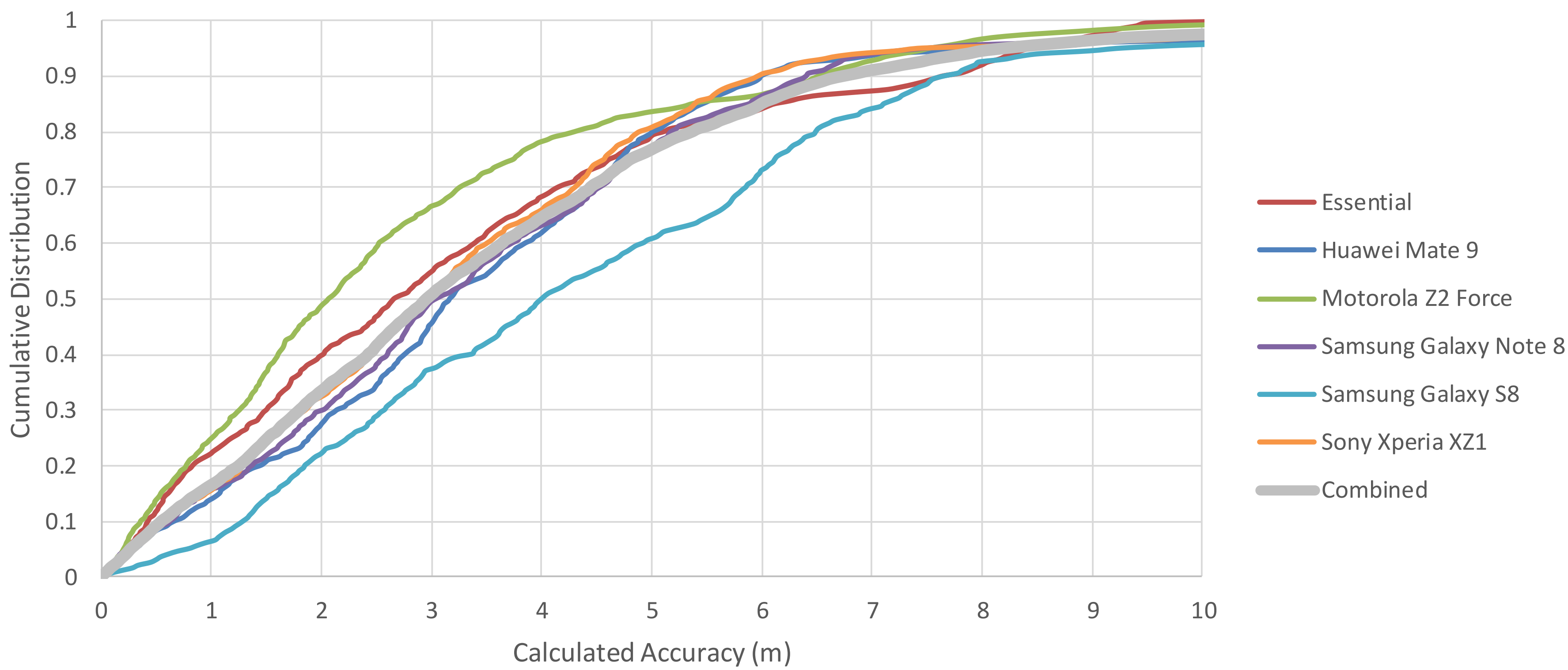



**Figure 9.16 Polaris Wireless CHI Dense Urban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.3.3 Urban Morphology Distributions

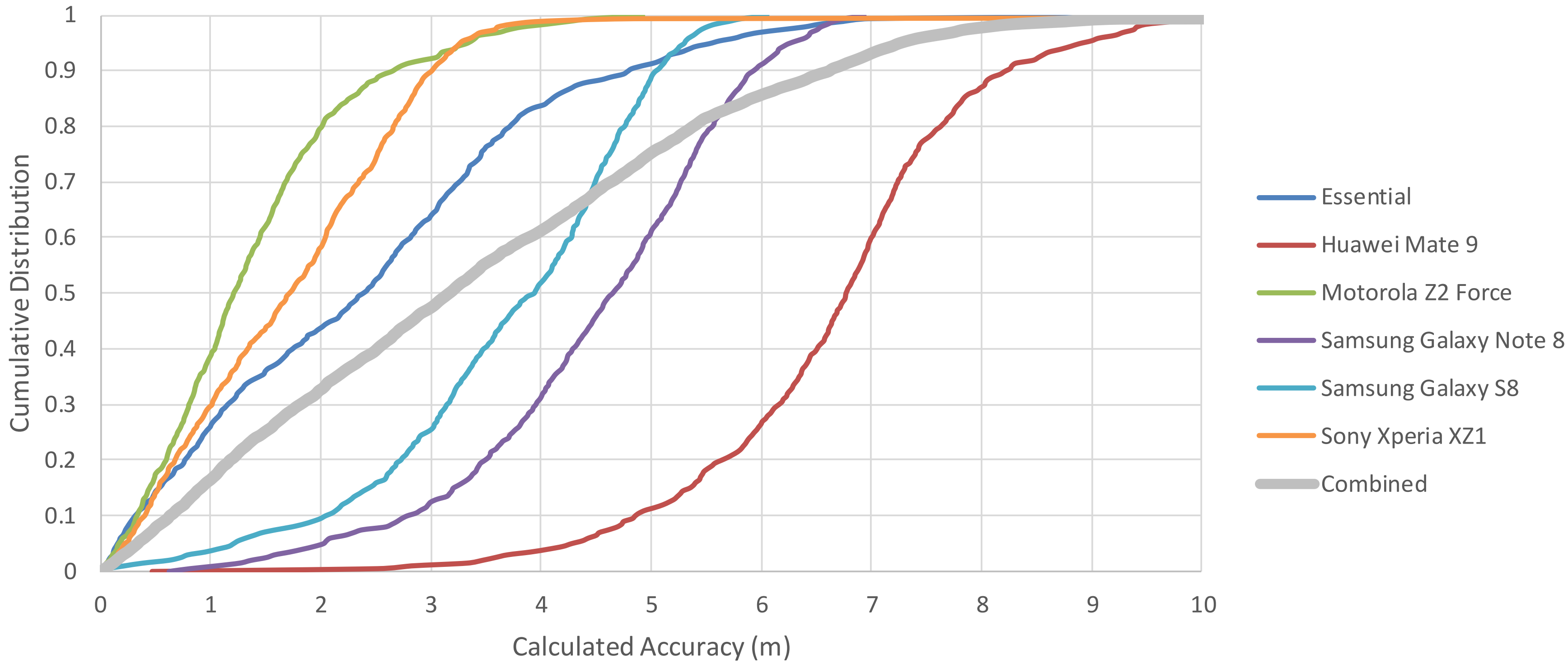



**Figure 9.17 Polaris Wireless SFO Urban Aggregate and Per Handset Vertical Accuracy CDF**

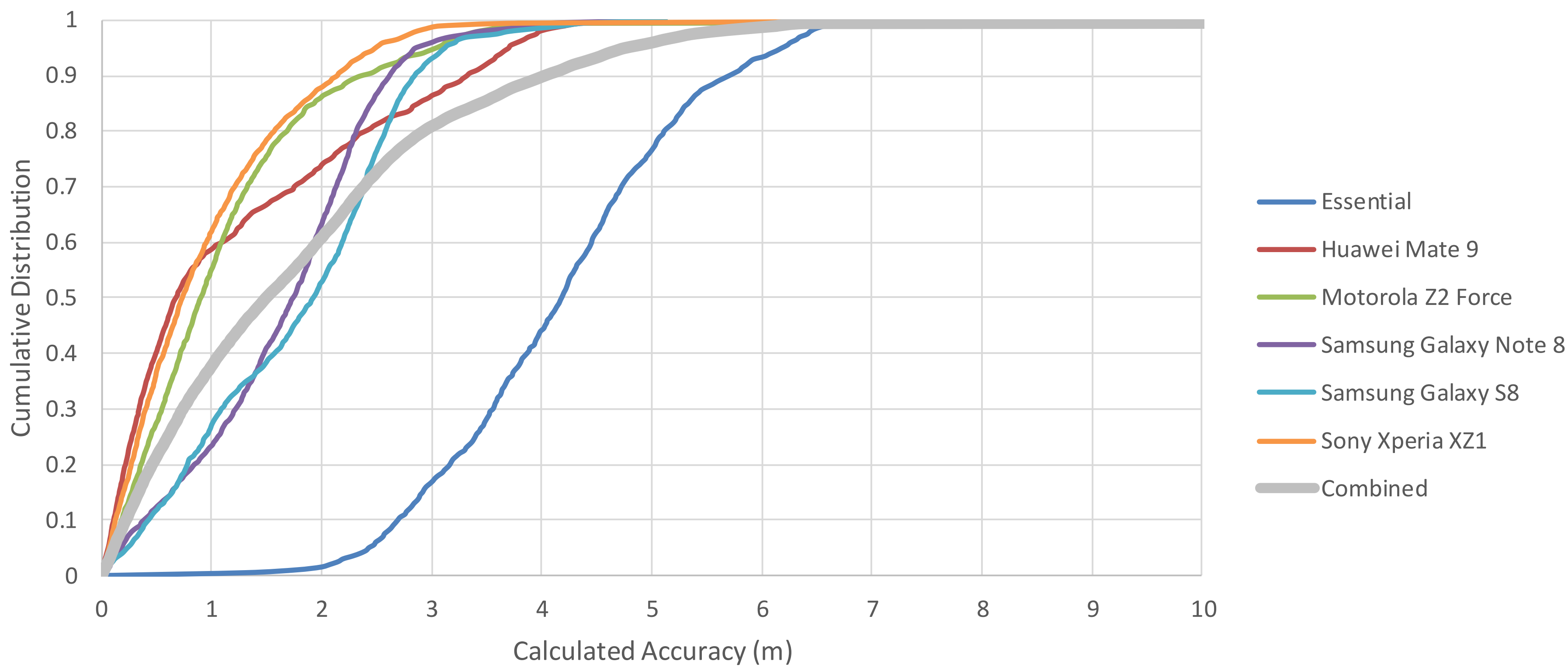



**Figure 9.18 Polaris Wireless ATL Urban Aggregate and Per Handset Vertical Accuracy CDF**

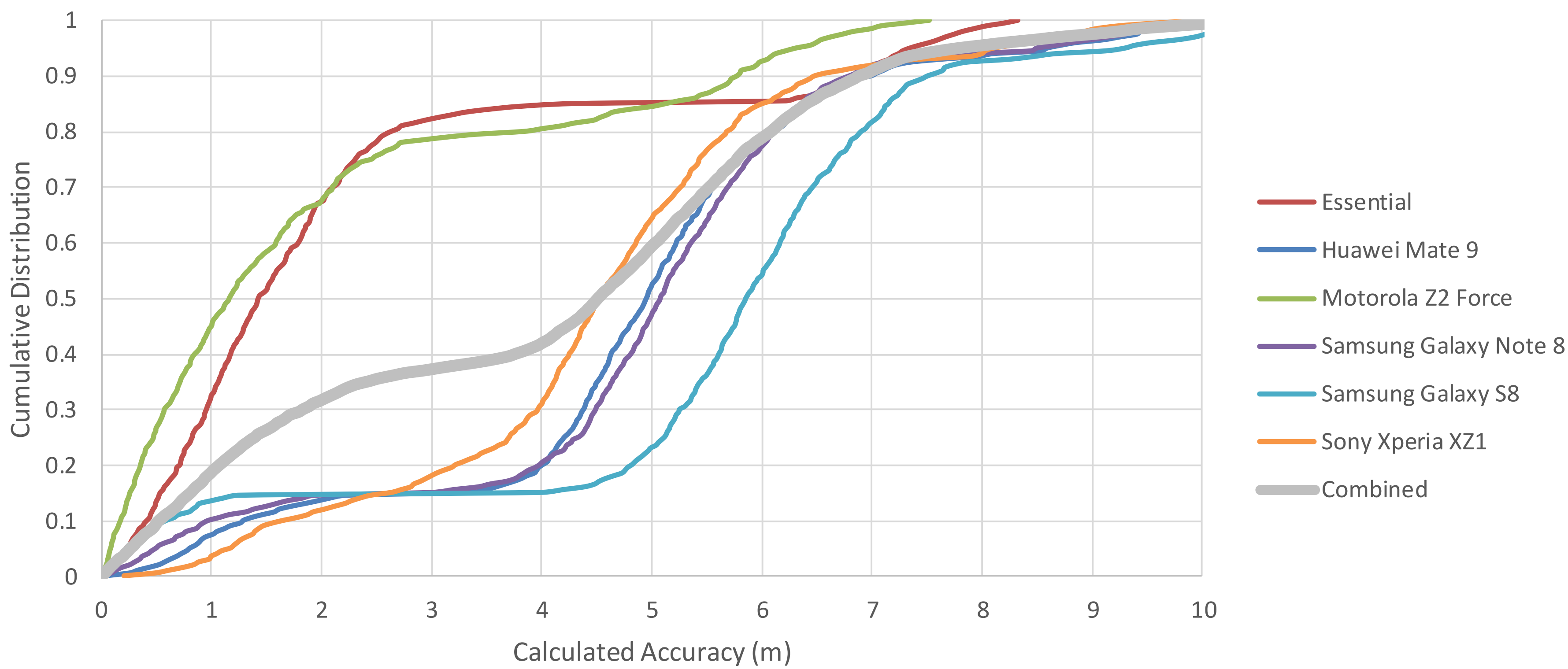



**Figure 9.19 Polaris Wireless CHI Urban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.3.4 Suburban Morphology Distributions

