Adaptive Sampling in Ocean Observation

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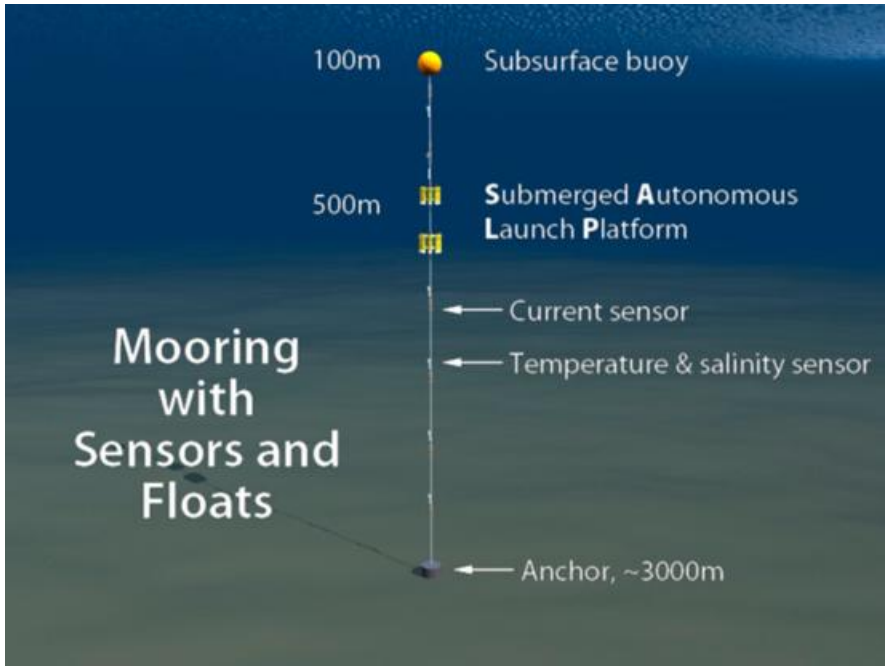
Outline

- Adaptive sampling = Adapting sampling strategy based on observations, to make observations more effective and efficient.
- Brief review of adaptive sampling for moored instruments
- Adaptive sampling for autonomous underwater vehicles (AUVs)
  - Capturing peak-chlorophyll water samples in a phytoplankton thin layer
  - Tracking an upwelling front
  - Targeted sampling when yo-yoing through distinct water columns
- Towards a synergistic adaptive ocean observing system (cabled observatory + AUVs)

Adaptive Sampling for Moored Instruments

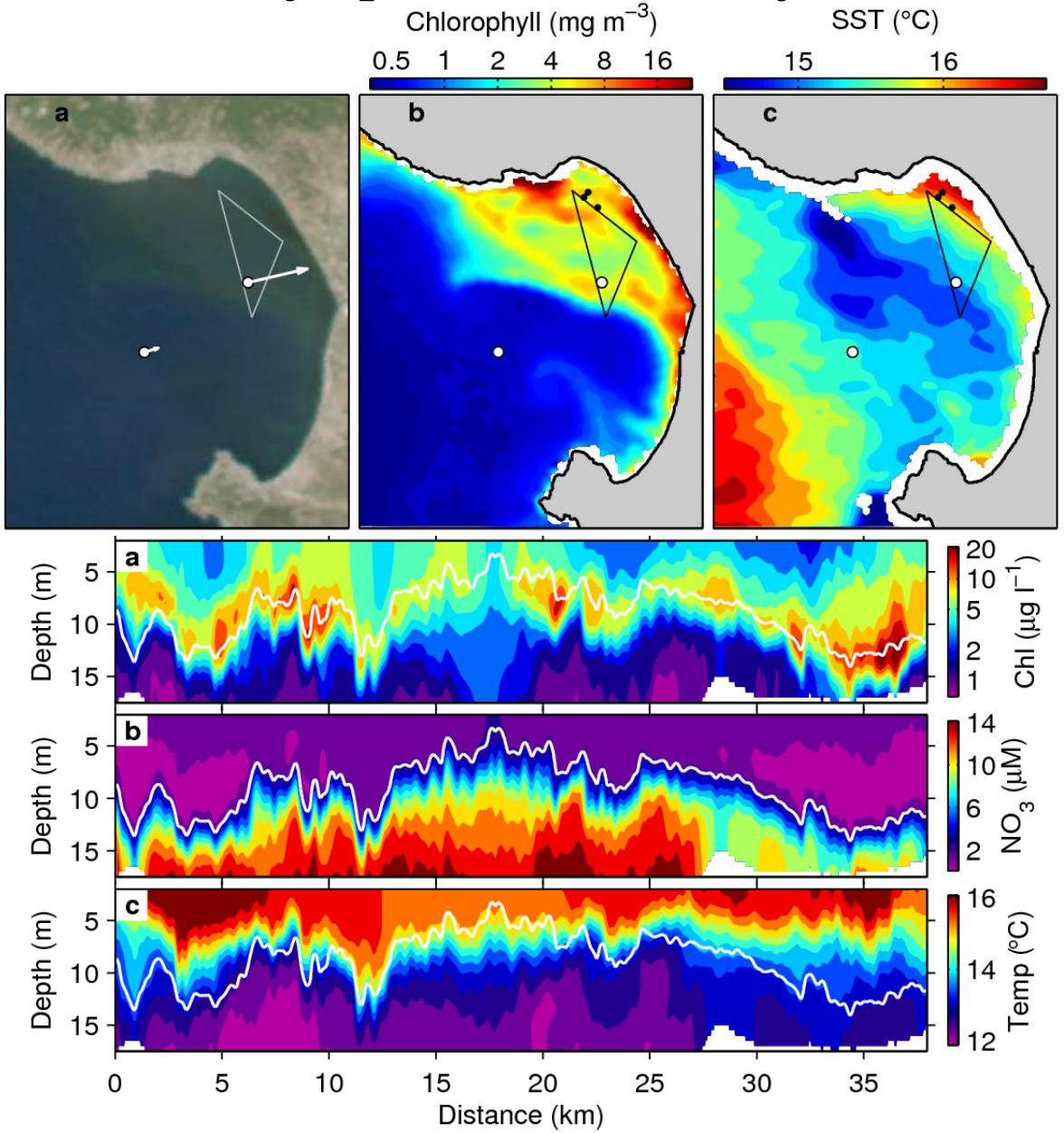
- Increasing sensors' sampling rate when some oceanographic event is detected, e.g., on detection of internal waves [Irish et al., 1984].

