

Capturing the Key Oceanographic Signals with Autonomous Underwater Vehicles

Yanwu Zhang and James G. Bellingham

Monterey Bay Aquarium Research Institute



Monterey Bay Aquarium Research Institute (MBARI)



Todd Walsh © 2007



November 2010

MBARI founder David Packard:

“Send instruments to sea, not people.

Return information to shore, not samples”



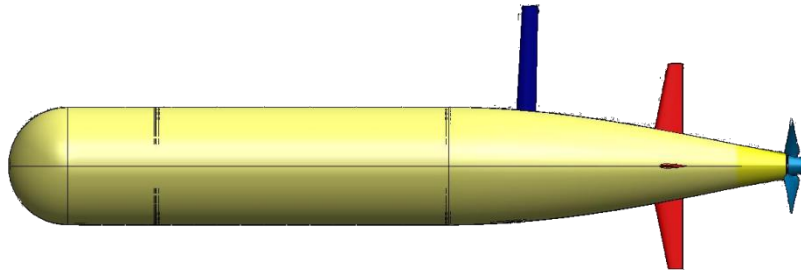
Outline

- State-of-the-art of Autonomous Underwater Vehicles (AUVs)
- Designing AUV survey strategies for capturing key signals in the ocean.
 - Synoptic mapping of an ocean field
 - Ocean flux estimation
 - Capturing peak samples from a thin layer
- Ongoing and future work

State-of-the-art of AUVs



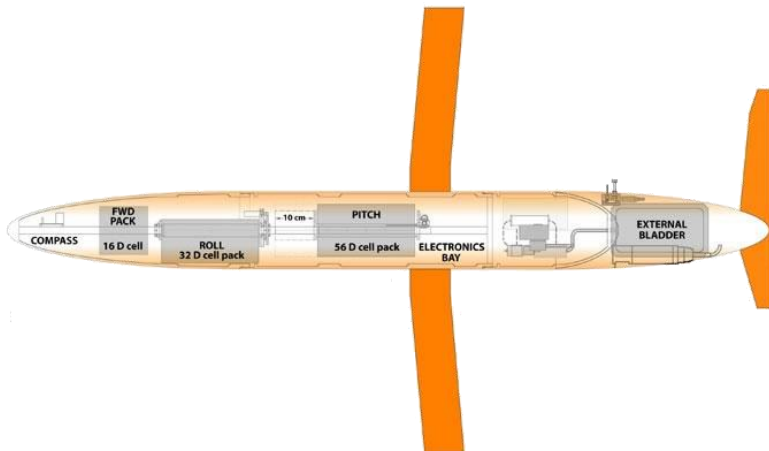
MBARI Dorado
500 kg. 1.5 m/s.
Carries many sensors, but only lasts a day.



MBARI Tethys

110 kg. 0.5 m/s and 1 m/s.

Can run slowly for a long distance or faster for a shorter distance. Can wait in drifting mode until something interesting happens.



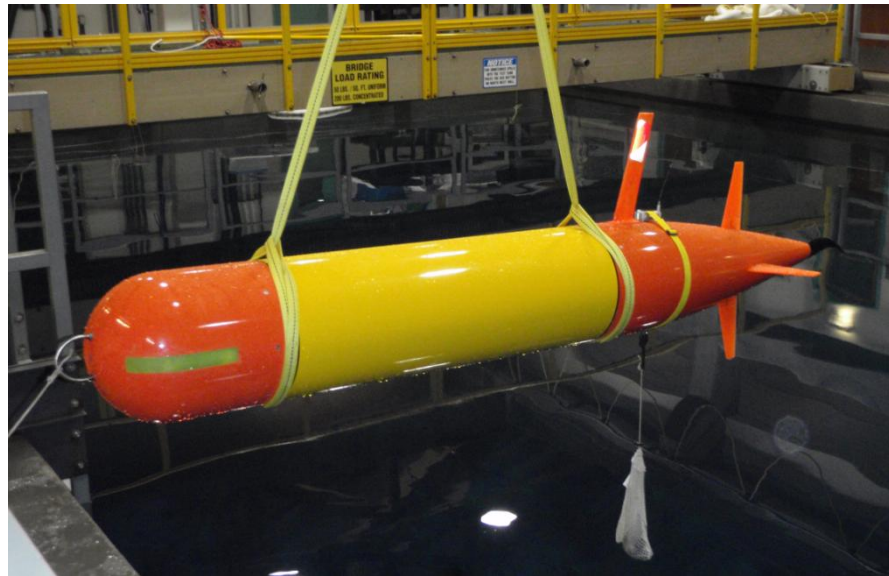
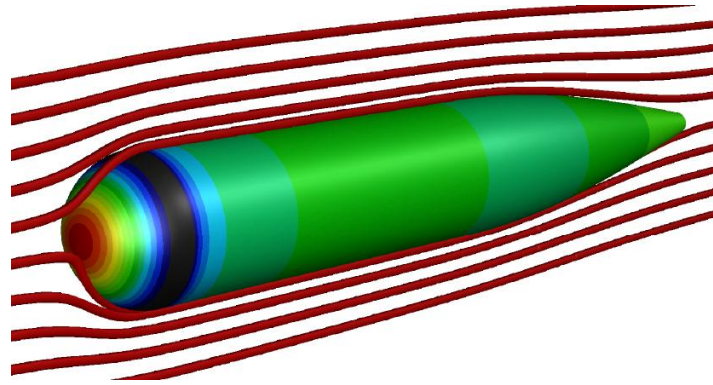
Scripps Spray (Russ Davis)

48 kg. 0.27 m/s.

Can run for months, but can only carry a few sensors, and goes quite slowly.

