Towards Establishing Long Term Geodetic Benchmarks on the Seafloor using Underwater Acoustic GPS

Committee on Seismology & Geodynamics
New Opportunities to Study Tectonic Precursors
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OUTLINE

- Introduction & Background
- Prior Work (NUWC)
- GABBIES (Geodetic Acoustic Benchmark Beacon – Inverted Echosounder)
- Navy Acoustic Navigation Beacons
- Future Plans

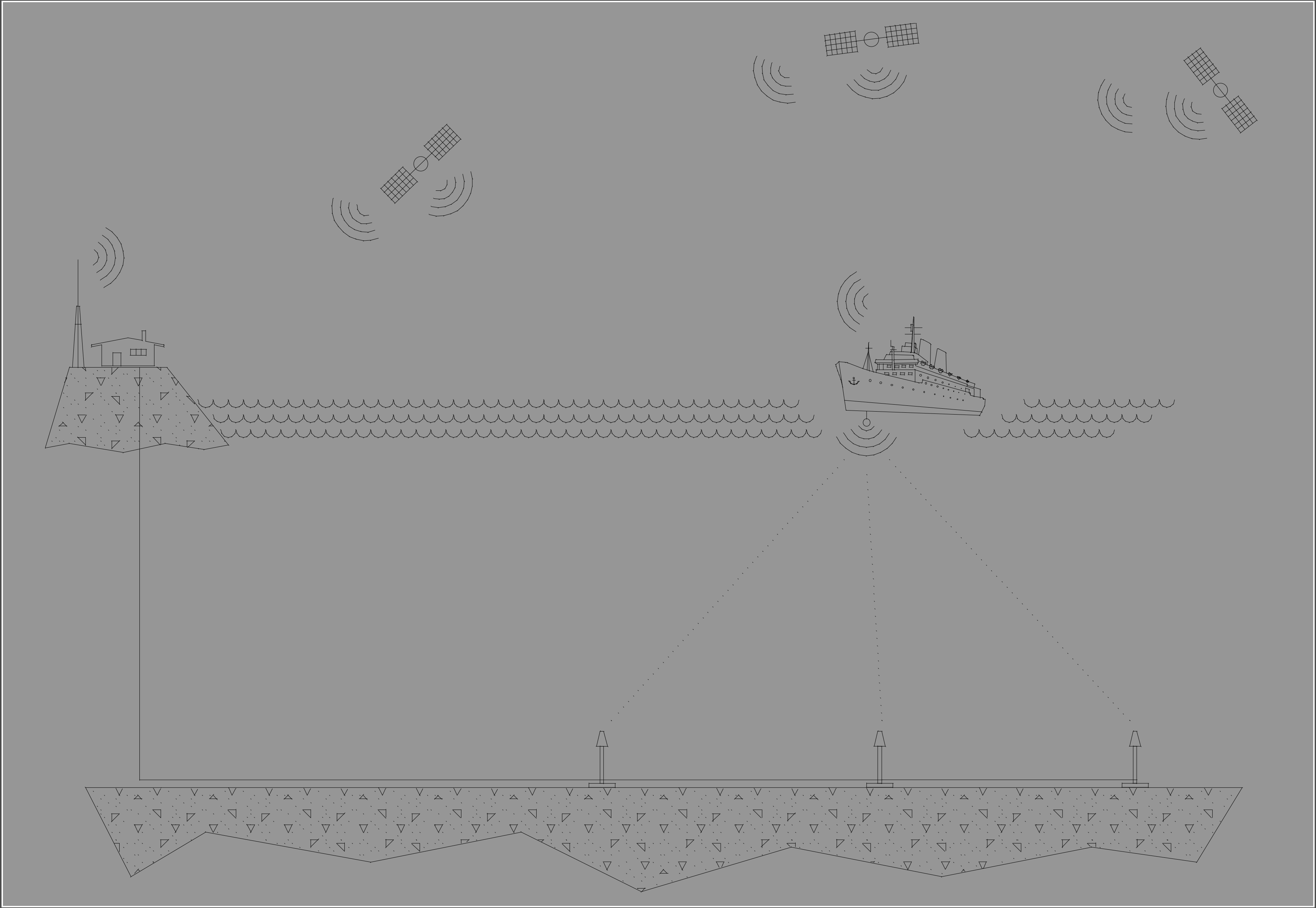
Bottom Line Up Front

- Long term seafloor geodesy is economically feasible by combining:
  - Underwater Acoustics
  - GPS
  - Autonomous Surface Vehicles
- Seafloor Sensors:
  - Transponders
  - Beacons
  - Hydrophones
- Hydrophone (with acoustic modem):
  - Highest accuracy
  - Lowest power for long duration deployments (25+ years)

