Capturing the Key Oceanographic Signals with Autonomous Underwater Vehicles

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M B A R I

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Monterey Bay Aquarium Research Institute (MBARI)

MBARI founder David Packard:

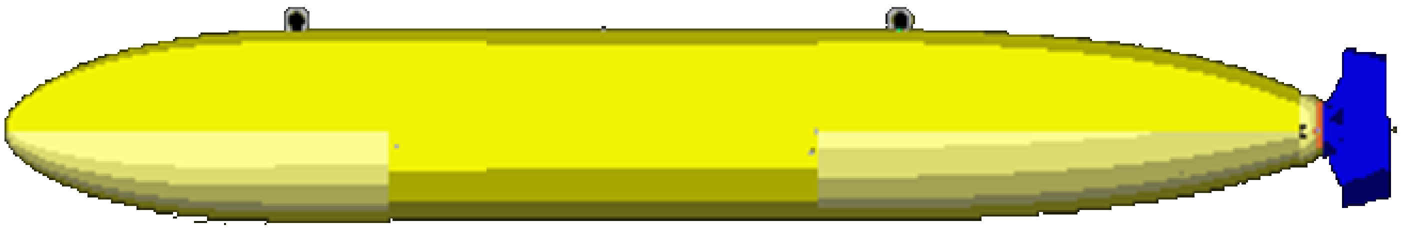
"Send instruments to sea, not people.

Return information to shore, not samples"

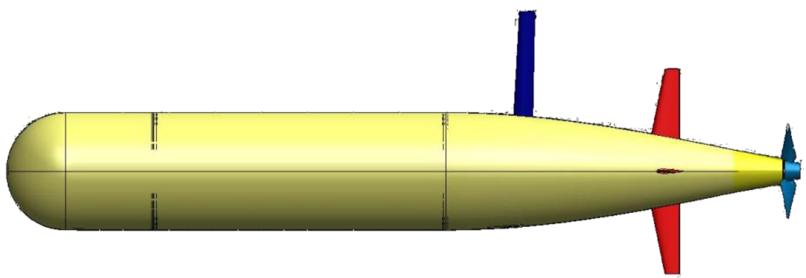
Outline

- 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

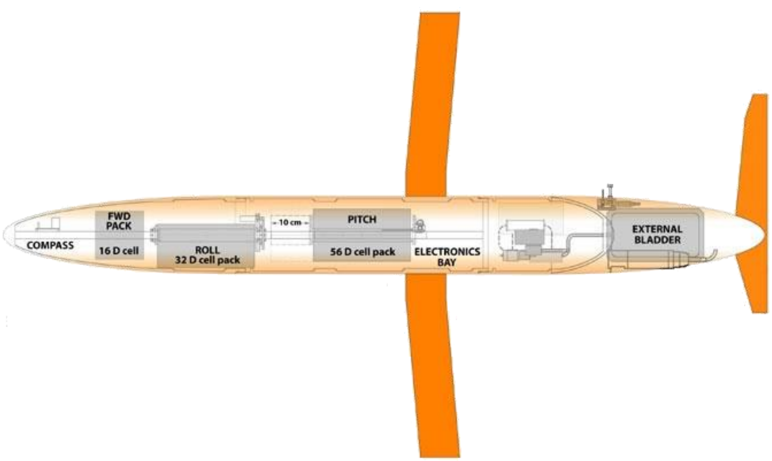
State-of-the-art of AUVs



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



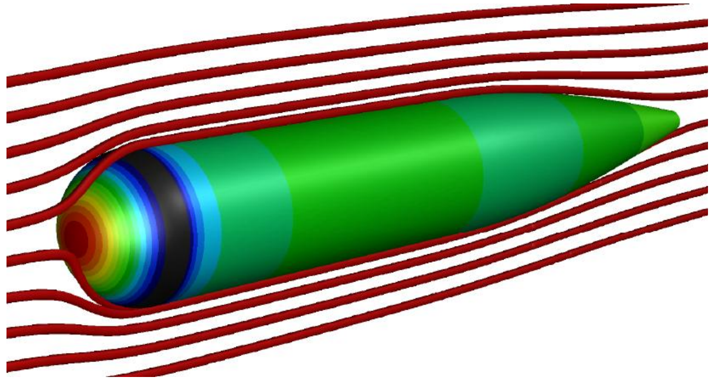
MBARI Tethys
110 kg. 0.5 m/s and 1 m/s.
Can run slowly for a long distance or faster for a shorter distance. Can wait in drifting mode until something interesting happens.

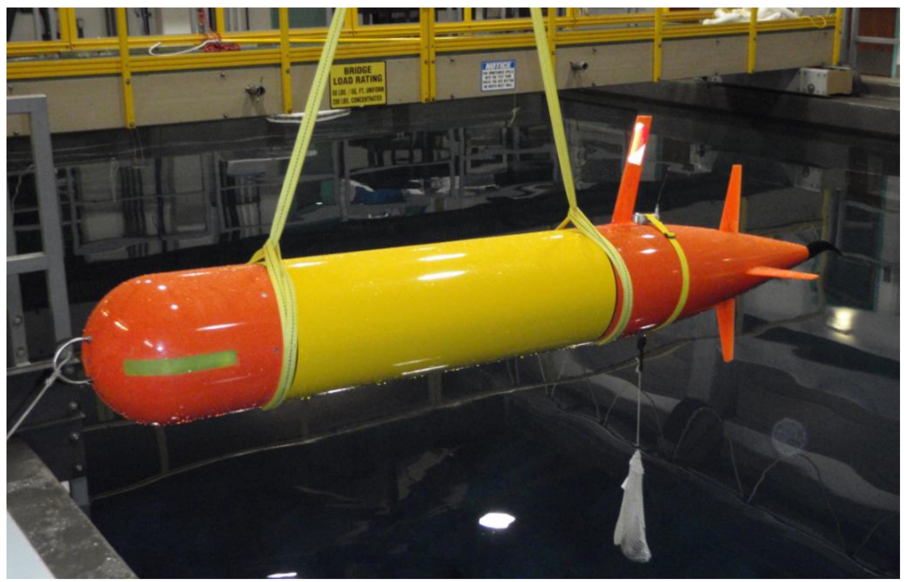


Scripps Spray (Russ Davis)
48 kg. 0.27 m/s.
Can run for months, but can only carry a few sensors, and goes quite slowly.