Bellingham

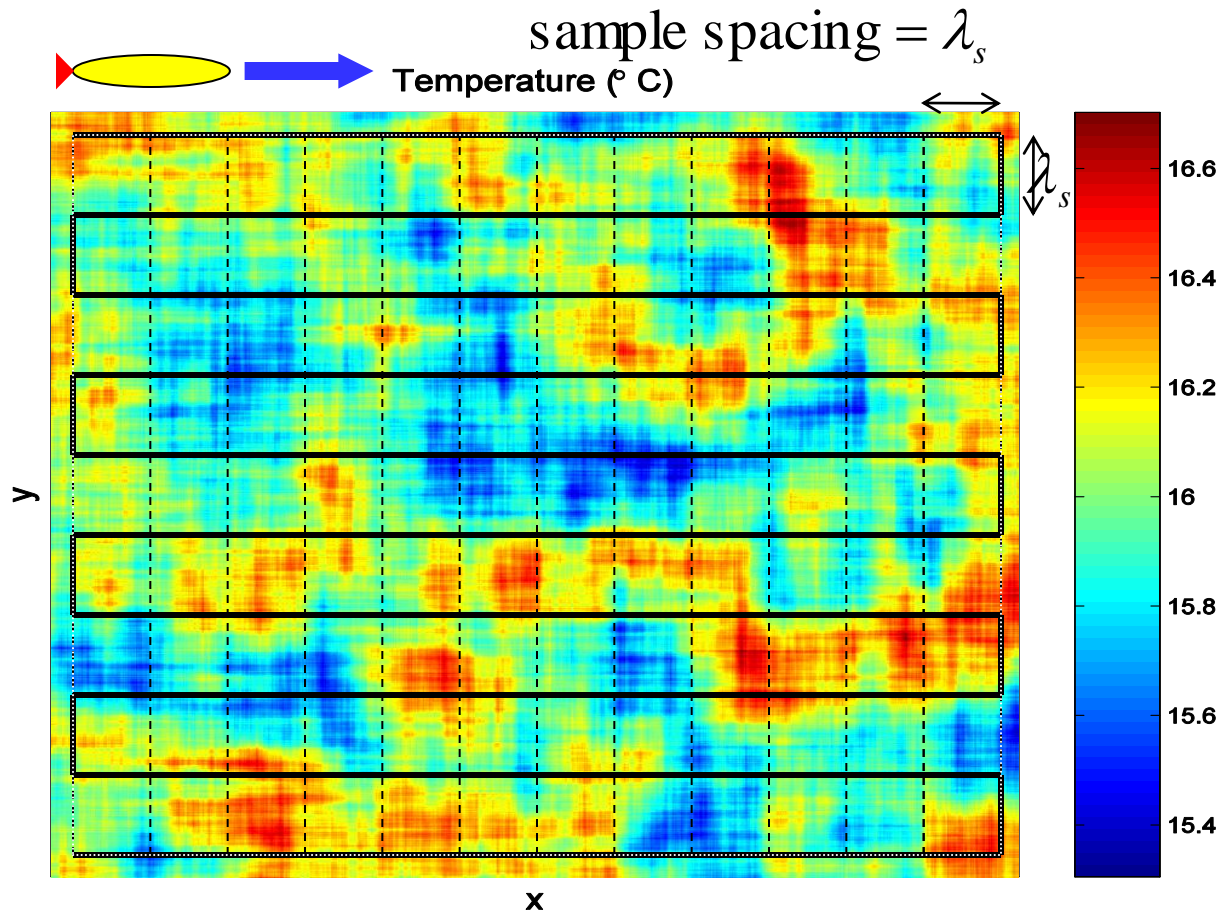
MBARI Tethys AUV



J. G. Bellingham, Y. Zhang, J. E. Kerwin, J. Erikson, B. Hobson, B. Kieft, M. Godin, R. McEwen, T. Hoover, J. Paul, A. Hamilton, J. Franklin, and A. Banka, “[Efficient Propulsion for the Tethys Long-Range Autonomous Underwater Vehicle](#)” *Proc. IEEE AUV'2010*, pp. 1-6, Monterey, CA, U.S.A., September 2010.