Seafloor Sensors for Underwater
Acoustic Positioning

- Transponder – device that transmits a reply pulse after receiving an interrogation pulse
- Beacon – device that transmits multiple pulses continuously after turn-on
- Hydrophone – only receives pulses
- Acoustic <u>transmission</u> requires high power (100's of Watts) but Acoustic <u>reception</u> requires low power (milli-Watts)
- Minimize transmissions from seafloor

SURVEYING



Traditional Positioning Models

- Spherical

$$\left.\begin{aligned} R_i &= c_i\left(t_i^a - t^e\right) \\ R_i &= c_i\left(t_i^a - t_i^e\right) \end{aligned}\right\} \quad R_i = c_i t_i^t$$

- Hyperbolic

$$\left.\begin{aligned} R_i &= c_i\left(t_i^a - t^e\right) \\ R_i &= c_i\left(t_i^a - t_i^e + t^b\right) \end{aligned}\right\} \quad R_i - R_1 = c_i\left(t_i^a - t_1^a\right) = c_i \Delta t_i^a$$

- Elliptical

$$R_i + R_1 = c_i\left(t_o^a - t^e\right) + \left(t_i^a - t_o^a\right) = c_i\left(t_i^a - t^e\right)$$

$$\boxed{R_i = \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2} \quad ; \quad i = 1 \ldots N}$$

New Developments: Models

- Spherical with ESV Bias Estimation (SBE)

$$R_i = \left(c_i + b^c\right)\left(t_i^a - t_i^e\right)$$

- Hyperbolic with ESV Bias Estimation (HBE)

$$R_i = \left(c_i + b^c\right)\left(t_i^a - t_i^e + t^b\right)$$

$$R_i = \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2} \quad ; \quad i = 1 \ldots N$$

New Developments: Models

$$\mathbf{x} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ b^{t}, t^{e} \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ b^{c} \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ b^{t}, t^{e} \\ b^{c} \end{bmatrix}$$

