



# 4 DOWN, 50 TO GO; AN UPDATE ON HARBOR SURVEYS IN THE UNITED STATES

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ILA 36 – Orlando Florida

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# What Requirements Must be Met?

## ◆ Requirements

- ◆ Accuracy, availability, integrity, continuity

## ◆ Accuracy Requirements

- ◆ Aviation: NPA – RNP 0.3 (309 meters)
- ◆ Maritime: HEA (8-20 meters)

## ◆ Limitations

- ◆ Spatial and temporal variations in TOA observed by the receiver and presented to the position solution algorithm



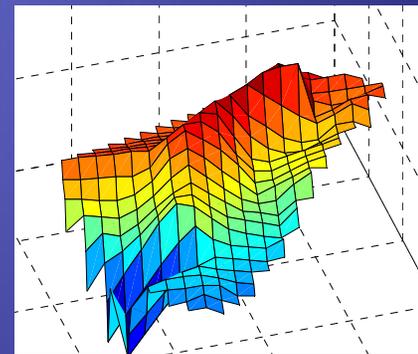
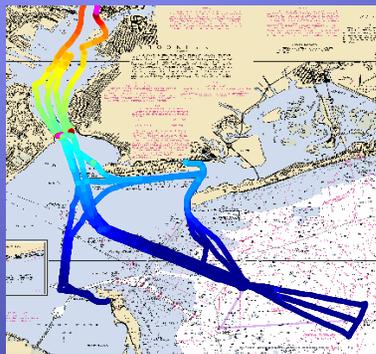
# Maritime Solution: HEA Nav Concept

## ◆ ASF corrected TOAs

- ◆ To remove spatial component:

- ◆ Use published grid, interpolate between grid points

- ◆ Issues include grid density, regions of interest, and grid creation



- ◆ To remove temporal component:

- ◆ Local monitor receiver, broadcast offsets over LDC

- ◆ Issues include correlation distance, monitor averaging, multiple monitor interpolation



# Goals for Today

## ◆ Spatial ASF Grids

- ◆ Harbor Survey Methodology
- ◆ Converting to a grid
- ◆ Required grid density
  - ◆ Performance examples

## ◆ Temporal Corrections

- ◆ LDC architecture for live broadcast of differential corrections

## ◆ Prototype eLoran Receiver

- ◆ Sample navigation performance



# Harbor Survey Methodology

- ◆ **Identify the HEA area and generate sail plans that will cover all of the areas of interest**

- ◆ typically a 200m spacing

- ◆ Tracks must be planned on inside and outside edges of channels

- ◆ in general the area of interest needs to be over-bounded.

- ◆ **Conduct field test**

- ◆ Static monitor somewhere in the harbor area (harbor monitor)

- ◆ Perform data collection mapping throughout the harbor; measure ASFs and GPS position



# Harbor Survey Methodology

- ◆ **Convert the measured ASFs to relative ASFs by subtracting the reference site ASF for the corresponding times of the vessel ASF measurements.**
  - ◆ This eliminates any temporal variations (due to daily, seasonal, weather, or system timing effects) from the measurements.
- ◆ **Create spatial ASF grid from tracks of relative ASFs**
- ◆ **Procedure developed and refined over a series of harbor surveys**
  - ◆ New London
  - ◆ New York
  - ◆ Norfolk
  - ◆ Boston



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# NY Harbor Phase I

Continuous vessel tracks in upper harbor

Static locations in upper harbor

Vessel

Van on shore



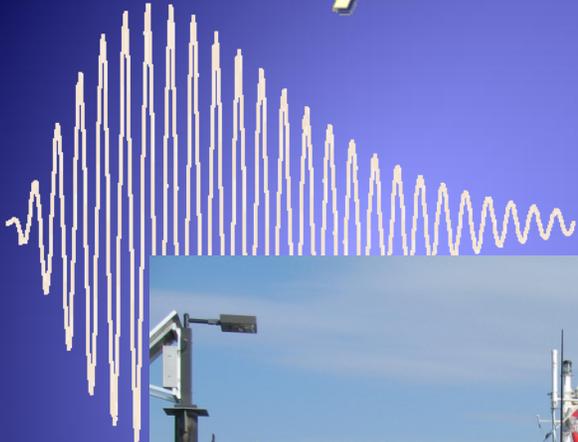
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# Survey Vessel, Launch#5



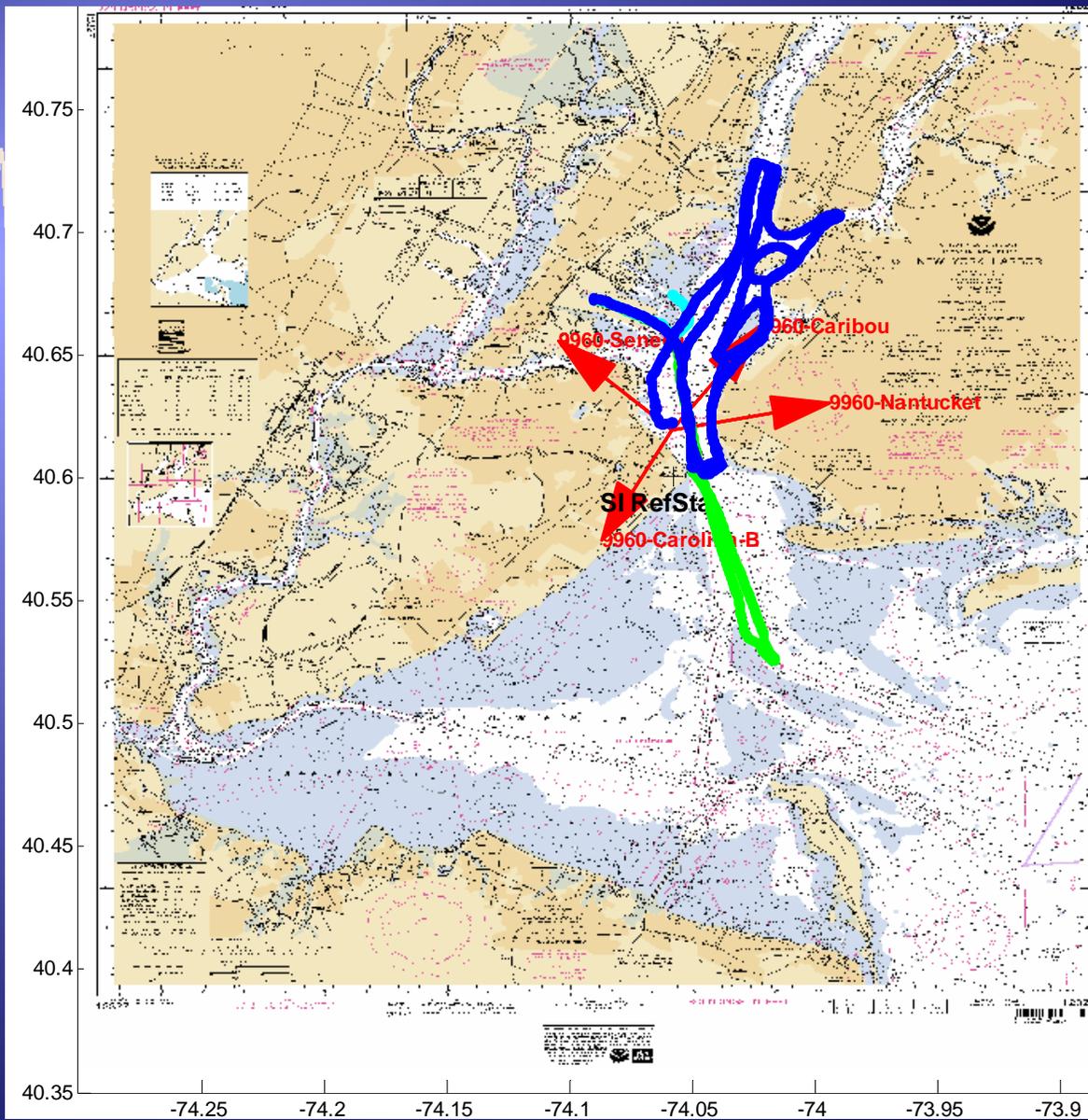
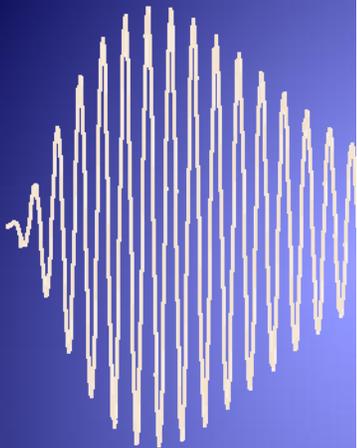
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# NY Harbor PH1 Coverage



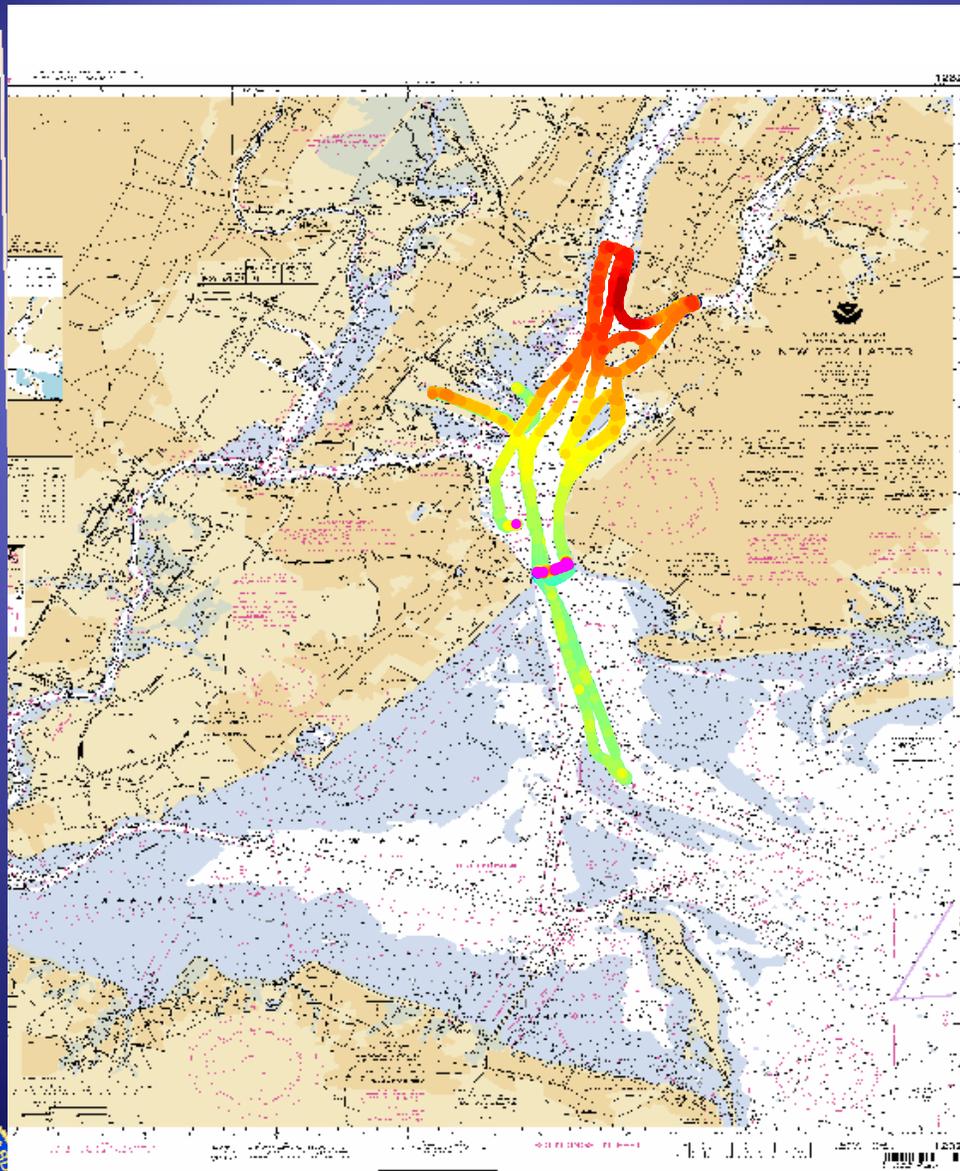
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# Nantucket Relative ASFs



- ASF<=-1
- -1<ASF<=-0.95
- -0.95<ASF<=-0.9
- -0.9<ASF<=-0.85
- -0.85<ASF<=-0.8
- -0.8<ASF<=-0.75
- -0.75<ASF<=-0.7
- -0.7<ASF<=-0.65
- -0.65<ASF<=-0.6
- -0.6<ASF<=-0.55
- -0.55<ASF<=-0.5
- -0.5<ASF<=-0.45
- -0.45<ASF<=-0.4
- -0.4<ASF<=-0.35
- -0.35<ASF<=-0.3
- -0.3<ASF<=-0.25
- -0.25<ASF<=-0.2
- -0.2<ASF<=-0.15
- -0.15<ASF<=-0.1
- -0.1<ASF<=-0.05
- -0.05<ASF<=-1.1102e-016
- -1.1102e-016<ASF<=0.05
- 0.05<ASF<=0.1
- 0.1<ASF<=0.15
- 0.15<ASF<=0.2
- 0.2<ASF<=0.25
- 0.25<ASF<=0.3
- 0.3<ASF<=0.35
- 0.35<ASF<=0.4
- 0.4<ASF<=0.45
- 0.45<ASF<=0.5
- 0.5<ASF<=0.55
- 0.55<ASF<=0.6
- 0.6<ASF<=0.65
- 0.7>ASF



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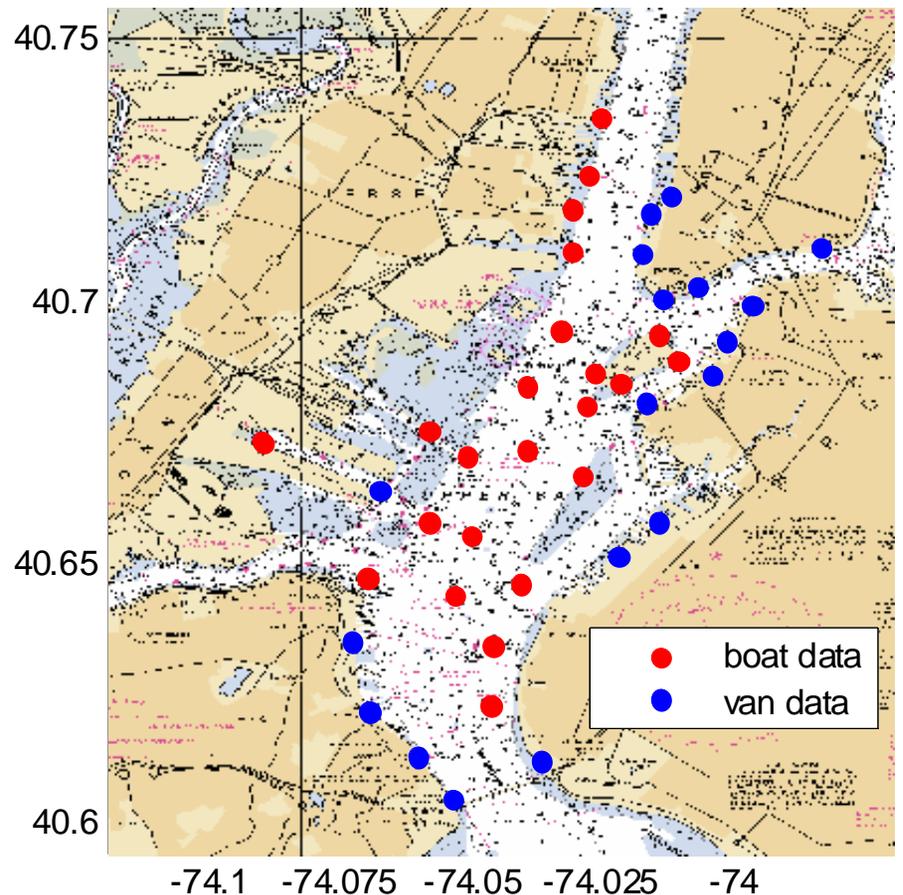


# Static Points

◆ Vessel collected data at 25 static locations in the harbor

◆ Held station next to buoy, pier, etc.