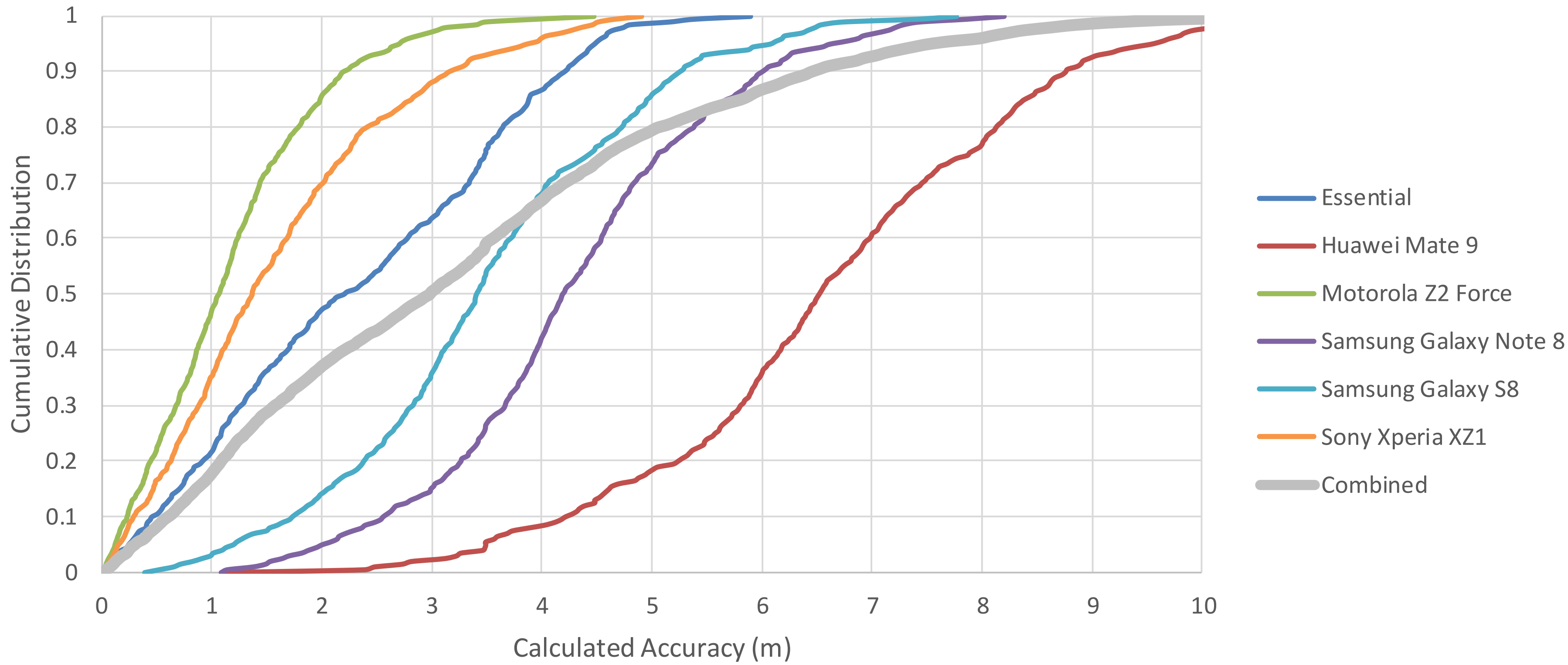



**Figure 9.20 Polaris Wireless SFO Suburban Aggregate and Per Handset Vertical Accuracy CDF**

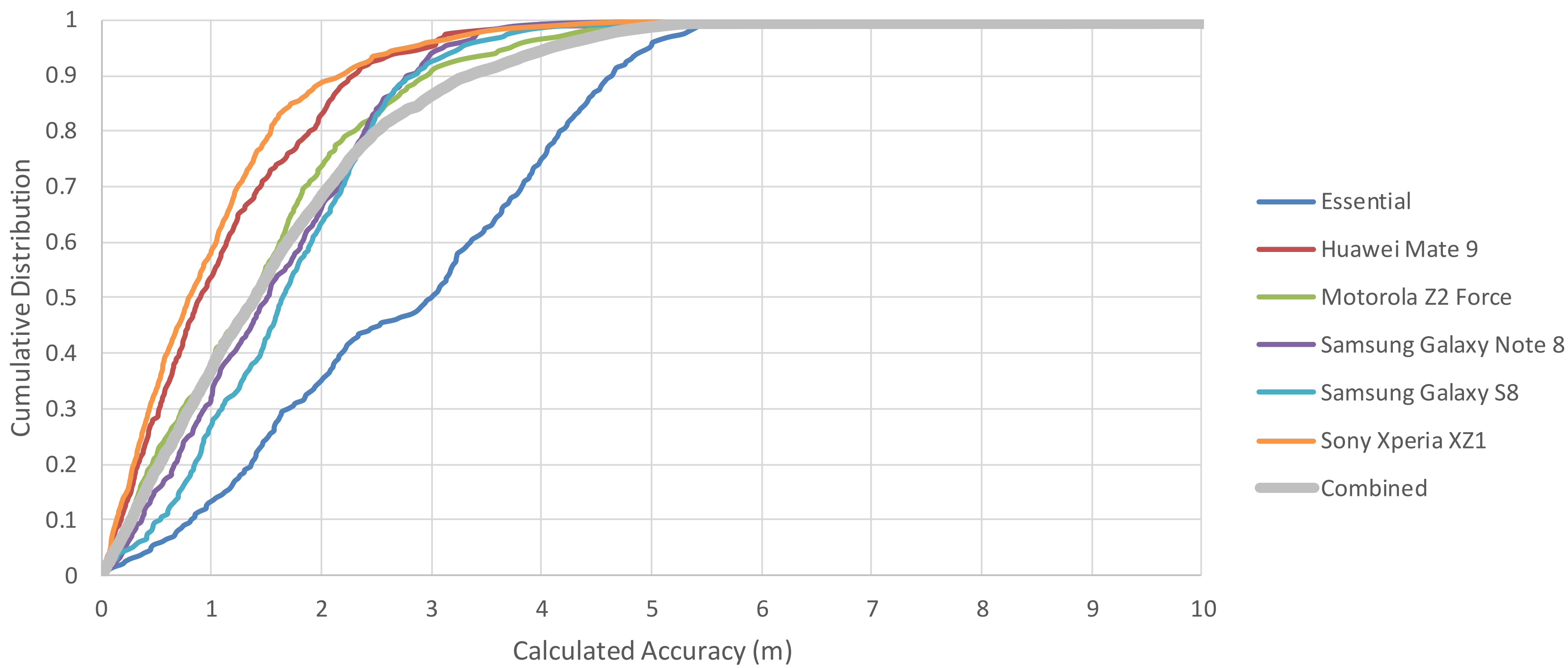



**Figure 9.21 Polaris Wireless ATL Suburban Aggregate and Per Handset Vertical Accuracy CDF**

### 9.3.5 Rural Morphology Distributions

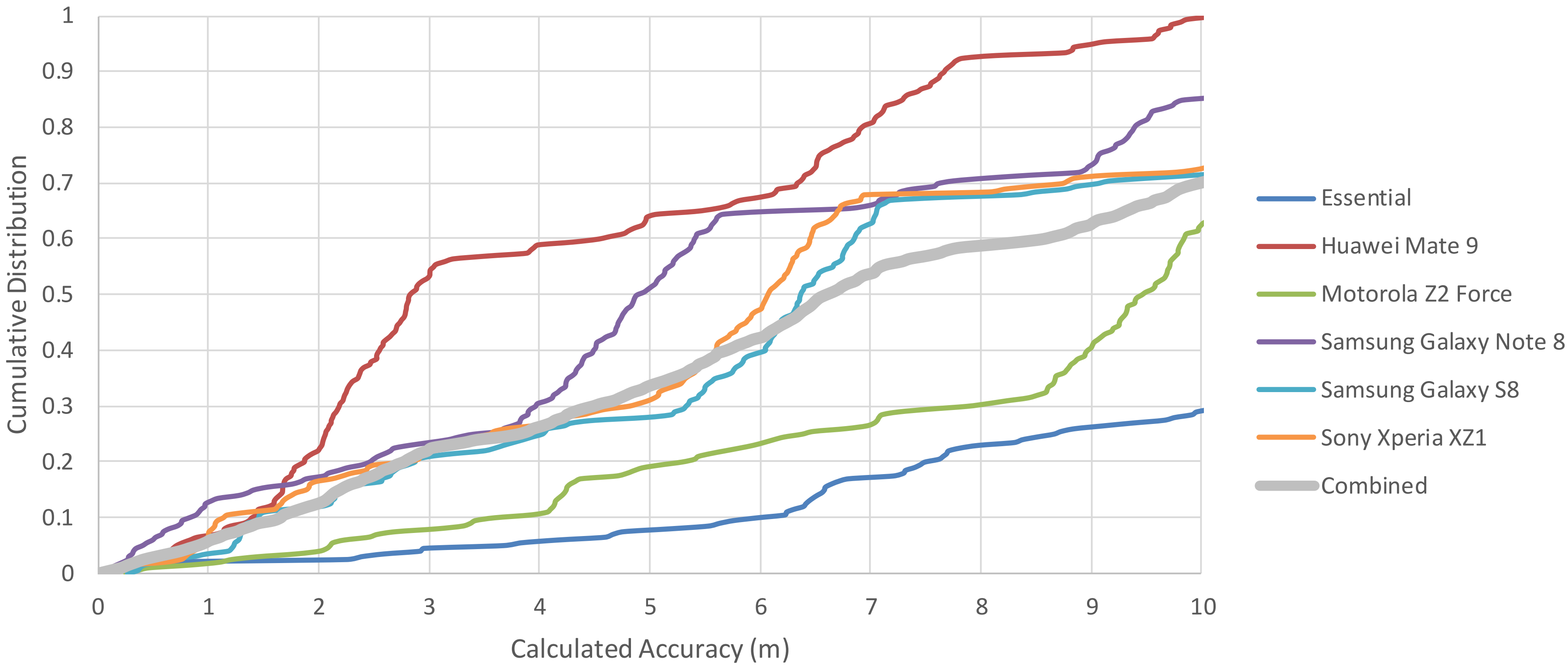



**Figure 9.22 Polaris Wireless SFO Rural Aggregate and Per Handset Vertical Accuracy CDF**

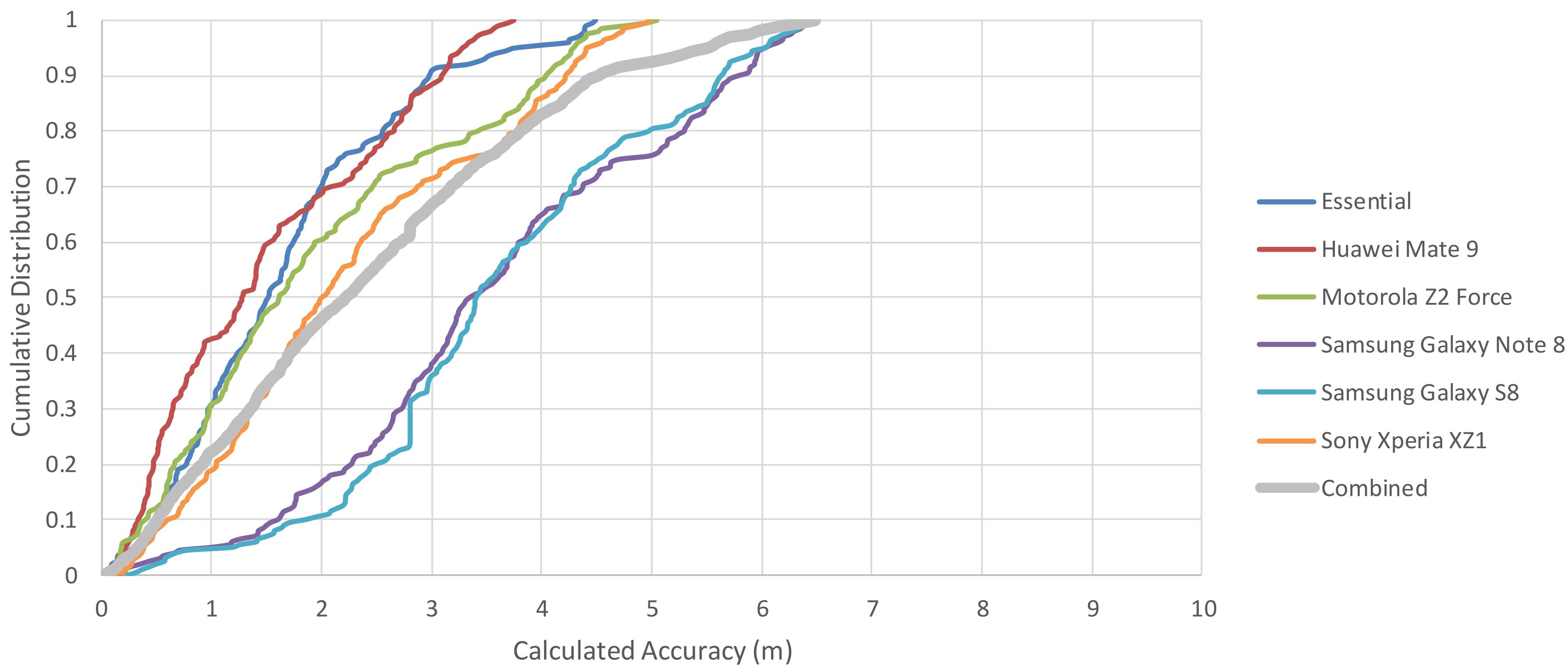



**Figure 9.23 Polaris Wireless ATL Rural Aggregate and Per Handset Vertical Accuracy CDF**

## 9.4 Observed Z-axis Location Accuracy Characteristics

In this section analysis is performed to distinguish and highlight key reasons behind the Z-axis performance measured in this test campaign.

### 9.4.1 Handset Barometric Sensor Biases

The data from this exercise suggests that handset barometric sensors frequently have a significant and consistent bias in their pressure sensor measurement, which can be a dominant source of vertical positioning error when not calibrated out. This can be seen in the signed vertical error probability density function (pdf) and CDF plots shown in this section.

#### 9.4.1.1 How to Interpret Signed Vertical Error pdf and CDF Distributions

The plots in this section show the distribution of the signed vertical error between each fix's reported height and true height, for each mobile test device, in each market. Unlike traditional pdf and CDF error plots, these plots are quantified for both negative and positive displacement from truth, which allows visualization of biases present in each mobile device's barometric sensor.

For each of the following plots, each trace is a distribution of the signed vertical distance between reported height and true height for all the fixes of a single mobile device. Traces are grouped into plots by vendor and market – so for example, each mobile device used by Polaris Wireless in all the testing performed in the San Francisco area are shown in Figure 9.24 and Figure 9.25.

Bin size for these distribution plots is 0.2 meters. (Bin size in histograms is the class interval used to accumulate the counts which fall within each such interval). In pdf plots, the value shown on the y-axis is the number of fixes falling within this bin divided by the total number of fixes in the set – shown as a percentage. The value on the x-axis is the center of the bin. So, for example, in Figure 9.24 , it can be seen that 6.4% of fixes for the Huawei Mate 9 device used by Polaris Wireless in the San Francisco market testing had a signed vertical error of between -7.1 and -6.9 meters.

In CDF plots, this percentage is accumulated, starting at the lowest value of signed horizontal error, and rising to the value shown on the x-axis. So, for example, in Figure 9.25, it can be seen that 32.7% of Huawei Mate 9 device fixes have a signed vertical error of -6.9 meters or less (i.e., more negative).

These pdf and CDF plots convey the relative amounts of positive or negative vertical error present in a population of fixes, caused by all sources of error. For the plots in this section, each trace represents the error distribution for all the fixes for each single mobile device for all buildings and all test points in one Test Bed region. Error caused by sources common to all devices – such as building effects or weather compensation – would tend to manifest in a common way, and the distributions would not diverge significantly. However, error caused by fixed amounts of error in the devices themselves will cause the traces in these plots to diverge. Thus, by looking at the differences of the traces for the devices in a single test region using a single vendor's solution, it is possible to spot and roughly quantify mobile device barometric sensor biases.

The ideal signed vertical error pdf plot would be a very narrow spike, centered at zero, representing perfect accuracy, no biases, and no error from any source. The real world presents a very different picture, however. For example, in Figure 9.24, it is visually quite clear that each mobile device has a distinct 'typical' amount of bias across all the fixes taken in the San Francisco region. The Huawei Mate 9 has the most negative bias, then the Samsung Galaxy Note 8, then the Samsung Galaxy S8, then the Sony Xperia XZ1. The Motorola Z2 Force device has the most centered signed vertical error and is thus the best performing device. In contrast, the Essential device has a noticeably positive bias.

The plots in this section provide a way to separate and roughly quantify the amount of error caused by device biases, versus the amount of error caused by other sources. For example, note how in Figure 9.24 the curve for each trace has a roughly similar width – on the order of about plus/minus two or three meters. This spread represents the error from all other sources apart from device biases. In contrast, the divergence in the centers of the distributions for each device – in this case from about minus seven to plus three meters – represents the error caused by device biases. From this simple visual interpretation, it is clear that error caused by mobile device biases dominate overall error, at least for this vendor in this test region.

CDF plots provide an alternative way to visualize these same concepts, and more clearly and accurately illustrate the extent of mobile device biases, as illustrated in Figure 9.25. With a CDF visualization, the traces overlap less, making it easier to quantify the bias by looking at the x-axis offset. For example, by looking at where each CDF trace crosses the 50th percentile, it can be seen that the biases for each mobile device are approximately as follows:

- Huawei Mate 9 -6.8 meters
- Samsung Galaxy Note 8 -4.4 meters
- Samsung Galaxy S8 -3.5 meters

- Sony Xperia XZ1 -1.5 meters
- Motorola Z2 Force +0.4 meters
- Essential +2.8 meters

The breadth of a CDF trace in its steep portion represents the amount of error caused by all other sources besides device bias, analogous to the width of the pdf distribution in Figure 9.24, as can be seen in Figure 9.25. However, in a CDF plot, it is easier to quantify and visualize behavior at the tails of the distribution. For example, in Figure 9.25, it can be seen that positive errors occurred for all mobile devices in about 10% of fixes, most likely due to combined building/weather effects.

#### 9.4.1.2 Signed Vertical Error Distributions for Polaris Wireless San Francisco Mobiles

Figure 9.24 and Figure 9.25 show the pdf and CDF signed vertical error per-device distributions for Polaris Wireless test devices for all fixes taken in the San Francisco market. Device biases range from approximately -7 to +3 meters, and the extent of vertical error around the bias point is on the order of +/-2 to 3 meters. A larger positive bias occurred for about 10% of fixes, as mentioned above.

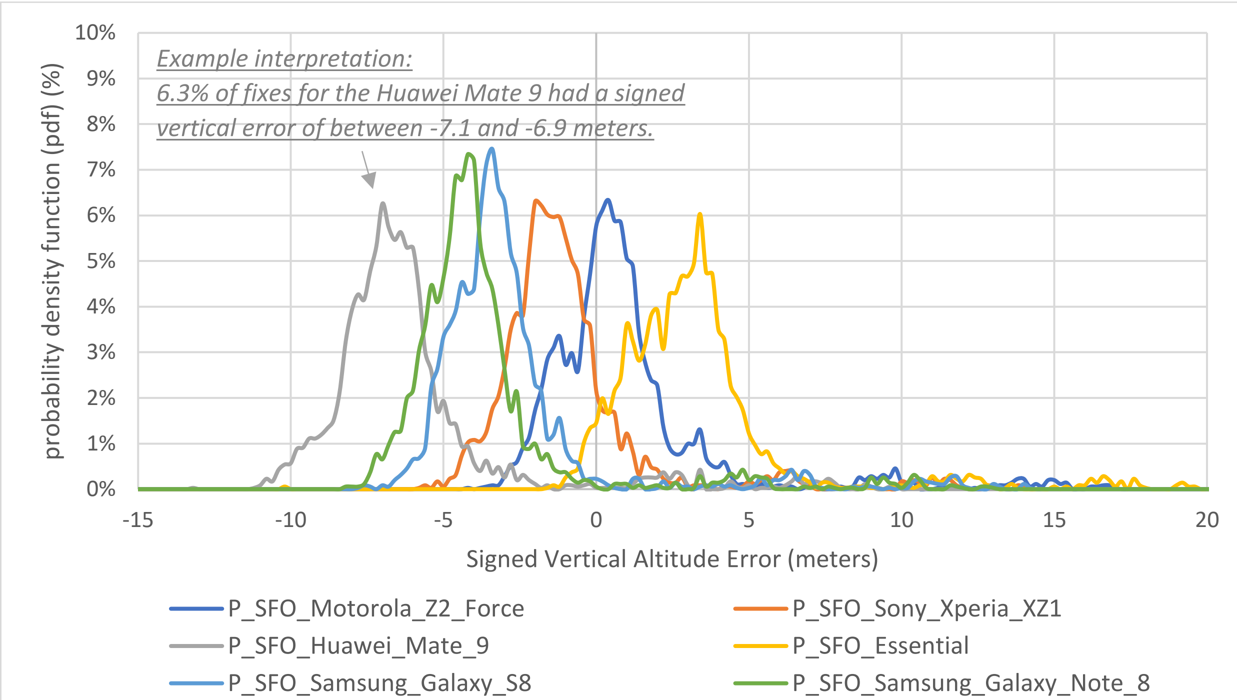



**Figure 9.24 – Signed Vertical Error pdf for Polaris Wireless San Francisco Test Devices**

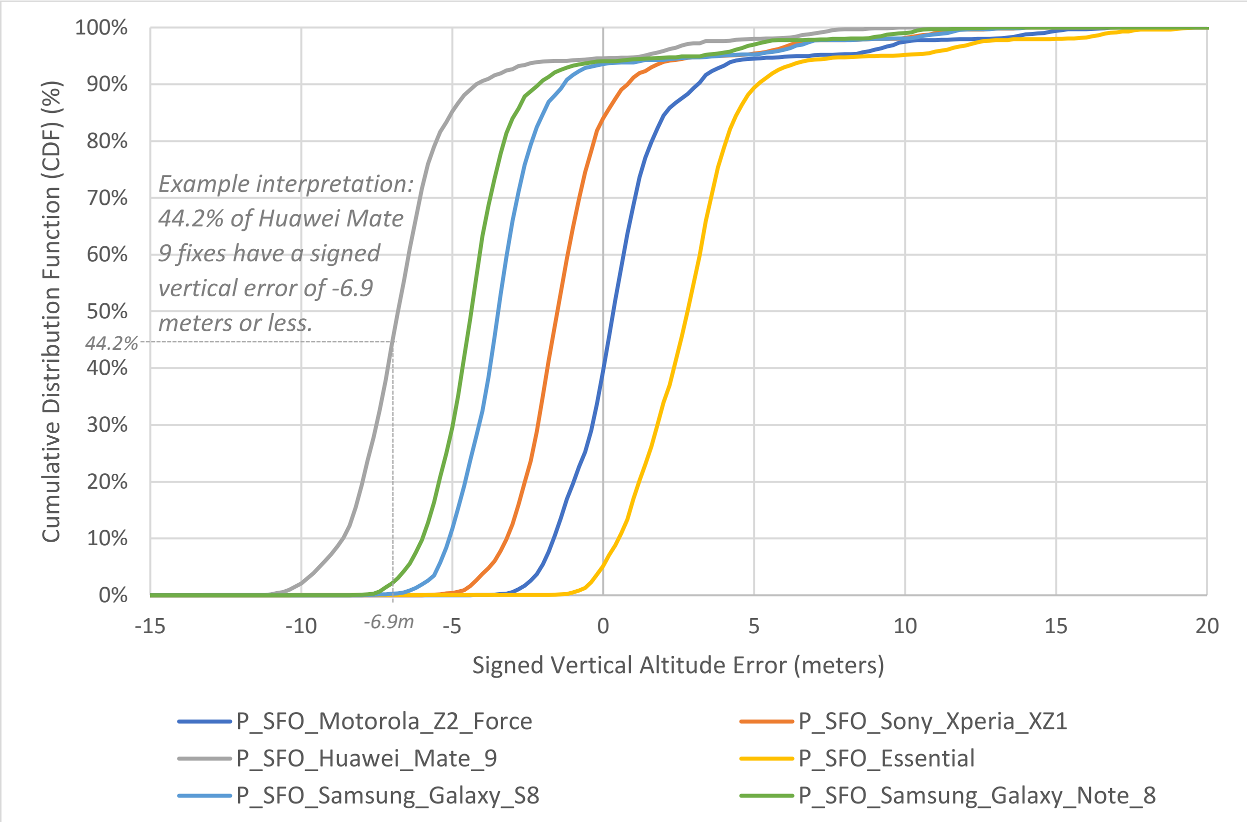



**Figure 9.25 – Signed Vertical Error CDF for Polaris Wireless San Francisco Test Devices**

#### 9.4.1.3 Signed Vertical Error Distributions for Polaris Wireless Atlanta Mobiles

Figure 9.26 and Figure 9.27 show the pdf and CDF signed vertical error per-device distributions for Polaris Wireless test devices for all fixes taken in the Atlanta market. Note that these are not the same physical devices as those used in San Francisco, and that there appears to be no particular correlation by model. For example, the Huawei Mate 9 device used in San Francisco has a significant negative bias, whereas the Huawei Mate 9 used in Atlanta has a modest positive bias. (This can also be seen in Figure 9.34 below broken out by building.)

