



SPACE-BASED POSITIONING
NAVIGATION & TIMING

NATIONAL EXECUTIVE COMMITTEE

Module 2

GPS Accuracy in an Urban & Suburban Environments (Census Data)



Knute A. Berstis, P.E.
Senior Advisor
National Coordination Office
For Space Based PNT
October 16, 2010



National Positioning, Navigation, and Timing (PNT) Architecture Study



- In 2006 the Assistant Secretary of Defense for Networks and Information Integration (ASD/NII) and the Under Secretary of Transportation for Policy (UST/P) sponsored a National Positioning, Navigation, and Timing (PNT) Architecture Study to “provide more effective and efficient PNT capabilities focused on the 2025 time frame...” ¹
- Several NOAA organizations, including the National Geodetic Survey (NGS), participated on the Architecture Development Team (ADT) and are, additionally, members of the Architecture Transition Team (ATT).
- The PNT Joint Capabilities Document (JCD) identified a number of validated gaps in capability which are projected to exist in the 2025 timeframe.

¹ National Positioning, Navigation, and Timing Architecture Study, Final Report, September 2008---This Document Is Cleared For Public Release



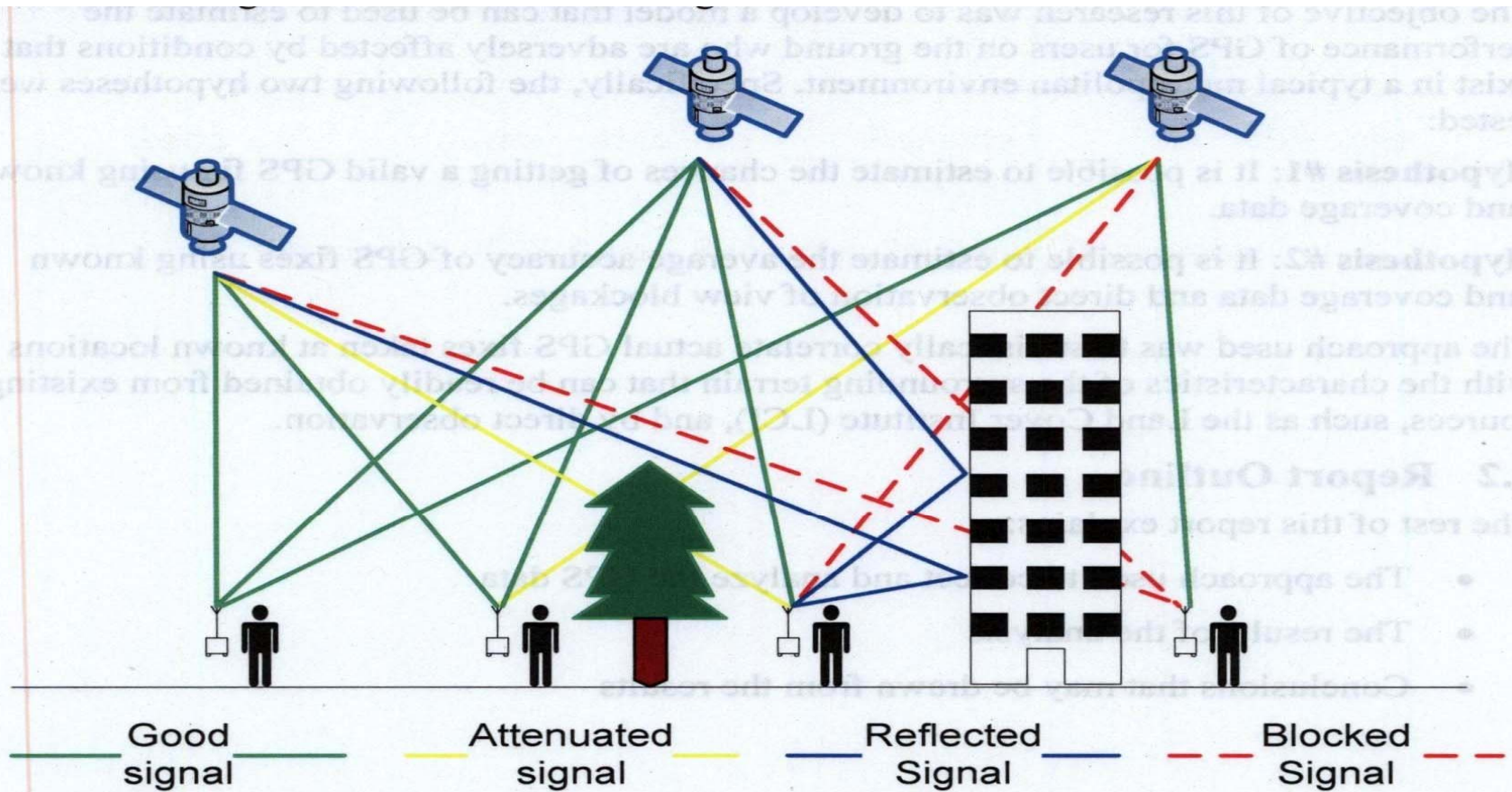
National Positioning, Navigation, and Timing (PNT) Architecture Study



- The team identified 7 gaps and the key gap related to this presentation was:
- ***Assured and real-time PNT in physically impeded environments.1***
- The large data set gathered (approximately 106 Million data points) during the Census Address Canvassing can provide a very good assessment of what are the PNT capabilities of GPS in a partially impeded physical environment in the 2009 time frame.

Caveats:

- Data is Title 13 data.
- Statistical data analysis procedures must be negotiated and approved by the Census Bureau.



GPS Signal Reception Problem Illustration

Bohne, Paul F. & Nobile, Marc P. MITRE Technical Report MTR070200, "Average GPS signal Availability Estimation", pp. 1-1, September 2007.



Address Canvassing

- **The Census Bureau used Hand Held Computers (HHCs) to capture GPS structure points for every housing unit during its Address Canvassing field operation**
 - ❖ **The Address Canvassing operation supported the 2010 Census**
 - ❖ **Address Canvassing was the first nationwide collection of housing unit structure points using GPS technology to be conducted by the Census Bureau**
 - ❖ **Field collection occurred in spring 2009**
 - ❖ **The HHC had Wide Area Augmentation System (WAAS) capability to increase point position accuracy to 3 meters or less in an unobstructed environment**



