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Optimal Detection of Surface Drifting Mine with Navy Ocean Model

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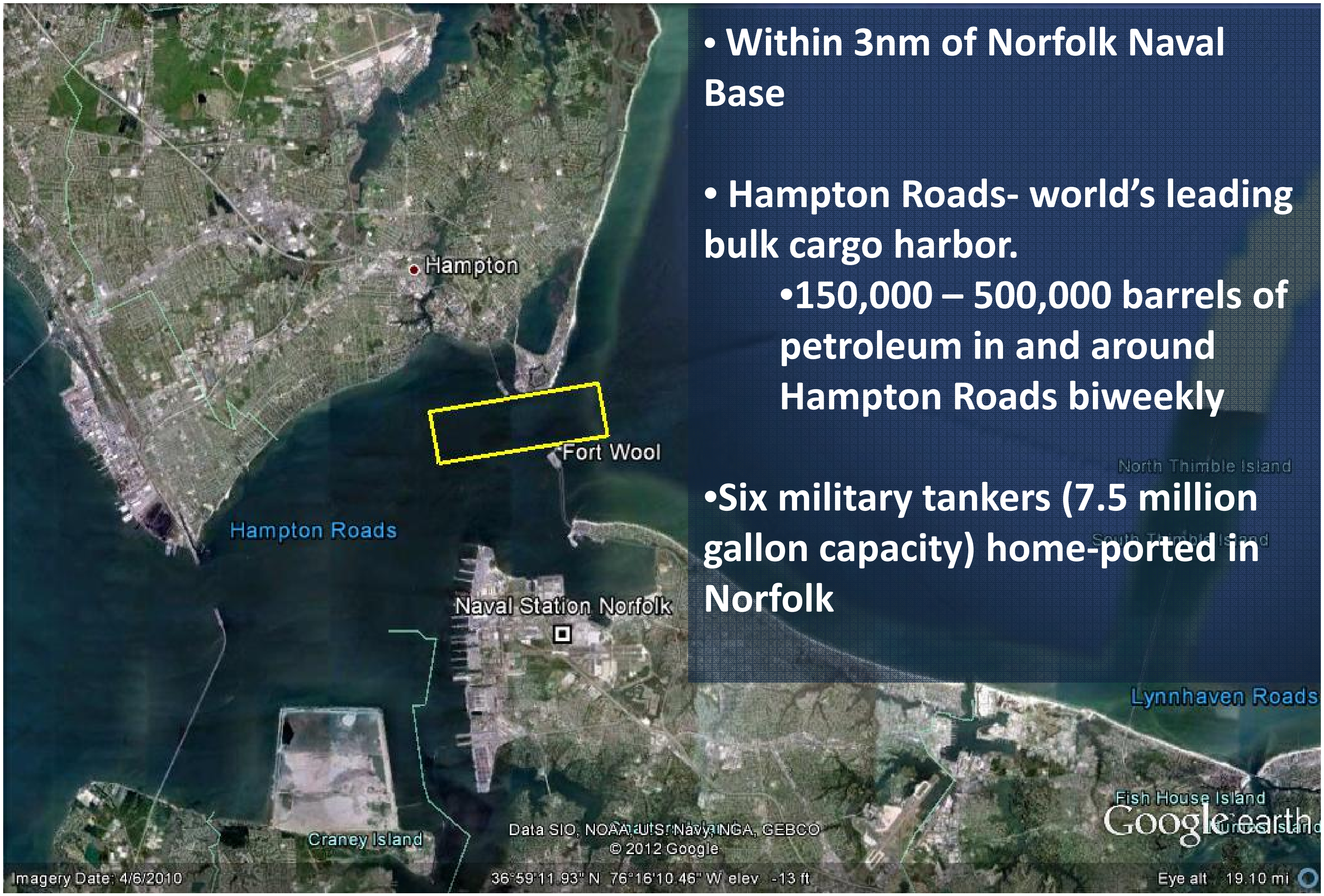
Purpose

- To provide methodology for optimizing locations of stationary sensors and UUV path planning intended for drifting mine detection using Navy ocean model

Specific Requirements

- Estimations of target movement
- Optimal sensor numbers
  (or number of UUVs)
- Optimal sensor locations
  (or UUV locations)