- Releasing profiling floats from a mooring when an eddy passes by [Bower et al., 2009].



From Woods Hole Oceanographic Institution website
http://www.whoi.edu/oceanus/viewImage.do?id=58546&aid=34106

Phytoplankton Thin Layers

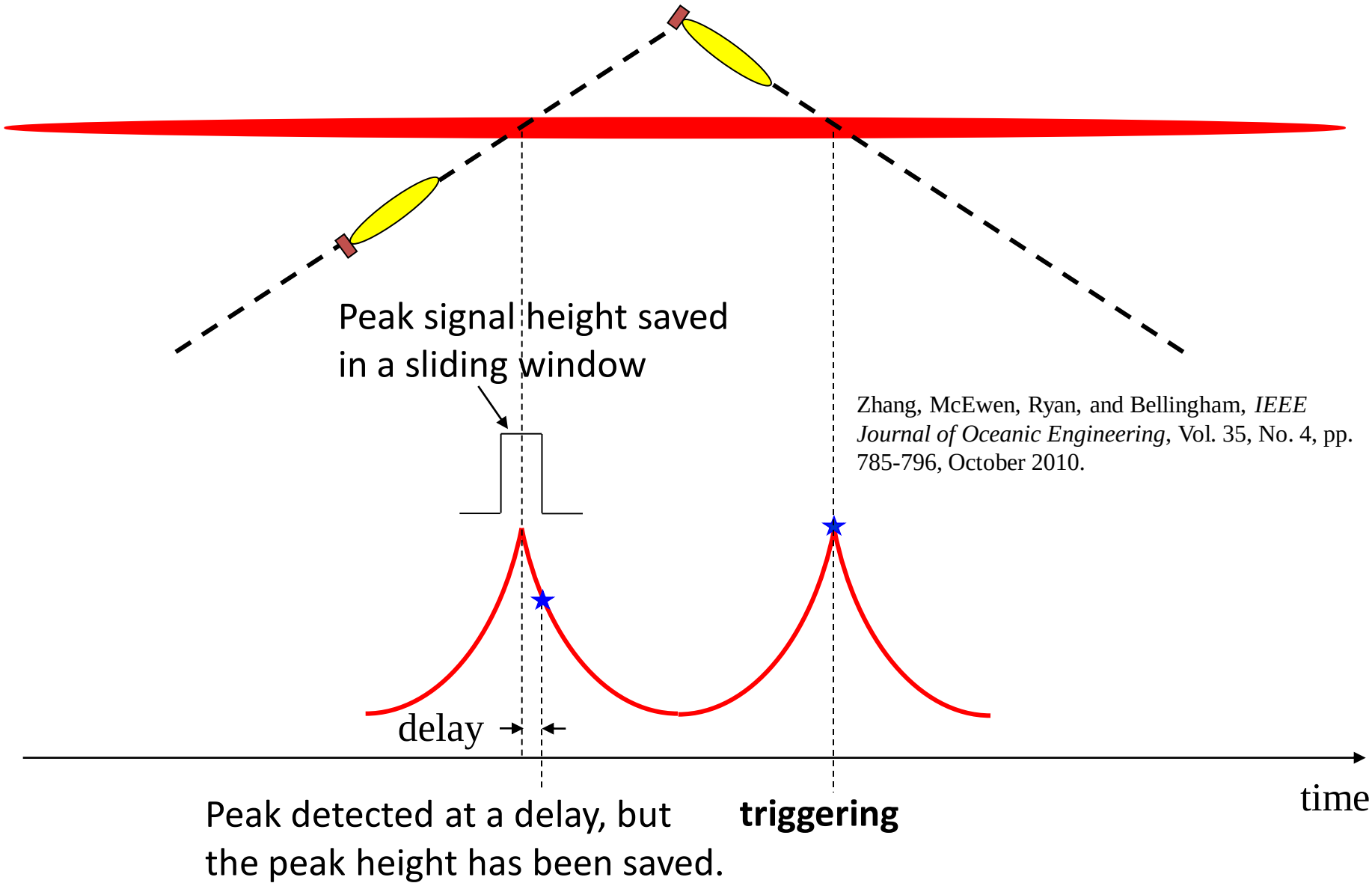


From Ryan et al., *Continental Shelf Research*, Vol. 30, pp. 7-16, 2010.