◆ Van collected data at 19 static locations around the harbor



# NY Harbor Phase II

Different Vessel

Continuous Track in lower harbor

Repeat Upper harbor

12 static locations



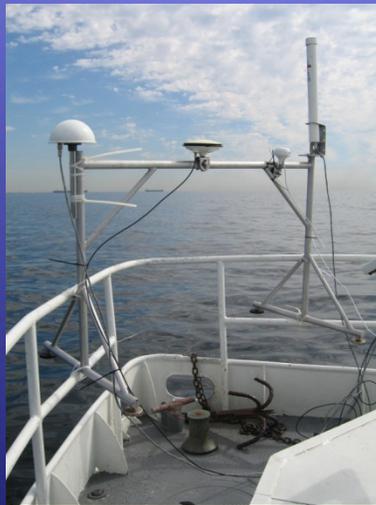
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# Survey Vessel, Jeanne II



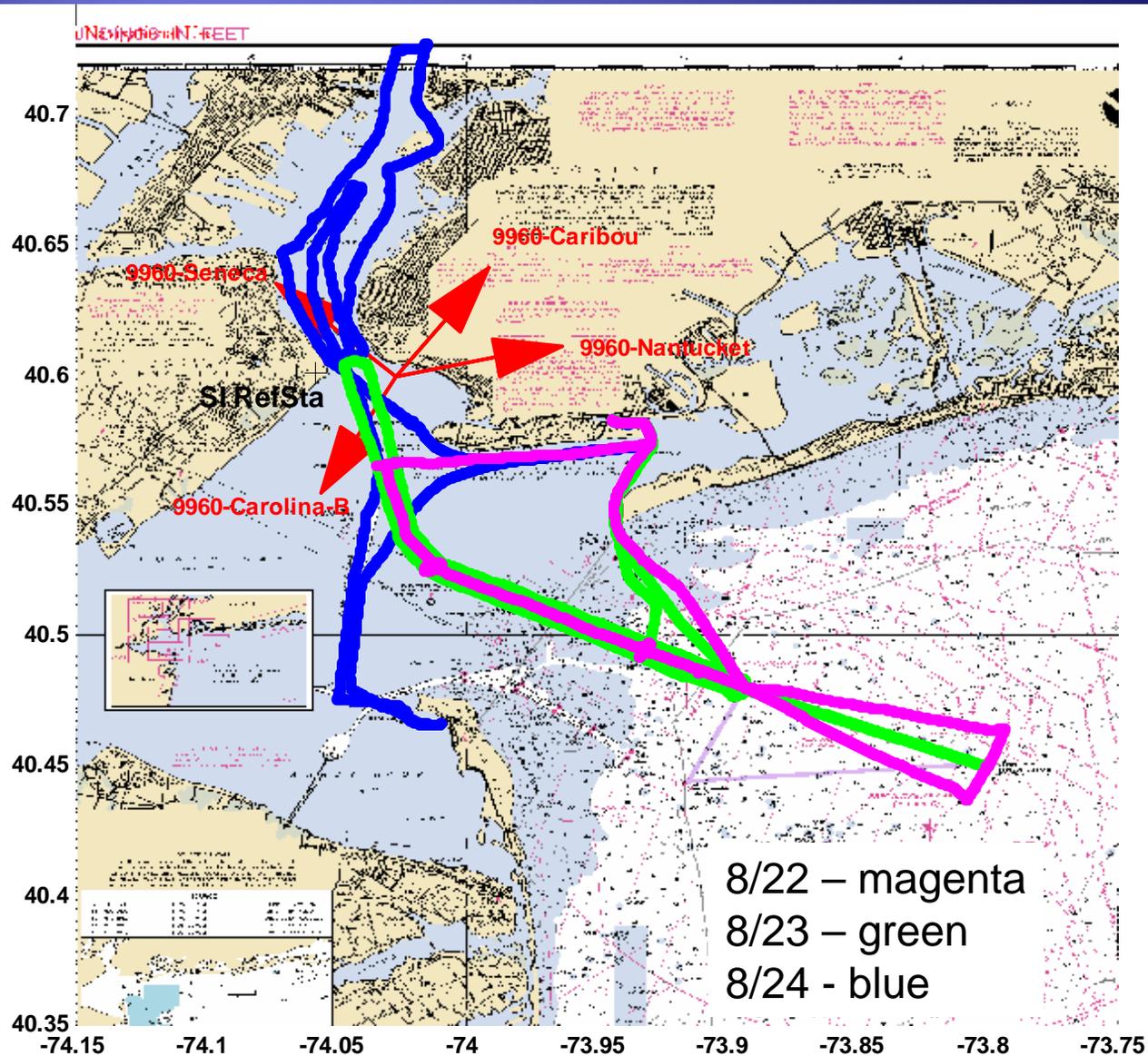
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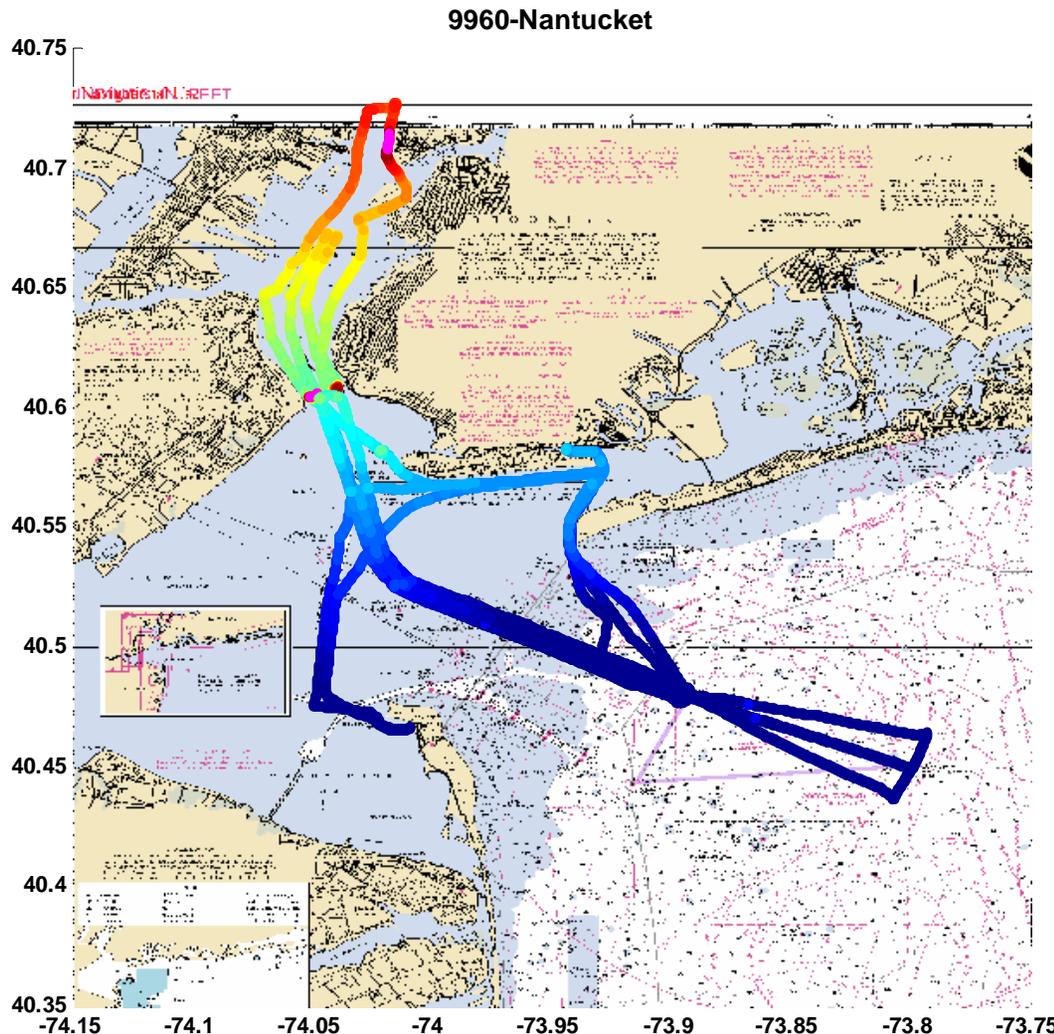
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# NY Harbor Phase II Coverage



# Nantucket Relative ASFs



- ASF <= -1
- -1 < ASF <= -0.95
- -0.95 < ASF <= -0.9
- -0.9 < ASF <= -0.85
- -0.85 < ASF <= -0.8
- -0.8 < ASF <= -0.75
- -0.75 < ASF <= -0.7
- -0.7 < ASF <= -0.65
- -0.65 < ASF <= -0.6
- -0.6 < ASF <= -0.55
- -0.55 < ASF <= -0.5
- -0.5 < ASF <= -0.45
- -0.45 < ASF <= -0.4
- -0.4 < ASF <= -0.35
- -0.35 < ASF <= -0.3
- -0.3 < ASF <= -0.25
- -0.25 < ASF <= -0.2
- -0.2 < ASF <= -0.15
- -0.15 < ASF <= -0.1
- -0.1 < ASF <= -0.05
- -0.05 < ASF <= -1.1102e-016
- -1.1102e-016 < ASF <= 0.05
- 0.05 < ASF <= 0.1
- 0.1 < ASF <= 0.15
- 0.15 < ASF <= 0.2
- 0.2 < ASF <= 0.25
- 0.25 < ASF <= 0.3
- 0.3 < ASF <= 0.35
- 0.35 < ASF <= 0.4
- 0.4 < ASF <= 0.45
- 0.45 < ASF <= 0.5
- 0.5 < ASF <= 0.55
- 0.55 < ASF <= 0.6
- 0.6 < ASF <= 0.65
- 0.7 > ASF



# Thames River

## USCG AUX Vessel Myst

Oct 2006

Nov 2006

## Test Van

Mar 2006

## Other vessels

Mar, Apr 2006

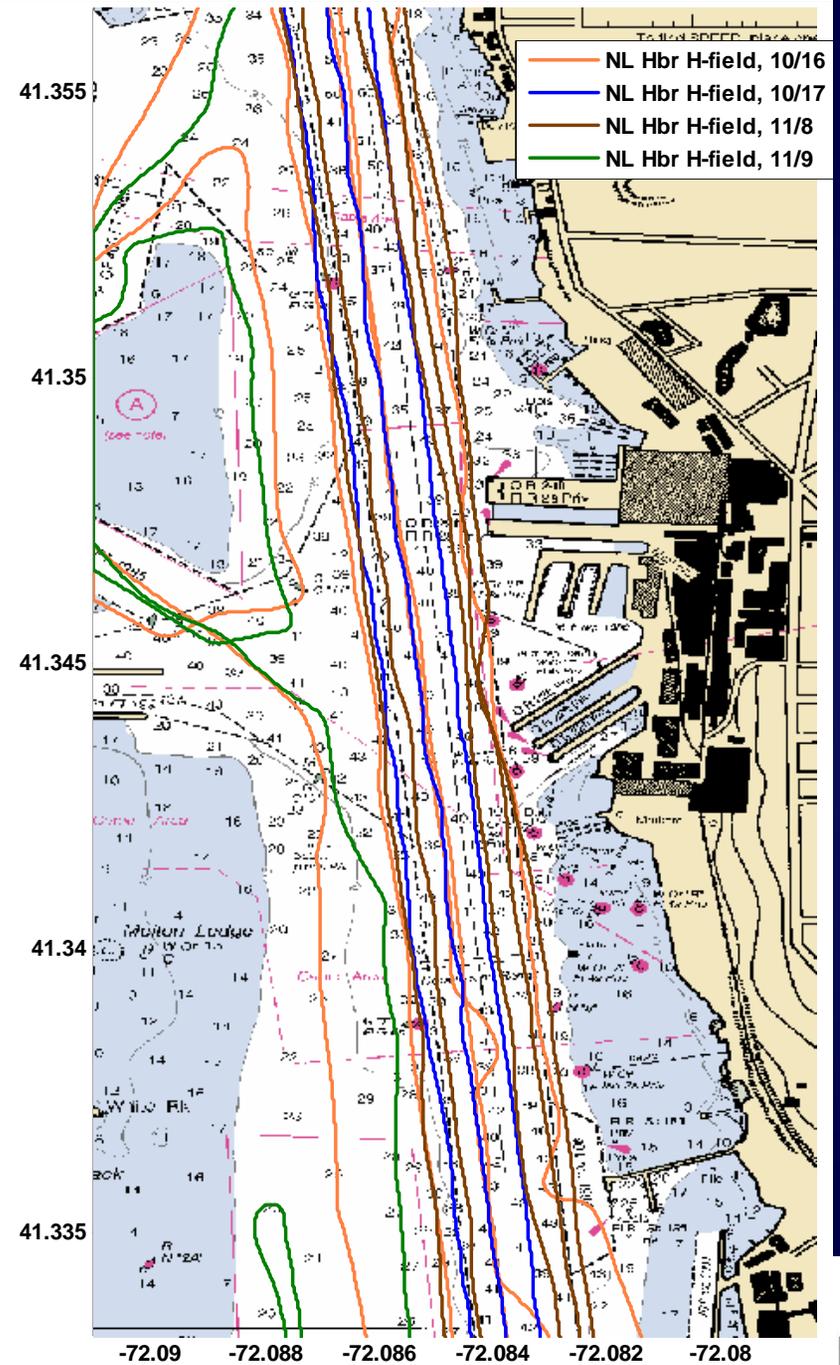
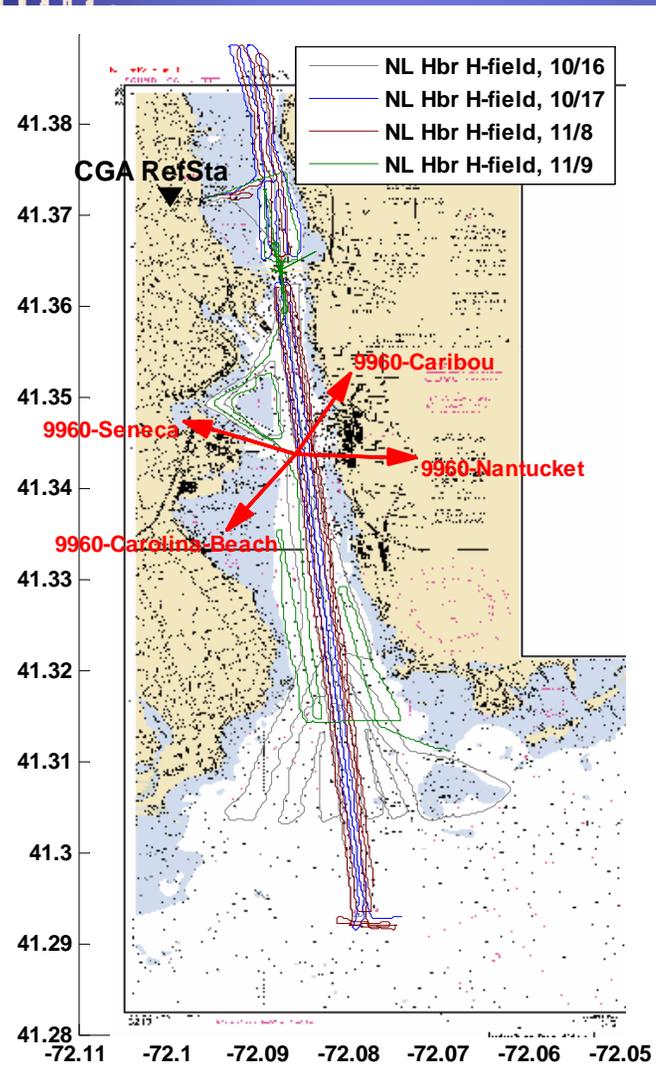