Overall, device biases for these devices ranged from approximately -2 to +3 meters, somewhat less than observed in San Francisco. The extent of vertical error around the bias point is a bit more than observed in San Francisco – on the order of +/-2 to 4 meters.

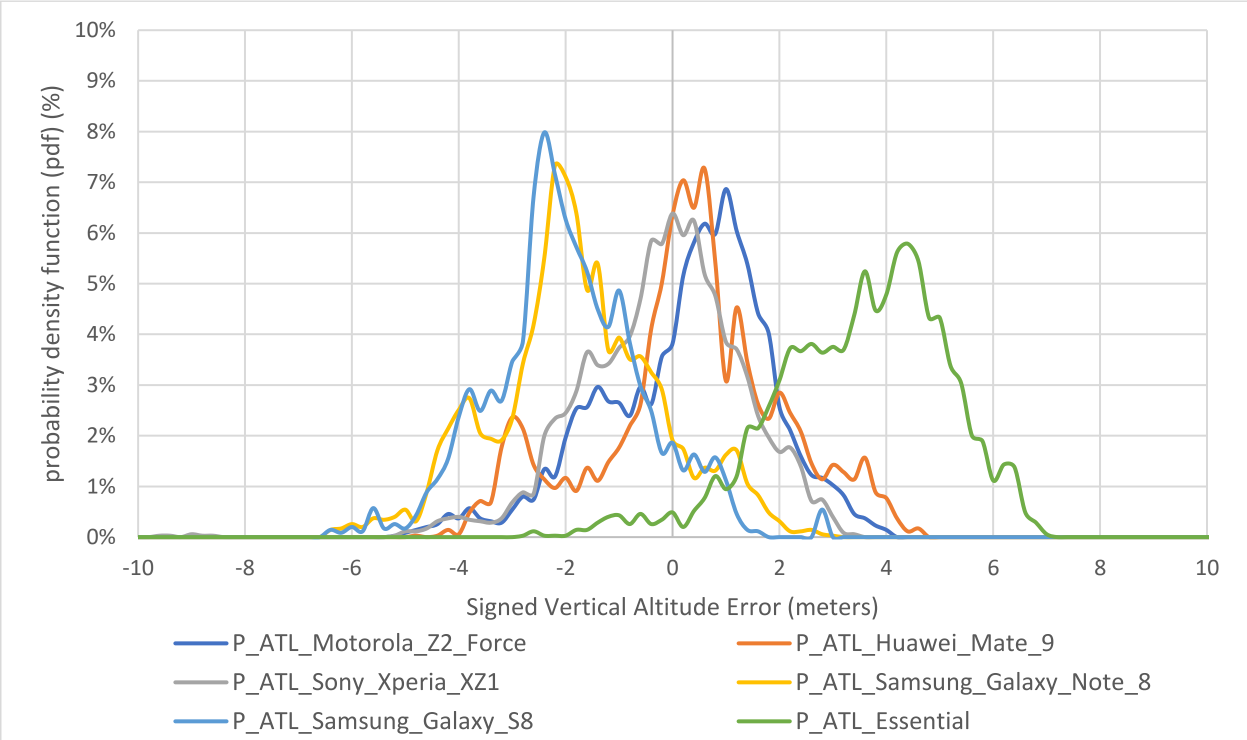



**Figure 9.26– Signed Vertical Error pdf for Polaris Wireless Atlanta Test Devices**

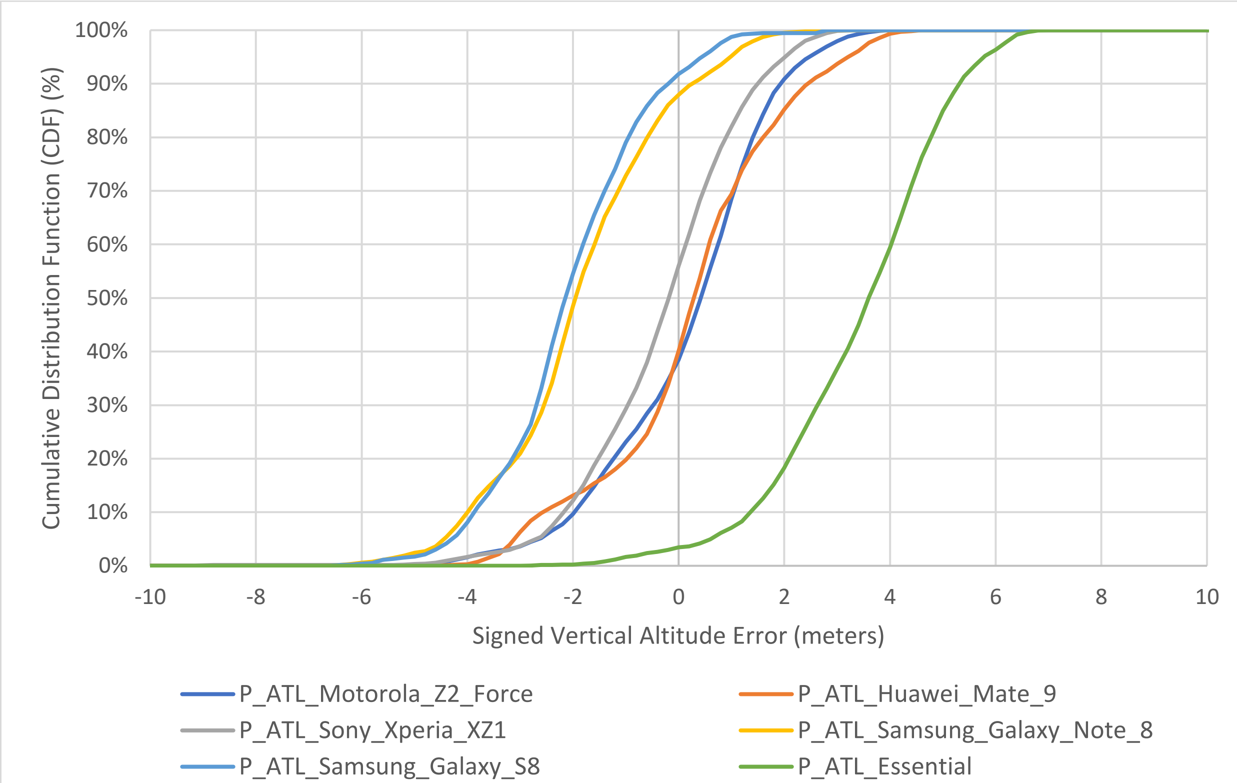



**Figure 9.27– Signed Vertical Error CDF for Polaris Wireless Atlanta Test Devices**

#### 9.4.1.4 Signed Vertical Error Distributions for Polaris Wireless Chicago Mobiles

Figure 9.28 and Figure 9.29 show the pdf and CDF signed vertical error per-device distributions for Polaris Wireless test devices for all fixes taken in the Chicago test area. Here the device biases range from approximately -6 to +1 m.

The extent of vertical error around the bias point is larger than that seen in the other cities, suggesting other factors such as weather and/or building effects played a more prominent role in Chicago. This is also seen in the wider spread of the pdf plots, which are clearly flatter than in San Francisco and Atlanta.

The two slopes in the CDFs, with the flatter slope at higher positive error values, correspond to the concentration of positive values seen on the right side of the pdfs, again most likely due to combined building/weather effects.

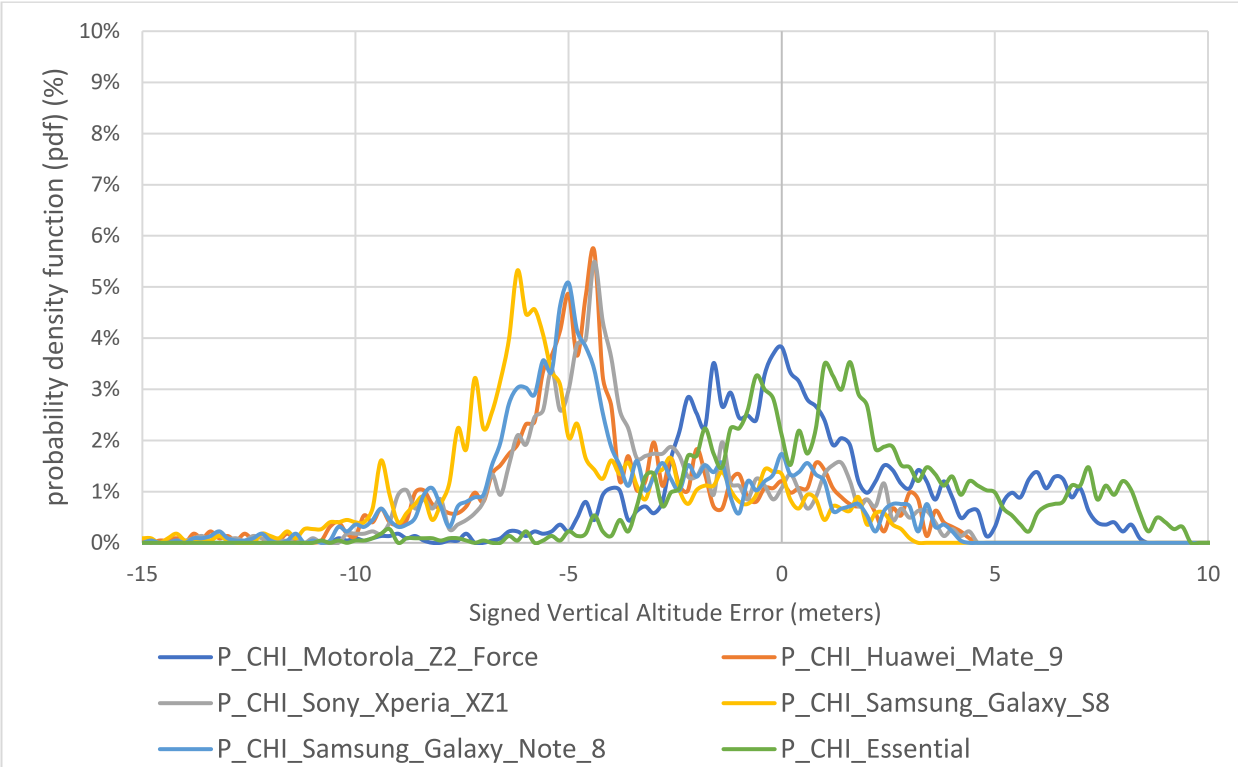



**Figure 9.28 – Signed Vertical Error pdf for Polaris Wireless Chicago Test Devices**

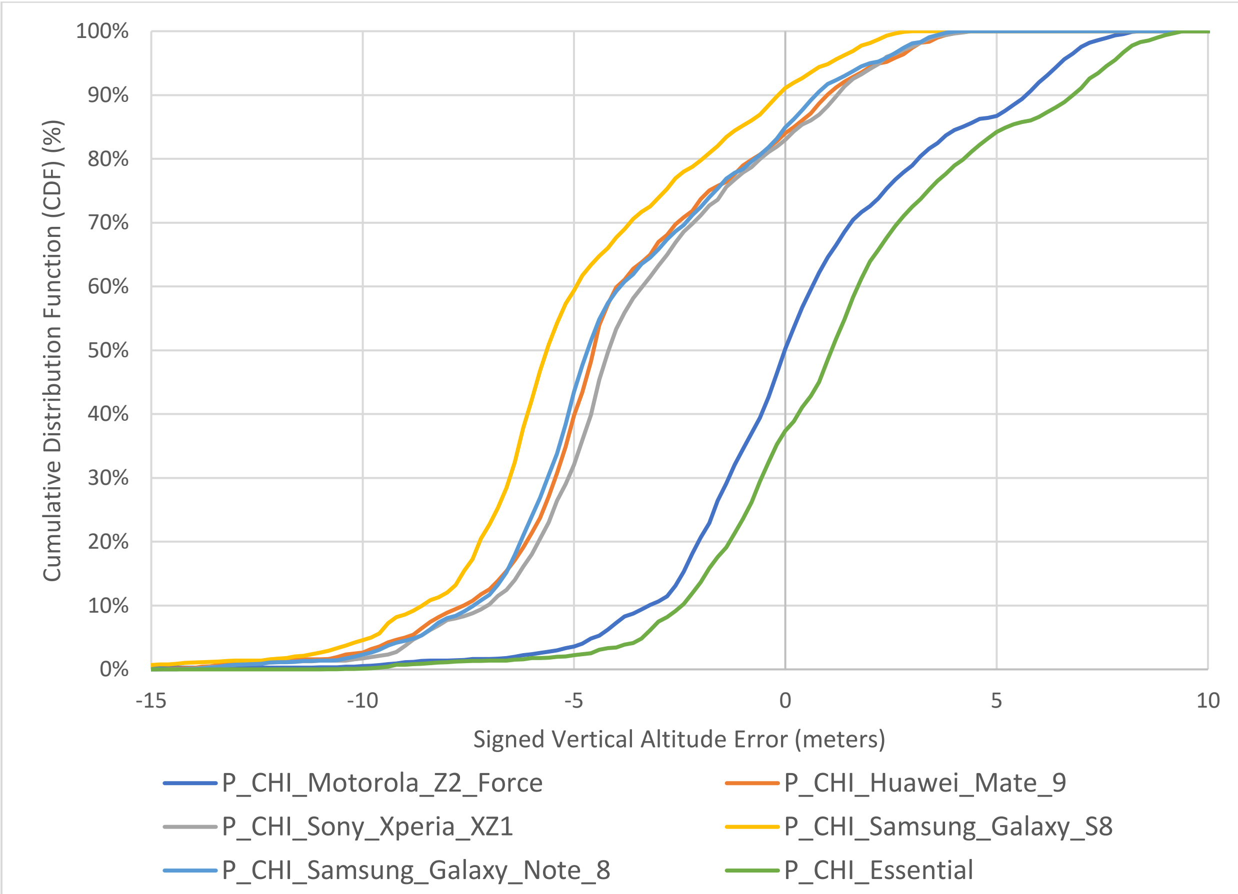



**Figure 9.29 – Signed Vertical Error CDF for Polaris Wireless Chicago Test Devices**

#### 9.4.1.5 Signed Vertical Error Distributions for NextNav San Francisco Mobiles

Figure 9.30 and Figure 9.31 show the pdf and CDF signed vertical error per-device distributions for NextNav test devices for all fixes taken in the San Francisco market.

NextNav device biases are within a few tenths of meters from zero, suggesting active mobile barometric device calibration is used. The extent of vertical error around the bias point is on the order of +/- 1 to 2 meters, suggesting an effective weather compensation implementation.

