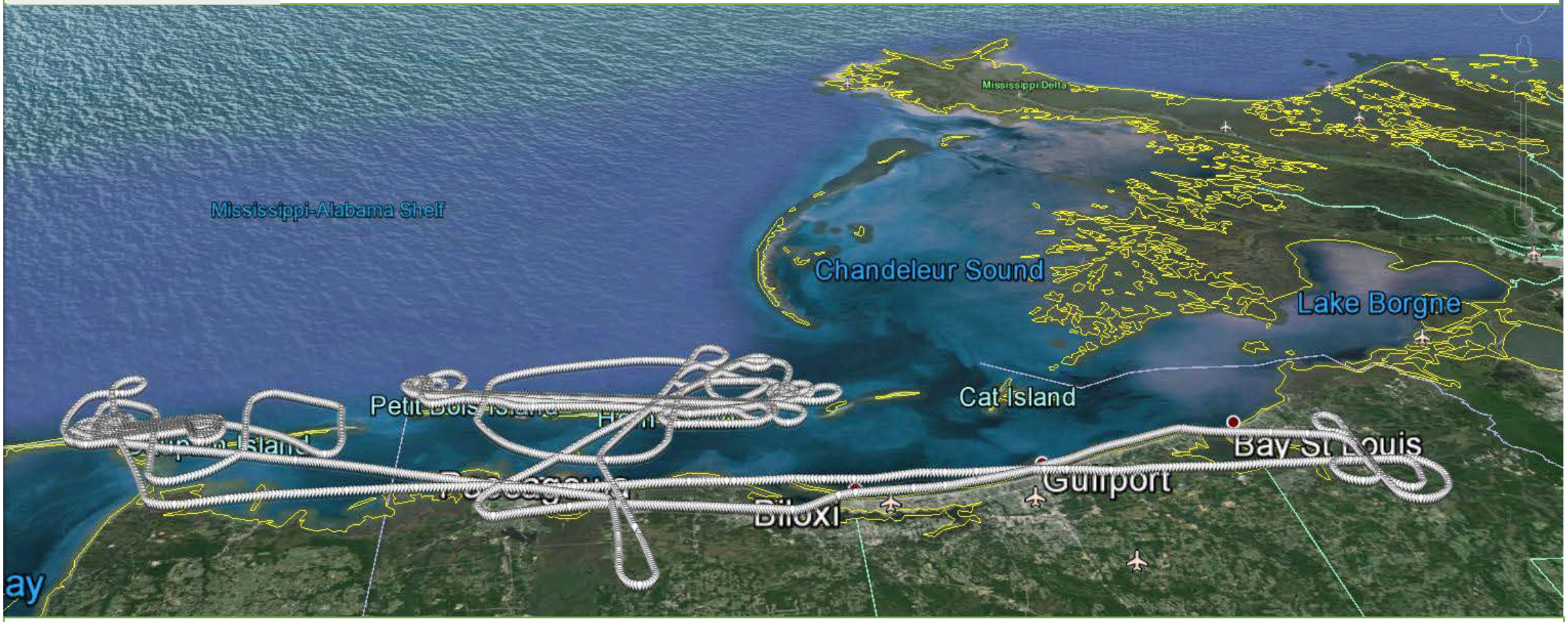
Extending the Range of Post-Processed Kinematic Positioning for Airborne Lidar Systems (CZMIL)



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17th Annual JALBTCX Airborne Coastal Mapping and Charting Workshop, 19-21 July 2016

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

BACKGROUND: HSRC and JALBTCX

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

- HYDROGRAPHIC SCIENCE RESEARCH CENTER (HSRC) is conducting this research on behalf of Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX)……

INTRODUCING HSRC

BACKGROUND: INTRODUCING HSRC

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

HSRC was created in 2001 to conduct advanced research in hydrographic sciences towards becoming a national center of excellence in hydrography.

PEOPLE

Ken Barbor
Director HSRC

Ian Church
Assistant Professor

CURRENT STUDENTS

1. Lauren Quas
Master's Student, CONCORDE
2. Maxwell Williamson
Master's Student, CONCORDE
3. Johnson Oguntuase
Master's Student, LiDAR Data Processing
4. Joshua Bergeron
Master's Student, LiDAR Data Processing
5. Dennis Wilson
Master's Student, LiDAR Data Processing
6. Kandice Gunning
PhD Student, Oyster Reef Mapping
7. Clayton Dike
PhD Student, Mississippi Sound Barrier Islands

The center has been involved in the development of CZMIL system for Airborne LiDAR Bathymetry

THE BIG QUESTIONS

WHY EXTENDING THE RANGE?

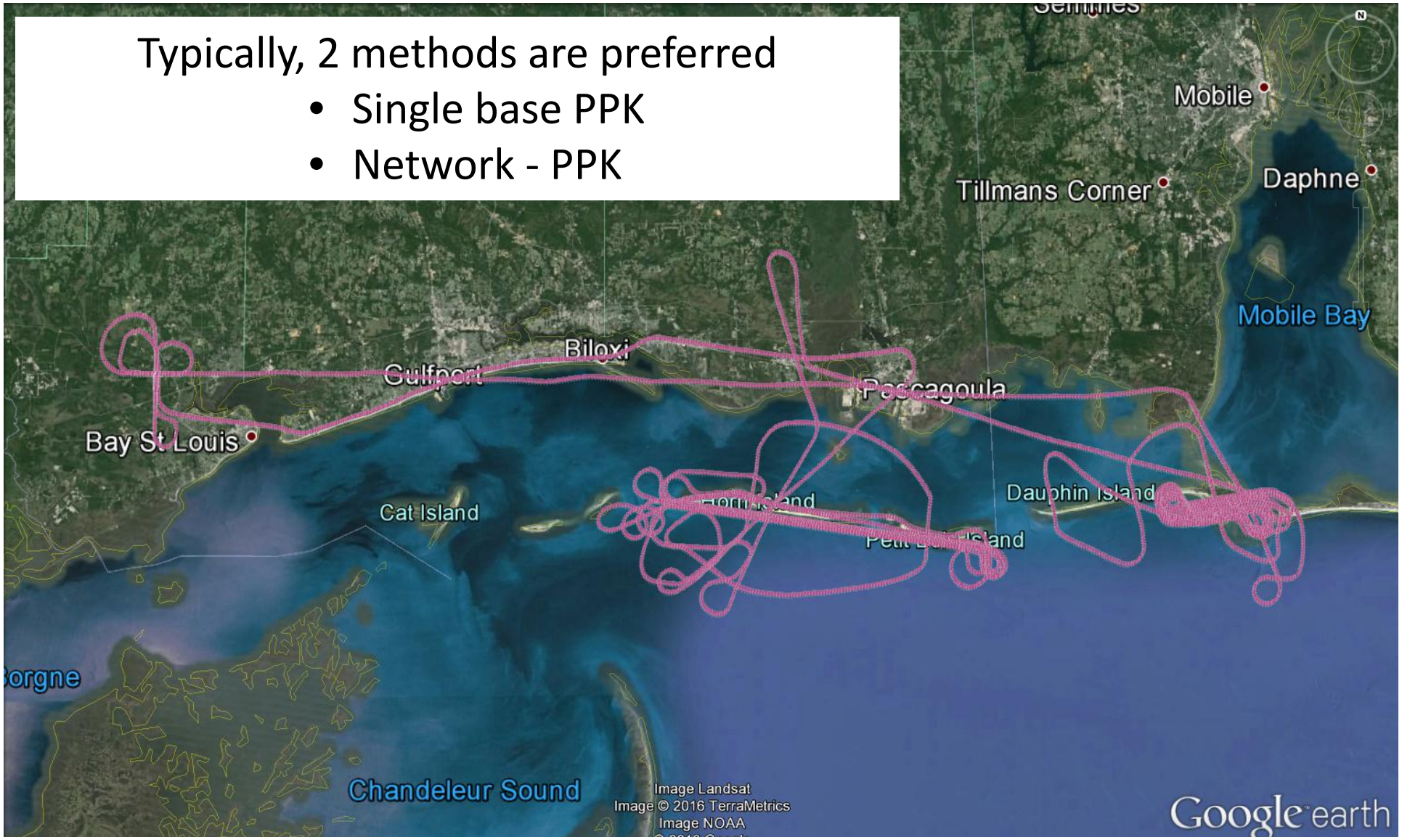
IF WE DO, WILL IT MEET THE REQUIRED SPECIFICATION?

Image: courtesy http://graphicriver.net

BACKGROUND: Methods of Positioning

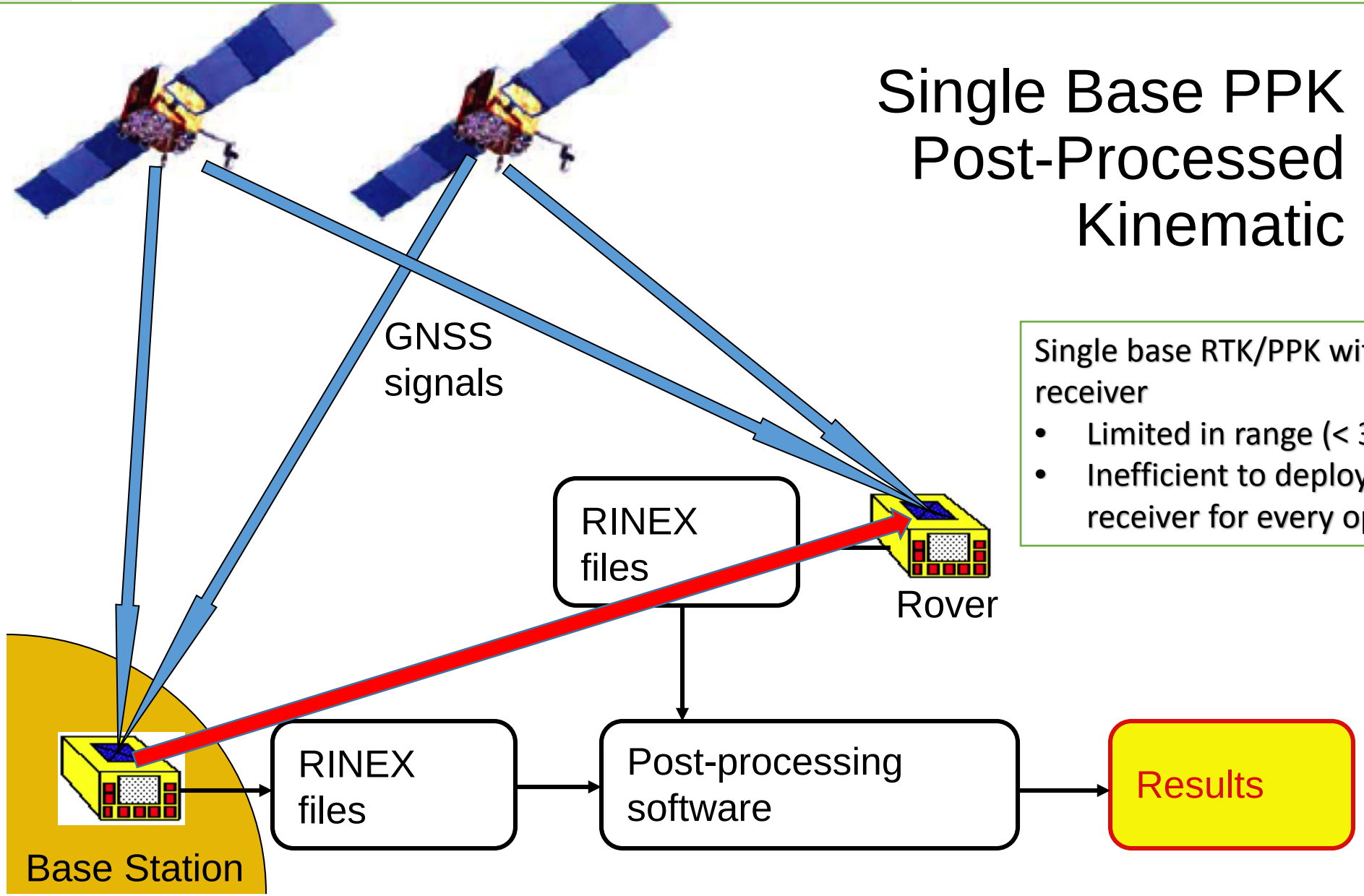
Typically, 2 methods are preferred

- Single base PPK
- Network - PPK



BACKGROUND: What is Single base PPK?

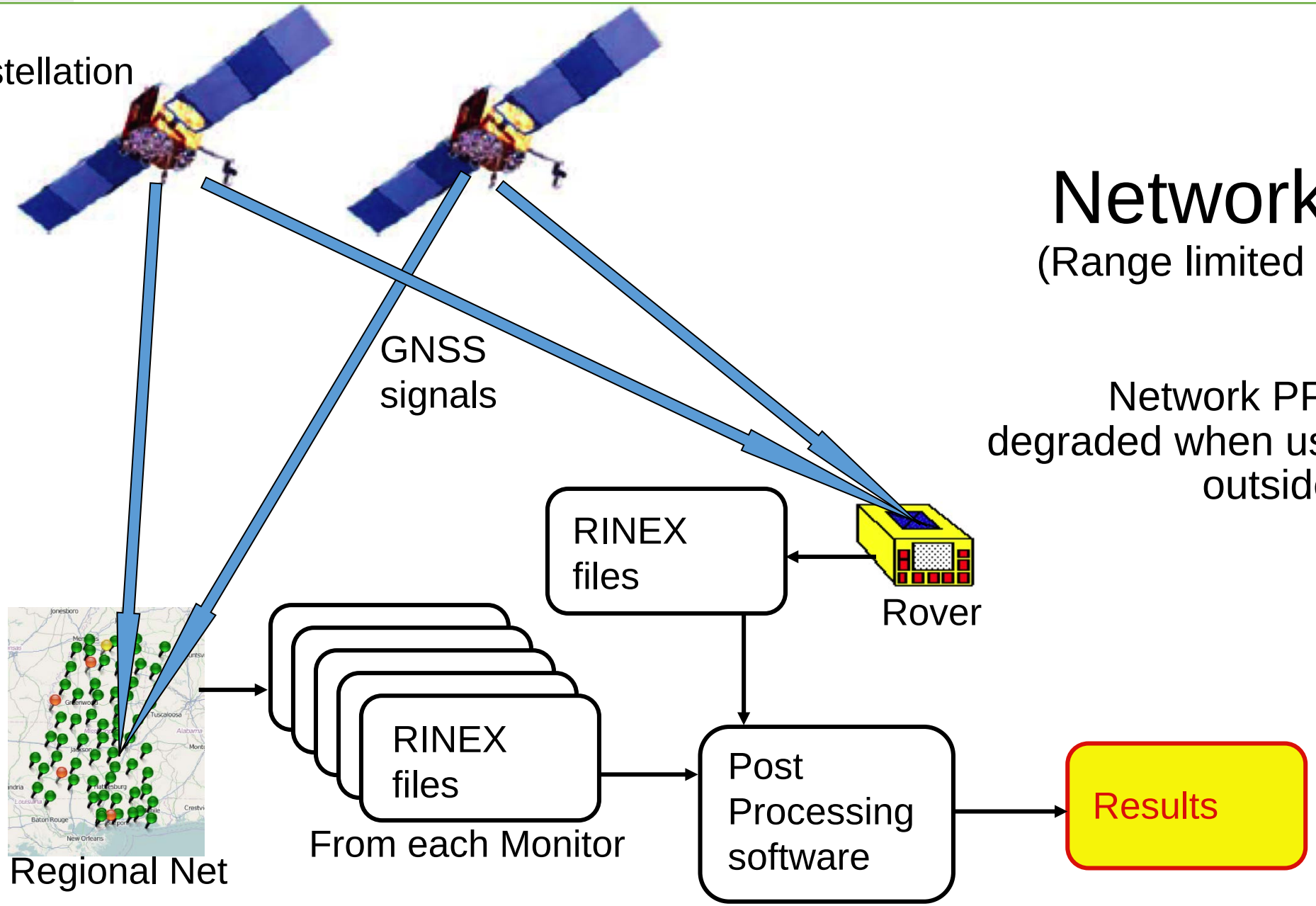
Single Base PPK Post-Processed Kinematic



Single base RTK/PPK with 1 reference receiver

- Limited in range (< 30Km)
- Inefficient to deploy reference receiver for every operation.