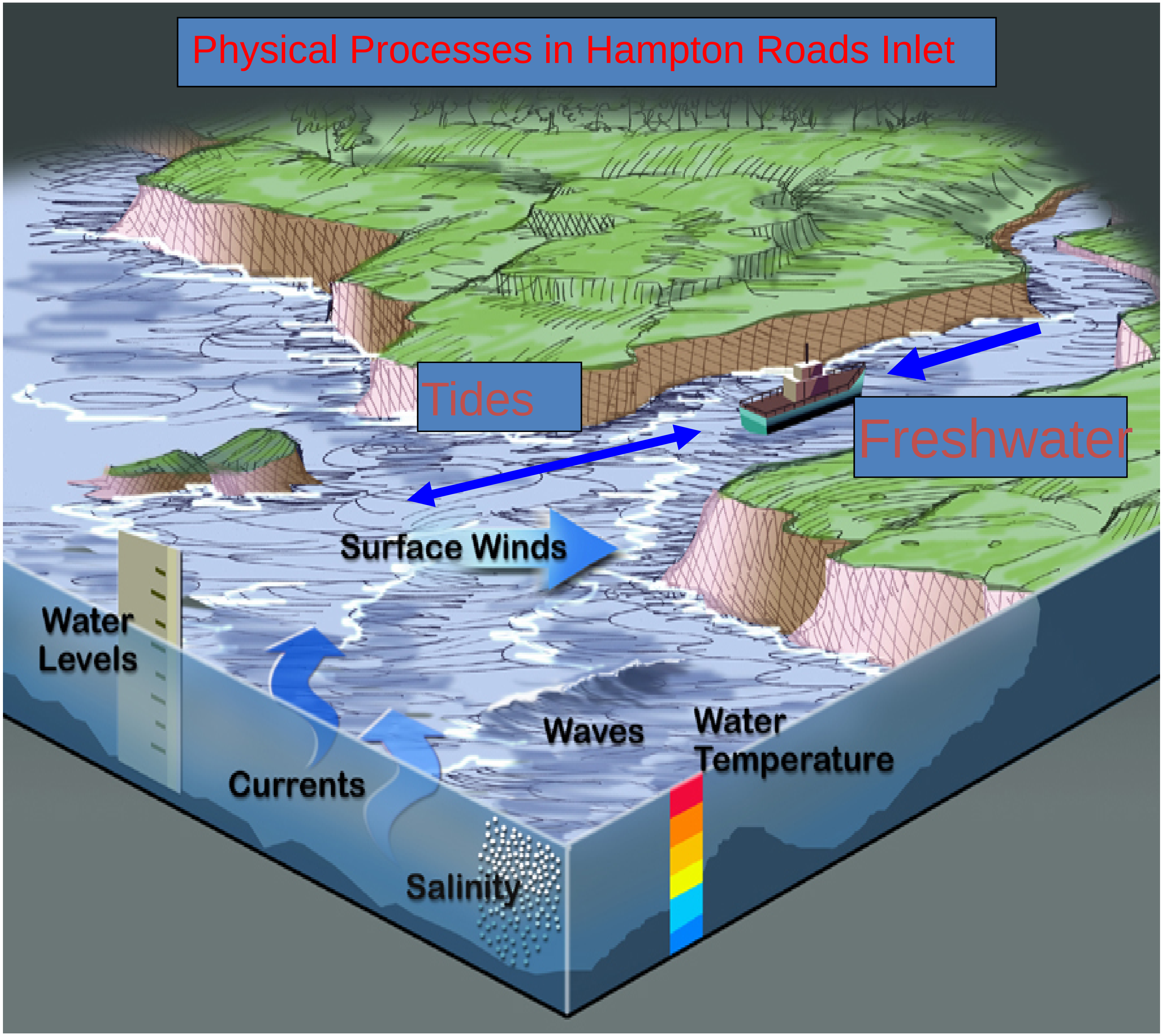
Hampton Roads Inlet



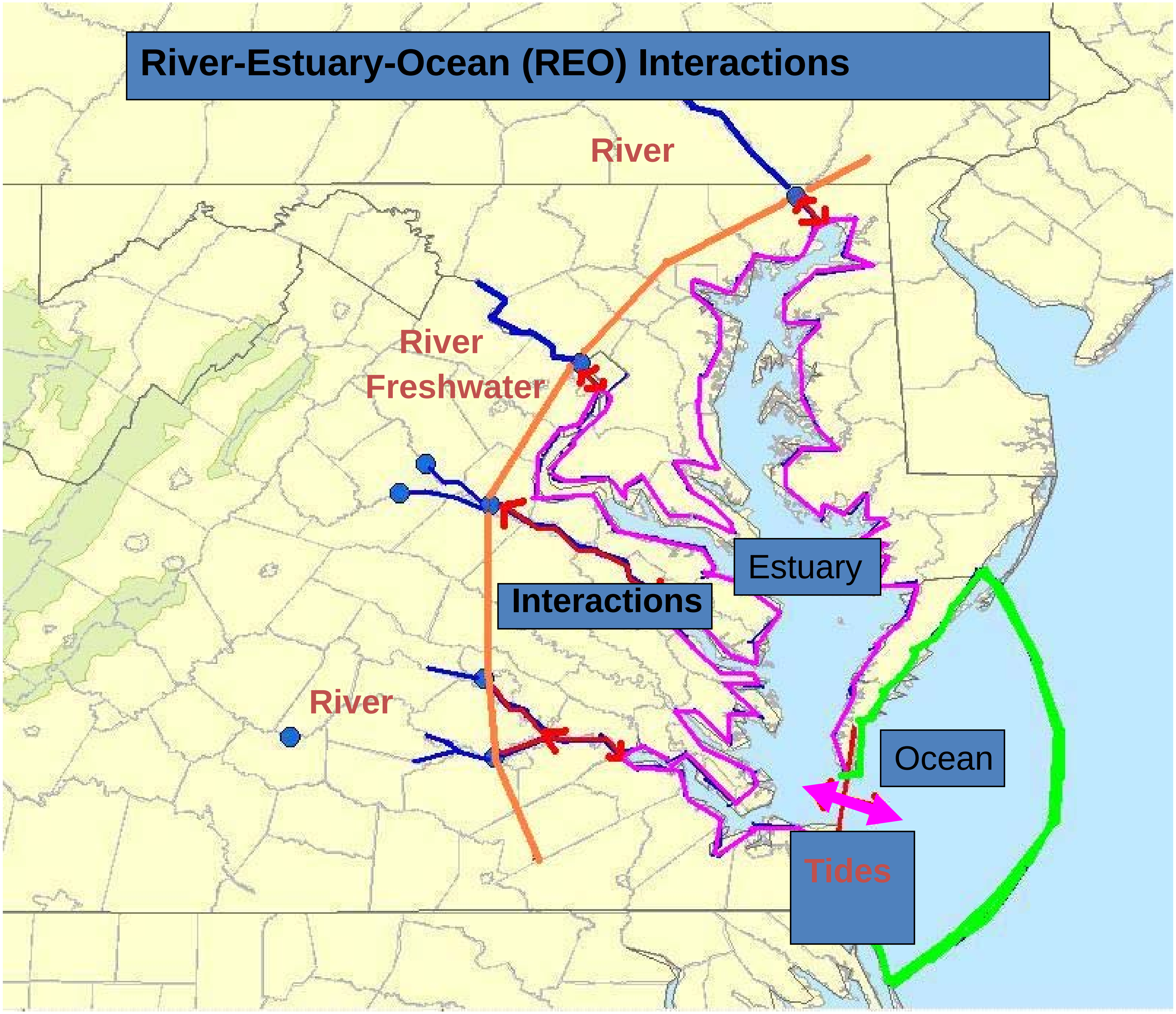
- Within 3nm of Norfolk Naval Base

- Hampton Roads- world's leading bulk cargo harbor.
  - 150,000 – 500,000 barrels of petroleum in and around Hampton Roads biweekly

- Six military tankers (7.5 million gallon capacity) home-ported in Norfolk



Physical Processes in Hampton Roads Inlet
Tides
Freshwater
Surface Winds
Water
Levels
Currents
Waves
Water
Temperature
Salinity


River-Estuary-Ocean (REO) Interactions
River
River
Freshwater
Estuary
Interactions
River
Ocean
Tides

Prediction of Mine Drifting

6 DOF Model

$$m\frac{d\mathbf{V}}{dt} = (\rho\Pi - m)g\mathbf{k} + f_{drag}\mathbf{e}_d + f_{lift}\mathbf{e}_l$$

$$\mathbf{I} \bullet \frac{d\mathbf{\Omega}}{dt} = \mathbf{r}_v \times \mathbf{f}_b + \mathbf{r}_f \times \left(\mathbf{f}_{drag} + \mathbf{f}_{lift}\right) + \mathbf{M}_r$$

V → Mine Drifting Velocity

Ω → Mine Angular Velocity

Definition of (f_{drag}, f_{lift}, M_r)

$$f_{drag} = \frac{1}{2} C_d \rho A_w (V - V_o)^2$$

$$f_{lift} = \frac{1}{2} C_l \rho A_w (V - V_o)^2$$

$$M_r = \frac{1}{2} C_m \rho \Pi_w (V - V_o)^2$$

V_o → Ocean Velocity (from Navy Ocean Model)