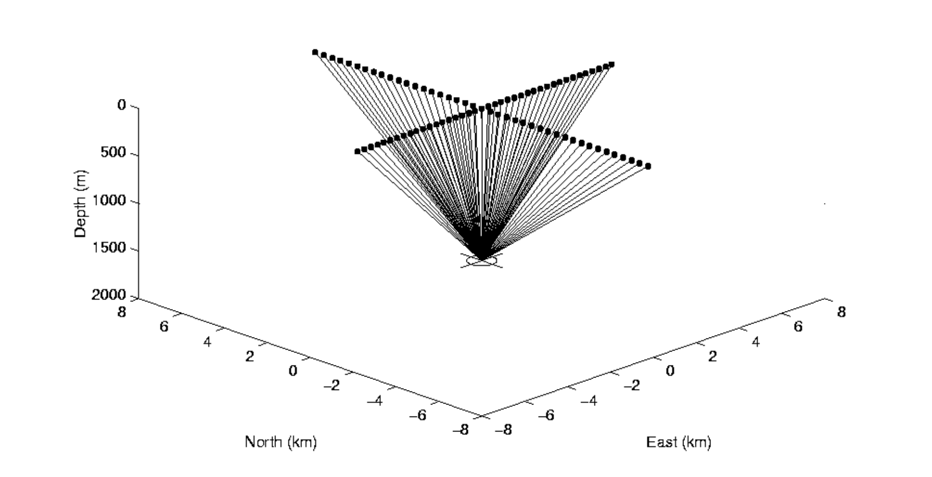
SLS

HLS

HBE

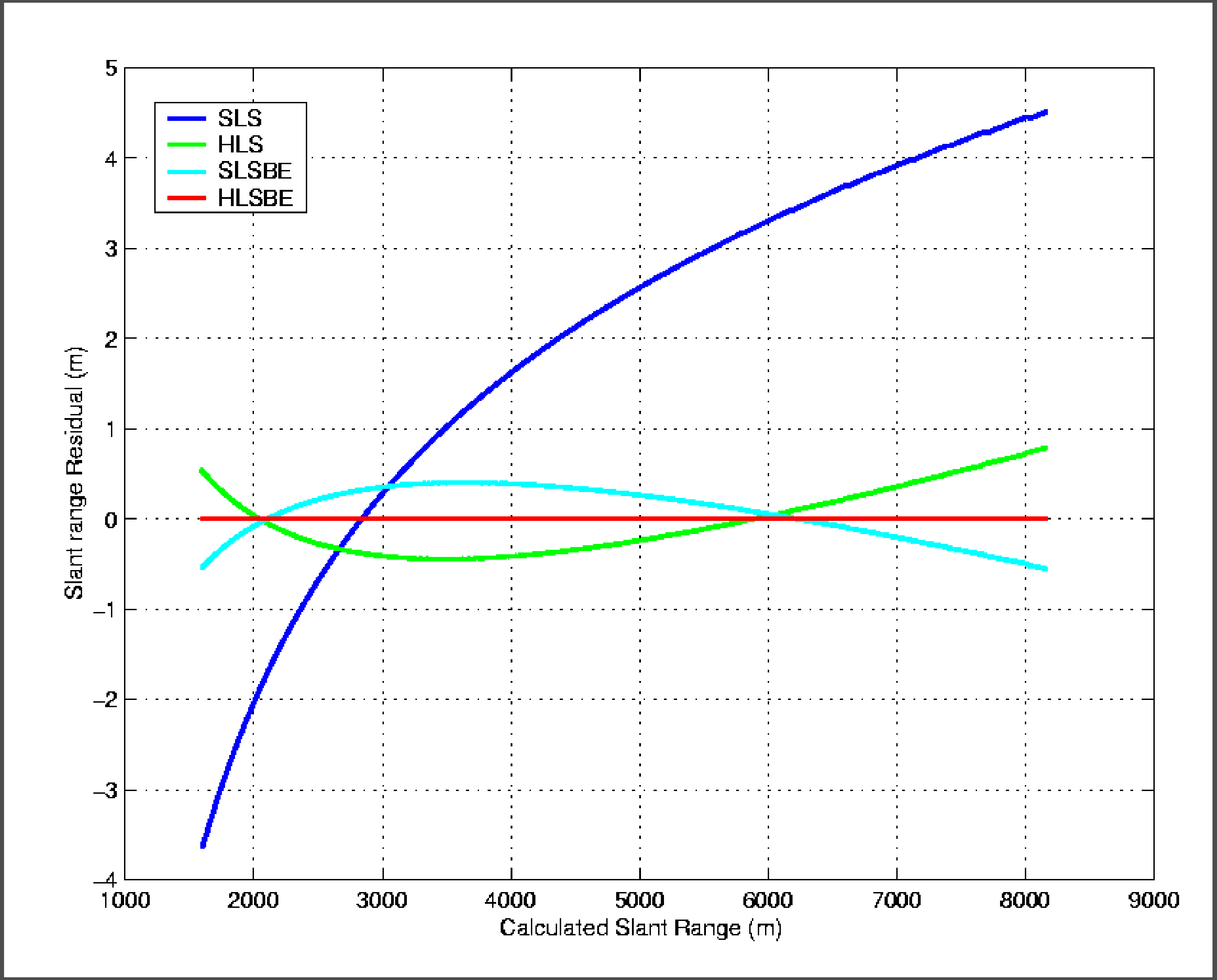
SBE

New Developments: Models

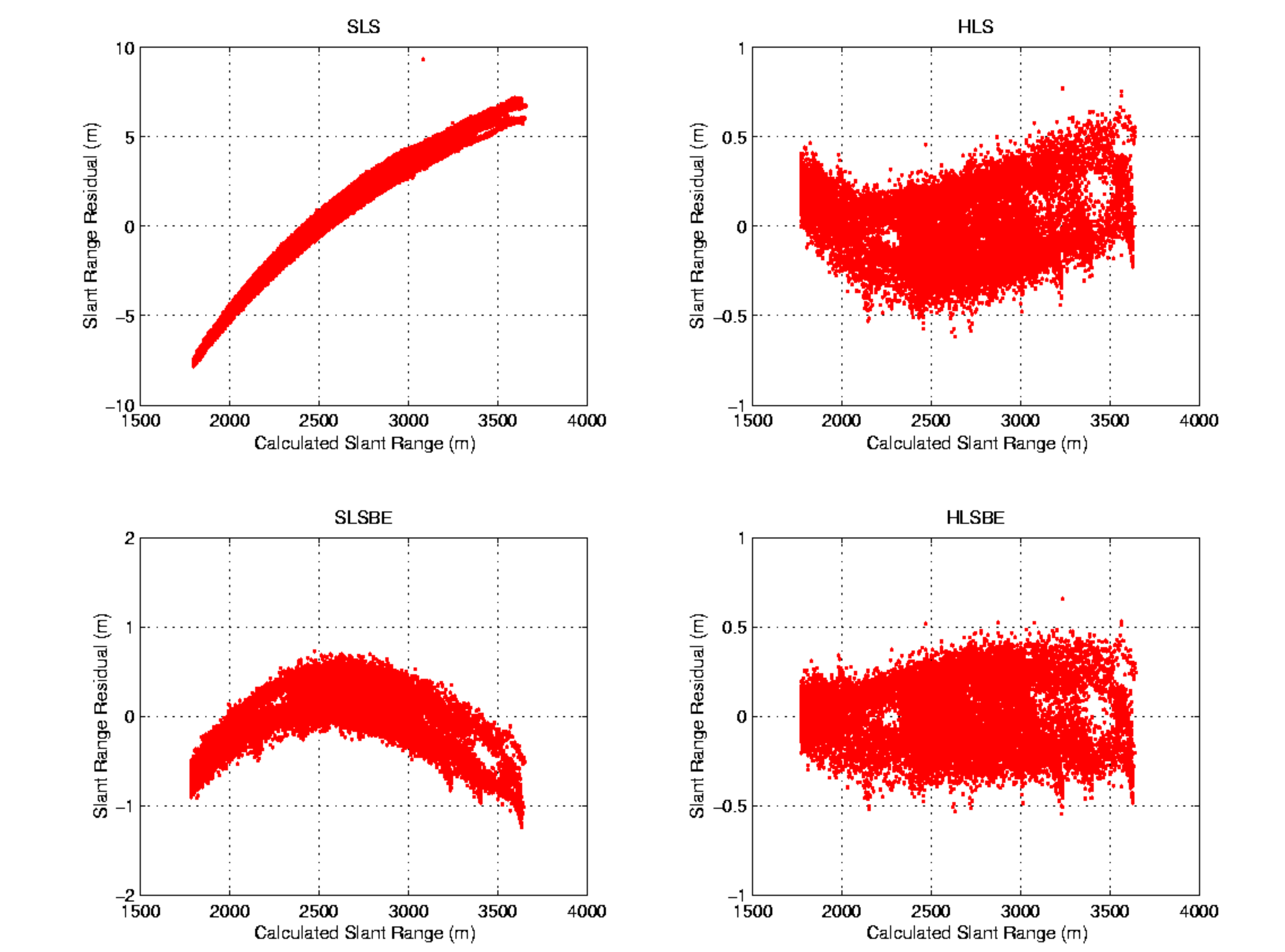


MODEL	NORTH	EAST	ORTHO HT	TB	CB
SLS	0.00	0.00	-1600.00	-	-
HLS	0.00	0.00	-1600.00	0.0	-
SLSBE	0.00	0.00	-1600.00	-	0.00
HLSBE	0.00	0.00	-1600.00	0.0	0.00
SLS	0.00	0.00	-1606.78	-	-
HLS	0.00	0.00	-1597.09	4.1	-
SLSBE	0.00	0.00	-1602.98	-	1.14
HLSBE	0.00	0.00	-1600.00	2.0	0.63