BACKGROUND: What is NETWORK-PPK(NPPK)?

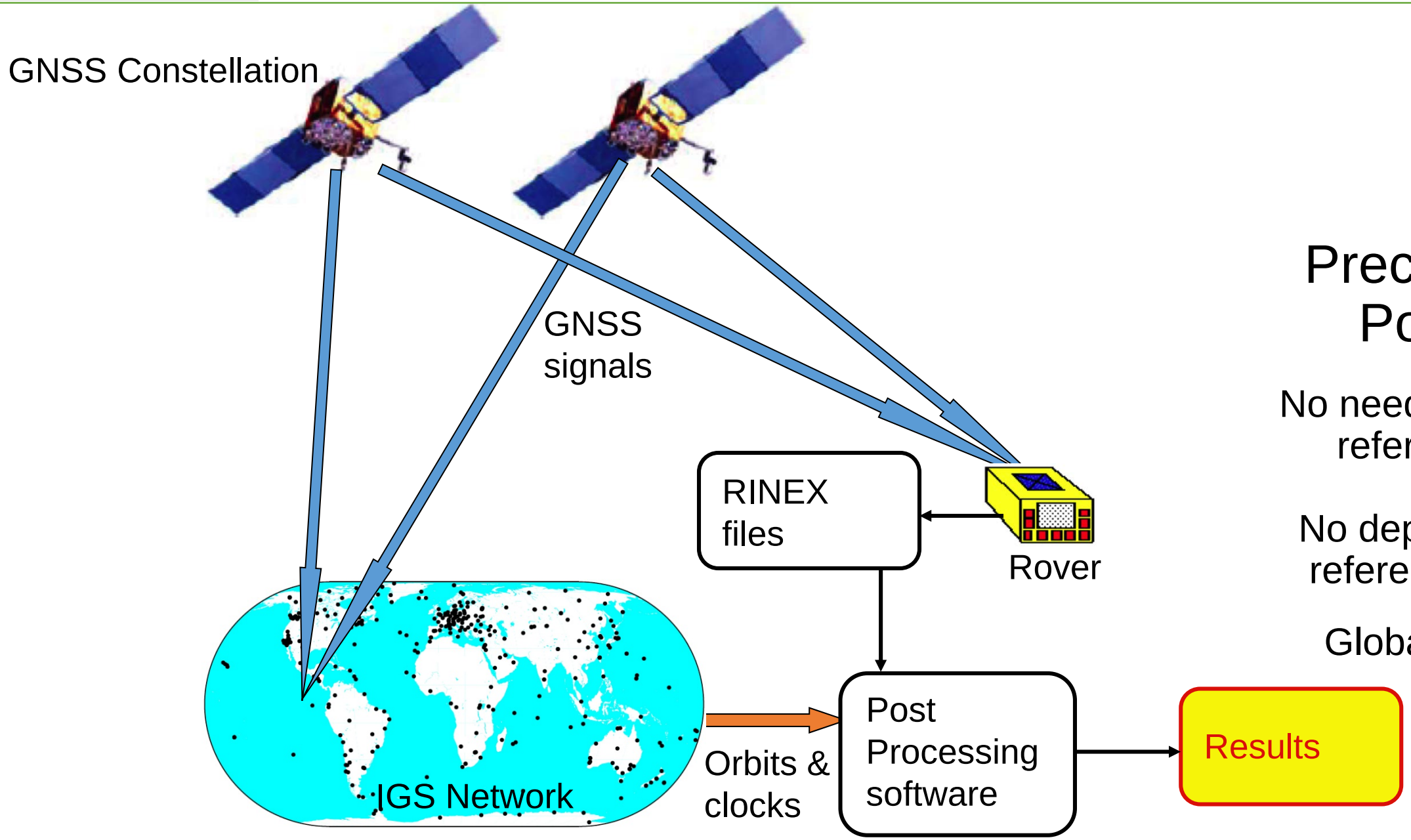


Network – PPK

(Range limited by differential troposphere)

Network PPK solution is degraded when user location is outside the network

BACKGROUND: What is PPP?



PPP
Precise Point Positioning

No need to deploy a reference station

No dependence on reference Network

Global availability

BACKGROUND: Data used for this study

- Project Locations:

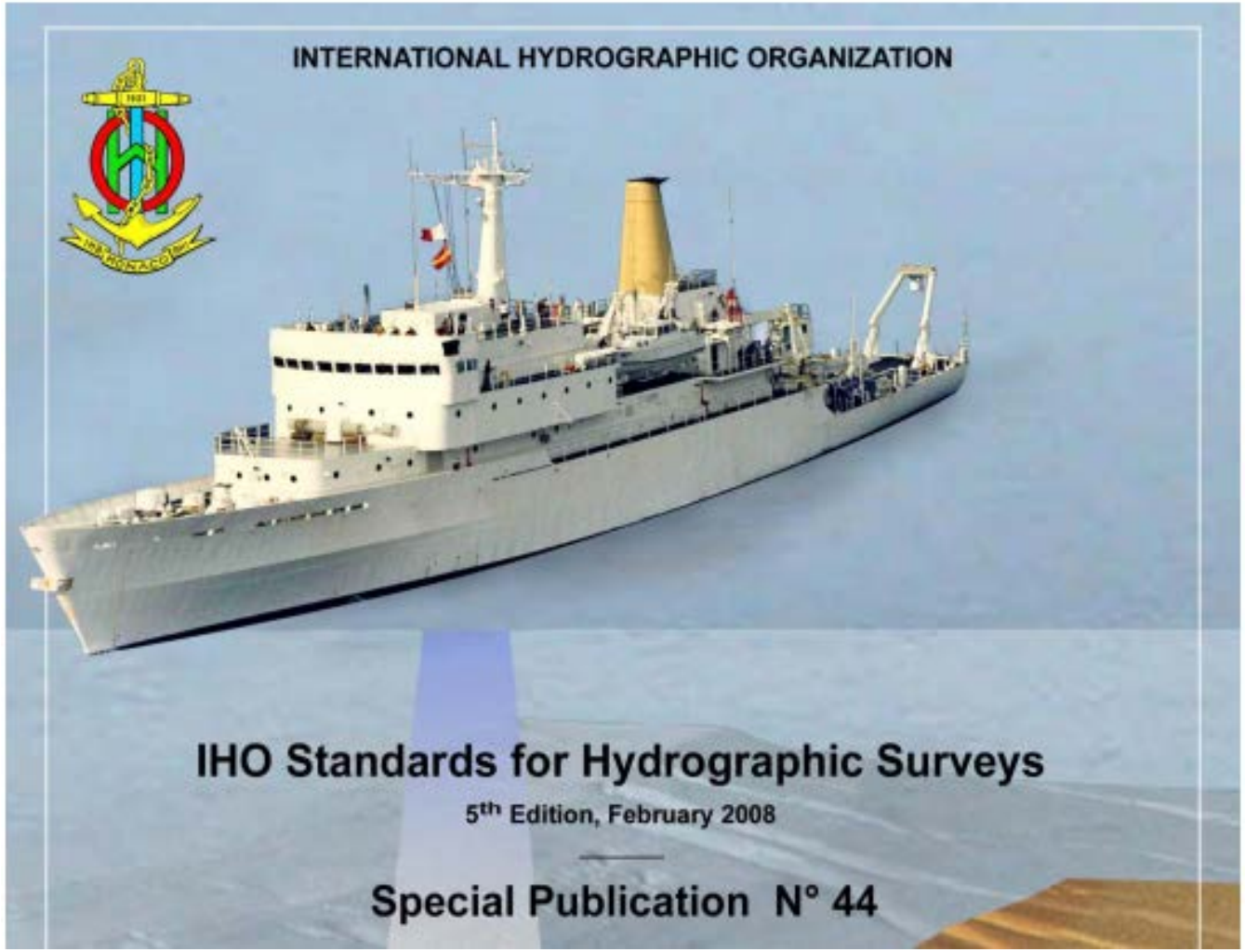
  Horn & Dauphin Island, US (May 20th , 2012)

  Hog & Nantucket Islands, US (June 06th, 2015)

METHOD

- Network PPK (N-PPK) as reference solution
  - Single base versus N-PPK
  - PPP versus N-PPK
- Evaluate performance at two project locations

Specifications for Performance Evaluation



https://www.iho.int/iho_pubs/standard/S-44_5E.pdf

NOS HYDROGRAPHIC SURVEYS SPECIFICATIONS AND DELIVERABLES

May 2015

http://www.nauticalcharts.noaa.gov/hsd/specs/Specs_2015.pdf

Office of Coast Survey (OCS), National Ocean Service (NOS), NOAA

Specifications for Performance Evaluation

IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)
5th Edition February 2008

TABLE 1
Minimum Standards for Hydrographic Surveys
(To be read in conjunction with the full text set out in this document.)

Reference	Order	Special	1a	1b	2
Chapter 1	**Description of areas.**	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Chapter 2	**Maximum allowable THU 95% *Confidence level***	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Para 3.2 and note 1	**Maximum allowable TVU 95% *Confidence level***	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Glossary and note 2	***Full Sea floor Search***	Required	Required	Not required	Not required
Para 2.1 Para 3.4 Para 3.5 and note 3	***Feature Detection***	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Para 3.6 and note 4	**Recommended maximum Line Spacing**	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Chapter 2 and note 5	**Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)**	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	**Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)**	10 metres	20 metres	20 metres	20 metres
Chapter 2 and note 5	**Mean position of floating aids to navigation (95% *Confidence level*)**	10 metres	10 metres	10 metres	20 metres

Specifications for Performance Evaluation

- Evaluate performance with respect to IHO's/NOAA's specification for THU and TVU

95% conf. level		Special Order Unit (m)	Order 1a Unit (m)	Order 1b Unit (m)	Order 2 Unit (m)
		2	5+5% of d	5+5% of d	20+5% of d
THU	for d=5	2	5.25	5.25	20.25
	a=	0.25	0.50	0.50	1.00
	b=	0.0075	0.013	0.013	0.023
	depth/				
TVU	5	0.25	0.50	0.50	1.01
	8	0.26	0.51	0.51	1.02
	10	0.26	0.52	0.52	1.03
	20	0.29	0.56	0.56	1.10
	30	0.34	0.63	0.63	1.21

NOAA's Specs (May 2015)

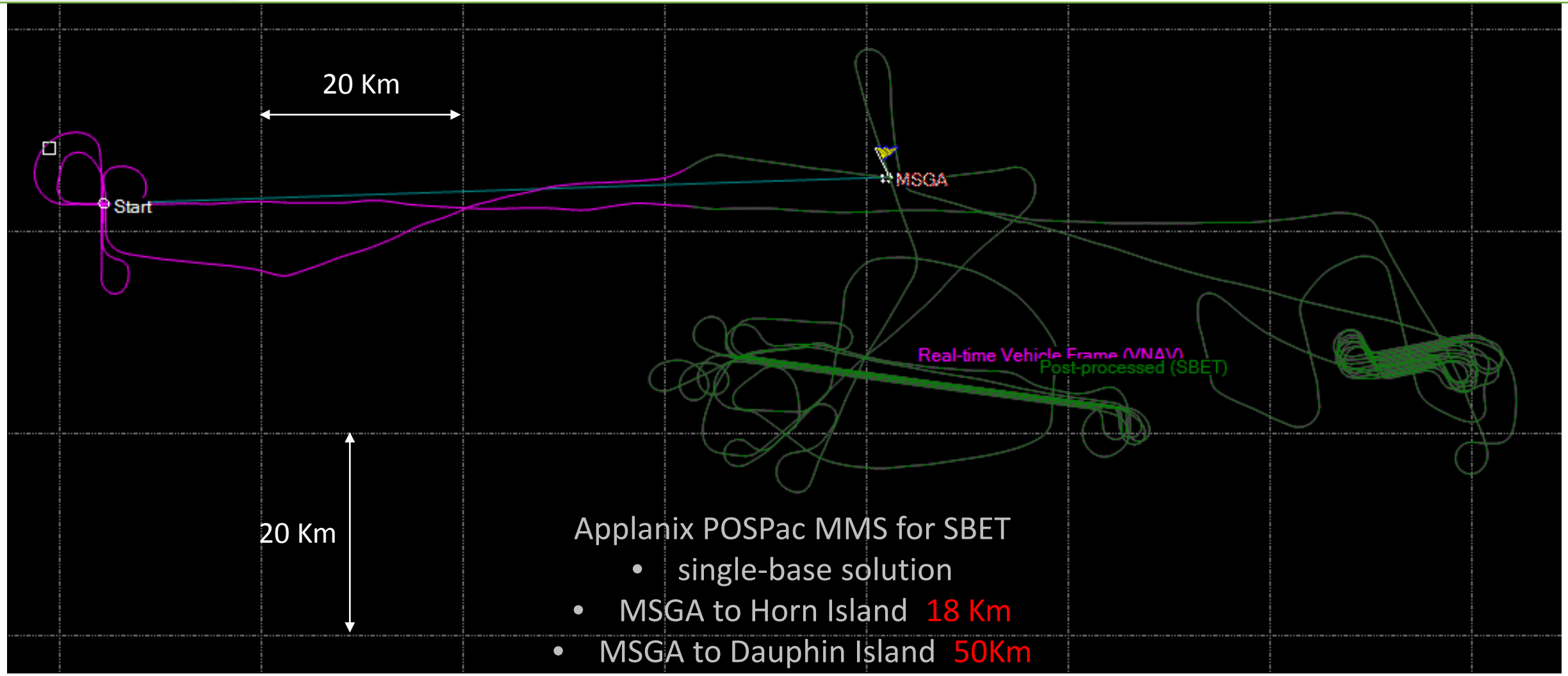
THU = 5m + 5% of depth

$$TVU = \sqrt{a^2 + (b * d)^2}$$

Where d = depth

http://www.nauticalcharts.noaa.gov/hsd/specs/Specs_2015.pdf

METHOD: Post-processed Data (S-PPK)