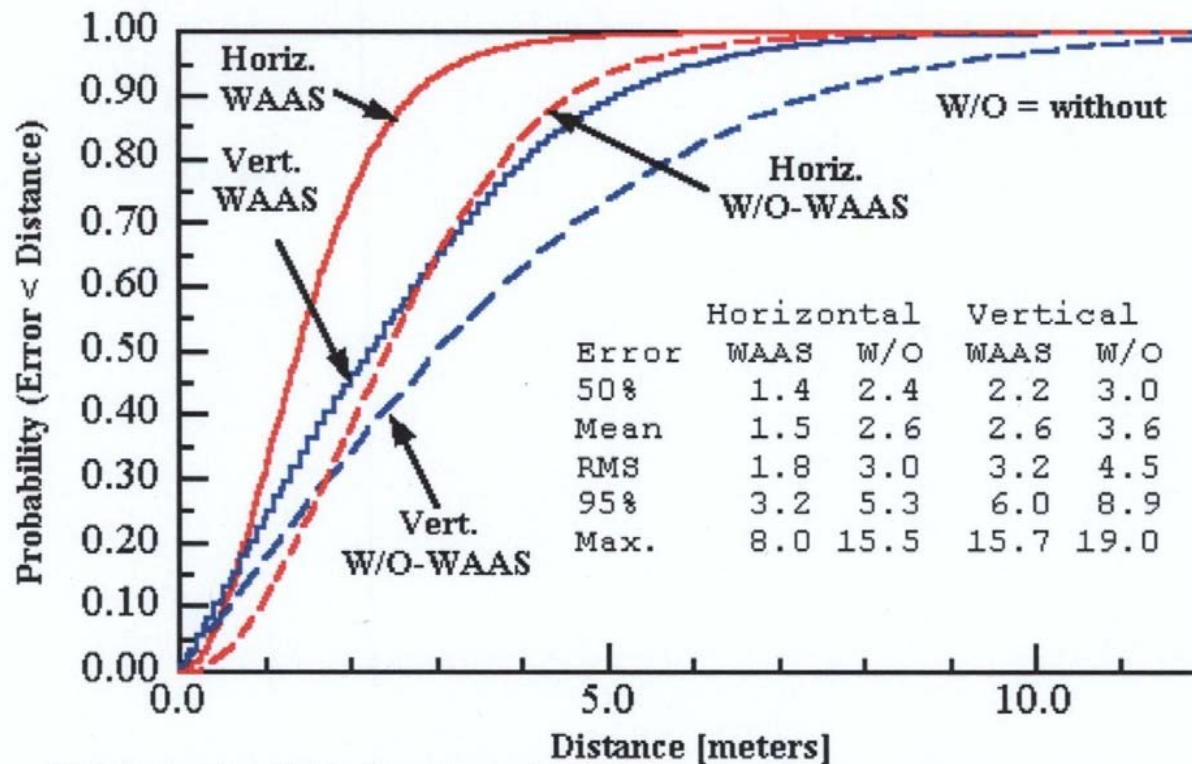
Census Bureau / NGS Partnership



- For this historical undertaking the Census Bureau has partnered with NOAA's National Geodetic Survey (NGS) to extend the 3 meter accuracy coverage by post processing HHC data with Continuously Operating Reference Stations (CORS).
- NGS customized post processing software for Census Bureau.
- The NGS – provided software has been installed on Census Bureau computers.
- The Census Bureau completed post-processing the housing unit structure points in January 2010.



WAAS VS. NON-WAAS COMPARISON Garmin GPSMAP 76 with GA29 antenna



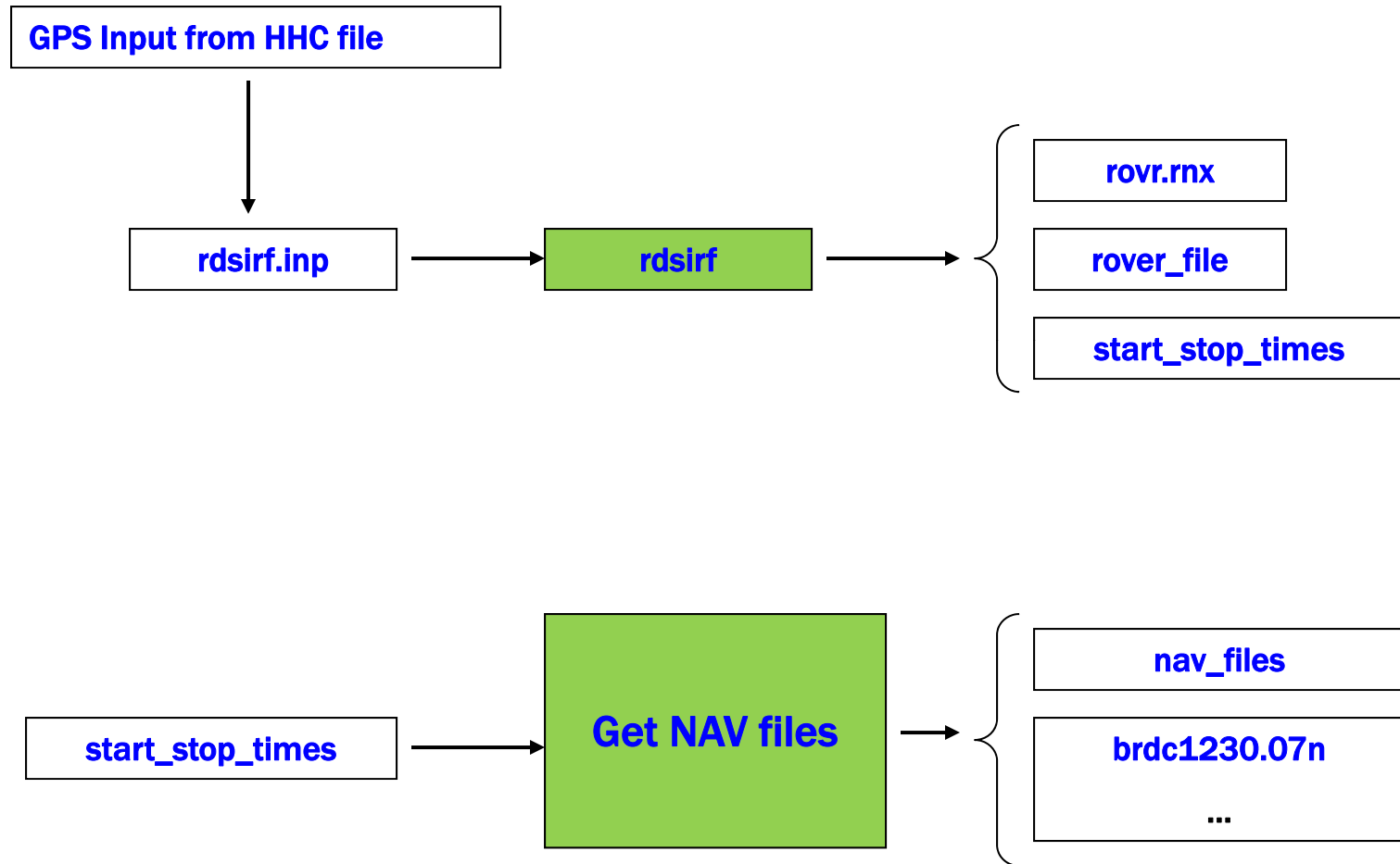
172815 samples (4 days) each session
WAAS & Non-WAAS non-simultaneous
Samples every 2 seconds

Note: Max. error depends greatly on the length of the observation period and is generally not a robust statistic.