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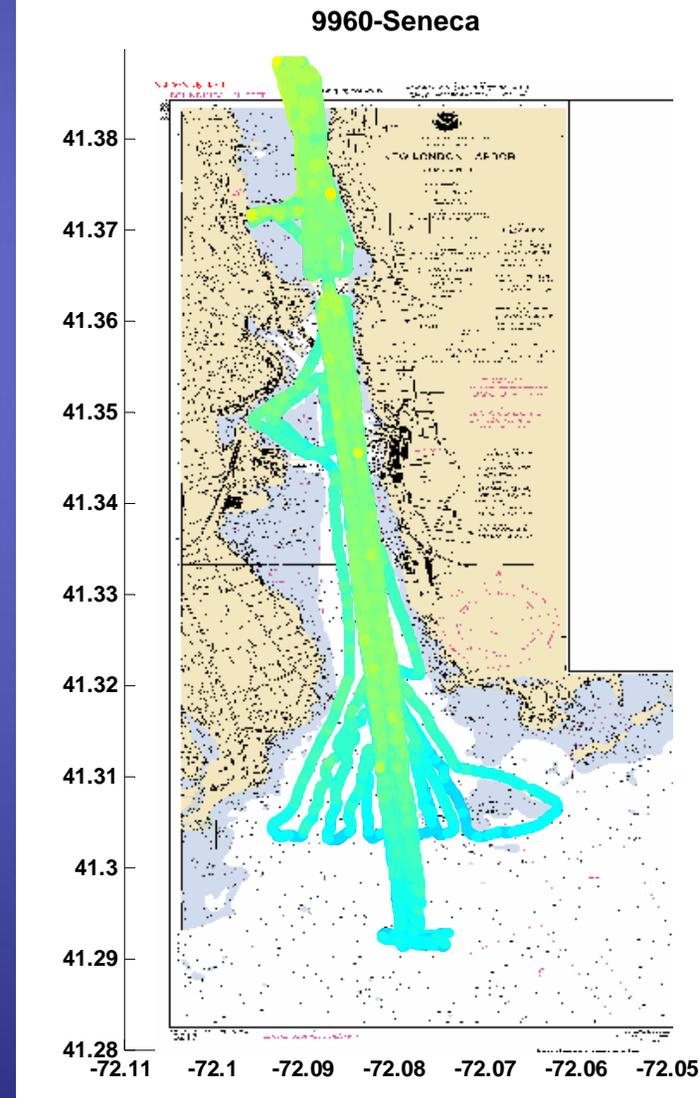
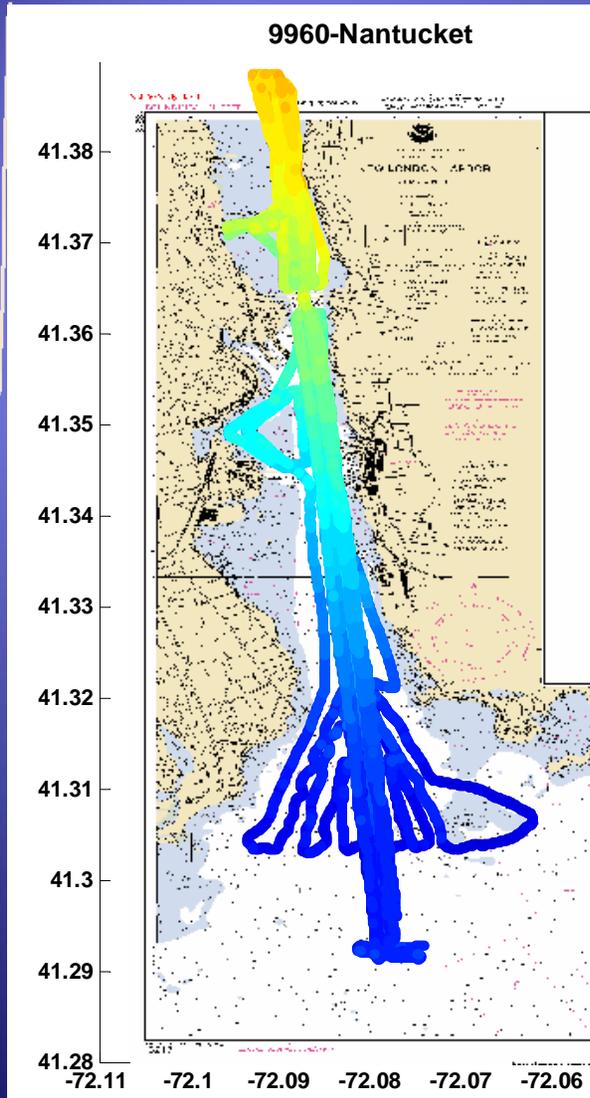
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# Locations/Tracks



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# Thames Relative ASF Data



- -0.95<ASF<=-0.9
- -0.9<ASF<=-0.85
- -0.85<ASF<=-0.8
- -0.8<ASF<=-0.75
- -0.75<ASF<=-0.7
- -0.7<ASF<=-0.65
- -0.65<ASF<=-0.6
- -0.6<ASF<=-0.55
- -0.55<ASF<=-0.5
- -0.5<ASF<=-0.45
- -0.45<ASF<=-0.4
- -0.4<ASF<=-0.35
- -0.35<ASF<=-0.3
- -0.3<ASF<=-0.25
- -0.25<ASF<=-0.2
- -0.2<ASF<=-0.15
- -0.15<ASF<=-0.1
- -0.1<ASF<=-0.05
- -0.05<ASF<=0
- 0<ASF<=0.05
- 0.05<ASF<=0.1
- 0.1<ASF<=0.15
- 0.15<ASF<=0.2
- 0.2<ASF<=0.25
- 0.25<ASF<=0.3
- 0.3<ASF<=0.35
- 0.35<ASF<=0.4
- 0.4<ASF<=0.45
- 0.45<ASF<=0.5
- 0.5<ASF<=0.55
- 0.55<ASF<=0.6
- 0.6<ASF<=0.65
- 0.65<ASF<=0.7
- 0.7<ASF<=0.75
- 0.75<ASF<=0.8
- 0.8<ASF<=0.85
- 0.85<ASF<=0.9
- 0.9<ASF<=0.95
- 1>ASF



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# Norfolk

Chesapeake Bay approach channel into Norfolk Harbor



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# Survey Vessel, Halcyon Lace



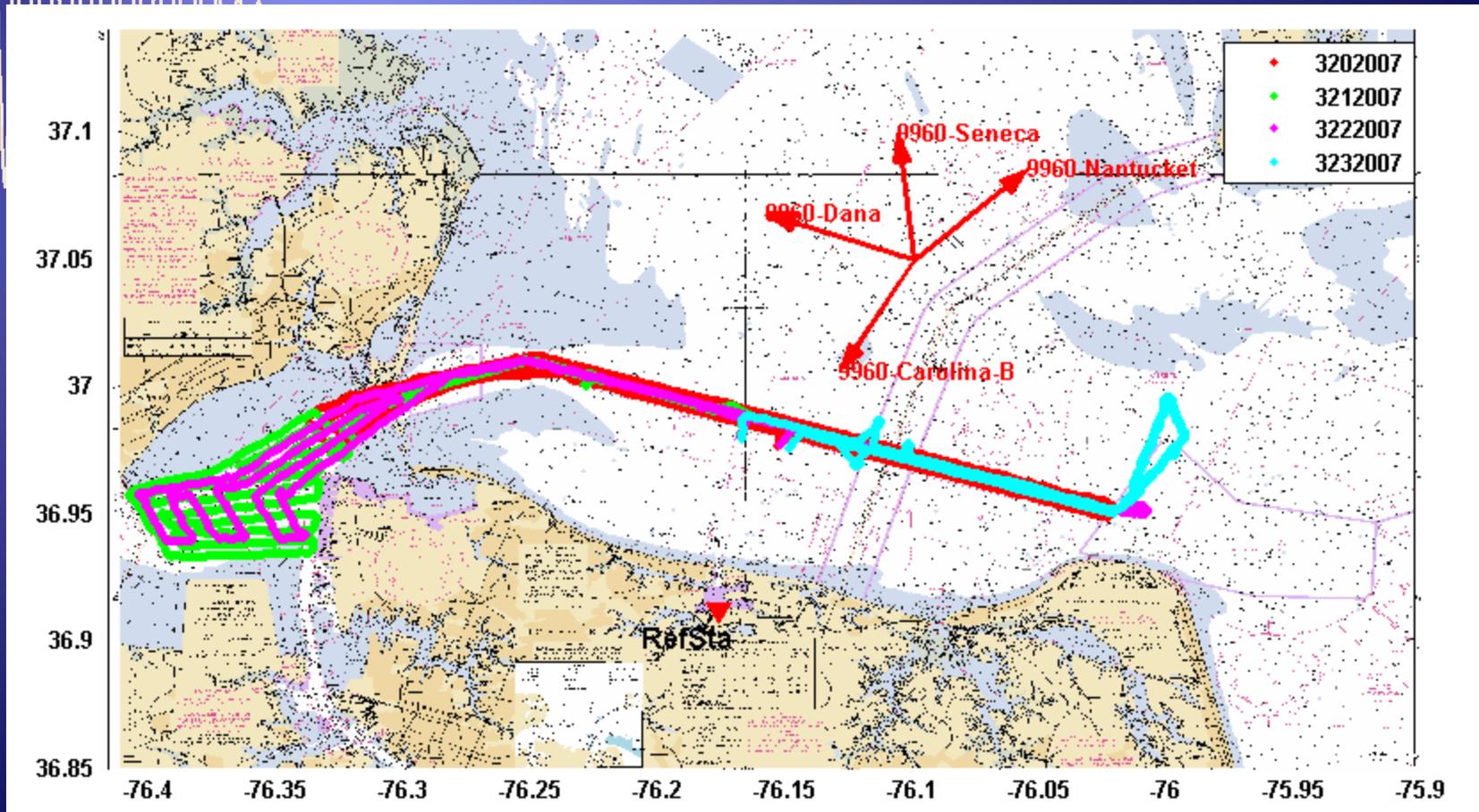
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# Norfolk Harbor Coverage



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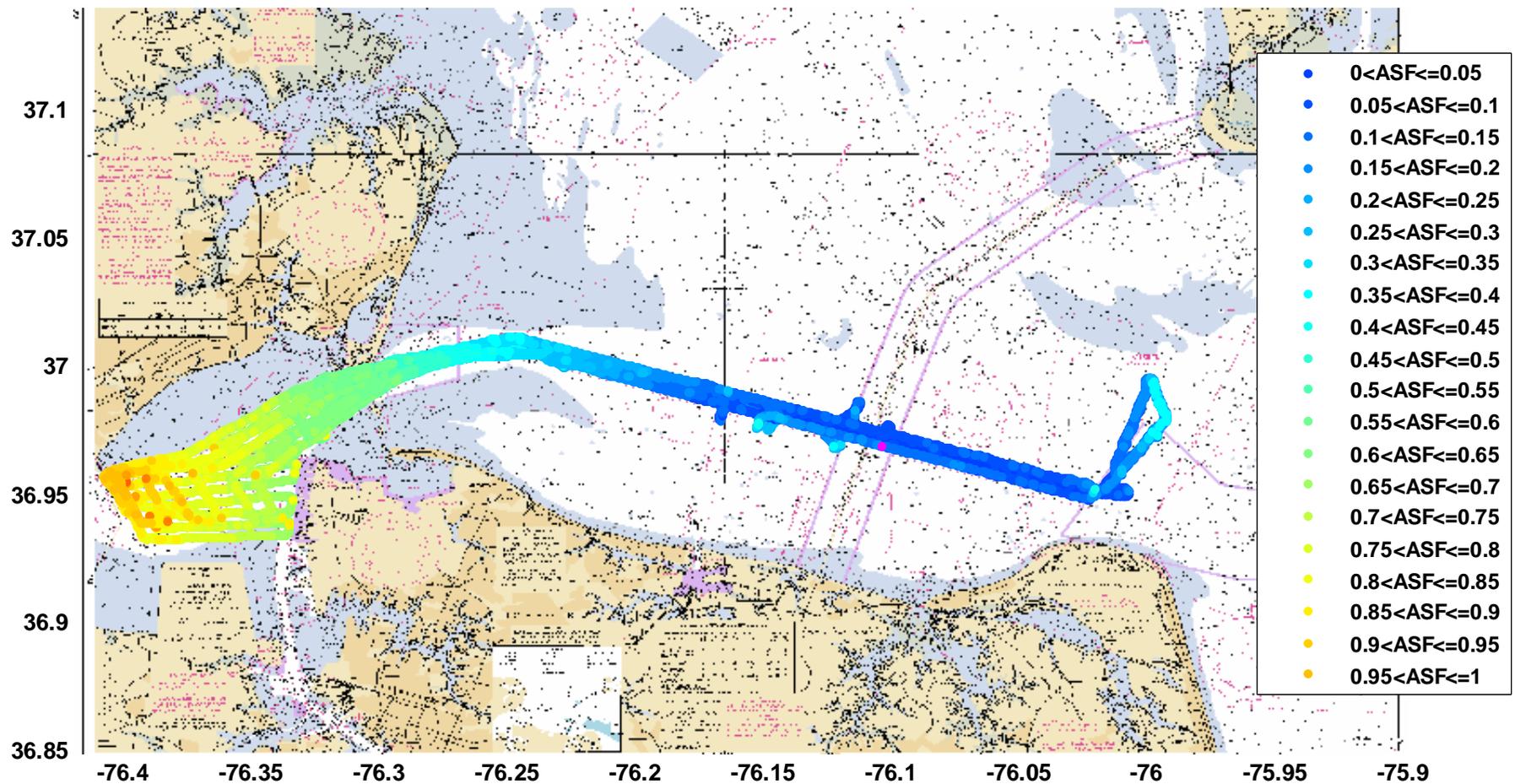
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# Seneca Relative ASFs