Applanix POSPac MMS for SBET

- single-base solution
- MSGA to Horn Island 18 Km
- MSGA to Dauphin Island 50Km

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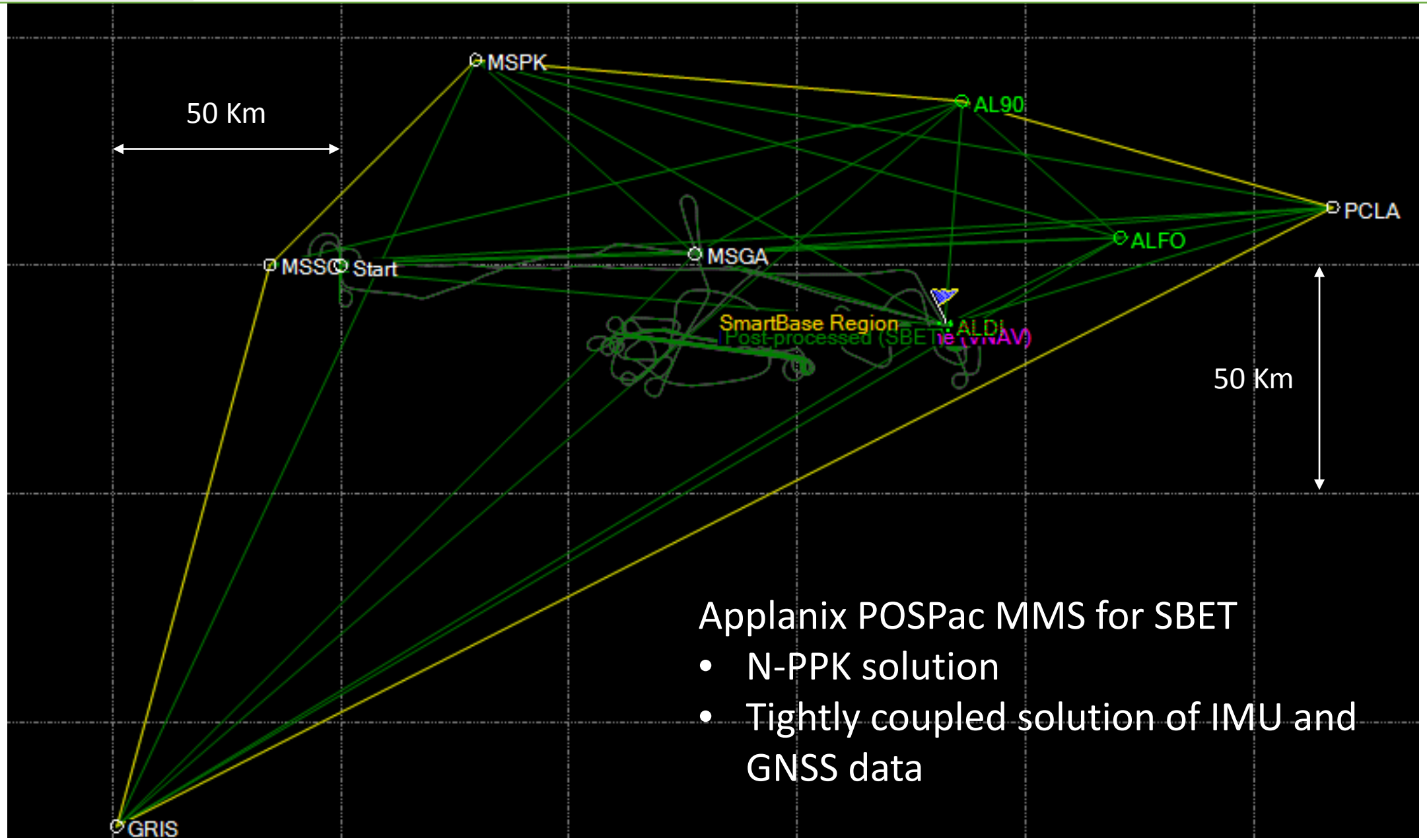
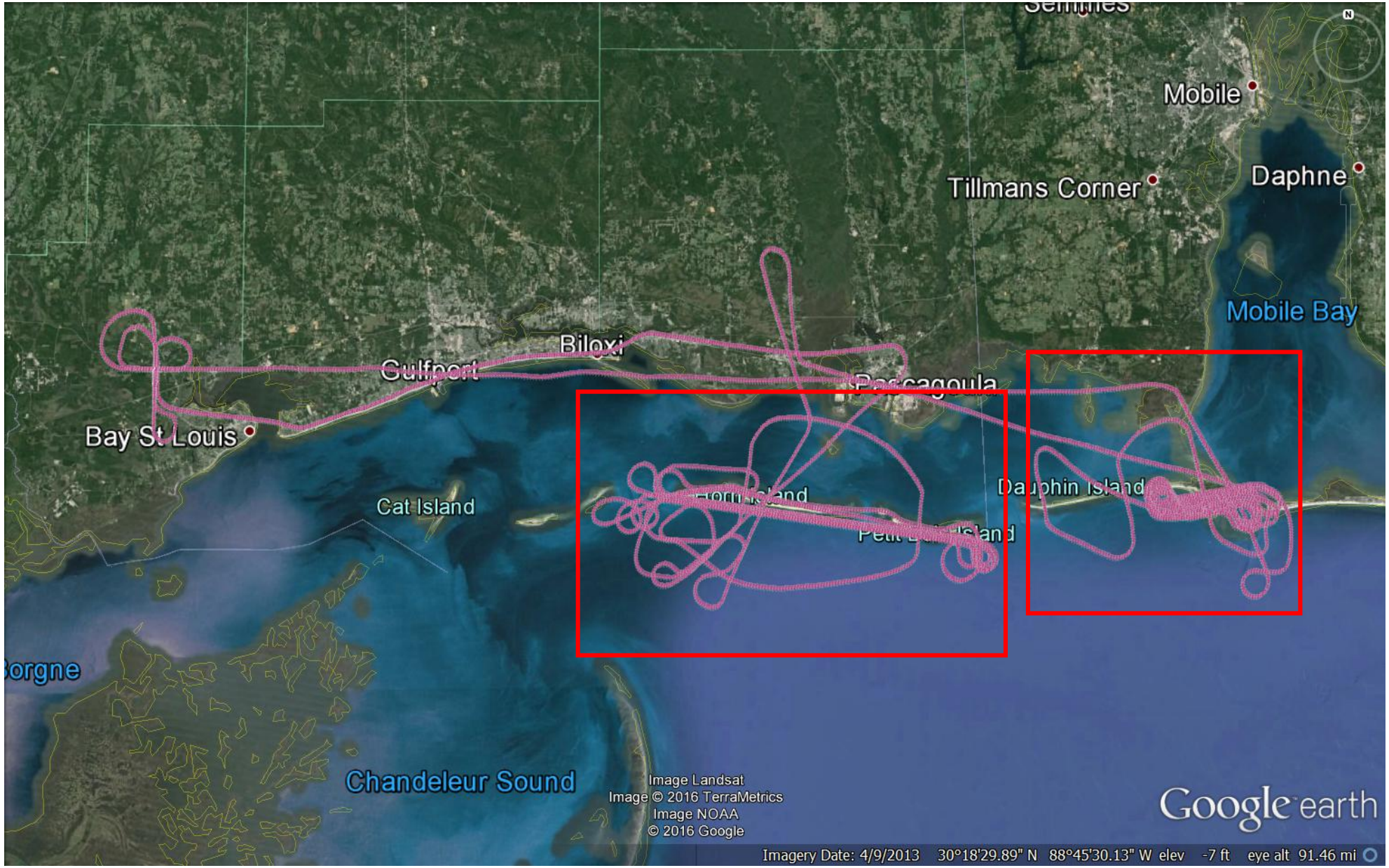
METHOD: Post-processed Data (N-PPK)



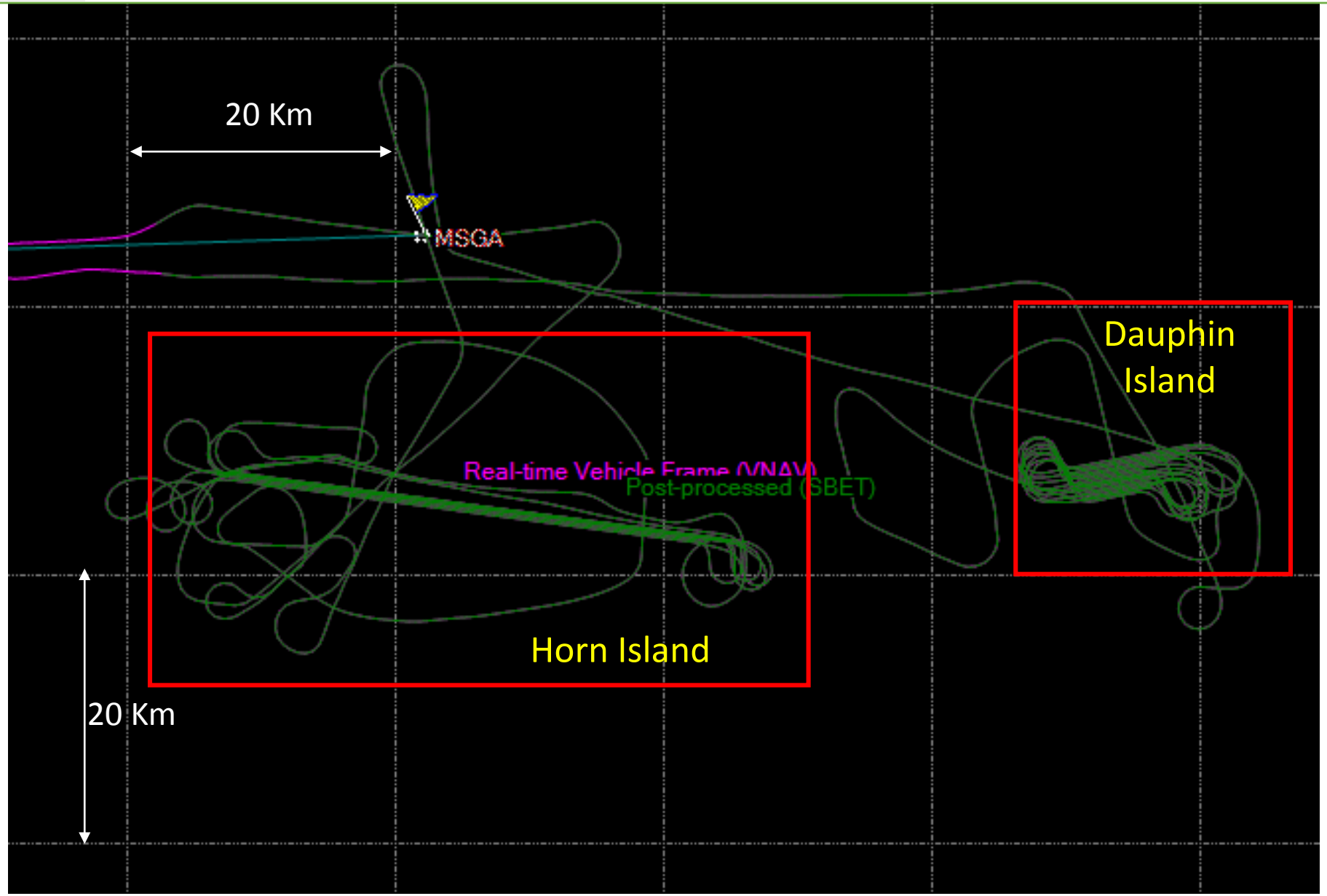
Applanix POSPac MMS for SBET

- N-PPK solution
- Tightly coupled solution of IMU and GNSS data

Assessing Performance at Horn and Dauphin Island



Assessing Performance at Horn and Dauphin Island



Results: Time series plot (Horn Island)

Standard deviation (σ) for dataset

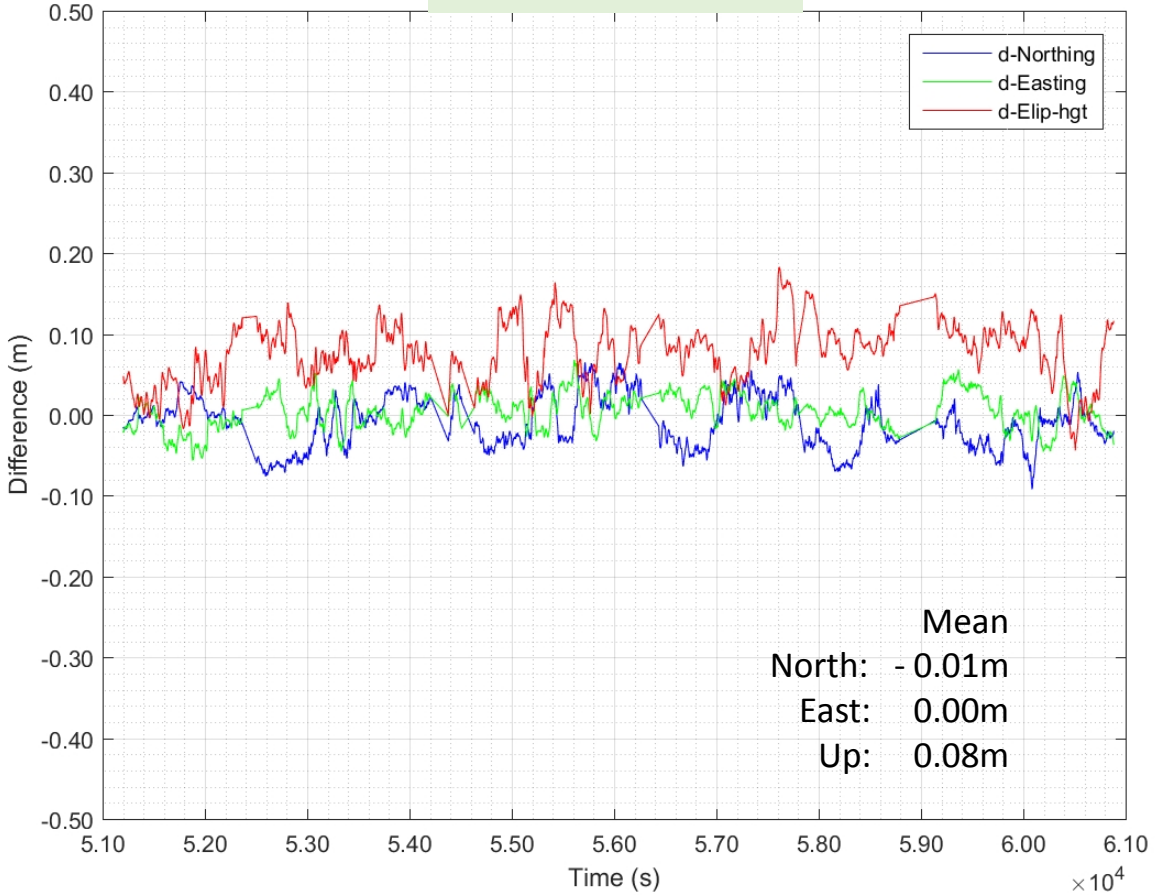
North: 0.03m
East: 0.02m
Up: 0.04m

North:
East:
Up:

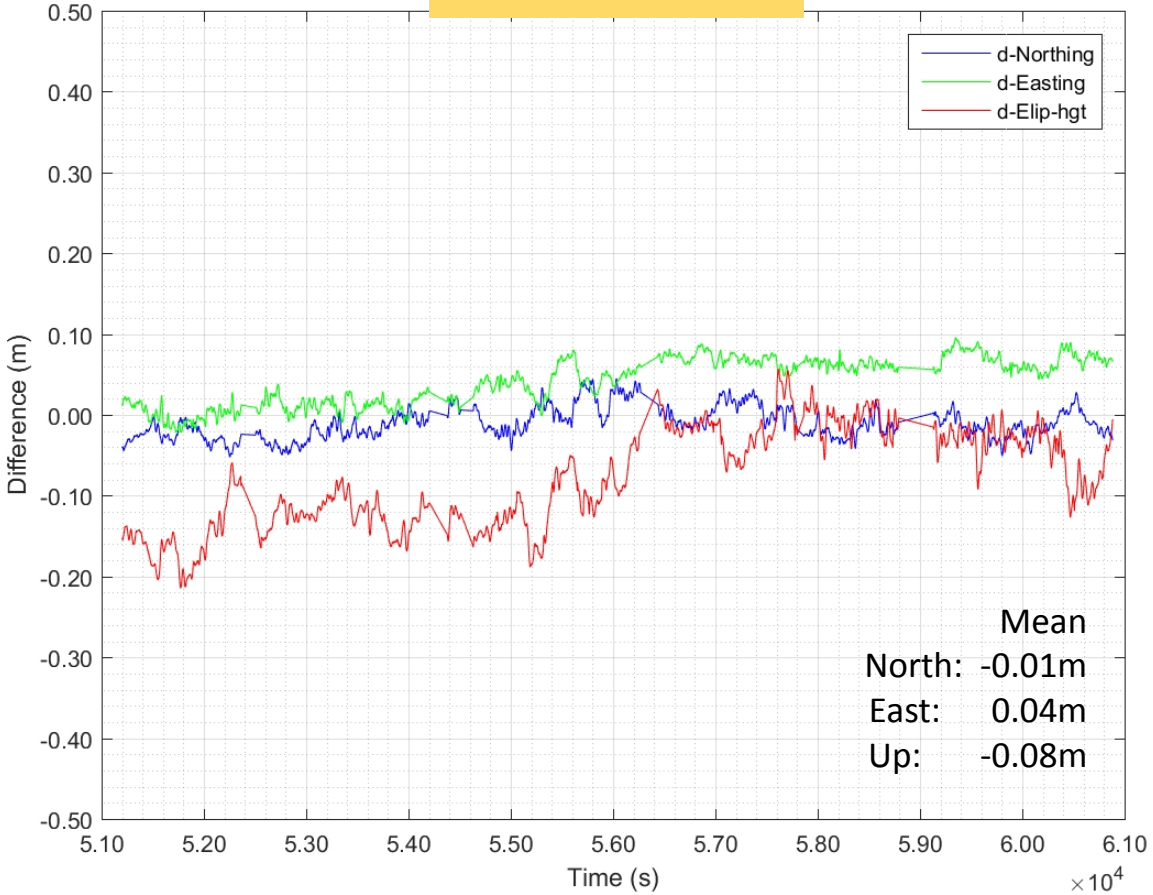
Standard deviation (σ) for dataset

North: 0.02m
East: 0.03m
Up: 0.06m

NPPK vs. SB-PPK



NPPK vs. PPP



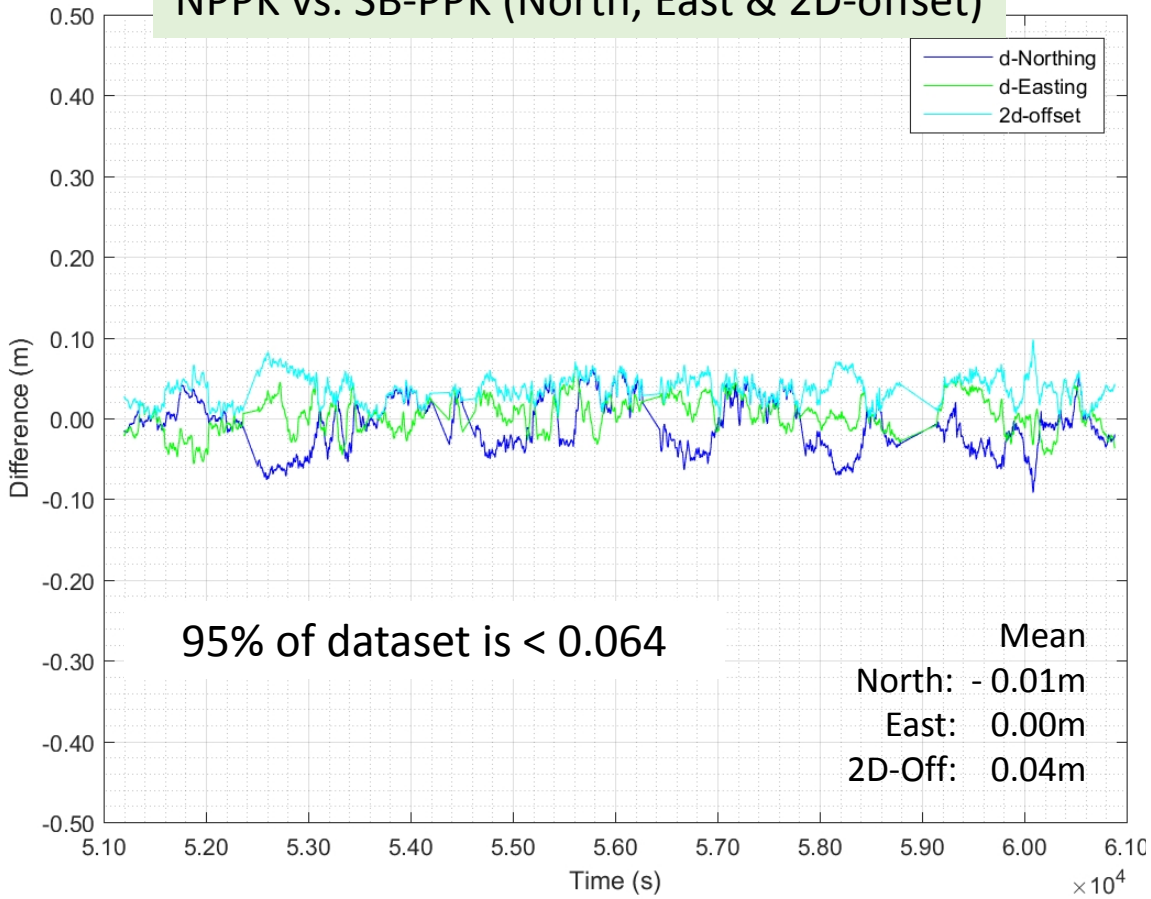
Analysis: 2D-Performance Evaluation (Horn Island)

95% Confidence (2σ)
North: 0.06m
East: 0.04m
2D-offset: 0.03m

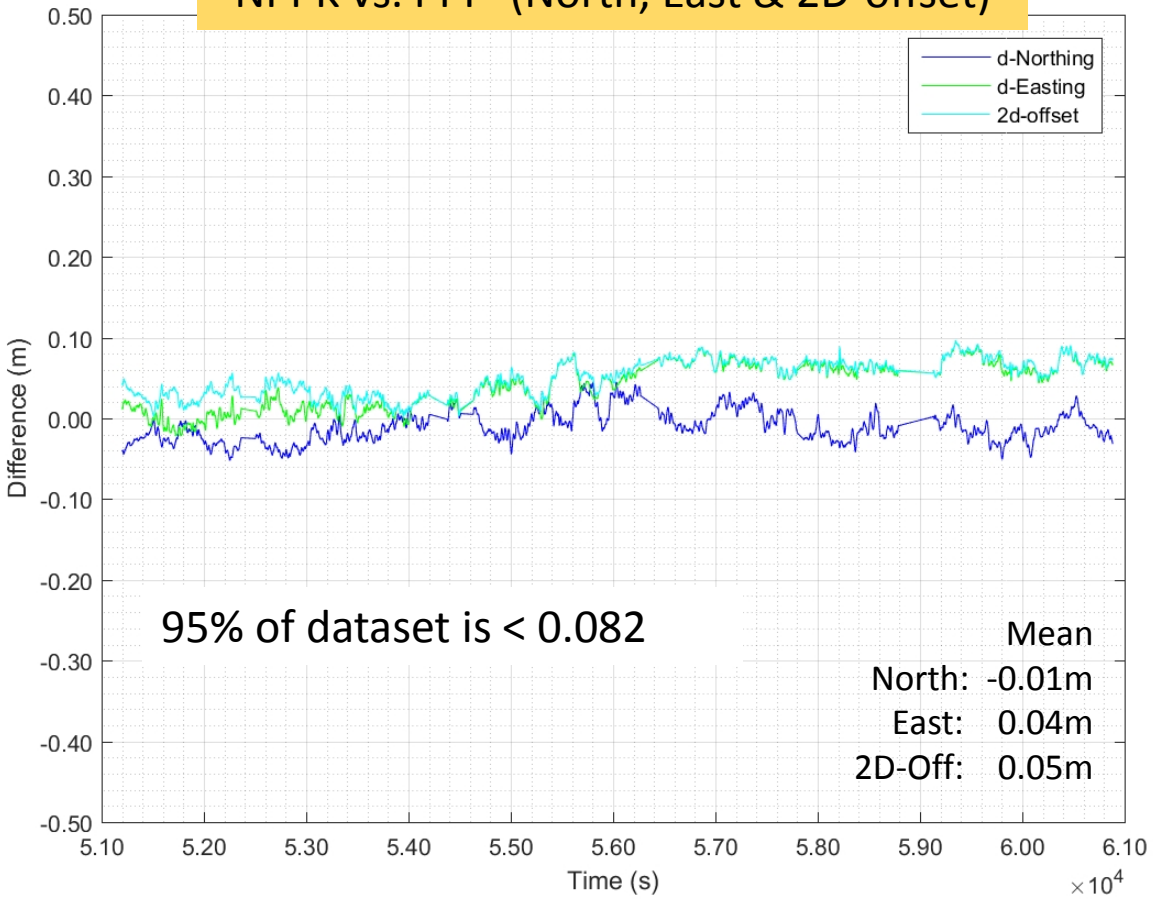
North:
East:
2D Offset:

95% Confidence (2σ)
North: 0.04m
East: 0.06m
2D-offset: 0.04m

NPPK vs. SB-PPK (North, East & 2D-offset)



NPPK vs. PPP (North, East & 2D-offset)



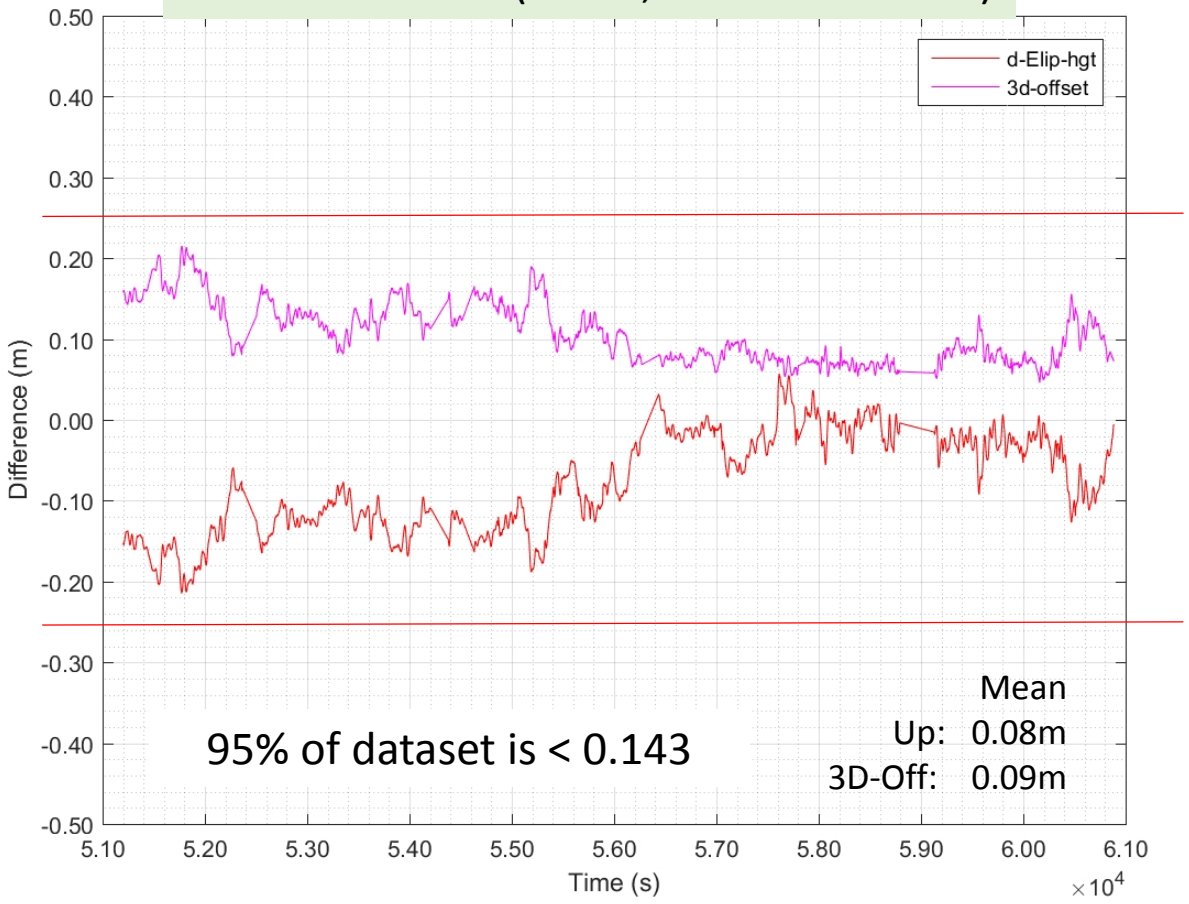
Analysis: 3D-Performance Evaluation (Horn Island)

95% Confidence (2σ)
Up 0.07m
3D-offset: 0.07m

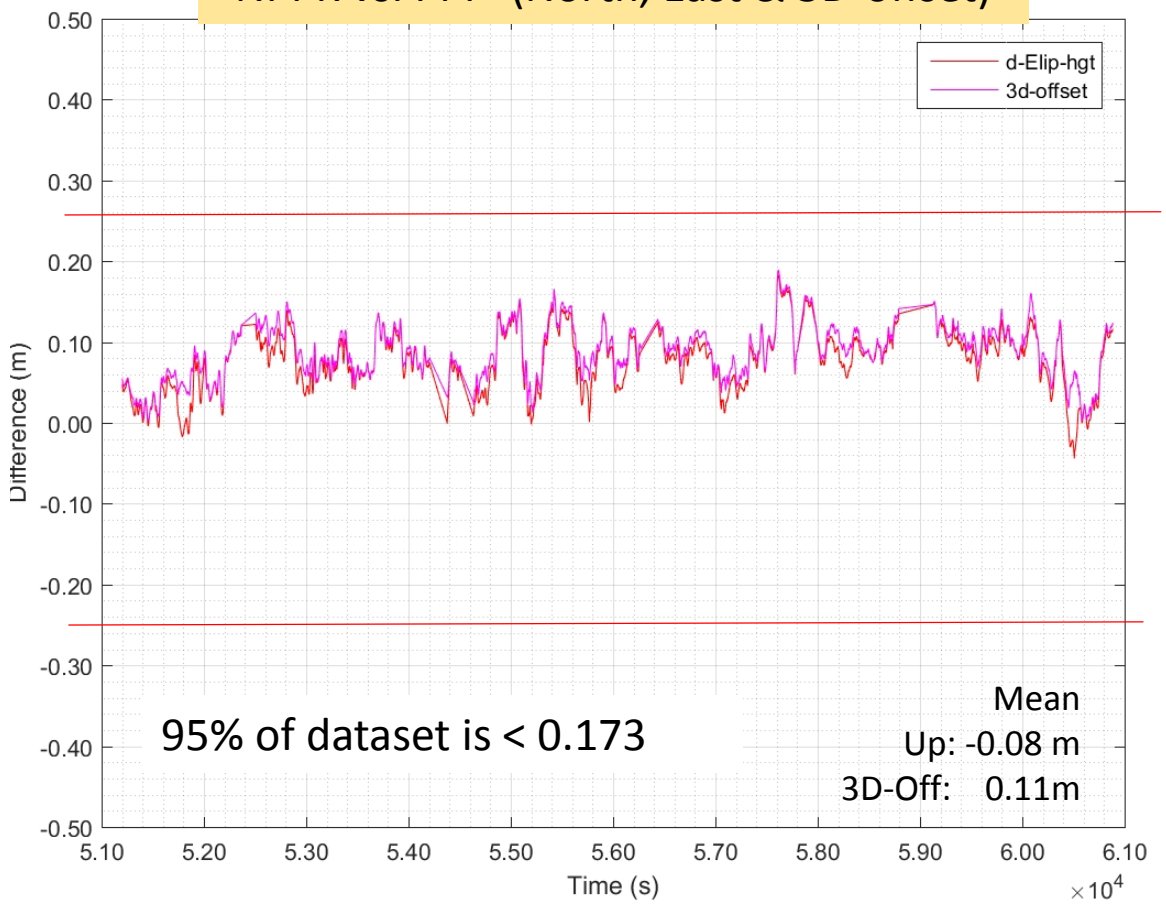
Ell-Hgt:
3D Offset:

95% Confidence (2σ)
Up: 0.12m
3D-offset: 0.07m

NPPK vs. SB-PPK (North, East & 3D-offset)



NPPK vs. PPP (North, East & 3D-offset)



Results: Time series plot (Dauphin Island)

Standard deviation (σ) for dataset

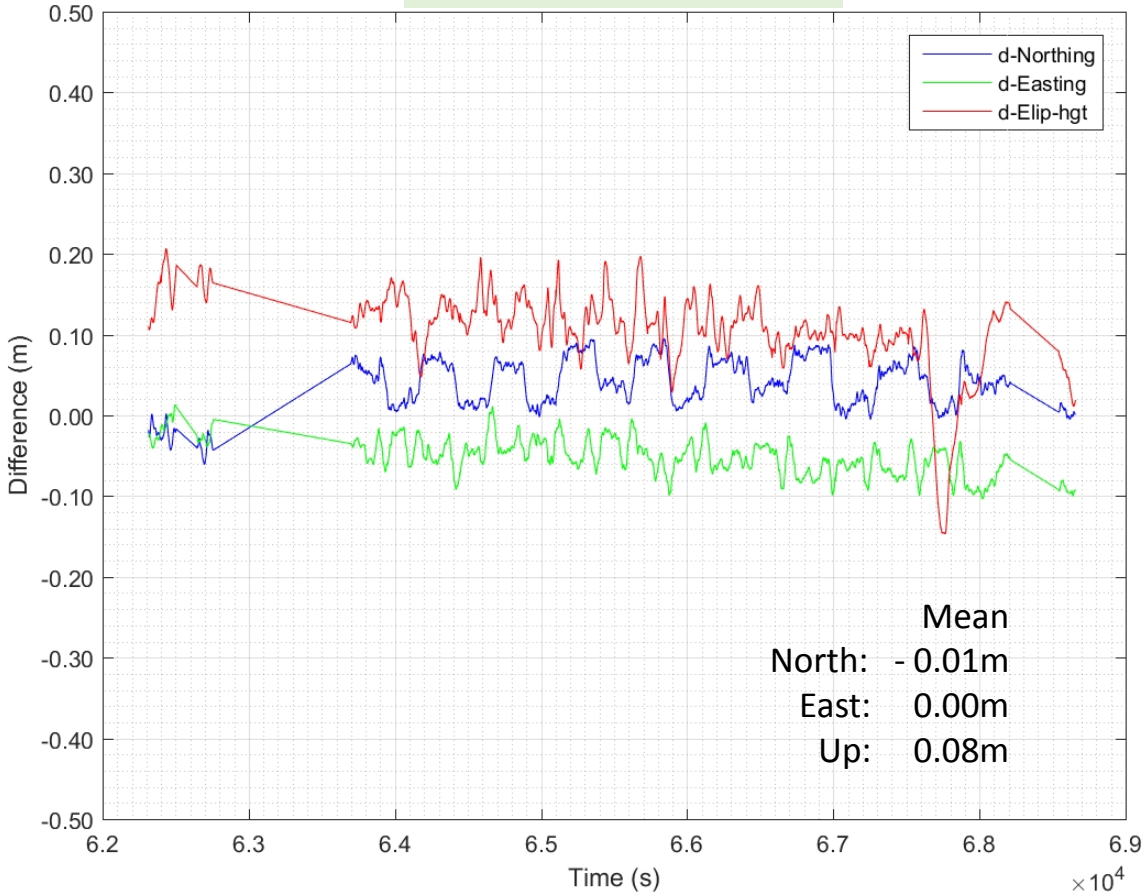
North: 0.03m
East: 0.02m
Up: 0.05m

North:
East:
Up:

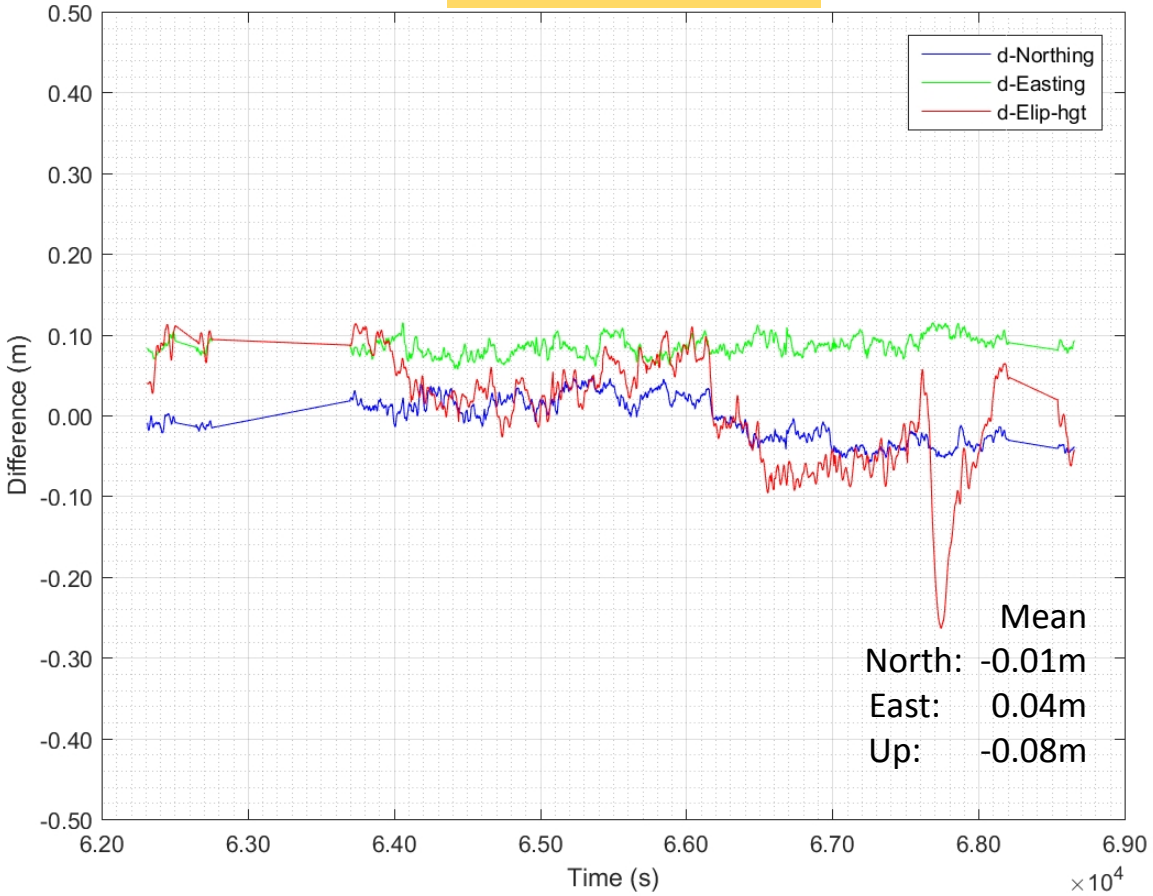
Standard deviation (σ) for dataset

North: 0.03m
East: 0.01m
Up: 0.07m

NPPK vs. SB-PPK



NPPK vs. PPP



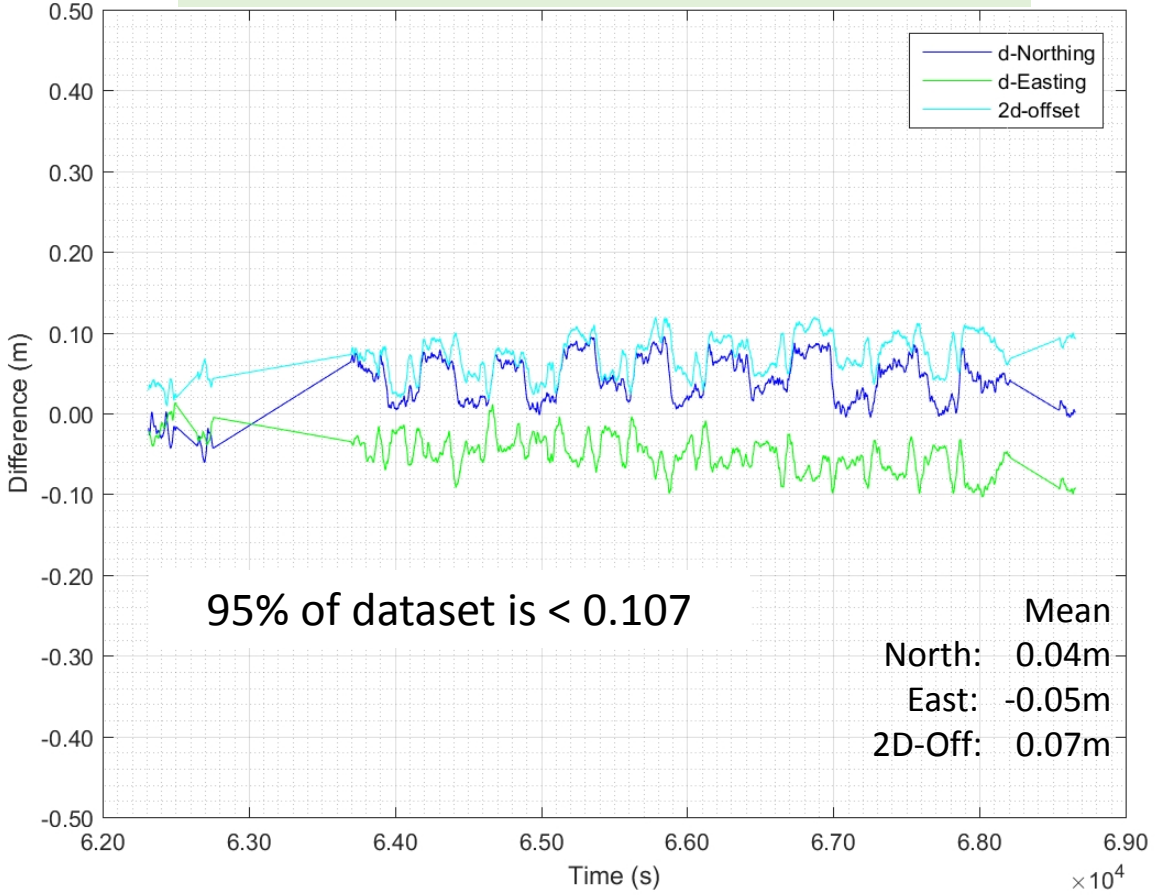
Analysis: 2D-Performance Evaluation (Dauphin Island)

95% Confidence (2σ)
North: 0.06m
East: 0.04m
2D-offset: 0.05m

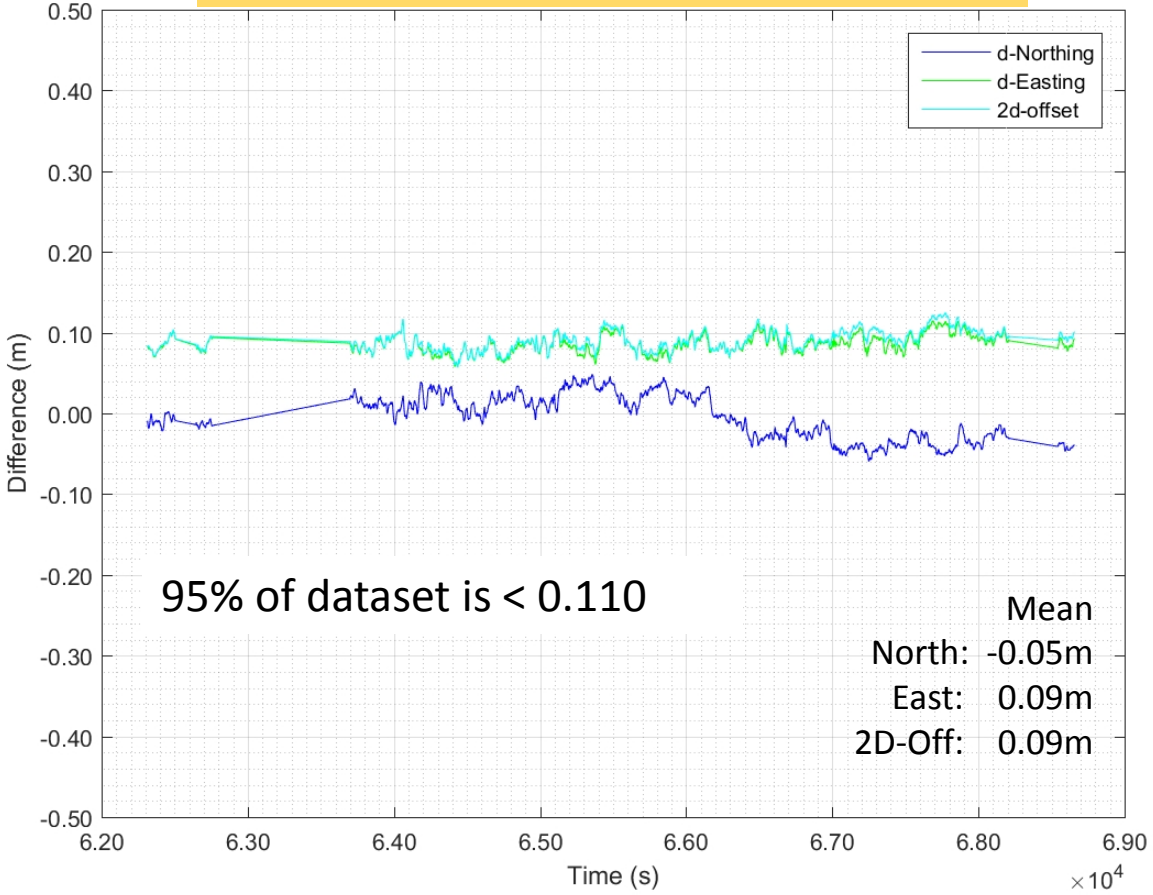
North:
East:
2D Offset:

95% Confidence (2σ)
North: 0.05m
East: 0.02m
2D-offset: 0.02m

NPPK vs. SB-PPK (North, East & 2D-offset)



NPPK vs. PPP (North, East & 2D-offset)



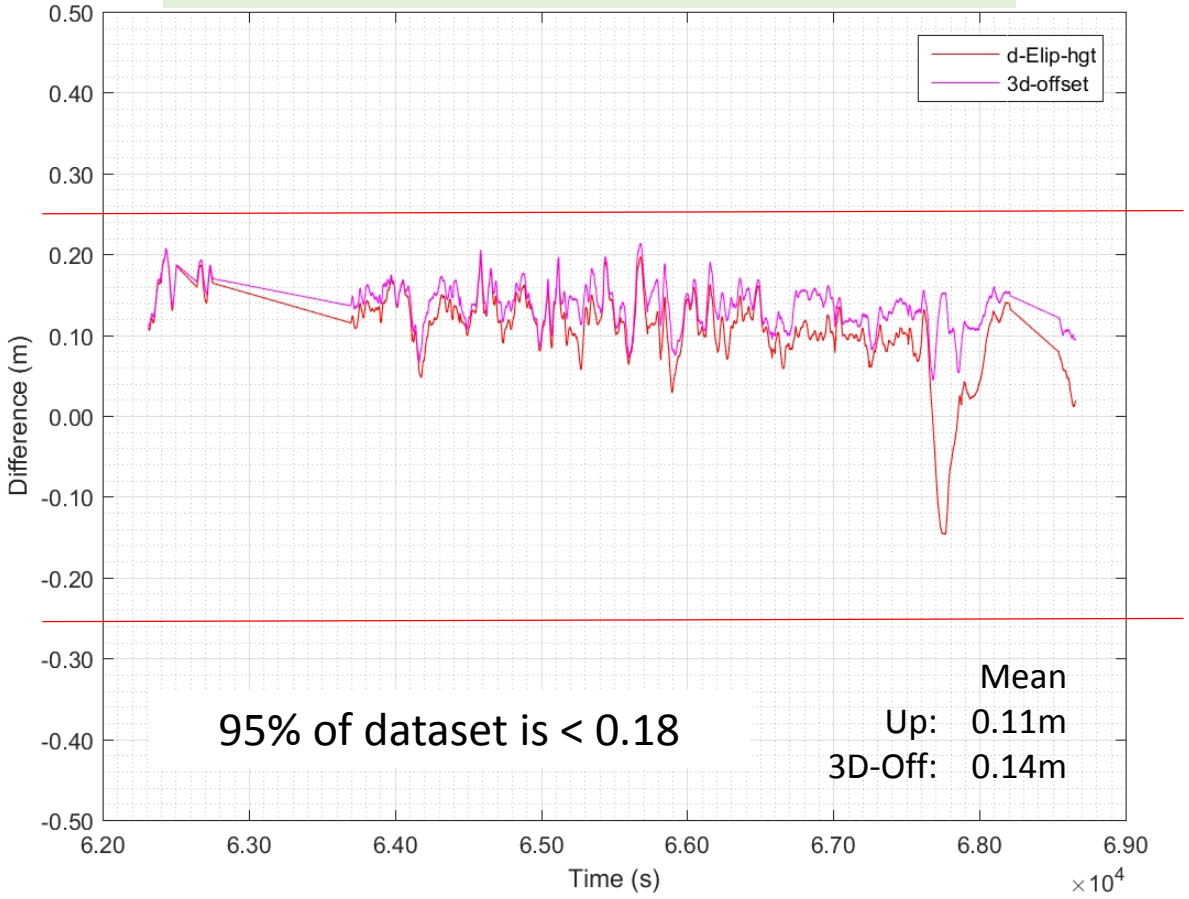
Analysis: 3D-Performance Evaluation (Dauphin Island)

95% Confidence (2σ)
Up 0.05m
3D-offset: 0.07m

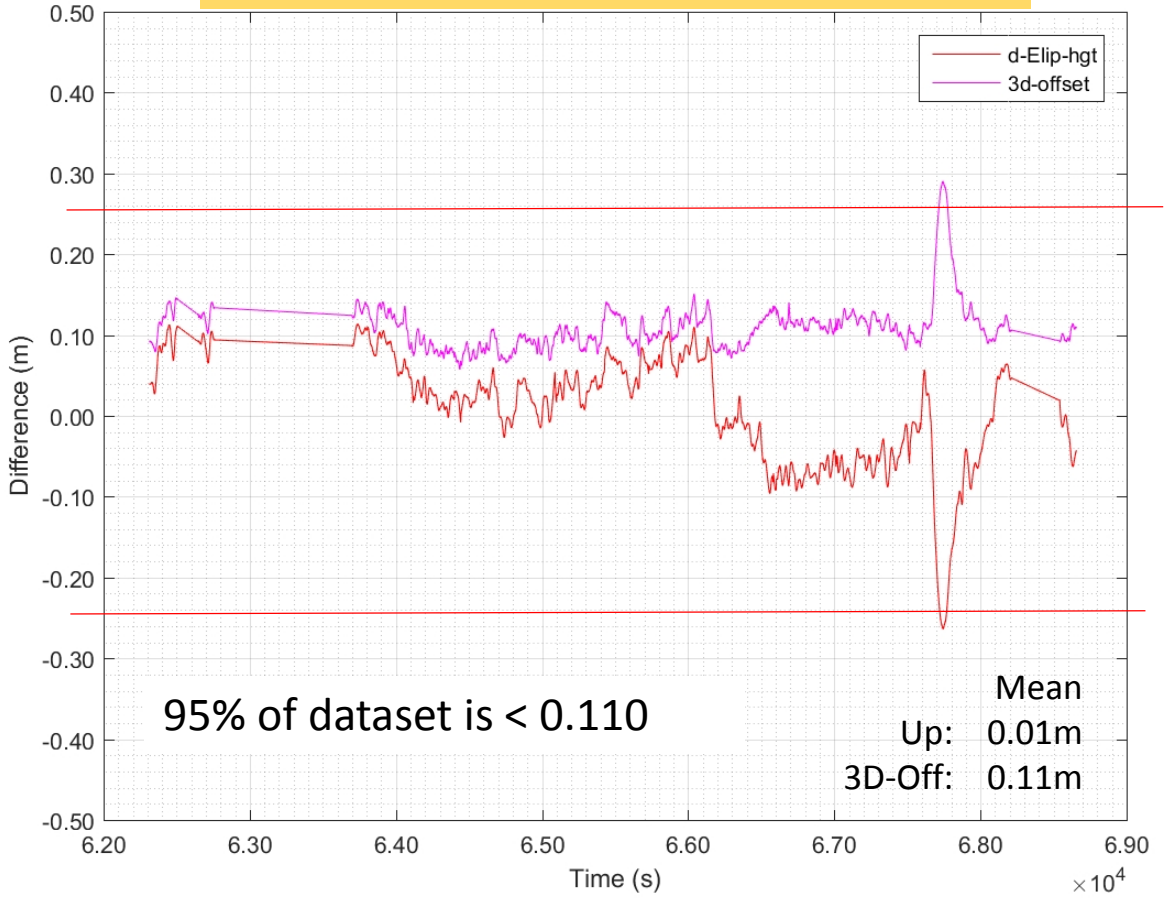
Ell-Hgt:
3D Offset:

95% Confidence (2σ)
Up: 0.13m
3D-offset: 0.06m

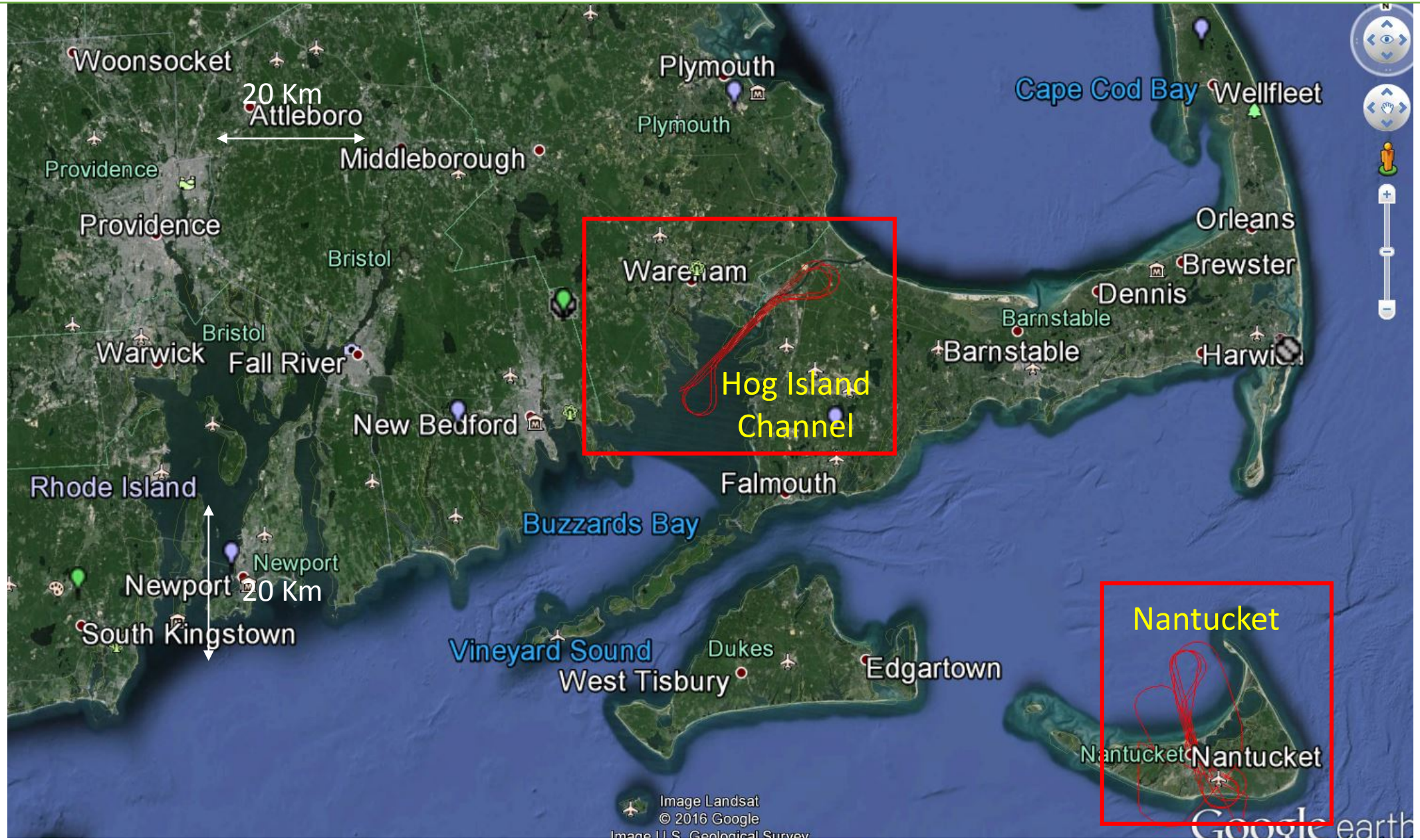
NPPK vs. SB-PPK (North, East & 3D-offset)



NPPK vs. PPP (North, East & 3D-offset)



Assessing Performance at Hog Island and Nantucket



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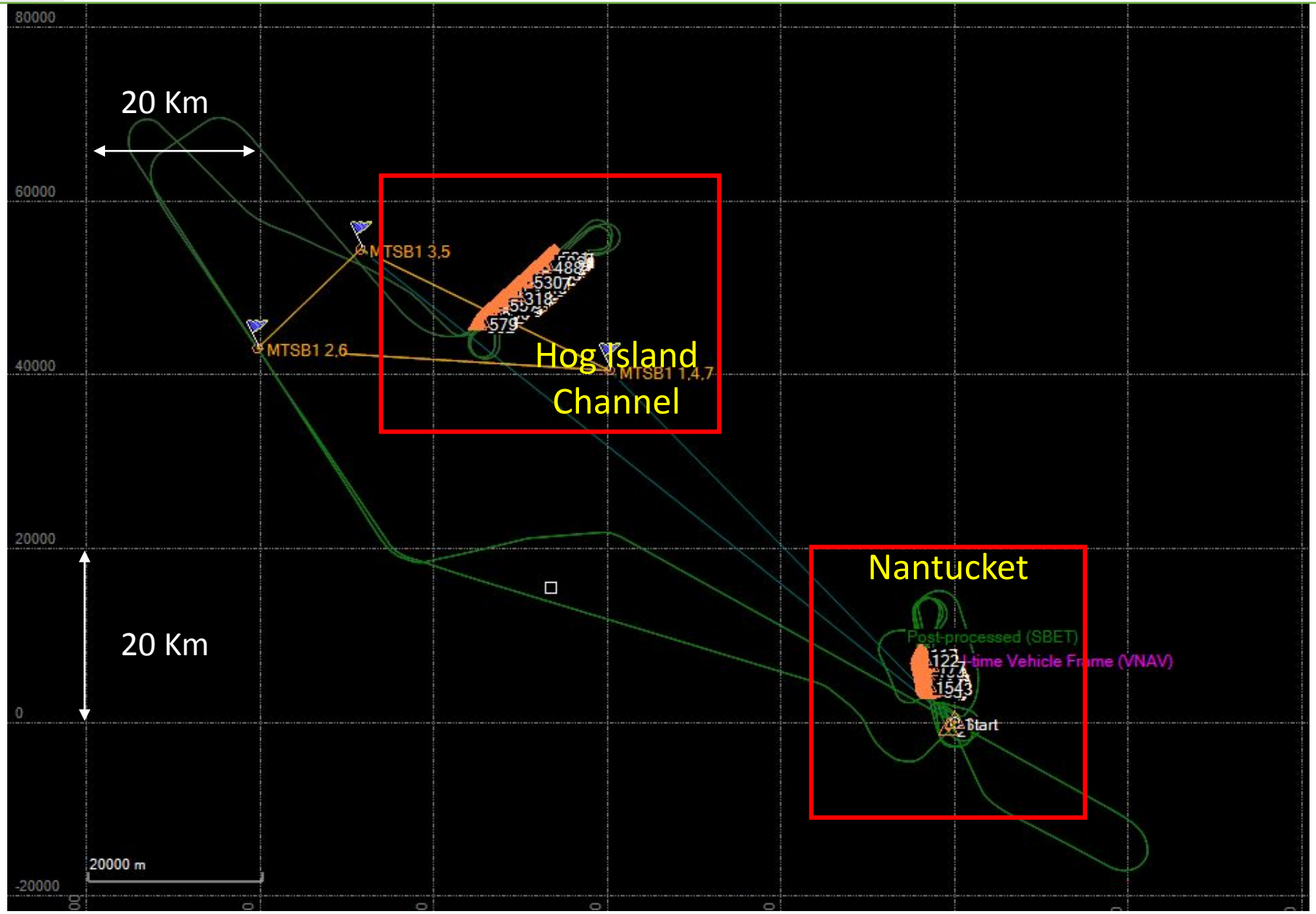
Assessing Performance at Hog Island and Nantucket