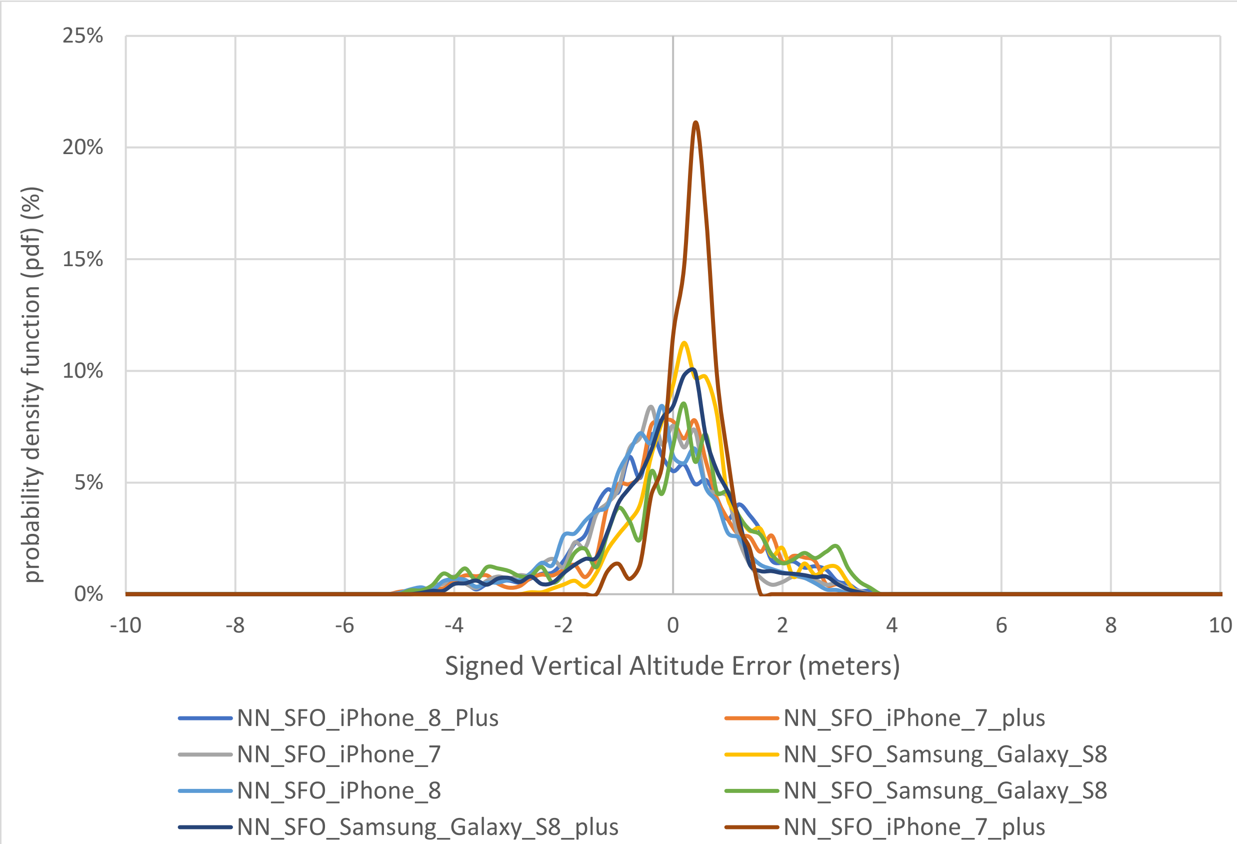



**Figure 9.30 – Signed Vertical Error pdf for NextNav San Francisco Test Devices**

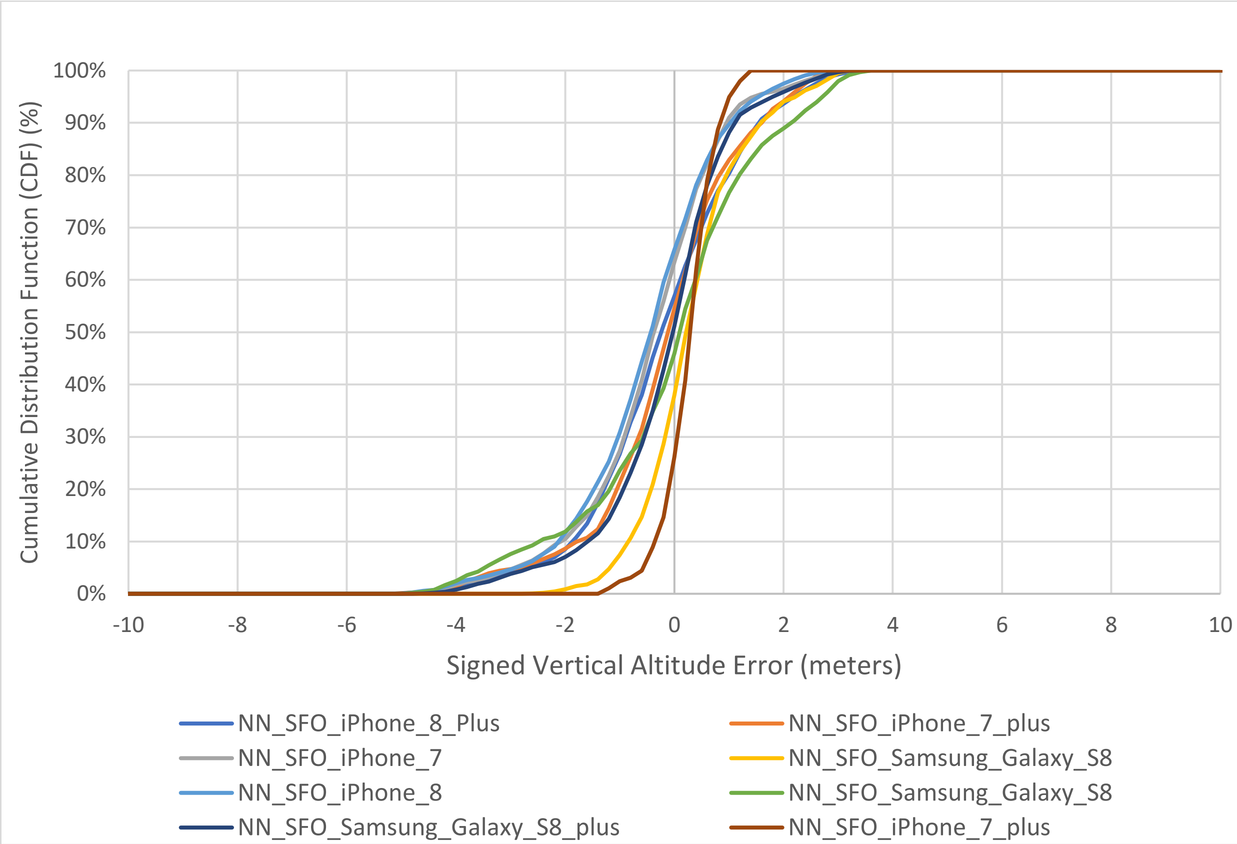



**Figure 9.31 – Signed Vertical Error CDF for NextNav San Francisco Test Devices**

### 9.4.1.6 Signed Vertical Error Distributions for NextNav Atlanta Mobiles

Figure 9.32 and Figure 9.33 show the pdf and CDF signed vertical error per-device distributions for NextNav test devices for all fixes taken in the Atlanta market.

Slightly more negative bias is noticed in the Atlanta test region, as compared to San Francisco, but still within approximately one meter. The extent of vertical error around the bias point is still on the order of +/-1 to 2 meters, similar to the San Francisco NextNav devices. One Samsung Galaxy S8 has an approximately 2-meter bias, suggesting it had a calibration issue.

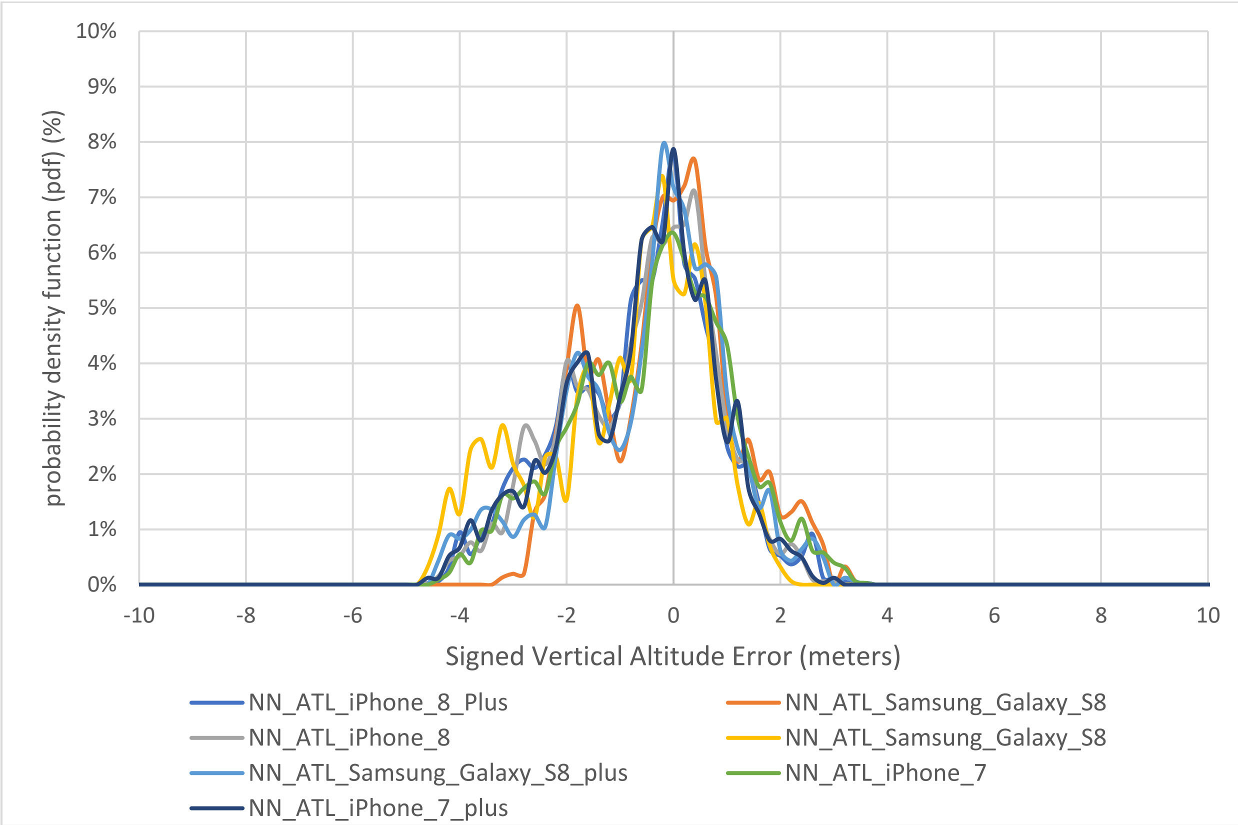



**Figure 9.32 – Signed Vertical Error pdf for NextNav Atlanta Test Devices**

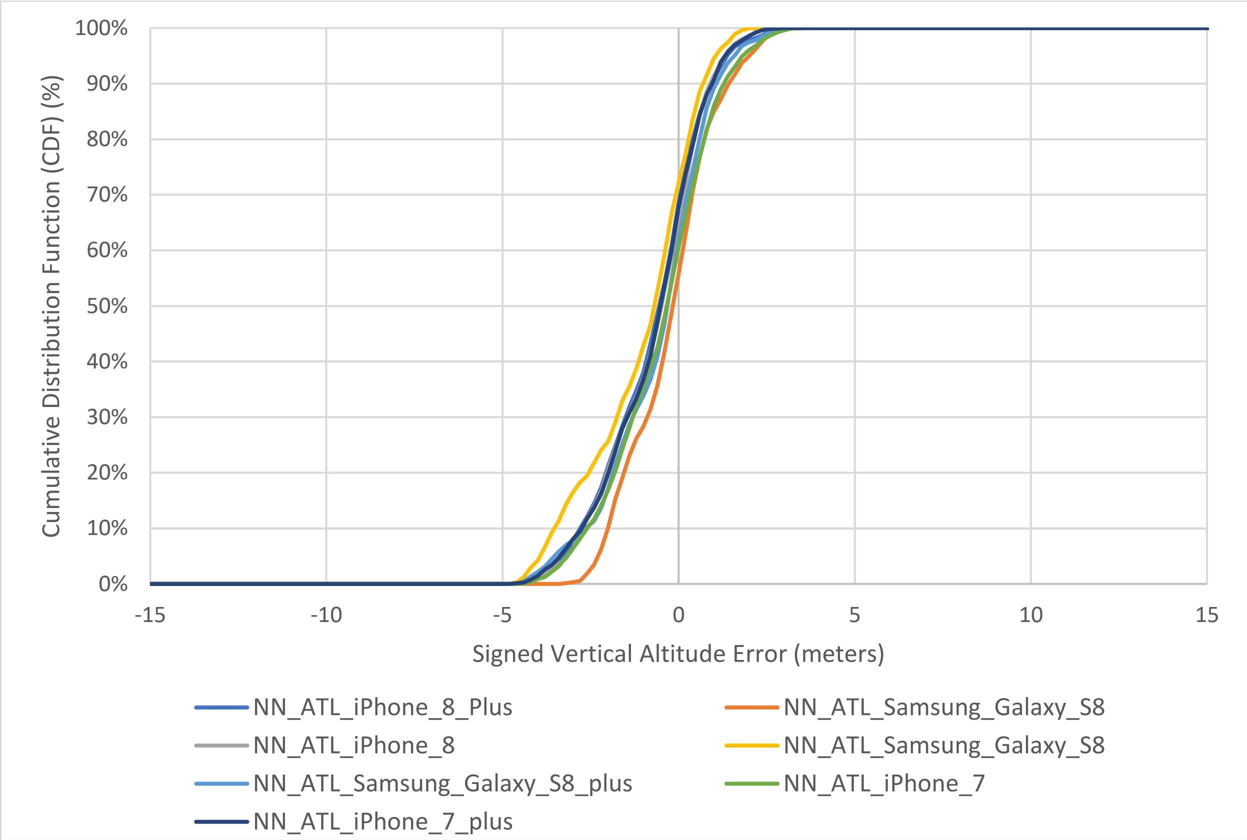



**Figure 9.33 – Signed Vertical Error CDF for NextNav Atlanta Test Devices**

#### 9.4.1.7 Barometric Sensor Bias Conclusions

Device biases were found to be significant for Polaris Wireless devices, ranging from about -7 to +3 meters, representing a dominant source of overall vertical positioning error. This is possibly due to not applying active background calibration during the test campaign. In contrast, NextNav device biases are much smaller – typically within about one meter – suggesting mobile device barometric sensor calibration is being successfully applied.

Overall vertical error in Polaris Wireless devices is in no small measure a result of these larger handset biases. Therefore, Polaris Wireless performance could likely be significantly improved should a more robust handset barometric sensor calibration approach be applied.

### 9.4.2 Variations by Building and Region

Figure 9.34 and Figure 9.35 show average signed vertical error by building for Polaris Wireless devices and NextNav devices. In these plots, signed vertical error for all the fixes made by a specific device at a specific building are averaged, and this average value is shown as a point on the graph. A designator is given for each building, which can be used to identify the test region and morphology of the building. The device models are shown but note that different physical devices were used in each test region.

Several trends emerge through this visualization:

- The excursion by building for Polaris Wireless devices, excluding a few outliers, is on the order of minus seven (-7) meters to plus seven (+7) meters. It can be easily seen that consistent biases in the mobile device barometric sensors are the primary source of this error, as described in detail in Section 9.4. Additionally, there are two instances of outliers: all devices for Building ‘SFR2,’ which is in the rural area in the foothills of the Sierras, had a positive 15-meter bias, and the Huawei Mate 9 device had a negative 12-meter bias for Building ‘ATS2’. The cause of these outliers cannot be ascertained but the first is likely due to the rural setting with fewer nearby weather reference stations. A smaller component of error can be seen to track by building (across handsets) and is thus driven by common factors such as weather or in-building effects.
- The excursion by building for NextNav devices, excluding a few outliers, is on the order of minus two meters to plus two meters. Notably, the different mobile devices appear consistent (as noted in Section 9.4 due to device barometric sensor calibration). The errors in most cases affect all devices under test and are thus driven by common factors such as weather or in-building effects.
- There is no apparent difference in performance by test region for NextNav devices. One can arguably see slightly less excursion in Atlanta vis-a-vis the other Polaris Wireless test regions, but this difference is modest and does not suggest a trend.
- Except for rural buildings, where there is one large outlier, no differences by morphology are observed.
- Note how in Figure 9.34 there is frequently no correlation in bias for the same handset model in different markets (which are different physical devices). For example, the Samsung Galaxy S8 and Samsung Galaxy Note 8 devices have modestly negative bias in Atlanta, but a strongly negative bias in the Chicago data. <u>This is anecdotal evidence that mobile device barometric sensor biases are not correlated by device model.</u>

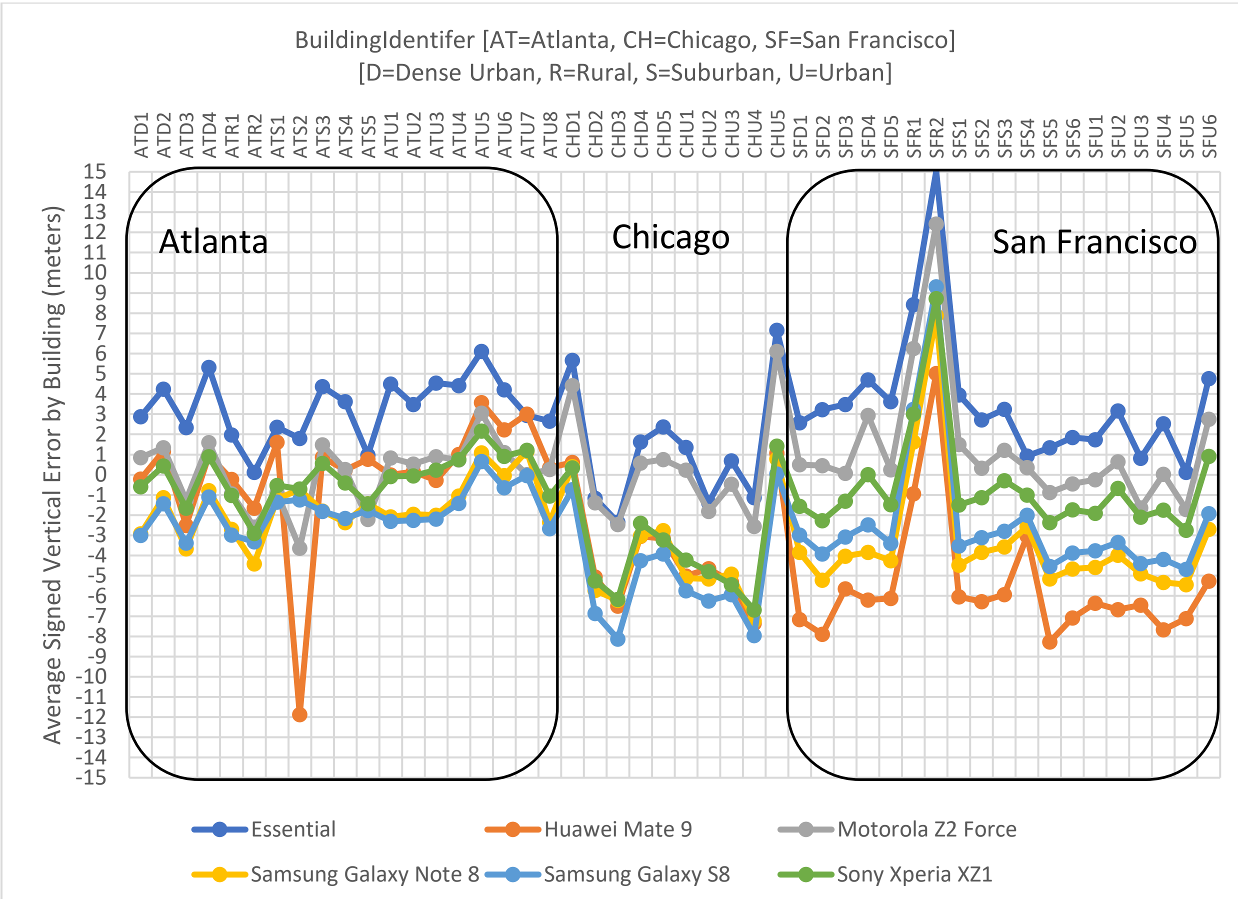



**Figure 9.34 – Average Signed Vertical Error by Building – Polaris Wireless Devices**

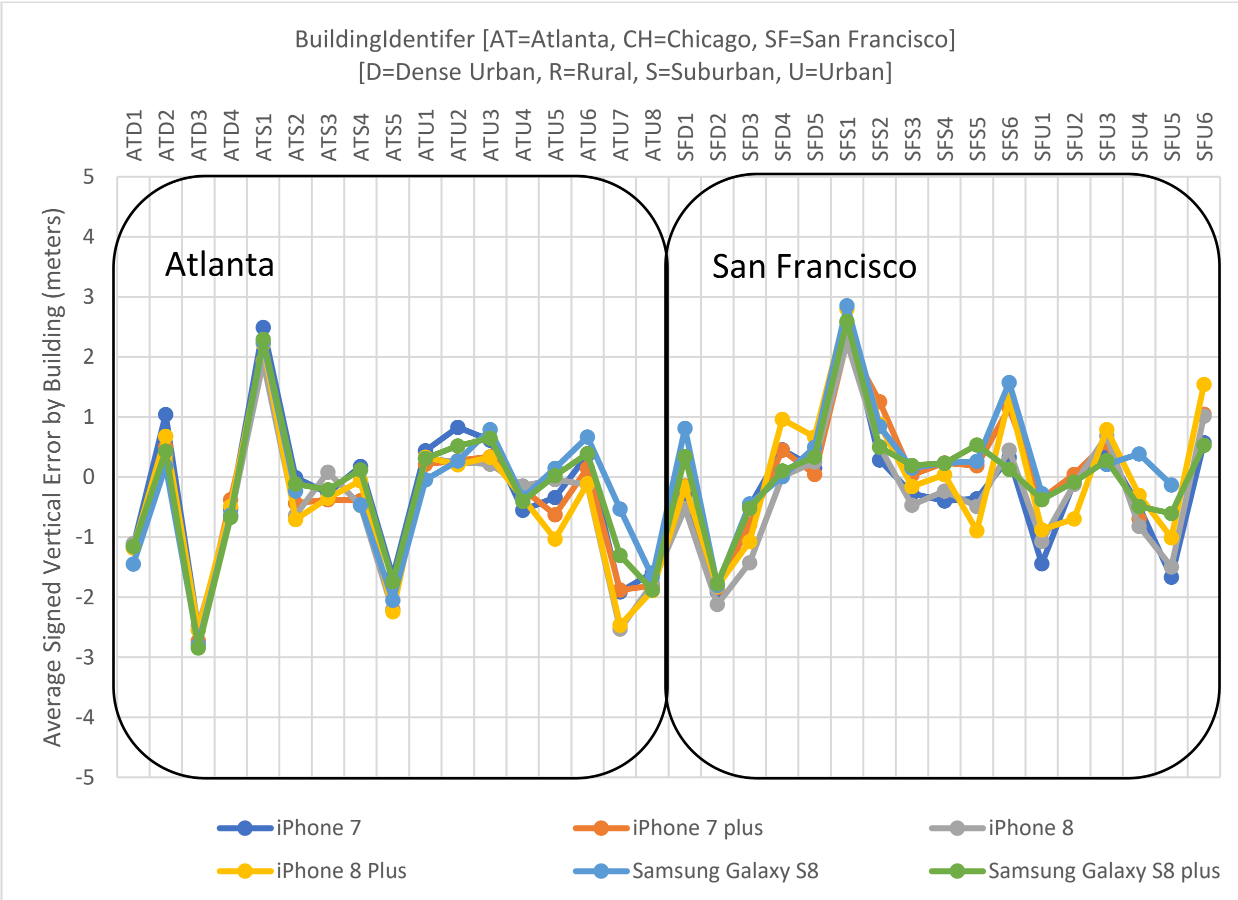



**Figure 9.35 – Average Signed Vertical Error by Building – NextNav Devices**

### 9.4.3 Temporal Variations and In-building HVAC Effects

24-hour test data collections were performed in three buildings – one each in San Francisco, Atlanta, and Chicago – in order to explore if variations as a function of time are present. The following describes the test points used:

- San Francisco: An approximately 50-story, sealed, predominantly glass exterior commercial building. Dense urban morphology.
- Atlanta: Large 50+ story sealed steel/concrete downtown hotel, in a dense urban region. Collection taken at a mid-level floor.