9960-Seneca



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# Boston Harbor

Continuous tracks inner harbor, main channels, and entrance approach area



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# Survey Vessel, Three J's



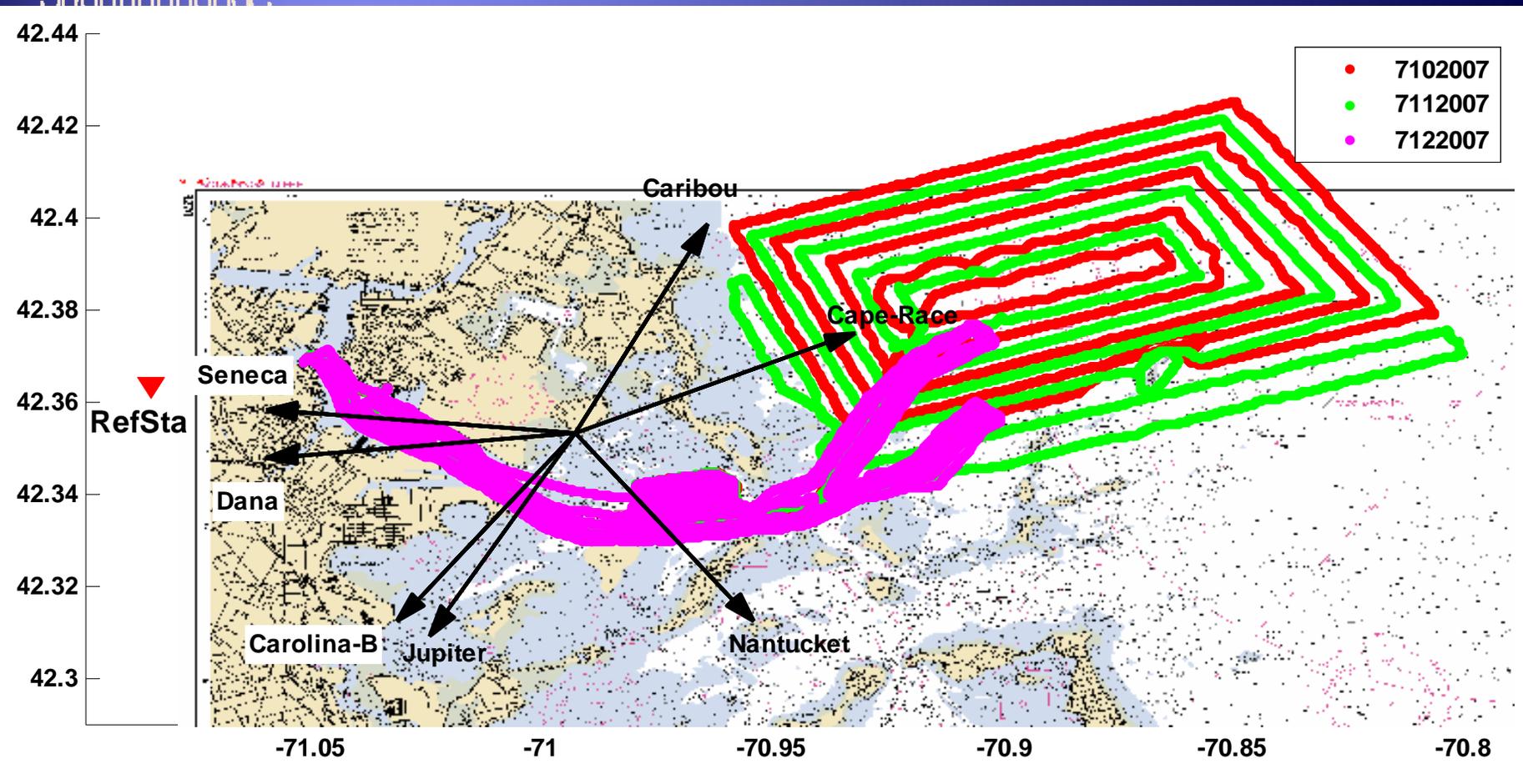
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# Boston Coverage Area



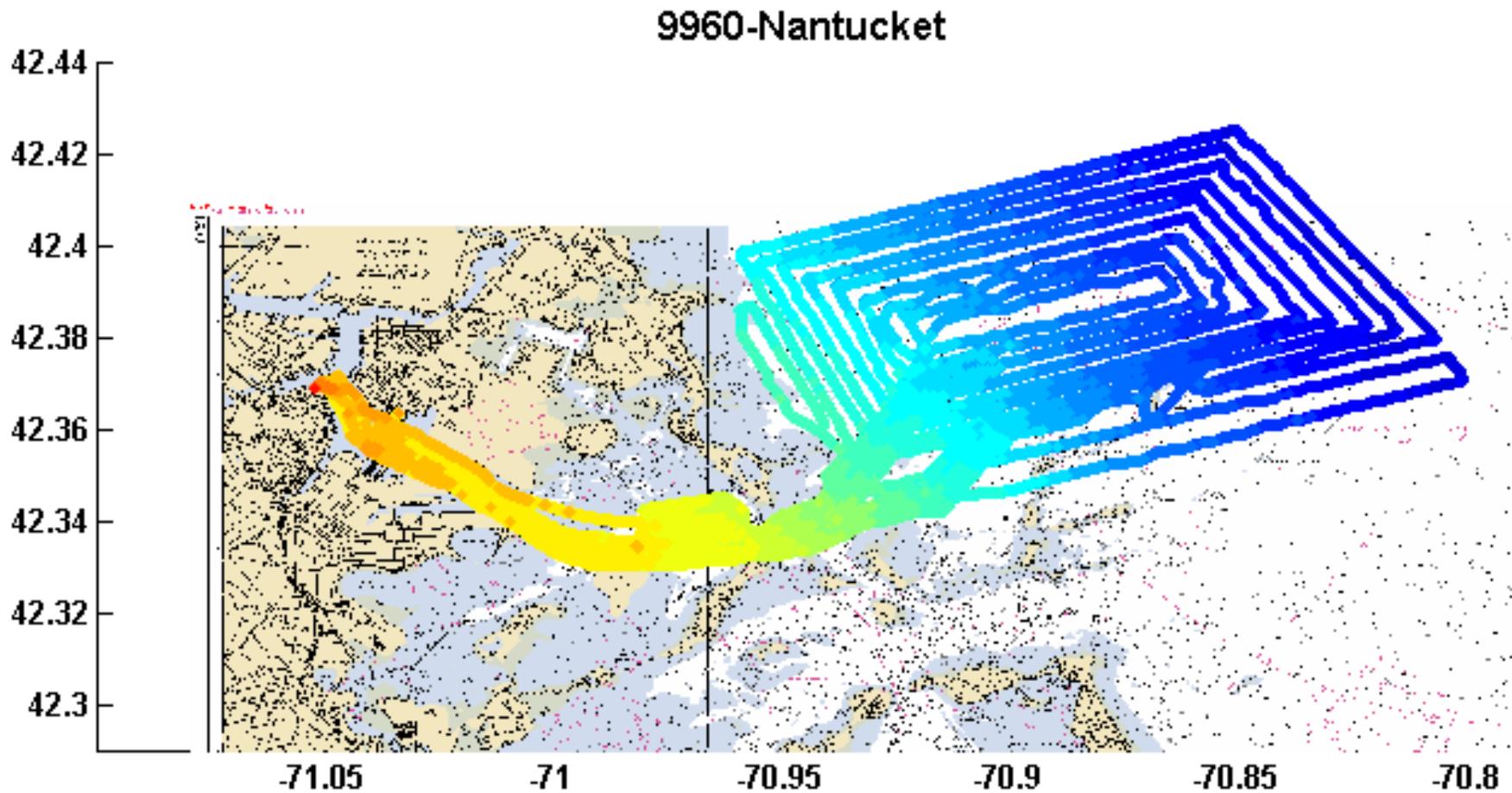
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# Nantucket Relative ASFs



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# Data Processing

- ◆ ASFs/TOAs processed to remove receiver filtering and velocity vector toward towers (and time lag)
- ◆ Precise track computed using L1/L2 GPS data post-processed with GrafNav s/w using CORS reference stations
- ◆ ASFs recalculated using precise track position and unfiltered TOAs
- ◆ Relative ASFs calculated  
( $ASF_{\text{boat}} - ASF_{\text{ref}}$ )



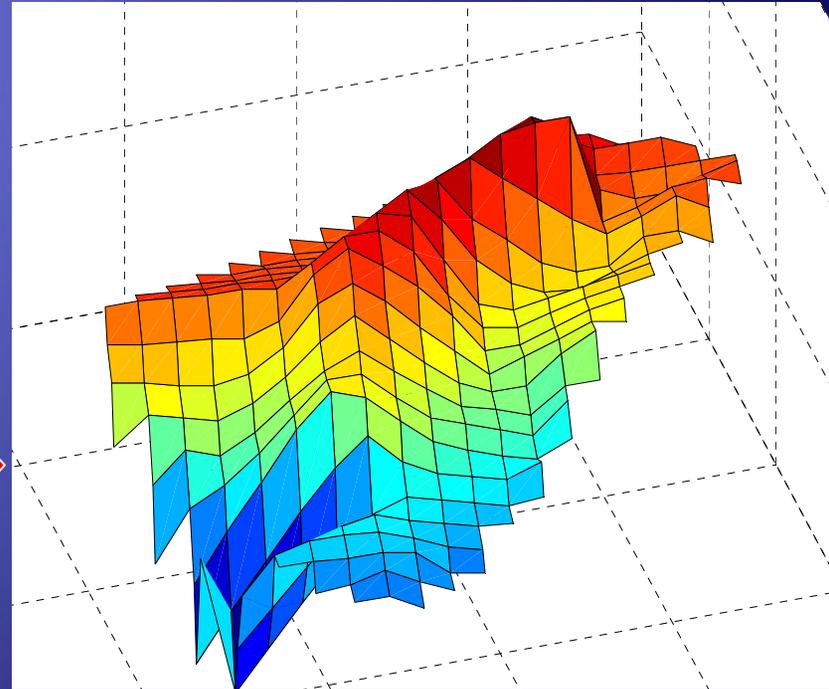
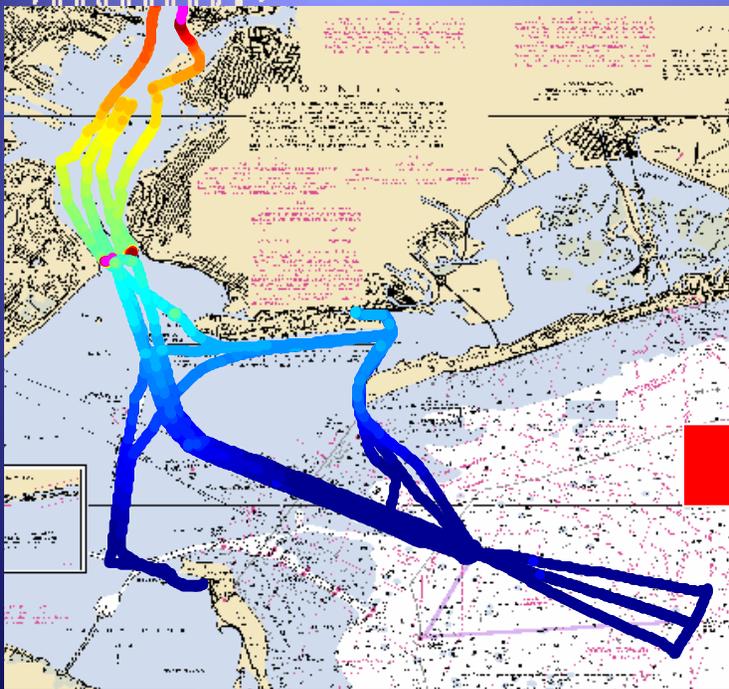
# Spatial ASF Grids

- Method for converting tracks to a grid
- Required grid density
- Performance examples



# Grid Development

- ◆ Overdetermined least squares estimation method akin to an “inverse interpolation” (ION GNSS 2006)



# Grid Creation

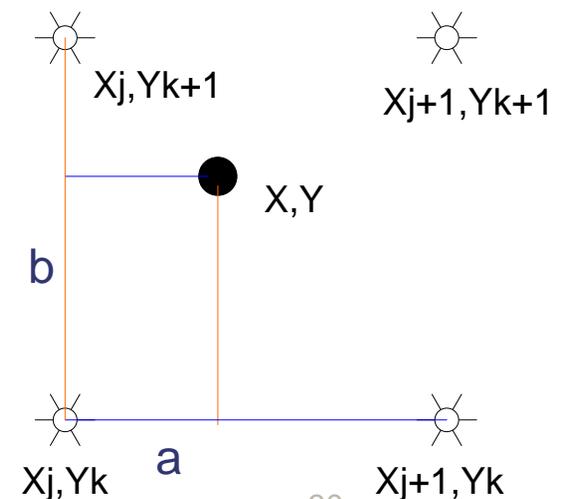
## ◆ Recall standard linear interpolation:

- ◆ Given a function at grid points, we can interpolate a general  $F(x, y)$  by

$$F(x, y) = (1-a)(1-b)F(x_j, y_k) + a(1-b)F(x_{j+1}, y_k) + b(1-a)F(x_j, y_{k+1}) + abF(x_{j+1}, y_{k+1})$$

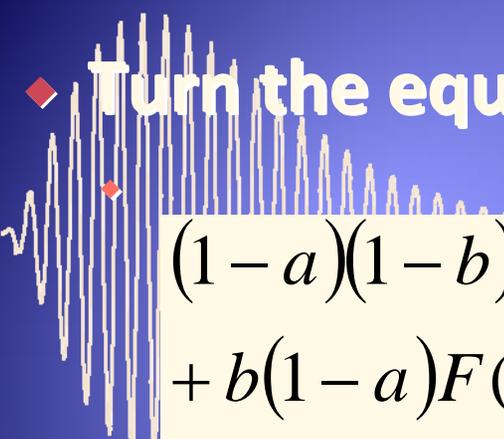
- ◆ with

$$a = \frac{x - x_j}{x_{j+1} - x_j} \quad \text{and} \quad b = \frac{y - y_k}{y_{k+1} - y_k}$$



