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

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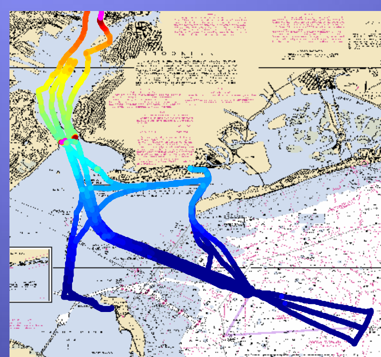
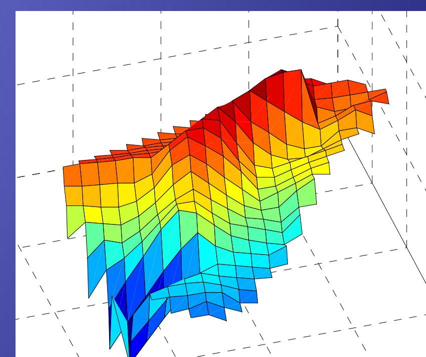
What Requirements Must be Met?

- **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

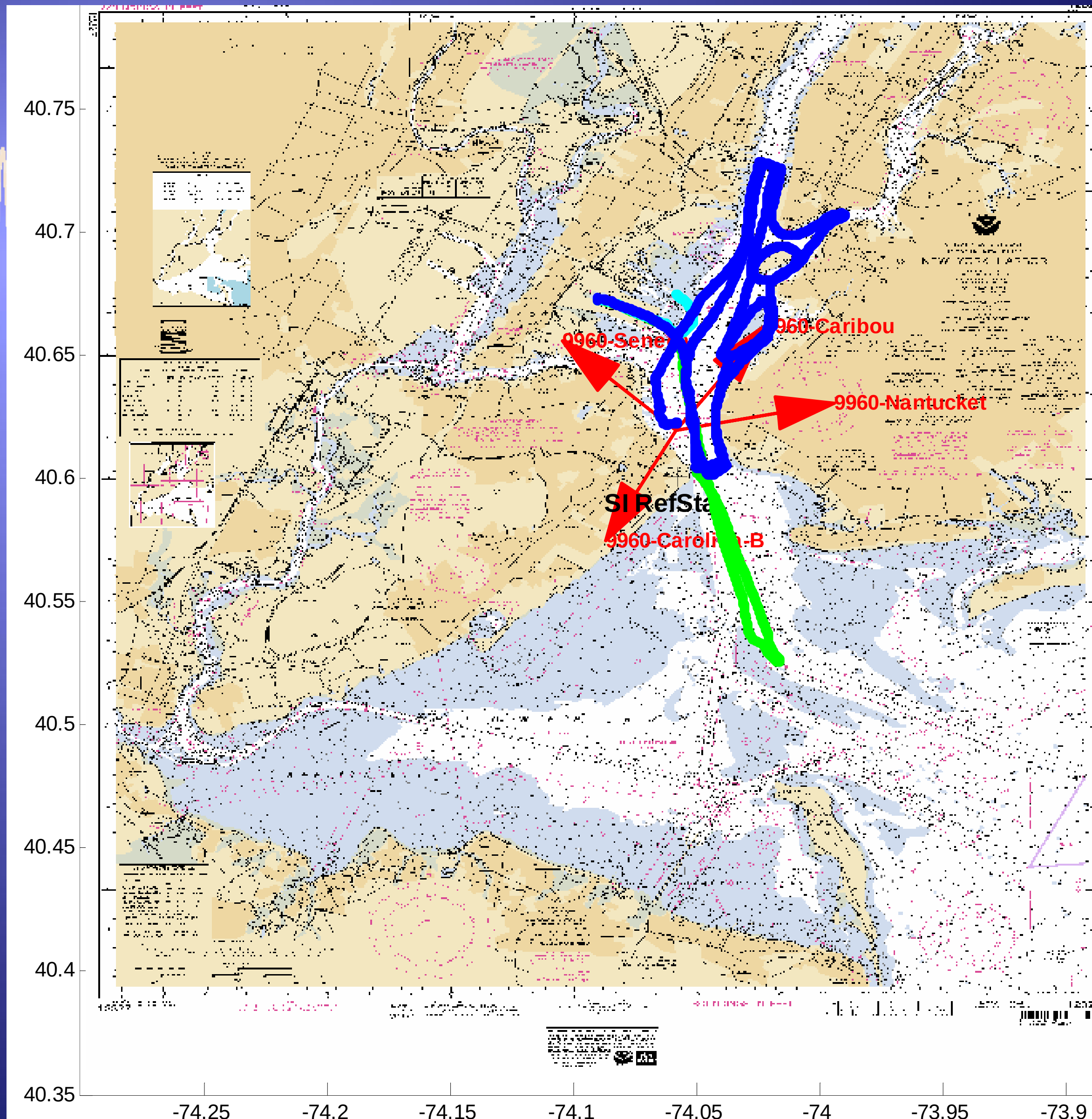
- **Convert the measured ASFs to relative ASFs by subtracting the reference site ASF for the corresponding times of the vessel ASF measurements.**
  - This eliminates any temporal variations (due to daily, seasonal, weather, or system timing effects) from the measurements.
- **Create spatial ASF grid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

NY Harbor Phase I

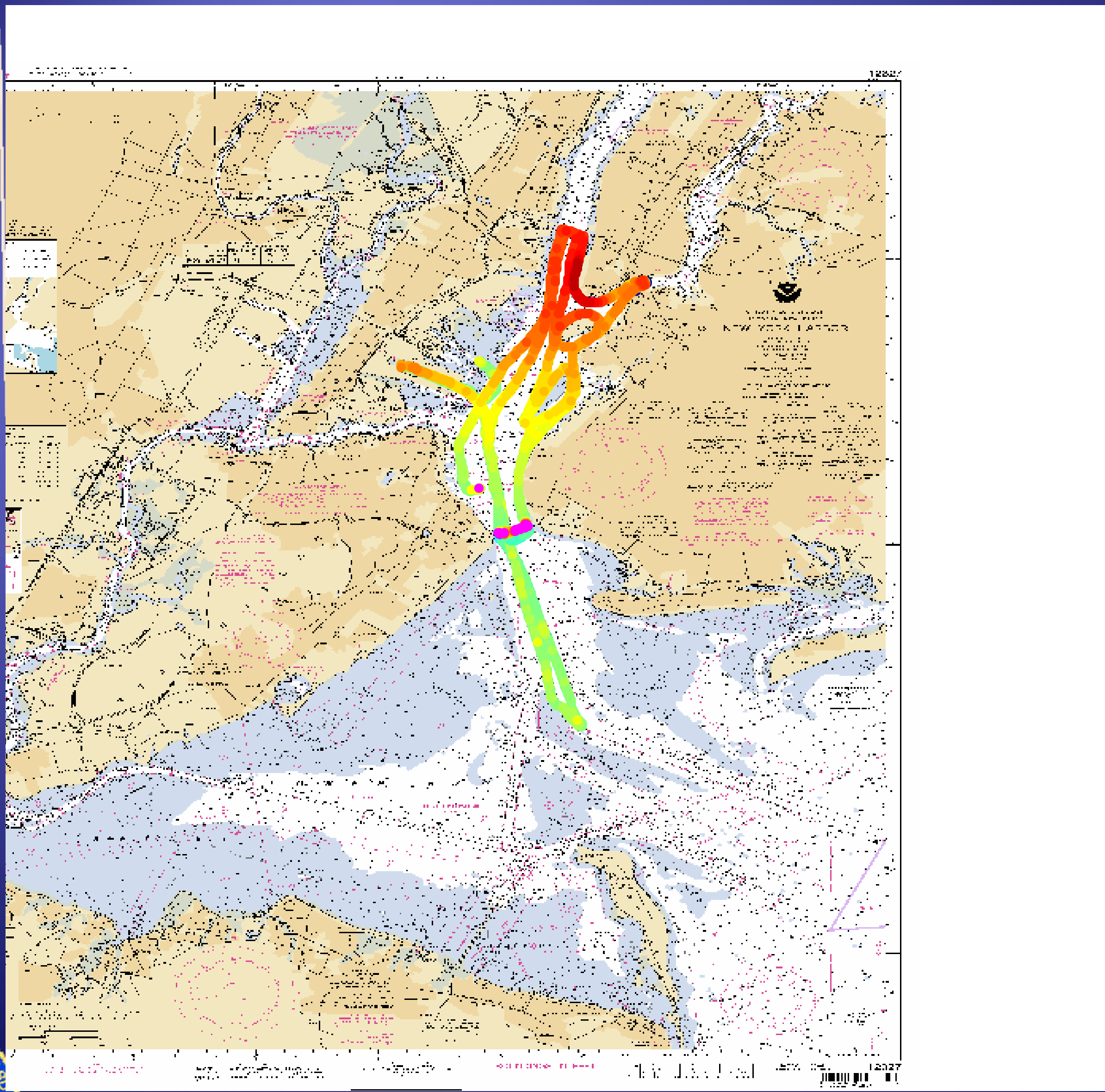
- **Continuous vessel tracks in upper harbor**
- **Static locations in upper harbor**
  - Vessel
  - Van on shore

Survey Vessel, Launch#5

NY Harbor PH1 Coverage



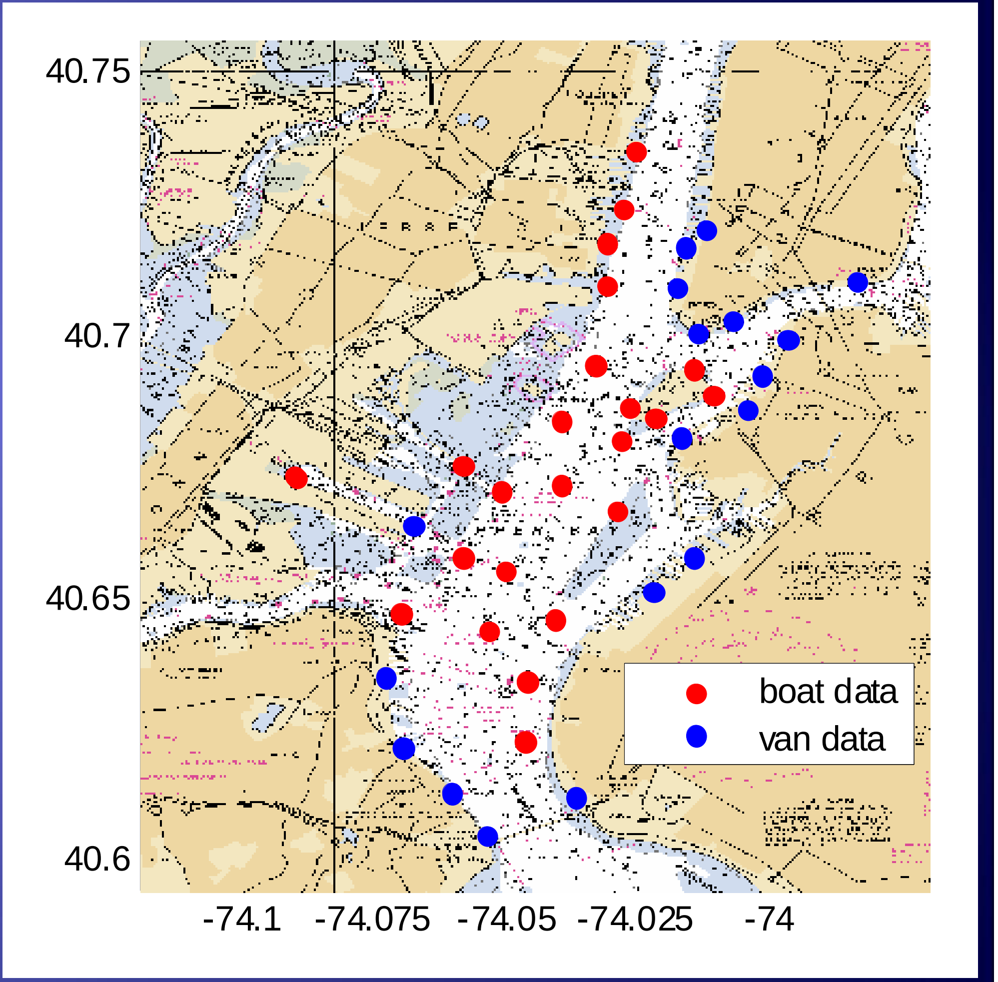
Nantucket Relative ASFs



- 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

Static Points

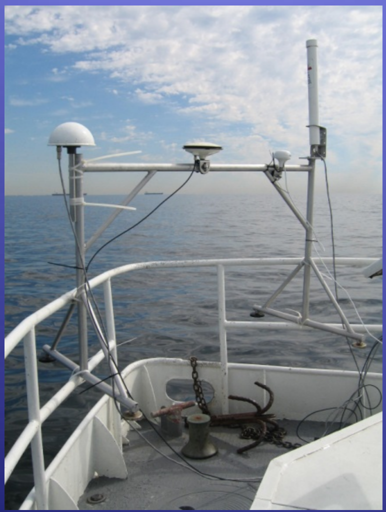
- **Vessel collected data at 25 static locations in the harbor**
  - Held station next to buoy, pier, etc.
- **Van collected data at 19 static locations around the harbor**