[1] Wilson, David L. *GPS WAAS Accuracy*.
<http://users.erols.com/dlwilson/gpswaas.htm>

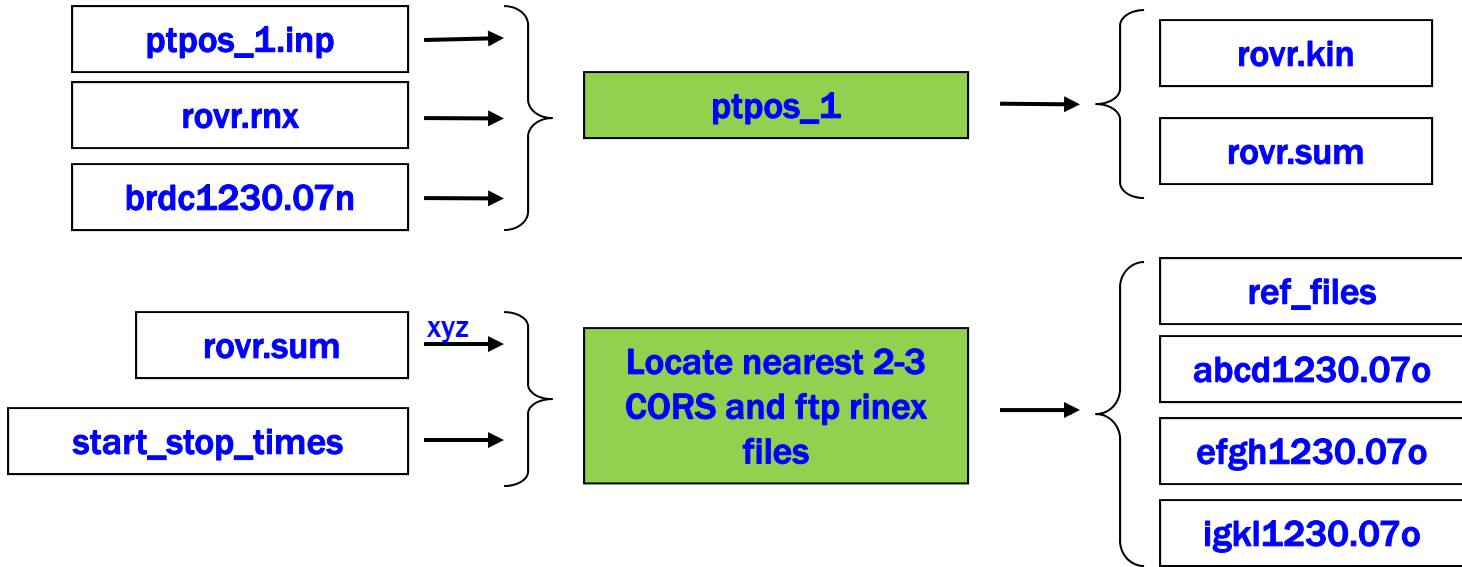


NGS Post Processing Block Diagram

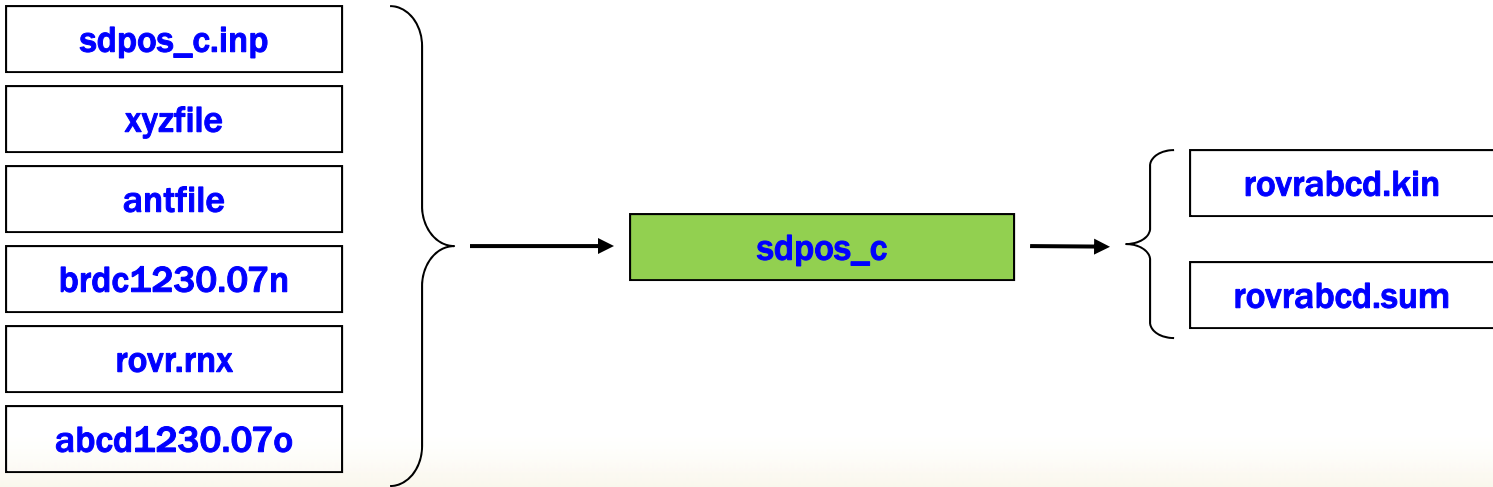




```
cat start_stop_times nav_files rovr_file > ptpos_1.inp
```



```
cat start_stop_times xyzfile antfile nav_files rovr_file ref_files > sdpos_c.inp
```