# “Inverse Interpolation”

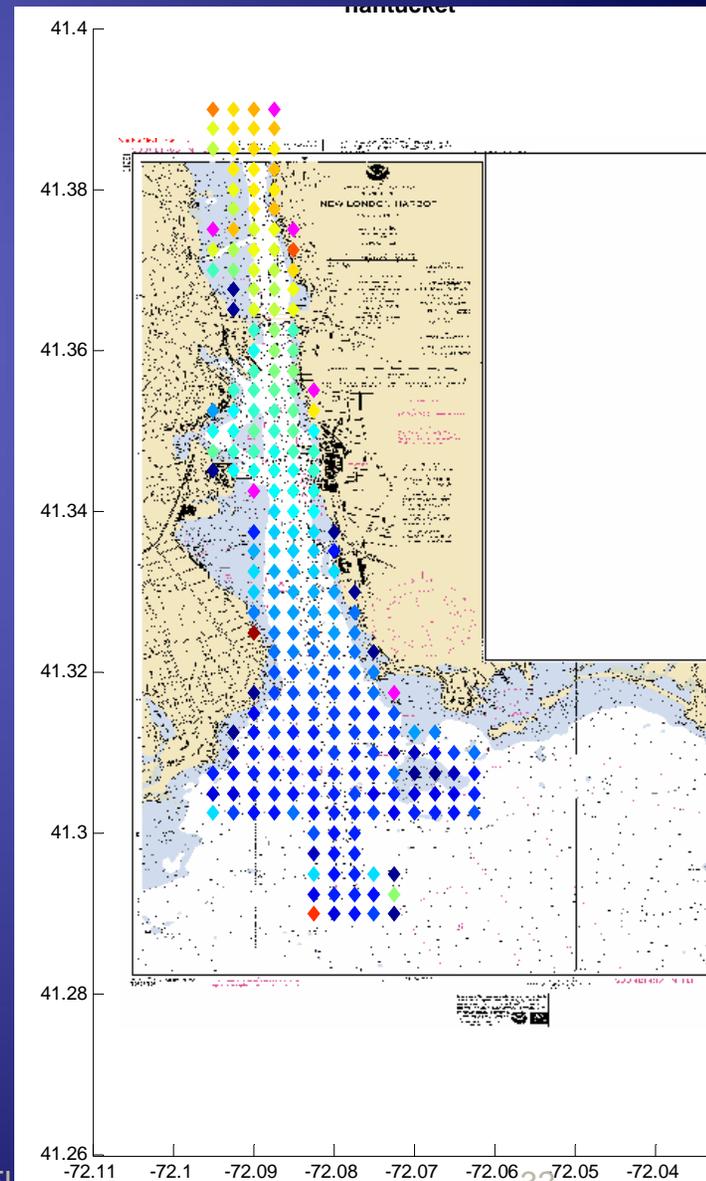
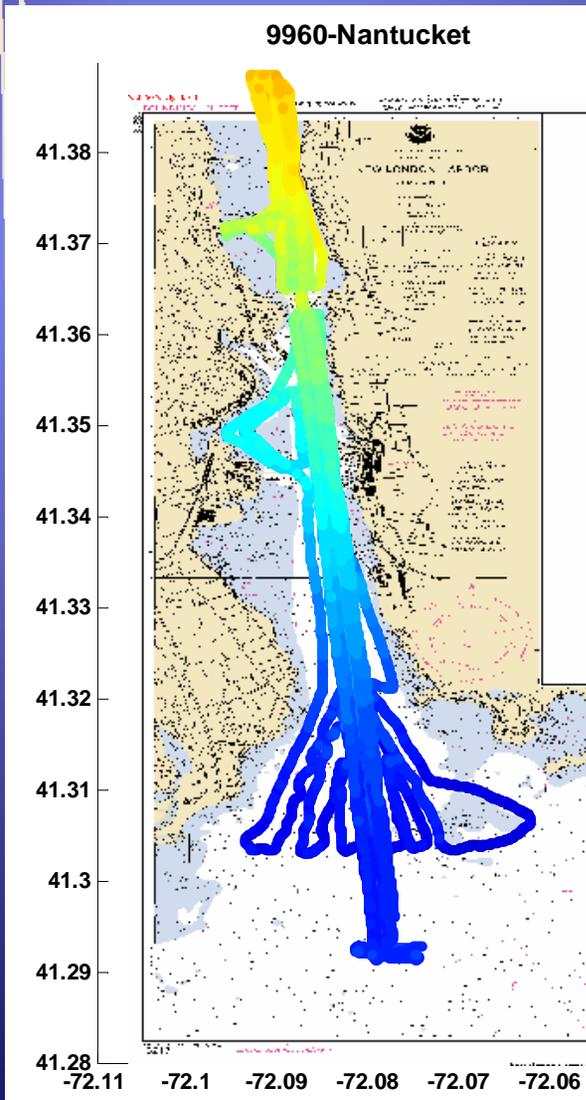
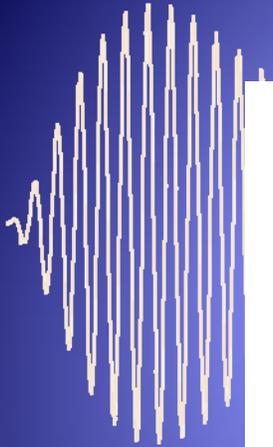
- ◆ Turn the equations around:


$$(1-a)(1-b)F(x_j, y_k) + a(1-b)F(x_{j+1}, y_k) + b(1-a)F(x_j, y_{k+1}) + abF(x_{j+1}, y_{k+1}) = F(x, y)$$

- ◆ a, b, and F(x, y) are known
- ◆ so each data point yields a linear equation in 4 unknowns
- ◆ solve large set of simultaneous linear equations to get grids



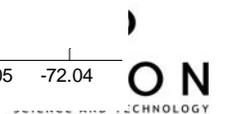
# Sample Grid - Nantucket



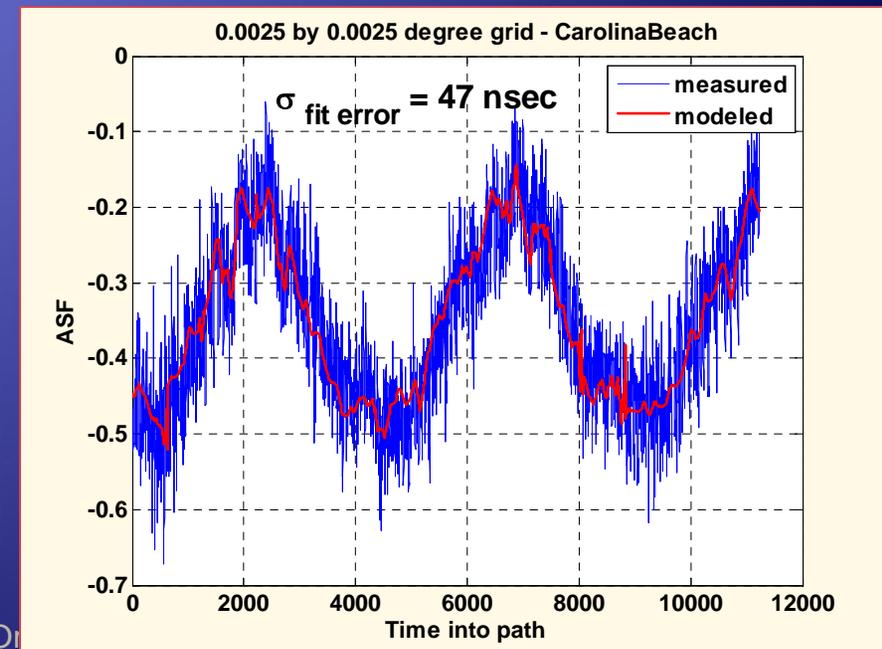
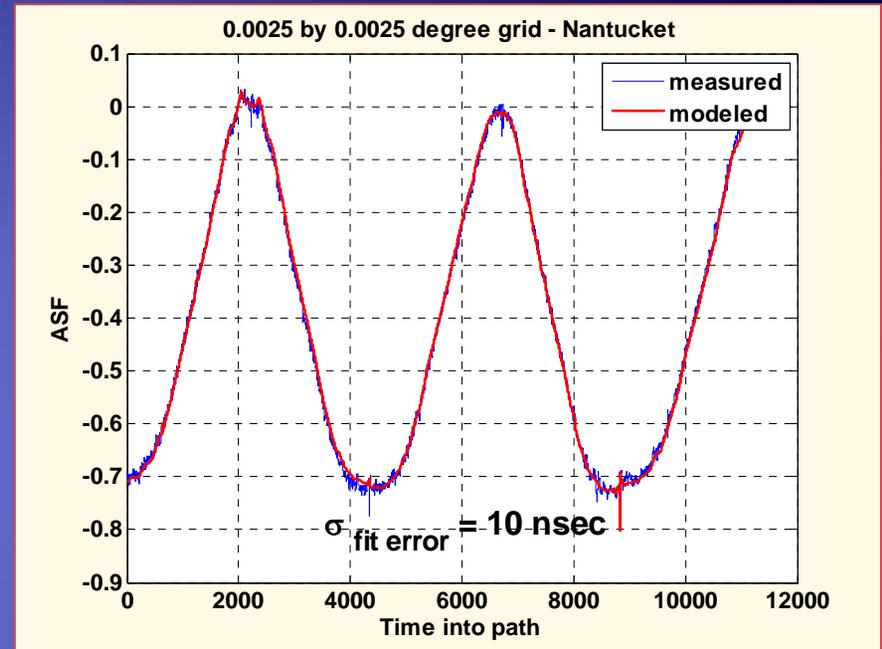
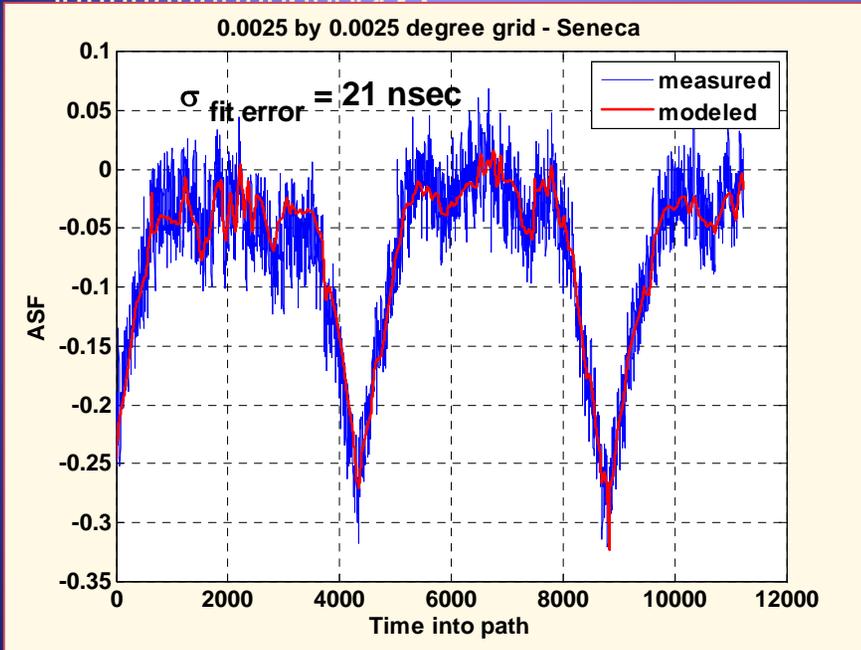
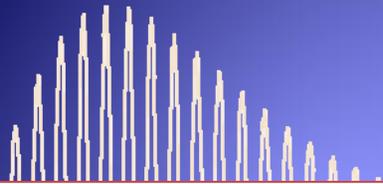
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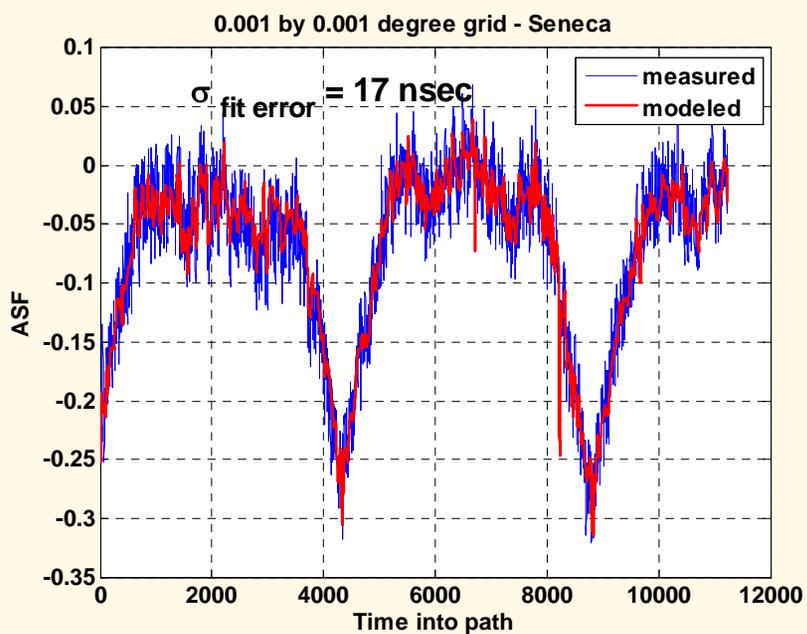
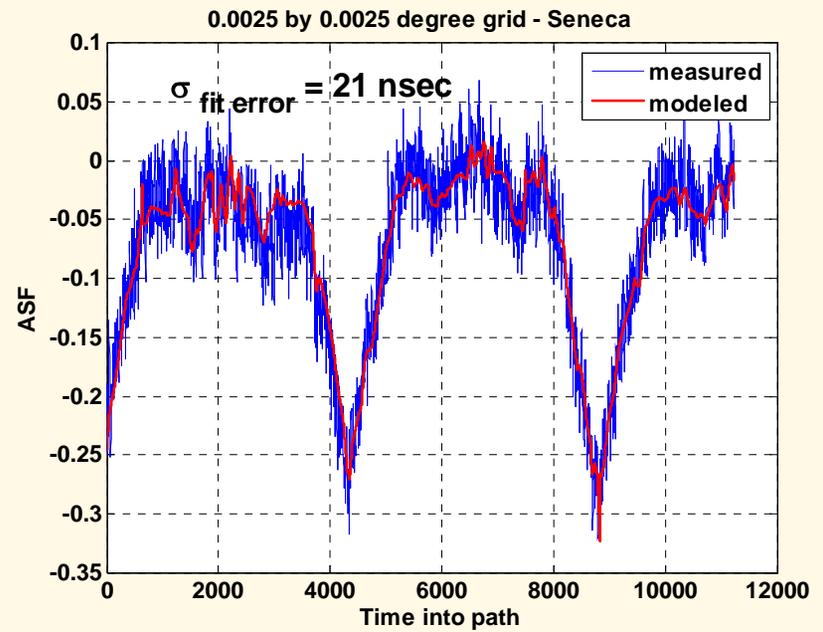
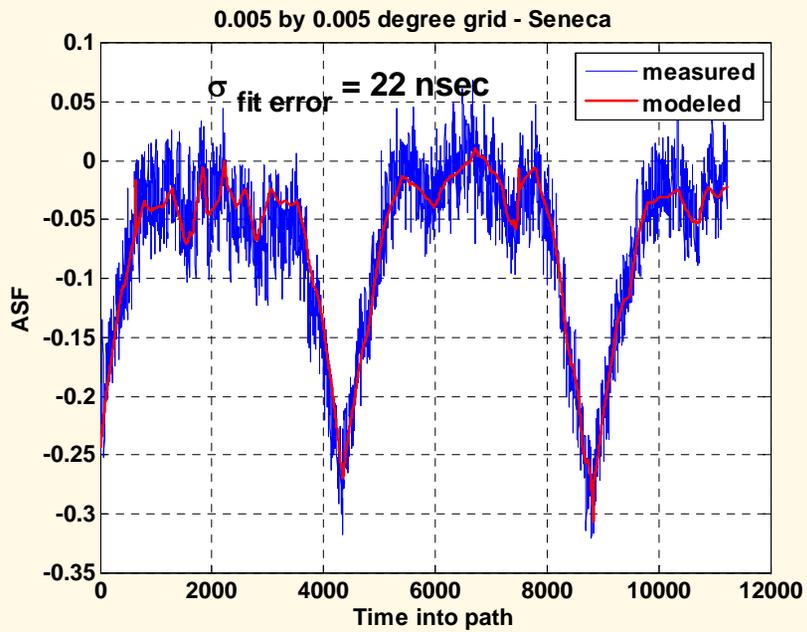
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# Grid fit to data