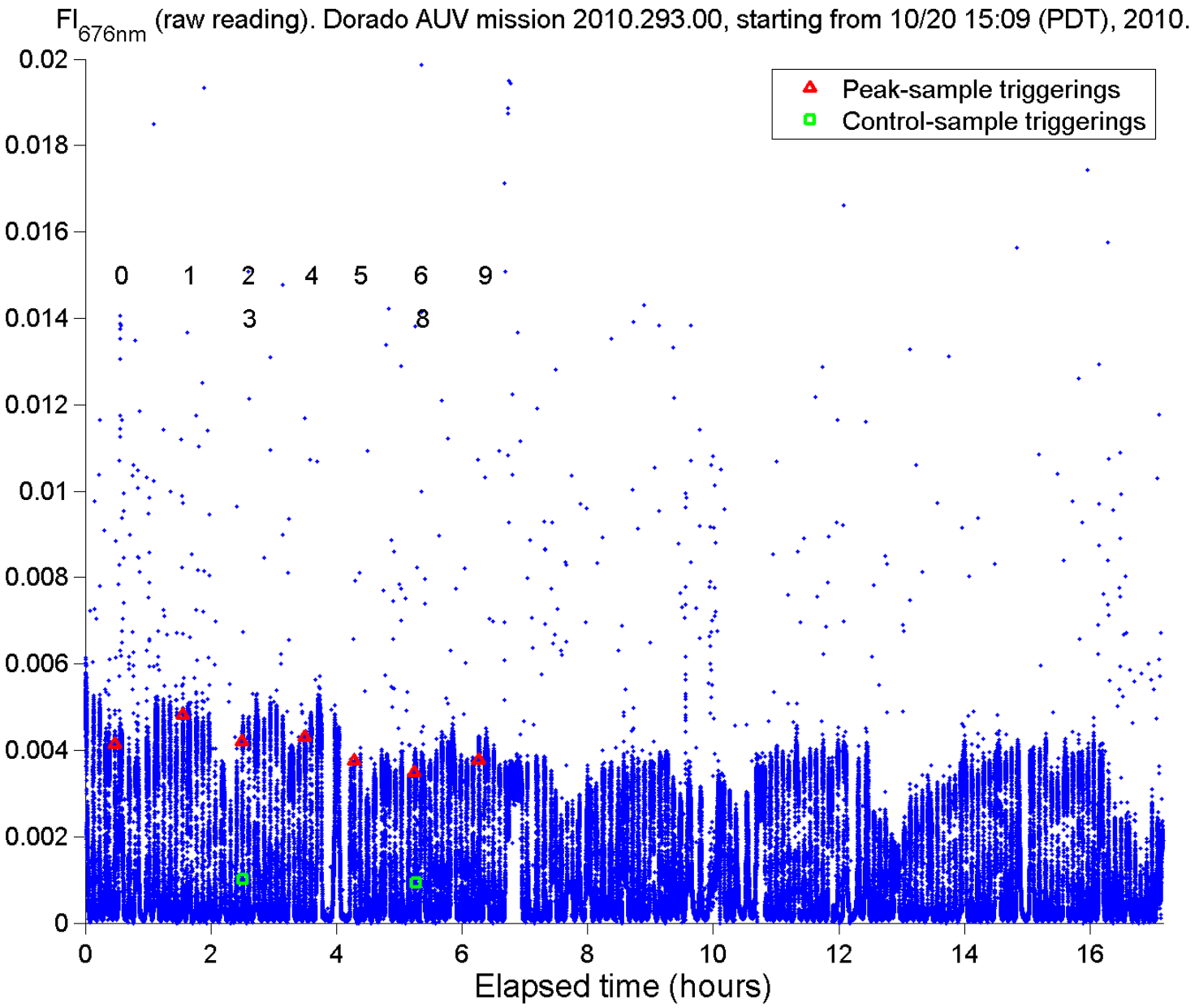
MBARI Dorado AUV

Courtesy of Larry Bird and Alana Sherman

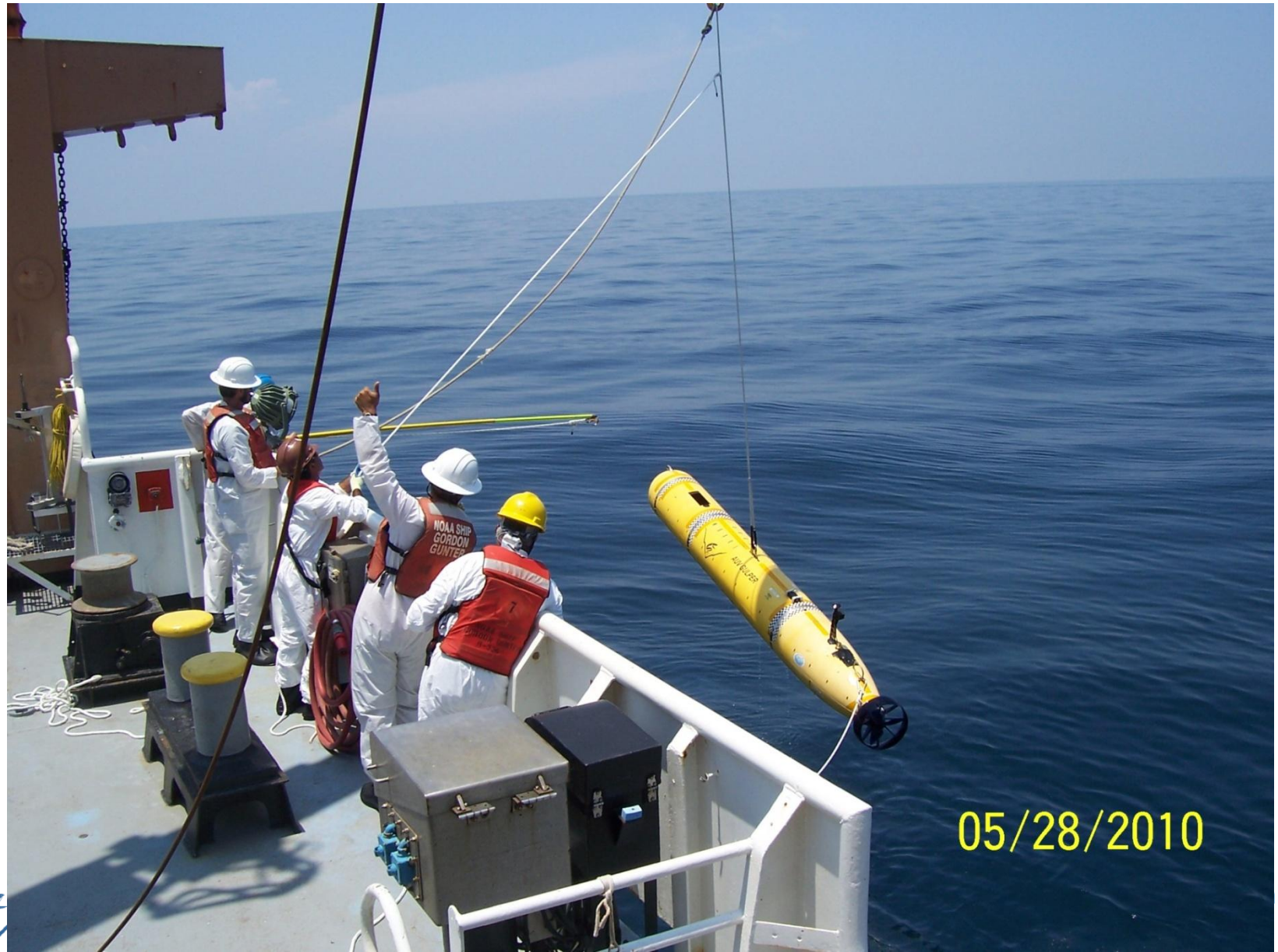
An Adaptive Triggering Method for the Dorado AUV