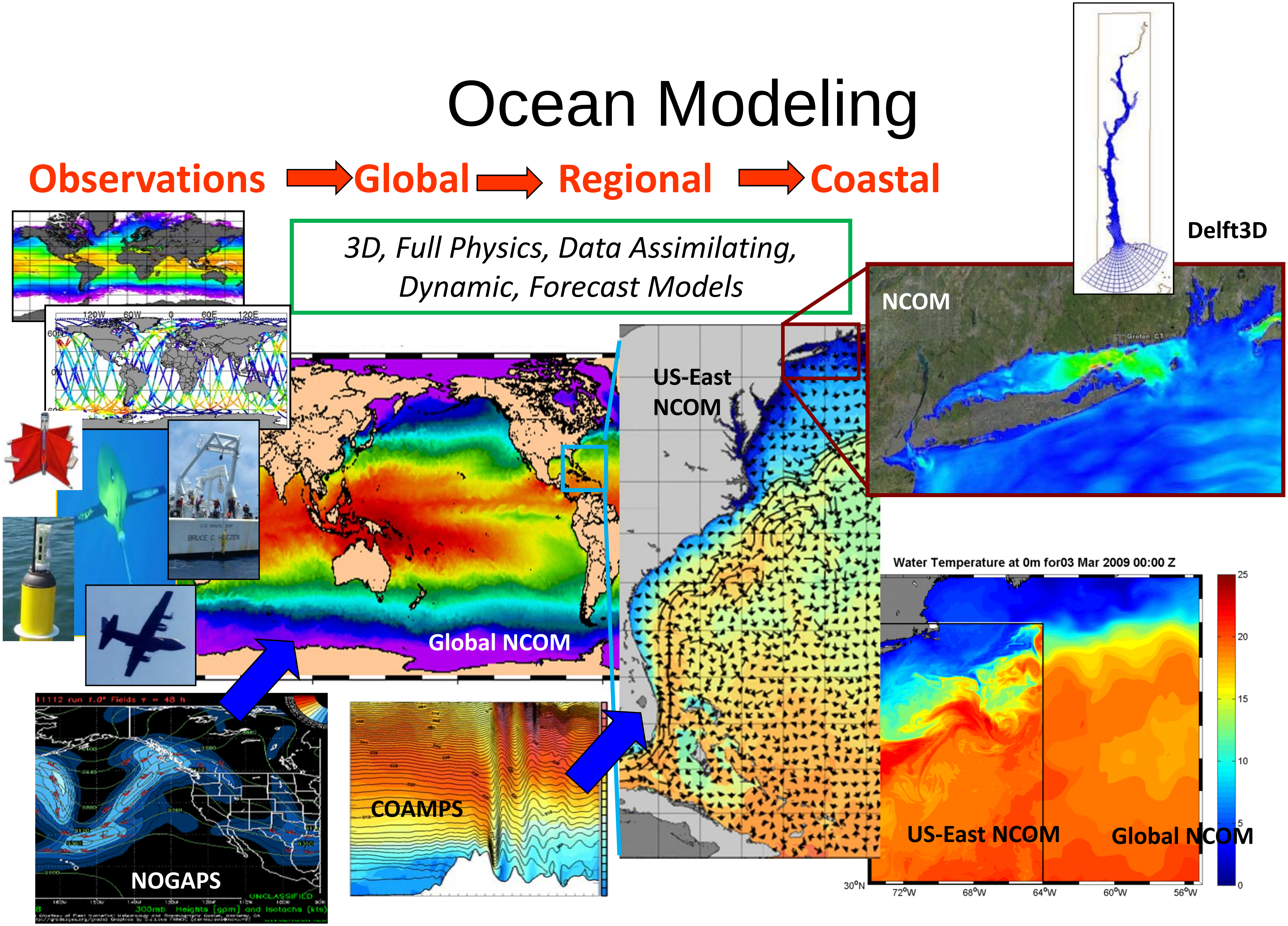
Π_w → Underwater volume

A_w → Underwater area

Ocean Modeling

Observations → Global → Regional → Coastal

3D, Full Physics, Data Assimilating, Dynamic, Forecast Models

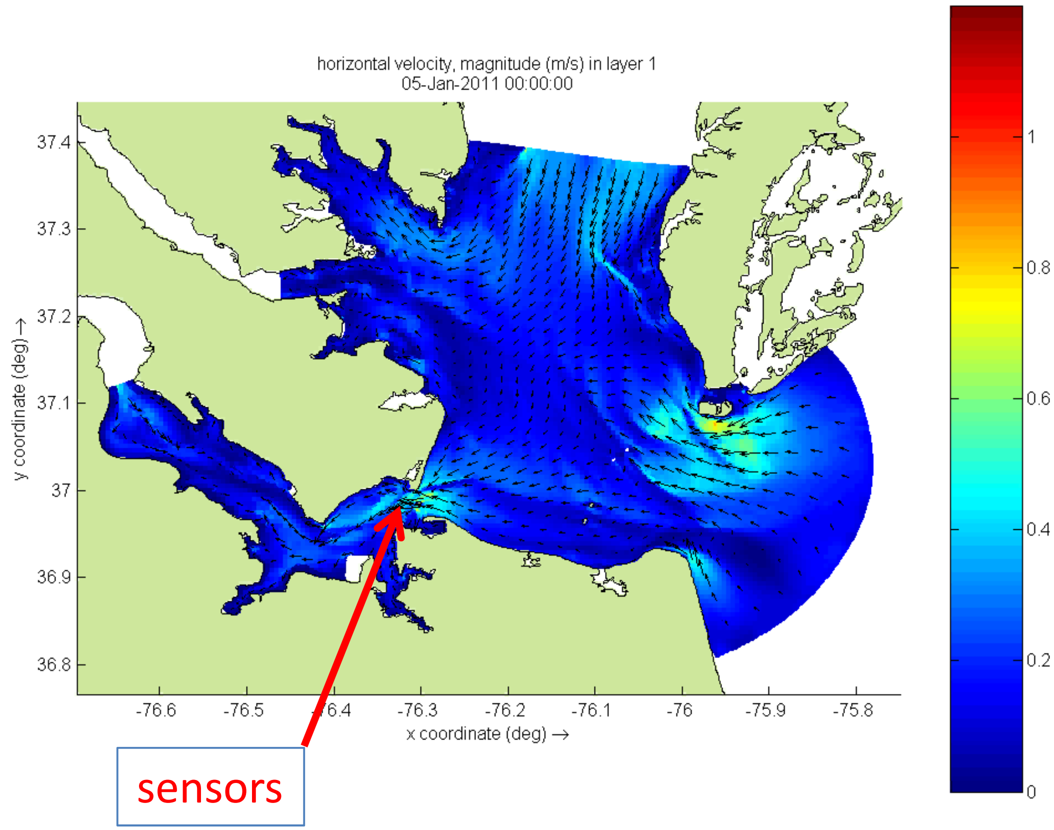


NAVO Coastal Model - Delft-3D

MIW – EXW – HLS: Port & Estuarine Modeling

Real-time

- Current
- T & S
- Waves
- Surface Elevation