Synoptic Mapping of an Ocean Field

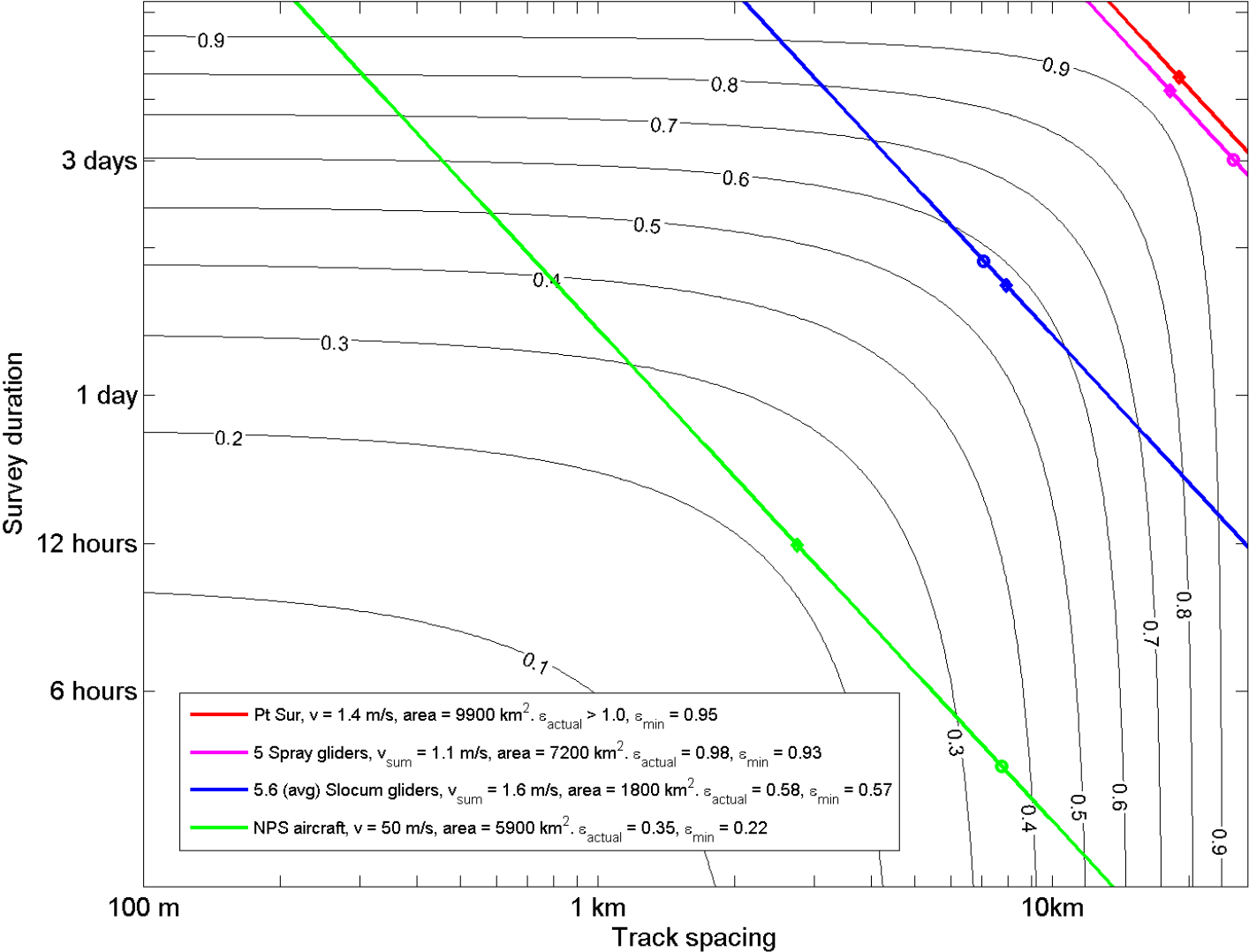


$$\text{AUV traveled distance } L \approx \frac{\text{survey area } A}{\lambda_s}$$

$$\text{Survey duration } \tau = \frac{L}{V} = \frac{A}{\lambda_s V}$$

J. G. Bellingham and J. S. Willcox
 “Optimizing AUV Oceanographic Surveys”
Proc. IEEE AUV'1996, pp. 391-398,
 Monterey, CA, U.S.A., June 1996.

Autonomous Ocean Sampling Network (AOSN) 2003 Experiment in Monterey Bay

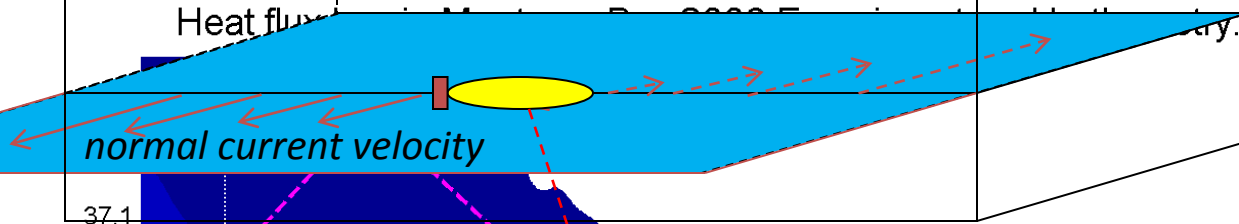


Ocean Flux Estimation

Control volume

Length L

Heat flux



Latitude

$$\text{Heat Flux} = \iint \rho C_p T (\vec{V} \cdot \vec{n}) dS$$

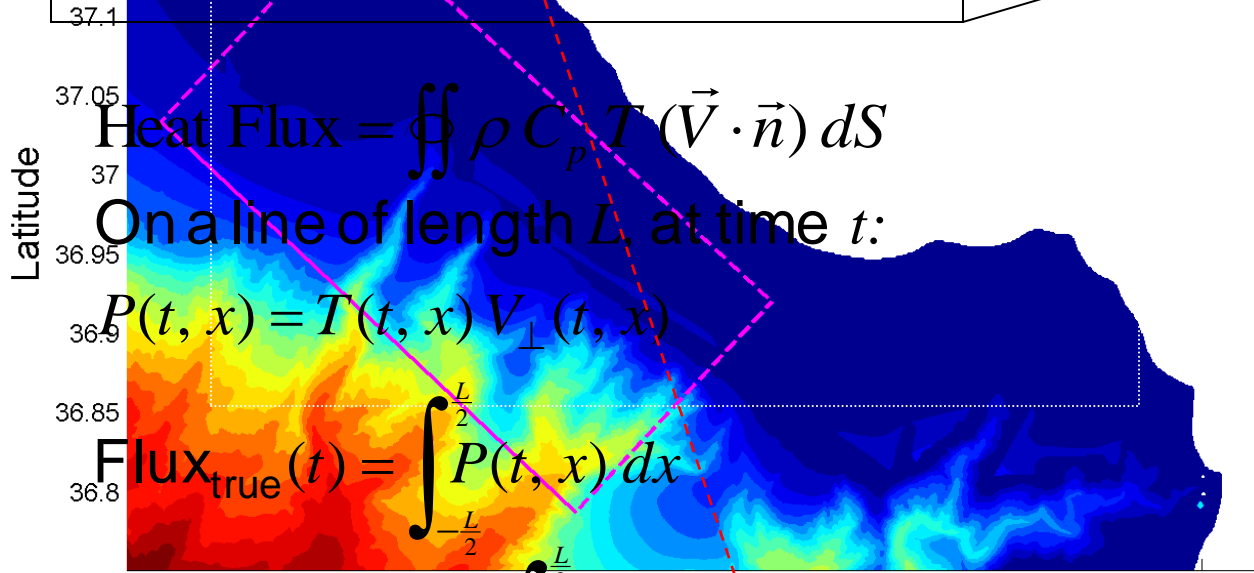
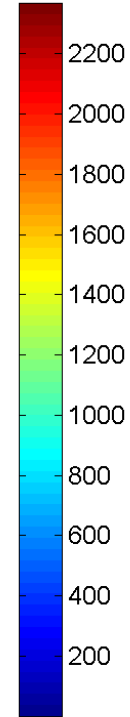
On a line of length L , at time t :