Bellingham

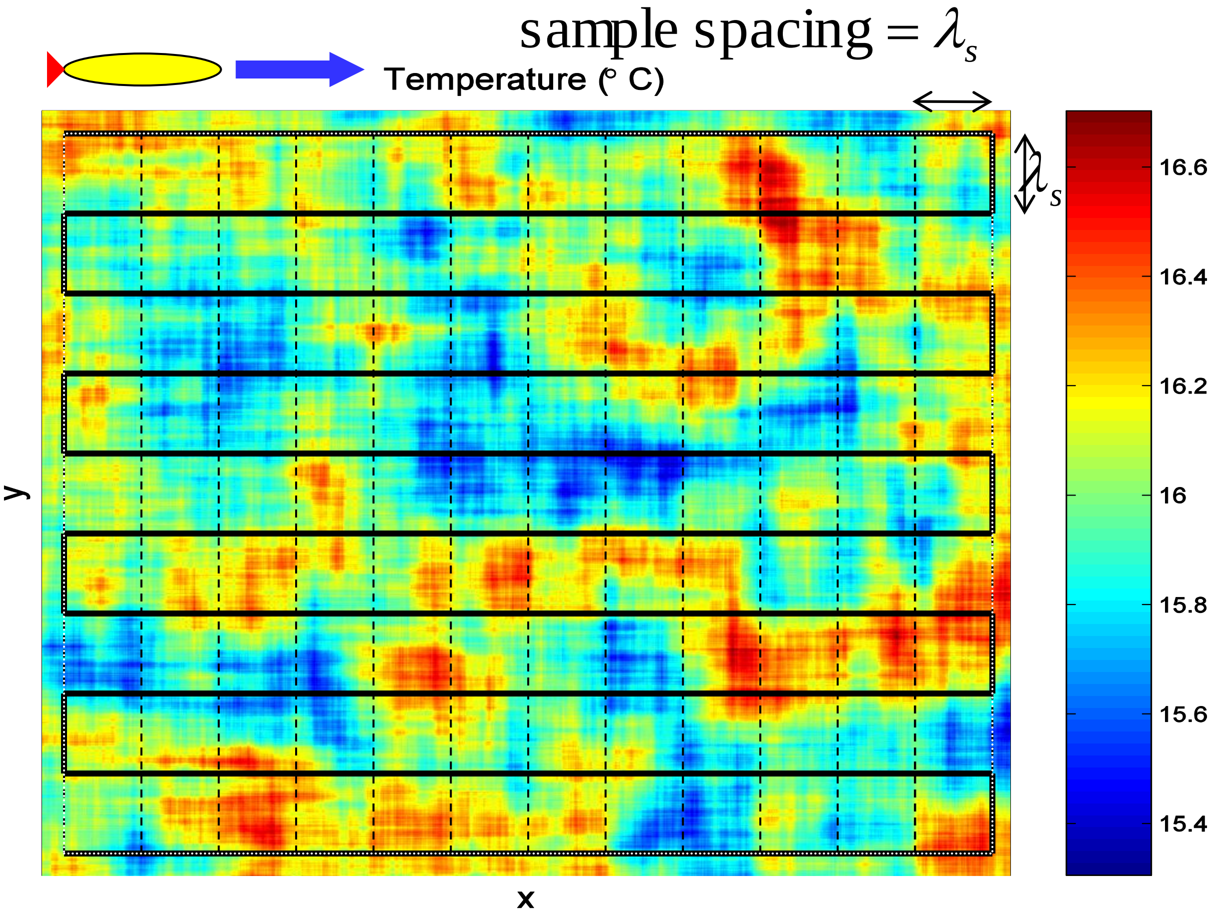
MBARI Tethys AUV





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

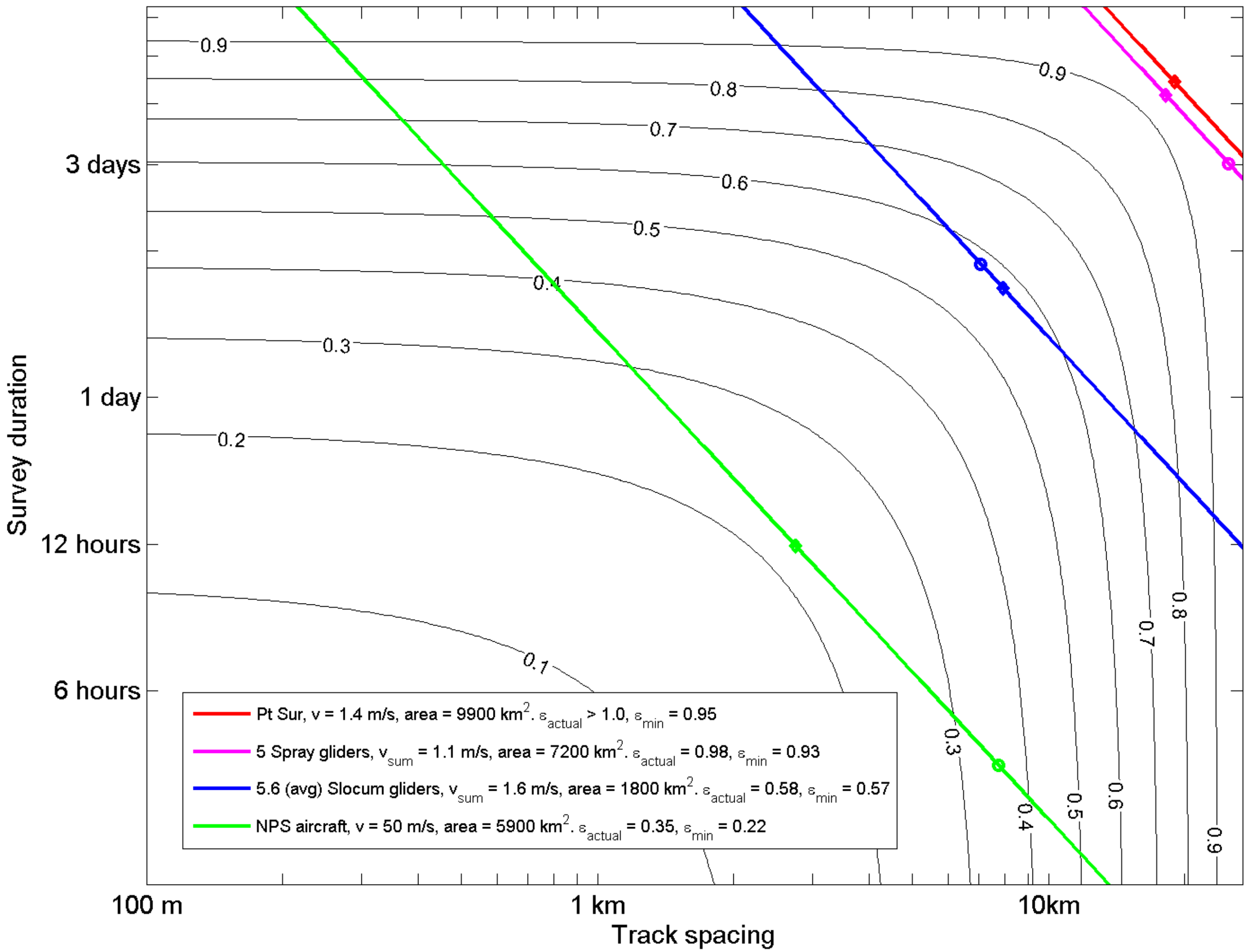


$$\text{AUV traveled distance } L \approx \frac{\text{survey area } A}{\lambda_s}$$

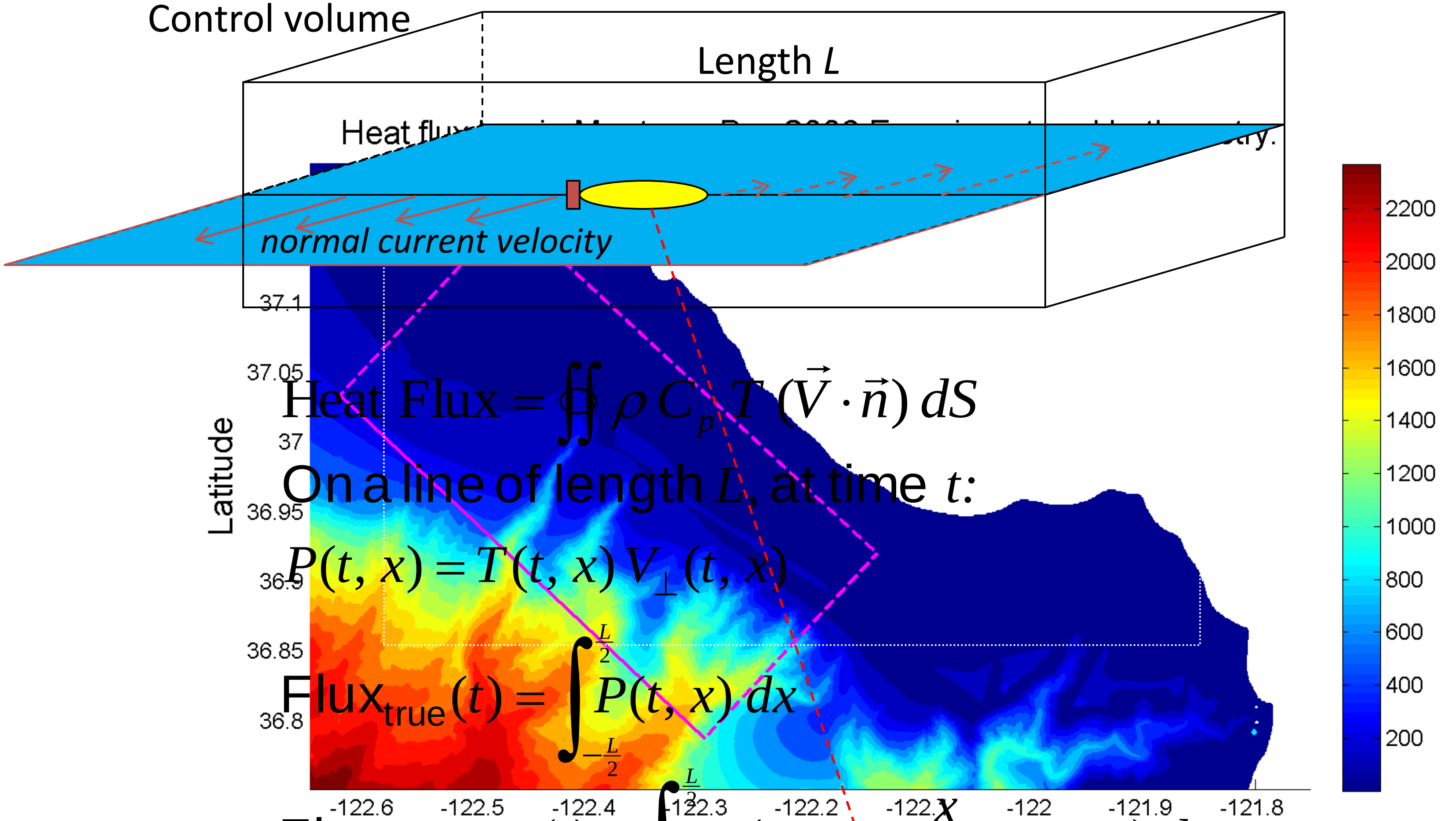
$$\text{Survey duration } \tau = \frac{L}{V} = \frac{A}{\lambda_s V}$$

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



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

On a line of length L, at time t:

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

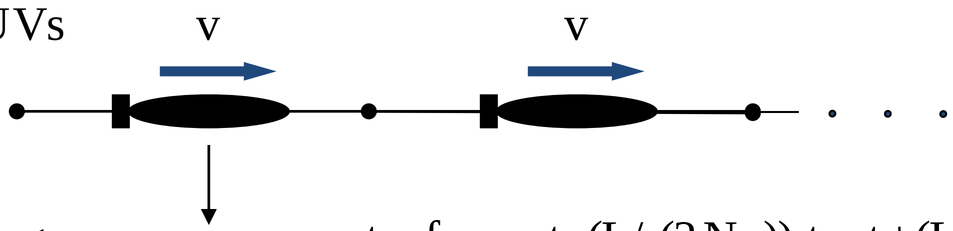
$$\text{Flux}_{\text{true}}(t) = \int_{-\frac{L}{2}}^{\frac{L}{2}} P(t, x)\, dx$$