- Chicago: 20+ story sealed steel/concrete commercial structure, with plaster finish and glass. Urban morphology.

An analysis of these data collections demonstrates that a cyclic temporal variation on the order of +/- 1 meter is apparent over a period of 24 hours. This phenomenon is common to both vendors, and all mobile devices. Since this variation would probably not have been reflected in the short-duration data collects, this temporal phenomenon represents an additional error source that should be taken in to account beyond the accuracy statistics published in this report.

In addition to the slow-moving, cyclic temporal phenomenon, this data also exhibits several sudden pressure / reported position discontinuities, consistent with in-building HVAC effects. Both effects can be seen in the plots in this section.

To view these effects, time-series plots were made spanning the 24-hour periods, showing time on the x-axis, and signed vertical error on the y-axis, as shown in Figure 9.36 through Figure 9.40. The fixes for each mobile are shown in a separate trace on the plots, and it can be clearly seen that all the devices are reacting in a similar way to common effects.

Figure 9.36 and Figure 9.37 - the San Francisco 24-hour collections – show clear evidence of in-building HVAC effects causing long-term errors of up to two meters and occasional short-term (transient-like) errors of up to three meters. Both slow-moving shifts and several rapid discontinuities are apparent. Between about 3pm and 6pm there is a downward shift of about one-half meter for all devices. In Figure 9.36, during the overnight hours between 6pm and 6am, there is a slow upward drift up to positive two meters for NextNav devices. Both phenomena seem likely to be caused by HVAC mode changes, though it may be possible that the latter was caused by a sudden calibration or weather-compensation adjustment in NextNav's location server. Additionally, there are several larger short-duration spike errors at the mode transitions of minus two and plus three meters. Note that these spikes occurred at exactly the same times in all devices simultaneously.

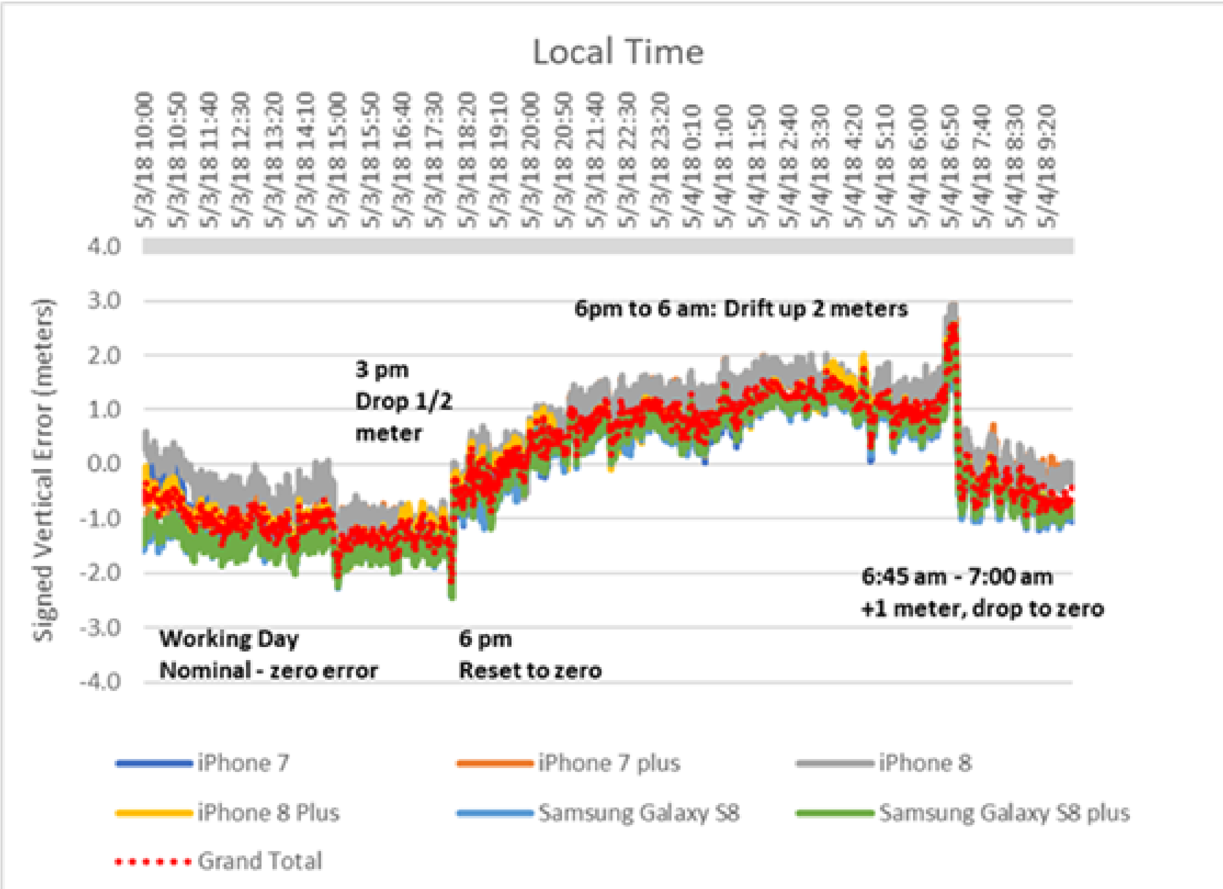



**Figure 9.36 – San Francisco 24-hour Collect Signed Vertical Error vs. Time – NextNav devices**

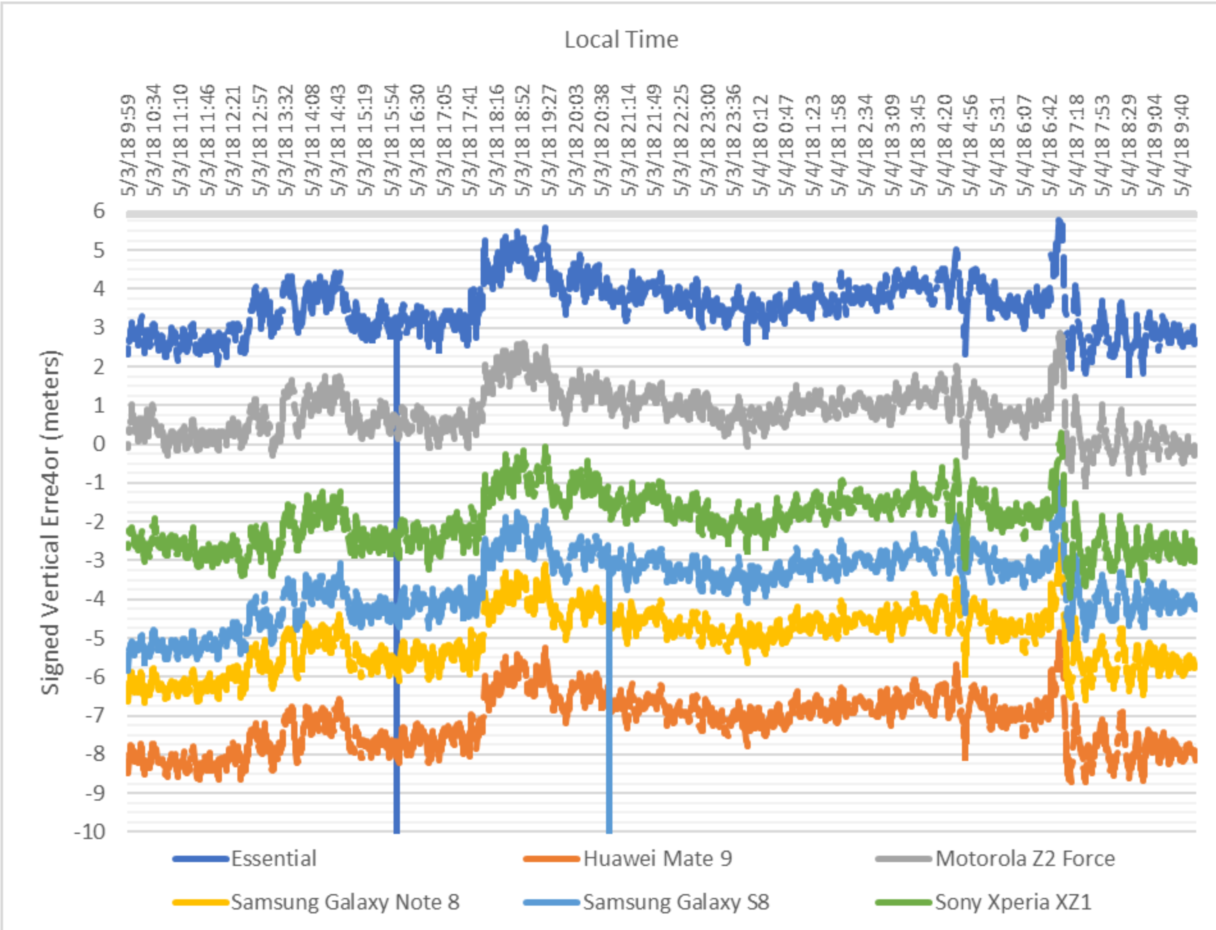



**Figure 9.37 – San Francisco 24-hour Collect Signed Vertical Error vs. Time – Polaris devices**

Figure 9.38 and Figure 9.39 - the Atlanta 24-hour collects – also show evidence of in-building effects, though of lower magnitude. In Figure 9.38, during the day, a small minus one-meter bias is apparent in NextNav devices. Then during the night, the bias drifts down two meters to minus three meters, then slowly moves back up during working hours, suggesting an HVAC mode change. Similarly, in Figure 9.39, equivalent amounts of drift are apparent in Polaris devices, occurring at the same times, clearly demonstrating a common in-building effect, though note that the absolute signed error values are dominated by barometric sensor calibration variances in Polaris devices. Short-duration spikes are less apparent in the Atlanta 24-hour data collects.

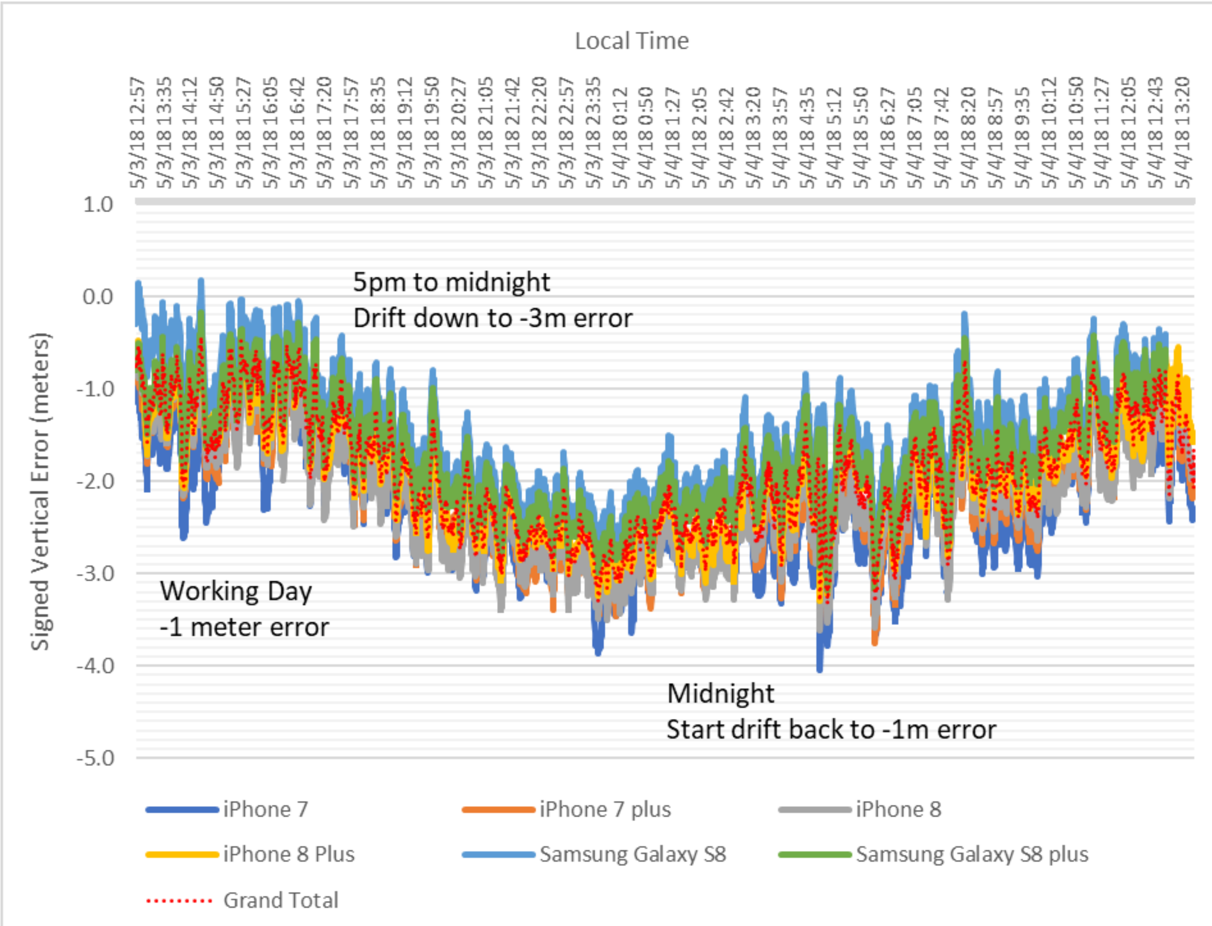



**Figure 9.38 – Atlanta 24-hour Collect Signed Vertical Error vs. Time – NextNav devices**

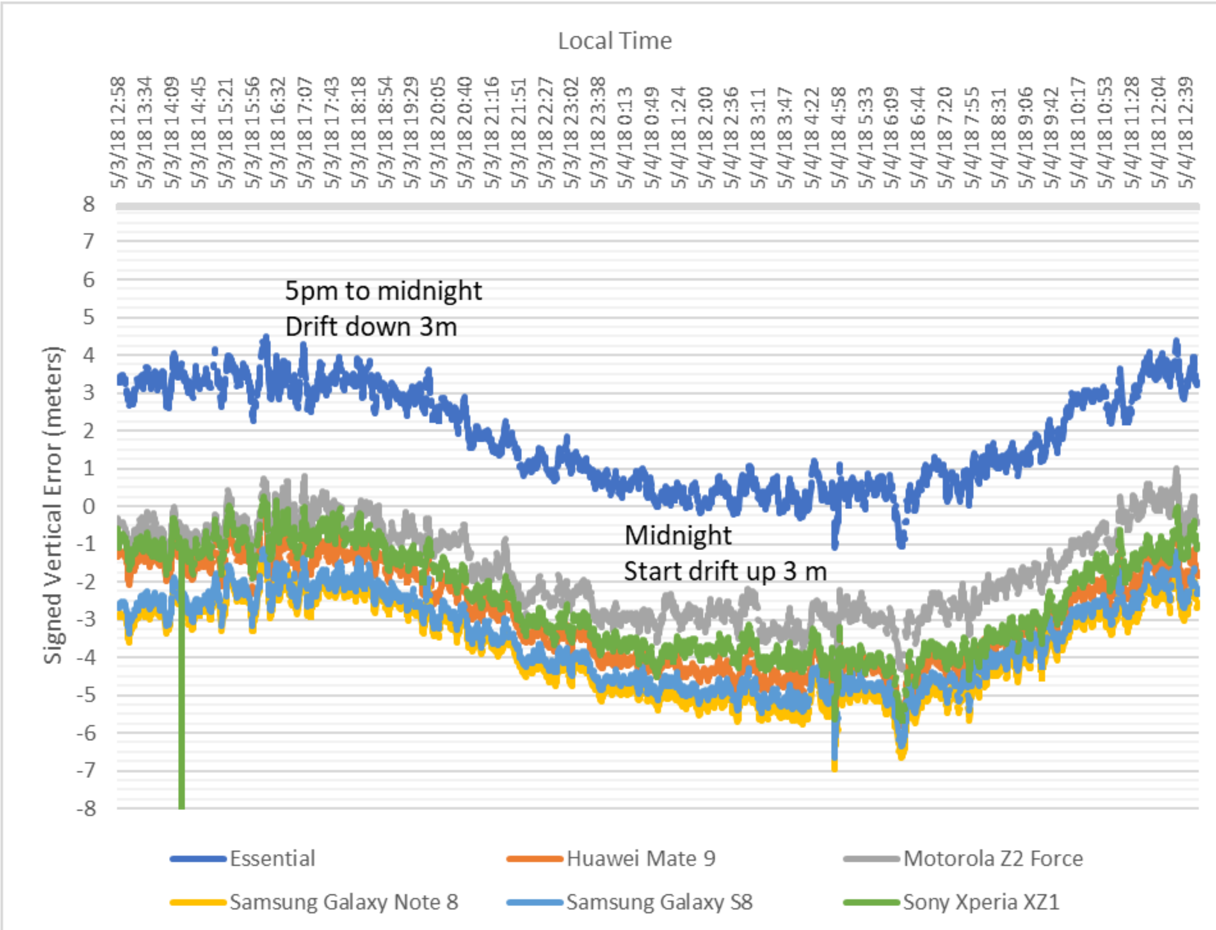



**Figure 9.39 – Atlanta 24-hour Collect Signed Vertical Error vs. Time – Polaris devices**

In Figure 9.40 - the Chicago 24-hour collect – during the middle of the night, variability seems to decline, and there is a modest downward drift of about one meter. However, large handset biases and generally larger per-fix variability make it difficult to conclusively determine that these are in-building effects.