to Capture Peak-Chlorophyll Water Samples in a Phytoplankton Thin Layer



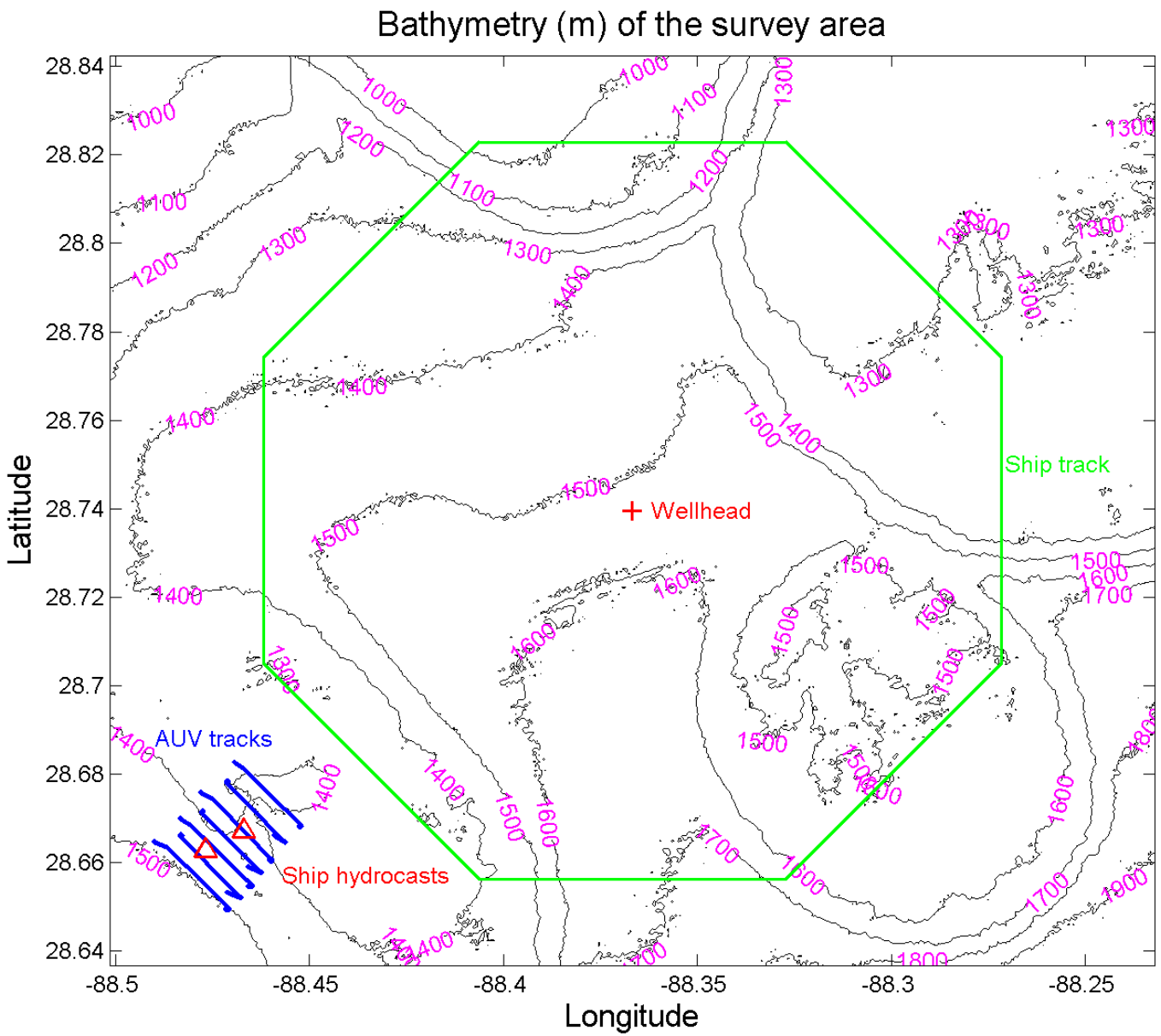
Peak-Capture Performance in an AUV Mission in BloomEx in October 2010