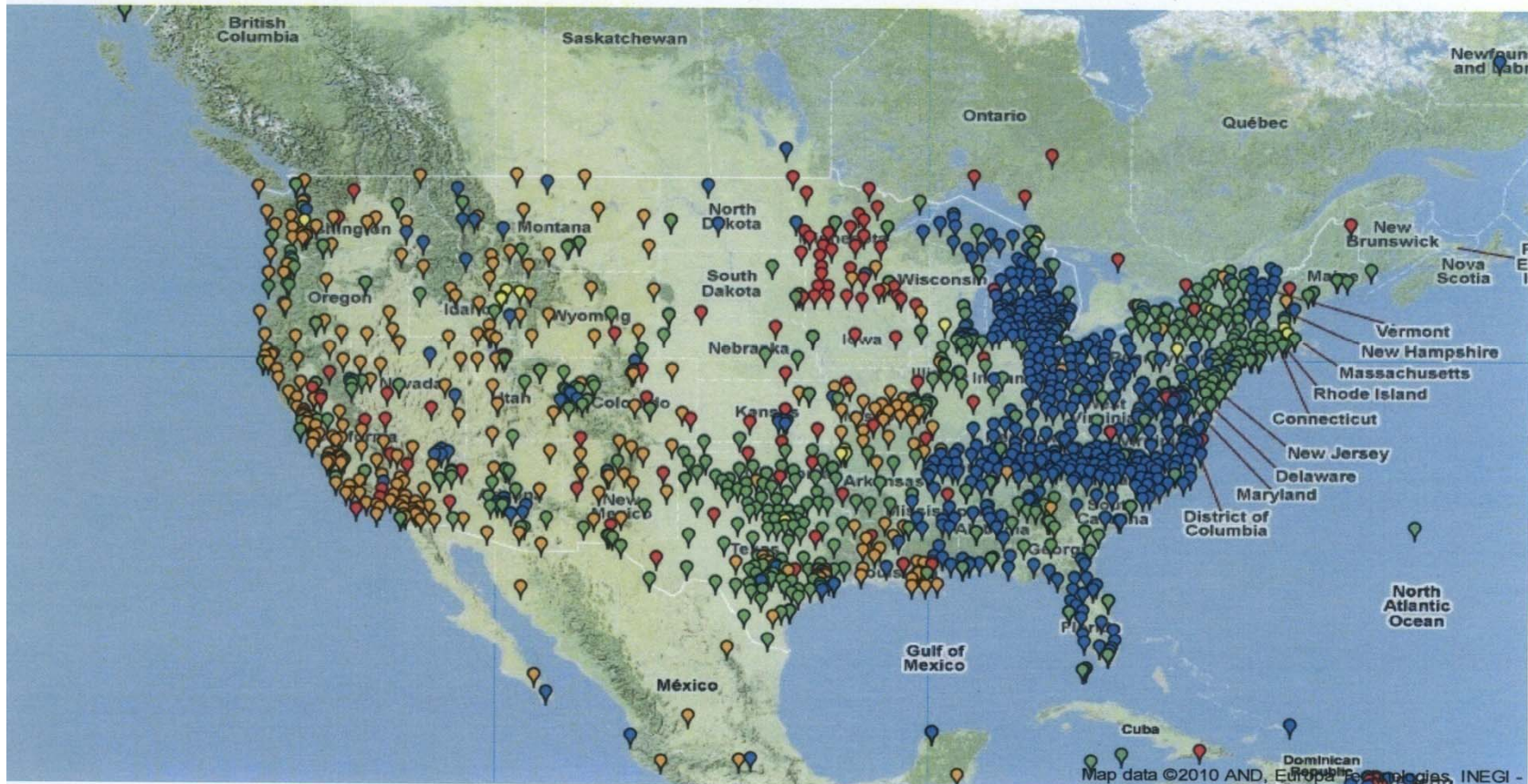


Present CORS Network

Receiver Sampling Rate

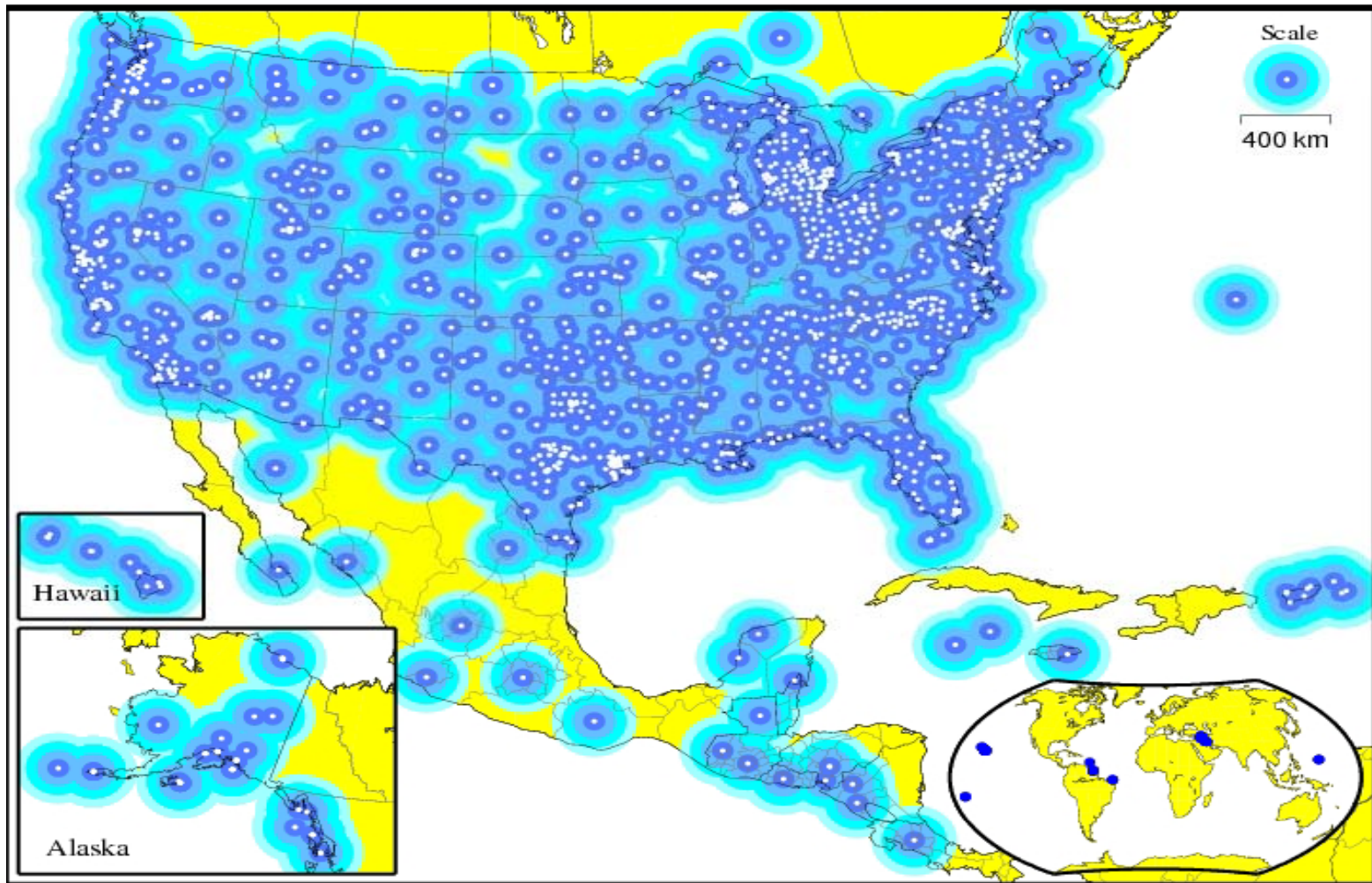
Click Icon to Display

1 sec 5 sec 10 sec 15 sec 30 sec All Decommissioned



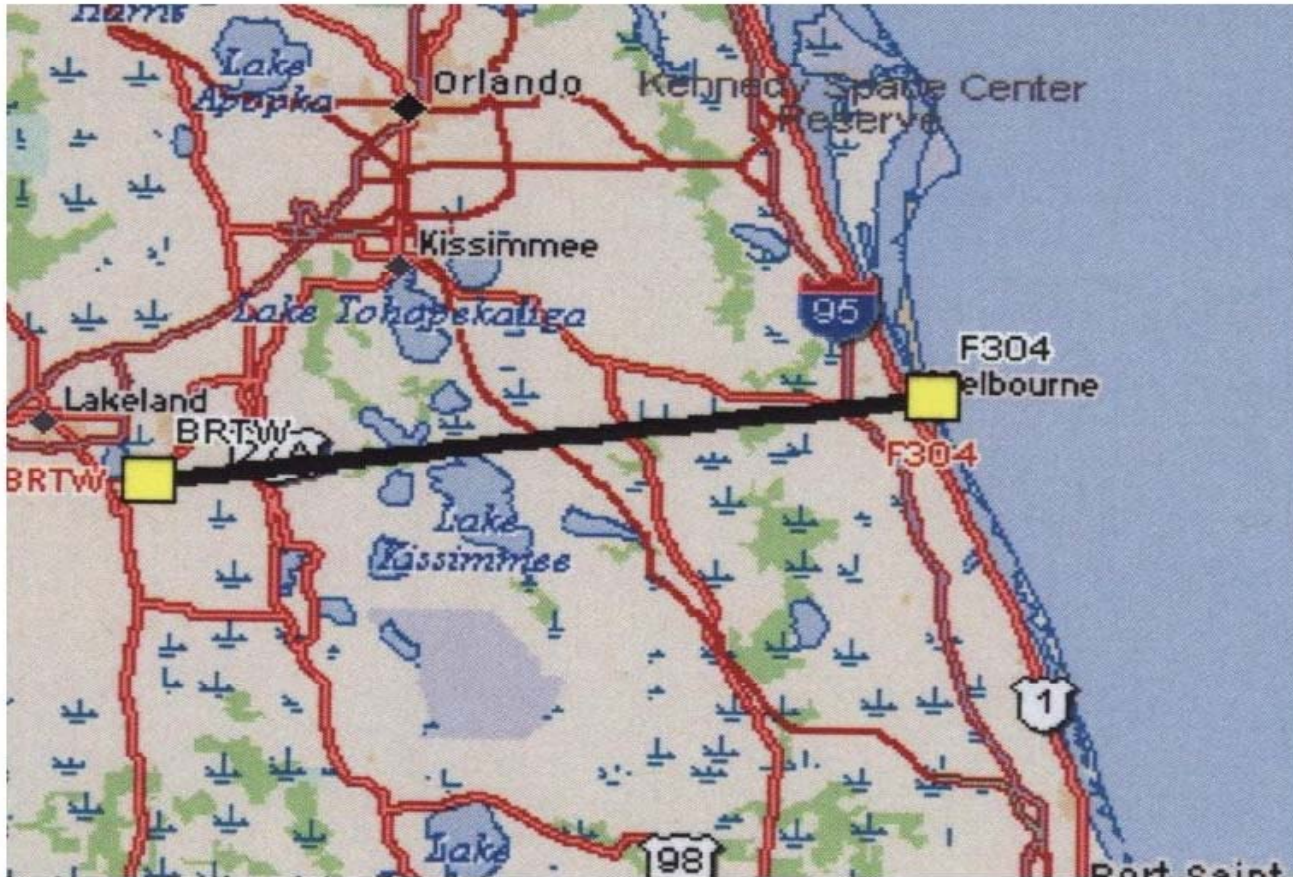


CORS Network Coverage with Reference Station Range of 200Kms