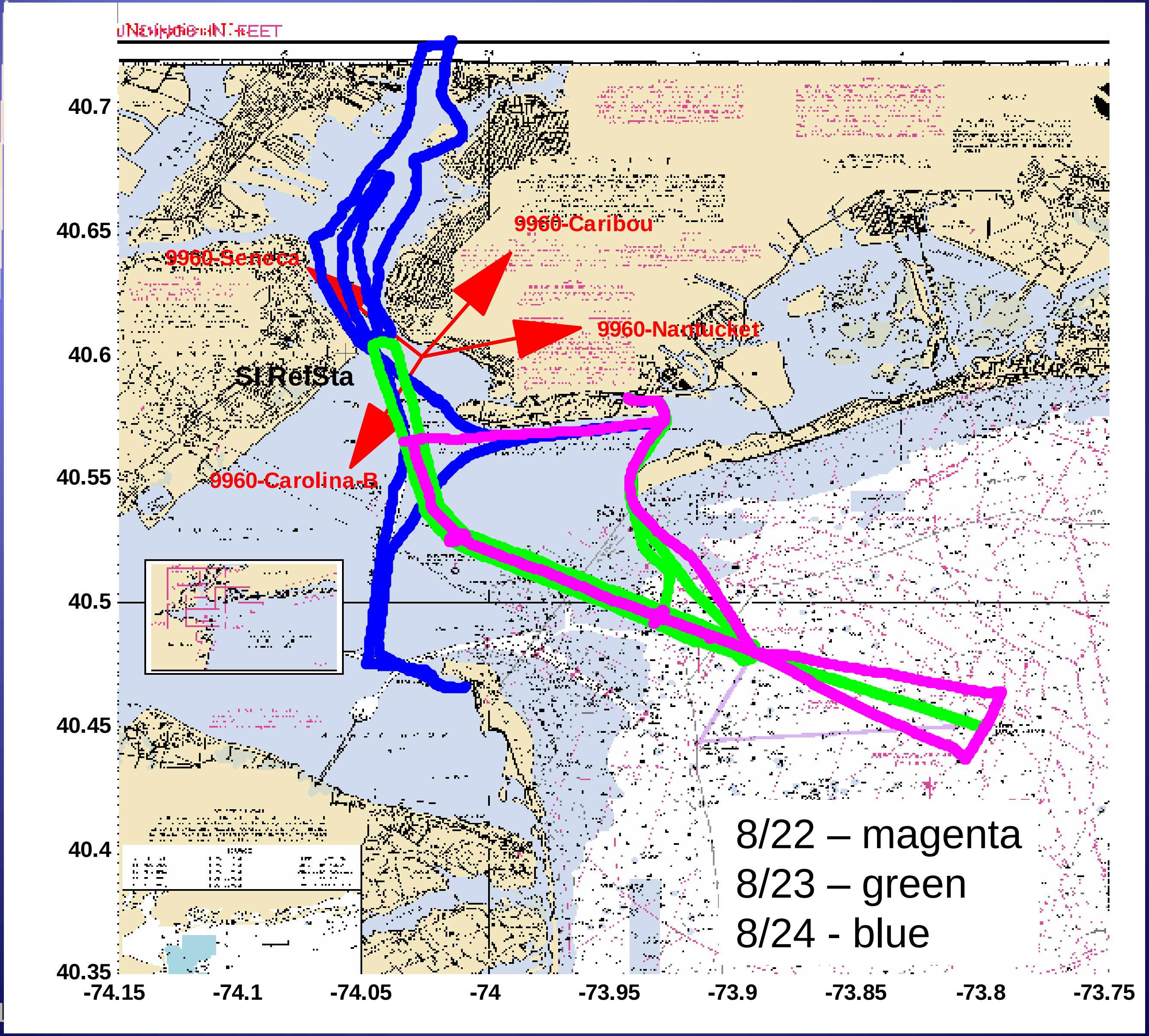
NY Harbor Phase II

- Different Vessel
- Continuous Track in lower harbor
- Repeat Upper harbor
- 12 static locations