Results: Time series plot (Hog Island)

Standard deviation (σ) for dataset

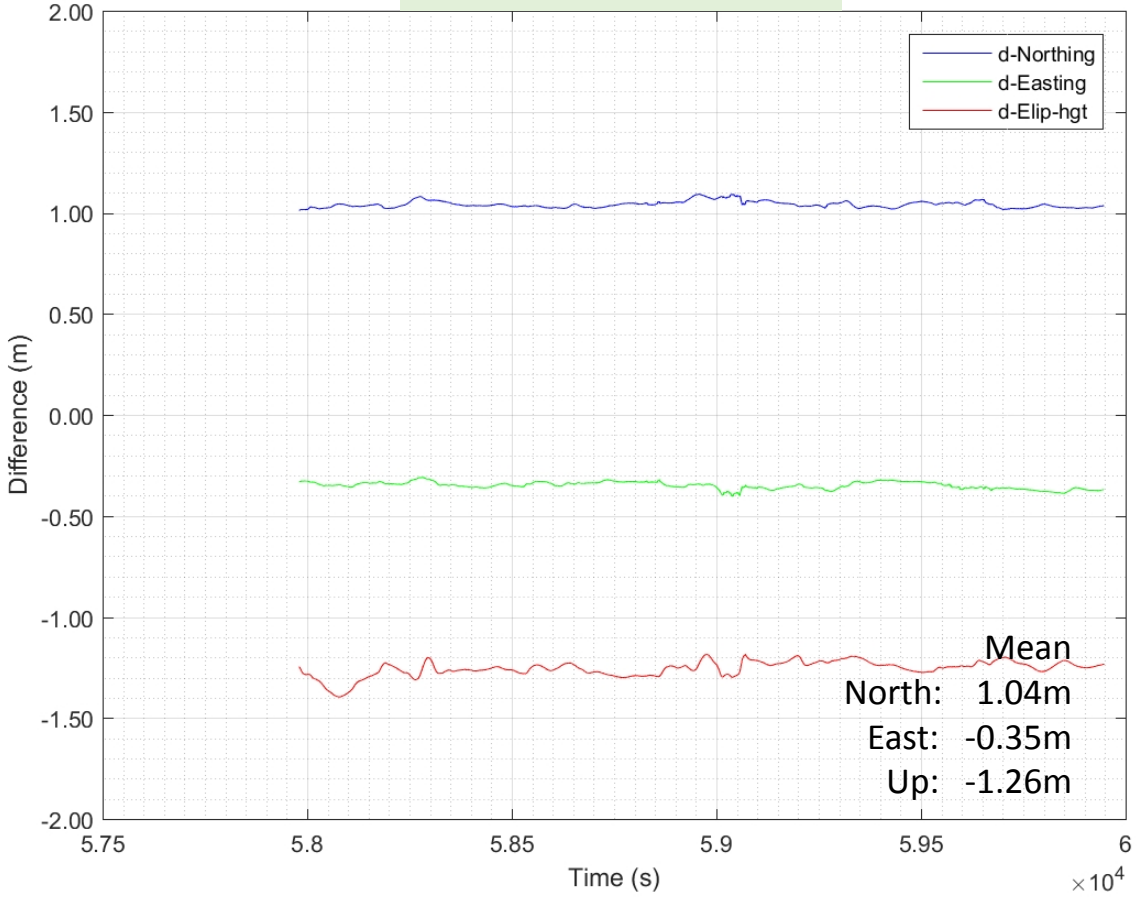
North: 0.02m
East: 0.02m
Up: 0.04m

North:
East:
Up:

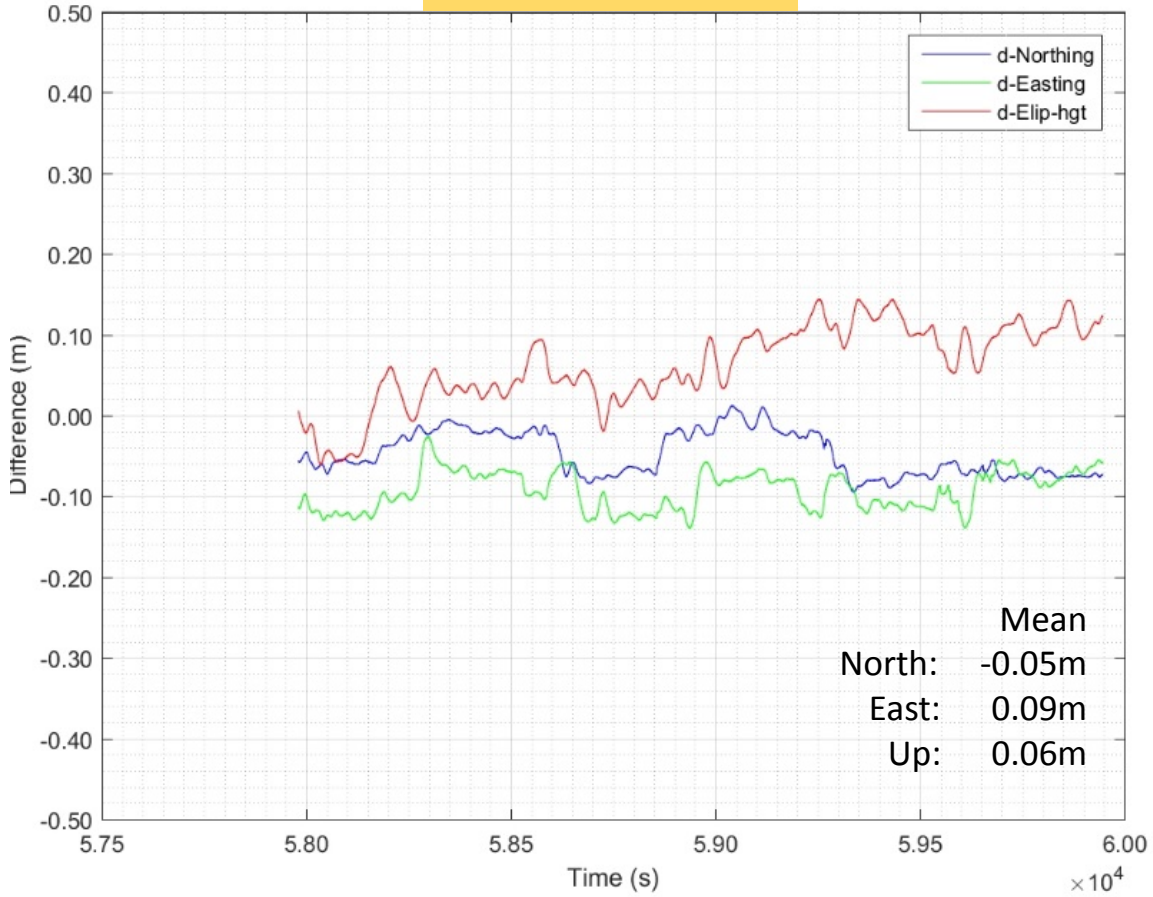
Standard deviation (σ) for dataset

North: 0.03m
East: 0.02m
Up: 0.05m

NPPK vs. SB-PPK



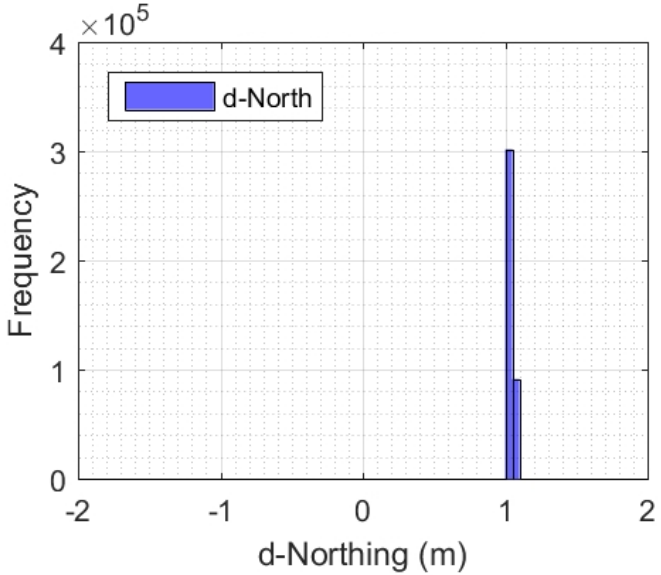
NPPK vs. PPP

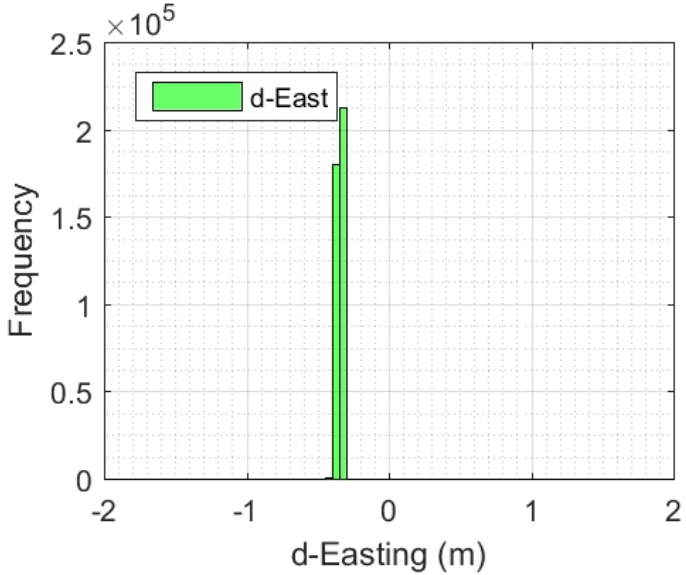


Results: Single base (SB) discrepancies (Hog Island)

NPPK vs. SB-PPK

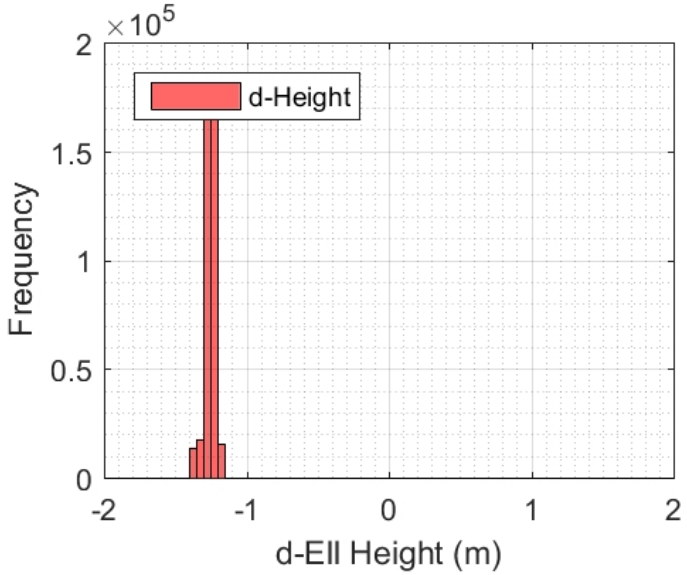
Mean: 1.04m
Std. dev. : 0.02m

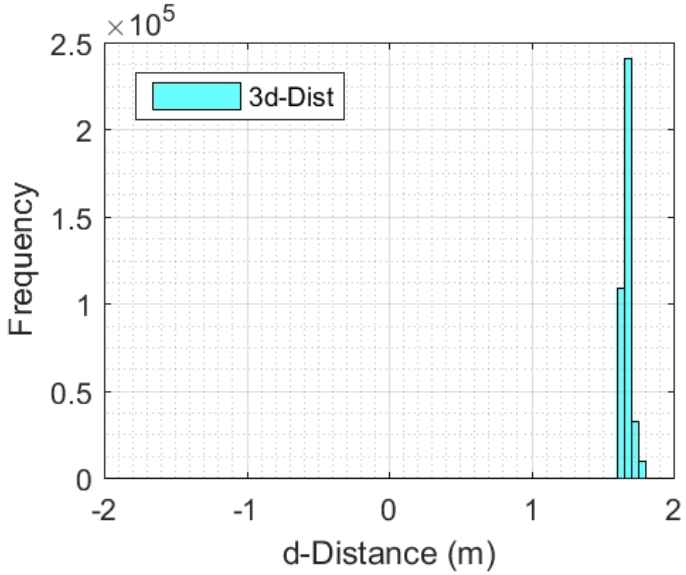




Mean: -0.35m
Std. dev.: 0.02m

Mean: -1.26m
Std. dev. : 0.04m



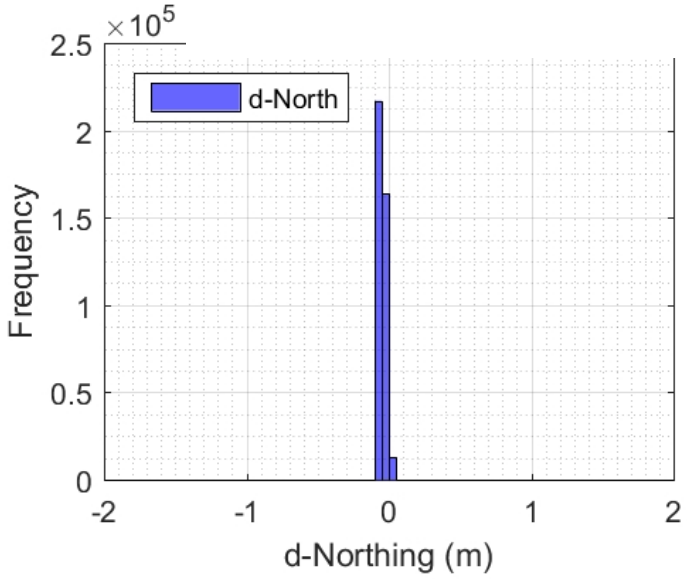


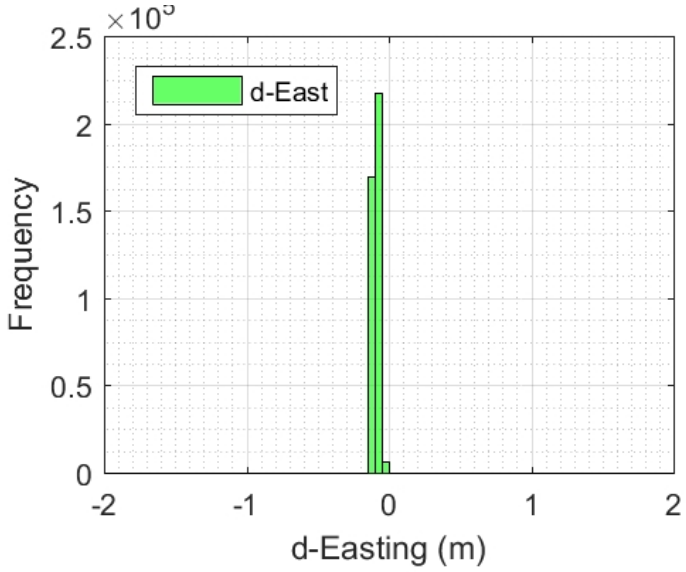
Mean: 1.67m
Std. dev. : 0.13m

Results: PPP discrepancies (Hog Island)