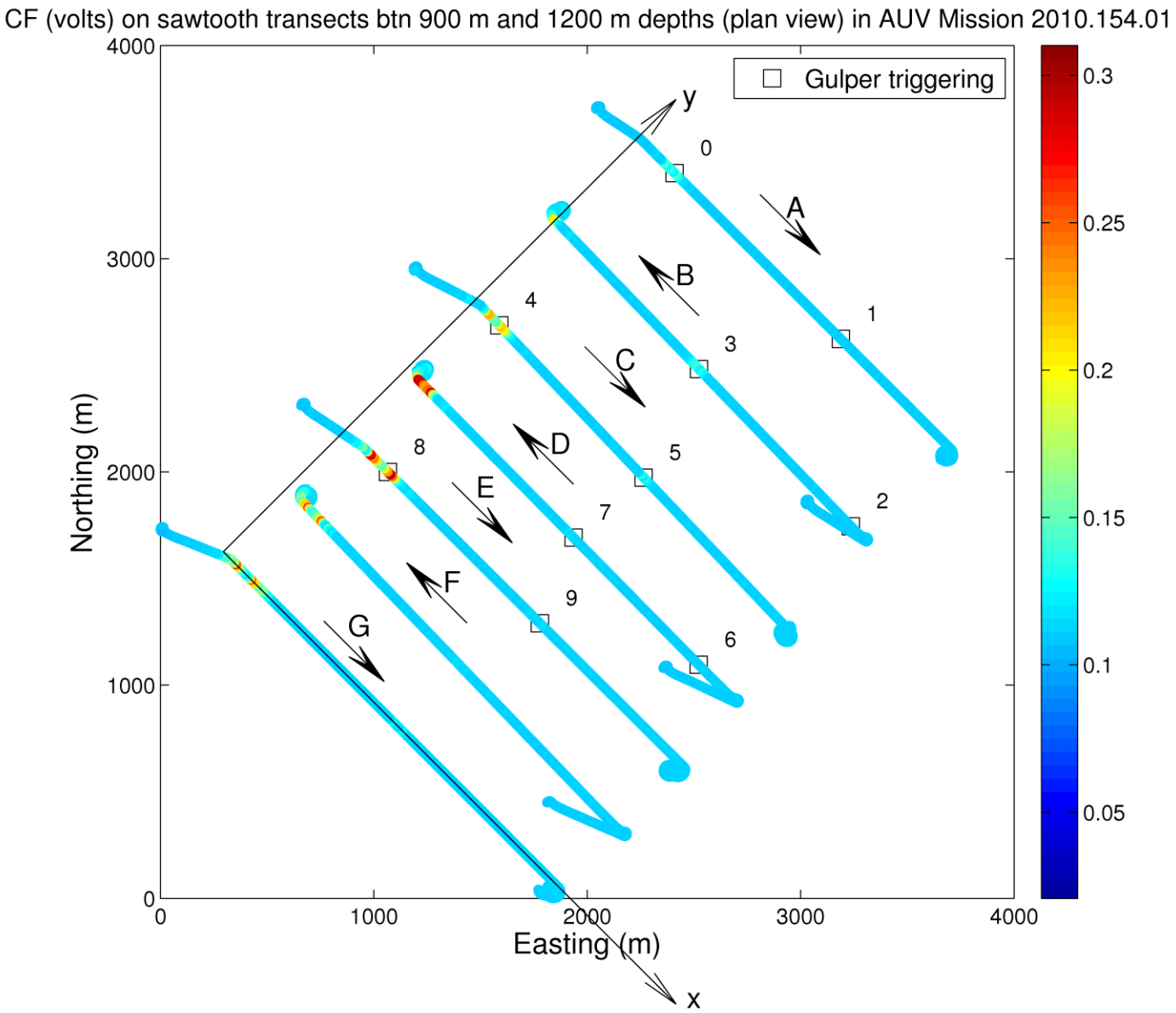
Dorado AUV Used in the 2010 Gulf of Mexico Oil Spill Response Scientific Survey