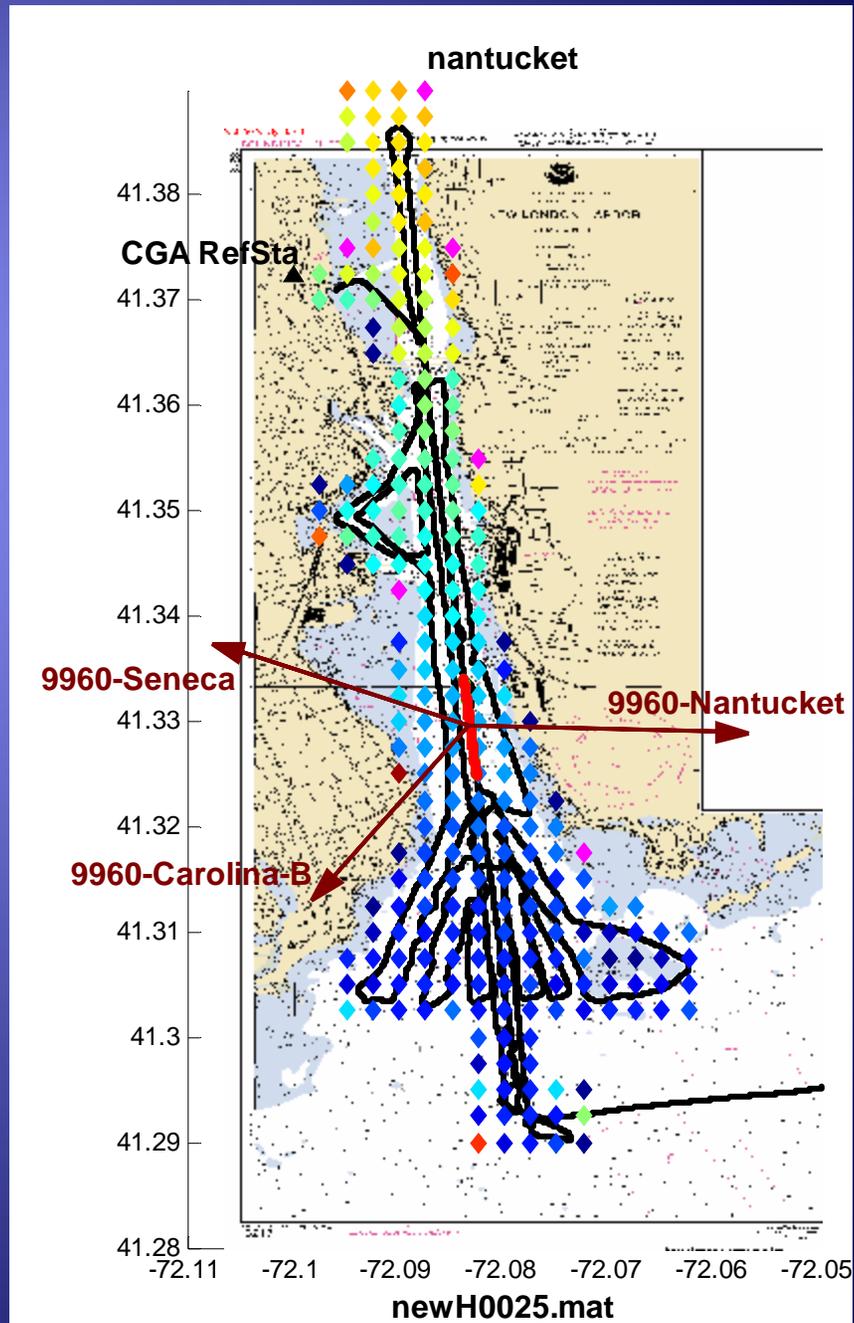




Resolution	~meters	Fit error in nsec		
		Seneca	Nantucket	Carolina Beach
0.0005	55	13	3	30
0.0010	110	17	7	40
0.0015	165	20	9	44
0.0020	225	21	10	47
0.0025	280	21	10	47
0.0050	560	22	10	48



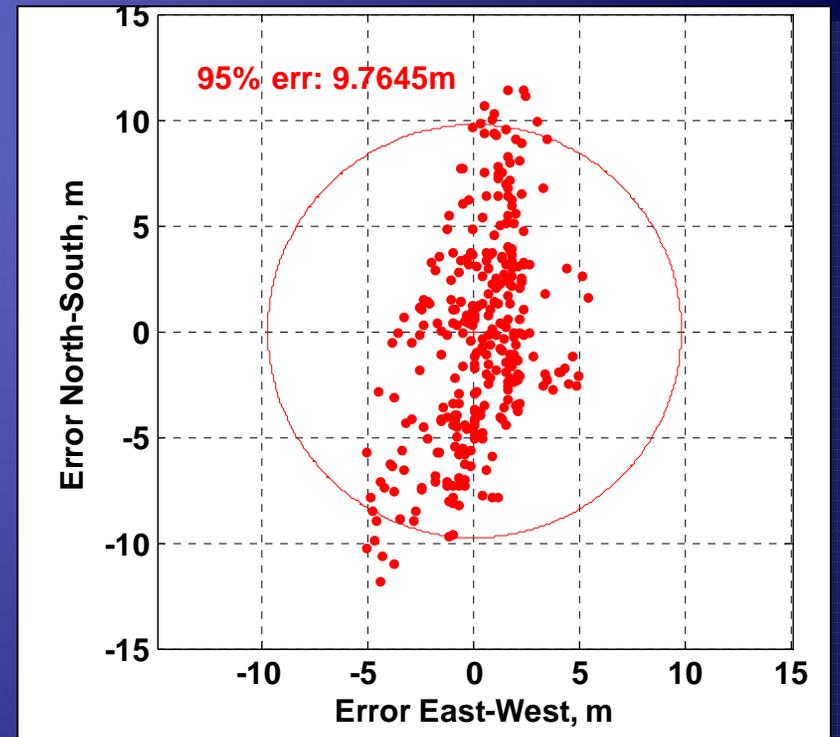
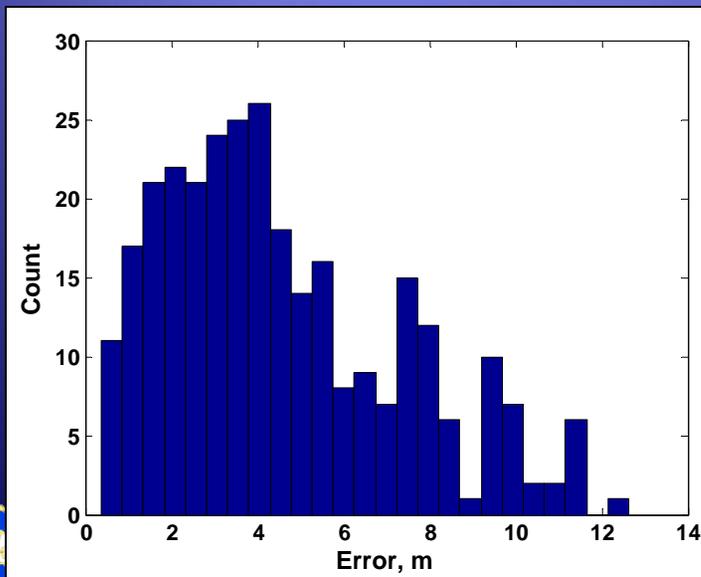
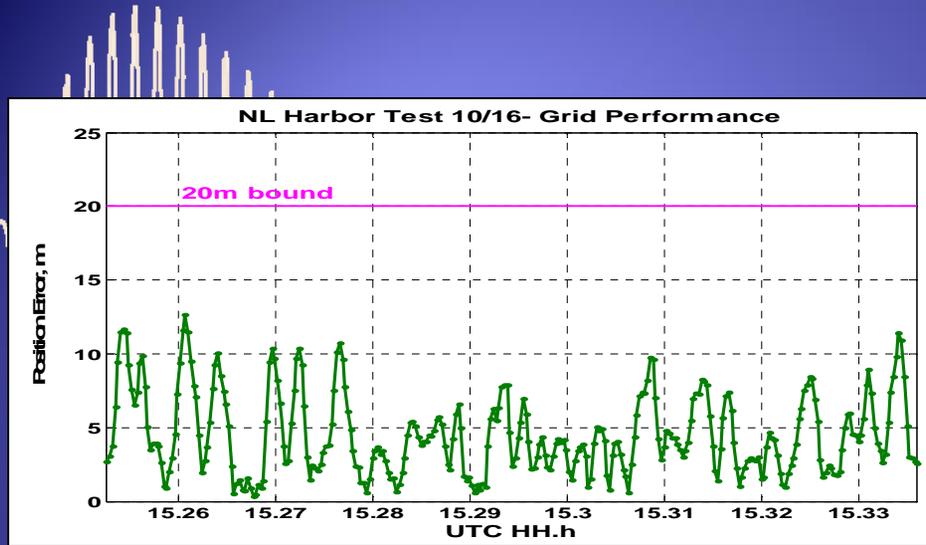
# Thames Performance Example



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# Thames Performance



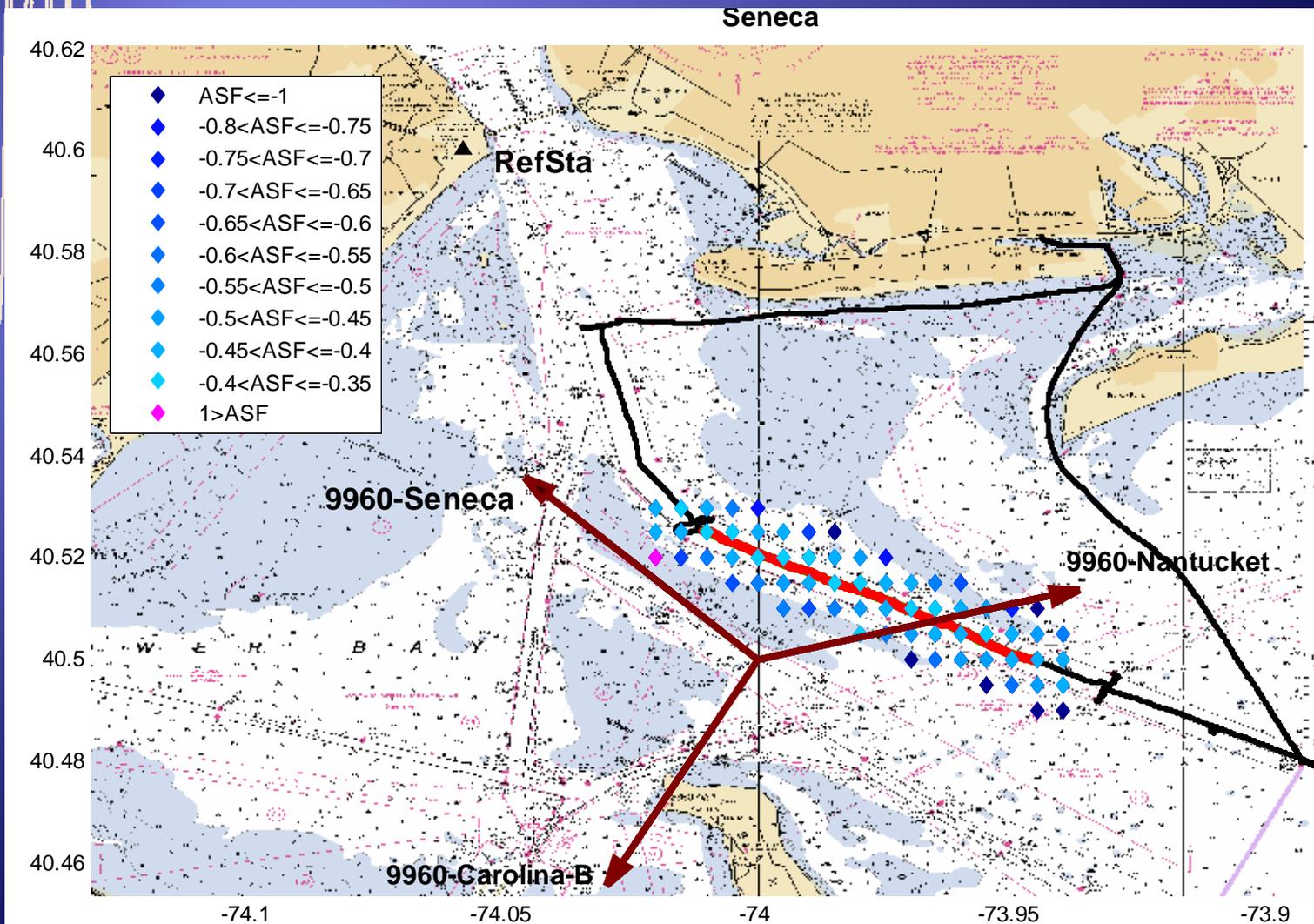
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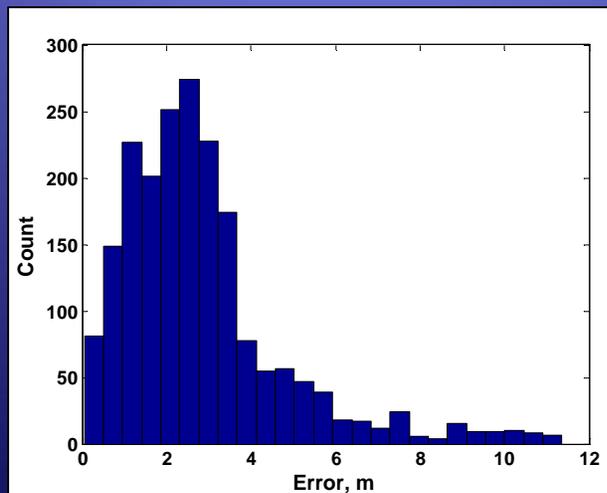
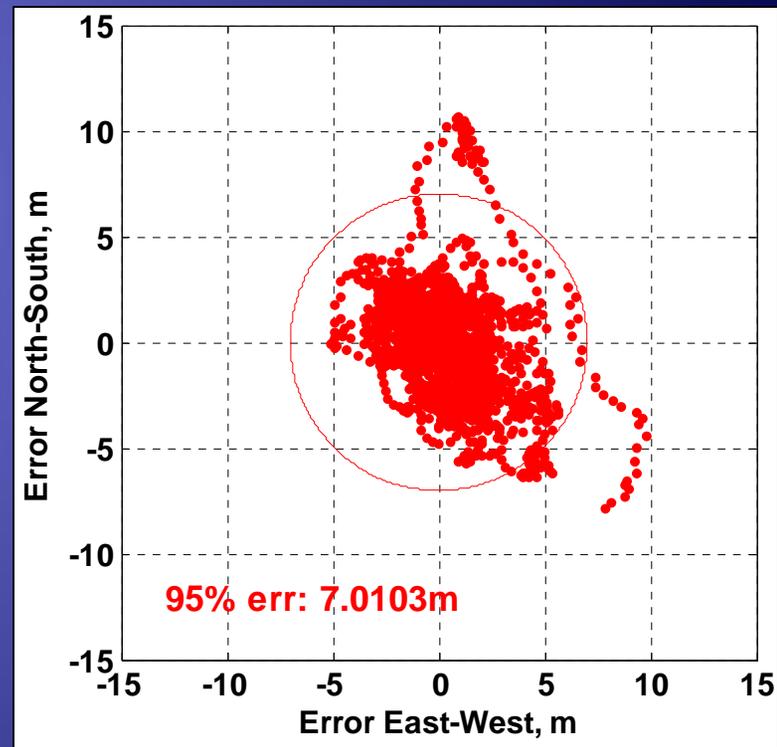
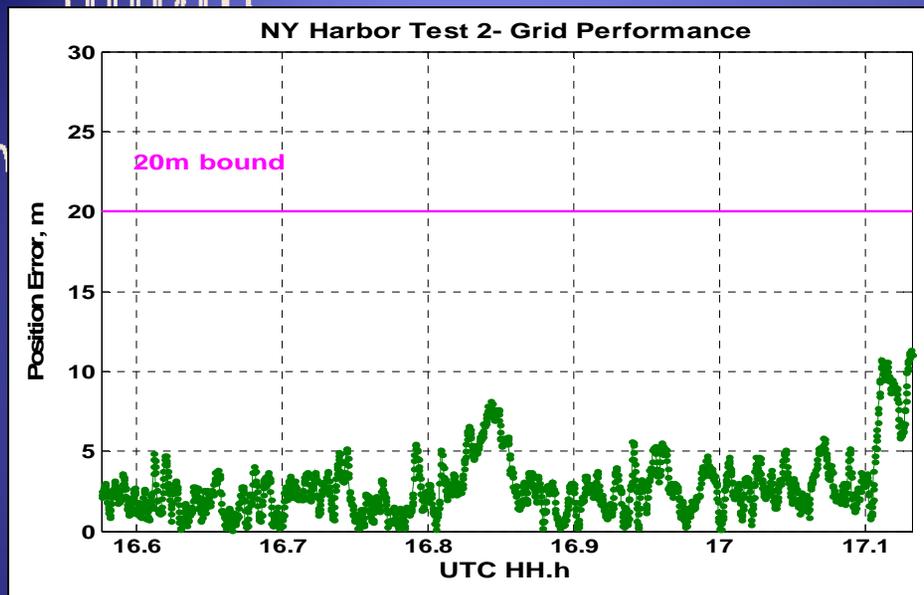
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# New York Performance Example