$$P(t, x) = T(t, x) V_{\perp}(t, x)$$

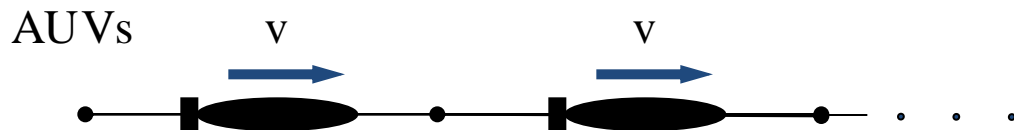
$$\text{Flux}_{\text{true}}(t) = \int_{-\frac{L}{2}}^{\frac{L}{2}} P(t, x) dx$$

$$\text{Flux}_{\text{estimated}}(t) = \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{P(\text{longitude}, x)}{\text{AUV speed}} dx$$

$$\text{Mean-square error (MSE): } \varepsilon = E\{(\text{Flux}_{\text{true}} - \text{Flux}_{\text{estimated}})^2\}$$

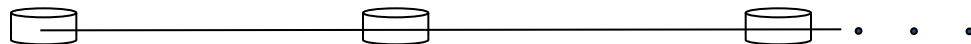


Flux Estimation by AUVs versus Moorings



Using measurements from $t - (L / (2Nv))$ to $t + (L / (2Nv))$ to approximate the snapshot at t : **temporal smearing**.

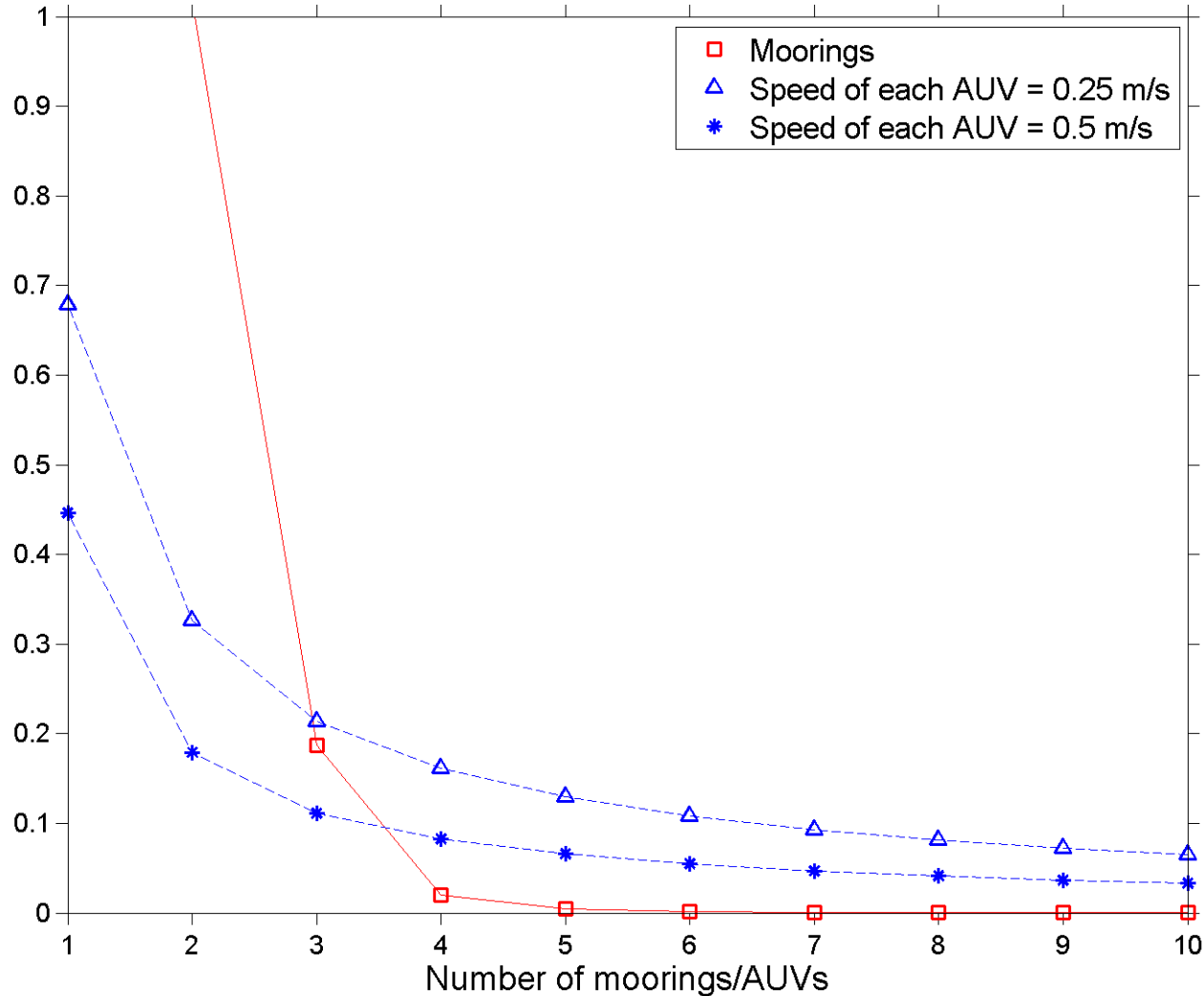
Moorings



Using measurement at one point to approximate the corresponding segment: **spatial aliasing**.