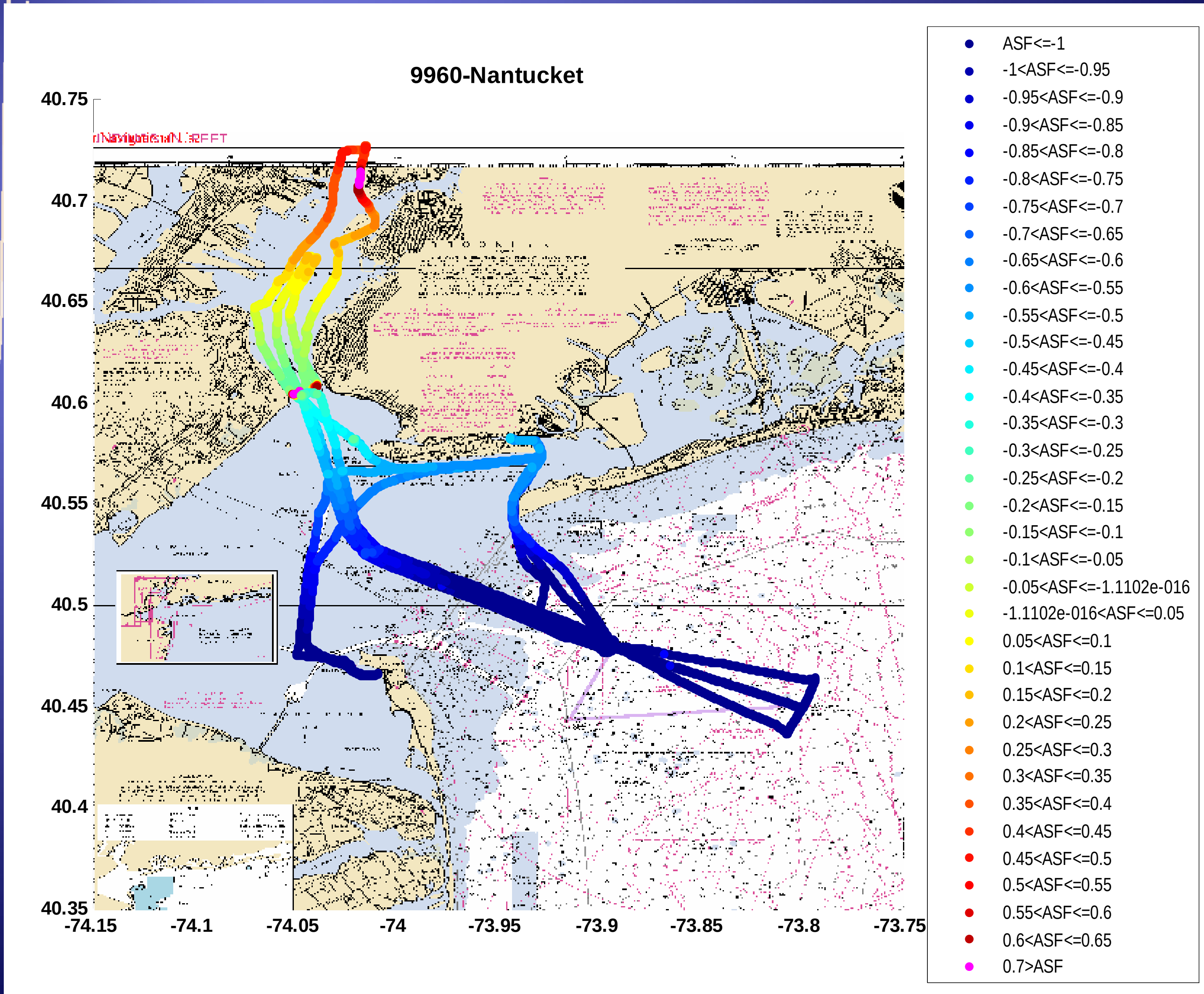
Survey Vessel, Jeanne II



NY Harbor Phase II Coverage



Nantucket Relative ASFs



Thames River

USCG AUX Vessel Myst

- Oct 2006
- Nov 2006

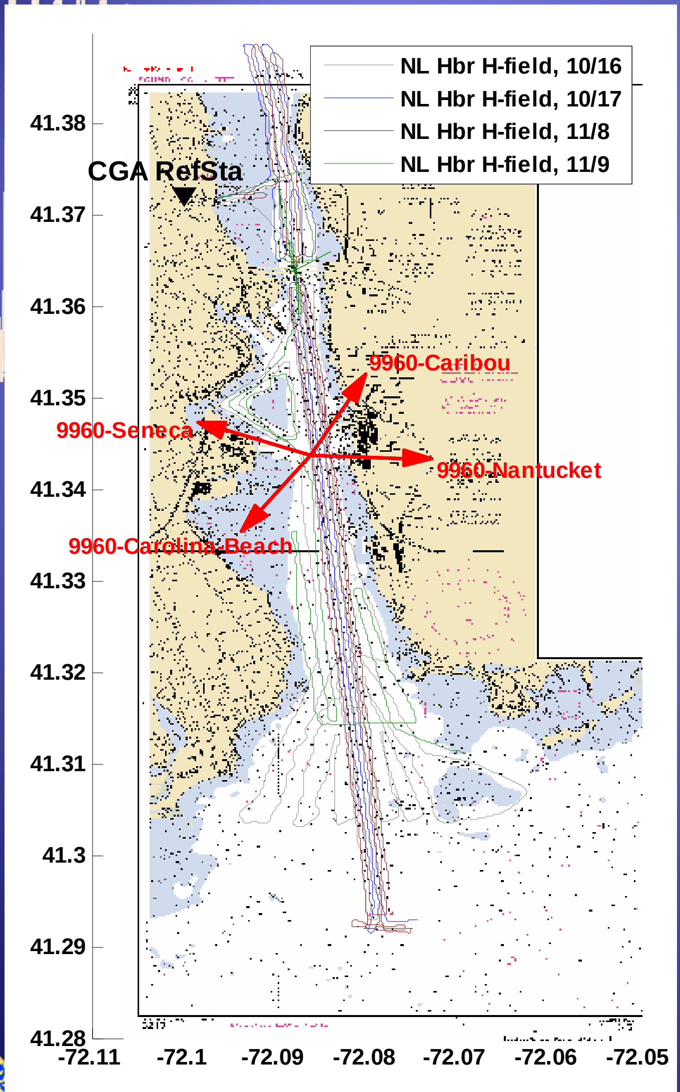
Test Van

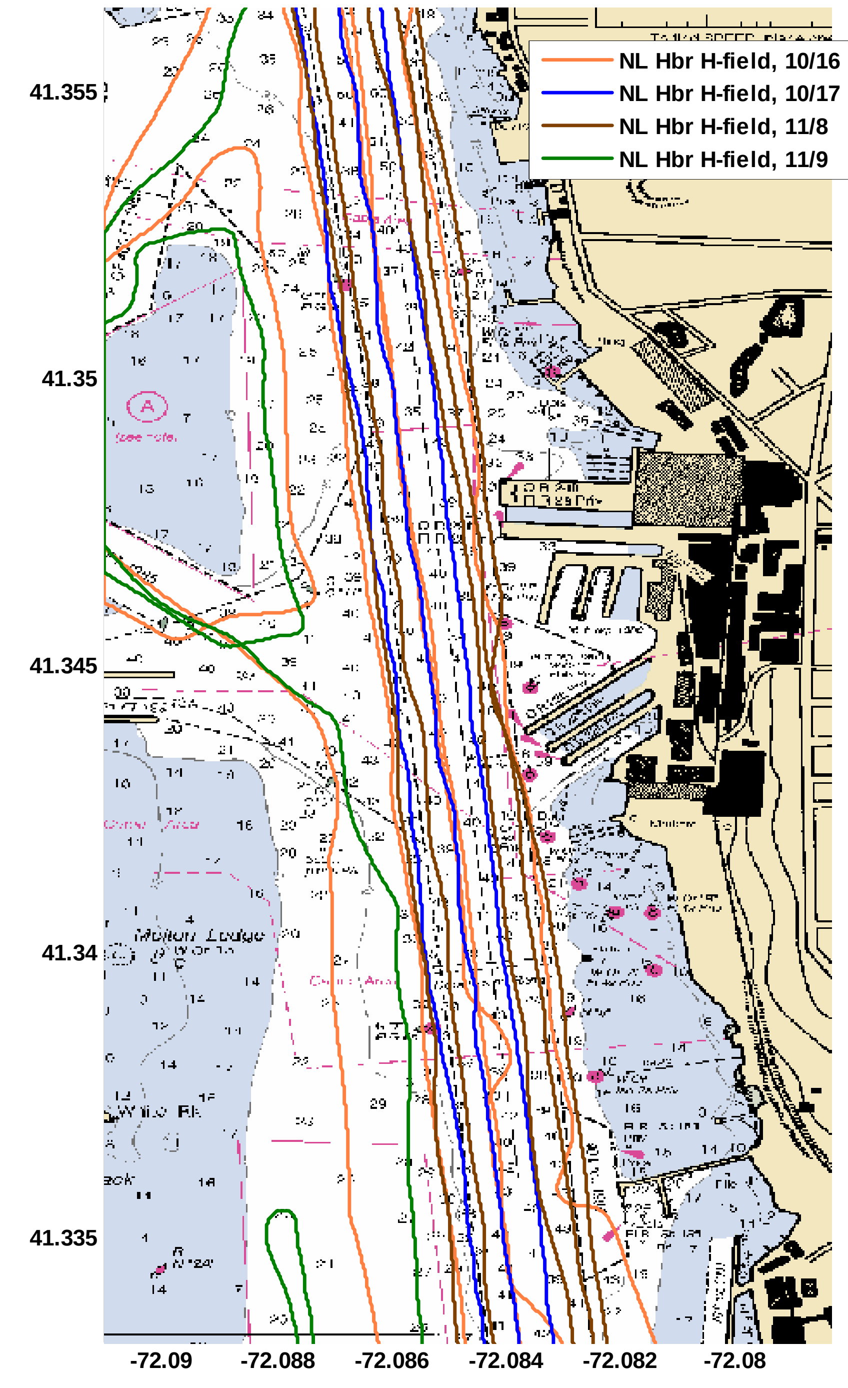
- Mar 2006

Other vessels

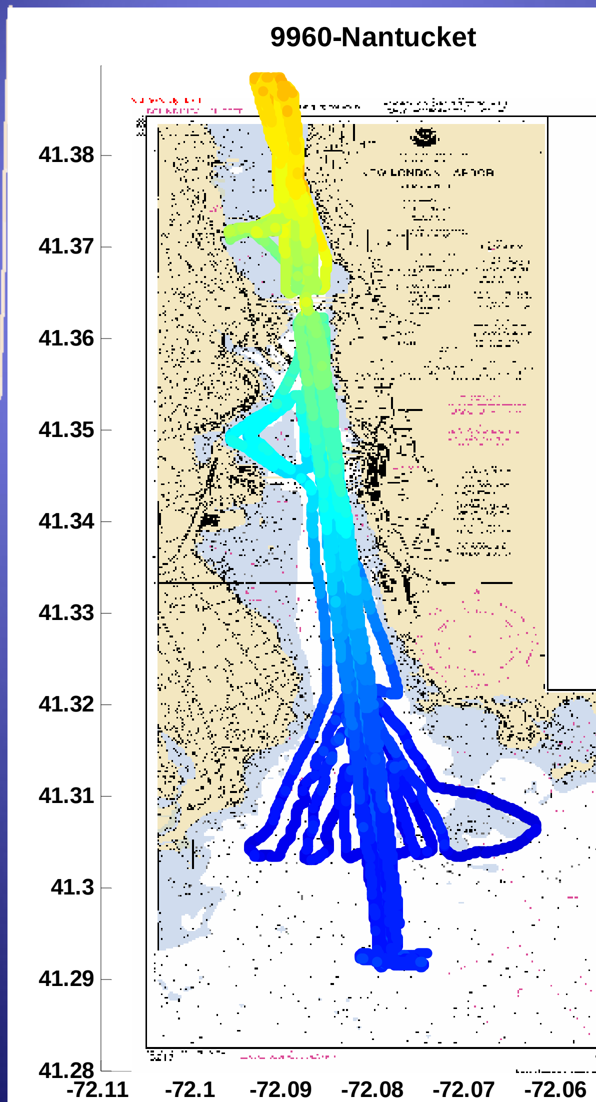
- Mar, Apr 2006

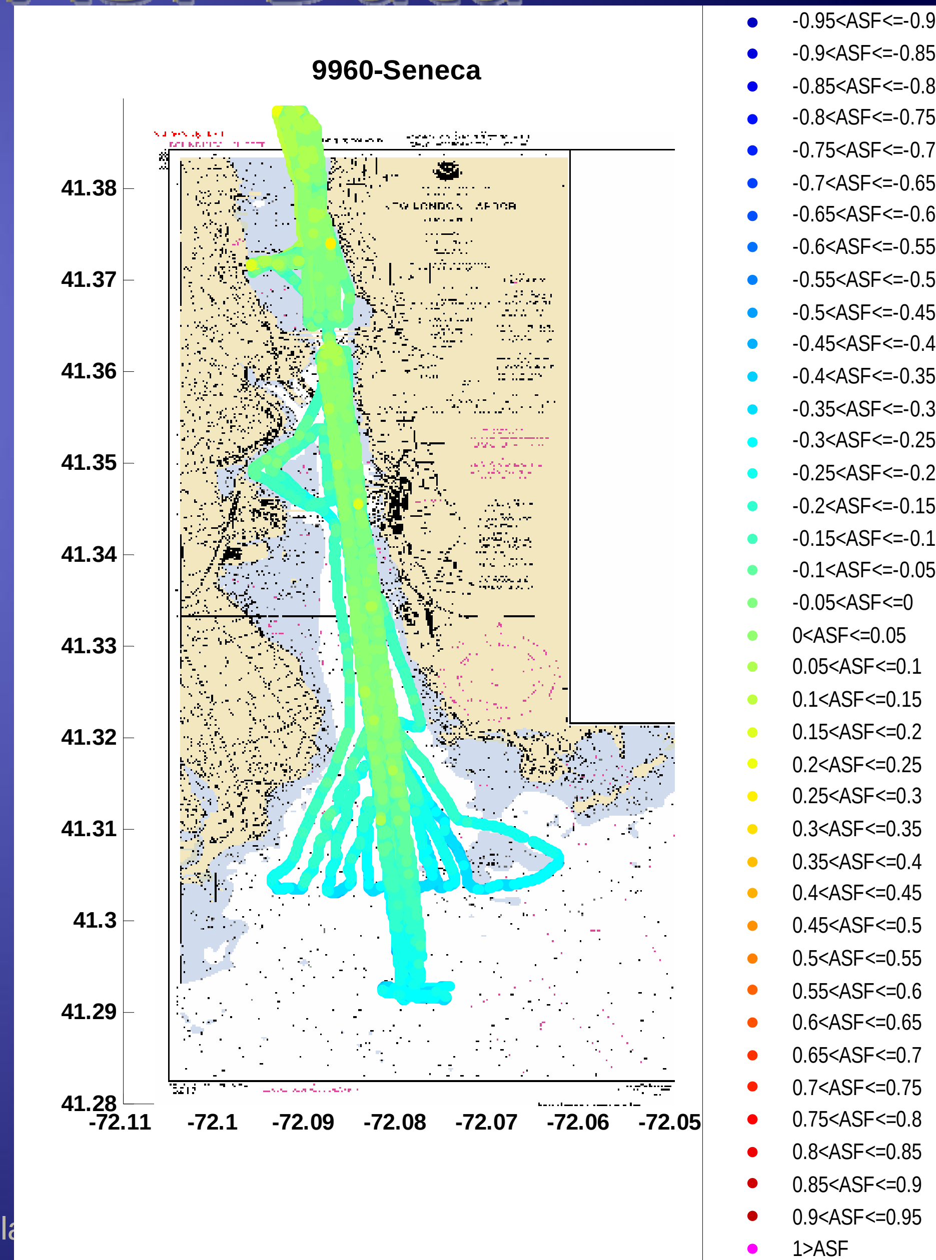
Locations/Tracks





Thames Relative ASF Data



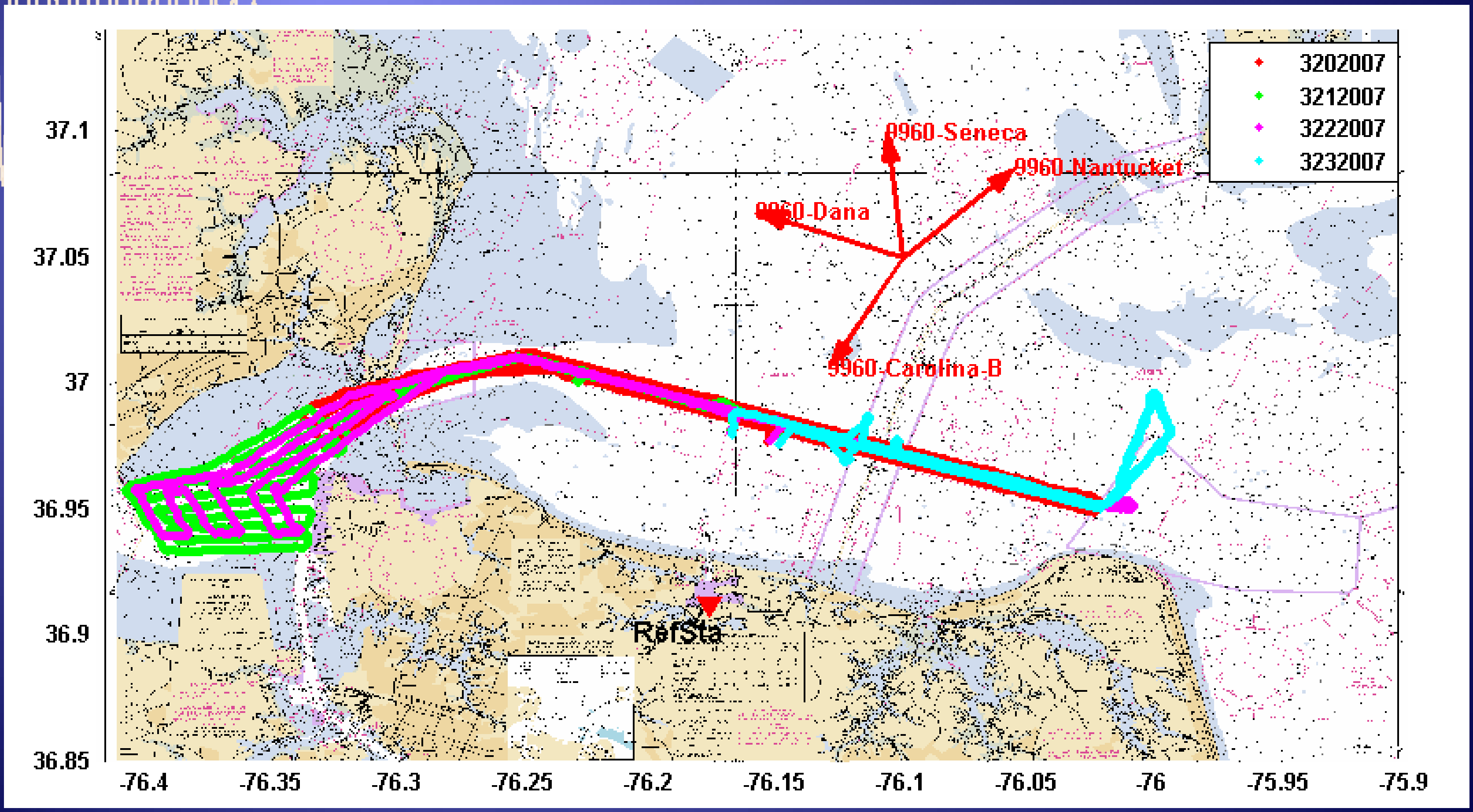


Norfolk

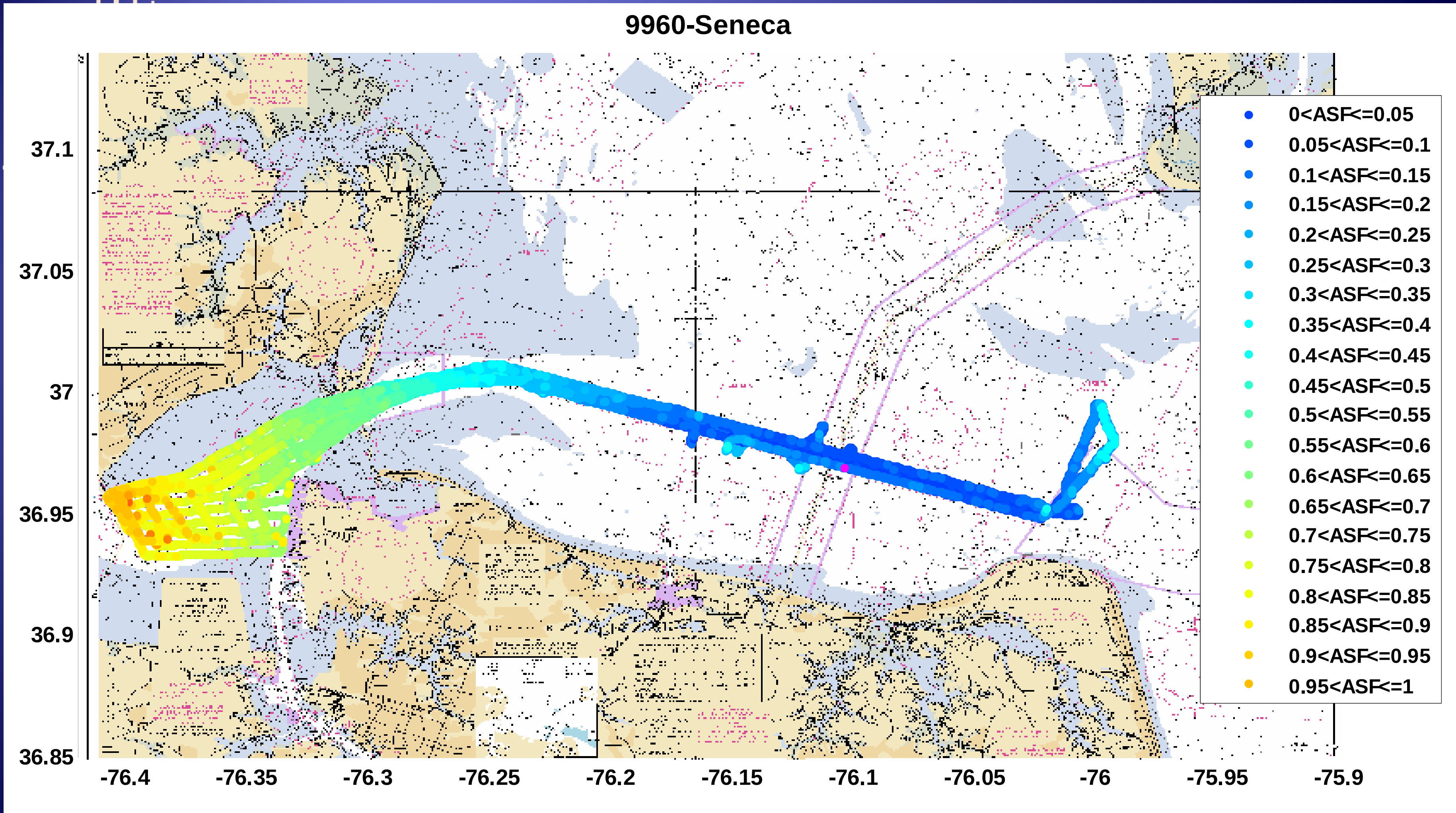
Chesapeake Bay approach channel into Norfolk Harbor