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

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

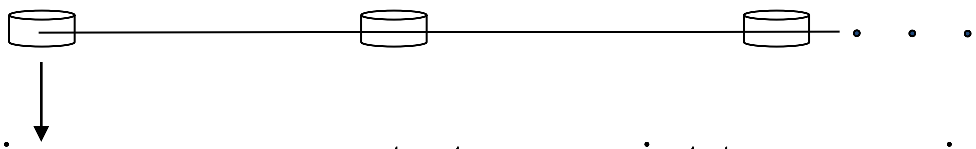
Flux Estimation by AUVs versus Moorings

AUVs



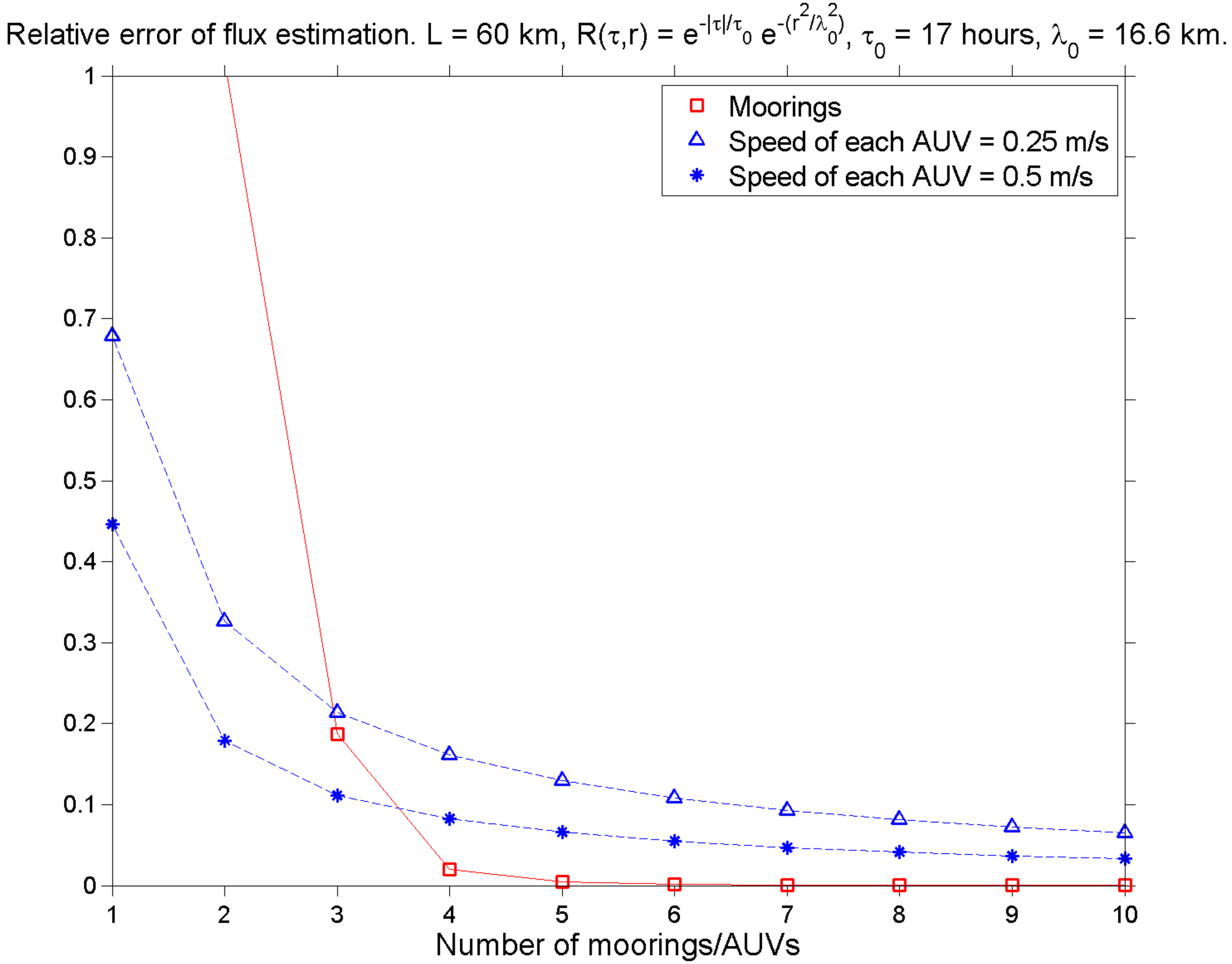
Using measurements from t-(L/ (2Nv)) to t+(L/ (2Nv))
to approximate the snapshot at t: temporal smearing.

Moorings



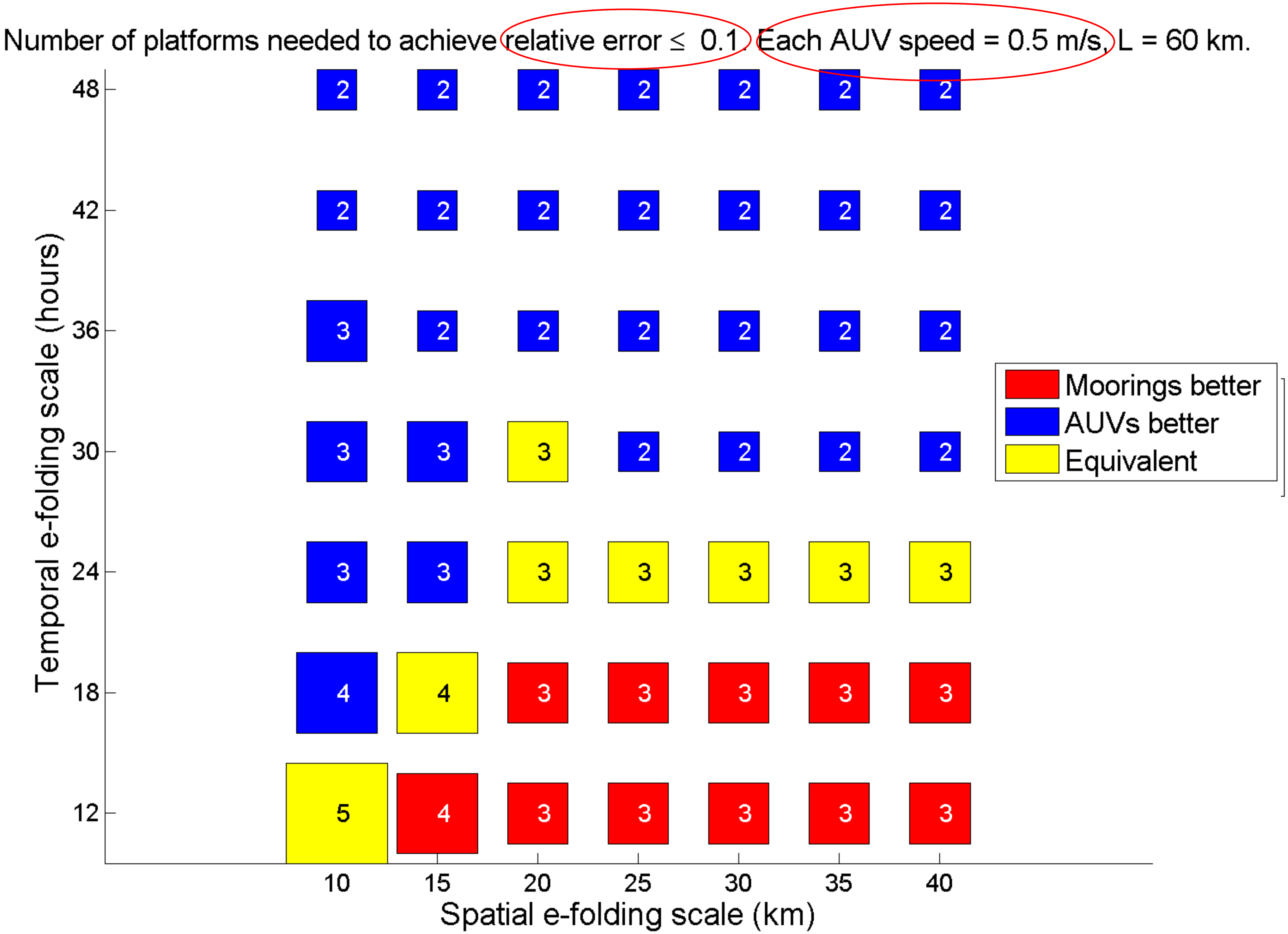
Using measurement at one point to approximate
the corresponding segment: spatial aliasing.