Heat Flux Estimation Performance of Mooring and AUVs

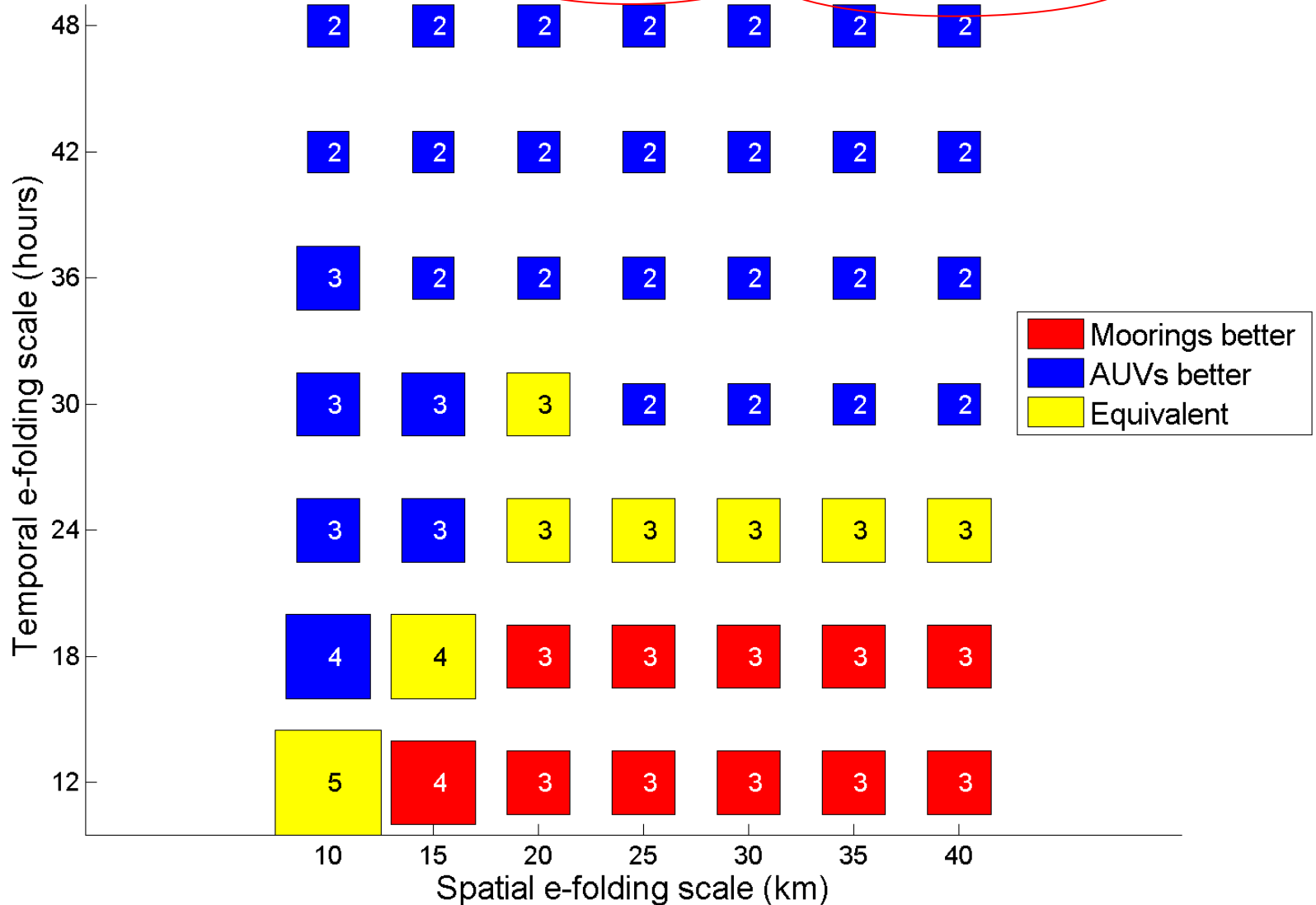
Relative error of flux estimation. $L = 60$ km, $R(\tau, r) = e^{-|\tau|/\tau_0} e^{-(r^2/\lambda_0^2)}$, $\tau_0 = 17$ hours, $\lambda_0 = 16.6$ km.



Y. Zhang, J. G. Bellingham, and Y. Chao, “[Error Analysis and Sampling Strategy Design for Using Fixed or Mobile Platforms to Estimate Ocean Flux](#),” *Journal of Atmospheric and Oceanic Technology*, Vol. 27, No. 3, pp. 481-506, March 2010.

Optimizing Platform Choice for Flux Estimation

Number of platforms needed to achieve relative error ≤ 0.1 Each AUV speed = 0.5 m/s, $L = 60$ km.