Dorado AUV Survey Tracks

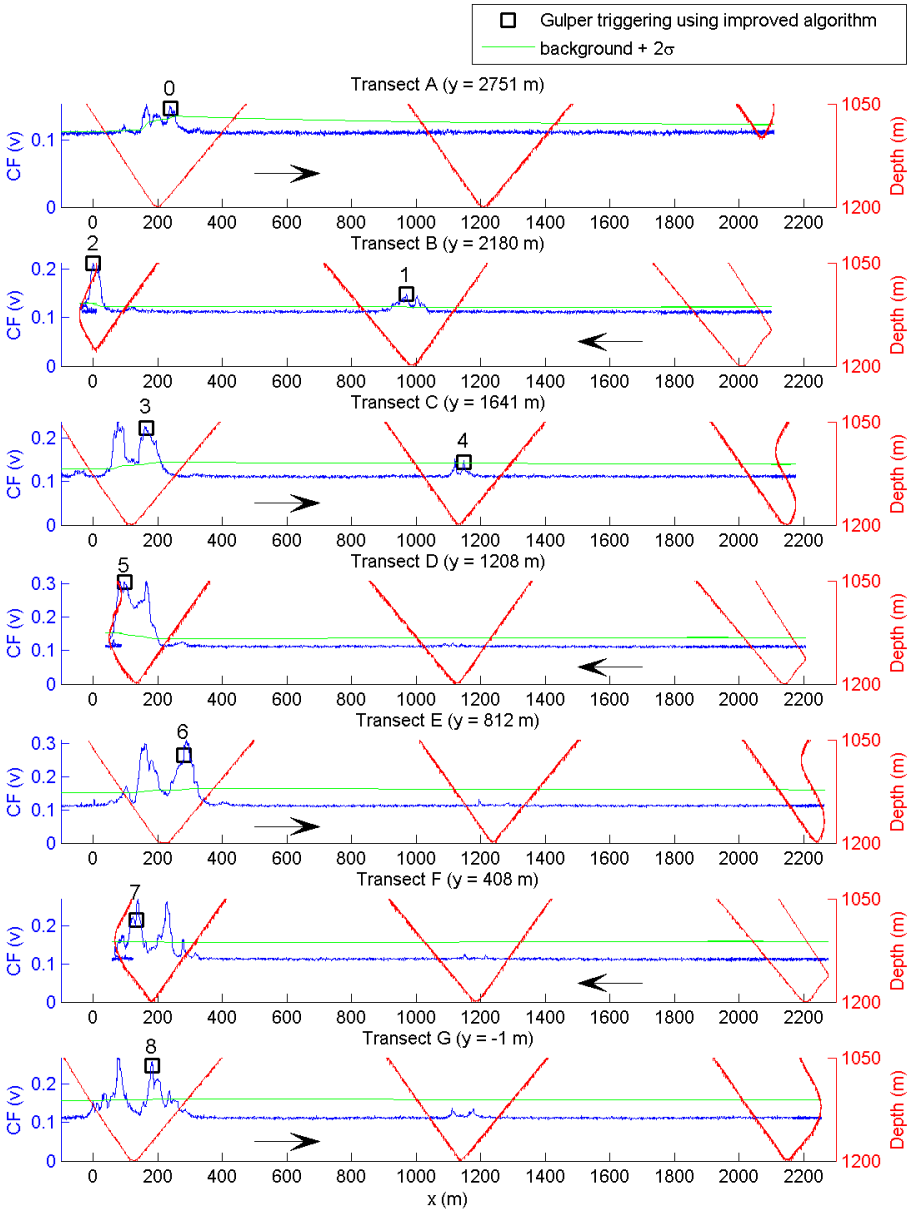


Dorado AUV Survey Tracks



2011

Capturing Peak-CDOM-Signal Water Samples Using an AUV



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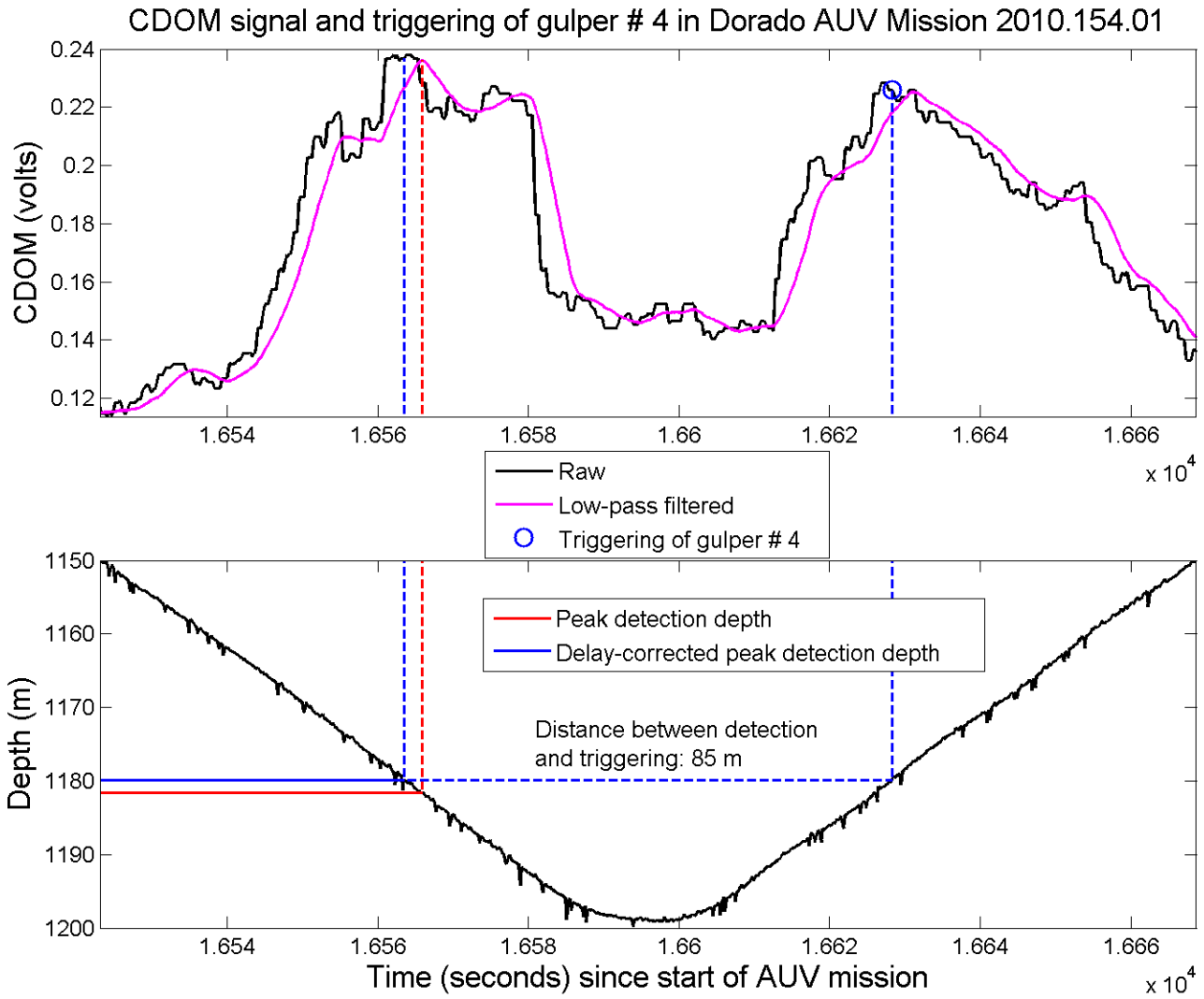