Survey Vessel, Halcyon Lace

Norfolk Harbor Coverage



Seneca Relative ASFs



Boston Harbor

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

Survey Vessel, Three J's

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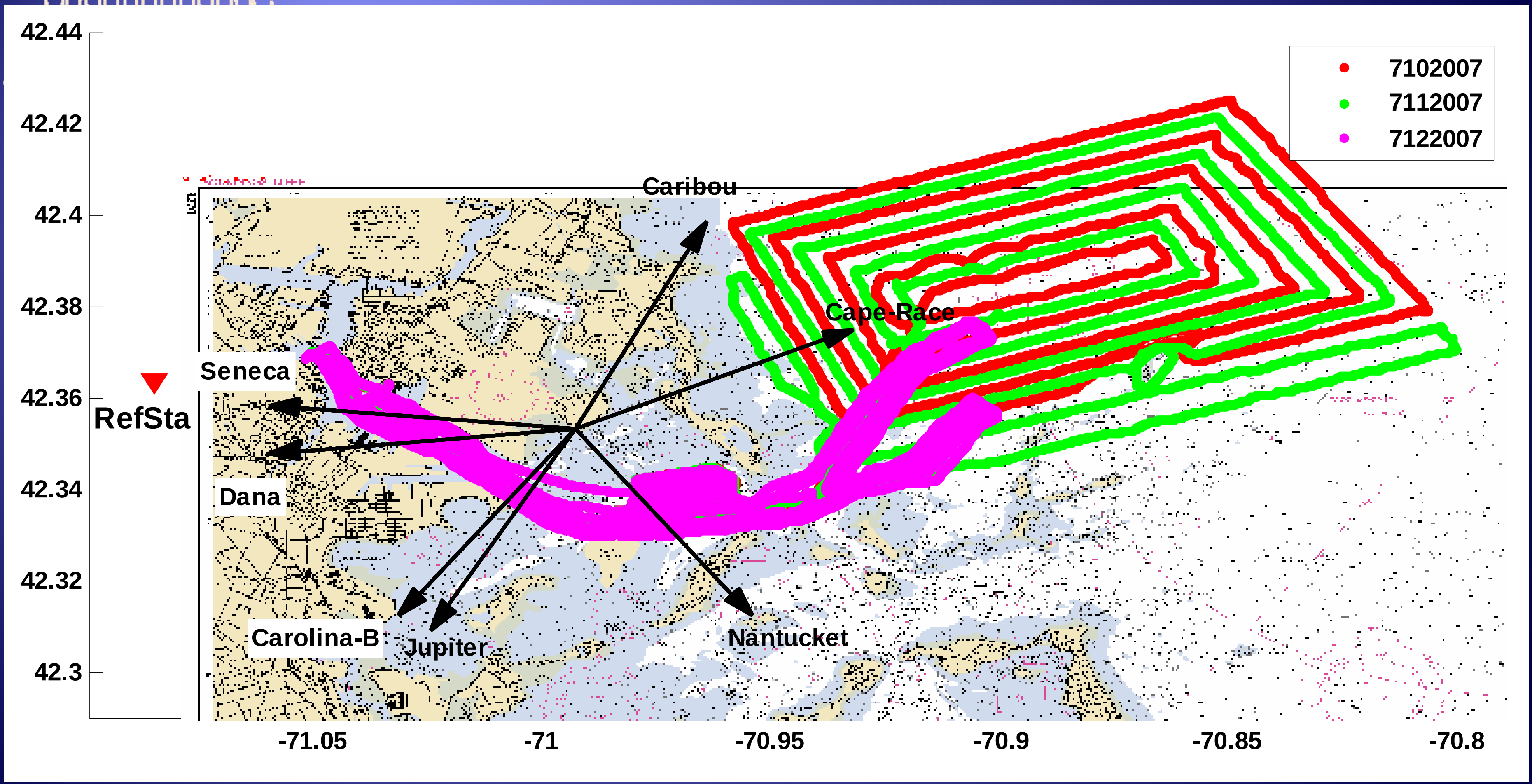
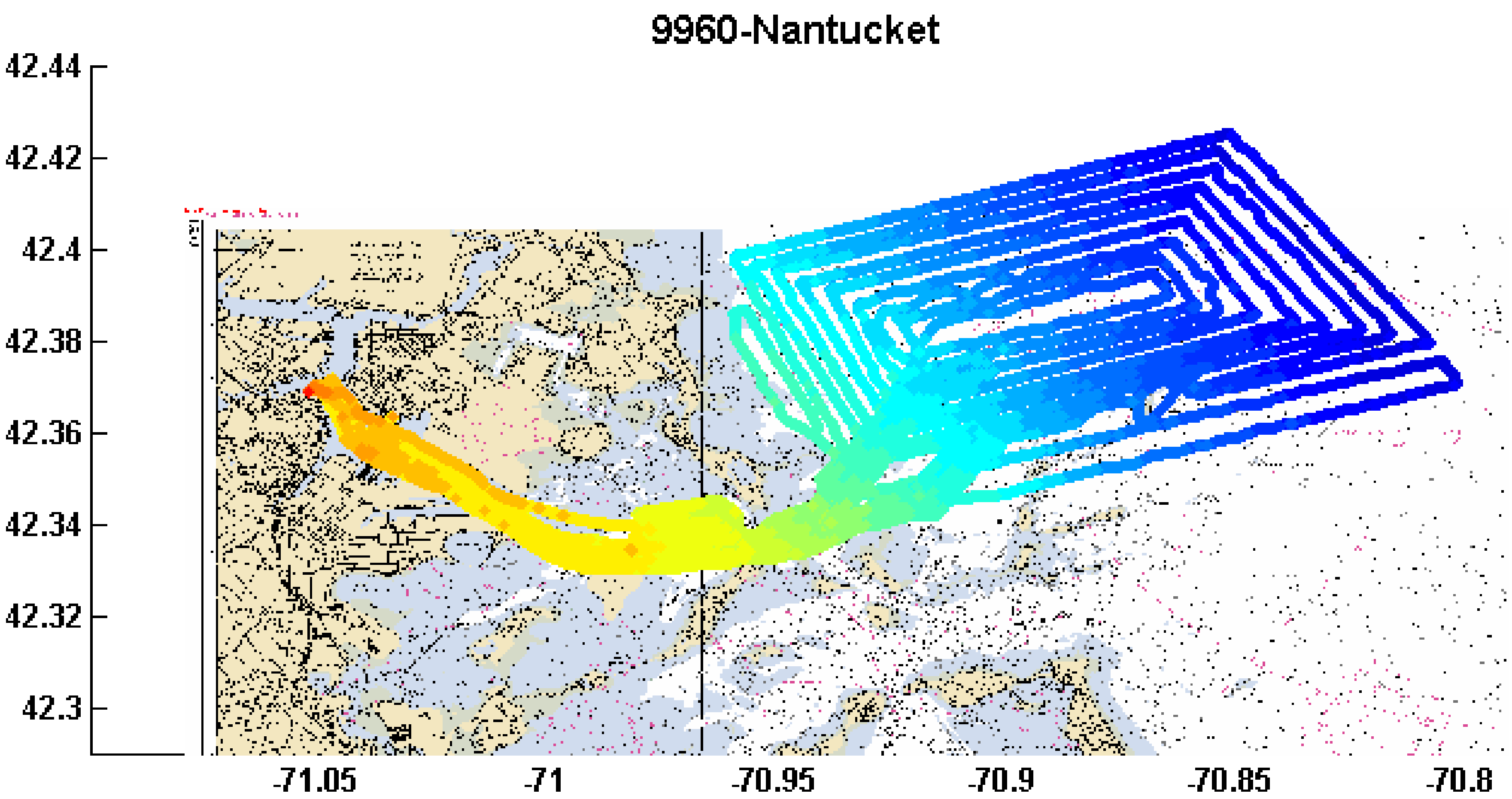
Boston Coverage Area



Nantucket Relative ASFs



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

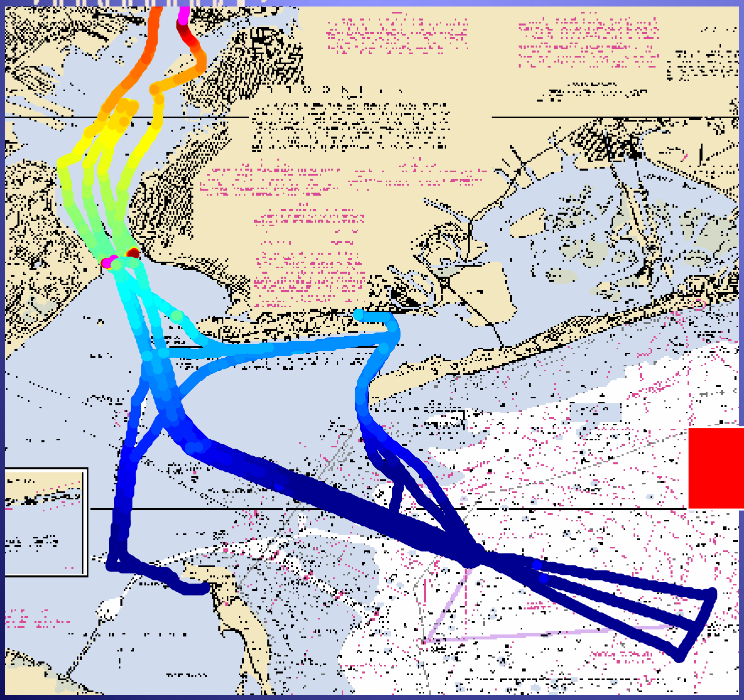
  $(ASF_{boat} – ASF_{ref})$

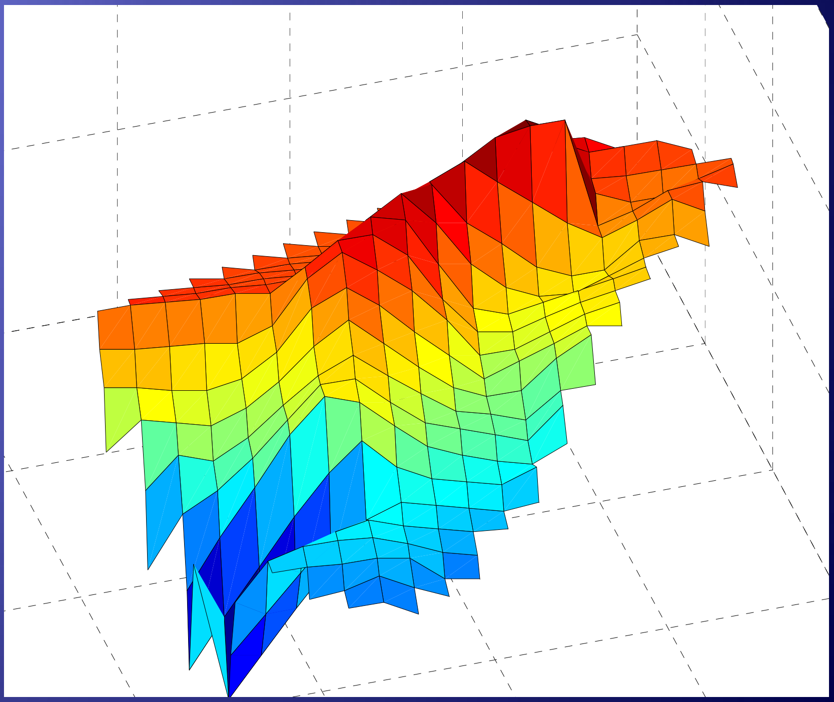
Spatial ASF Grids

- 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)**





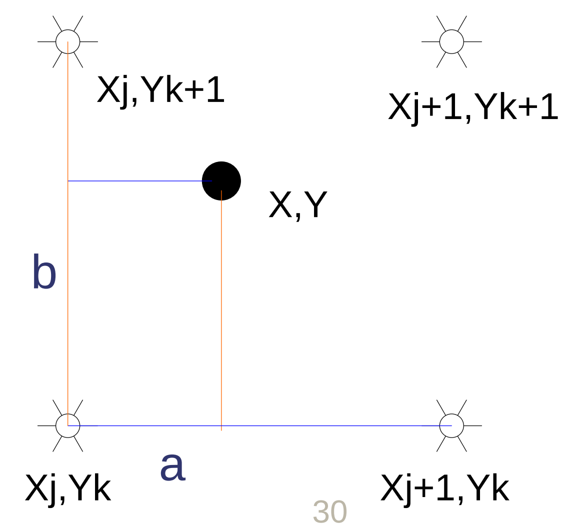
Grid Creation

- **Recall standard linear interpolation:**
  - Given a function at grid points, we can interpolate a general $F(x, y)$ by

$$
\begin{aligned}
F(x,y) \quad = \quad & (1-a)(1-b)F(x_j, y_k) + a(1-b)F(x_{j+1}, y_k) \\
& + b(1-a)F(x_j, y_{k+1}) + abF(x_{j+1}, y_{k+1})
\end{aligned}
$$

  - with

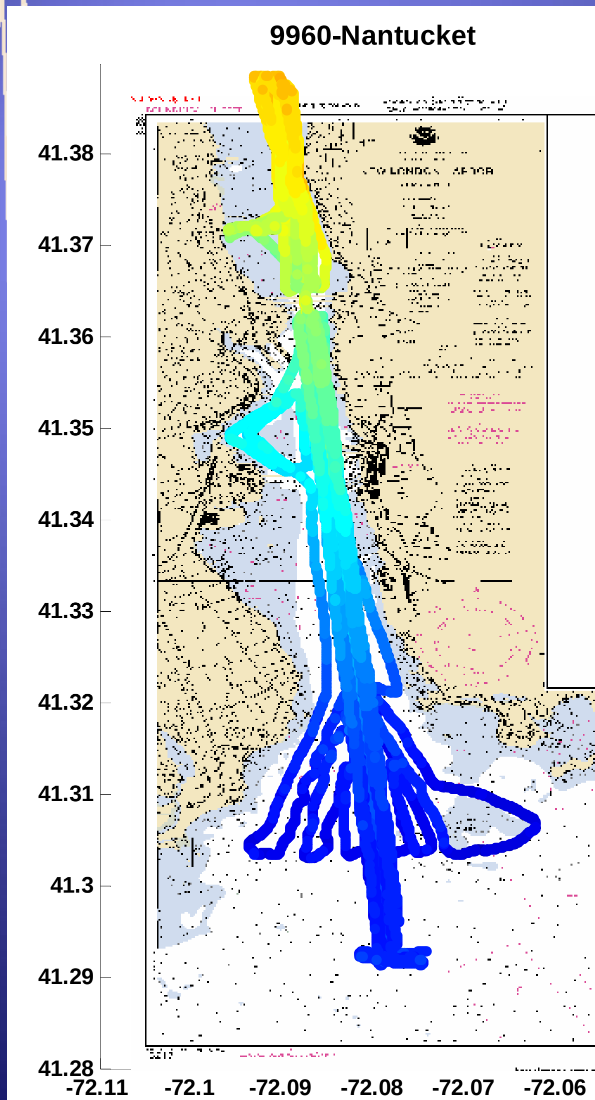
$$
a = \frac{x - x_j}{x_{j+1} - x_j} \quad \text{and} \quad b = \frac{y - y_k}{y_{k+1} - y_k}
$$

