# Smart Ocean Sensing Using the Telesupervised Adaptive Ocean Sensor Fleet

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NSTC

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NASA Wallops Flight Facility
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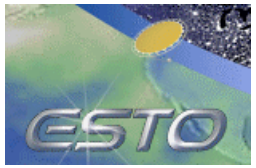
# Outline




- Motivation
- System overview / components
- System tests
- Supporting efforts
  - Simulator development
  - Adaptive sampling
  - HAB data visualization
- Conclusions / Future work

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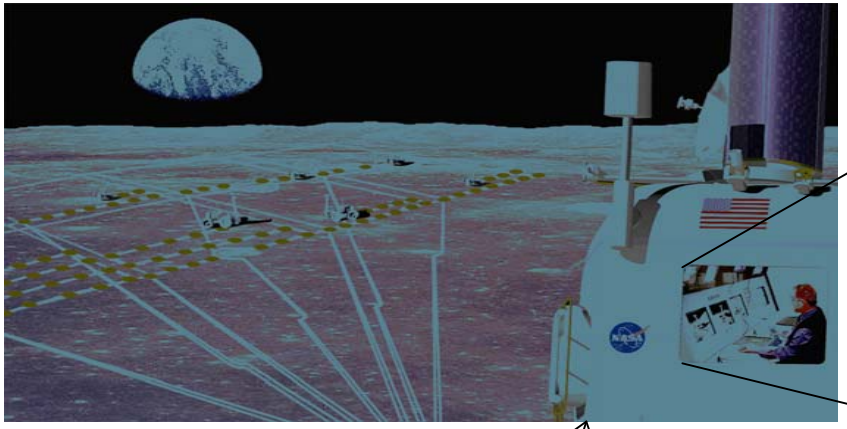
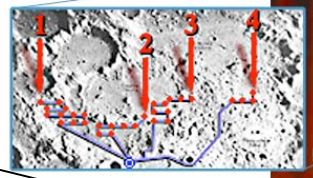
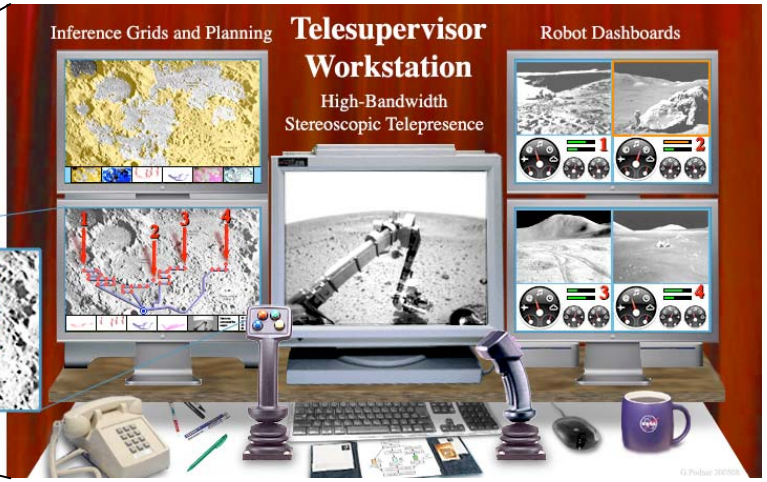
# Motivation

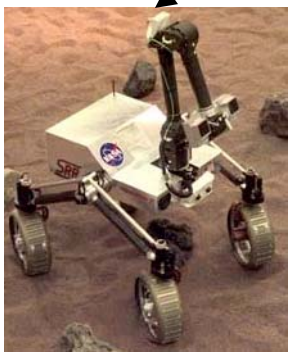
- Improved in-situ study of Harmful Algal Blooms (HAB)
  - Current sensing:  stationary, sparse, may require in-lab assay
- Establishment of sensor web capability combining ocean-deployed and space sensors
- Manageable demands on scientists for tasking, control, and monitoring
- Potential application to coastal pollutants, oil spills, hurricane factors, as well

# PROSPECT

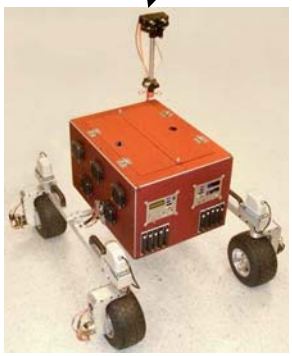






JPL SRR



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- One-to-many variable-autonomy telesupervision
- High-fidelity telepresence
- Lower-fidelity switch-in of distant expertise
- Hazard and Assistance Detection: task scheduling, health management
- Human-multirobot system metrics
- End-to-end system test in real-world prospecting task

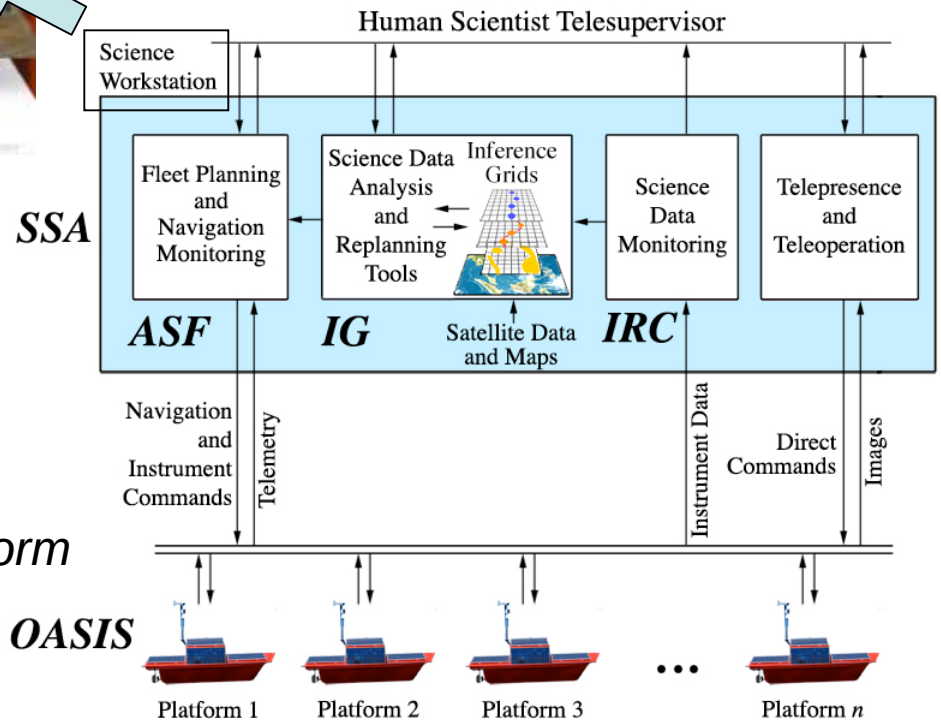
# OASIS Mapping of Harmful Algal Blooms


*High-level planning and monitoring*

*High-bandwidth, single-platform telepresence*

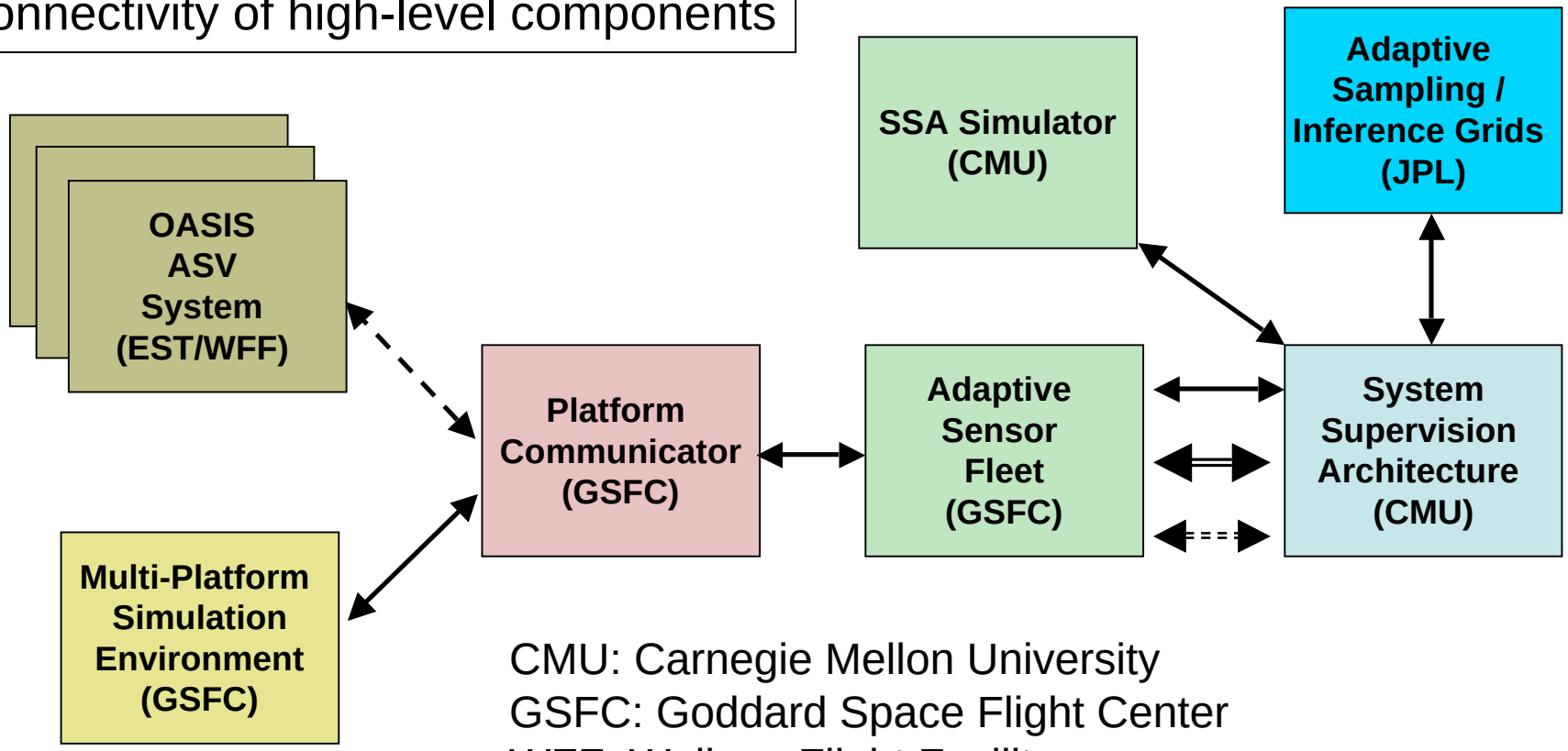
*Low-bandwidth, multi-platform telemetry*