Horizontal resolution 10-100 m or less

Delft3D - Chesapeake Bay

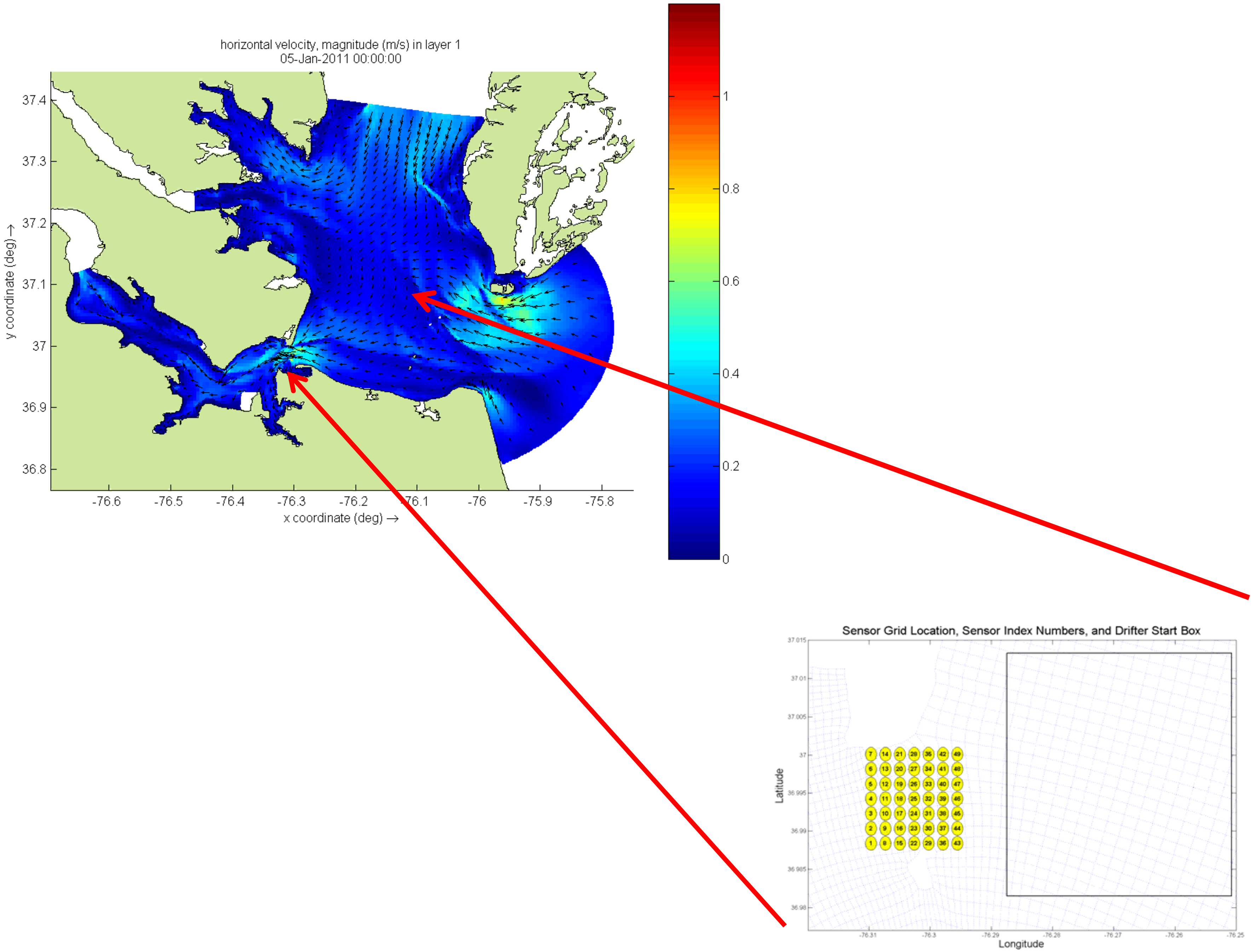
- Operational Model at NAVO
- Acting as a nested model, its flow forced at open boundaries by:
  - Temperature
  - Salinity
  - Velocity
  - Water level

  Provided by the USEAST Regional NCOM
- Local wind stress input forces flow at the free surface: COAMPS
- Tidal forcing