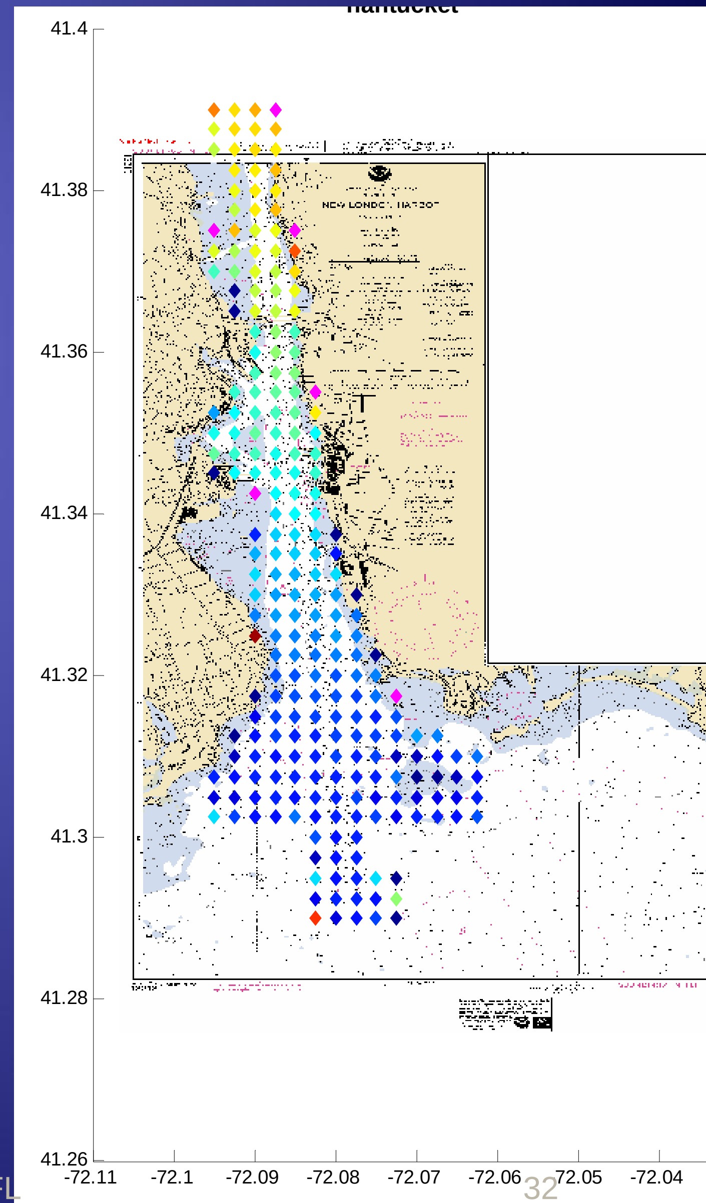


"Inverse Interpolation"

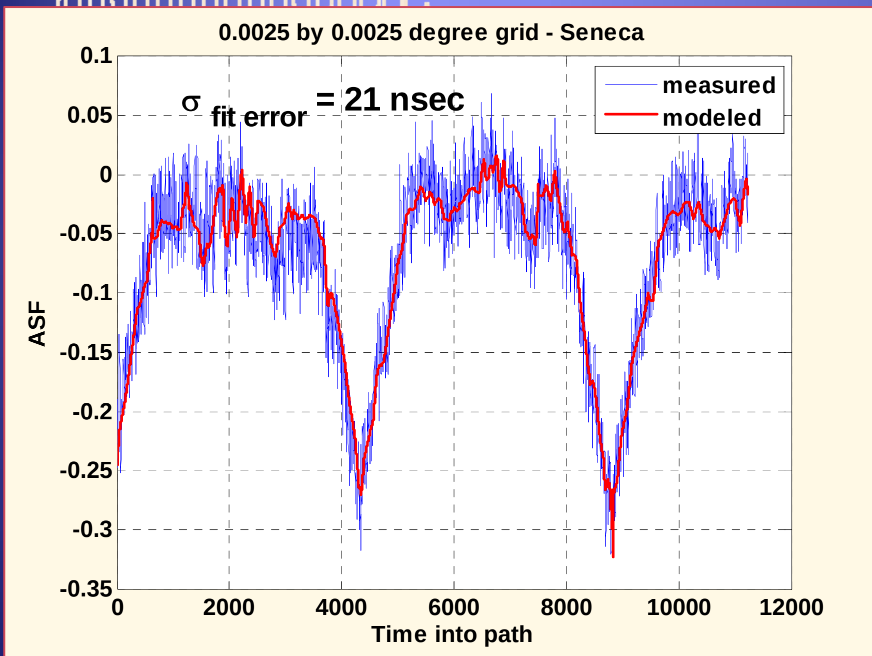
- **Turn the equations around:**
  - $$(1-a)(1-b)F(x_j, y_k) + a(1-b)F(x_{j+1}, y_k) + b(1-a)F(x_j, y_{k+1}) + abF(x_{j+1}, y_{k+1}) = F(x, y)$$
  - a, b, and F(x, y) are known
  - so each data point yields a linear equation in 4 unknowns
  - solve large set of simultaneous linear equations to get grids

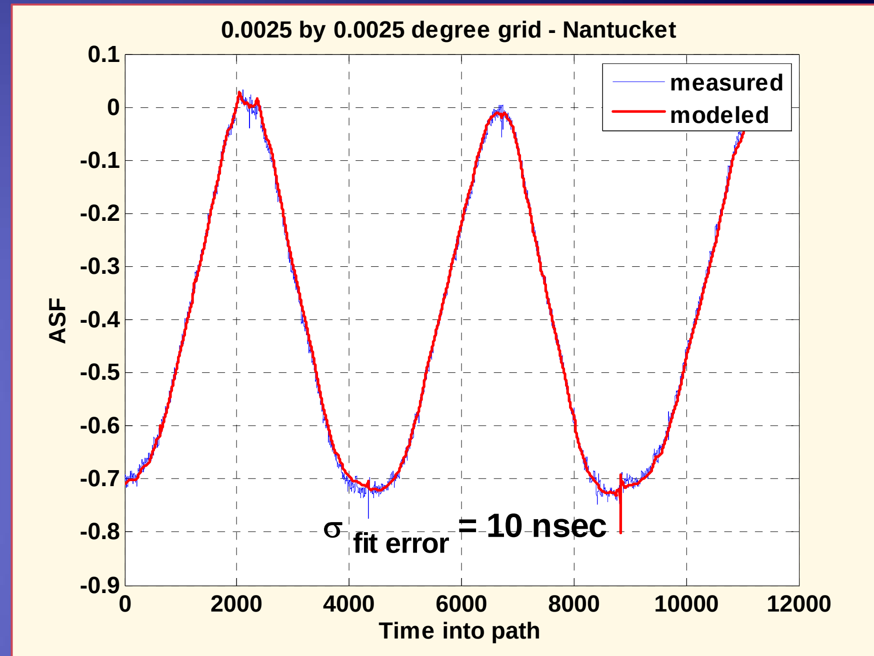
Sample Grid - Nantucket

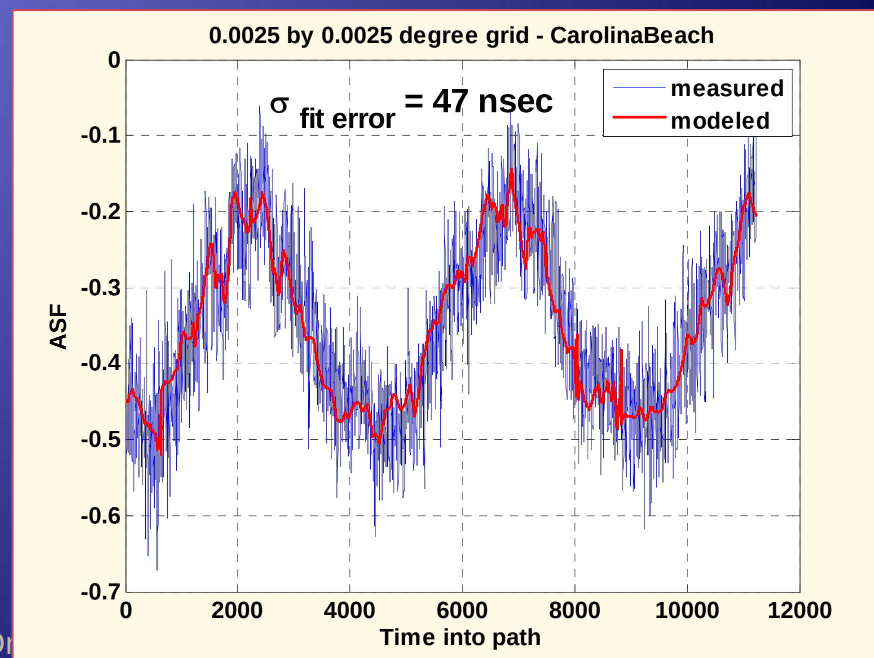


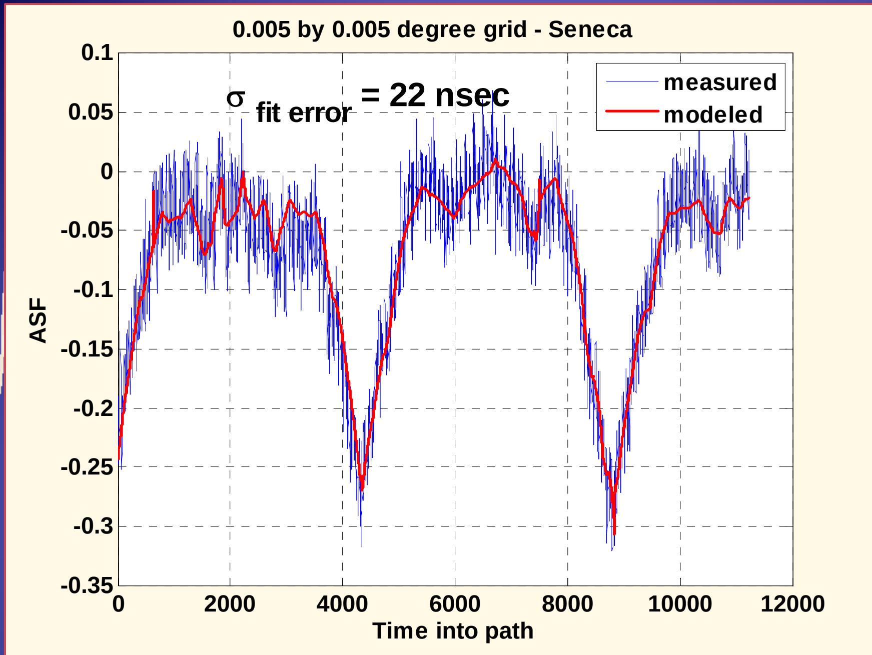


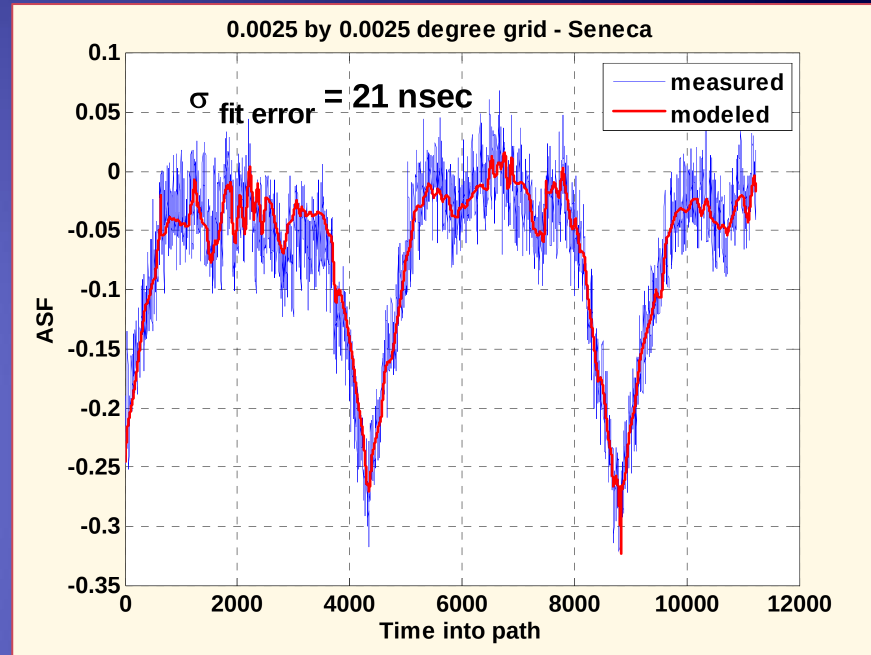
Grid fit to data

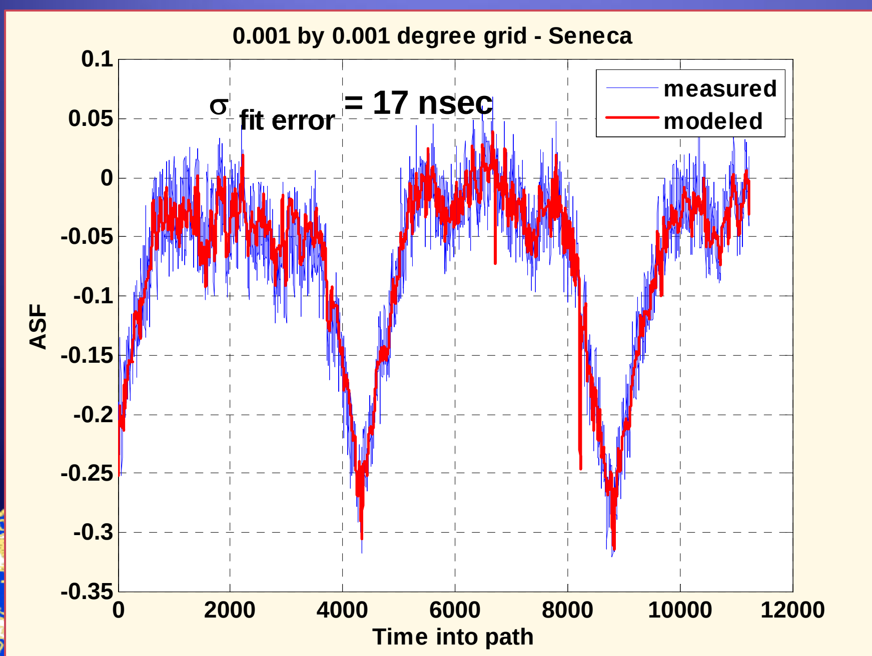












		Fit error in nsec		
Resolution	~meters	Seneca	Nantucket	Carolina Beach
0.0005	55	13	3	30
0.0010	110	17	7	40
0.0015	165	20	9	44
0.0020	225	21	10	47
0.0025	280	21	10	47
0.0050	560	22	10	48