Heat Flux Estimation Performance of Mooring and AUVs

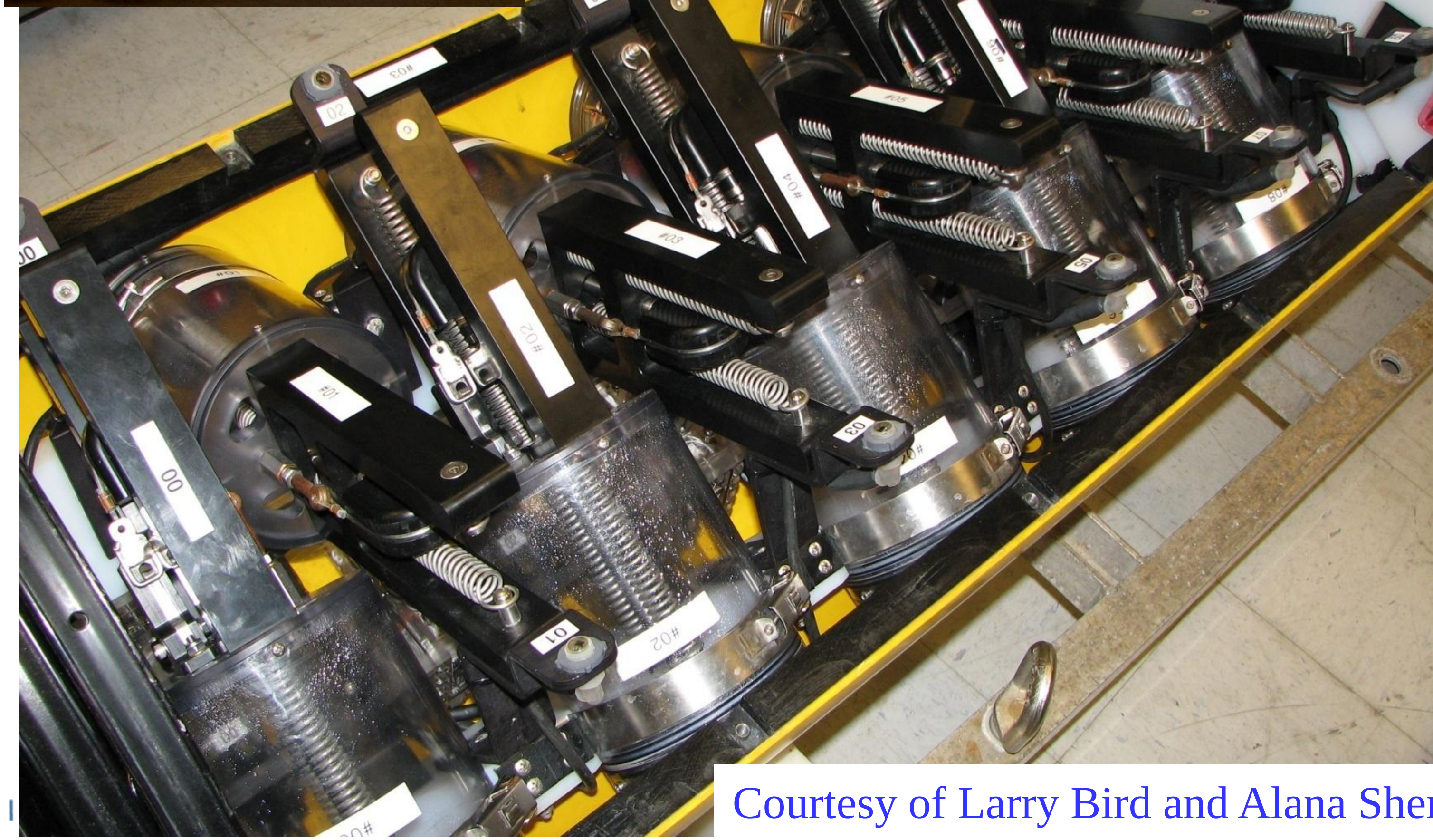


Y. Zhang, J. G. Bellingham, and Y. Chao, "Error Analysis and Sampling Strategy Design for Using Fixed or Mobile Platforms to Estimate Ocean Flux," *Journal of Atmospheric and Oceanic Technology*, Vol. 27, No. 3, pp. 481-506, March 2010.