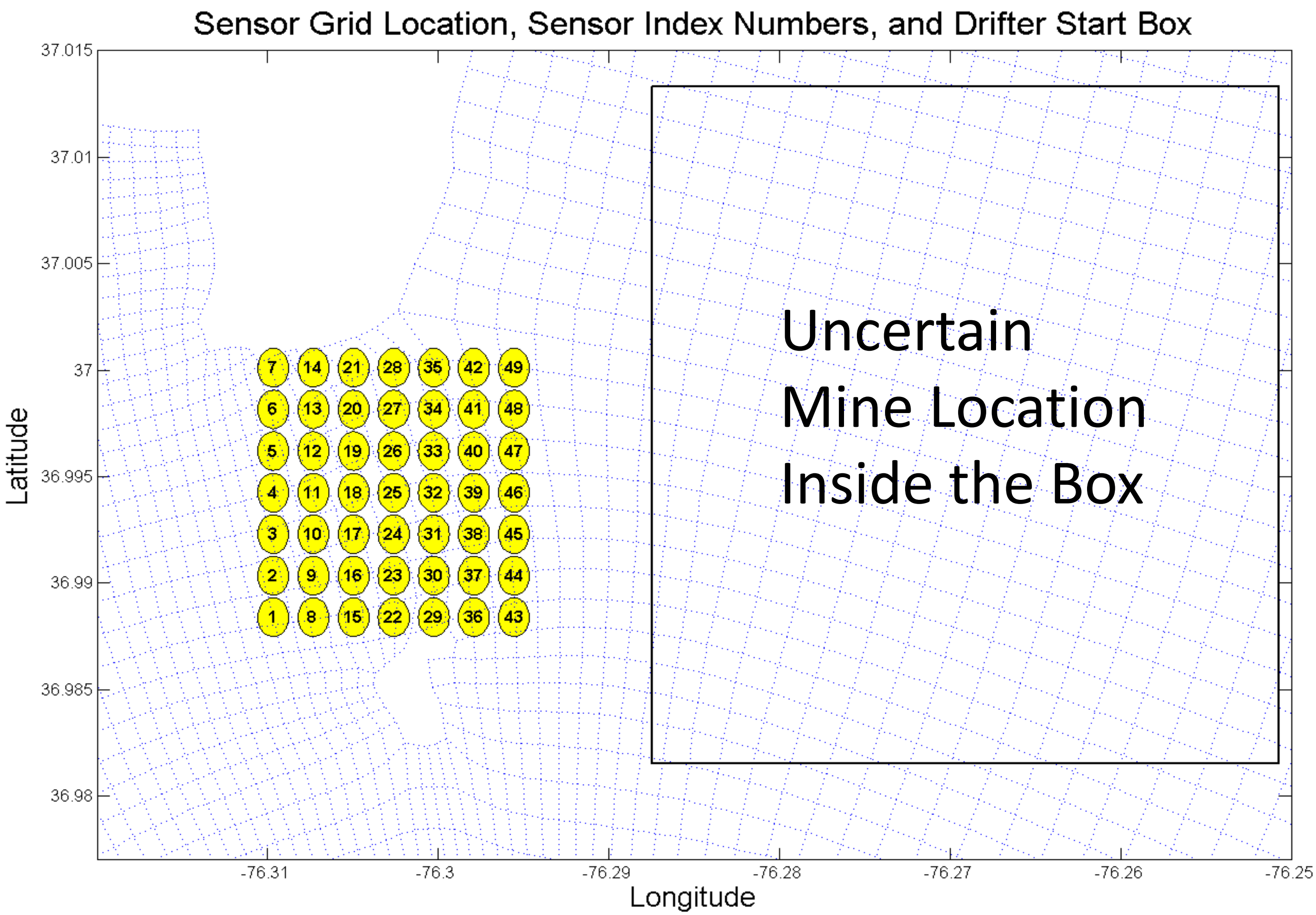
Ocean Velocity

Prediction of Mine Drift Trajectory

- July 28 – August 30, 2011
- Delft3D → Ocean Velocity (u_o, v_o)
- Mine Drift Model → Mine Position (x, y)
  → Mine Trajectory


horizontal velocity, magnitude (m/s) in layer 1
05-Jan-2011 00:00:00
y coordinate (deg) →
x coordinate (deg) →
37.4
37.3
37.2
37.1
37
36.9
36.8
-76.6
-76.5
-76.4
-76.3
-76.2
-76.1
-76
-75.9
-75.8
1
0.8
0.6
0.4
0.2
0
Sensor Grid Location, Sensor Index Numbers, and Drifter Start Box
Latitude
Longitude

Optimal Sensor Grid -Formation



Monte-Caro Simulation of Mine Trajectories

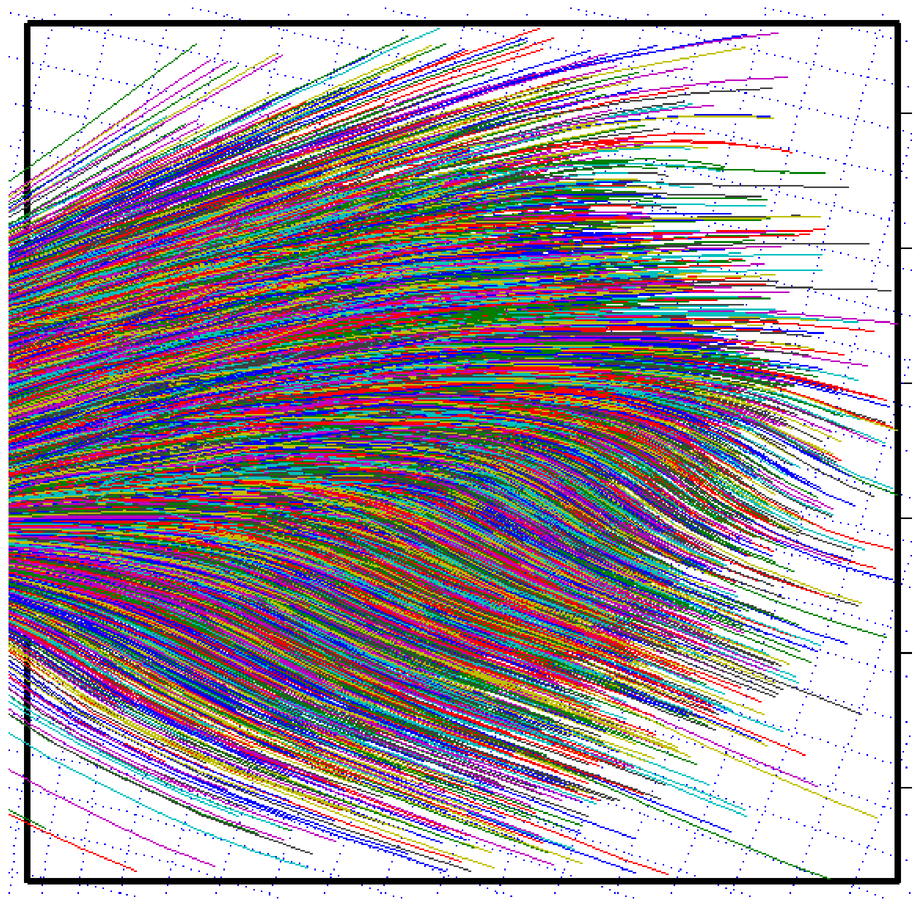
Procedures of the Monte-Carlo Simulation

- All drifters started with randomly selected position (Normal Distribution, Matlab) within 2 x 1.6nm (3.7 X 3 km) box
- Box located 0.75nm (1.4 km) east of Fort Wool
- 10,000 simulated drifters permitted to run at beginning of flood tide each day
- Flood period ~3hrs