NPPK vs. PPP

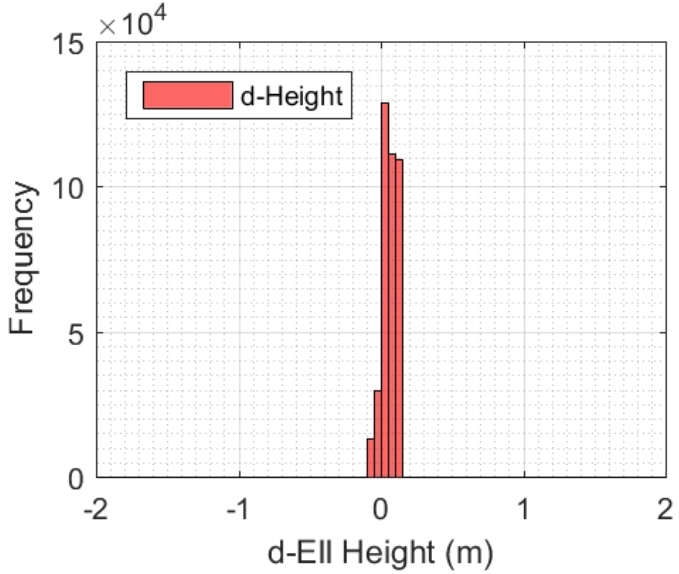
Mean: -0.05m
Std. dev. : 0.02m

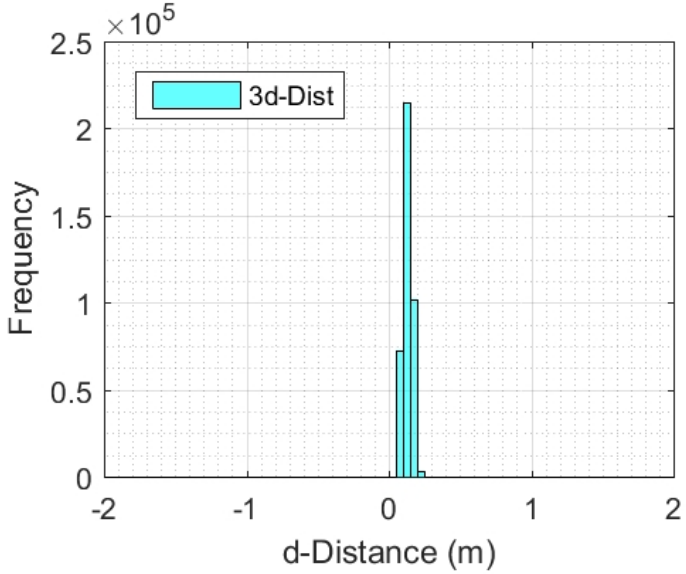




Mean: -0.09m
Std. dev.: 0.02m

Mean: 0.06m
Std. dev. : 0.04m





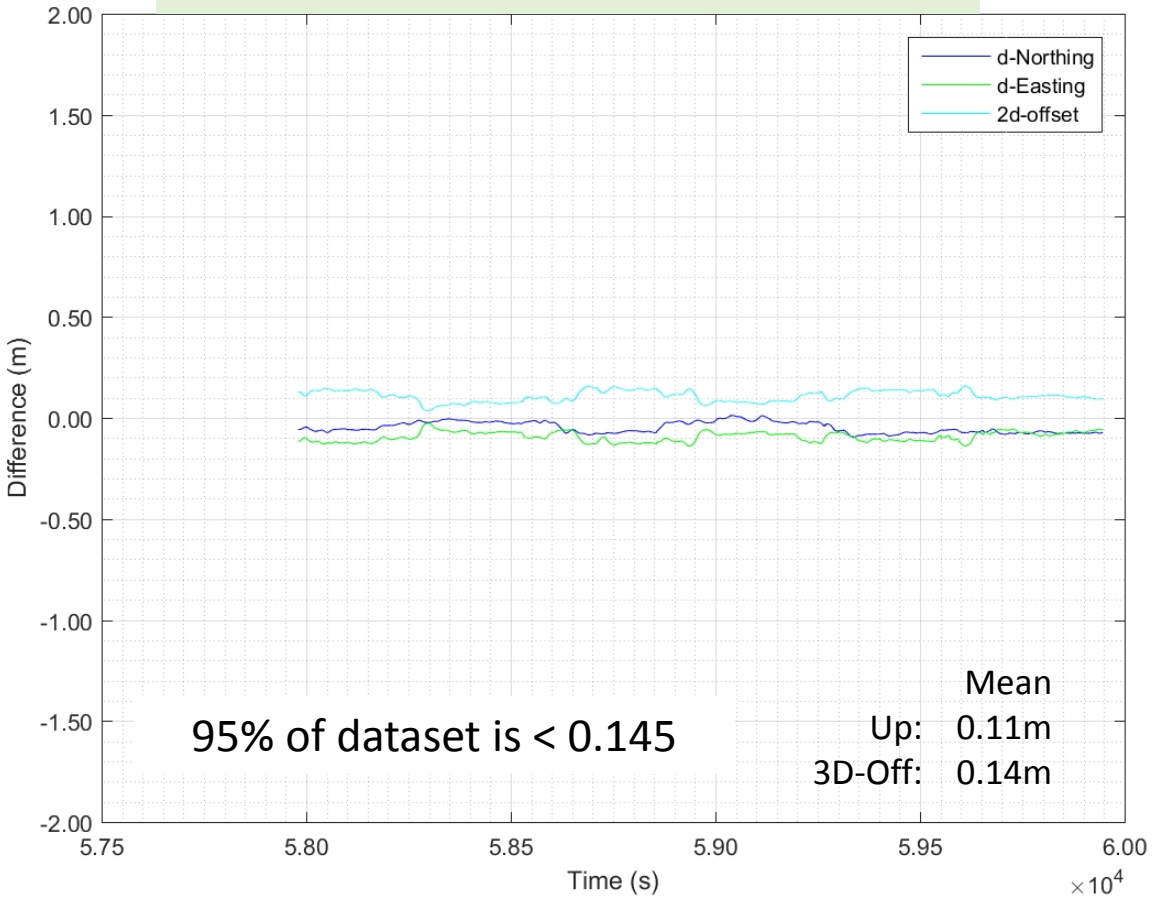
Mean: 0.13m
Std. dev. : 0.03m

Analysis: 2D & 3D Performance Evaluation (Hog Island)

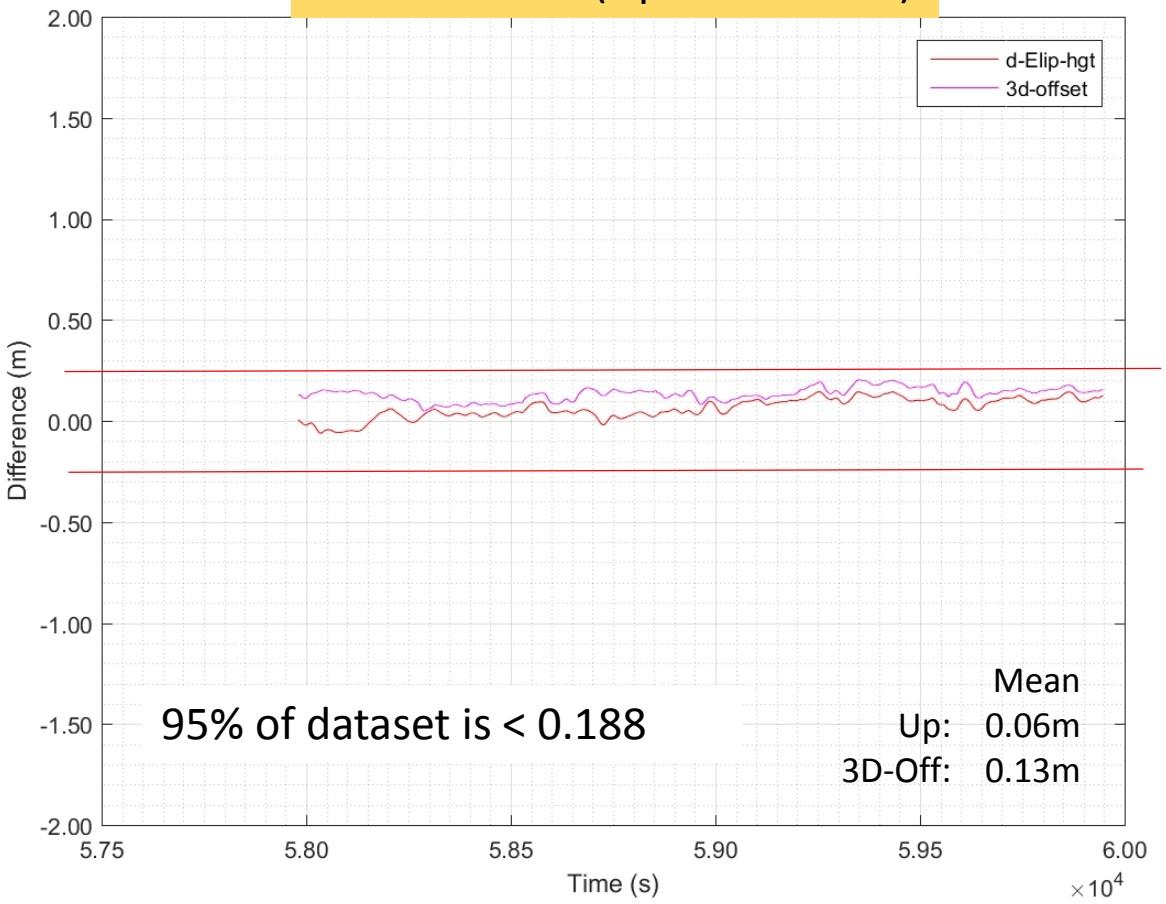
Standard deviation (σ)
2D 0.027m

Standard deviation (σ)
3D 0.033m

NPPK vs. PPP (North, East & 2D-offset)



NPPK vs. PPP (Up & 3D-offset)



Summary of Performance Evaluation

95% conf. level		Special Order Unit (m)	Order 1a Unit (m)	Order 1b Unit (m)	Order 2 Unit (m)
		2	5+5% of d	5+5% of d	20+5% of d
THU	for d=5	2	5.25	5.25	20.25
	a=	0.25	0.50	0.50	1.00
	b=	0.0075	0.013	0.013	0.023

Horn Island	Data size	2D Standard dev (σ)	3D Standard dev (σ)	95% of dataset (2D discr)	95% of dataset (3D discr)
NPPK vs SB-PPK	1,737,055	0.017	0.034	0.06	0.14
NPPK vs PPP	1,737,055	0.022	0.037	0.08	0.17
Dauphin Island					
NPPK vs SB-PPK	985,769	0.025	0.027	0.11	0.18
NPPK vs PPP	985,769	0.012	0.030	0.11	0.14
Hog Island					
NPPK vs PPP	39,318	0.027	0.033	0.15	**0.19**

Summary of Performance Evaluation

TELEDYNE OPTECH
Everywhereyoulook™

Optech CZMIL Nova

Advantages

- Accurate and seamless topography and water-depth measurements
- Short laser pulse widths enable true shallow-water bathymetry
- Circular scan pattern provides two 'looks' per target, for optimal object detection
- Web-based interface for real-time in-field remote diagnostics
- Simultaneous high-density topo/bathy data from a single laser
- Segmented detector capable of up to 70,000 measurements/second
- Lidar, hyperspectral, and RGB camera integrated on-board
- Weight and design optimized for airworthiness and military standards

	Parameters	Specifications
General Specifications	Operating altitude	400 m (nominal), up to 1,000 m
	Aircraft speed	140 kt
	Hyperspectral sensor	CASI-1
	Digital cameras	T4800
	Positioning & GPS/GNSS	Applar
	Positioning system	OmniS
Lidar Hydrographic Mode	Shallow channels measurement rate	70 kH
	Shallow channels maximum depth	2/K_d (l
	Deep channel measurement rate	10 kH
	Deep channel maximum depth	4.2/K_d
	Depth measurement accuracy	√(0.3
	Horizontal accuracy	(3.5 +
	Scan angle	20° cir
	Swath width	70% o
	Laser classification	Class 4
Lidar Topographic Mode	Measurement rate	80 kH
	Horizontal accuracy	±1 m,
	Vertical accuracy	±15 cr
Physical	Power requirements	85 A f
	Operating temperature	0°C to
	Storage temperature	-10°C
	Humidity	0-95%
	Sensor head	89 W
	Control & operations rack	59 W
	Data processing software	CZMIL

IHO ……. TVU (order 1a) $= \sqrt{0.5^2 + (0.013 * d)^2}$

CZMIL depth measurement accuracy $= \sqrt{0.3^2 + (0.013 * d)^2}$

CZMIL estimated depth uncertainty at **5m depth** $= 0.307m$

Lidar Hydrographic Mode	Shallow channels measurement rate	70 kHz
	Shallow channels maximum depth	2/K_d (bottom reflectivity > 15%)
	Deep channel measurement rate	10 kHz
	Deep channel maximum depth	4.2/K_d (bottom reflectivity > 15%)
	Depth measurement accuracy	$\sqrt{(0.3^2+(0.013d)^2)}$ m, 2σ, 0 – 30 m
	Horizontal accuracy	(3.5 + 0.05d) m, 2σ
	Scan angle	20° circular
	Swath width	70% of operating altitude
	Laser classification	Class 4 laser product: IEC 60825-1 Ed. 3.0 2014
Lidar Topographic Mode	Measurement rate	80 kHz
	Horizontal accuracy	±1 m, 2σ
	Vertical accuracy	±15 cm, 2σ

Summary of Performance Evaluation

CZMIL estimated depth uncertainty at (**5m depth**) $= 0.307m; as\ computed\ from\ \sqrt{0.3^2 + (0.013\ *\ d)^2}$

Location	Comparison against NPPK	Up Component (2σ), m	Estimated TVU, m
Horn Island	SB-PPK	0.074	0.319
Horn Island	PPP	0.118	0.332
Dauphin Island	SB-PPK	0.100	0.326
Dauphin Island	PPP	0.133	0.337
Hog Island	PPP	0.096	0.325

Summary of Performance Evaluation

Estimated uncertainty of depth (5m) measurement by CZMIL $= 0.31\ m$

Largest uncertainty for Single Base Solution at 95% confidence level:

- VU was ± 0.10m (2σ of up component)
- Estimated TVU ± 0.326m

Largest uncertainty for PPP Solution at 95% confidence level:

- VU was ± 0.13m (2σ of up component)
- Estimated TVU ± 0.337m

95% conf. level		Special Order Unit (m)	Order 1a Unit (m)	Order 1b Unit (m)	Order 2 Unit (m)
THU		2	5+5% of d	5+5% of d	20+5% of d
	for d=5	2	5.25	5.25	20.25
	a=	0.25	0.50	0.50	1.00
	b=	0.0075	0.013	0.013	0.023
	depth/				
TVU	5	0.25	0.50	0.50	1.01
	8	0.26	0.51	0.51	1.02
	10	0.26	0.52	0.52	1.03
	20	0.29	0.56	0.56	1.10
	30	0.34	0.63	0.63	1.21

From these evaluations, PPP passed, at least, the TVU for Order 1 surveys

Can the range of ALB systems be extended? YES!

Because with PPP, ALB systems and similar platforms operating in the coastal area would not be constrained by maximum base length to a reference receiver

However, It is expected that PPP solution method would improve as newer algorithms are developed

REFERENCES

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[3] H. B., L. H., & W. E. (2007). GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more. Choice Reviews Online, 45(11). doi:10.5860/choice.45-6185

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THANK YOU

QUESTIONS?