Optimizing Platform Choice for Flux Estimation



Capturing peak samples from a thin layer



Courtesy of Larry Bird and Alana Sherman

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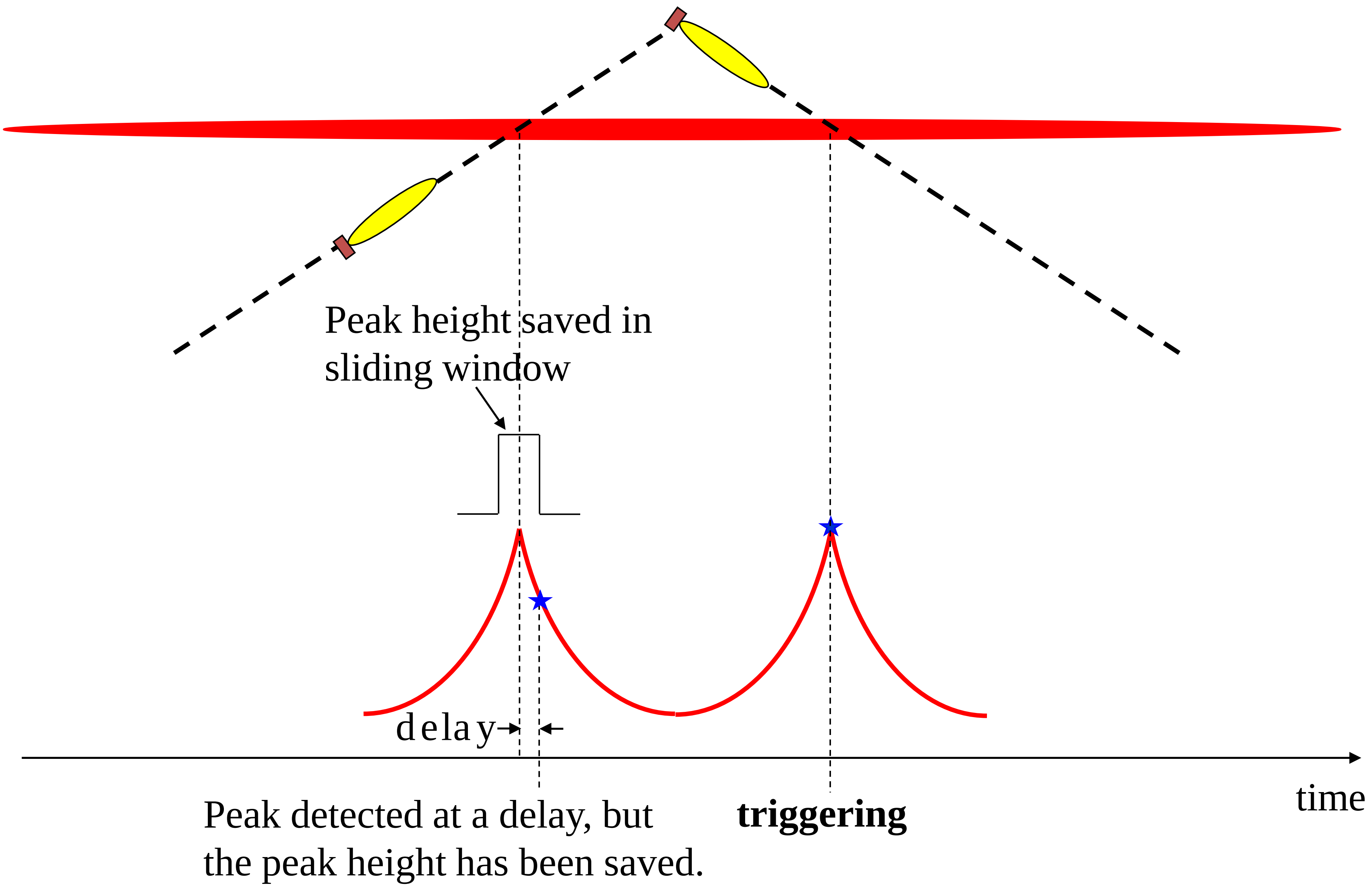
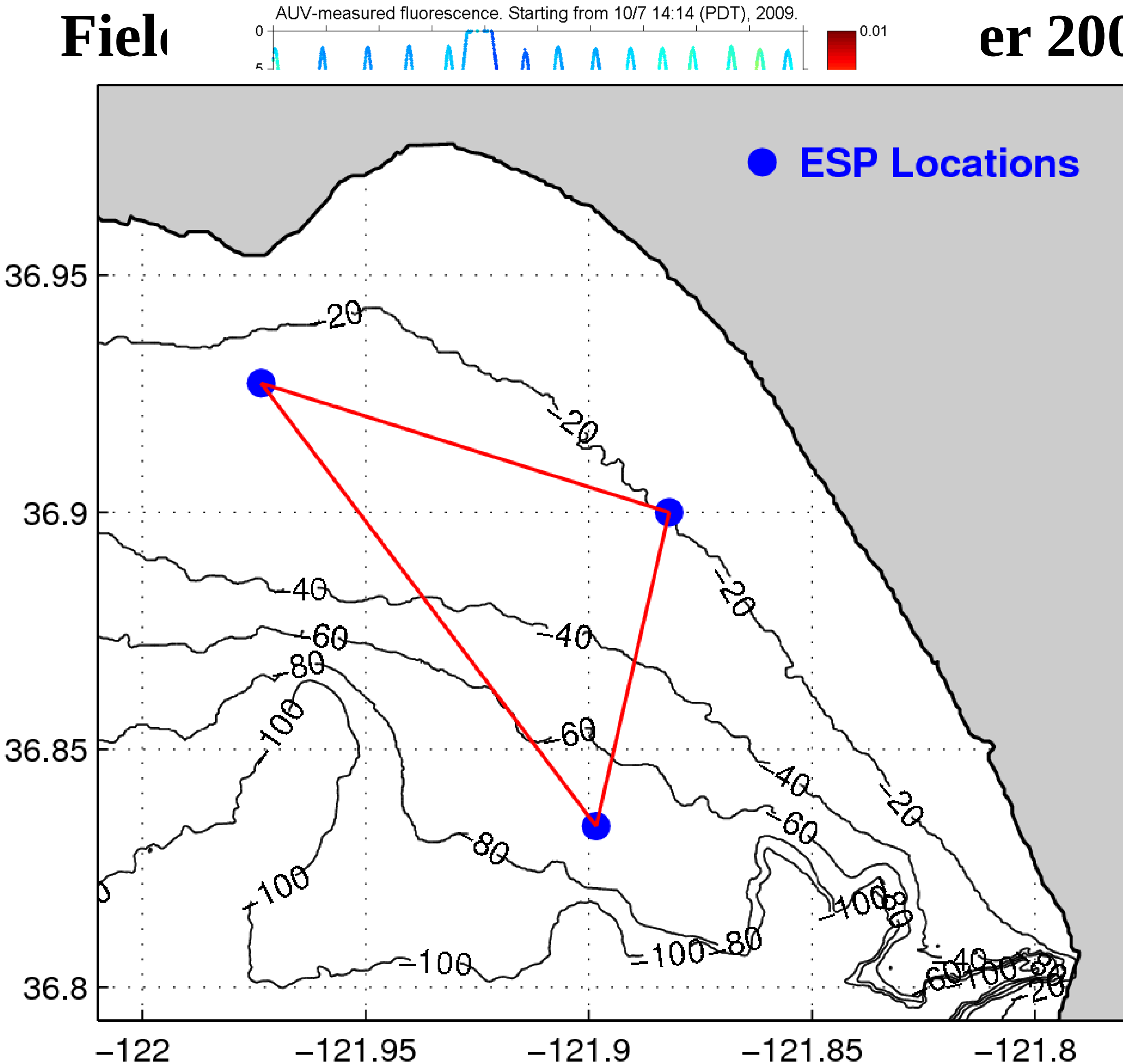
An Adaptive Triggering Method for Capturing Peak Samples in a Thin Phytoplankton Layer by an AUV