Flood Period

Day (2011)	Flood Time Period
7/28	10Z – 13Z
7/29	10Z – 13Z
7/30	11Z – 14Z
8/01	12Z – 15Z
8/02	13Z – 16Z
8/03	14Z – 17Z
8/04	14Z – 17Z
8/05	15Z – 18Z
8/06	16Z – 19Z
8/07	17Z – 20Z
8/08	18Z – 21Z
8/09	19Z – 22Z

Trajectories of Drifting Mines



Optimal Sensor Grid

- Sensors are hypothetical and ideal:
  - Modeled as perfect upward looking sonar systems
  - Circular detection footprint on the surface (radius = 100 m)
  - Drifting mines will be called if they enter the footprint

- Each drifter will only be called once

Probability of Detection

Probability of Detection - Assumptions

- Positive detection if drifter within radius for 5 seconds or more
- Based solely upon the three hour flood period

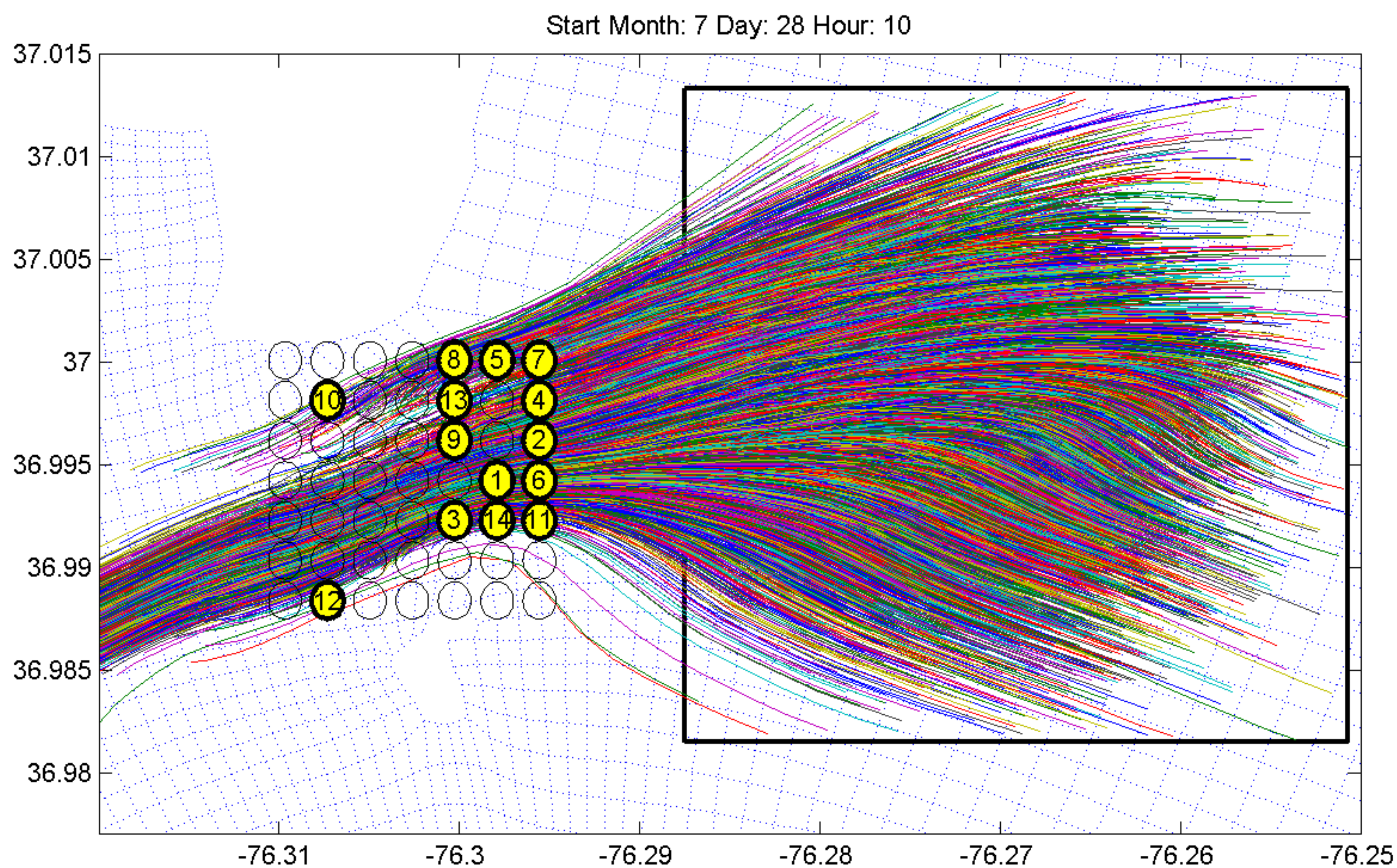
Probability of Detection – Ranking Sensors

- After 3hr flood period, ranking process of sensors
  - Sensor with the highest number of detections, “lead sensor” (or “best location” for UUV)
  - 2nd highest detections, not called by the lead sensor, “second place sensor”…
  - continued until all drifters that flowed through the grid were counted