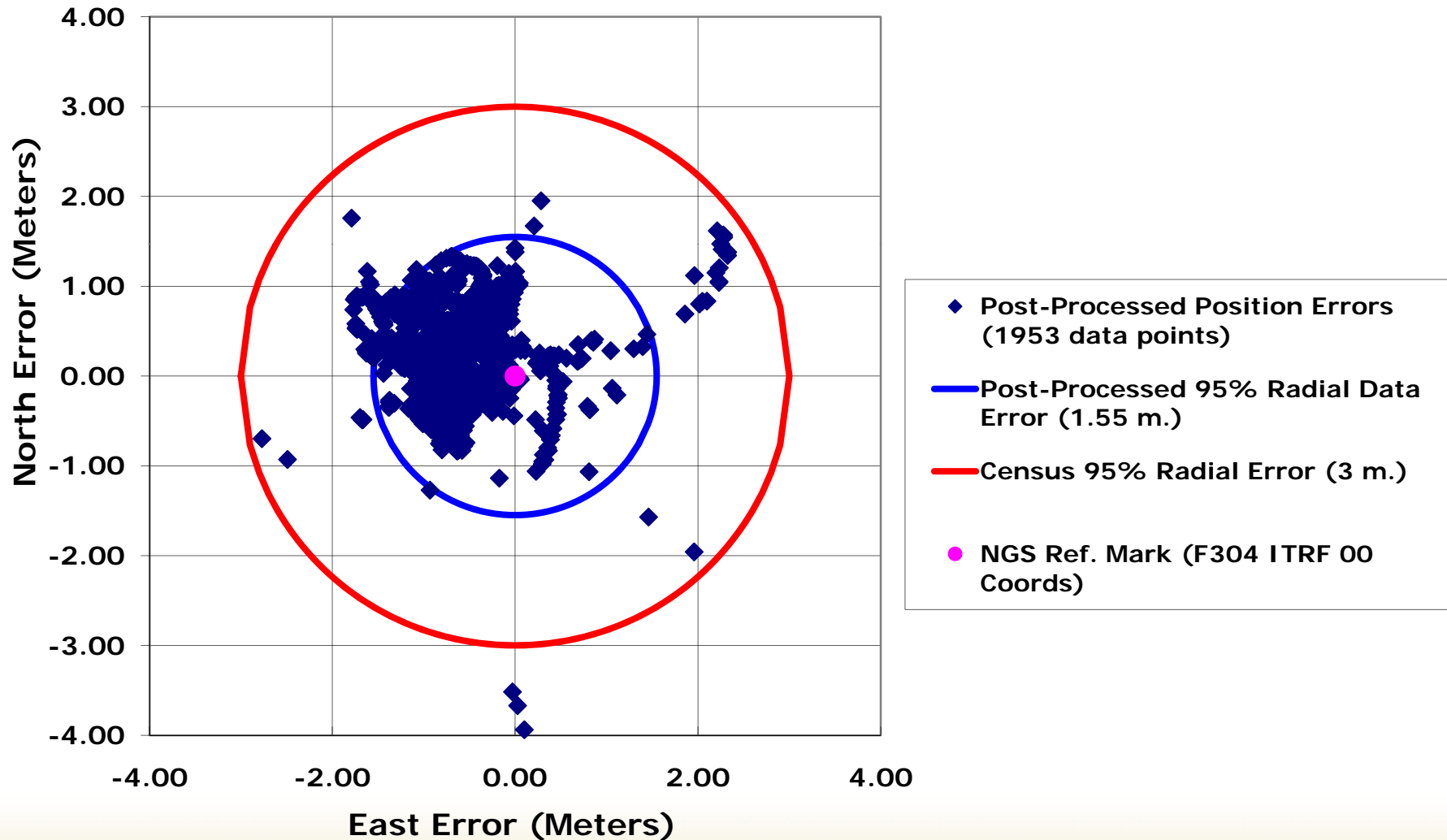


HHC Evaluation Unit Testing in Melbourne, FL 10/17/2006



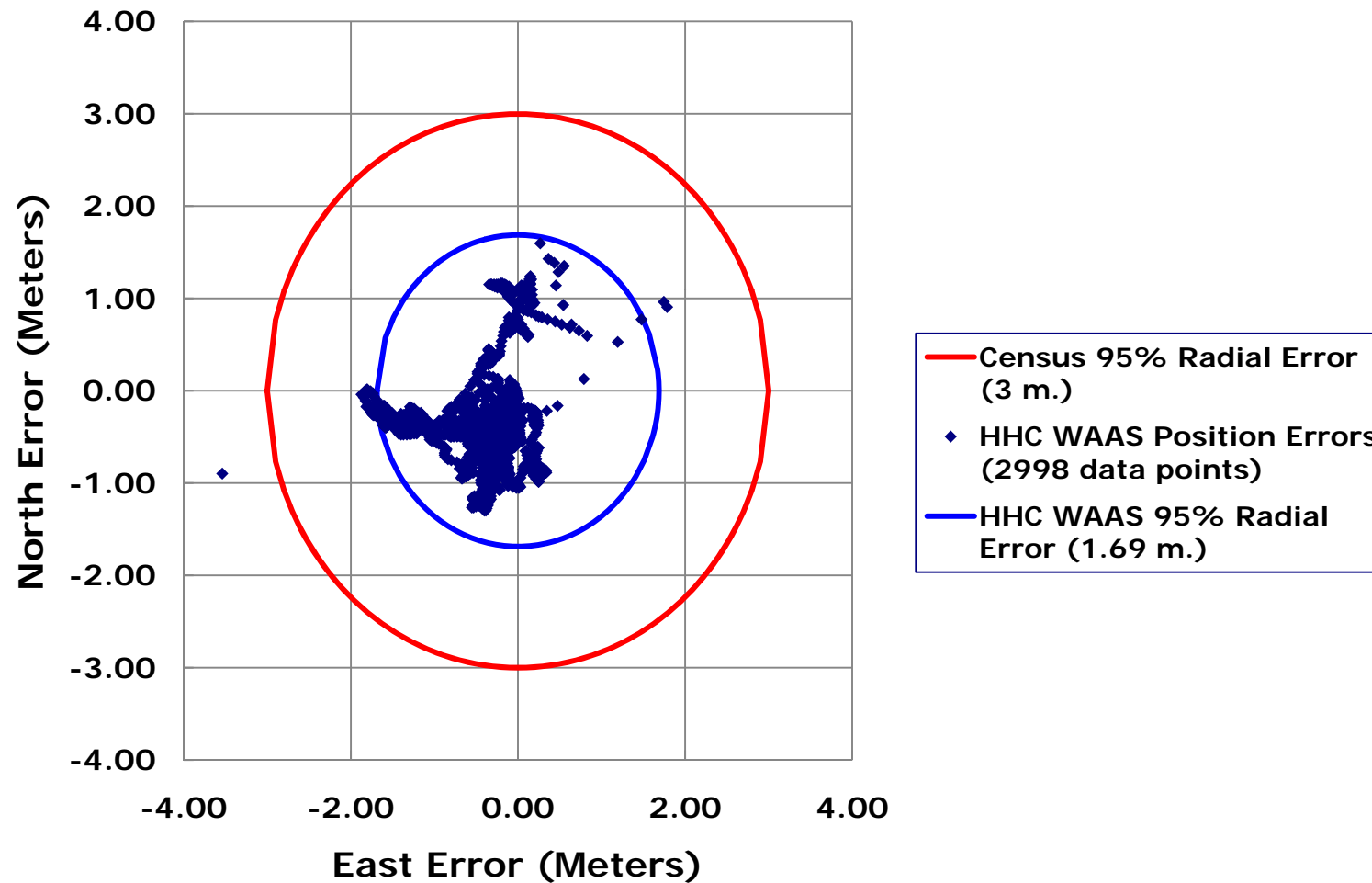


Post-Processed Position Errors at NGS MARK F304 (Melbourne, FL) re CORS BRTW Ref. Station @ 120 Km.





HHC WAAS Position Errors at NGS F304 (Melbourne, FL) Ref. Mark