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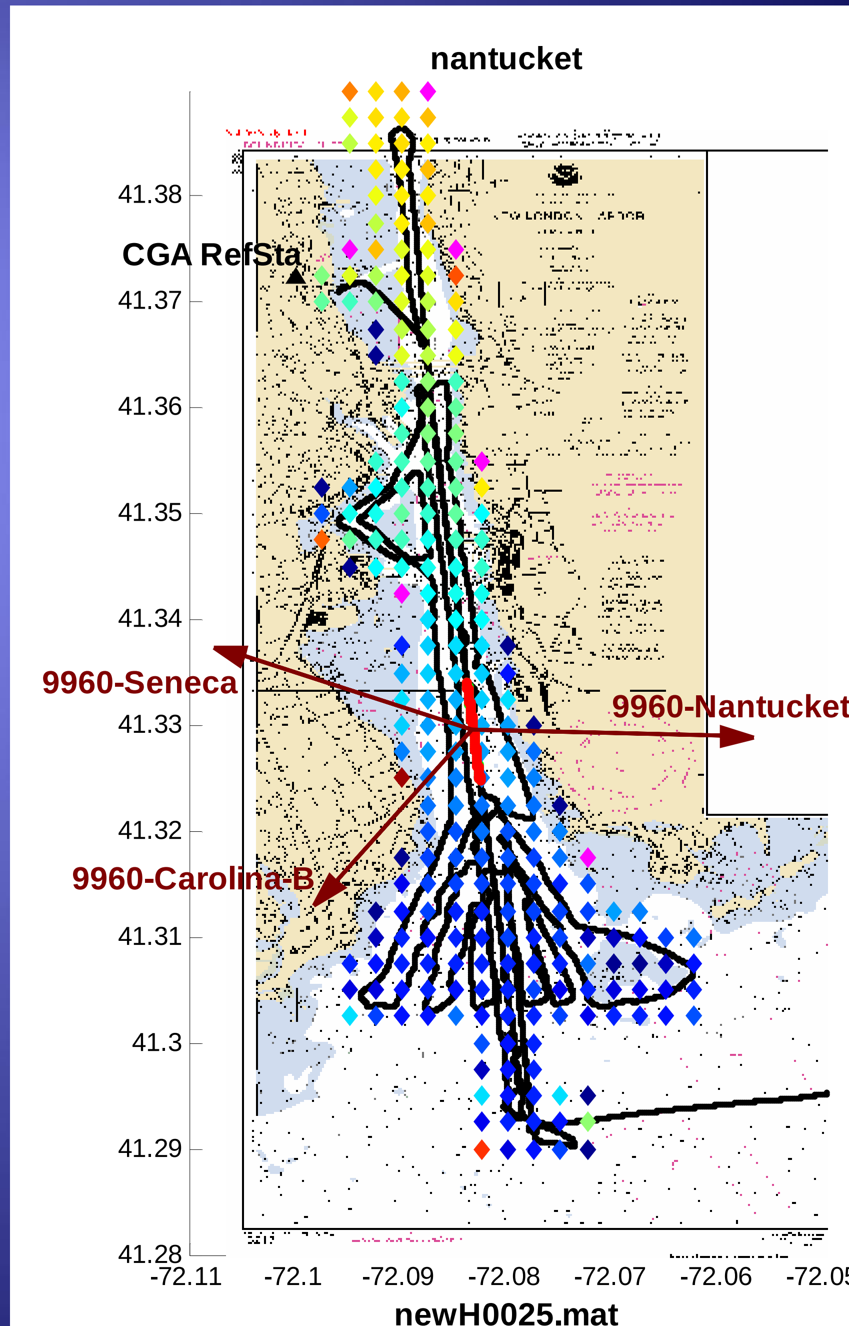
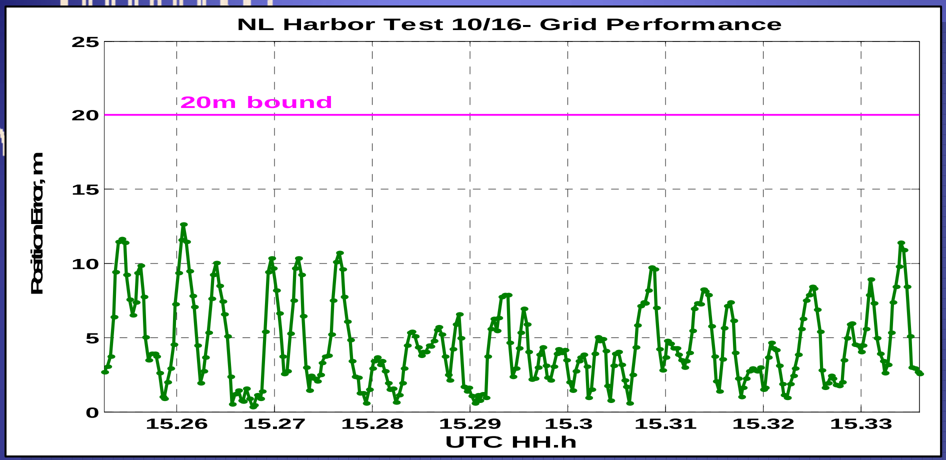
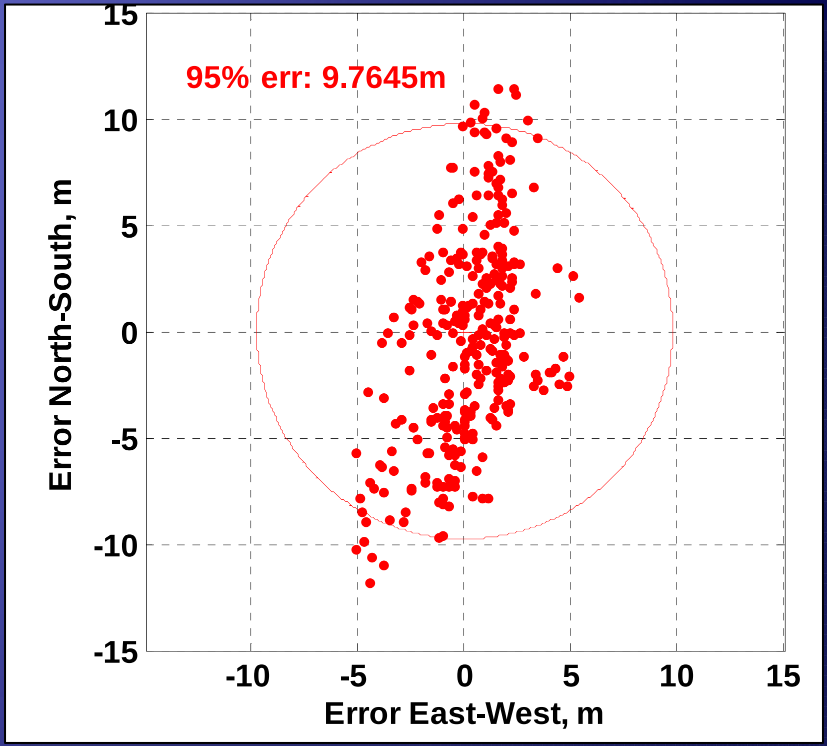
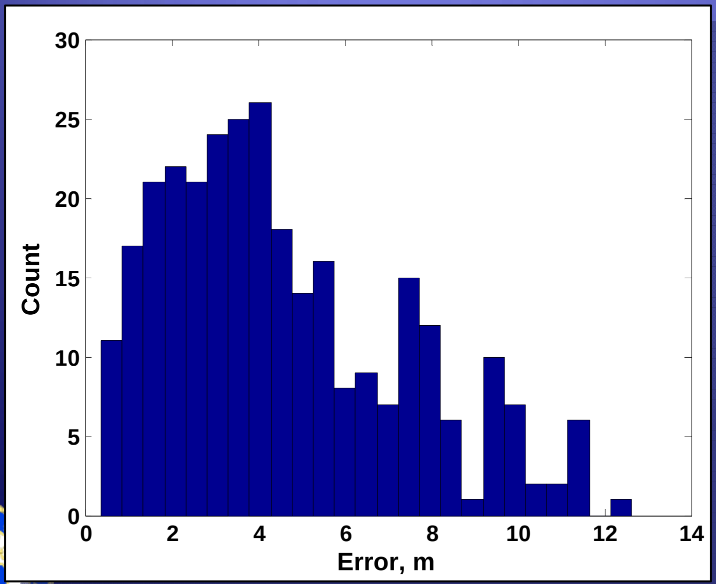
Thames Performance Example