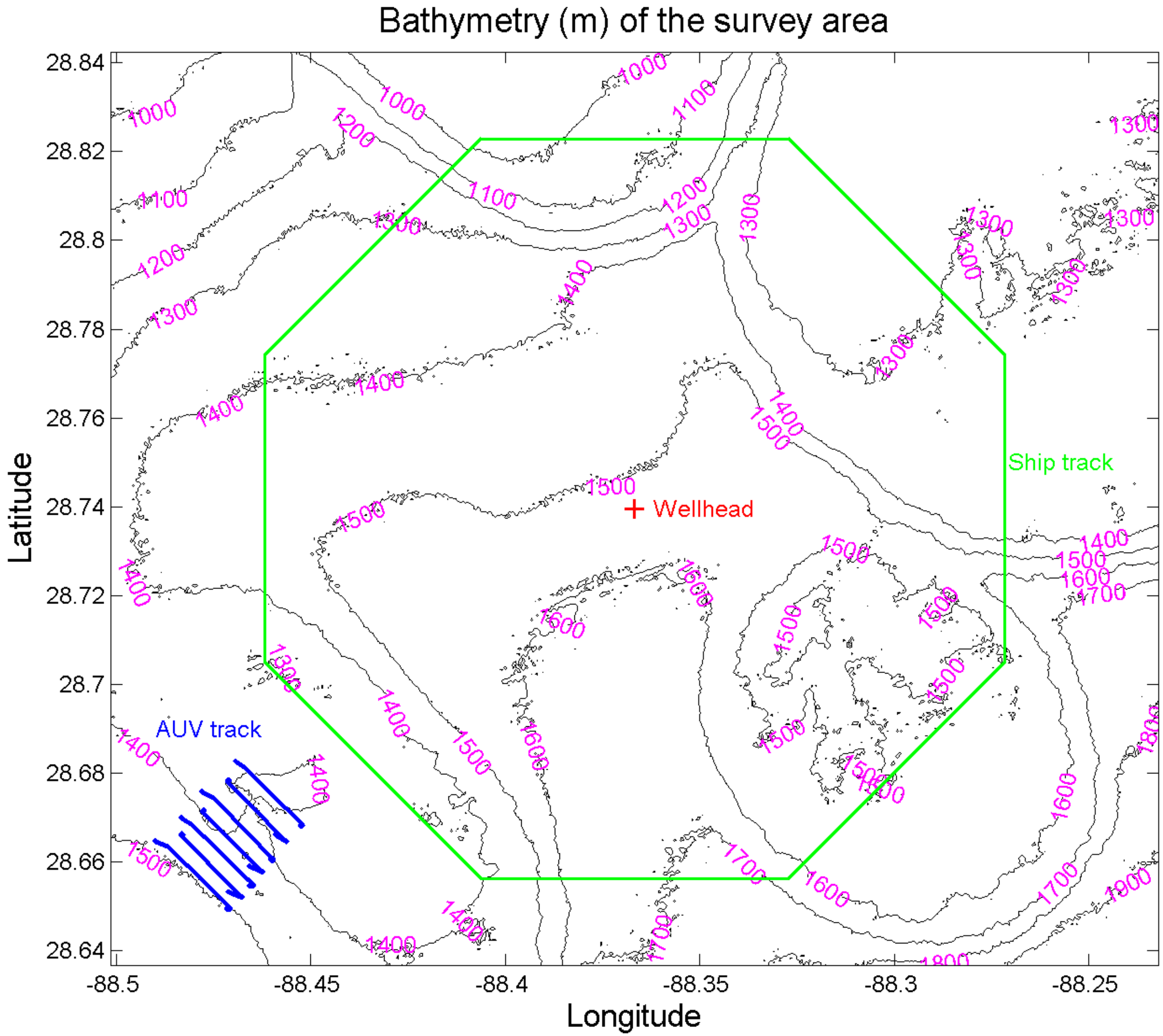
Fiel... er 2009



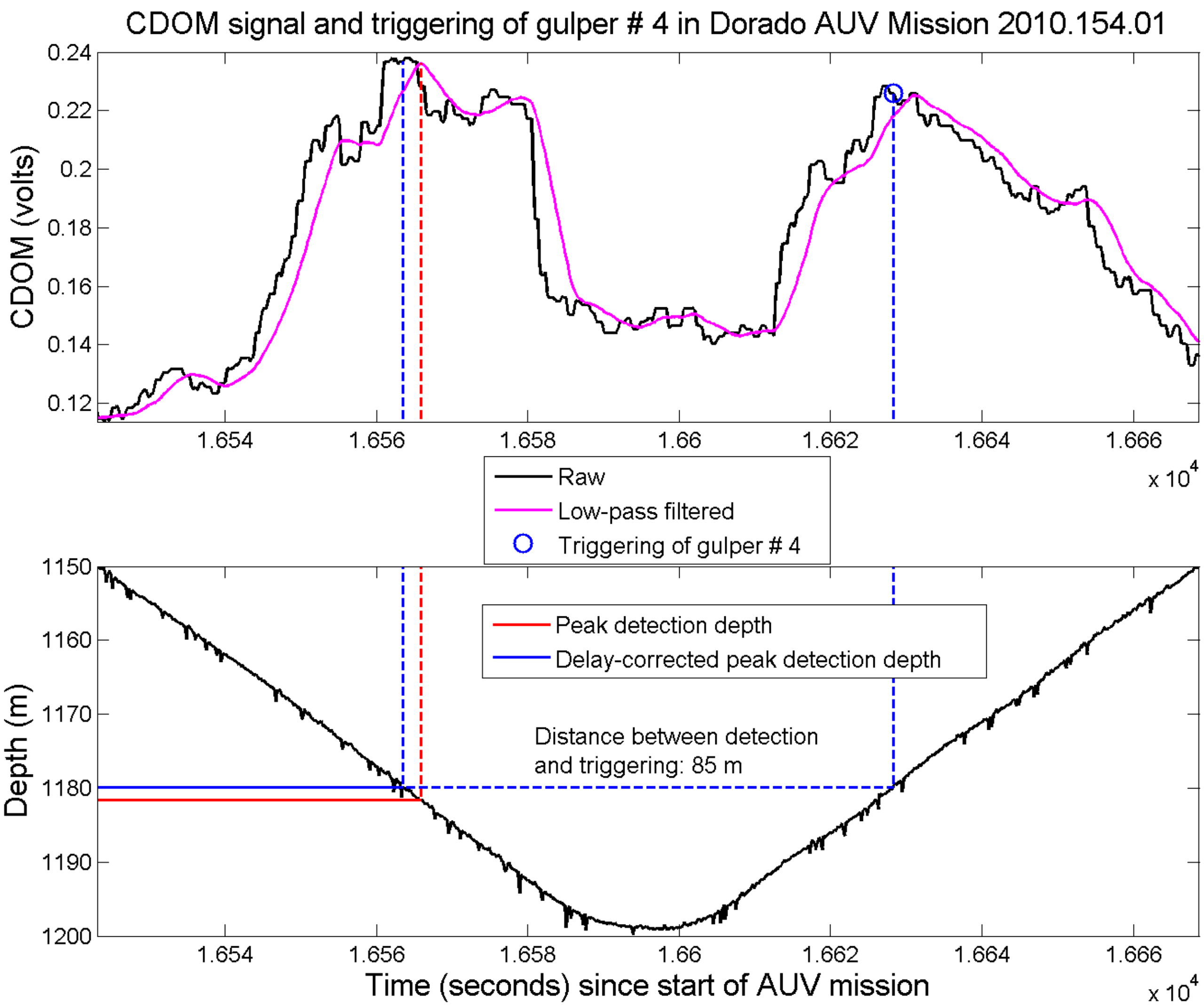
John Ryan

Y. Zhang, ... Triggering
Method fo... ...rwater Vehicle"
IEEE Journal of Oceanic Engineering, in press.

Gulf of Mexico Oil Spill Response Scientific Survey in 2010

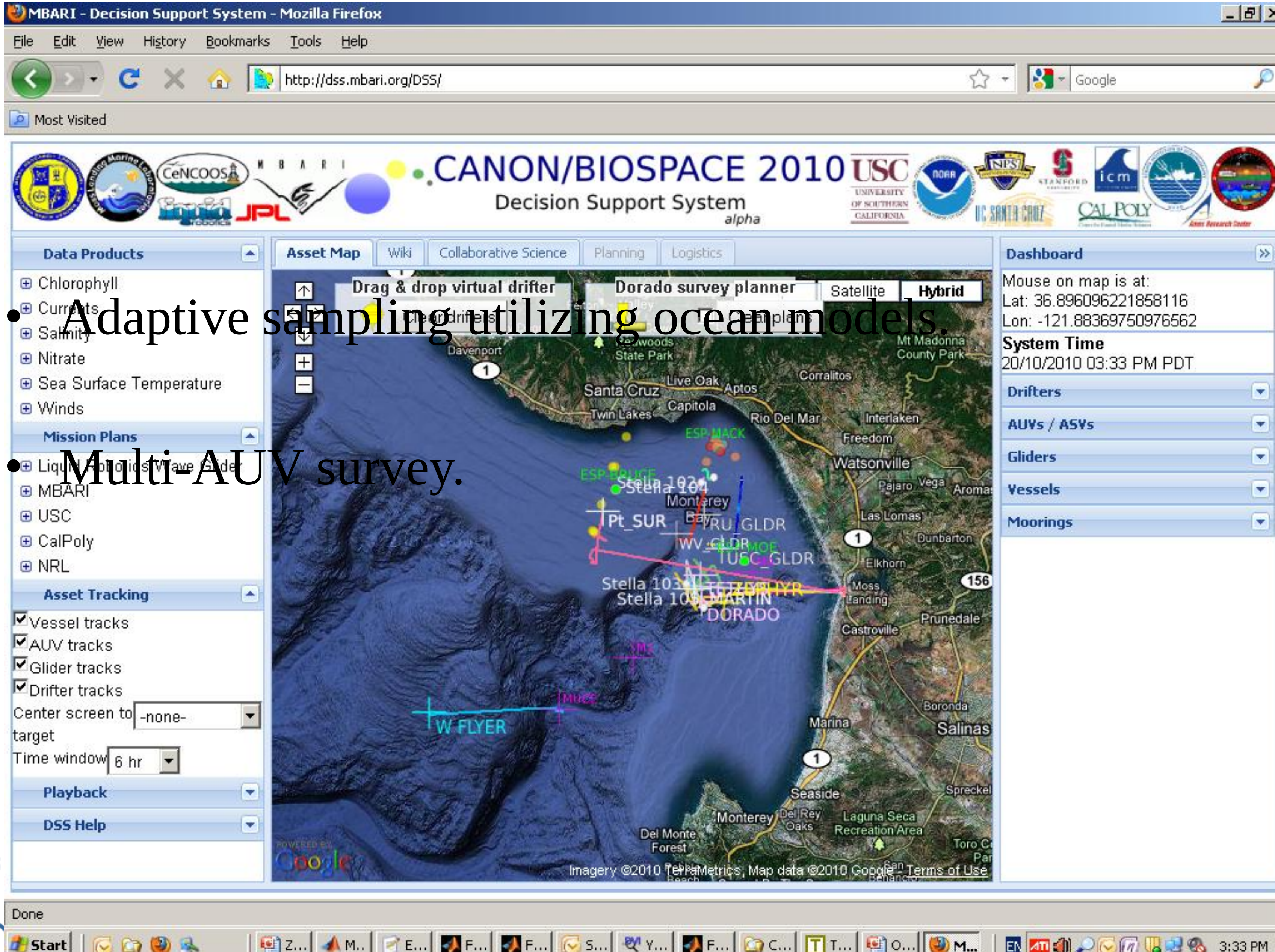


Gulf of Mexico Oil Spill Response Scientific Survey in 2010



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



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- Adaptive sampling utilizing ocean models.
- Multi-AUV survey.

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感谢母校!