New Developments: Models



New Developments: Models



CASE STUDY

AHRP

AUTEC

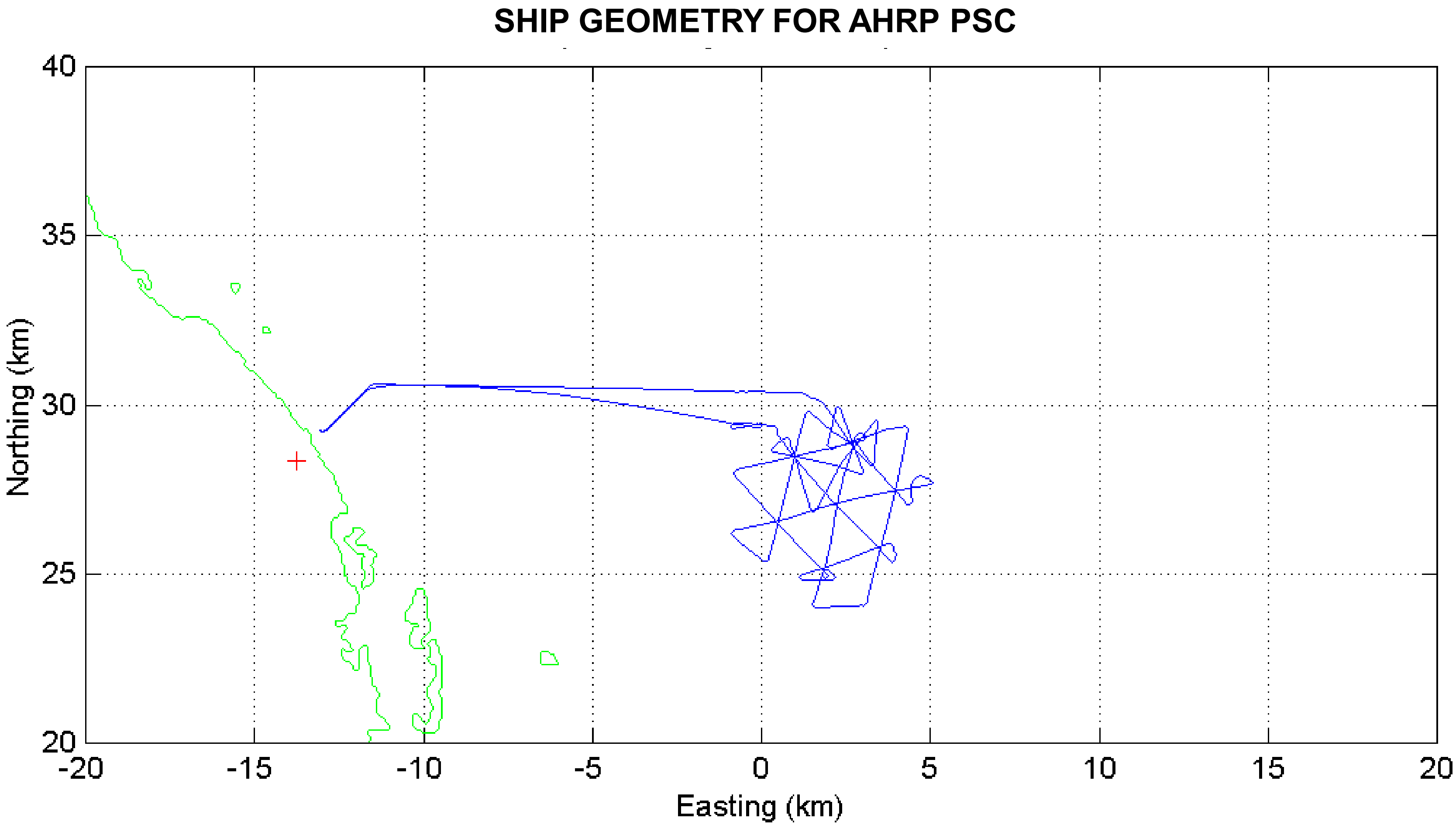

Bahamas
UNITED STATES
Grand Bahama
West End
Freeport
Little Abaco
Green Turtle Cay
Marsh Harbour
Abaco
26° N
Alice Town
Bimini Islands
Berry Is.
Spanish Wells
Harbour I.
Dunmore Town
Governor's Harbour
Nassau
Nicholl's Town
New Providence
Eleuthera
Rock Sound
Straits of Florida
Fresh Creek
Arthur's Town
Cat I.
New Bight
Andros
Exuma Cays
Cockburn Town
San Salvador
Conception I.
Rum Cay
Port Nelson
Great Exuma
George Town
Tropic of Cancer
Great Bahama Bank
Long I.
Deadman's Cay
Samana Cay
Crooked Island Passage
Crooked I.
Colonel Hill
Old Bahama Channel
Mayaguana
Duncan Town
Acklins I.
Abraham's Bay
Ragged I.
Caicos Passage
22° N
Turks & Caicos Is. (U.K.)
CUBA
Little Inagua
Caribbean Sea
Great Inagua
Lake Rosa
Matthew Town
76° W
72° W
ATLANTIC OCEAN
0 50 Miles
0 50 Kilometers
© MAPQUEST.COM