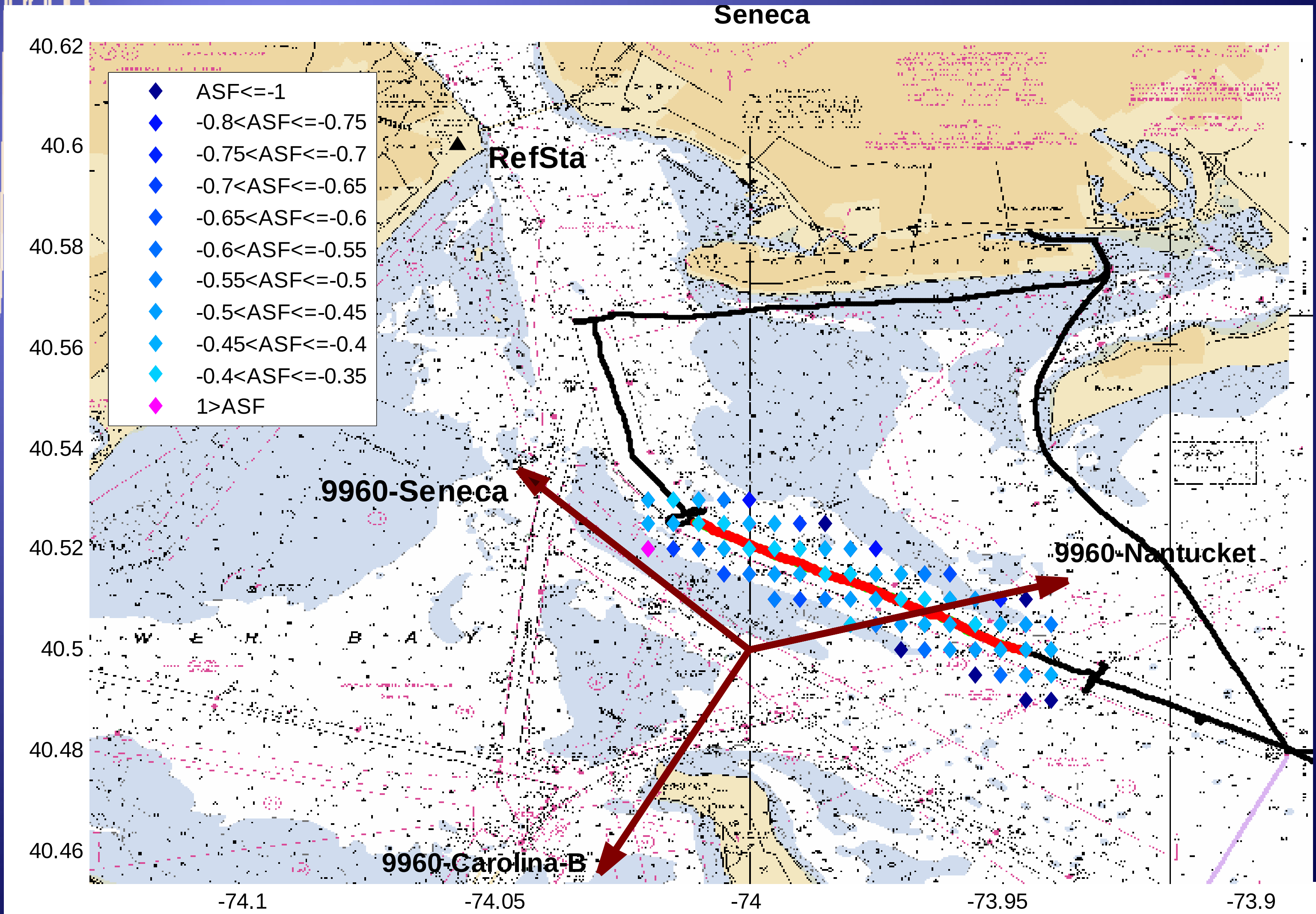
Thames Performance



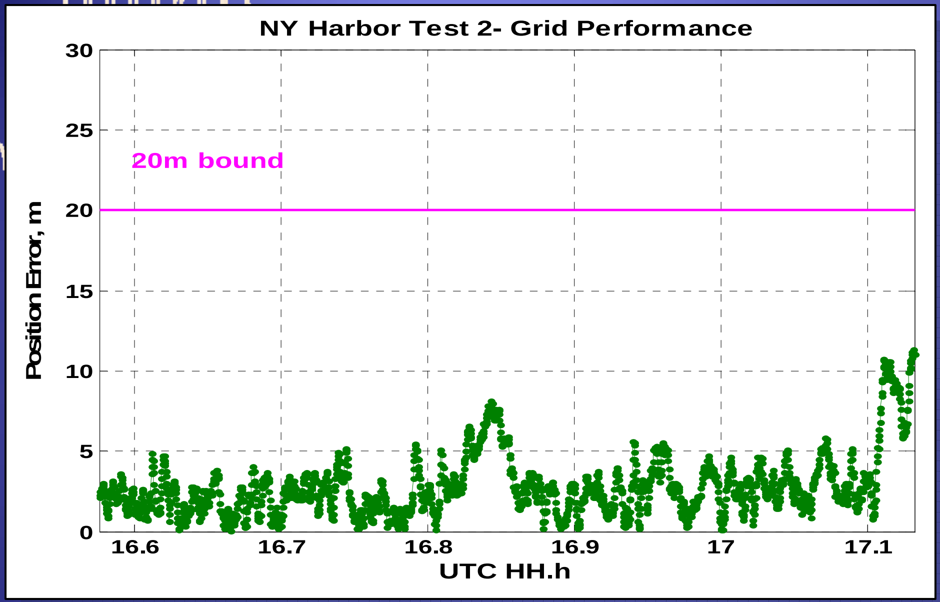


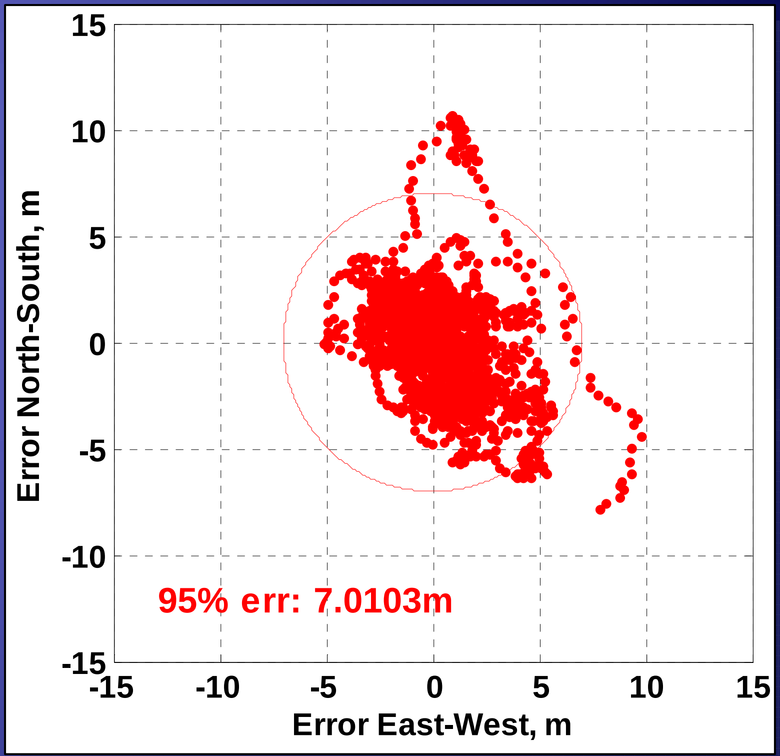


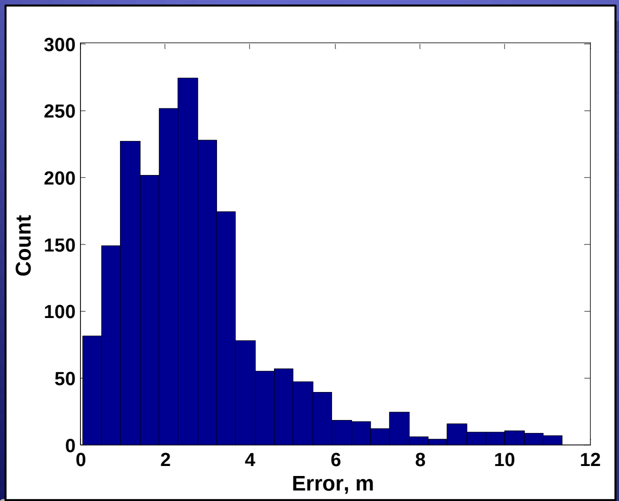
New York Performance Example



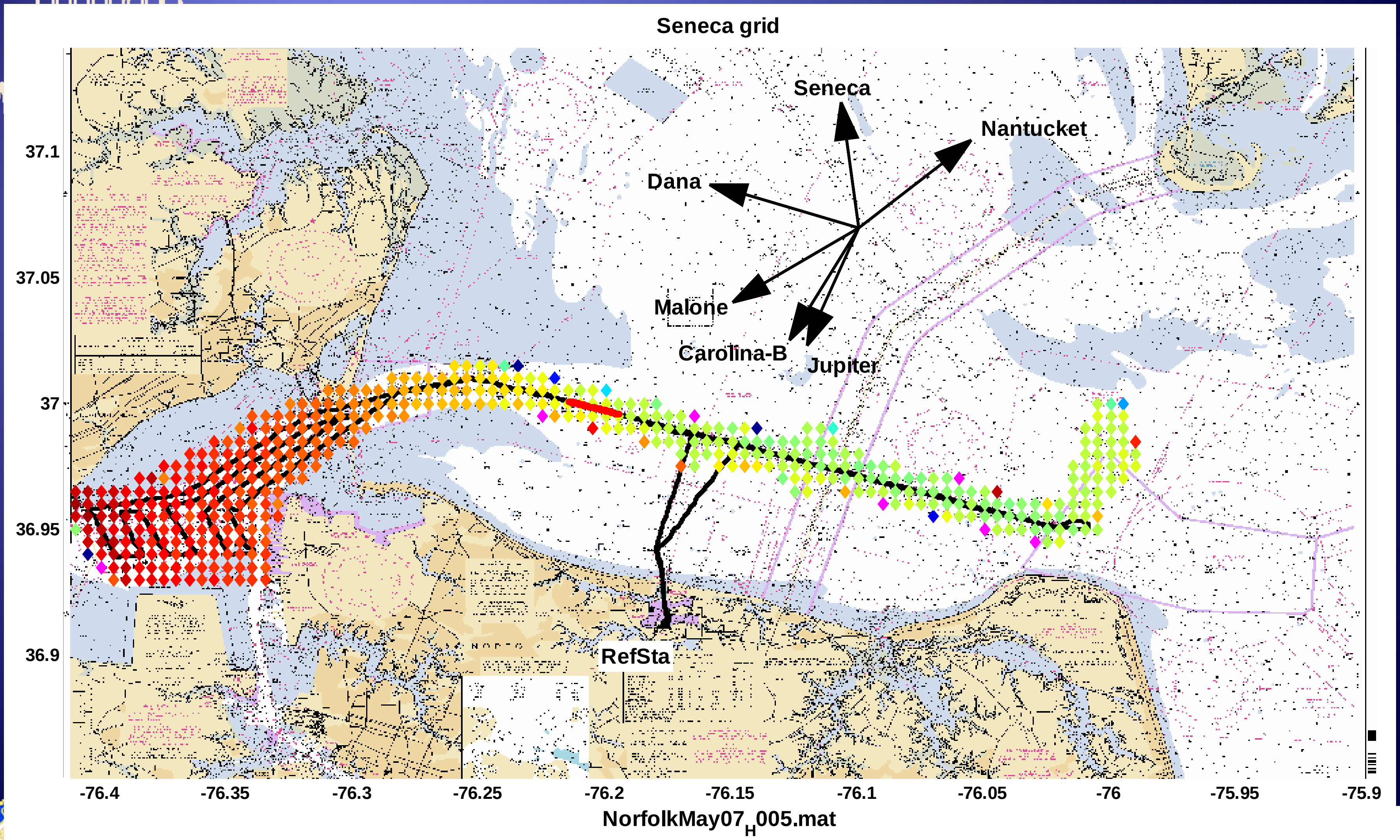
NY Performance – Error Dist.







Norfolk Performance Example



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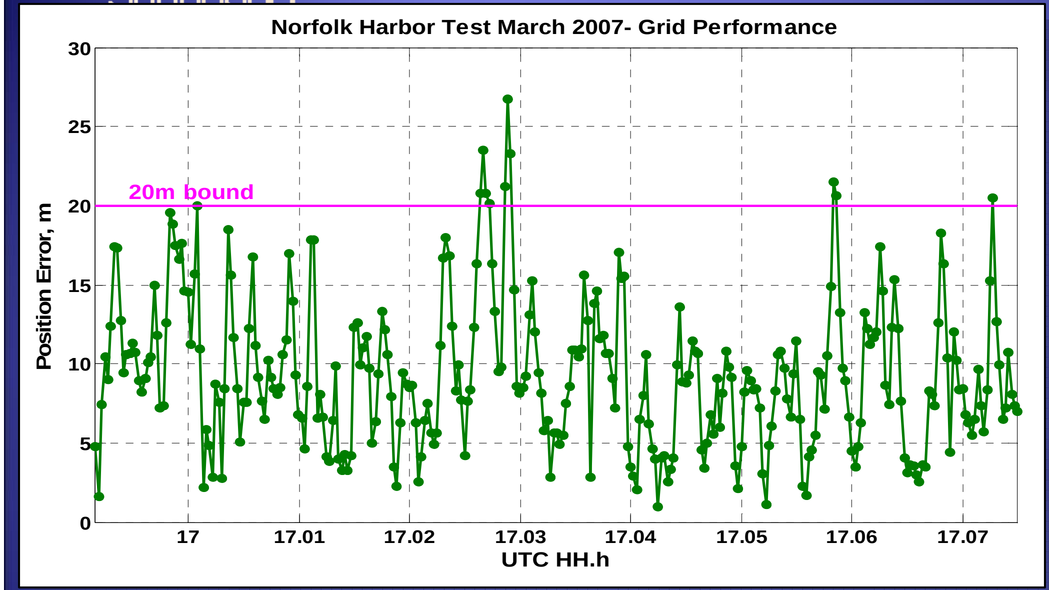
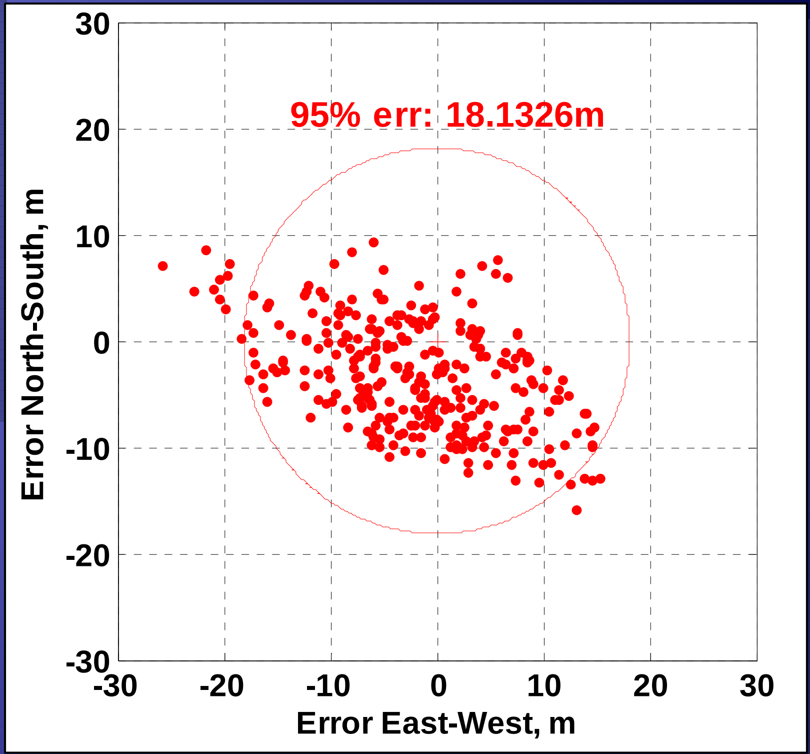
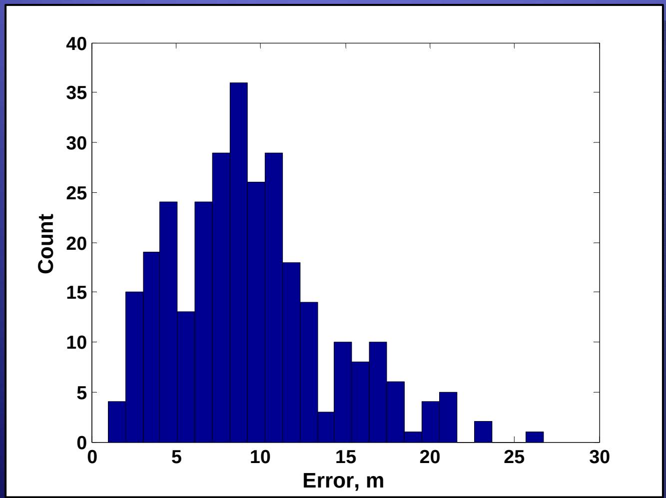
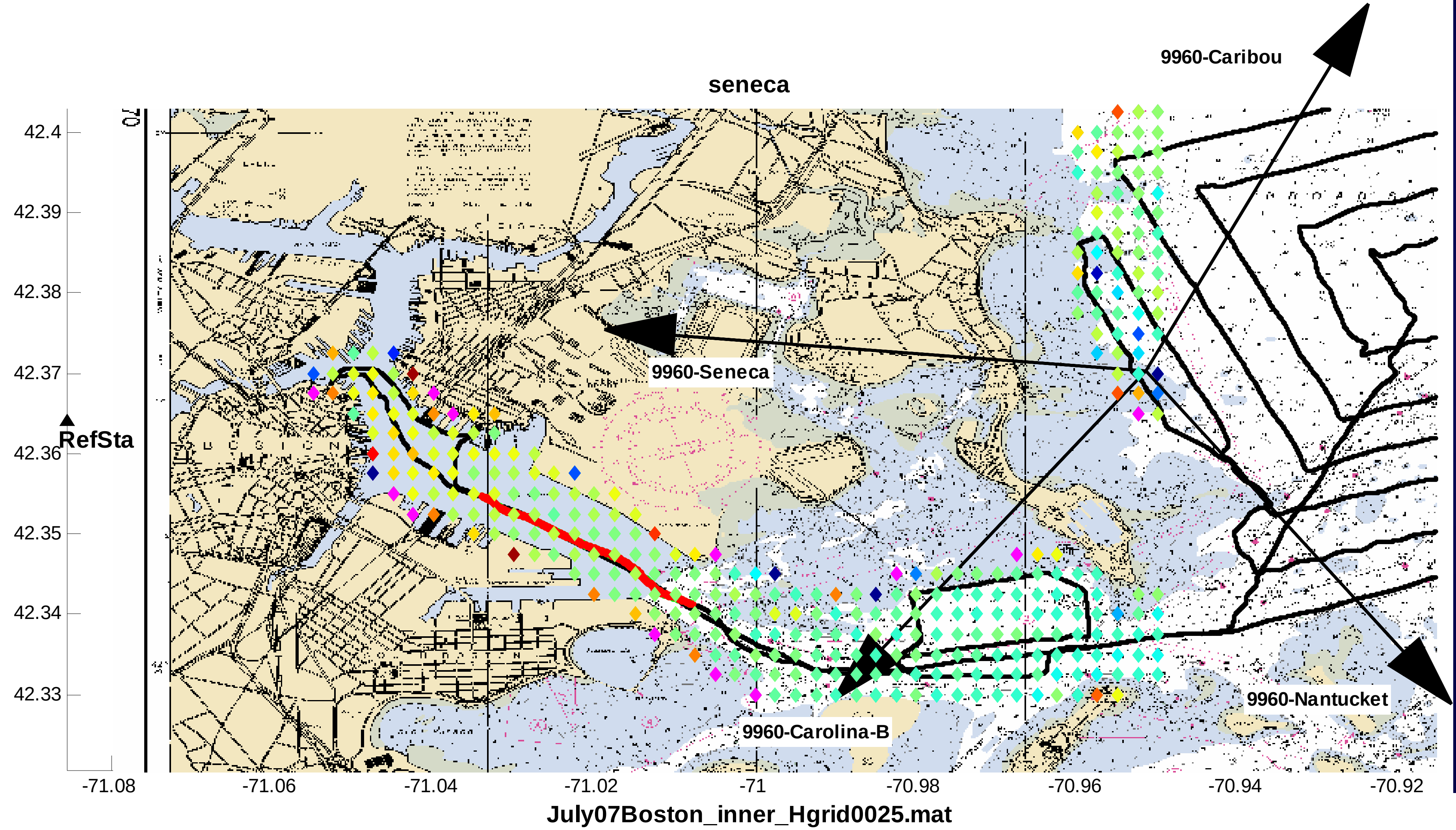
Norfolk Performance – Error Dist.