# NY Performance – Error Dist.



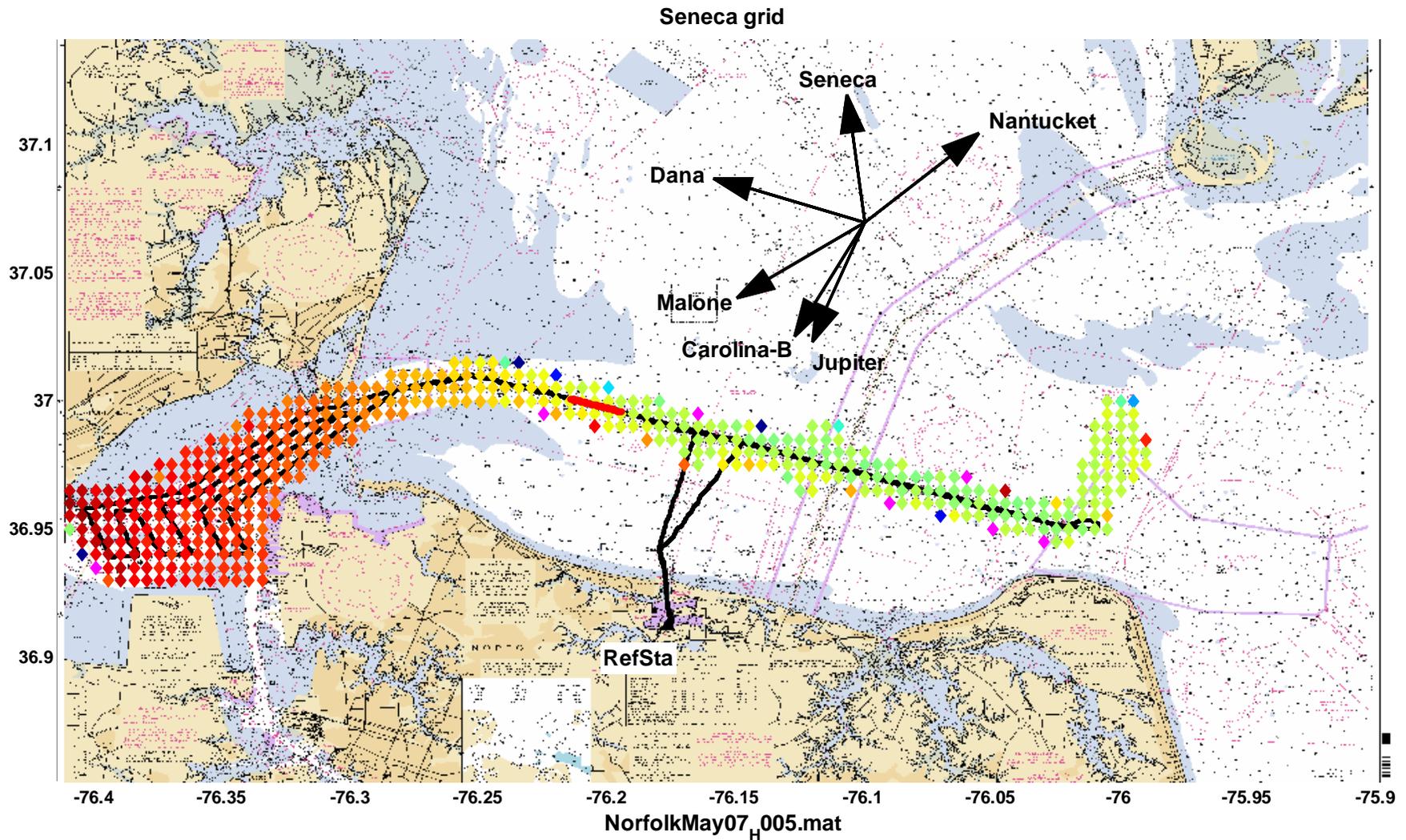
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# Norfolk Performance Example



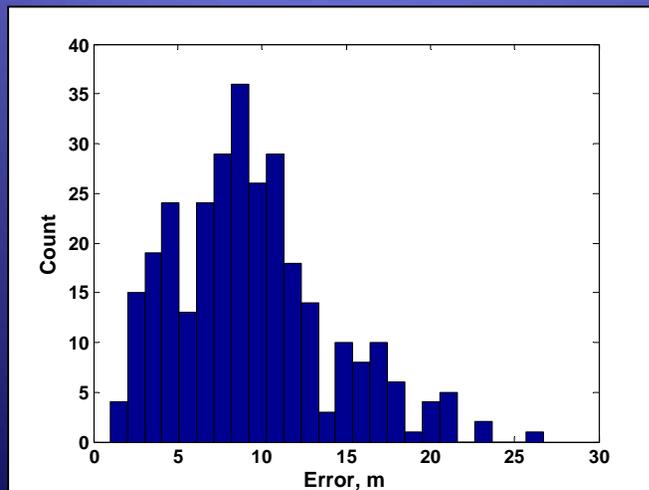
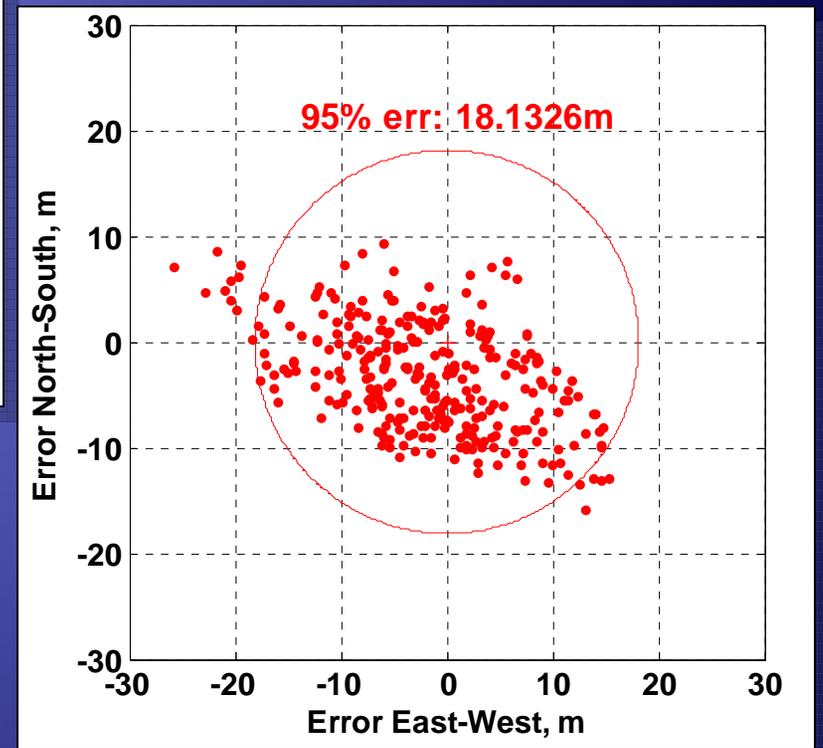
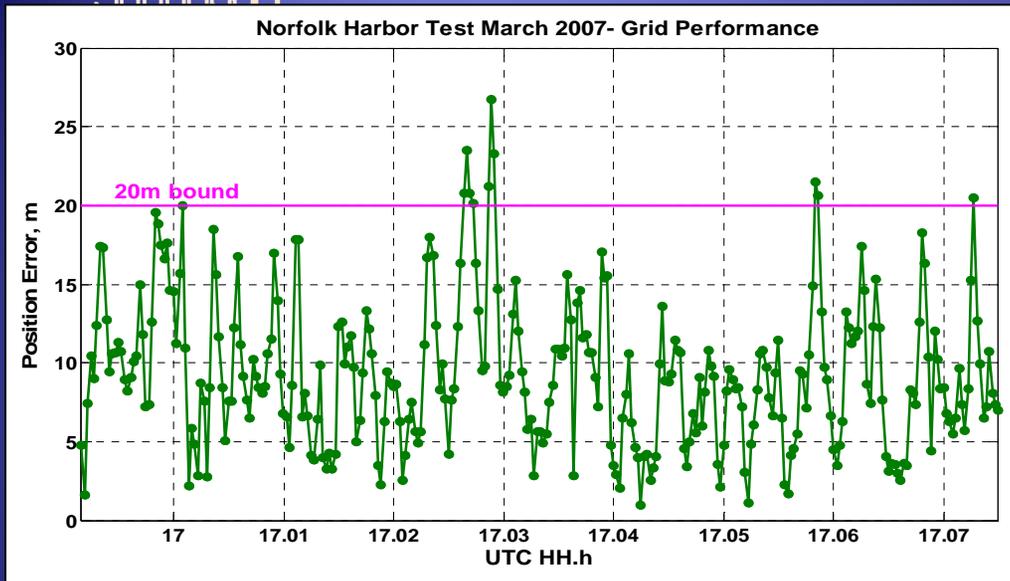
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# Norfolk Performance – Error Dist.



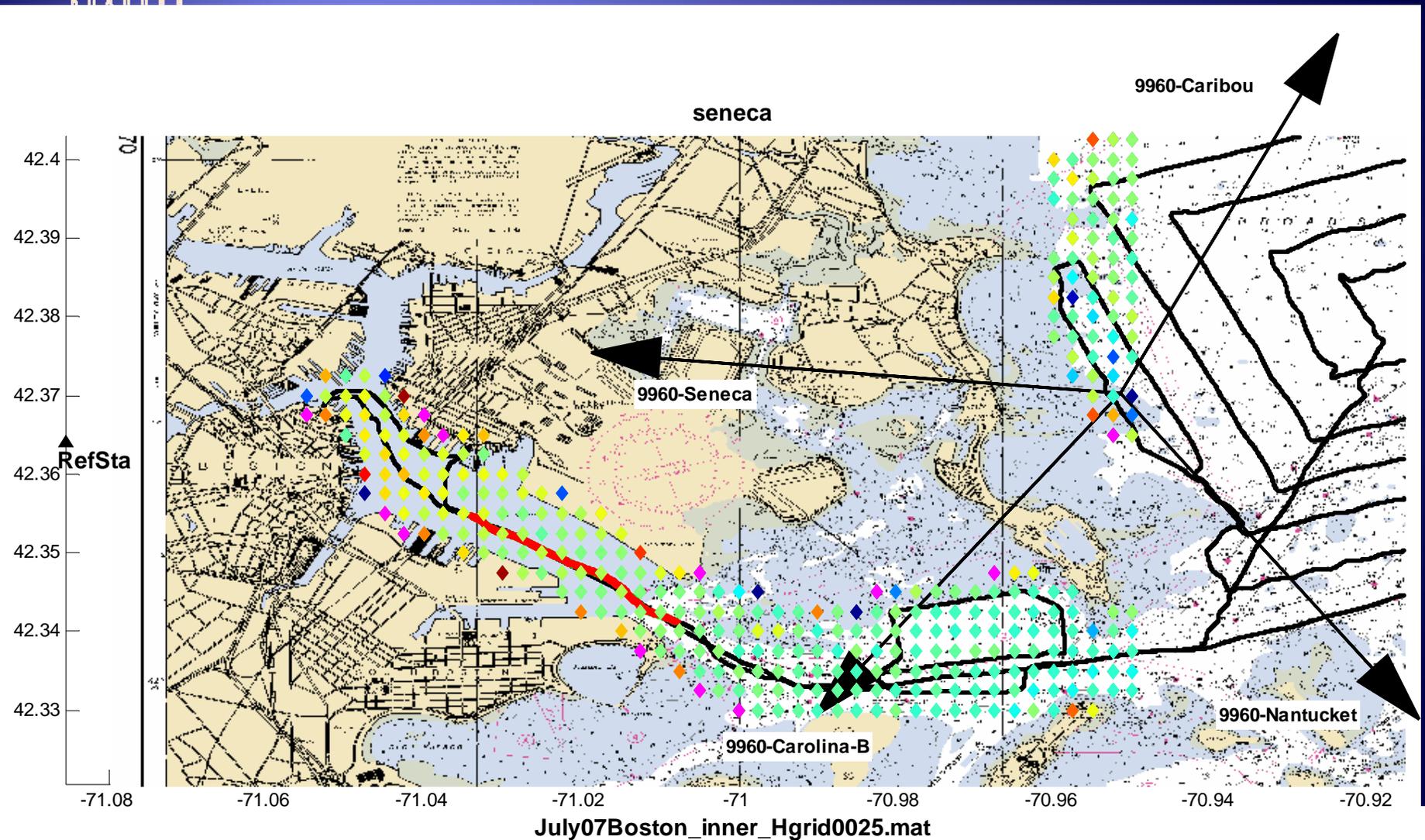
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# Boston Performance Example