- System Components
  - System Supervision Arch. (SSA)
  - Adaptive Sensor Fleet (ASF)
  - Instrument Remote Control (IRC)
  - Inference Grids (IG)
  - Marine platforms (OASIS)

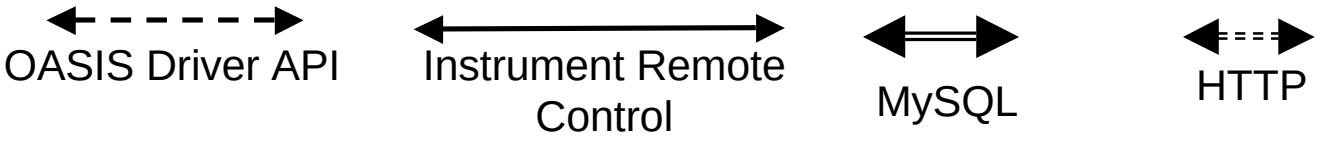


# Software Subsystems

Connectivity of high-level components

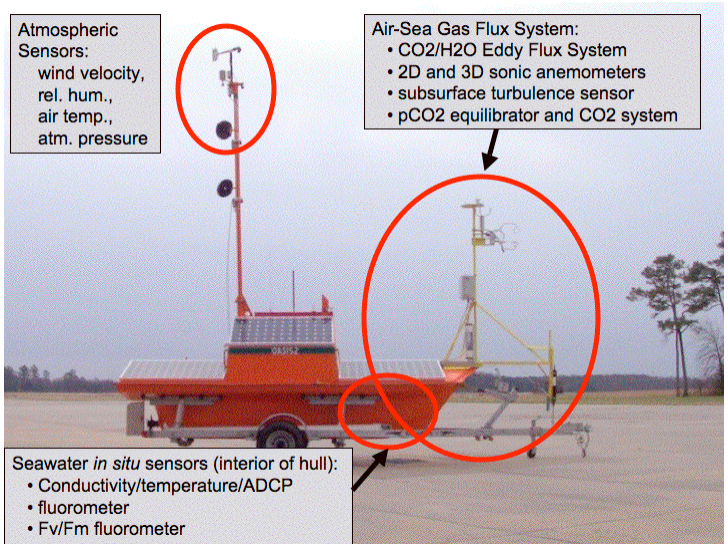



CMU: Carnegie Mellon University
GSFC: Goddard Space Flight Center
WFF: Wallops Flight Facility
EST: Emergent Space Technologies
JPL: Jet Propulsion Laboratory



# OASIS (Ocean-Atmosphere Sensor Integration System) Platforms

*OASIS about to launch*

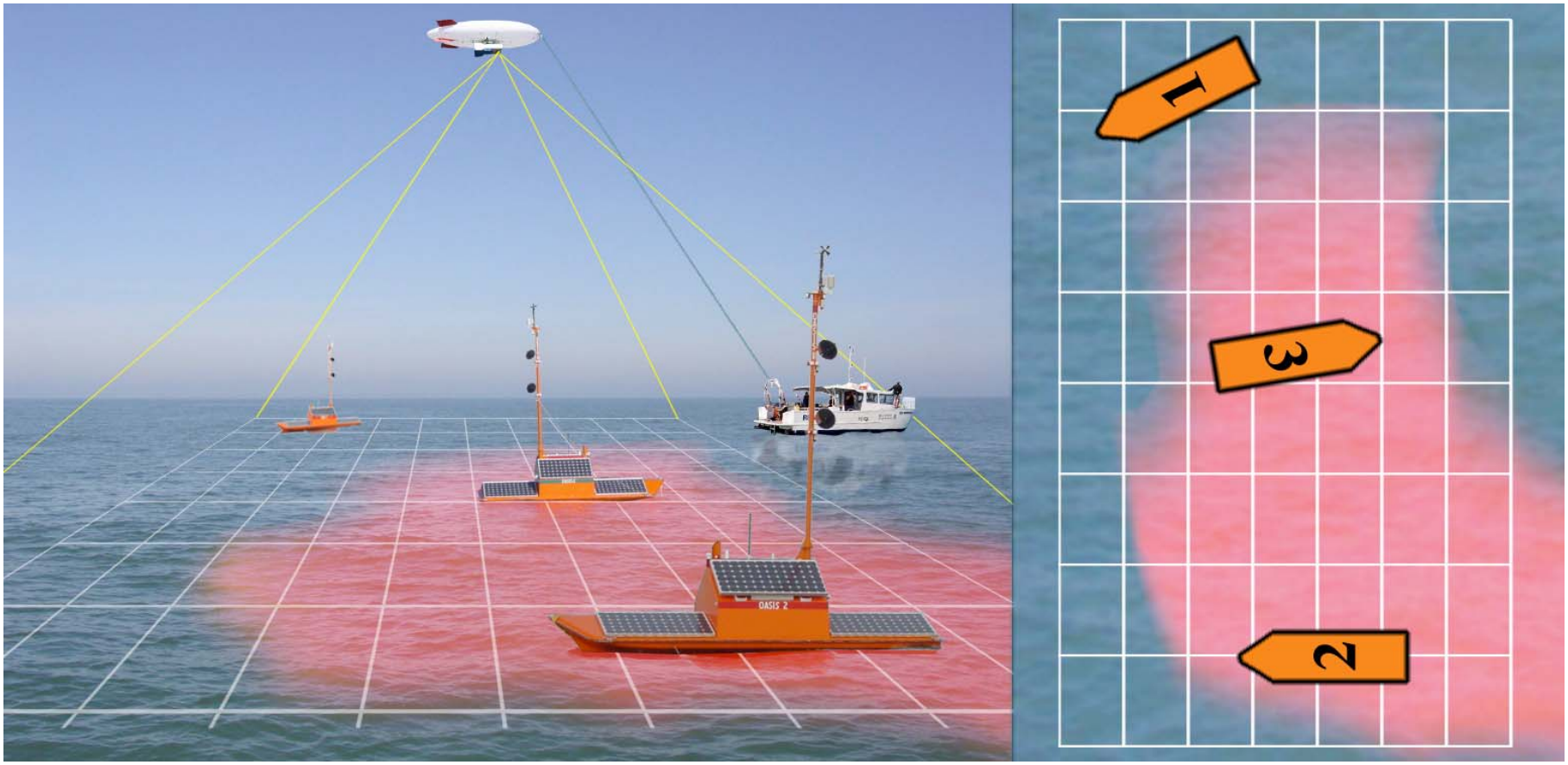



*OASIS features*

- Inexpensive ($20K), NOAA-funded autonomous surface platforms developed at Goddard Wallops Flight Facility (WFF) in cooperation with Emergent Space Technologies, Inc.

- As of June 2008, three operational OASIS platforms with barometer, fluorometer, and temperature, humidity, and salinity sensors (http://coastal.wff.nasa.gov/index.php?module=static&dir=/oasis)

# Field Test System (1)



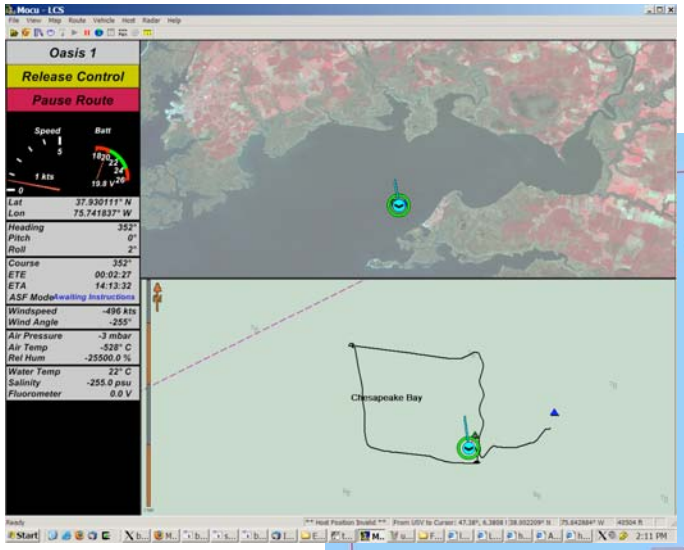

To confirm data from OASIS platforms:

- Aerial camera with sensors:
  latitude, longitude, altitude & heading
- Image the bloom and the boats

Use existing JPL software to geolocate boats and bloom.