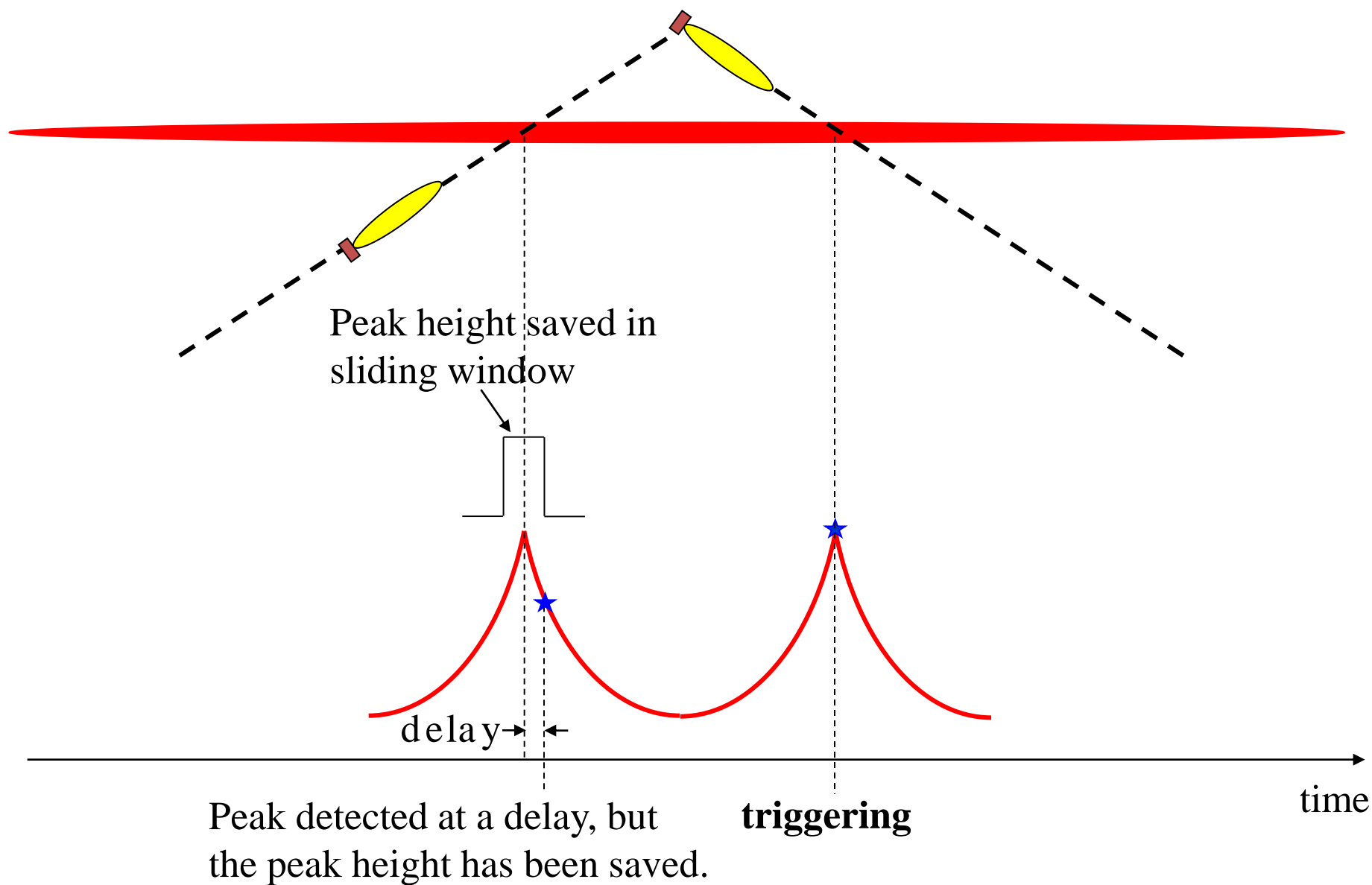
Capturing peak samples from a thin layer



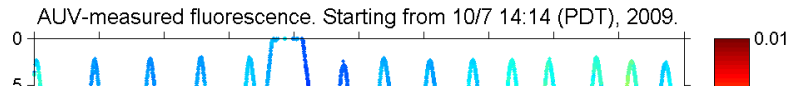
Courtesy of Larry Bird and Alana Sherman

November 2010

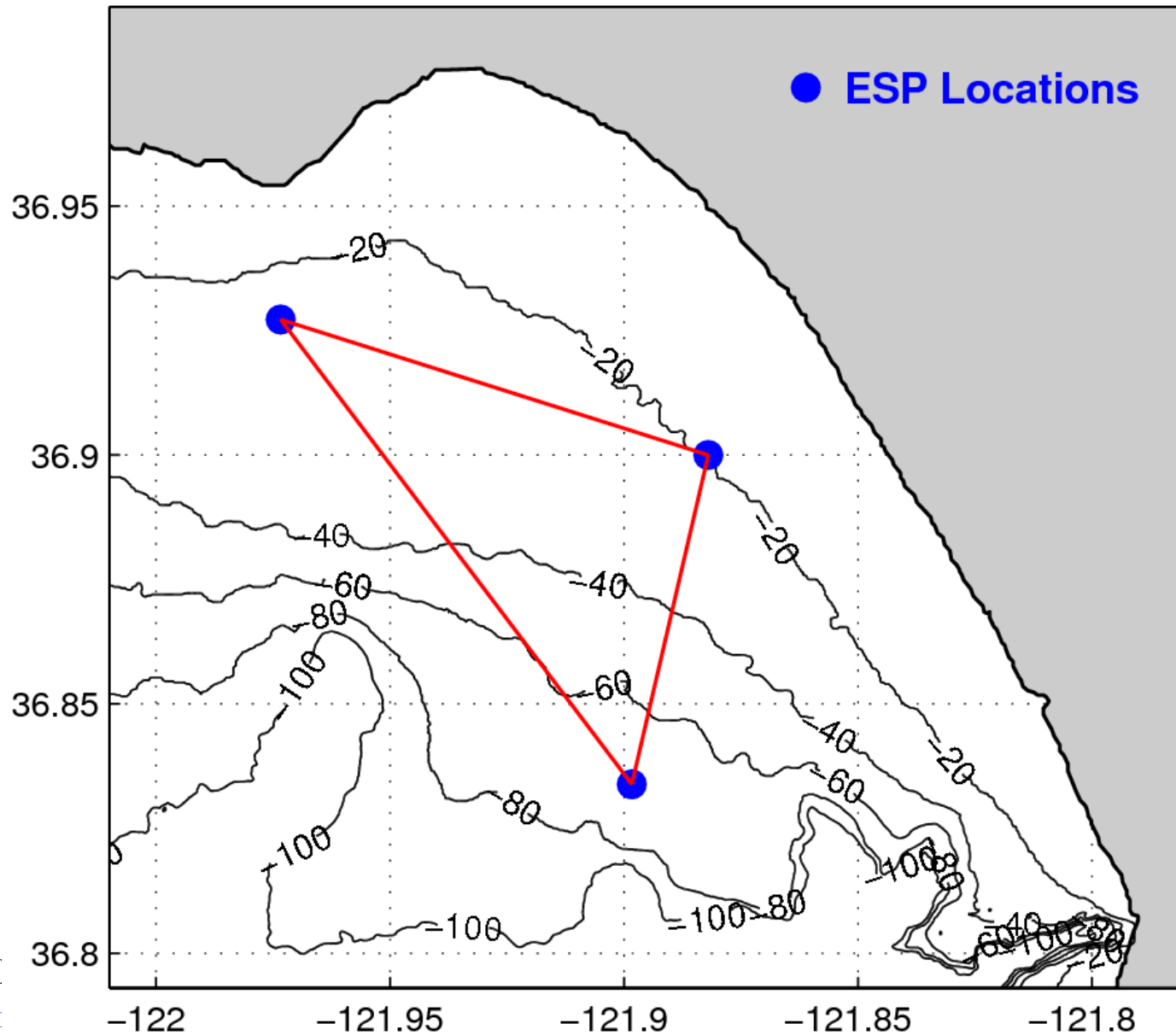
An Adaptive Triggering Method for Capturing Peak Samples in a Thin Phytoplankton Layer by an AUV