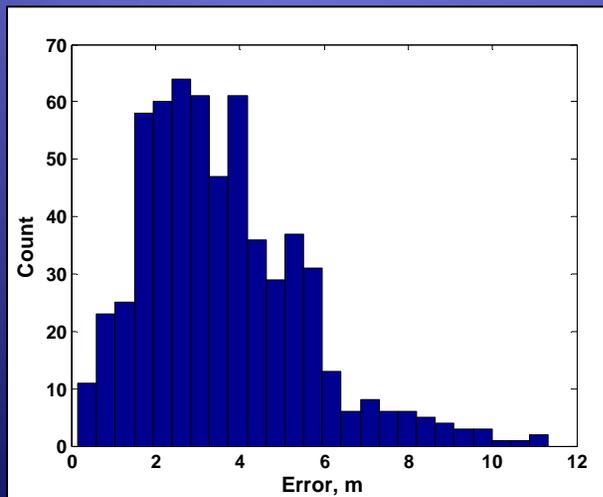
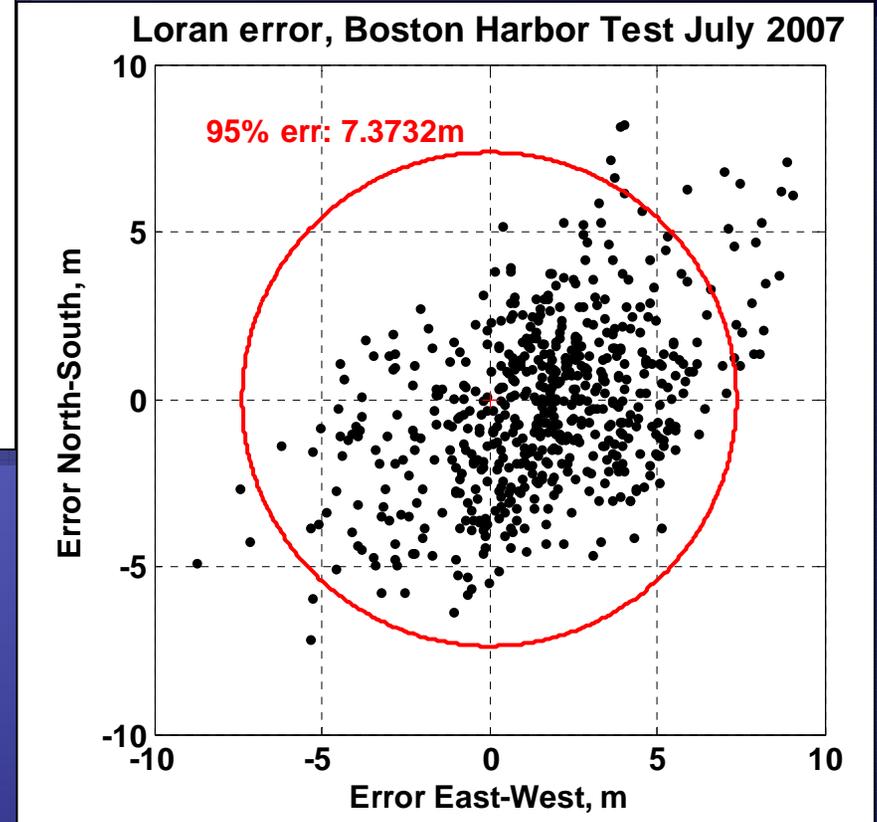
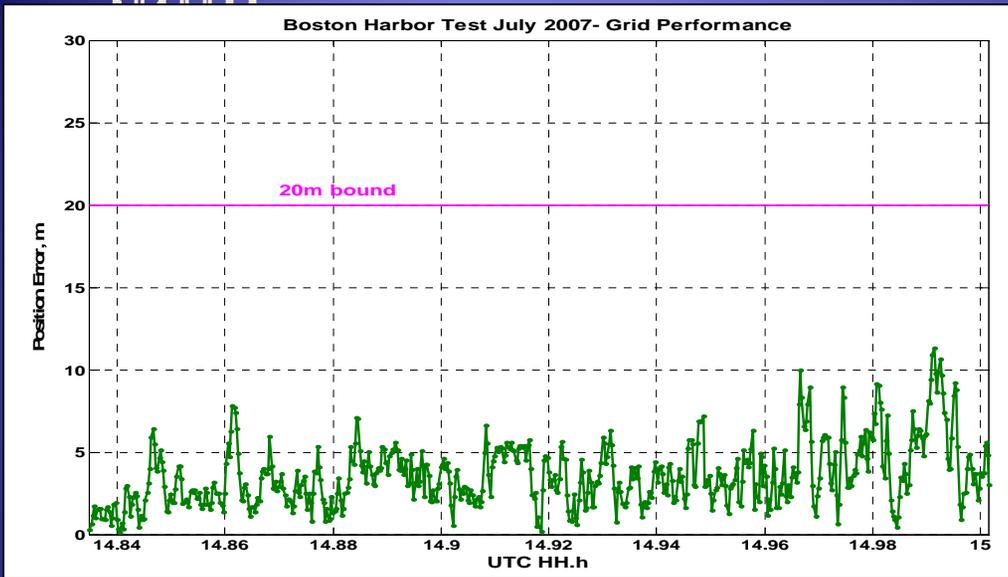
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# Boston Performance – Error Dist.



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# Temporal Corrections

- LDC Architecture
- Typical Spatial Correlation



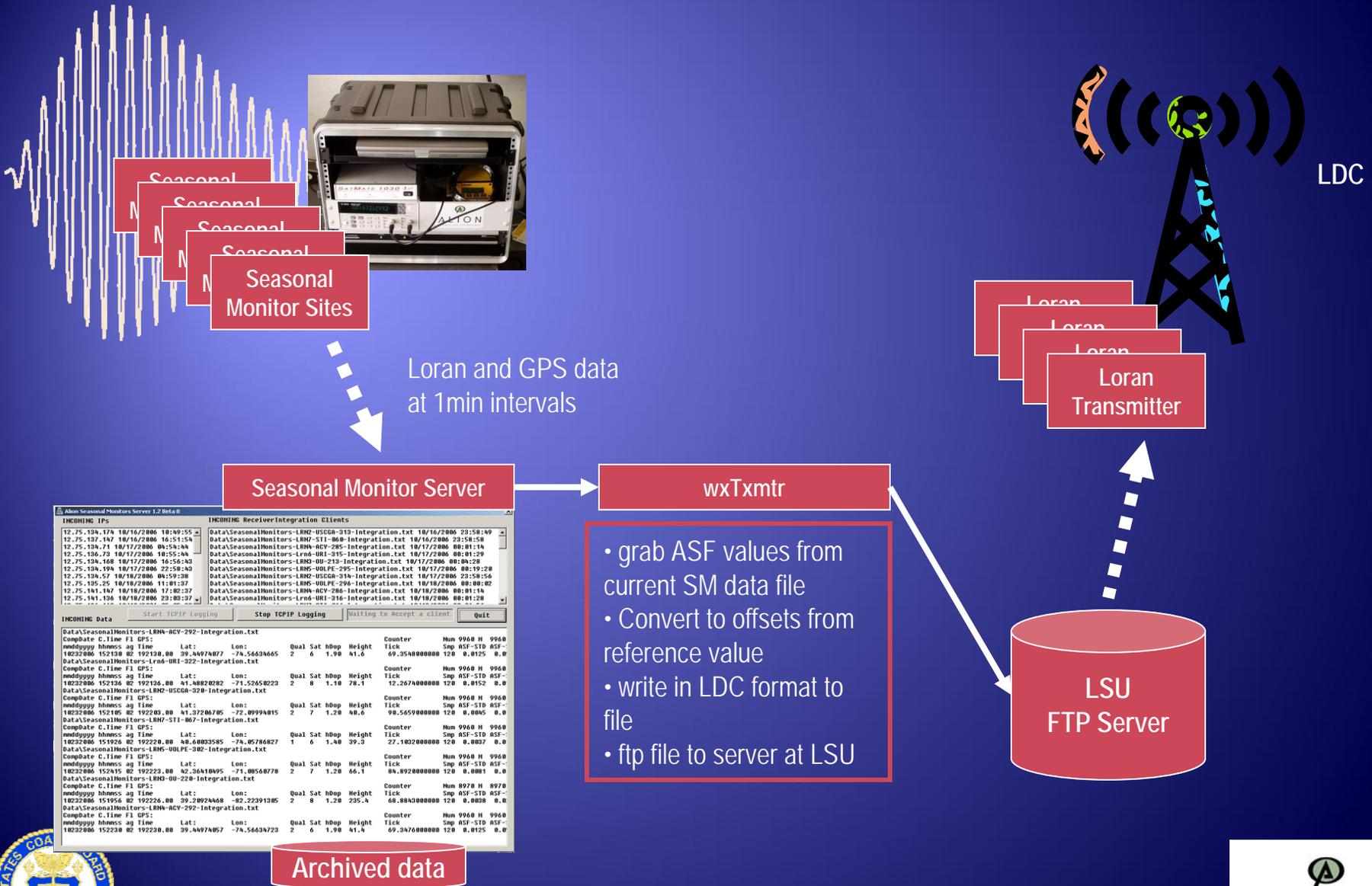
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# LDC Architecture



Alion Seasonal Monitors Server 1.2 Beta 8

INCOMING IPs

12.75.134.174	10/16/2006	10:49:55	DataSeasonalMonitors-LRN2-USCGA-310-Integration.txt	10/16/2006	23:58:49
12.75.137.147	10/16/2006	16:51:54	DataSeasonalMonitors-LRN7-STI-808-Integration.txt	10/16/2006	23:58:58
12.75.134.71	10/17/2006	04:54:44	DataSeasonalMonitors-LRN4-RCV-295-Integration.txt	10/17/2006	00:01:14
12.75.136.73	10/17/2006	10:55:44	DataSeasonalMonitors-LRN6-URI-315-Integration.txt	10/17/2006	00:01:29
12.75.134.148	10/17/2006	16:54:40	DataSeasonalMonitors-LRN6-URI-210-Integration.txt	10/17/2006	00:04:29
12.75.134.194	10/17/2006	22:58:40	DataSeasonalMonitors-LRN5-VOLPE-295-Integration.txt	10/17/2006	00:19:20
12.75.134.57	10/18/2006	04:59:38	DataSeasonalMonitors-LRN2-USCGA-314-Integration.txt	10/17/2006	23:58:56
12.75.135.25	10/18/2006	11:01:37	DataSeasonalMonitors-LRN6-VOLPE-296-Integration.txt	10/18/2006	00:00:02
12.75.141.147	10/18/2006	17:02:37	DataSeasonalMonitors-LRN4-RCV-286-Integration.txt	10/18/2006	00:01:14
12.75.141.136	10/18/2006	23:03:37	DataSeasonalMonitors-LRN6-URI-316-Integration.txt	10/18/2006	00:01:28

INCOMING Data

DataSeasonalMonitors-LRN4-RCV-292-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	152138	02	192138.00	39.44974077	-74.56626605
Qual	Sat	hdop	Height	Counter	Num
2	6	1.98	41.6	69.3548000000	120
0.0125	0.0				
DataSeasonalMonitors-LRN6-URI-322-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	152136	02	192136.00	41.48020292	-71.52658223
Qual	Sat	hdop	Height	Counter	Num
2	8	1.10	78.1	12.2474000000	120
0.0152	0.0				
DataSeasonalMonitors-LRN2-USCGA-320-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	152105	02	192205.00	41.37206705	-72.09994815
Qual	Sat	hdop	Height	Counter	Num
2	7	1.28	48.6	98.5659000000	120
0.0045	0.0				
DataSeasonalMonitors-LRN7-STI-807-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	151924	02	192224.00	40.68035355	-74.05786827
Qual	Sat	hdop	Height	Counter	Num
1	6	1.40	39.3	27.1032000000	120
0.0057	0.0				
DataSeasonalMonitors-LRN5-VOLPE-302-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	152415	02	192223.00	42.36410095	-71.08560778
Qual	Sat	hdop	Height	Counter	Num
2	7	1.20	66.1	84.8920000000	120
0.0081	0.0				
DataSeasonalMonitors-LRN6-URI-210-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	151954	02	192226.00	39.20924468	-82.22391305
Qual	Sat	hdop	Height	Counter	Num
2	8	1.28	235.4	66.8842000000	120
0.0068	0.0				
DataSeasonalMonitors-LRN4-RCV-292-Integration.txt					
ComDate	C.Line	F1	GPS:		
10222066	152230	02	192230.00	39.44974057	-74.56626723
Qual	Sat	hdop	Height	Counter	Num
2	6	1.98	41.4	69.3476000000	120
0.0125	0.0				

Archived data



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# Typical LDC Message Sequence



- ◆ Each message is 45 bits and takes 24 symbols to transmit at 1 symbol/group
- ◆ At 8970 takes 2.15sec/msg
- ◆ Time: 5 every 64 messages or ~ every 27.5sec
- ◆ ASF data repeats every 2.3 min



# eLoran Performance

- Prototype receiver
- Sample performance



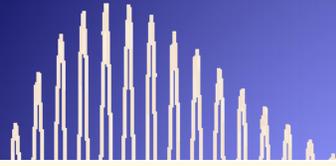
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# Prototype eLoran Receiver



## USCGA DDC Receiver

- TOAs
- demodulated LDC symbols
- real-time ASFs (for comparison)

## Matlab Script

- Lookup ASF grid value
- RS decode LDC symbols,
- Interpret transmitted data
- Apply transmitted temporal correction and reference station value
- Calculate position solution
- Output position as NMEA string



## Transview Display

- Display position tracks of eLoran, Loran, and GPS systems

## SatMate Receiver

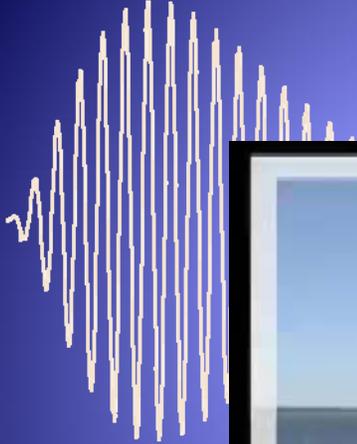
- Loran position

## NovAtel Receiver

- GPS position



# eLoran Results on the Thames



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# Conclusions

## ◆ Spatial ASF Grids

- ◆ Noise in the ASF measurements gets averaged out by the grid creation process
- ◆ 500m grid spacing is typically sufficient
  - ◆ Smaller spacing only if dictated by physical size of HEA
  - ◆ Smaller sizes just chase the noise in the measurements
- ◆ Harbor Survey procedure has been established and proven

## ◆ Temporal ASF

- ◆ Correct temporal value is critical to meeting HEA accuracy
- ◆ Currently under investigation:
  - ◆ Frequency (and filtering) of corrections
  - ◆ Monitor site spacing
  - ◆ End-state distribution architecture

## ◆ eLoran Receiver

- ◆ In areas where geometry / signal strength are poor, receiver performance becomes critical
- ◆ <20m real-time is difficult – even with ASF spatial (grid) and temporal corrections, requires a good receiver



# Acknowledgements

## ◆ Alion New London Team

- ◆ Christian Oates
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- ◆ Mark Wiggins
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## ◆ USCG Auxiliary

- ◆ Captain and crew of Launch #5 (New York)
- ◆ Captain and crew of Myst (New London)
- ◆ Captain and crew of Halcyon Lace (Norfolk)
- ◆ Captain and crew of Three J's (Boston)

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- ◆ CDR Chris Nichols
- ◆ LT Chris Dufresne



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# Questions?

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