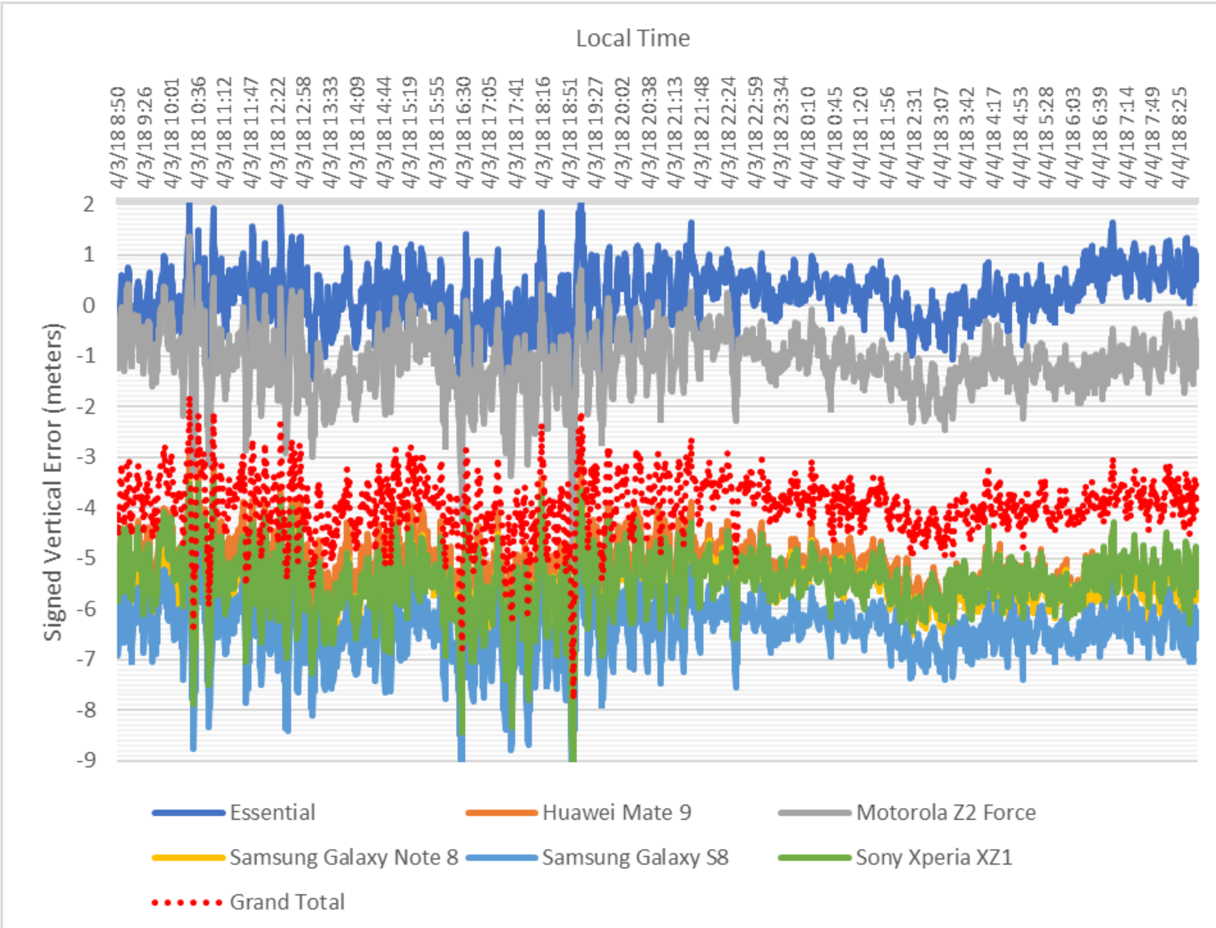



**Figure 9.40 – Chicago 24-hour Collect Signed Vertical Error vs. Time – Polaris Wireless Devices**

### 9.4.4 Weather Effects

Figure 9.41, Figure 9.42, Figure 9.43 capture the weather conditions present during testing in San Francisco, Atlanta and Chicago, by showing distributions of temperature, average and maximum wind, and the rate of change of barometric pressure. This information is based on government weather station data captured during the times when testing was performed and is shown here to convey the diversity of the weather conditions present during testing.

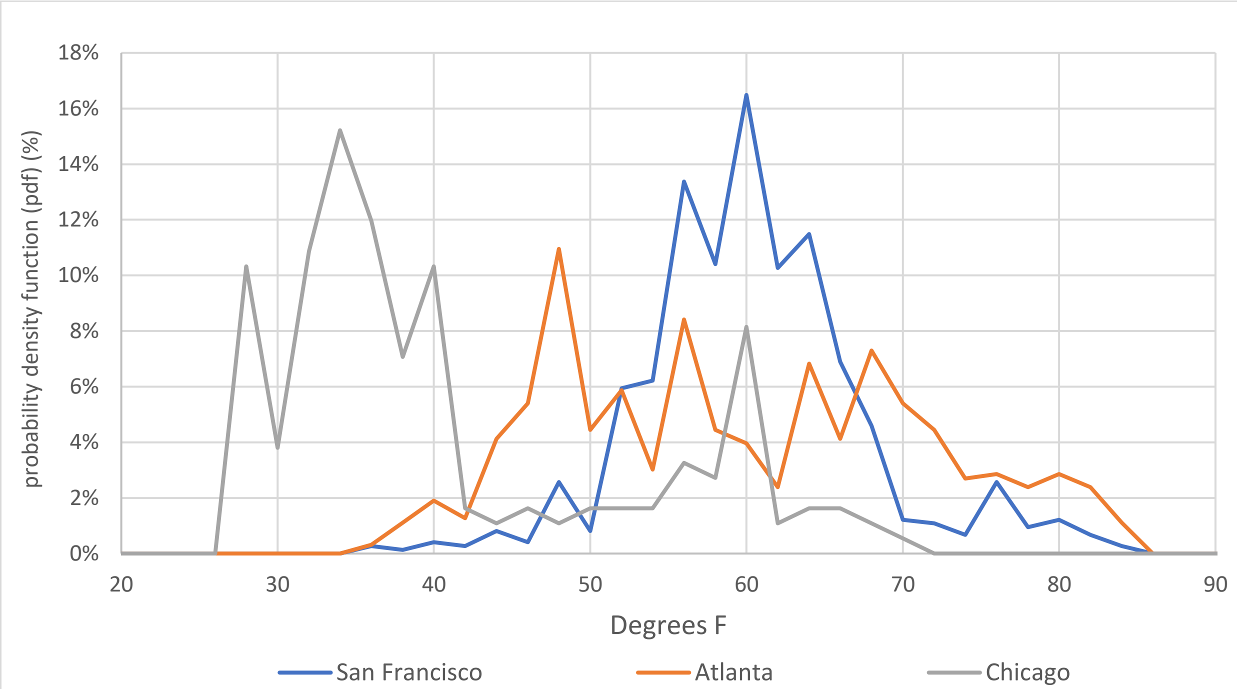



**Figure 9.41 – Distribution of Temperatures During Testing in Each Market**

From Figure 9.41, it can be seen that San Francisco had mild, temperate weather in the 50's through low 80's, as expected. At the same time, Chicago was still chilly, with temperatures in the 20's through 40's. Atlanta was in the middle. Thus, testing occurred in a diverse range of temperature values. However, very cold weather was not available during the data collection process. Large temperature differences between outdoor and in-building environments is a source of potential error in converting measured barometric pressure into estimated altitude. As a result, this report does not include impacts to Z-axis accuracy during extreme (well below freezing) low temperature conditions.

From Figure 9.42, it can be seen that typical, average wind values ranged from zero through about 20 to 25 miles per hour (mph). Maximum 'gust' wind values were somewhat higher, of course, ranging up to almost 40 miles per hour in Chicago. As expected, wind in Chicago was noticeably higher than in the other cities. Thus, a diverse set of wind conditions were encountered in this testing.

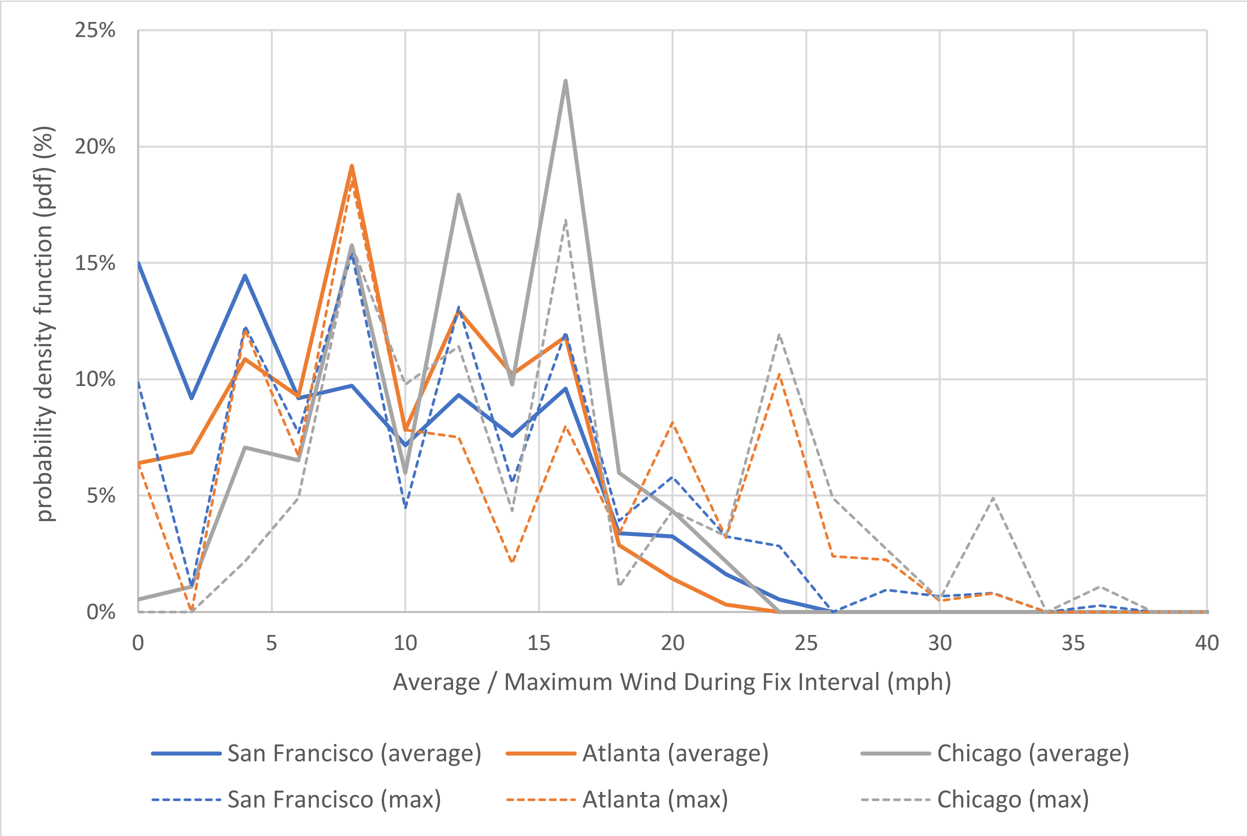



**Figure 9.42 – Distribution of Average and Maximum Wind During Testing in Each Market**

Figure 9.43 shows a distribution of the rate of change of barometric pressure present while testing occurred, which is an indicator of changing weather conditions and which potentially has an impact on weather compensation algorithms. As can be seen, barometric pressure change-rates spanned from about minus two to plus two millibars per hour. As was the case with wind and temperature, San Francisco had the most moderate change rates, Chicago had noticeably more dynamic weather conditions, and Atlanta was in the middle.

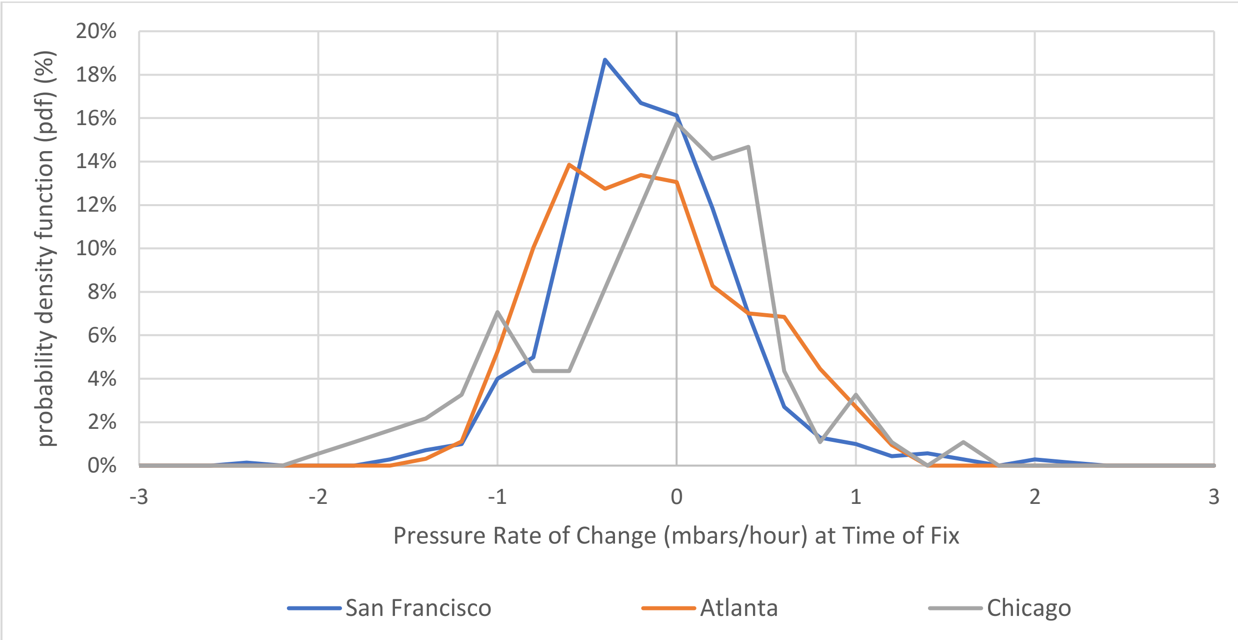



**Figure 9.43 – Distribution of Pressure Rate of Change During Testing in Each Market**

These graphs indicate that whereas extreme weather conditions were not encountered during the z-axis test campaign, a representative wide range of temperature, wind and barometric variations were encountered that are representative of a wide cross section of weather conditions in the US. The z-axis testing results obtained are therefore representative of these widely prevailing conditions. These results do not include impacts to barometric pressure-based altitude systems during extreme weather conditions (very high sustained wind speeds, very low temperatures, or very rapidly changing atmospheric pressure).

### 9.4.5 Reported Uncertainty and its Quality

Every location fix is delivered with an *uncertainty* – an 'educated guess' by the positioning system in real time as to the accuracy of the reported position. Uncertainty is NOT true error, but rather a guess of how much error is suspected to exist, made by the positioning system at the time the location fix is generated. Every uncertainty has an underlying 'confidence level' – which for this testing was fixed at 90%. This means that the positioning systems are 90% confident that the true horizontal error is within the reported uncertainty level.

The quality of this uncertainty estimator is important, so that fix recipients have some context as to how to use the reported position. This is particularly important when two or more positions must be compared to each other. One simple way to assess the quality of the reported uncertainty is to count how many fixes have a true error less than or equal to the uncertainty reported with the fix. If the underlying confidence level is 90%, this also means that true error should be at or below the reported uncertainty level approximately 90% of the time.

Figure 9.44 shows the percentage of fixes for each vendor/morphology permutation where true (empirically measured) error was less than or equal to the reported vertical uncertainty. Ideally, given the underlying confidence level used in this testing, this value should be 90%. When this percentage is above 90%, this means that the positioning system is being too conservative – its uncertainties are too large relative to the quality of the vertical errors produced. When this percentage is below 90%, this means that the reported uncertainties are too small – in other words the positioning system is not adequately reflecting all the error sources present in the system.

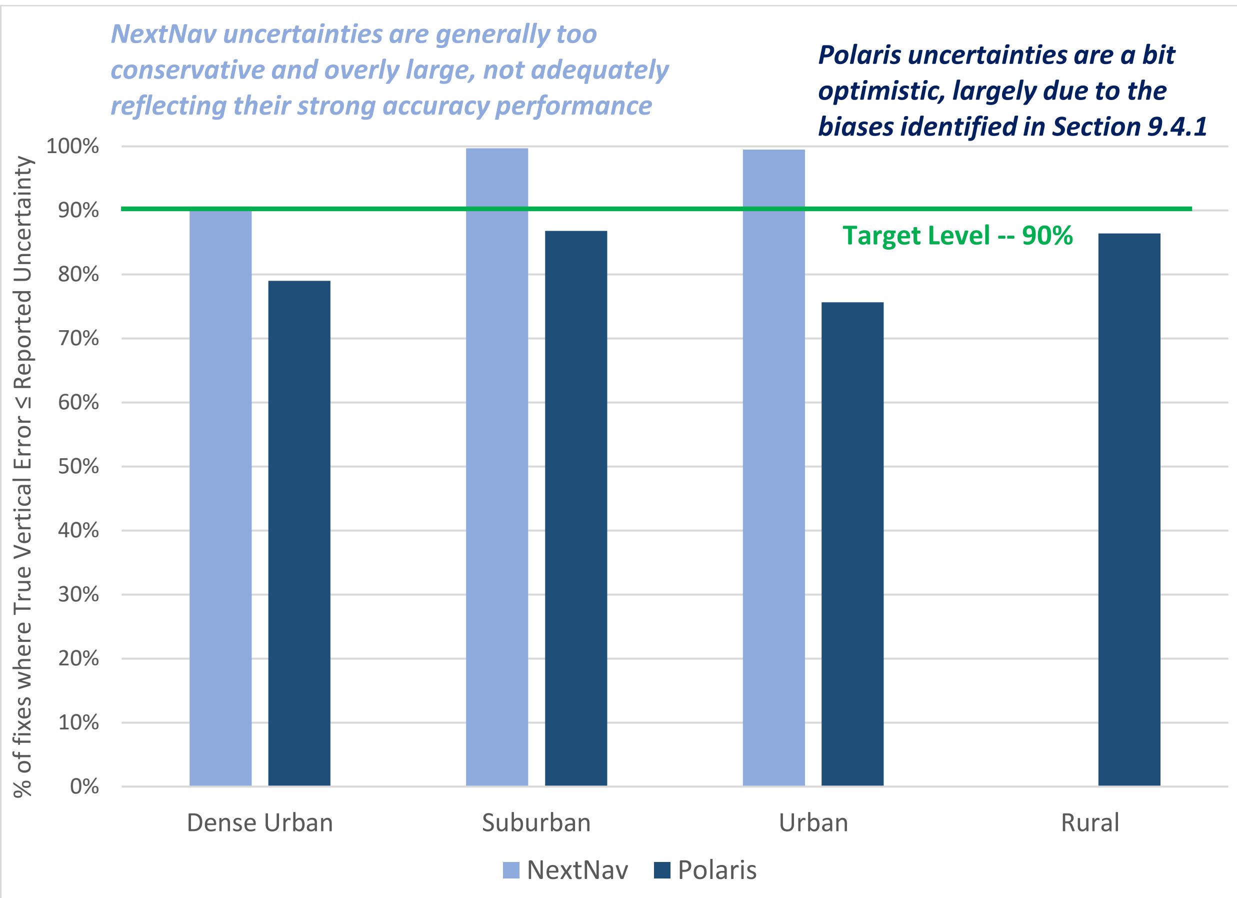



**Figure 9.44 – Uncertainty Quality – Ratio of Fixes Where True Error ≤ Reported Uncertainty**

From Figure 9.44 it is clear that the NextNav uncertainties are too conservative. The reported uncertainties are too large – typically at approximately 3.4 meters – not accurately reflecting their consistent vertical error performance, which is almost always below this value. Polaris Wireless uncertainties, in contrast, are somewhat optimistic. This is likely due to the mobile device barometric sensor biases described in Section 9.4.