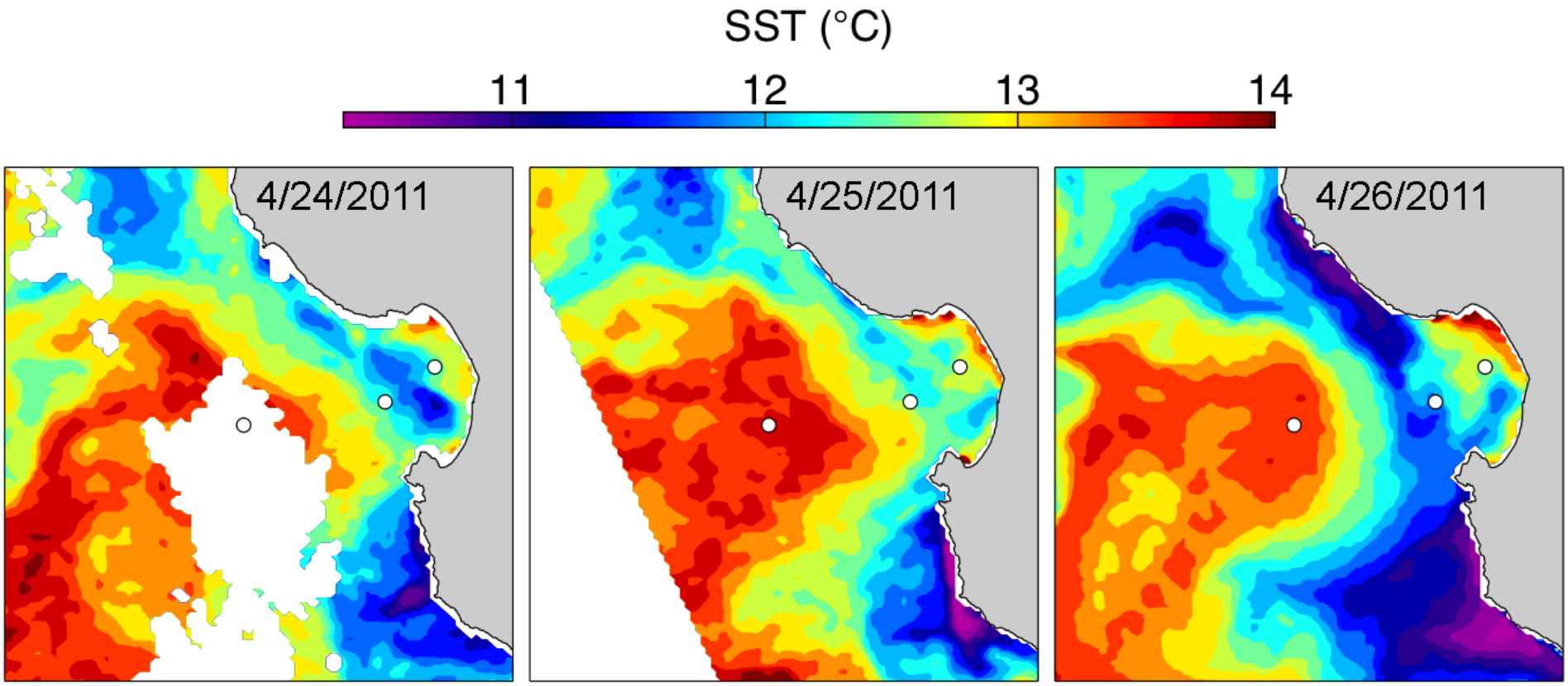
Capturing Peak-CDOM Water Samples



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," *Journal of Field Robotics*, Vol. 28, No. 4, pp. 484-496, July/August 2011.