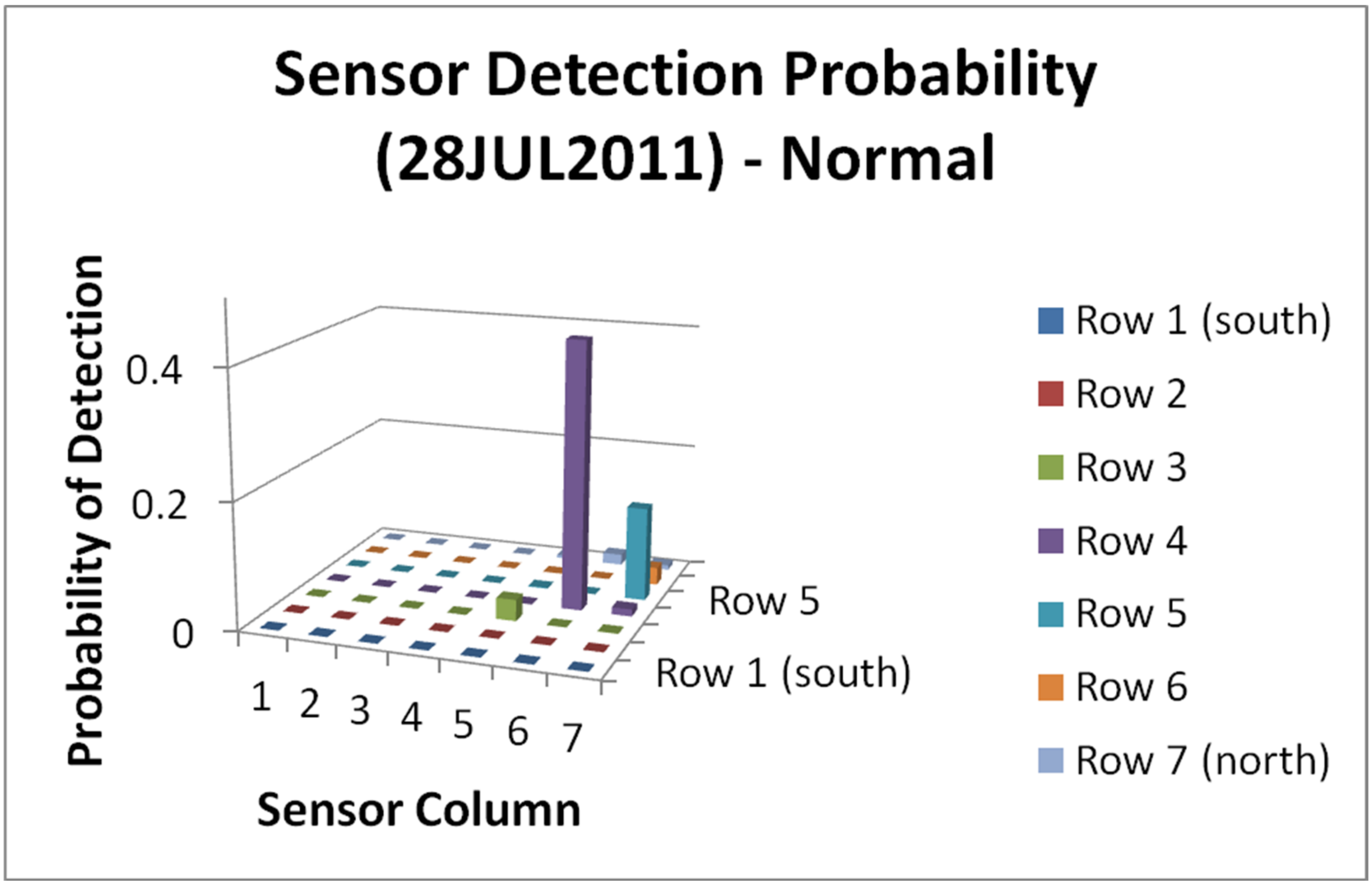
Probability of Detection – Sensor Detection Probability

- number of drifters each sensor called, not previously called by other sensors, divided by 10,000
- Equaled zero if:
  - All of the drifters were previously called
  - Not a single drifter flowed through its radius

Optimal Deployment of Stationary Sensors – Results



Optimal Deployment of Stationary Sensors – Sensor Location*



Optimal Deployment of Stationary Sensors – Sensor Number*

*Optimum sensor number – average value for 99% of total probability

Uniform	Days												
Pd	1	2	3	4	5	6	7	8	9	10	11	12	**Mean**
90%	6.3960	5.7517	5.8258	5.1278	4.5709	4.4934	5.1692	5.1833	5.6069	5.4840	5.4614	6.1694	5.4367
95%	7.5973	6.6427	7.5671	5.7656	5.5691	5.2273	5.9727	5.8936	6.7911	6.5520	6.4489	8.2564	6.5237
99%	10.8560	9.9734	10.2296	9.5674	7.7432	6.2715	9.1552	10.5417	10.1171	10.6267	10.8340	11.2742	9.7658

Normal	Days												
Pd	1	2	3	4	5	6	7	8	9	10	11	12	**Mean**
90%	3.1350	3.7985	3.3369	3.4169	2.9500	3.2805	3.2687	3.8439	4.0632	4.0070	3.8286	4.1375	3.5889
95%	4.5772	5.2384	4.2491	4.2928	3.7010	4.0136	4.2500	4.7895	4.9115	5.0953	5.0435	5.0651	4.6022
99%	7.2518	8.7979	6.8719	6.4432	5.2712	5.5278	6.7500	7.4348	7.6643	8.0463	7.8424	8.5749	7.2064

- 8 sensors for Normal (99% of total prob)

Conclusions

- Navy ocean model → methodology for optimizing stationary sensor employment in an inlet
- The results can be used for UUV path planning to get optimal detection

QUESTIONS?