# Field Test System (2)

OCU



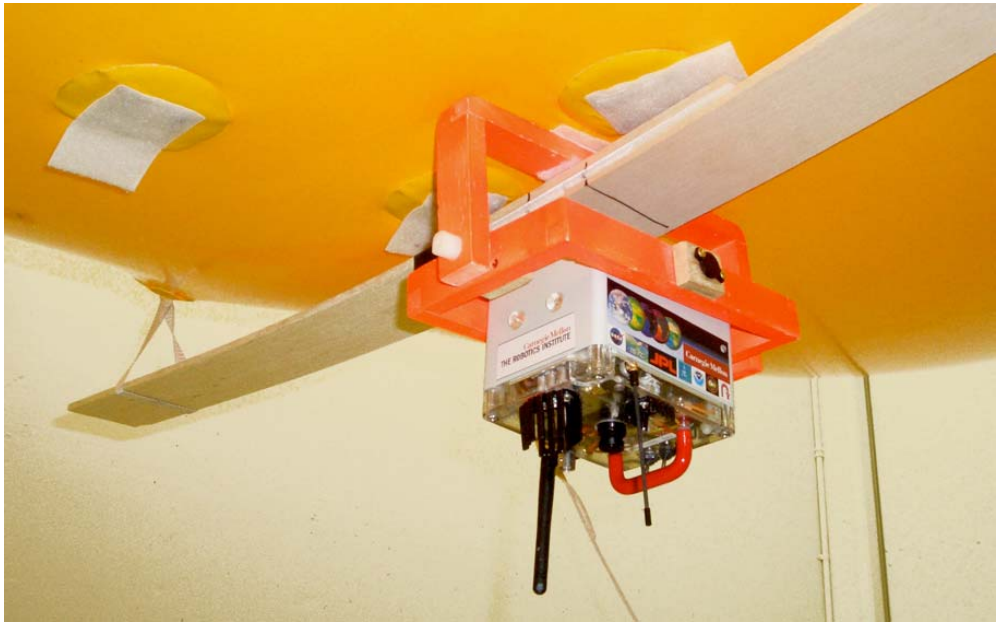

Path planning

Observation / Validation

Dye spray system

OASIS platforms

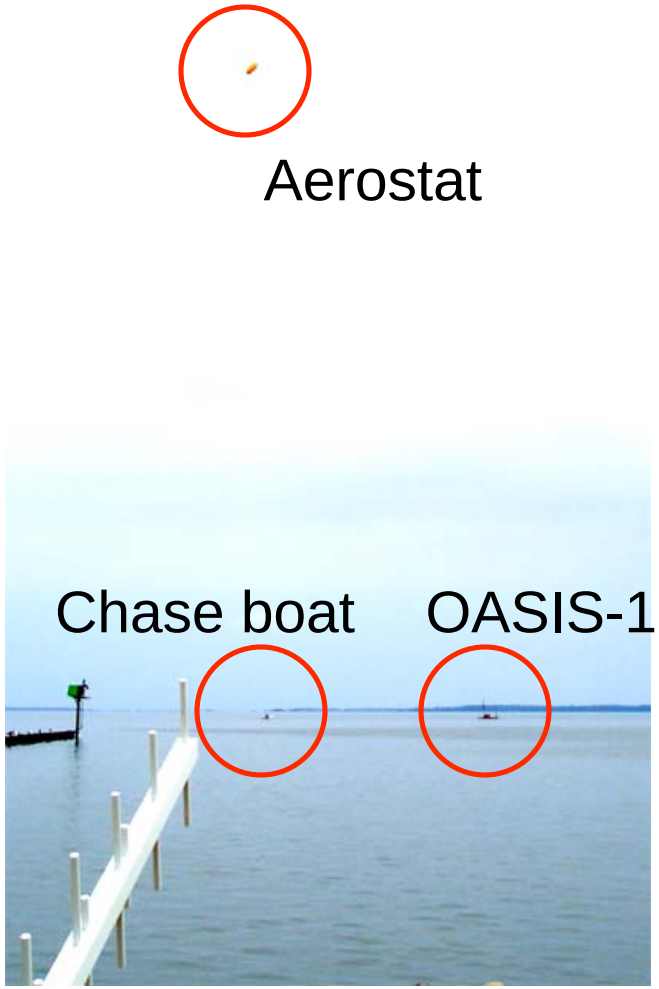
# Field Test System (3)



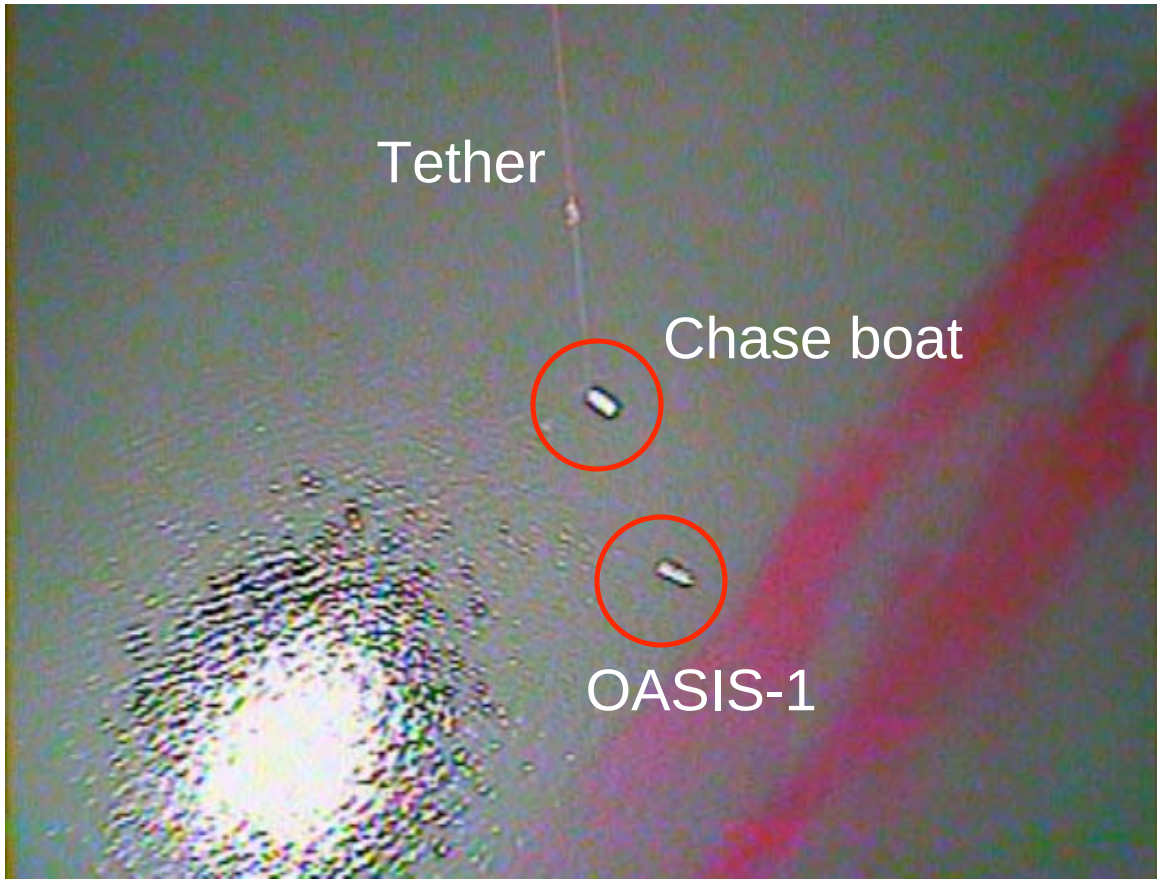
- Instrument/avionics package: GPS, altimeter, compass, serial link, color camera, video transmitter

- Spray system: 8 nozzles on back of motorboat connected to 55-gallon drum and sump pump