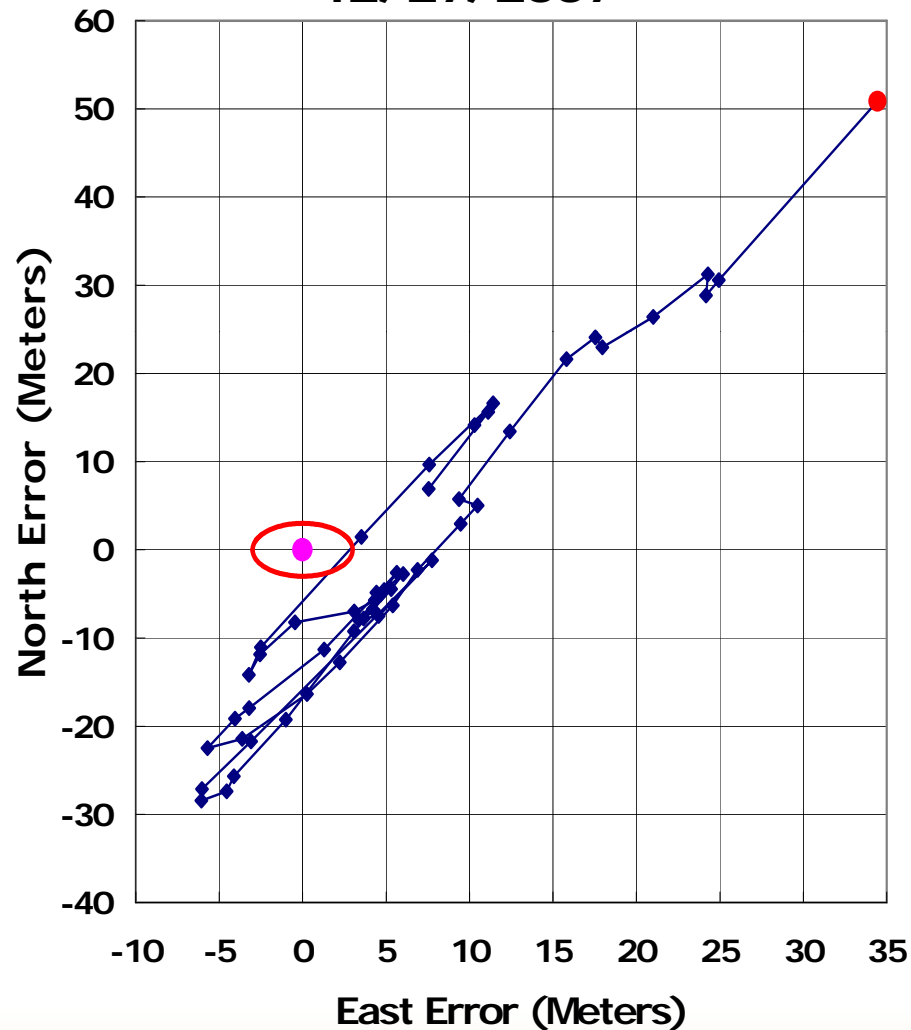
GPS Post Processed & WAAS Accuracy at Melbourne, FL NGS Reference Marks



Post Processed with 120 Km Ref. Station	1.55 m. (95%) @ F304
WAAS @ F304	1.69 m. (95%)
WAAS @ 5062 (THRON)	1.50 m. (95%)
WAAS Post Processed with 120 Km Ref. Station	1.70 m. (95%) @ F304