Boston Performance Example



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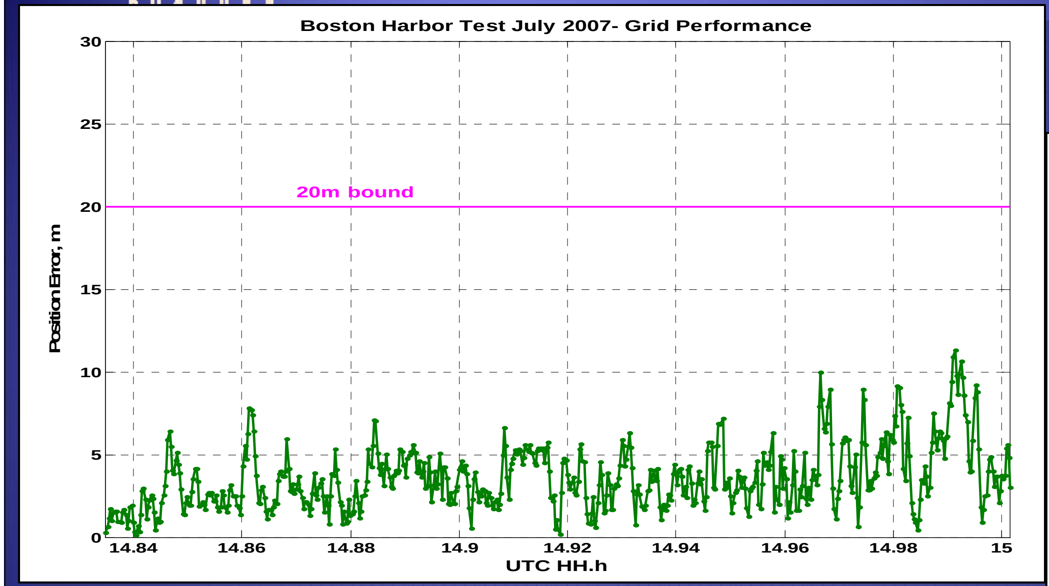
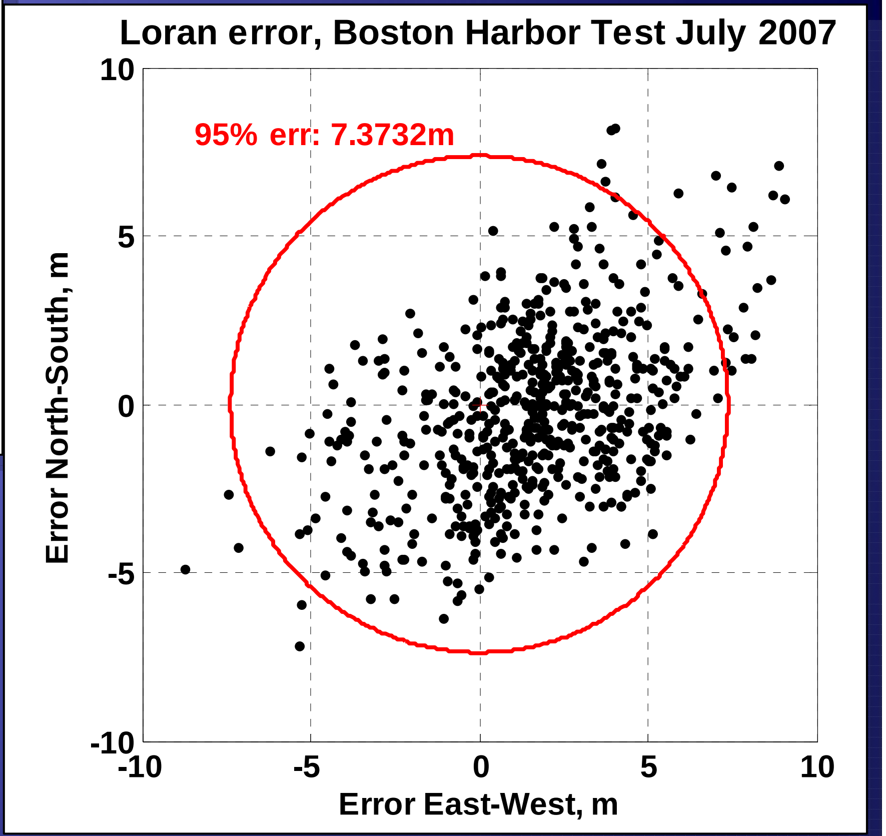
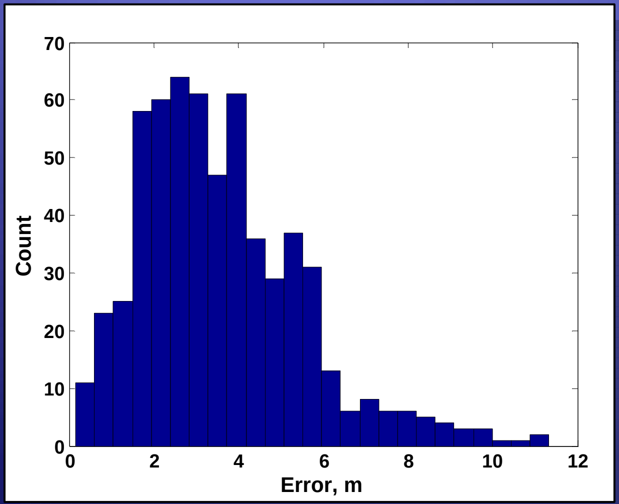
Boston Performance – Error Dist.



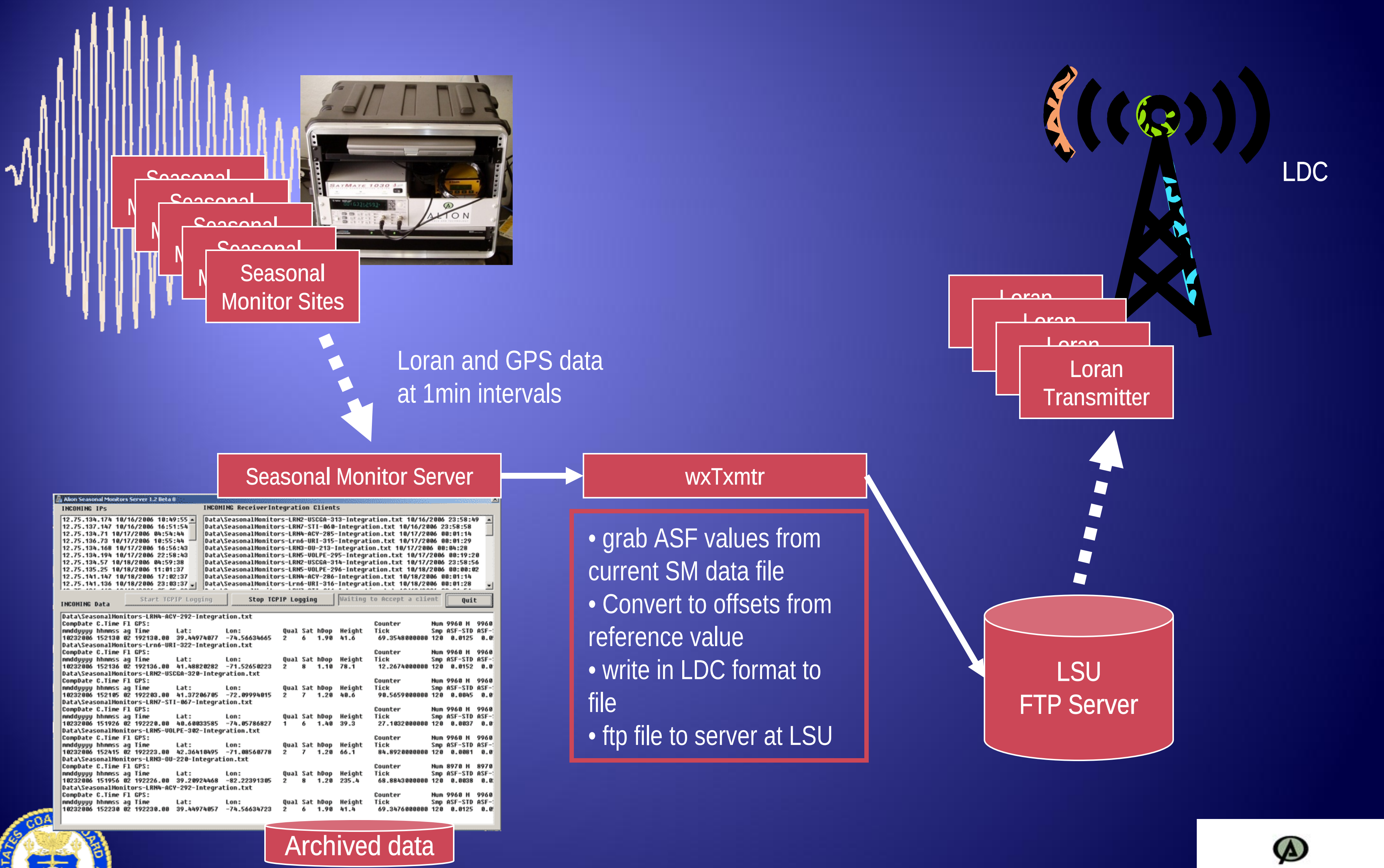




Temporal Corrections

- LDC Architecture
- Typical Spatial Correlation

LDC Architecture



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

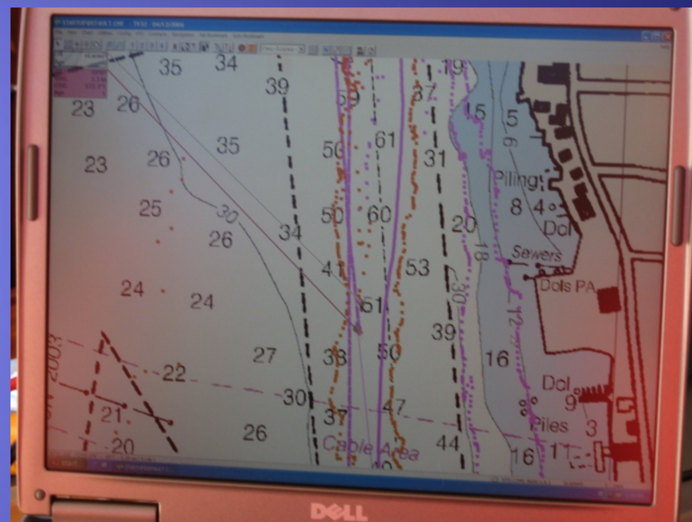
Prototype eLoran Receiver

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

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

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  - Christian Oates
  - Ruslan Shalaev
  - Mark Wiggins
  - Ken Dykstra
- **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)
- **USCG Loran Support Unit**
  - CDR Chris Nichols
  - LT Chris Dufresne

Questions?

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