# 21 August 2007 Test with Aerostat

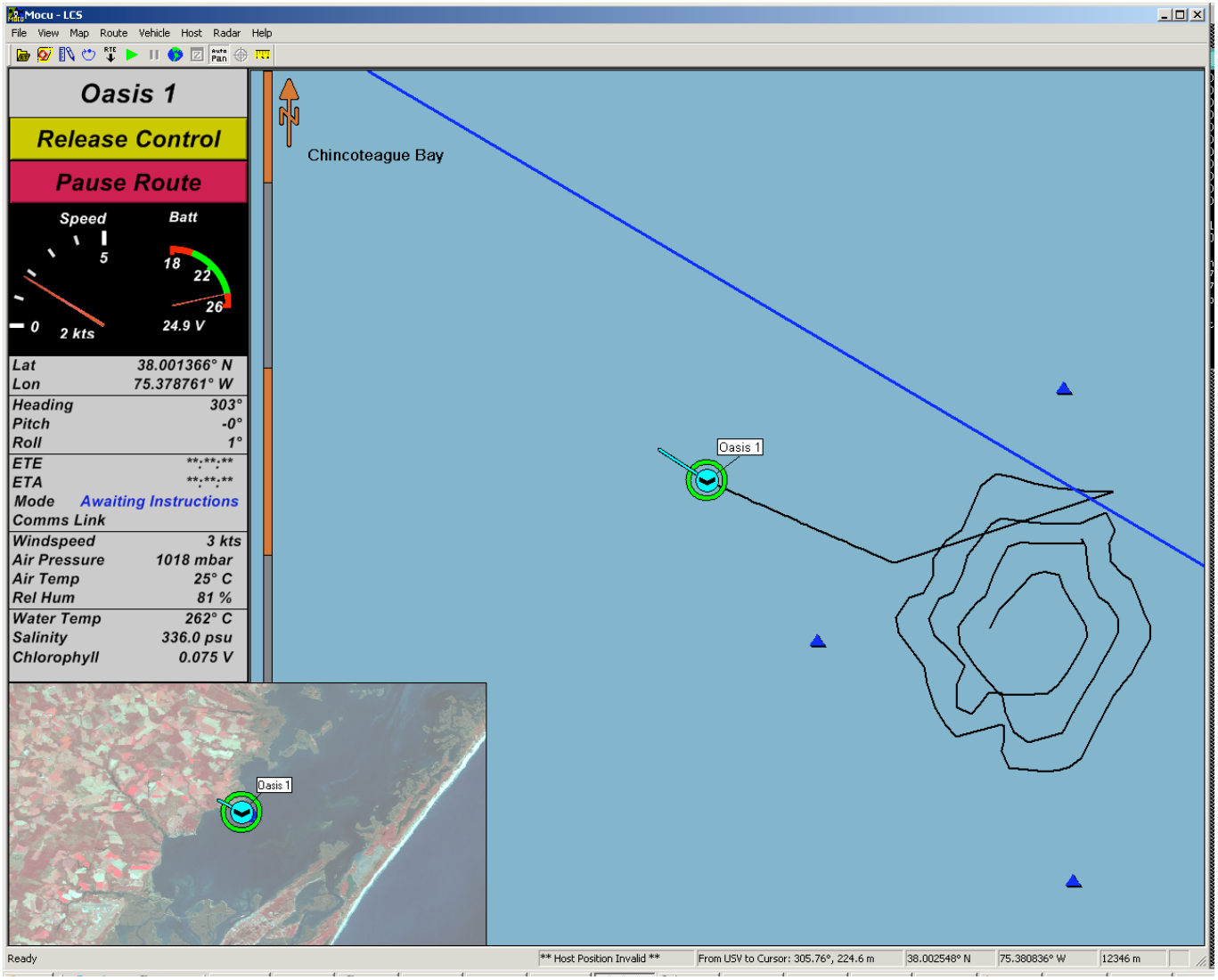



Aerostat deployed



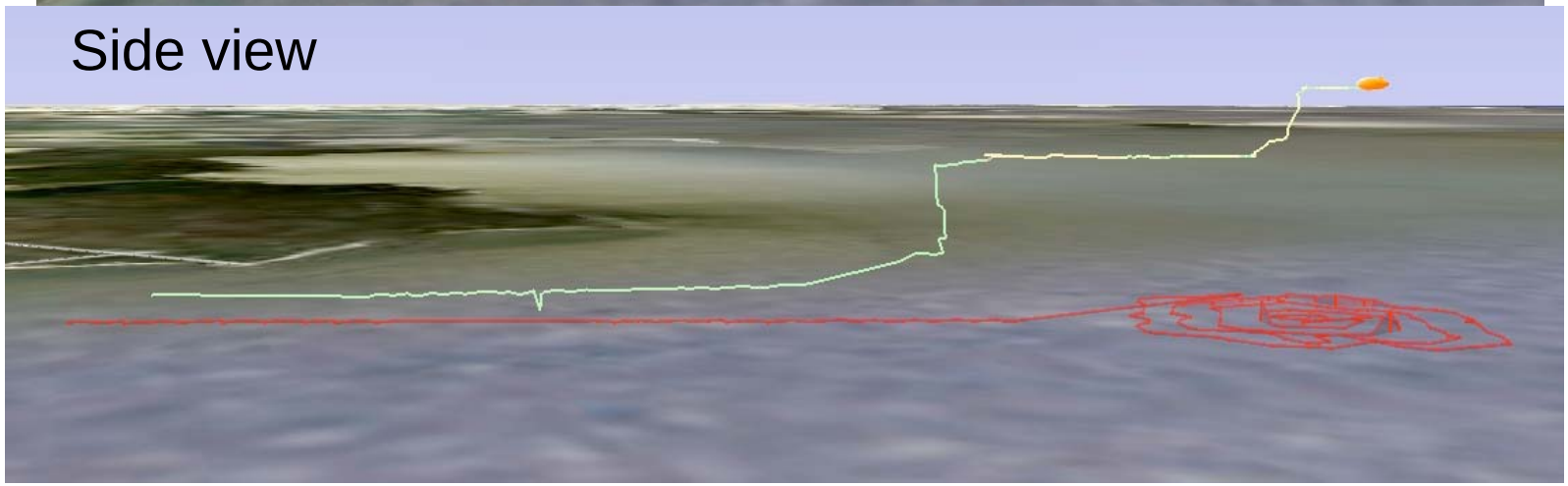

View from aerostat: chase boat, OASIS-1 and rhodamine dye

# 21 August 2007 Test with Aerostat



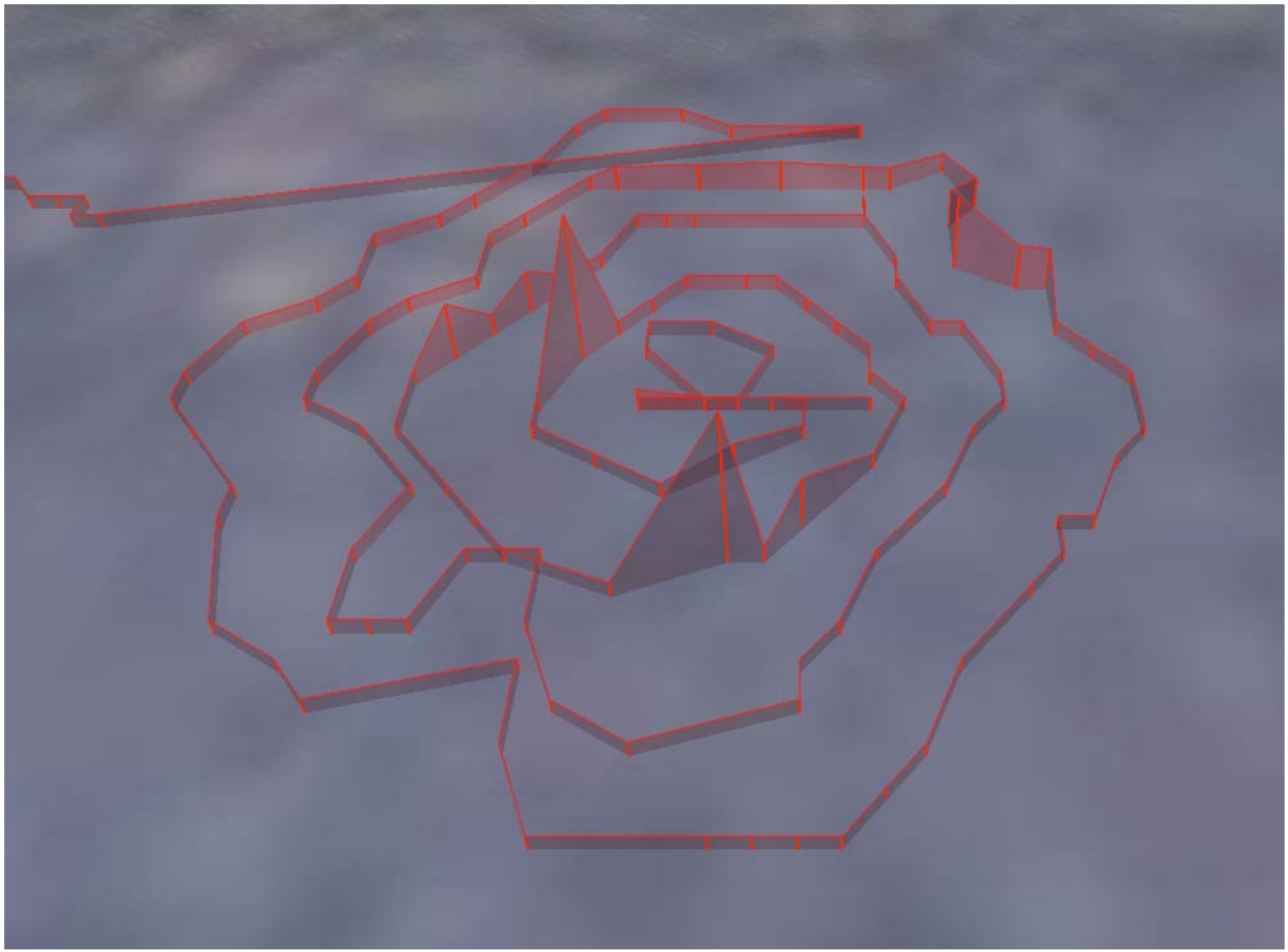