### 9.4.6 Latency and Yield

Latency and yield are not relevant for this testing, given that proprietary applications were used by both vendors to initiate and deliver fixes. These apps produced Z-axis fixes at a fixed interval of time, thus from the perspective of the tester, latency appears to be a constant value. Also, only completed fixes were delivered to the tester by the vendors, thus yield always appears to be 100%.

Once Z-axis mechanisms have been built into commercial phones, working with commercial Z-axis-capable location servers and other wireless network elements, the context of what latency and yield means for Z-axis will become clear, and testing methods can be developed. Until these commercial architectures emerge, yield and latency are not meaningfully measurable quantities.

# 10. Lessons Learned from the First Z-Axis Test Campaign

This section contains lessons learned from Stage Z testing that apply to planning and execution of the test campaign. These lessons can be taken as observations from actual test execution experience and potentially serve as a guide for making process and procedural improvements to future Z-axis testing cycles.

## 10.1 Project set up and planning

Initial planning was based on a straight projection timeline with a bottom-up approach to task planning and overall durations needed. There were external commitments and factors that applied a top-down influence on how the project tasks, milestones and timelines were executed. This applied pressure to the overall time and resource needs to properly execute a condensed Stage Z test campaign with a very demanding reporting schedule.

*We learned that additional time (or resource costs) need to be allocated by all parties for project scope and reporting requirements.*

## 10.2 Building acquisition and challenges

The Stage Z test methodology requires a higher degree of test building access than previous stages for x/y testing. Furthermore, the requirements for Stage Z testing were different than previous stages which caused some of the pre-existing Test Bed buildings (or points within those buildings) to no longer be viable for Stage Z. The Test Administrator FES needed considerable additional effort in both time and resources to identify, qualify and secure these new test locations.

> **Private Tenant Space**: Proper scouting and qualification for Stage Z takes time. Many properties used in previous Stages were easier to acquire due to FES' ability to test in common spaces. For Stage Z, access to test points in separate HVAC spaces led to the need to access private tenant spaces. This is an unusual request for many people. Private businesses have a variety of legitimate concerns about who FES were, why they were asking for access to their private, paid space and what all of the equipment was for. While many of the commercial property managers were OK with providing assistance for accessing the common spaces, they were not willing to introduce the site acquisition team to their tenants or to encourage interaction with them out of fear of disturbing the tenant.

*The amount of time needed to manage expectations and assuage common concerns increased the level of effort by at least 2x.*

**Access Costs**: Many of the private tenants requested a payment from Test Bed, LLC to access their properties. For commercial spaces there were additional costs when testing in locations such as hotel rooms or private conference suites.

*Access fees increased overall allocated budget for site access by a considerable amount.*

**Time Allowed and Compressed Schedules**: The overall Stage Z execution and reporting timeline was condensed enough that not all test buildings and test points could be secured prior to beginning formal data collection. This created an additional strain on the FES team from a resource and scheduling perspective. Not only did it strain the test team, it created additional scheduling challenges with both ground truth survey companies and the tenant's space being accessed.

Because of the out-of-sequence test schedule, multiple visits to each test point were needed. It is FES' preference to perform these tasks (scouting, surveying, and testing) in a single one or two-day visit. The disconnected, multiple trips caused some friction with building management at some locations. Push back and some management fatigue were experienced at some locations that required scheduling for tenant access, blocks of hotel rooms, conference room time, security or maintenance escorts, and locations needing multiple days for revisits.

*The site acquisition process is recommended to be completed prior to scheduling any data collection activities and not performed in parallel*.

**Loss of previously used buildings**: Beyond technical reasons where a test building was not viable for the technology under test, there were additional factors that contributed to some test buildings dropping out of the test bed and needing replacement. These may have been due to building volunteer fatigue, pre-testing by potential test bed participants who knew the location of some test buildings, or even construction and new tenant blocking.

*Building and test point acquisition is the most difficult execution element for any stage of testing and care should be taken to minimize volunteer impact and anything that would jeopardize losing a building or a test point from testing.*

## 10.3 Testing Hardware

**Tool Setup / Software configuration:** The test devices and software required for generating test calls in Stage Z were provided by the participants and required manual installation and configuration. This by itself was not an issue but it did not allow FES to utilize their automated method for managing test devices and placing test calls. Software configurations had default settings that were not consistent with test settings and required frequent checking or correcting. The test calls themselves had to be manually placed. All of these manual interactions are opportunities where mistakes can occur even with the most diligent of test engineers.

*Test devices and test software should be configured in a way that test setup and execution can be an automated process and thus reduce the opportunity for error.*

**Dry Run and System Functionality Testing**: Early testing delays and some retesting caused by unforeseen issues have made it clear that a pretest dry run period is needed to allow for functionality testing and setup adjustments before official stage testing begins.

*All future test stage planning should account for the pretest period.*

**Device Software Updates**: Because the test software on the devices was not a commercial load, it was dependent on a particular operating system version. The test devices used were from a variety of carriers and OS versions. A few of the test devices encountered unplanned software upgrades despite every effort from the testing team to prevent this. These software updates had the potential to render the participant's test software unusable. A rollback of OS in many cases was not possible and the test devices had to be replaced.

*Ensure forward compatibility of test software or allow for additional back up test handsets.*

## 10.4 Data Collection

Call data collection methodology was changed for Stage Z and was largely a manual process. Furthermore, the test point naming and execution method was out-of-sequence to ensure test and data integrity. The complex test point visitation requirements to randomize data collection, as well as the need to manually re-configure test software at each visit to a test point, lead to a greater number of failed starts and higher likelihood of missed call data going undiscovered until data validation is completed. This approach to randomized data collection also causes some friction with building management and security planning in some test locations due to the additional time needed to execute testing per building.

*It is recommended that test automation and test point execution be automated as much as possible.*

## 10.5 Data Processing

No major issues were encountered with data processing.

## 10.6 Reporting

**Readiness prior to testing**: Reporting requirements, including individual workbook contents, should be determined prior to beginning data collection and analysis. In new stages not previously tested, it is understood that some reporting needs will not be evident until data is processed. The unique content of Z-axis testing, e.g., barometric and weather data, required major modification to existing analysis templates as well as re-processing individual workbooks at times. This additional time and effort contributed to overall slip of forecasted reporting timelines.

*If possible, determine reporting requirements and formats prior to beginning data collection. For new stages and technologies, allow additional time for comments, analysis and edits to the reporting milestone.*

## 10.7 Balancing Stakeholder's Interests

One observation on this project was the large number of stakeholders and challenges it presented in meeting overall objectives while also balancing needs of each party. For FES as the 3rd party vendor, there were instances of tension between delivery and timelines or costs. By and large, these issues were well managed through good communication and cooperation of all parties. However, it did require a re-forecasting of stage costs and expenditures.

## 10.8 Overlapping Test Milestones

The time needed for the testing effort was estimated for both field testing and data analysis of stage milestones on a chronological, continuous timeline. Overlapping Test

Bed stages challenged the original resource planning as well as placed additional strain on building participants.  Additional data processing resources were also needed to keep up with the amount of data being delivered with multiple overlapping milestones.

*Anticipate more time and additional staffing to accommodate scheduling in buildings that require second or third shift access, weekend work due to building access limitations or project timeline adjustments.*

# 11. SUMMARY FINDINGS AND ASSESSMENT

In this section, the structure and results of this testing are summarized. Additionally, recommendations are made for next steps.

## 11.1 Summary of Testing

In this testing, two proprietary vendor solutions were evaluated to determine the extent to which mobile device barometric sensor measurements can be used to quantify altitude. As noted above, the Stage Z test not designed to establish any comparison between the tested vendor's solutions.

Testing was conducted exclusively within structures, in numerous indoor environments, in a wide variety of buildings, in dense urban, urban, suburban, and in some cases rural morphologies, in three regions around Atlanta, Chicago, and San Francisco. Testing occurred in a total of 48 buildings, in 312 test points. A total of 30 smartphone devices of 12 distinct model types produced over 100,000 fixes.

### 11.1.1 Test Limitations and Assumptions

This testing used proprietary vendor-provided applications, which worked with each vendor's proprietary servers, to essentially perform a 'proof of concept' test. A fundamental assumption is that the results of these proprietary vendor solutions are reflective of what can be achieved in a final production environment. However, these solutions are not commercially available for the purpose of E9-1-1 in their present state. The "at-scale" architecture for a universal E9-1-1 altitude determination capability was not tested in this exercise.

This testing was confined entirely to determining altitude. No effort was made to determine actual building floor, or to assess the quality of the building databases that would be needed to convert an altitude to a floor level for purposes of utilizing Z-axis information to respond to an indoor wireless 9-1-1 call.

While reasonably comprehensive, the number of regions, buildings and test points used in this testing does not capture every possible indoor environment. Likewise, while the weather conditions encountered in the testing were reasonably diverse, extreme weather conditions were not encountered in this testing.

The number of mobile devices used was limited to a small number of Android and Apple smartphone models (though Apple devices were only tested by one vendor). No testing was performed using any other mobile device platform, or feature phones. Also, the total number of devices tested was limited, which is important given the significance of mobile device barometric sensor biases, as described below.

## 11.2 Performance Results Summary

Overall, bottom-line performance varied significantly by vendor solution, as follows:

- 80% of NextNav fixes had a vertical error of 1.8 meters or less.
- 80% of Polaris Wireless fixes had a vertical error of 4.8 meters or less.

In addition, approximately one meter of drift error was observed over a 24-hour period in large, sealed buildings, which appears to be the result of diurnal HVAC effects.

It should be noted, however, that NextNav was not tested in rural morphologies or in Chicago, which therefore excluded colder temperatures and higher winds from their overall performance evaluation. In addition, Polaris Wireless was not tested on Apple iOS devices.

The difference in results between the two technologies, as tested, is potentially driven by one factor: mobile device barometric sensor biases, and specifically the extent to which these biases are accounted for using active calibration measures versus a manual one-time calibration method at the beginning of testing. Based on the limited number of technology solutions tested, the contrast in performance illuminates an important message of this particular test, which is that *Active calibration of individual mobile devices seems essential to achieve consistent, usable Z-axis measurements for indoor wireless 9-1-1 calls because handset barometer biases significantly affect the accuracy of barometric pressure-based estimation systems*.

All other error sources were found to be less significant than mobile device barometric sensor biases:

- Weather compensation was found to be well implemented by both vendors, with no more than a meter or two of error introduced.
- In large, sealed structures, approximately one meter of additional drift error was observed, which appears to be the result of diurnal HVAC effects. Since testing was not performed extensively over long durations and at night, this error should be taken into account in addition to the 80$^{th}$ percentile error quantified above. A few very rapid error spikes on the order of one meter were occasionally observed at HVAC mode transitions but are not believed to be a significant error source given their short duration.

- Apart from the in-building phenomena described above, no significant difference in performance was observed by building type.
- Morphology (with the exception of one rural site) and region of the country do not appear to have a significant effect on performance overall.

## 11.3 Key Observations and Remaining Questions

The results of Stage Z testing provide some key observations. These include:

- Compensated barometric pressure-based altitude estimation is a complex process that must contend with many potential environmental error sources.
- Barometric pressure-based altitude estimation technologies are being developed. However, after widely canvassing the field of vendors, only two vendors felt their systems were sufficiently mature to begin formal assessment in the Test Bed.
- Neither of the two vendors that did participate in the Test Bed have integrated their Z-Axis estimation systems into off-the-shelf commercial mobile devices. As a result, to evaluate these two technologies, some artificial steps and accommodations had to be taken to produce the location estimates in the test campaign.

While the results of the testing provide helpful data and lessons learned, numerous key questions remain that could not be answered through the Stage Z testing:

- How a barometric pressure-based altitude estimation technology would perform in a real-world production deployment (integrated into a wireless network and a commercial mobile device in normal use).
- What yield (or availability) to expect in a real-world production deployment.
- What latency to expect in a real-world production deployment.
- How a barometric pressure-based altitude estimation system would scale from a small handful of individually calibrated test handsets (six per region in the initial Test Bed) to hundreds of millions of devices across the U.S.
- How one-time manual calibration would perform on an iOS device.
- How Z-Axis accuracy degrades with the age of the barometer, as barometer manufacturers have indicated that accuracy degrades as the sensors age (i.e., from the

time of manufacture of the mobile device) though no test handsets over 1.5 years old were included in this initial Test Bed campaign.

- How Z-Axis accuracy degrades with lower-end devices.
- The performance of devices with active mobile device barometric sensor bias calibration in rural morphologies, in very cold weather, and in high winds.
- The extent to which individual barometer bias in a given handset can be adequately calibrated out of the altitude estimate in a standardized, production environment, once integrated into a wireless carrier's network, and with mobile devices in normal use.
- How barometer bias for a given sensor varies over time and other factors, and how frequently the sensor needs to be calibrated to effectively manage errors.
- The extent to which, and how, altitude could be accurately converted into building floor level for pressure-based estimation systems. A technology feasibility study prior to further research and testing might be the first step.
- The extent to which the accuracy of the barometer reading is affected by an active call on the mobile device.

As noted above, the Test Bed can be made available to administer additional rounds of Stage Z testing if additional Z-axis technology vendors would like to participate. Further testing could address these issues. In addition, multiple vendors have indicated their Z-Axis solutions will likely be available, to the point of entry into the Test Bed for formal evaluation, in the next 12 months.

## 11.4 Next Steps

Additional focus is needed in the following areas moving forward:

### 11.4.1 Better Understand the Extent of Mobile Device Barometric Sensor Biases

The number of smart phone devices and models used in this testing was limited. Given that mobile device barometric sensor biases were found to be a dominant error source, additional effort is needed to understand the extent and nature of these biases, using a larger and more diverse sample of mobile devices. It is particularly important to understand the extent of biases in completely uncalibrated devices, so as to quantify achievable Z-axis performance when no calibration mechanism is available at all.

Measuring a mobile device's barometric sensor bias is a relatively simple matter of taking a single pressure reading using an app, then comparing this reading to true barometric pressure measured with a lab-grade instrument at the same physical location. This operation could be repeated for several hundred to a thousand real-world devices, allowing generation of a real-world bias distribution. From this distribution, an estimate of achievable altitude error without any calibration could be modeled, leveraging the results from this test.

### 11.4.2 Develop and Test Commercial Z-axis Implementations

As noted above, key questions remain regarding altitude determination and how mobile device barometric sensor bias calibration could be scaled up and made available to all (or some) devices in America for use in E9-1-1 calls. And new standards may be needed. There also are open issues about whether support can be provided effectively for most existing mobile devices, or primarily new devices. In addition, questions remain about the performance of non-higher end smartphones. These questions need to be answered, and production architectures developed, in order to move forward with Z-axis technology. Once one or more production implementations emerge, altitude determination performance should be reassessed using production components and systems.

### 11.4.3 Assess Floor Level Determination

The 9-1-1 community have consistently asked for floor level, rather than altitude in meters, as floor level is what a first responder actually needs to serve a caller. Although this is addressed by DL, it would be very beneficial for Z-axis systems to provide the next step of floor determination. Since a floor level determination falls outside the scope of an altitude estimate, a potential next step prior to further testing might be a feasibility analysis to understand the limits of the technology to convert altitude into floor level, and to assess the quality of the databases that would enable that undertaking.

## 11.5 Challenges to Identifying a Z-axis Metric Based on Stage Z

The results of Stage Z demonstrates that it is challenging to identify a Z-axis metric that can be consistently replicated in a live 9-1-1 calling environment with only two technology vendors participating in this round of Z-axis testing, under somewhat artificial conditions. Consistent with the FCC's *Fourth Report & Order* (para. 4 and 170), the proposed Z-Axis metric must be vendor-neutral and achievable across the entirety of carrier networks within the timeframe prescribed by Commission rules. It is unclear at this time whether the required calibration to overcome handset biases (the dominant error source) can be deployed and relied on in a live 9-

1-1 calling environment. Going forward, the Test Bed can be made available to administer additional rounds of Stage Z testing for Z-axis technology vendors interested in participating.

# ADDENDUM

**(1) NextNav Comments on Z-Axis Test Bed Results/Recommendations**

**(2) Polaris Wireless Commentary on Stage Z Testing and Report**

## Disclaimer

The following Vendor Commentaries were drafted independently by each vendor, NextNav and Polaris Wireless respectively, who participated in the Z-Axis Testing, and do not reflect the views or opinions of the Test Bed LLC, the Test Bed Technical Advisory Committee (TAC), the participating Carriers, CTIA, or the Z-Axis Working Group. The publication of such commentaries as addenda to the Z-Axis Report was an opportunity afforded to each vendor, and does not constitute an endorsement or agreement by the Test Bed LLC or the Test Bed TAC of the views, opinions, and content described therein. The Test Bed LLC assumes no responsibility for the content, accuracy or completeness of the information presented in the vendor commentaries.

# NextNav Comments on Z-Axis Test Bed Results/Recommendations

NextNav was pleased to participate in the recently completed CTIA/ATIS Z-Axis testing program and is appreciative of the opportunity to include comments and observations on the Test Bed Report. As an initial matter, NextNav has long been recognized for pioneering the approach of using localized weather calibration of barometric pressure sensors to accurately determine altitude. NextNav has been pursuing this technology approach for nearly a decade and demonstrated the first viable implementation six years ago, as part of the FCC's CSRIC III advisory council's industry-wide independent testing program for E911 indoor location technologies (4Q12). Using prototype receivers equipped with low-cost, commercially-available barometric pressure sensors, NextNav has demonstrated 'floor level' capabilities since those initial CSRIC III trials.

Positive test results in 2012 from CSRIC III's indoor location testing program from multiple vendors led directly to an FCC-proposed rulemaking in 2014. While the rulemaking and the resultant 4$^{th}$ Report and Order in 2015 focused on improving horizontal accuracy for E911 callers in indoor locations, the rulemaking also noted the strong need for accurate vertical location in large urban markets and the positive technical progress towards that end demonstrated in the trials. The FCC's final Order, as noted in this Test Report, asked the wireless carriers to determine through independent test what accuracy metric would be achievable in the 2021/23 timeframe, and to propose such a metric to the FCC for finalization of the Order's requirement.

The CTIA/ATIS Z-Axis Test Bed sought to determine what accuracy could be achieved using current handset technology and altitude determination systems. The data contained in this report suggests that 1.8 meters, 80% of the time represents an accuracy level that is achievable in the near-term. While performance at the 80$^{th}$ percentile has tended to be a common benchmark for analyzing location technologies, performance results from this Z-Axis testing program at the 94$^{th}$ percentile were at a level generally considered floor level (3 meters).