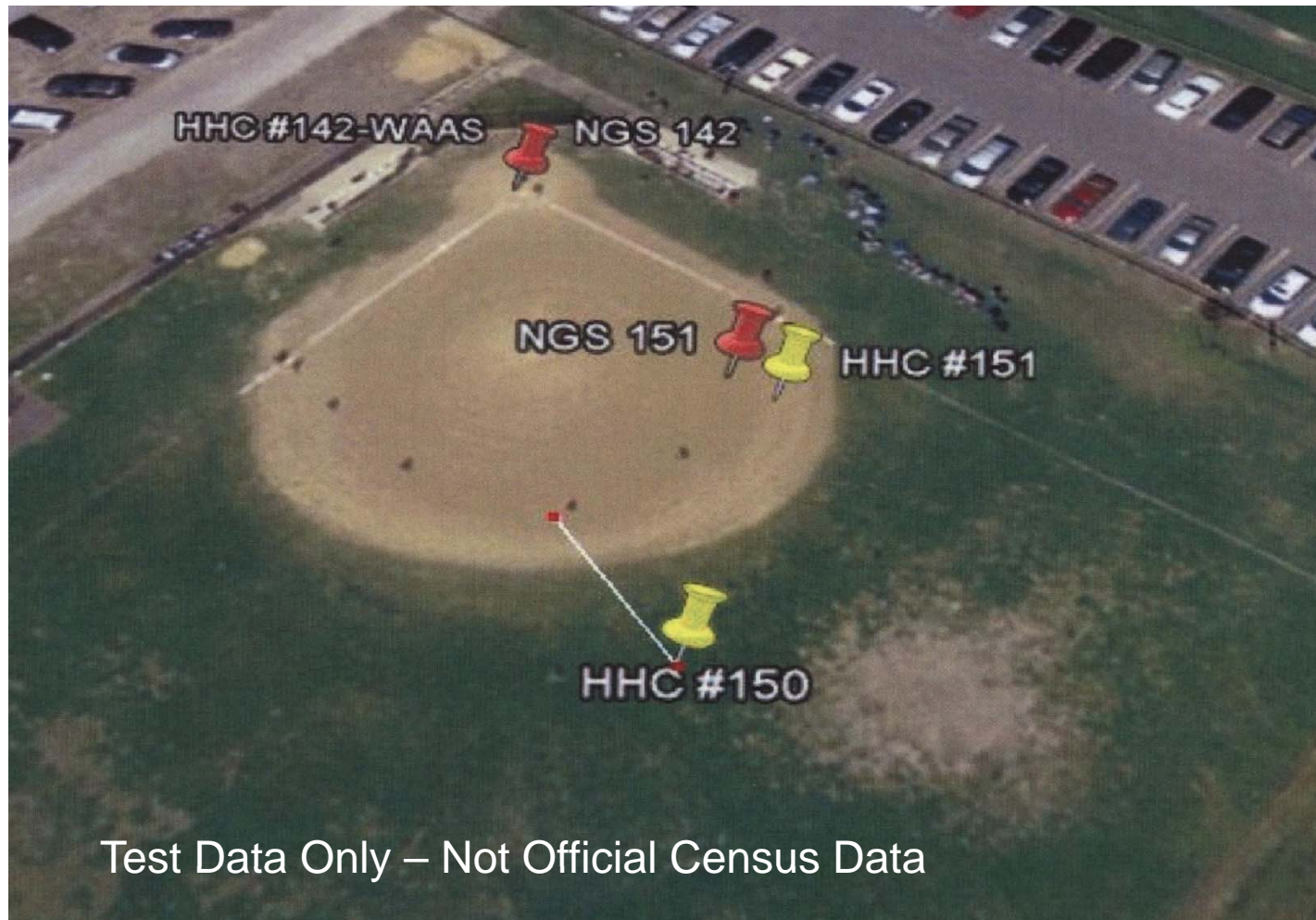
Garmin Post Processed GPS Errors re NGS Mark @ GPS Bldg. #11 Corbin, VA 12/27/2007



- ◆ Garmin GPS Errors re NGS mark at Bldg. #11 - 9/60 (15%) Missing Data
- Census 95% Radial error (3 m.) - No Data Within Census Accuracy
- NGS Mark @ Building # 11
- Tap & Go - First Data Point



Baseball Park Results November 2008



Test Data Only – Not Official Census Data



Table 2 Post Processed “Church II” Results

RMS (m.)	WAAS? Yes=2 No=1	East Error (m.)	North Error (m.)	Time HH/MM/S S	Data Point Desig.
25.5	1	2.09	-1.74	143343	H1
32.5	1	2.58	-0.46	143514	H2
35.7	1	5.82	-5.5	143914	H5
18.2	1	1.85	-0.78	144015	H6
12.8	1	4.54	1.66	144111	H7
2.1	1	-3.5	5.3	144214	H8
3.5	1	2.19	-3.4	144325	H9
13.1	1	-8.23	3.56	144431	H10
13.6	1	-3.9	1.33	144600	H11
16.2	1	-0.1	0.47	144709	H12
6.6	1	-9.91	7.3	144809	H13
47.9	1	-4.59	1.82	144908	H14
20	1	-22.17	6.93	145108	H15
20.7	1	-15.84	6.51	145206	H16

About 30% of Post Processed Data Within 3 m. of Map Spot

About 60% of Data Within 5 m. of Map Spot in a partially obstructed environment.



Maryland Test Results November 2008



- **First Data Set from Harris with SiRF Chip Set Message ID-28 Enabled**
 - Test Data Only – Not Official Census Data
- **5 Test Address Canvassing Residential Areas, a Parking Lot and a Baseball Park**
- **400 Data Points were Post Processed; Post Processed Points used as Data Quality Indicator for Map Spot Data**
- **Parking Lot - 2 of 3 Post Processed Points within 3 Meters. All Map Spots Were WAAS Corrected**



Maryland Residential Area Test Results

11/20 & 11/21/2008



- **11/20 – 16% of Map Spot Data Within 3 m. of Post Processed Data; 36% Within 5 m.**
- **11/20 - WAAS Corrections on 25% of Data (200 Data Points)**
- **11/21 – 14% of Map Spot Data Within 3 m. of Post Processed Data; 31% Within 5 m.**
- **11/21 - WAAS Corrections on 18% of Data (196 Data Points)**



Imagery of Maryland Suburbs Where Initial Tests Were conducted





Results from NGS Post-Processing Software



TOTAL OUTPUT	75,715,492	% of TOTAL
Acceptable Solutions / Data Meets Census Requirements	60,454,515	79.84%
Unacceptable Solutions / Data Requirements Not Met	12,449,324	16.44%
No Solution for Raw GPS or Post Processed Data	2,811,653	3.71%



POTENTIAL SOLUTIONS



DISTANCE (m) RAW to PP	Number of MSPs	% of MSPs	AVG DISTANCE RAW to PP	AVG RMS RAW to PP
0 - 5.0	32,661,843	54.03%	2.70	1.70
5.0 - 10.0	16,269,070	26.91%	7.06	2.02
10.0 - 15.0	6,036,542	9.99%	12.13	2.18
15.0 - 20.0	2,620,523	4.33%	17.18	2.25
Greater than 20.0	2,866,537	4.74%		



EU – US Working Group C Study



EU-US Cooperation on Satellite Navigation
Working Group C

**COMBINED PERFORMANCES FOR
OPEN GPS/GALILEO RECEIVERS**

Final version

July 19, 2010



Summary Study Conditions¹



- **Population data obtained from the Center for International Earth Science Information Network at Columbia University.**
- **Cities exceeding a half million people were selected.**
- **Total of 5173 sites used to produce separate statistics in open sky and urban sites.**
- **Mask angles of 15 and 30 degrees used in addition to multipath models in urban sites.**
- **GPS and GALILEO (Walker 27/3/1) constellations of 24 and 27 satellites respectively were considered.**
- **Future GPS-III, Galileo and combined GPS-III/Galileo signals considered.**

¹ *Combined Performances for Open GPS/GALILEO Receivers, EU-US Cooperation on Satellite Navigation, Working Group C, July 19, 2010*



Half-Sky Study Global Statistics of Mean HPE for Average Solar Cycle



HPE

		SF: BOC(1,1)	SF: MBOC	DF: MBOC- BPSK10
	HPE	Open Sky	Open Sky	Open Sky
GPS	%ge pdop • 10 & nsat • 4	63.16%	63.16%	63.16%
	mean	9.39	7.68	4.08
	stdev	1.94	2.08	0.60
	RMS	9.59	7.96	4.12
	Median	9.33	7.77	3.96
	95th	12.59	11.03	5.11
Galileo	%ge pdop • 10 & nsat • 4	78.57%	78.57%	78.57%
	mean	10.48	9.09	6.11
	stdev	2.18	2.17	1.02
	RMS	10.70	9.35	6.20
	Median	10.42	9.01	6.25
	95th	14.17	12.81	7.47
GPS & Galileo	%ge pdop • 10 & nsat • 4	98.92%	98.92%	98.92%
	mean	6.11	5.28	3.22
	stdev	1.30	1.36	0.57
	RMS	6.24	5.45	3.27
	Median	6.05	5.31	3.18
	95th	8.34	7.58	4.10