OCU View: search pattern executed by OASIS-1 platform

# 21 August 2007 Test with Aerostat

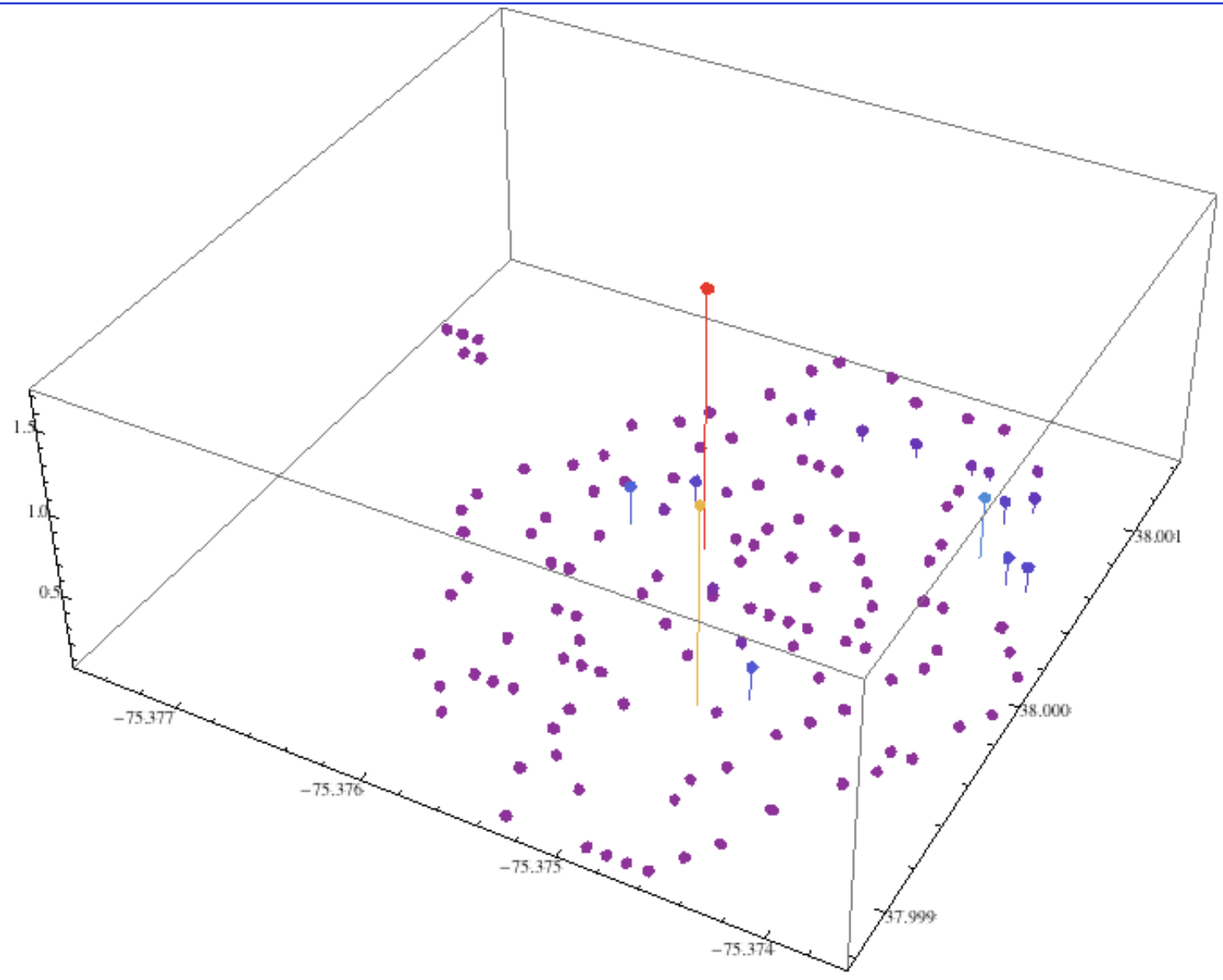

Aerostat (white) and OASIS-1 (red) trajectories:  overlay on satellite imagery

# 21 August 2007 Test with Aerostat

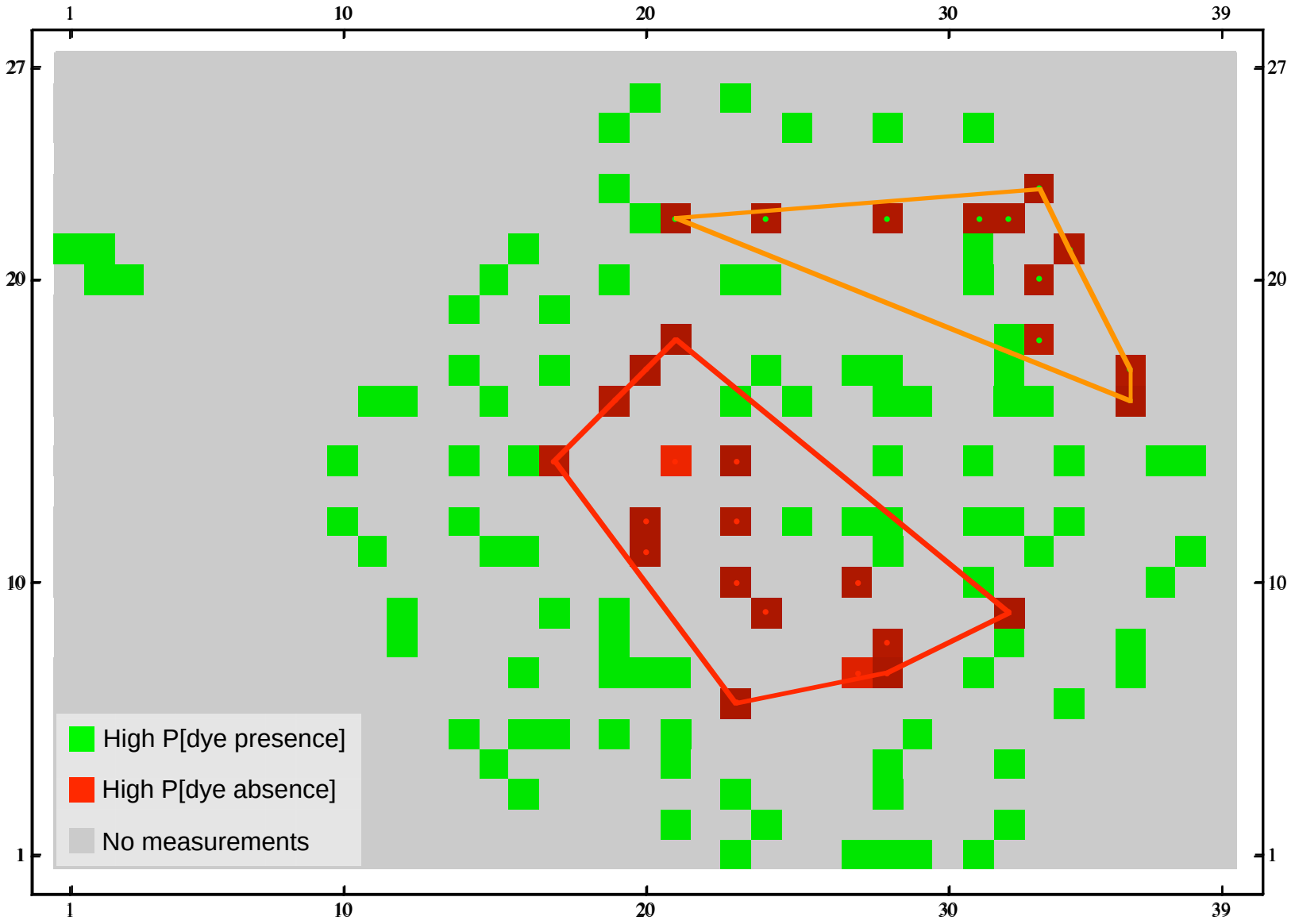