To gain additional comfort, it should be noted this is not the first, nor even the second, time this level of accuracy has been demonstrated in wireless carrier-supervised independent testing (including by CTIA/ATIS and this same FES testing team). NextNav also participated in CTIA's Stage 2 testing program during 2016. While Stage 2 concentrated on horizontal accuracy, the vertical results of both NextNav and other participants were recorded as well. NextNav's horizontal results from Stage 2 exceeded the FCC's desired 50m/80% horizontal accuracy objective, and as importantly, delivered vertical results of 1.7m/80%, nearly identical to the vertical results from this Z-Axis testing program. The vertical results from CTIA's Stage 2 tests were particularly positive since the test criteria mandated the use of common, commercially-available sensors in a handset over which the location technology vendor had no control (for NextNav's location system, Bittium handsets were utilized). Bittium followed Bosch's recommended sensor installation and calibration processes while manufacturing the devices and provided the handsets directly to the FES test team. In the Stage 2 tests, NextNav had no opportunity to calibrate the pressure sensor in any way (either manually pre-test or in background software during the tests).

While these three independent trials, over a six-year timeframe, used three different approaches to manage device performance (a manual calibration, a high-quality implementation at the factory and a software-based "background calibration"), the common denominator among all of the tests was NextNav's managed weather reference station network and compensation algorithms.

NextNav believes Test Bed, LLC did an admirable job of structuring a test environment consistent with the Z-Axis Working Group's recommendations and ATIS-0500030. While every possible test condition and outlier case cannot reasonably be replicated, it is clear all key testing constraints and factors (commercial devices, sensor types, ages, building types, weather conditions, morphologies, multi-floor testing, extended-time testing, etc.) were professionally identified, tested and recorded. NextNav monitored data from the tests in coordination with FES, and all identified concerns were quickly resolved. As a result, NextNav concurs completely that the raw data presented in the Report is accurate and supportable as it relates to NextNav's testing performance.

However, in an attempt to isolate and ascribe behavior to different elements of the vendors' location systems, the report draws certain observations and conclusions that are speculative at best and counter to the test data at worst. This is concerning because a hallmark of prior testing and reporting has been a focus on performance analysis as opposed to speculation about specific implementation choices. Key areas of concern regarding the system-level conclusions are:

- The characterization of "periodic background calibration" versus "one-time manual calibration". The Report makes a major point of attributing the preponderance of difference in accuracy between the two vendors to one having used a periodic background calibration of sensor bias during the test program versus the other using only an initial manual calibration at the beginning of the test. This assertion is not only unsupported by the facts, it is counter to data CTIA Test Bed, LLC has before it. First, if periodic background calibration was essential to achieving the positive results NextNav achieved, then NextNav could never have achieved comparable results in two prior rounds of testing, one of which relied on an initial calibration by NextNav, and the other relying on the device manufacturer's own implementation. A more appropriate observation, supported by the test results, would be to note that some portion of the difference in consistency between the two vendors appeared to be due to the relative efficacy of each vendor's sensor calibration process and algorithms.

- The Report's assertion that the dominant source of error was sensor bias calibration rather than other system variables, including accuracy and stability of the respective weather reference networks and associated compensation algorithms. It is essentially impossible to separate individual error sources within any multi-input and correction system without direct access to all elements of the system in a carefully controlled lab environment. In fact, while the test teams may speculate about various inputs and correction mechanisms a location vendor may employ, they simply do not have visibility into the inner workings of any vendor's multi-element correction system. For example, how much of GPS, MBS or OTDOA horizontal accuracy error is attributable to RF multi-path, DOP angularity, network component timing errors, hybridization algorithms, or any of multiple other sources? Other than the obvious conclusion that installed sensor bias can significantly impact accuracy, it is inaccurate to suggest that handset variability results from one of the vendors confirms that sensor bias is the dominant source of overall error. Weather is the dominant source of altitude measurement error and variability, with multiple components, including device performance and reference network precision, utilized to correct that impact. Individual error elements simply cannot be sufficiently isolated, or assessed as dominant, for overall error budgets of 1.8 meters at 80%. A single-meter error source (HVAC cycling) is extremely significant to a 1.8 – 3 meter system even if it is of lesser significance to a 5-7 meter system.

As detailed in the report, NextNav achieved consistent results across morphologies, markets and during the 24-hour tests. Overall, each of the effects highlighted by the Z-Axis Working Group as potentially impacting a barometric-based altitude system were exercised, and NextNav's system was able to compensate effectively for all of them. Some important observations regarding the NextNav results:

- The results demonstrated reasonable consistency between handsets, weather, building types, environments and time of day – demonstrating the efficacy of the overall altitude determination system (< 1m @ 80%).
- The only detectable variation (>1m) in NextNav performance was the Dense Urban test in Atlanta. NextNav believes that result is skewed by the fact that 45% of the Atlanta Dense Urban points (more than 20% of total Dense Urban points), were in a single building. The San Francisco Dense Urban points, on the other hand, were distributed among a larger number of buildings, resulting in performance consistent with all other test points. It is important for the reader not to ascribe this to a "bad building". Rather, it is a combination of the building effects, the building location relative to NextNav's network and other factors. This reflects the importance of evaluating the system as a whole across the entire test campaign, rather than attempting to zero-in on potentially non-correlated results and variables.
- NextNav's results were consistent across age of handsets, with the oldest devices (2016 models) performing identically to the newest (2018).

- Weather transitions did not meaningfully impact NextNav's accuracy, highlighting the performance of its system even in rapidly changing conditions. 1mbar / hour, for example, represents ~10m / hour in implied altitude change.

Beyond validating overall vertical accuracy performance of vendor systems, the Test Report reveals significant positive conclusions for barometric pressure-based altitude systems. These include:

- Current commercial handsets can provide floor level vertical accuracy when paired with appropriate altitude determination systems (3 meters accuracy 94% of the time);
- No major performance differences were noted among cities and among suburban, urban and dense urban morphologies (in spite of differing building types, heights and construction methods);
- Time of day fluctuation, HVAC fluctuation, weather fluctuation all induce errors to the altitude systems tested, but those errors are modest overall and contained within a reasonable overall error budget (3m/80%);
- Individual handset brands, ages and sensor types can provide comparably accurate results as part of an effective altitude determination system;
- Low-cost, low-impact software operated in a managed system that includes trusted localized reference stations can provide very high accuracy with existing handsets.

**(End of 'NextNav Comments on Z-Axis Test Bed Results/Recommendations')**

# Polaris Wireless Commentary on Stage Z Testing and Report – July 12, 2018

**Overview**

Polaris Wireless appreciates the opportunity to provide commentary on Stage Z testing and report. As part of the report preparation process, participating Stage Z vendors were invited by the Test Bed to review and comment on draft 2.0 of the Stage Z report. Polaris Wireless provided a commented and edited response identifying factual errors, misleading statements, and misrepresented side-by-side performance comparisons. Specific issues included:

- The report states that Polaris Wireless requested indoor building (set-up) calibration. Polaris Wireless never requested such calibration nor does the Polaris Wireless location capabilities require any building calibration.
- The report states that Polaris Wireless 'chose' to disable active compensation. The Test Bed specifically denied the Polaris Wireless request for this feature.
- The report states that Polaris Wireless requested 5 test calls be placed outside of a test market and 10 calls be placed within each test market. This was the procedure outlined by the Test Bed and was not the procedure requested by Polaris Wireless.
- The report states that performance results for each vendor are not meant for direct side-by-side comparison given that technologies under test are different, the solutions included different sensor bias compensation procedures, the solutions were tested in different markets, and the solutions were tested on different devices. Nevertheless, the report concludes with multiple direct side-by-side comparisons of vendor performance that clearly misrepresent results.
- Testing procedures did not consistently apply ATIS-0500030 regarding test guidelines for barometric sensor-based z-axis solutions, specifically related to the Chicago test market.

It is disappointing that the Test Bed decided to simply use the draft version 2.0 as the final version 3.0 report without addressing these issues. This commentary addresses these issues for the record and presents additional Polaris Wireless performance results drawn completely from Stage Z test data.

While there is no reason to question the Polaris Wireless performance numbers in the report for what was tested, these results do not reflect the currently available Polaris Wireless barometric sensor-based capabilities that were proposed for testing. One of the most significant sources of error for barometric sensor-based location solutions, as clearly stated in the report by the Test Bed, is bias in the device barometric sensors. Polaris Wireless proposed to include an active compensation correction model that operates in an application running in the background of the device. Based on a conversation with the Test Bed and reviewing subsequent instructions on allowable procedures provided by the Test Bed, Polaris Wireless did not enable available active sensor compensation for Stage Z testing.

To address this significant disparity in testing procedures, Polaris Wireless presented to the Test Bed a couple of options to verify Polaris Wireless compensated results as a supplement to this report. The Test Bed was unresponsive to this request, so Polaris Wireless is using this commentary as a forum to present actual Stage Z test data that has been reprocessed to illustrate the performance improvement of the Polaris Wireless vertical location solution with at least limited active sensor bias compensation.

**About Polaris Wireless**

Polaris Wireless is an innovator of software-based wireless location solutions, including hybrid capabilities for both horizontal and vertical location determination, and does not require network hardware or hardware or firmware to be installed in devices. The Polaris Wireless solution uses a proprietary measurement domain hybrid algorithm that leverages inputs from a wide range of sources (wireless networks, devices, and available third party sources) to calculate device location. Polaris Wireless applied for participation in Stage Z testing and did so for the sole purpose of receiving an independent verification of the currently available, complete Polaris Wireless vertical location capability.

**Polaris Wireless Hybrid Vertical Location Solution – Baro + 3D Wi-Fi**

For Stage Z testing, Polaris Wireless originally proposed a hybrid vertical location solution that combines both barometric sensor-based measurements along with a Wi-Fi measurements. The latter requires the addition of 3D Wi-Fi database and improves overall accuracy, compensation models, and robustness for when barometric pressures are unstable. Because third party 3D Wi-Fi databases are not available, Polaris Wireless initiated a campaign to pseudo-crowd source this data, including in the three test markets. This initiative was clearly stated in the Polaris Wireless proposal. The Stage Z report states that this activity was to "collect test and calibration data within test buildings" which is not accurate and may leave the reader with the incorrect perception that Polaris Wireless requires 'building calibration' as part of the vertical location solution. Actual crowd sourcing data collection used commercially available handsets, not test phones, and the resulting 3D Wi-Fi database did not include any ground truth measurements or related calibration. All contracted field crews were provided with Polaris Wireless credentials to ensure full disclosure. Finally, to provide additional data for Test Bed analysis, the Polaris Wireless Stage Z proposal suggested that performance be calculated in three manners: baro-only, 3D Wi-Fi only, and Baro + 3D Wi-Fi hybrid.

The Test Bed was notified by a building owner that Polaris Wireless had requested building access for data sourcing purposes. The Test Bed subsequently asked Polaris Wireless to stay out of buildings in the test markets. The Test Bed also expressed concerns about the viability of crowd sourcing a nationwide 3D Wi-Fi database and stated that Stage Z testing was intended for existing solutions available nationwide. Given these concerns stated by the Test Bed, Polaris Wireless ceased all crowd sourcing activities in the test markets and withdrew the 3D Wi-Fi component of the hybrid location solution. This sequence of events transpired before vendors were selected for participation in testing.

**Active Sensor Bias Compensation**

Without the aid of a 3D Wi-Fi database, correcting for the impairments in barometric pressure sensor measurements becomes critically important. The Stage Z report identifies device barometric sensor bias as a leading source of location error in barometric-based solutions. The Polaris Wireless Stage Z proposal included several manners in which to compensate for this sensor bias error, including active compensation through an application running in the background of devices during testing. To provide additional data for Test Bed evaluation, the Polaris Wireless proposal recommended that results be presented in both uncompensated and compensated manners. After a meeting to discuss operational procedures, the Test Bed replied in an e-mail that Polaris Wireless's proposed active sensor compensation stating that "we have determined that your suggested procedure does not reflect real world usage conditions, and therefore we will be using the following process". That e-mail also included a list of allowable procedures. Based on Polaris Wireless's interpretation of these instructions, Polaris

Wireless did not enable active sensor compensation for Stage Z testing. Polaris Wireless also presumed the Test Bed similarly restricted all vendors under test from enabling an in-market active sensor bias compensation capability and therefore all solutions under test would be similarly impaired.

In the draft version 1.0 of the Stage Z report, it was obvious that the other vendor included active compensation with their solution under test. In version 2.0 of the stage Z report, the Test Bed conveyed their understanding that the Polaris Wireless active compensation proposal required "in-building (setup) calibration through their test application." This is a clear misunderstanding by the Test Bed of the Polaris Wireless request and solution. At no time did Polaris Wireless request in-building calibration in test markets nor does the Polaris Wireless active compensation feature require such in-building calibration. In fact, it is just the opposite. The Polaris Wireless active compensation models seek outdoor ground-level environments for such updates. The Stage Z report also misstates that Polaris Wireless "chose to disable" this feature and that both vendors were provided the same procedures. In fact, Polaris Wireless did not enable this feature based on the Test Bed's verbal and written instructions. The unfortunate consequence of this misunderstanding is that the two solutions under test operated under very different procedures (one without active compensation and one with active compensation) which is a major reason performance results cannot be compared directly.

**Test Markets**

Stage Z testing did not consistently apply the guidelines outlined in ATIS-0500030 *Guidelines for Testing Barometric Pressure-Based Z-Axis Solutions*. These guidelines reflect the combined effect of the top three error sources, which are weather, device bias, and indoor building effect, such that results can be extrapolated outside of the testbed. As it relates to weather effects, ATIS-0500030 recommends testing in a northern city, such as Chicago during extremely cold weather, may be necessary to supplement the testing in Atlanta and San Francisco. ATIS-0500030 further states, "For test results from the test bed to be extrapolated to areas outside of the test bed, at a minimum the compensation network vendor or wireless carrier must be able to certify that these three compensation factors are consistent with those present in the test bed locations". This document was published in May 2016 thereby affording all interested vertical location vendors sufficient notice of a northern market being included in Stage Z testing.

The Test Bed did include Chicago as a test market but only required that Polaris Wireless be tested in this market, a market specifically chosen per ATIS guidelines and to stress the weather impact of barometric-based Z-axis solutions. The fact that the other vendor was not tested in Chicago further invalidates any direct comparison of results as stated by the Test Bed in the report.

**Polaris Wireless Active Compensation Recommendation**

Upon realization discrepancy in active compensation between the two solutions under test, Polaris Wireless suggested that the Test Bed either:

1. Conduct limited retesting in a test market with the Polaris Wireless active compensation feature enabled; or,
2. Present results that included a limited active compensation model that periodically updates sensor bias thereby representing some aspect of Polaris Wireless active compensation. Polaris Wireless provided such

a reprocessed dataset, in advance of Polaris Wireless receiving detailed test results, for consideration and verification by the Test Bed.

Because Stage Z testing was intended to be a technology evaluation, either performing limited in-market testing with the Polaris Wireless active compensation enabled or examining reprocessed test data would provide the Test Bed with the ability to assess the performance difference of the same solution with and without full compensation. This comparison is what was originally proposed by Polaris Wireless. The Test Bed did not respond to Polaris Wireless's suggestions.

**Reprocessed Test Data Representing Limited Active Compensation**

The information that follows is Polaris Wireless's reprocessing of actual test data to emulate performance with limited active sensor bias compensation. Polaris Wireless acknowledges that this information is not part of the formal Stage Z test report. Nevertheless, this analysis is drawn completely and only from actual Stage Z collected test data. Polaris Wireless active compensation models run in real-time with ongoing updates to sensor bias error corrections. For the sake of simplicity, sensor bias in the reprocessed data was adjusted once per month for collected test data. These results were compiled by Polaris Wireless before receiving test results from the Test Bed.

Figure 1 and Table 1 below represent aggregate vertical accuracy of the Polaris Wireless barometric-based vertical location capability. There are two results presented:

1. All test markets as reported by the Test Bed with no active compensation.
2. All test markets with reprocessed results with limited active compensation.

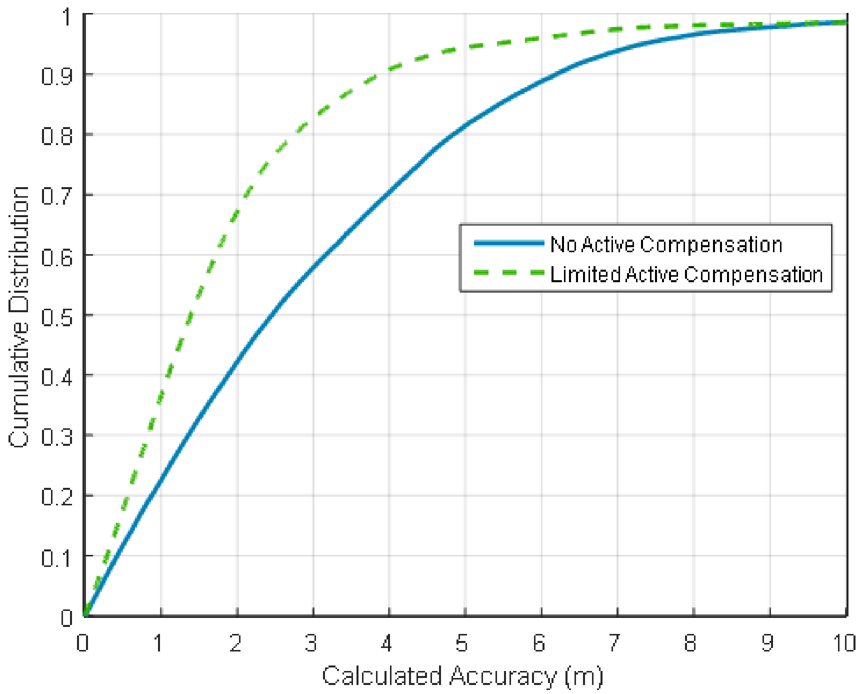



***Figure 1. Polaris Wireless Aggregate Accuracy Performance CDF, All Test Markets and Morphologies (unofficial)***

The differences are meaningful and the differences clearly verify the Test Bed's statement that barometric sensor bias error represents a major source of error in barometric sensor-based vertical location technology. This figure also illustrates the impact active sensor compensation has on location performance for the Polaris Wireless vertical location solution.

| **Data Analysis** | **Limited Active Compensation** | **Markets and Morphologies** | **Aggregate Accuracy (m) 80% Percentile** |
|---|---|---|---|
| As Tested | Disabled | All | 4.8 |
| Reprocessed | Enabled | All | 2.8 |

***Table 1. Polaris Wireless Aggregate Accuracy Performance Results (unofficial)***

Given the significant differences in these results, Polaris Wireless encourages the Test Bed to either:

1. Verify these reprocessed results as a supplement to the Stage Z report; or,
2. Agree to a retest of the Polaris Wireless vertical location solution, with and without active compensation.

Either option would enable the Test Bed to complete their stated objective of conducting an independent assessment of "available" vertical location solutions from participating vendors.

## (End of 'Polaris Wireless Commentary on Stage Z Testing and Report')