Urban Global Study (30 Deg.) Global Statistics of HPE for Peak Solar Cycle



HPE		BOC(1,1)	MBOC	Dual Frequency
		Urban	Urban	Urban
GPS	Availability [%]	57,28	57,28	57,28
	Mean [m]	11,19	6,43	7,26
	StDev [m]	0,93	0,69	0,90
	RMS [m]	11,23	6,47	7,32
	Median [m]	11,14	6,40	7,24
	95th perc. [m]	12,66	7,65	8,72
Galileo	Availability [%]	75,02	75,02	75,02
	Mean [m]	11,36	6,97	7,85
	StDev [m]	2,16	1,52	1,86
	RMS [m]	11,56	7,13	8,07
	Median [m]	11,31	6,68	7,52
	95th perc. [m]	15,93	10,03	11,57
GPS + Galileo	Availability [%]	98,93	98,93	98,93
	Mean [m]	6,82	4,11	4,37
	StDev [m]	0,70	0,49	0,54
	RMS [m]	6,86	4,14	4,40
	Median [m]	6,71	4,03	4,30
	95th perc. [m]	8,02	5,05	5,31



Census Accuracy vs. EU-US Studies



	2 sigma (95%)	GPS and Galileo 2 sigma (95%)
GPS L1 C/A –Post Processed	15 - 20 m.	10.9 m. 30 Deg. Mask
Half Sky / GPS-III or Galileo	12.6 – 14.2 m.	8.3 m.
Urban 30 deg. Mask / GPS III-F or Galileo	12.7 – 15.9 m.	8.0 m.



Automated Map Spot Accuracy Analysis





TOYON SBIR Phase II Multipath Mitigation Antenna



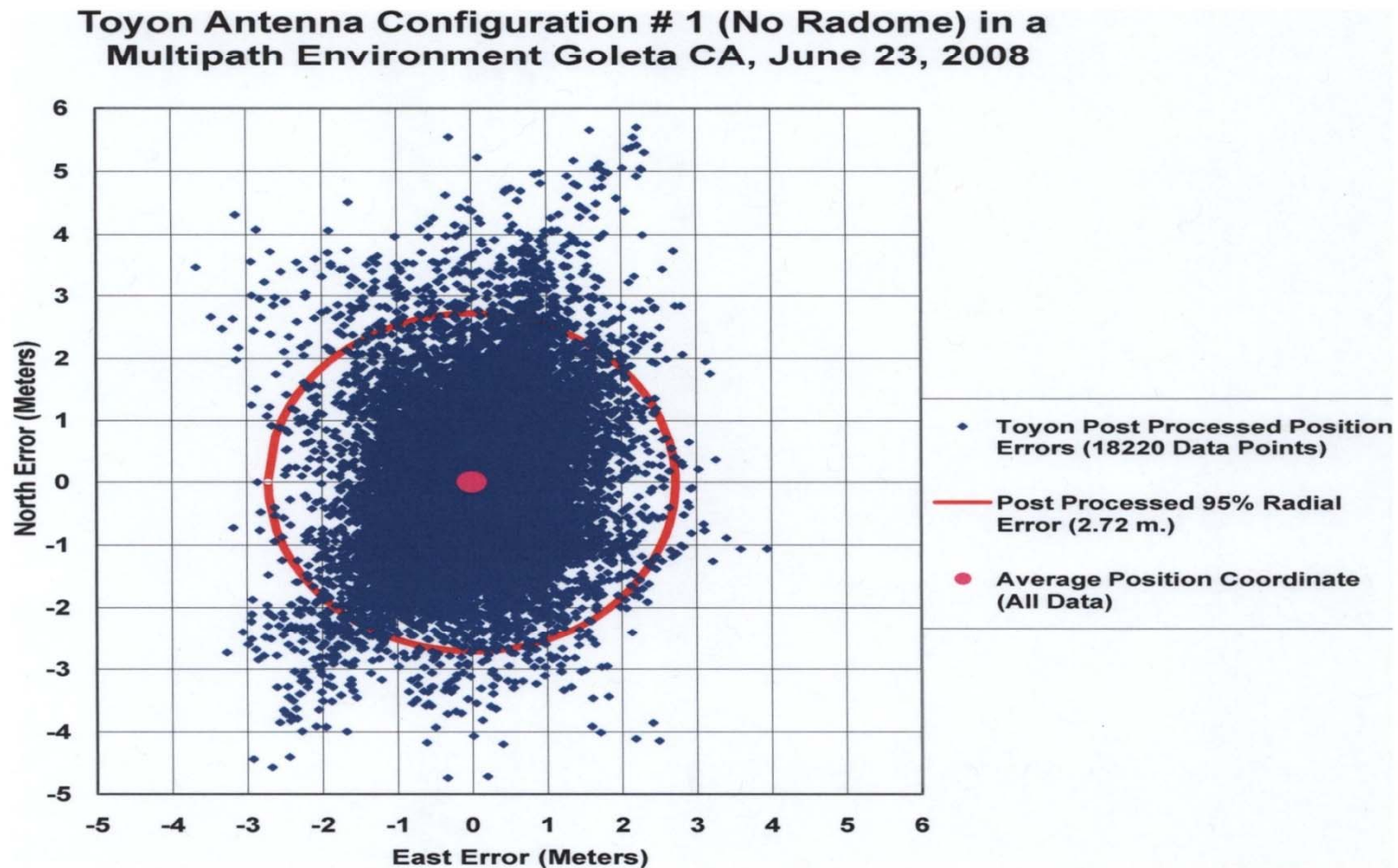


Toyon Research Prototype SBIR Phase II Antenna





Post Processed Accuracy Using a Multipath Mitigation Antenna About 3.5 m. from Residence





Summary Test Conclusions

- **NGS Post-Processing accuracy using CORS Reference stations was less than three meters (95%) in unobstructed environments.**
- **Three meter GPS accuracy may not be achievable at all map locations due to multipath and blocked signals; Census Bureau has a partnership in place to obtain the best possible GPS coordinates under these conditions.**
- **Post-processed coordinates minus map spot coordinates in partially obstructed environments less than five meters that meet the Census specification may range from 30% to 60% in a given address block from analysis of preliminary data.**
- **The Census Bureau and NGS are working together to ensure the highest quality of GPS collected data.**



Next Steps



- **Evaluate the effectiveness of post-processing of housing unit structure points captured using GPS technology in Address Canvassing.**
 - Research ways to evaluate accuracy relative to specific housing structures.
 - Explore how to best evaluate housing structure accuracies under various conditions (i.e. with and without ground cover).
- **Recommend possible improvements (both hardware, software, and new GPS signals) to improve coordinate accuracy data quality percentage.**
 - Test automated spatial analysis capability offered by Sanborn.
 - Conduct R & D to configure a more robust handheld GPS unit for obstructed environments.