Rhodamine dye concentrations mapped during search path

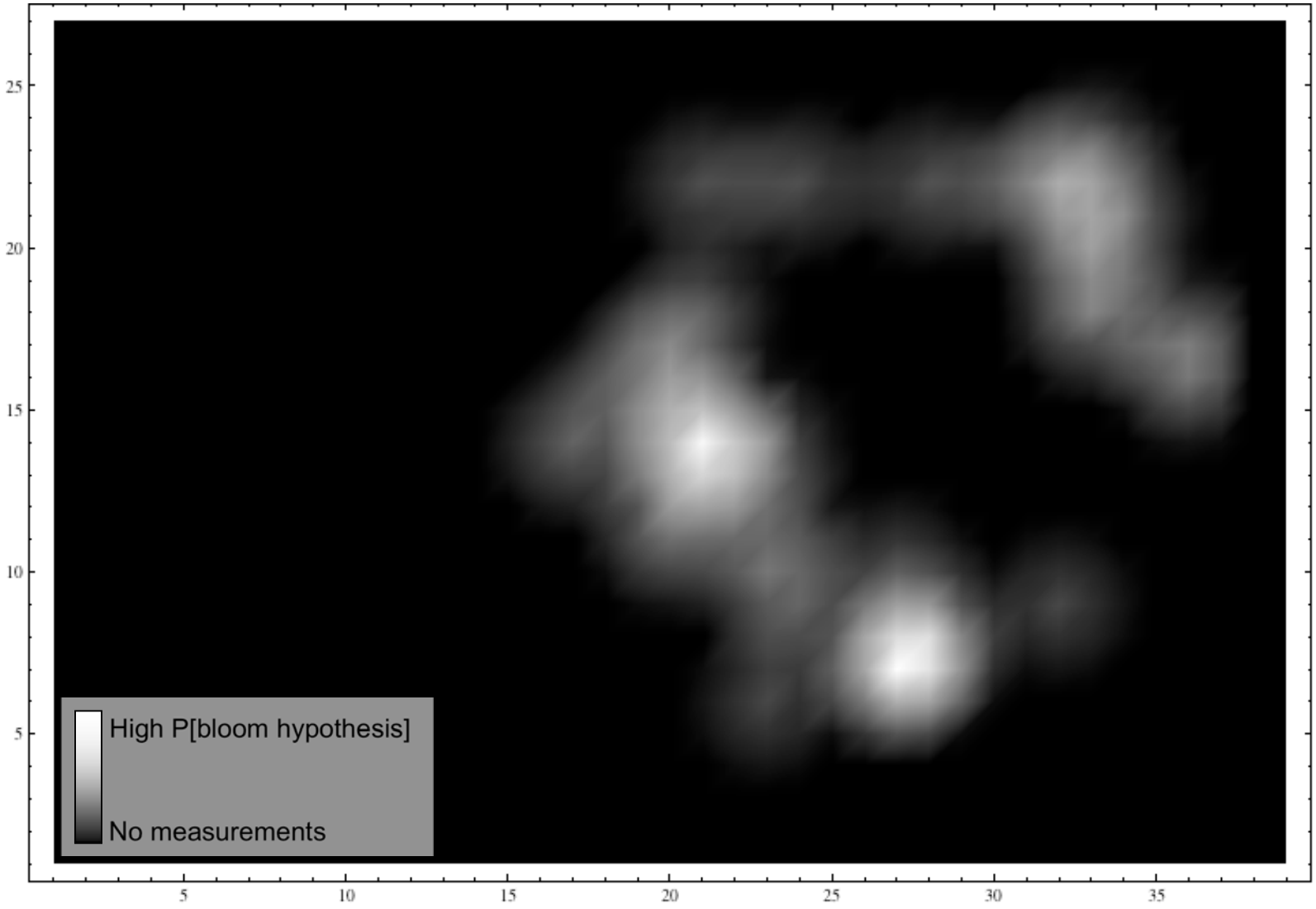
# Measured Dye Concentrations



# Inference Procedure: Dye Absence Detection

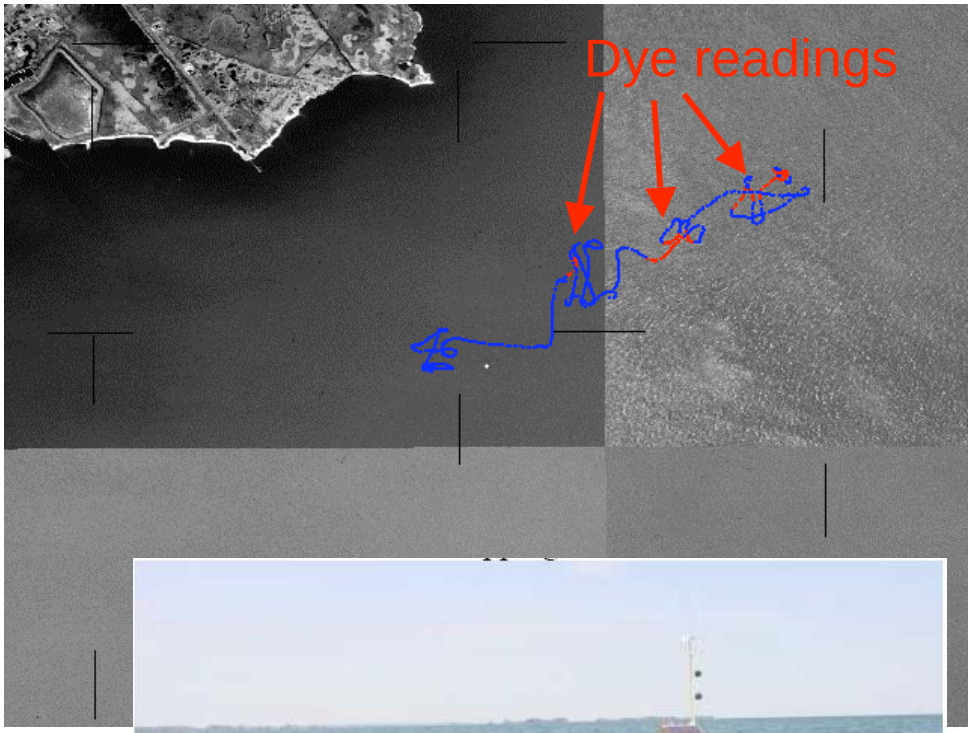


# IG: Probabilistic Bloom Hypotheses



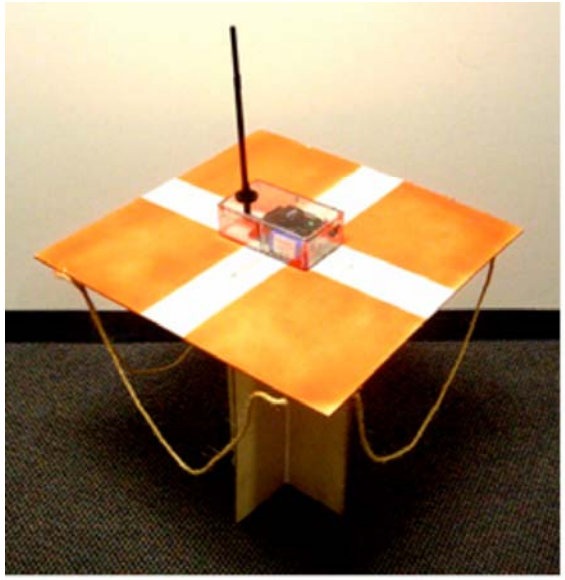
# IG: Dynamic Task Sound?