Field



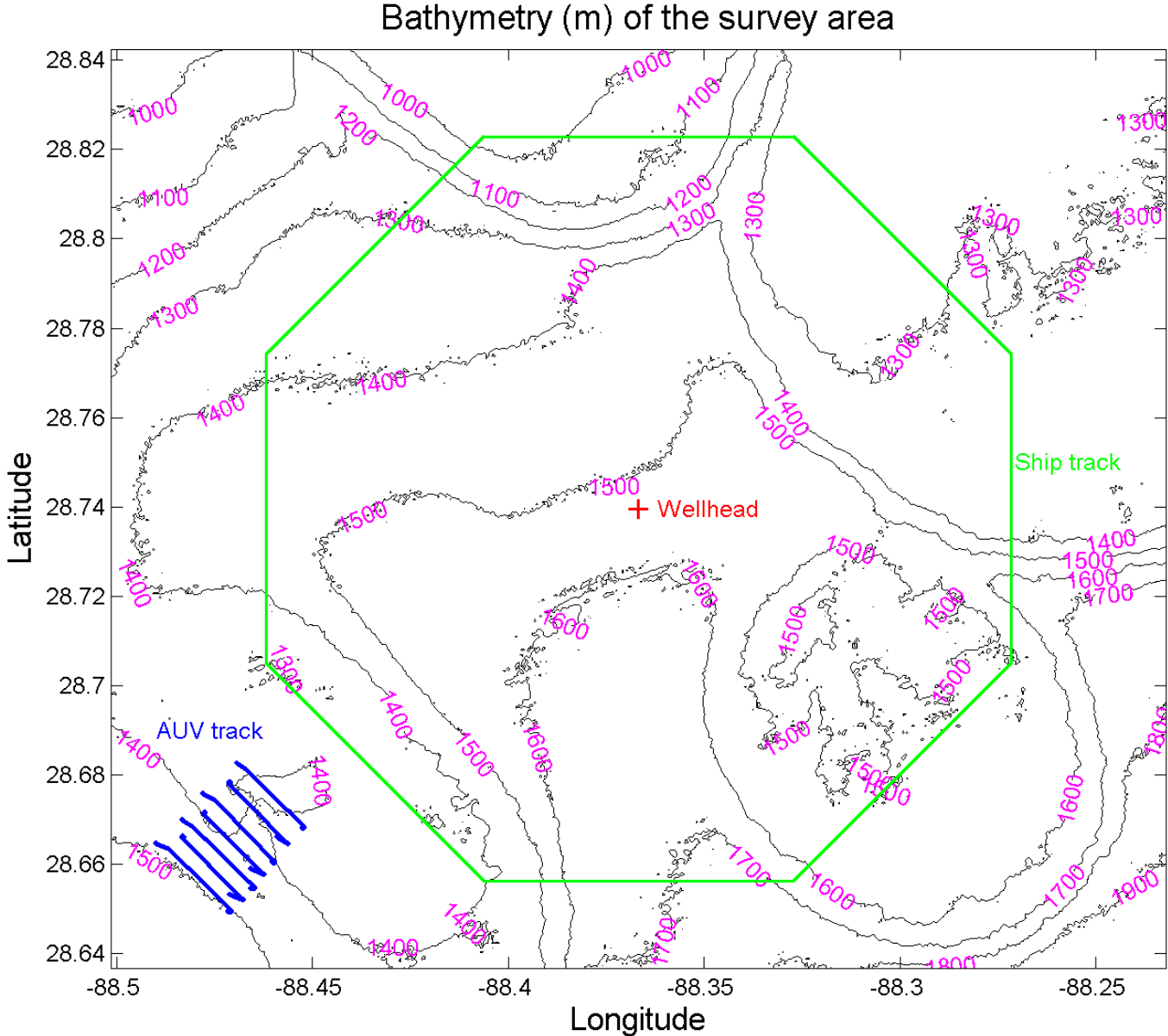
er 2009



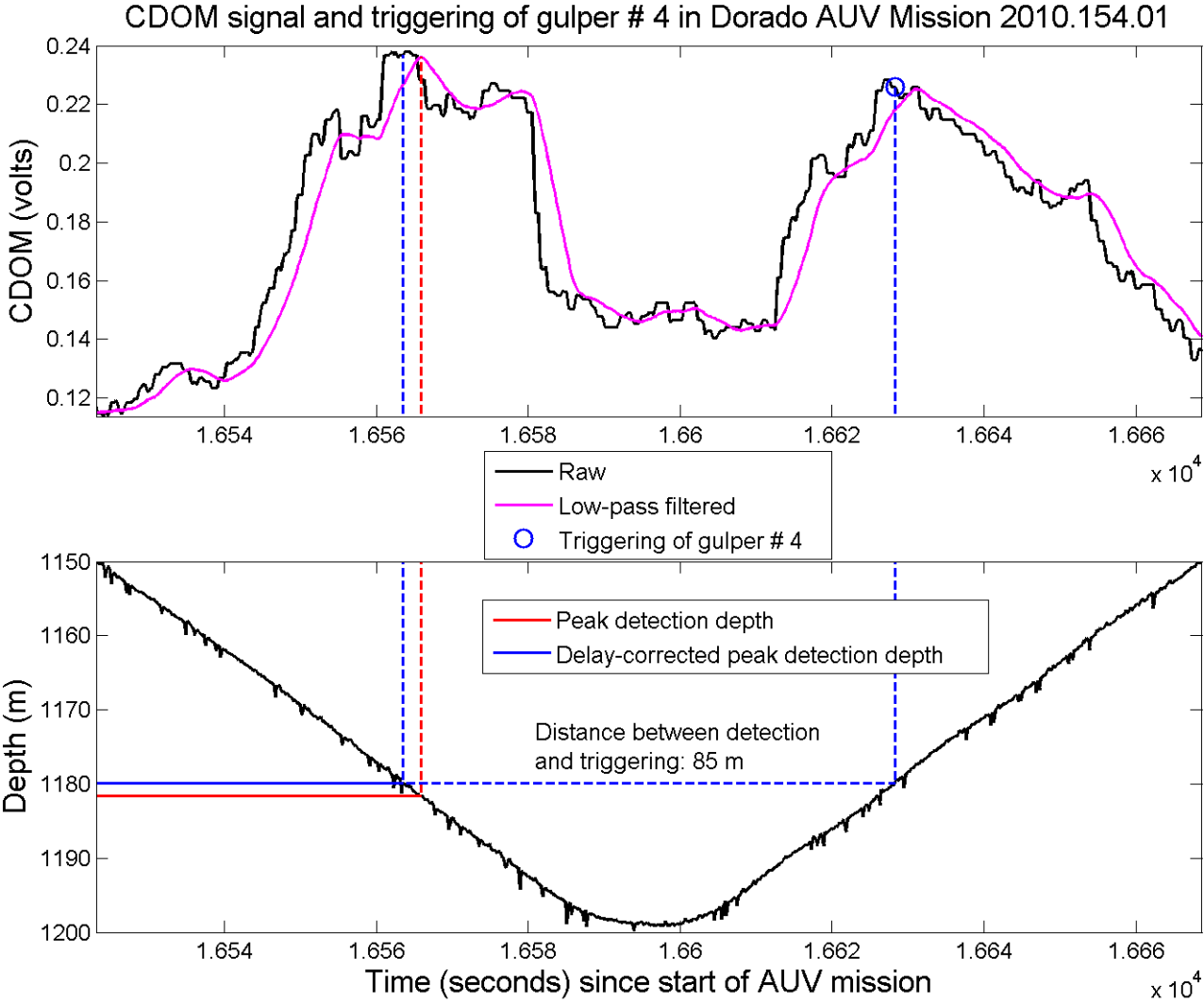
John Ryan

Triggering
rwater Vehicle”

Gulf of Mexico Oil Spill Response Scientific Survey in 2010



Gulf of Mexico Oil Spill Response Scientific Survey in 2010



Y. Zhang, R. S. McEwen, J. P. Ryan, J. G. Bellingham, H. Thomas, C. H. Thompson, and E. Rienecker “[A Peak-Capture Algorithm Used on an Autonomous Underwater Vehicle in the Gulf of Mexico Oil Spill Response Scientific Survey](#),” to be submitted to *Journal of Field Robotics*.

Ongoing and Future Work

MBARI - Decision Support System - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://dss.mbari.org/DSS/

Most Visited

CeNCOOS JPL CANON/BIOSPACE 2010 Decision Support System alpha USC UNIVERSITY OF NORTHERN CALIFORNIA NOAA NIN STANFORD UNIVERSITY icm CAL POLY

Data Products

- Chlorophyll
- Currents
- Salinity
- Nitrate
- Sea Surface Temperature
- Winds

Mission Plans

- Liquid
- Solid
- Wave
- Under

Asset Tracking

- Vessel tracks
- AUV tracks
- Glider tracks
- Drifter tracks

Center screen to target: -none-

Time window: 6 hr

Asset Map Wiki Collaborative Science Planning Logistics

Drag & drop virtual drifter

Dorado survey planner

Satellite Hybrid

Mouse on map is at:
Lat: 36.896096221858116
Lon: -121.88369750976562

System Time
20/10/2010 03:33 PM PDT

Drifters

AUVs / ASVs

Glider

Vessels

Moorings

Done

Start Z... M... E... F... F... S... Y... F... C... T... O... M... EN am 3:33 PM

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感谢母校!



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