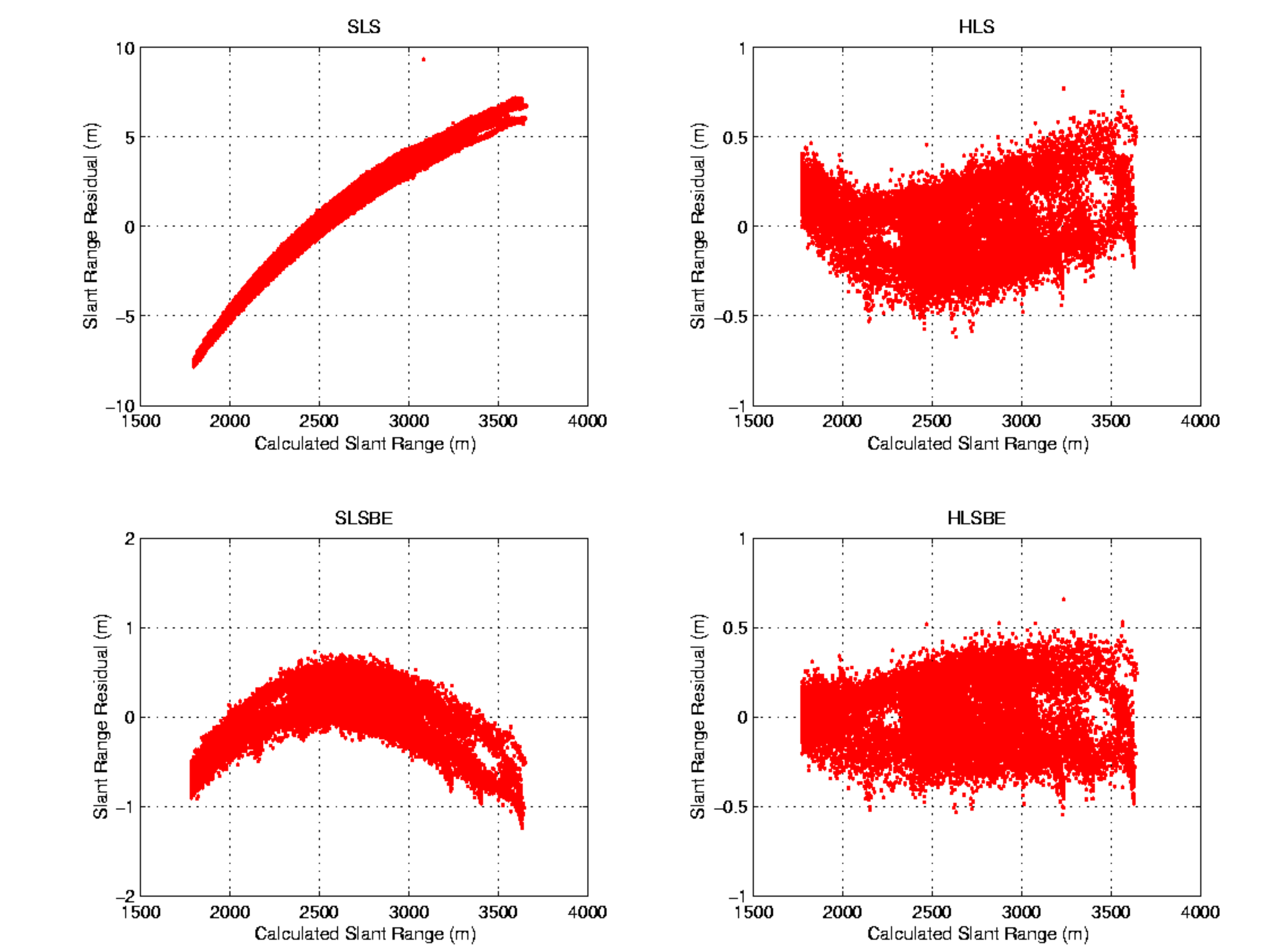
TOTO

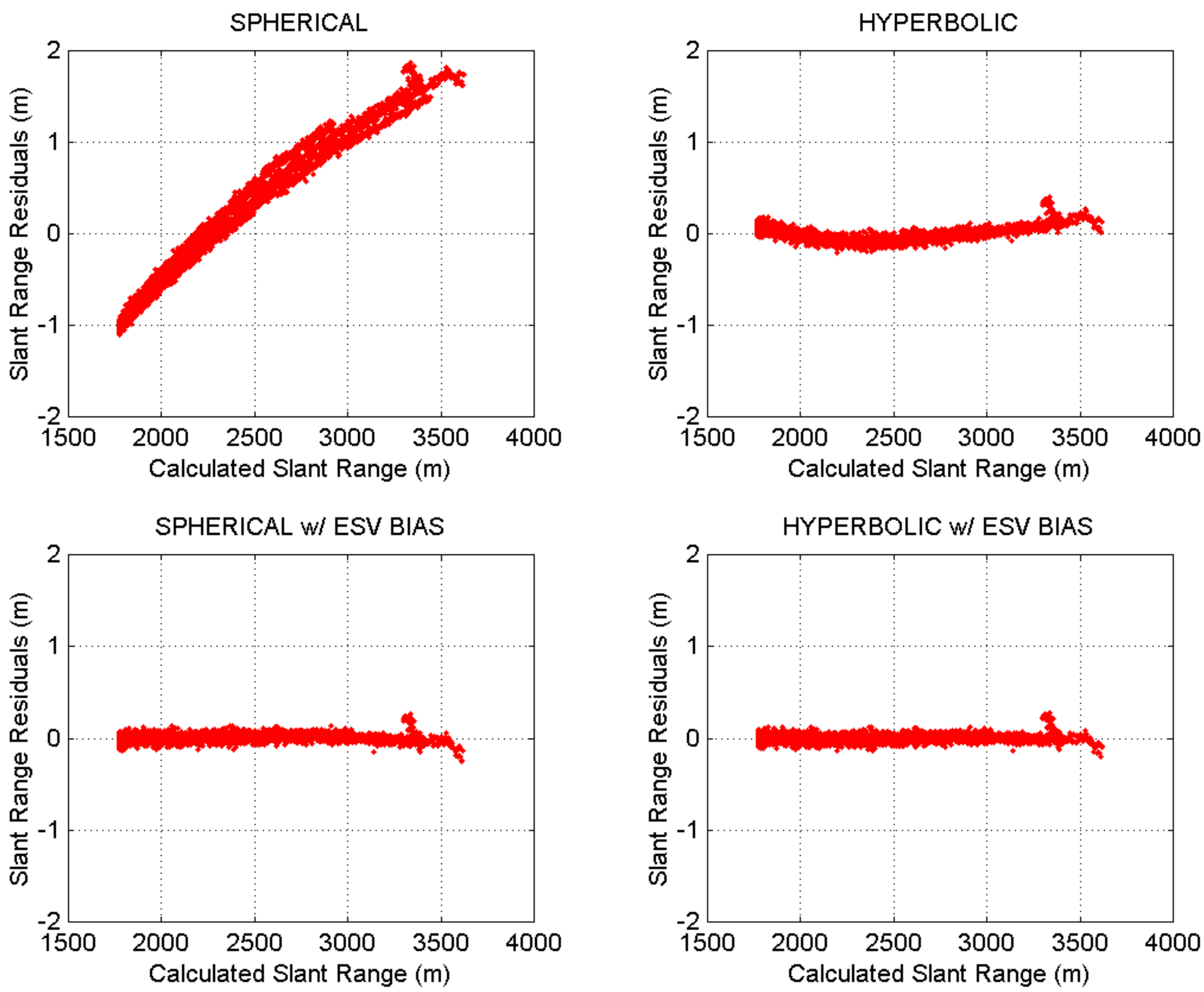

U.S. NAVY

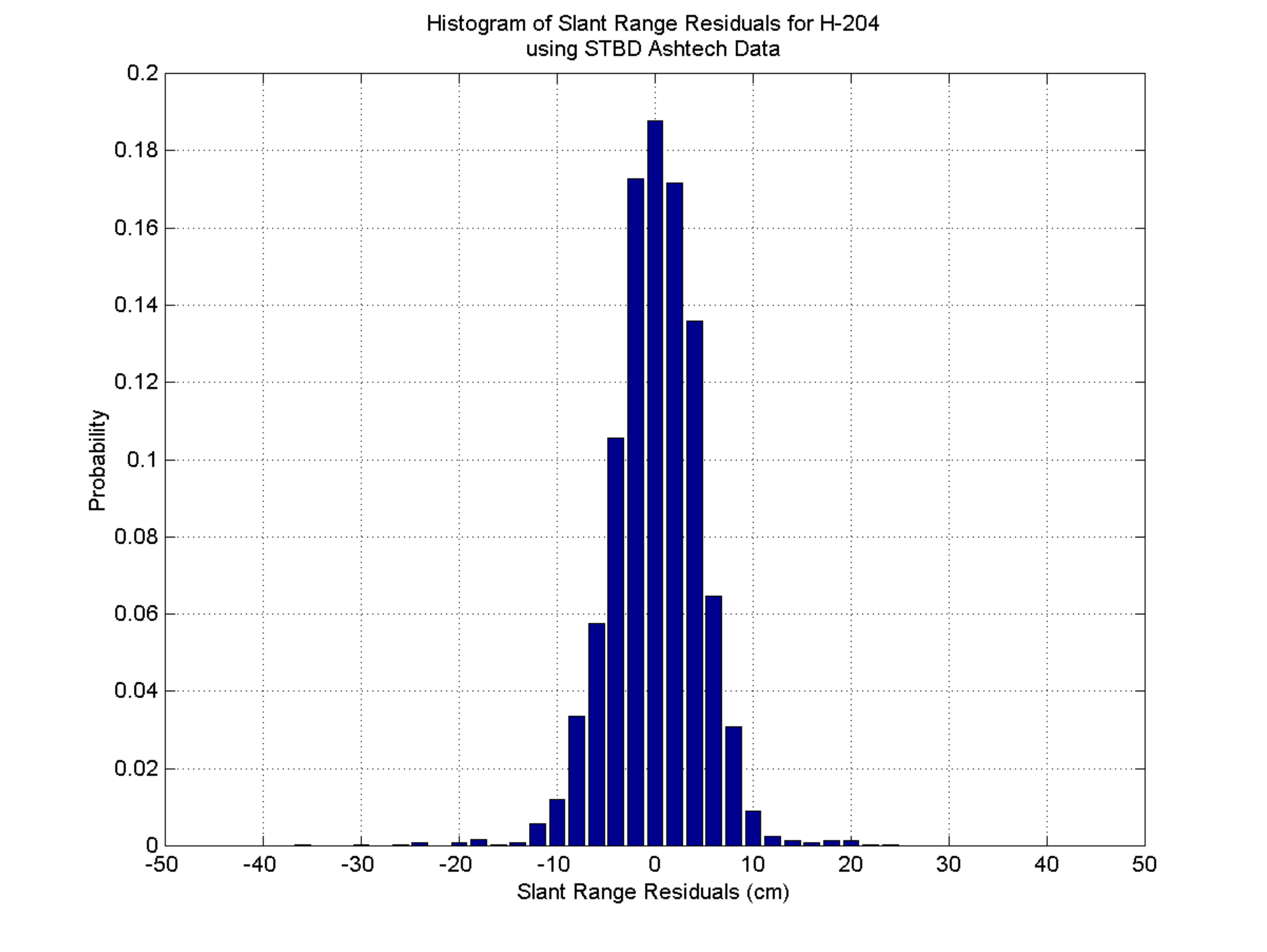

U.S. NAVY

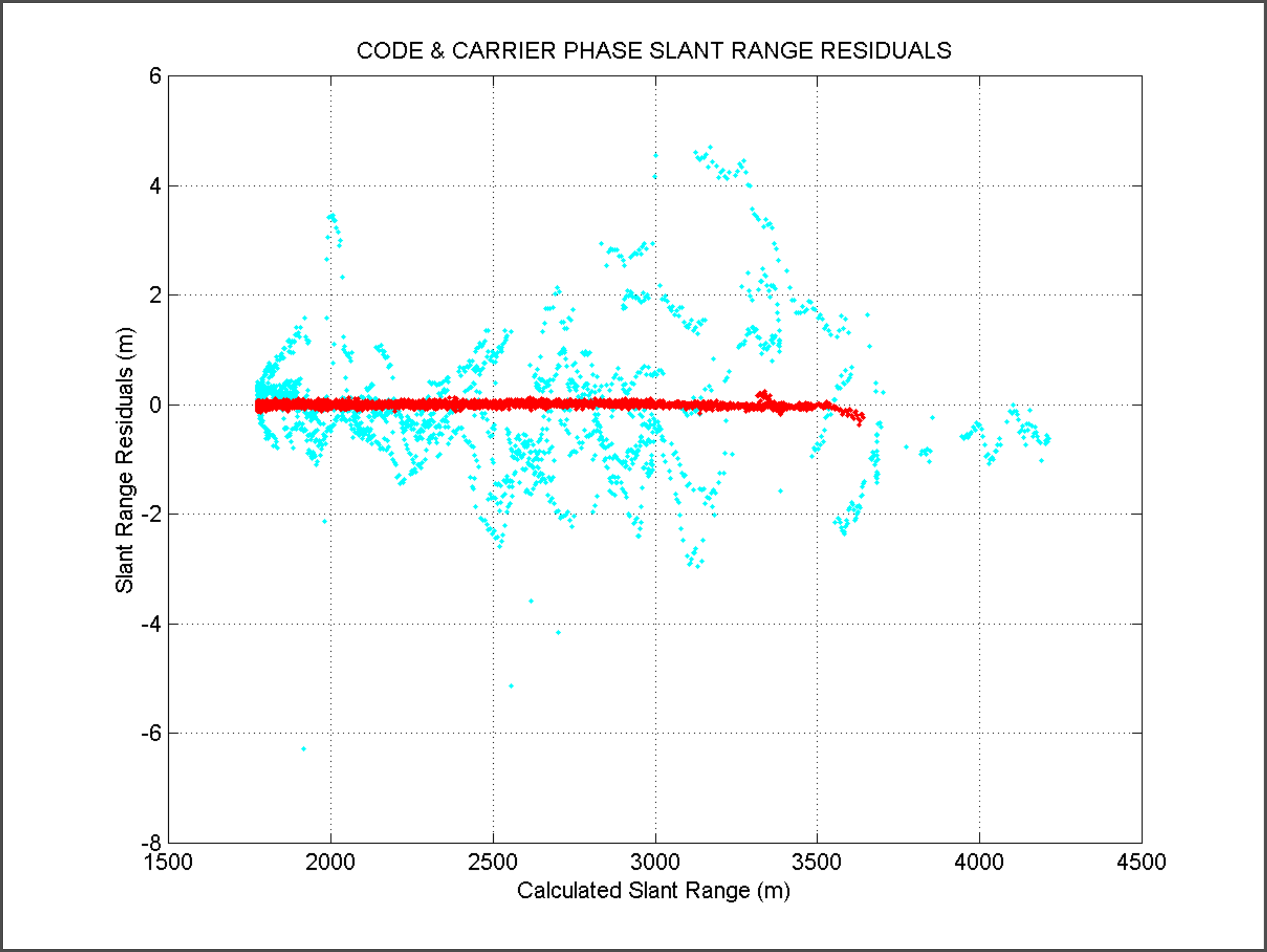
U.S. NAVY


SHIP GEOMETRY FOR AHRP PSC
Northing (km)
40
35
30
25
20
-20
-15
-10
-5
0
5
10
15
20
Easting (km)


SLS
HLS
SLSBE
HLSBE
Slant Range Residual (m)
Calculated Slant Range (m)
1500
2000
2500
3000
3500
4000
10
5
0
−5
−10
1
0.5
0
−0.5
−1
2
1
0
−1
−2


SPHERICAL
HYPERBOLIC
SPHERICAL w/ ESV BIAS
HYPERBOLIC w/ ESV BIAS
Slant Range Residuals (m)
Calculated Slant Range (m)
2
1
0
-1
-2
1500
2000
2500
3000
3500
4000


Histogram of Slant Range Residuals for H-204
using STBD Ashtech Data
Probability
Slant Range Residuals (cm)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-50
-40
-30
-20
-10
0
10
20
30
40
50


CODE & CARRIER PHASE SLANT RANGE RESIDUALS
Slant Range Residuals (m)
Calculated Slant Range (m)
6
4
2
0
-2
-4
-6
-8
1500
2000
2500
3000
3500
4000
4500

GABBIES Deployment

Navigation Beacons

CONCLUSIONS

- Low power acoustic seafloor instruments have been developed and refined through 3 generations for US Navy
- Models and algorithms to achieve < 0.1 cm geodetic position (horizontal) have been validated
- Surface system can be autonomous vessels transmitting GPS synchronized acoustic signals
- **Long term seafloor geodetic benchmarks are technically and economically feasible**

Future Plans