# 21 Feb 2008 Mapping Test




- Difficulties with autonomous tracking of the dye patch due to drift

# Instrumented Drift Buoy

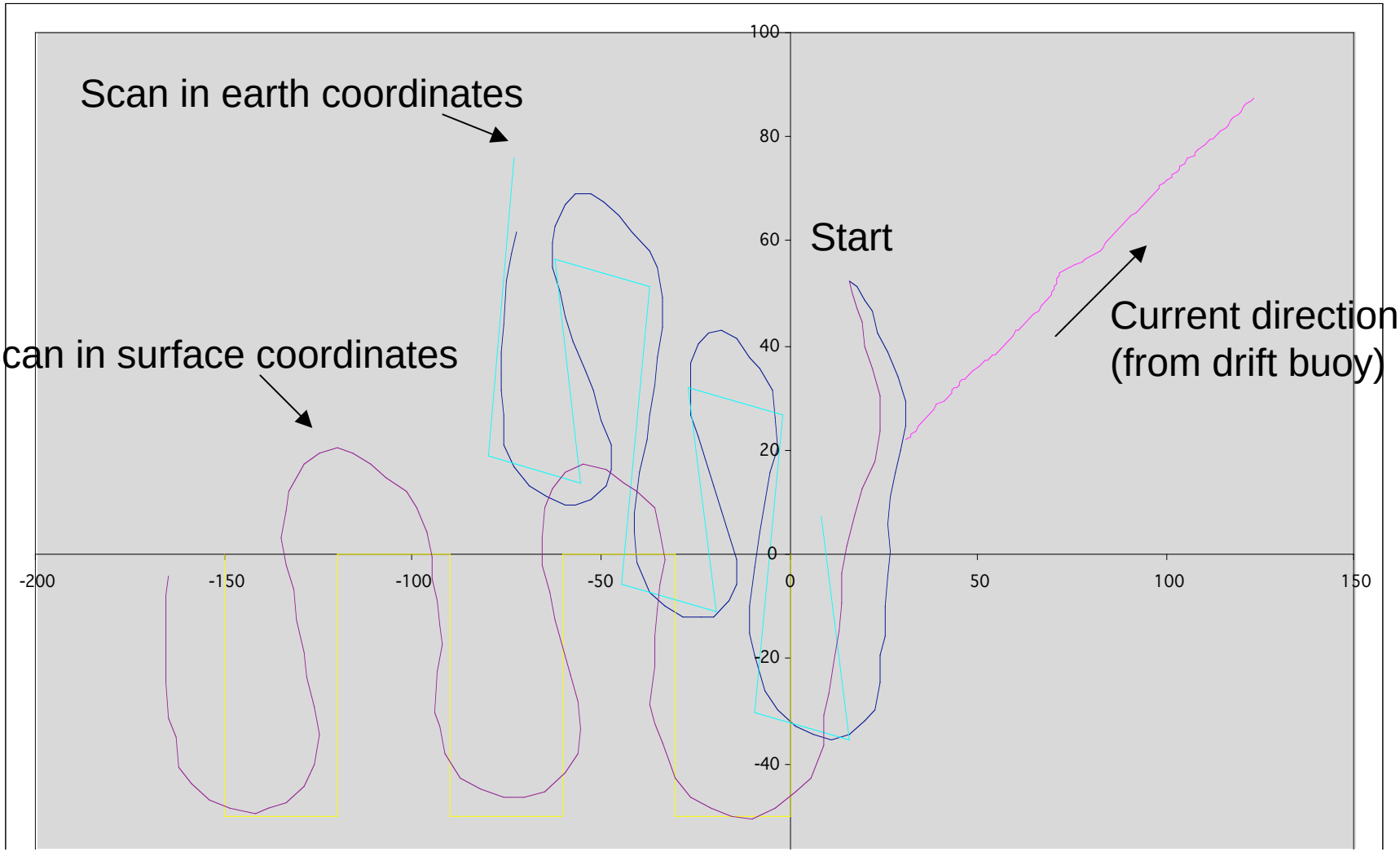


Instrumented drift buoy

April 2008 test in Allegheny River

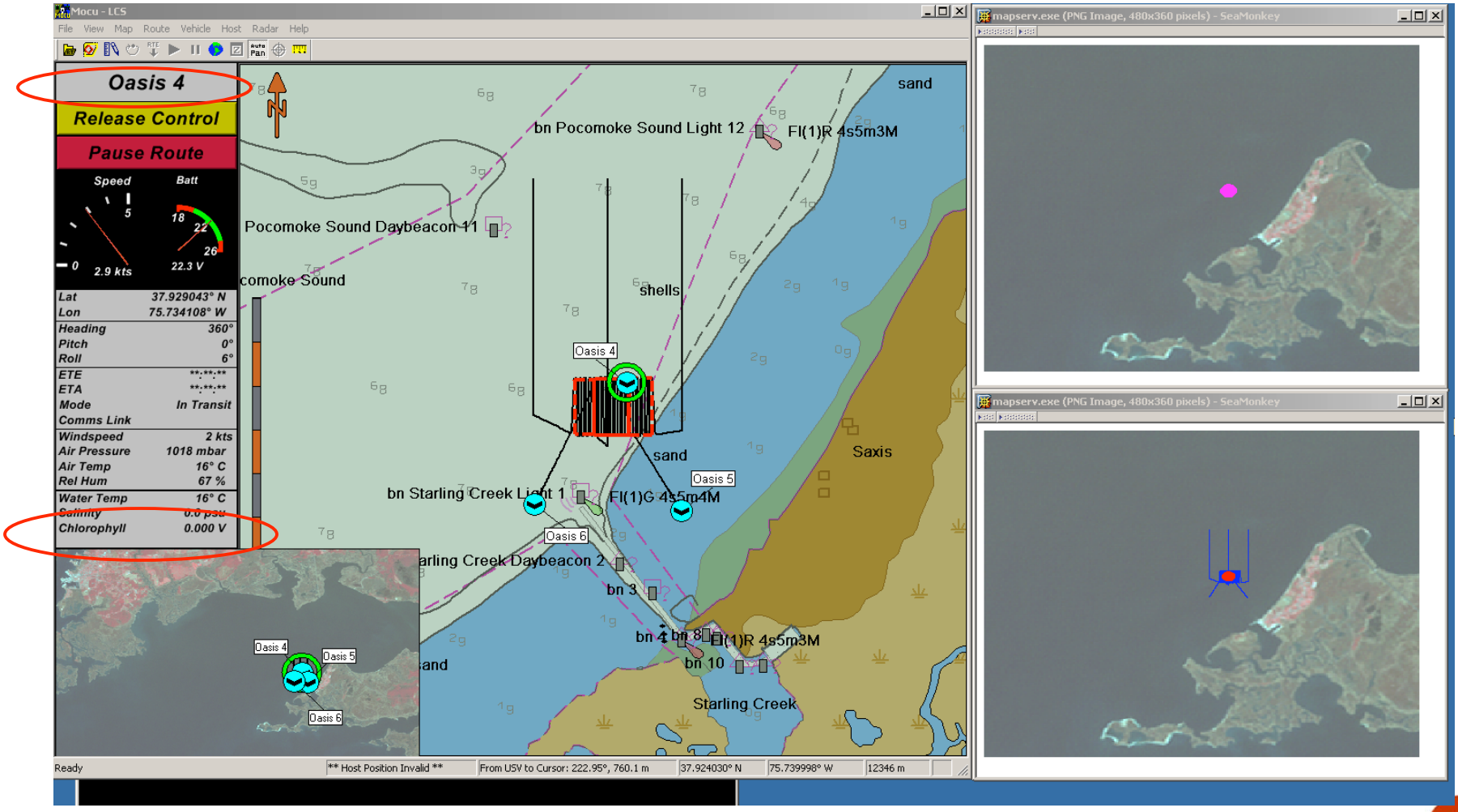
- Instrumented drift buoy:  GPS, data transmitter, high-gain receive antenna at ground station
- Initial check-out in Pittsburgh's Allegheny River

# Target-Drift Compensation Results




- Single OASIS platform in Chesapeake Bay off Greenbackville, MD

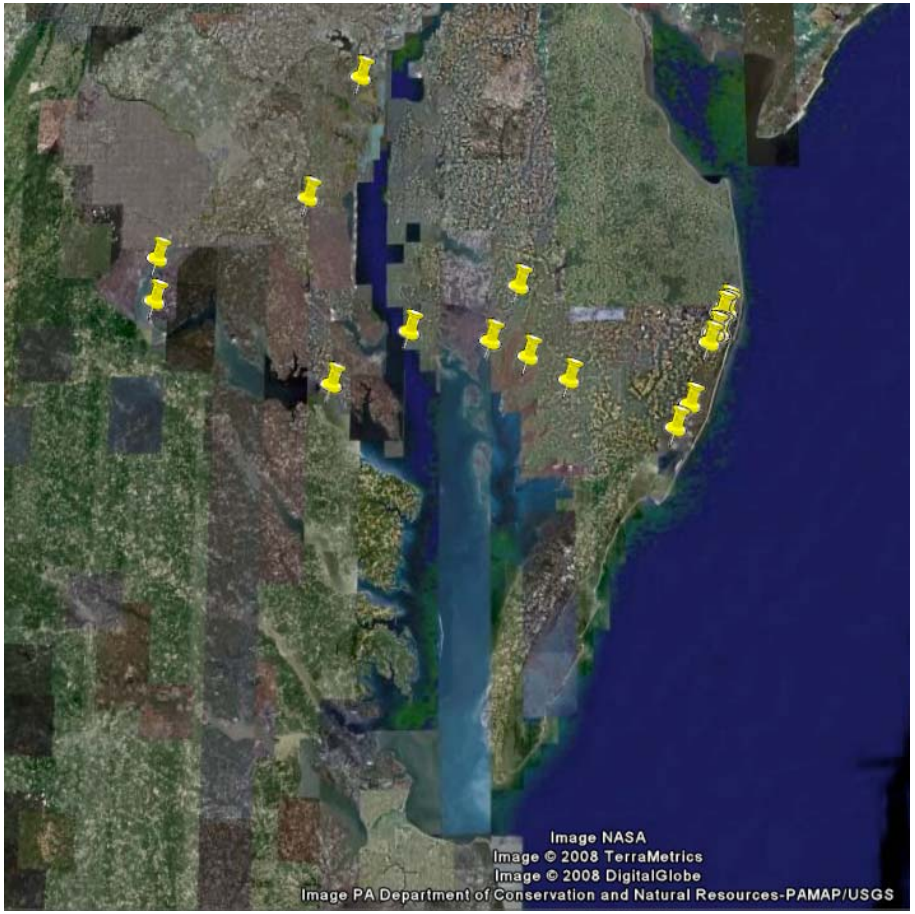
# In-Simulation Multiboat Dye Mapping



# HAB Occurrence in the Chesapeake

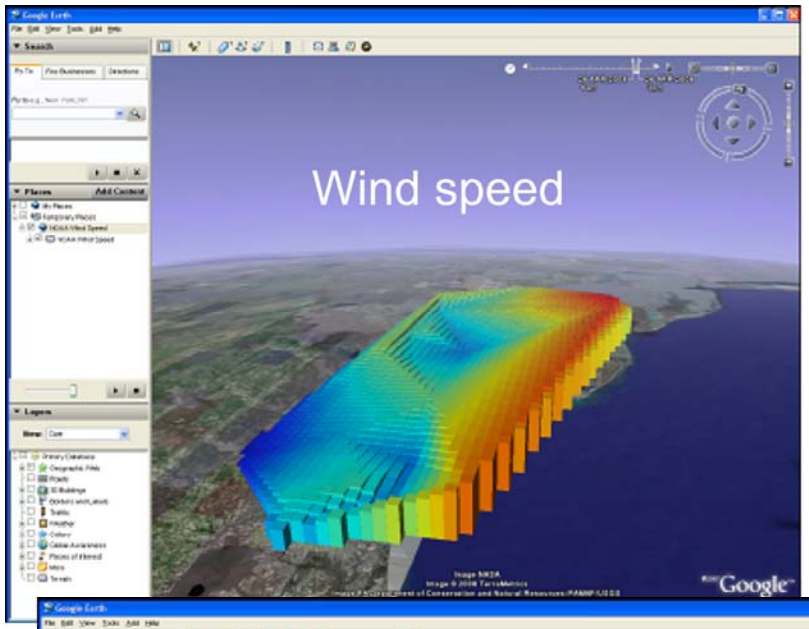
Based on the Maryland DNR HAB news database between 2001 to 2006:

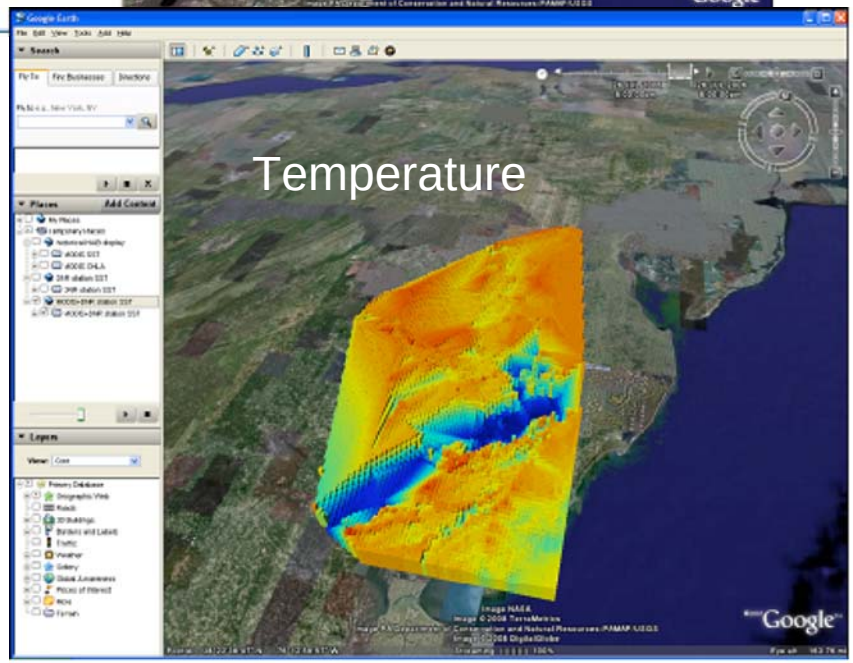
- On average, one to two visible blooms occur per year
- The visible blooms are reported to have been seen over a span of one to five weeks




Locations of largest blooms (cell count greater than 1 million/mL) from 1980-2006.

# Chesapeake Bay HAB Data Visualization Tool



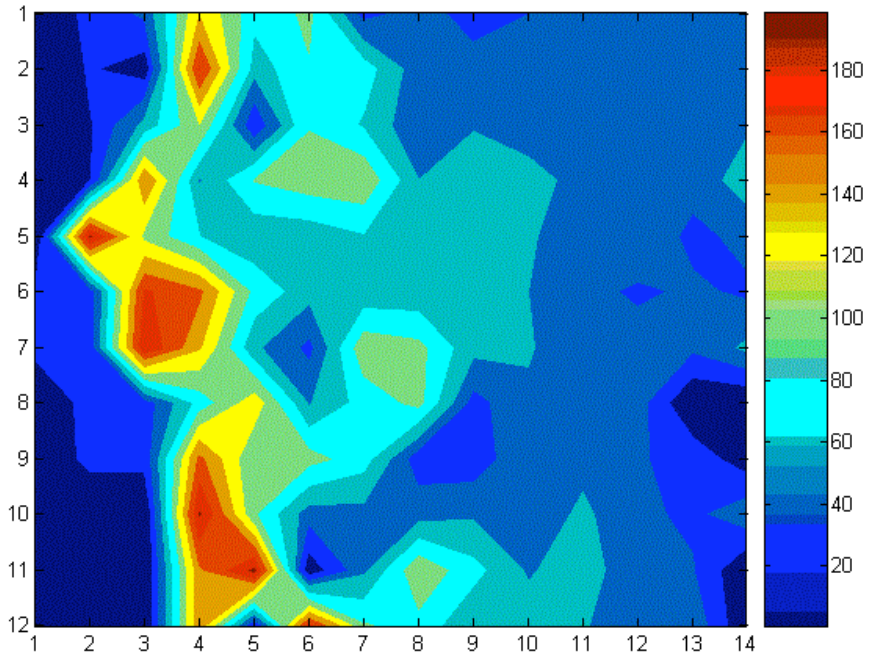




- Google Earth-based
- Automatically harvests HAB-relevant web-based data
- Features
  - One-day or chronological display of:
    - NOAA buoy wind speed
    - MODIS temperature
    - Maryland DNR station data
    - HAB news report data
  - HAB size and duration prediction

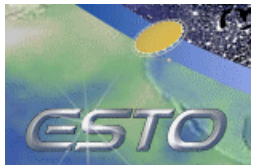
# Adaptive Sampling

*How does a robot team select resource-constrained observation paths that minimize the uncertainty of mapping a hotspot field?*

*Plankton density (chl-a) field of Chesapeake Bay bounded within latitude 38.48-38.59N and longitude 76.49-76.34W*



# Multi-Robot Adaptive Exploration Problem (MAXP)




- Cast exploration task as sequential decision-theoretic planning problem
- Continuous, spatially correlated measurements in a hotspot field
- Adopts continuous-state, non-Markovian structure
- Adaptive model-based strategy to perform both wide-area coverage and hotspot sampling; spans the entire adaptivity spectrum

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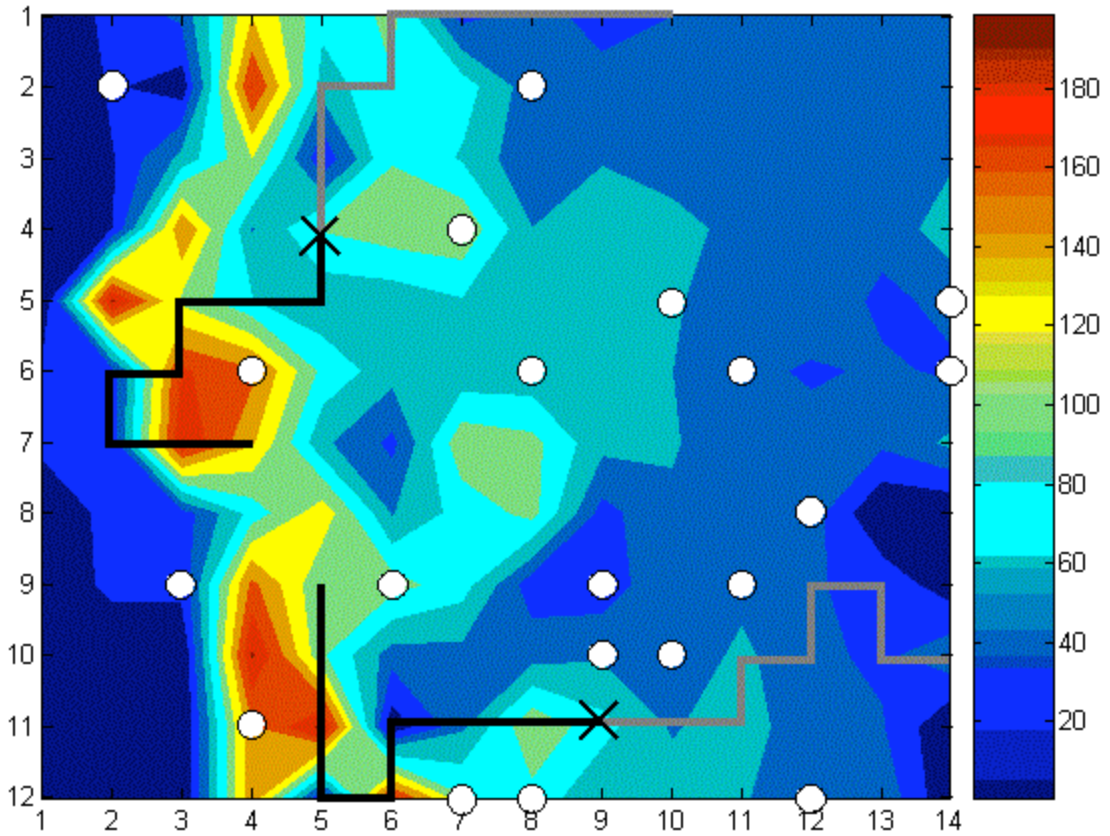
# Plankton Density Field of Chesapeake Bay

- Exploration region discretized into 14× 12=148 sampling locations
- 2 robots start at '×'s
- 20 locations randomly selected as known data



# Performance Comparison

| | | MSRE | | chl-a yield | |
|---|---|---|---|---|---|
| Exploration strategy | Model | 1R | 2R | 1R | 2R |
| Adaptive aMAXP/RTDP | ℓGP | 0.284 | 0.241 | 1660 | 1607 |
| Adaptive aMAXP/URTDP | ℓGP | 0.250 | 0.197 | 1652 | 1815 |
| Greedy | ℓGP | 0.338 | 0.260 | 1840 | 1647 |
| Non-adaptive MAXP | GP | 0.325 | 0.333 | 1165 | 1240 |
| Greedy | GP | 0.401 | 0.407 | 967 | 982 |

- Strategies for log-GP obtain higher plankton yield
- aMAXP achieves lower MSRE than non-adaptive and greedy strategies

Details: "Adaptive Multi-Robot Wide-Area Exploration and Mapping", Proceedings of the 7th International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Estoril, Portugal, May 2008.

# Conclusions

- Goal:  Dynamic, adaptive, real-time HAB measurements
- Current status
  - End-to-end system integration and preliminary dye mapping
  - Drift compensation working, about to perform multi-platform dye mapping
- Future work:
  - Apply adaptive sampling techniques to real boats
  - Real HAB characterization
  - Cueing by other sensors, including satellite-based