Coastal upwelling in Monterey Bay



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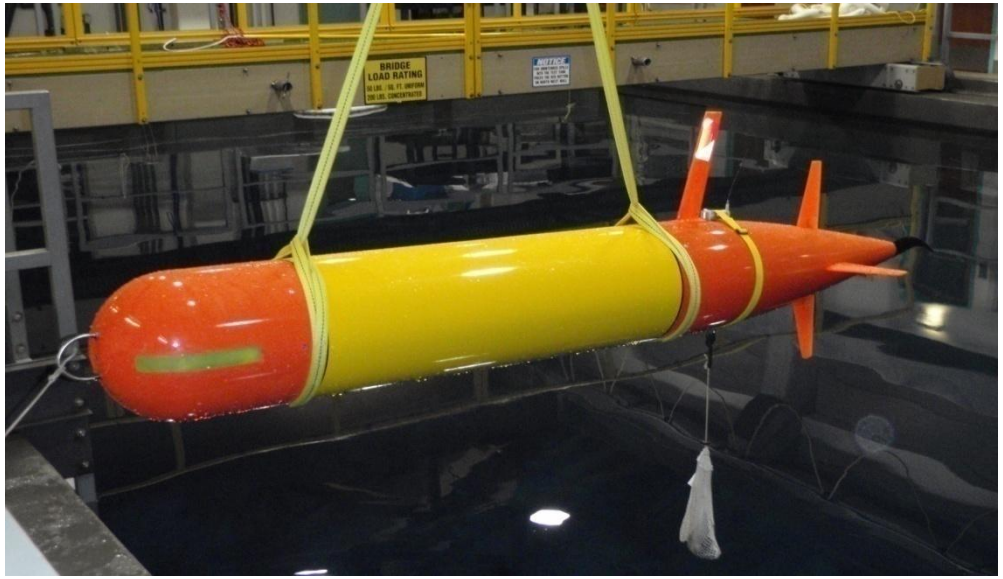
Tethys Long-Range AUV



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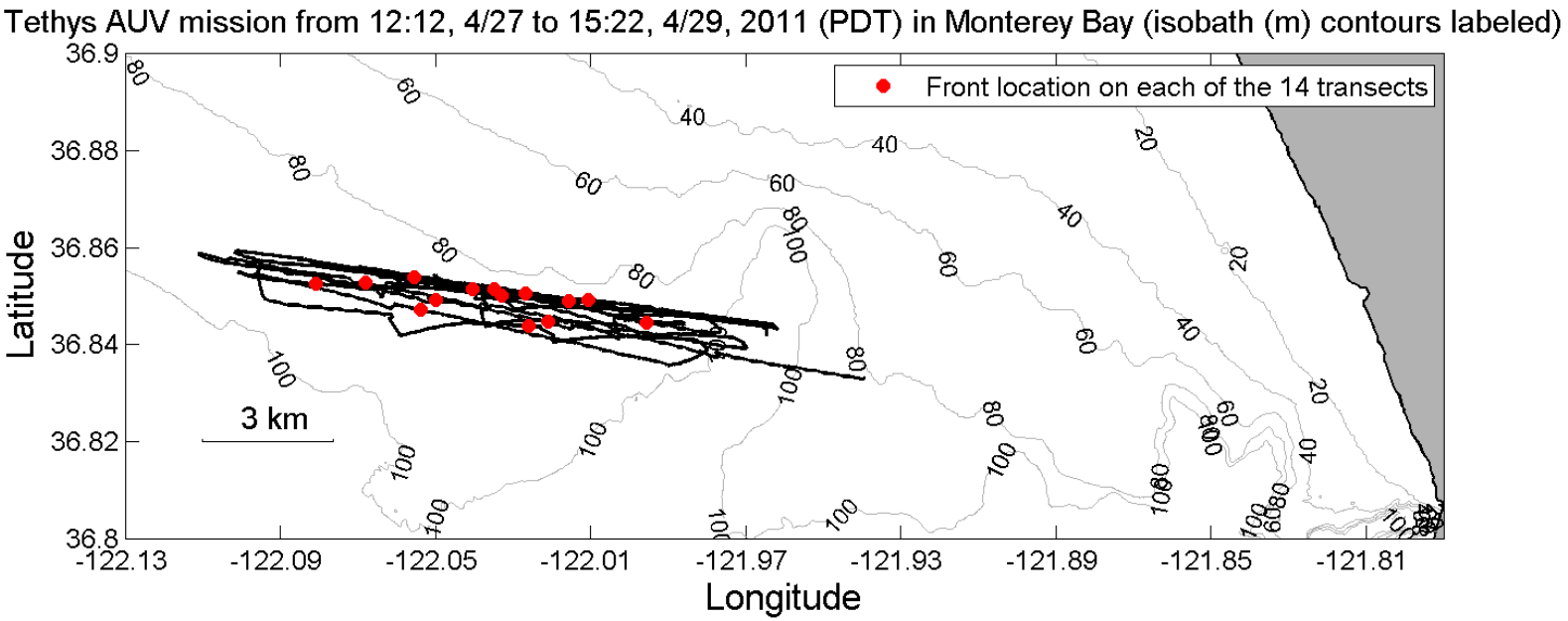
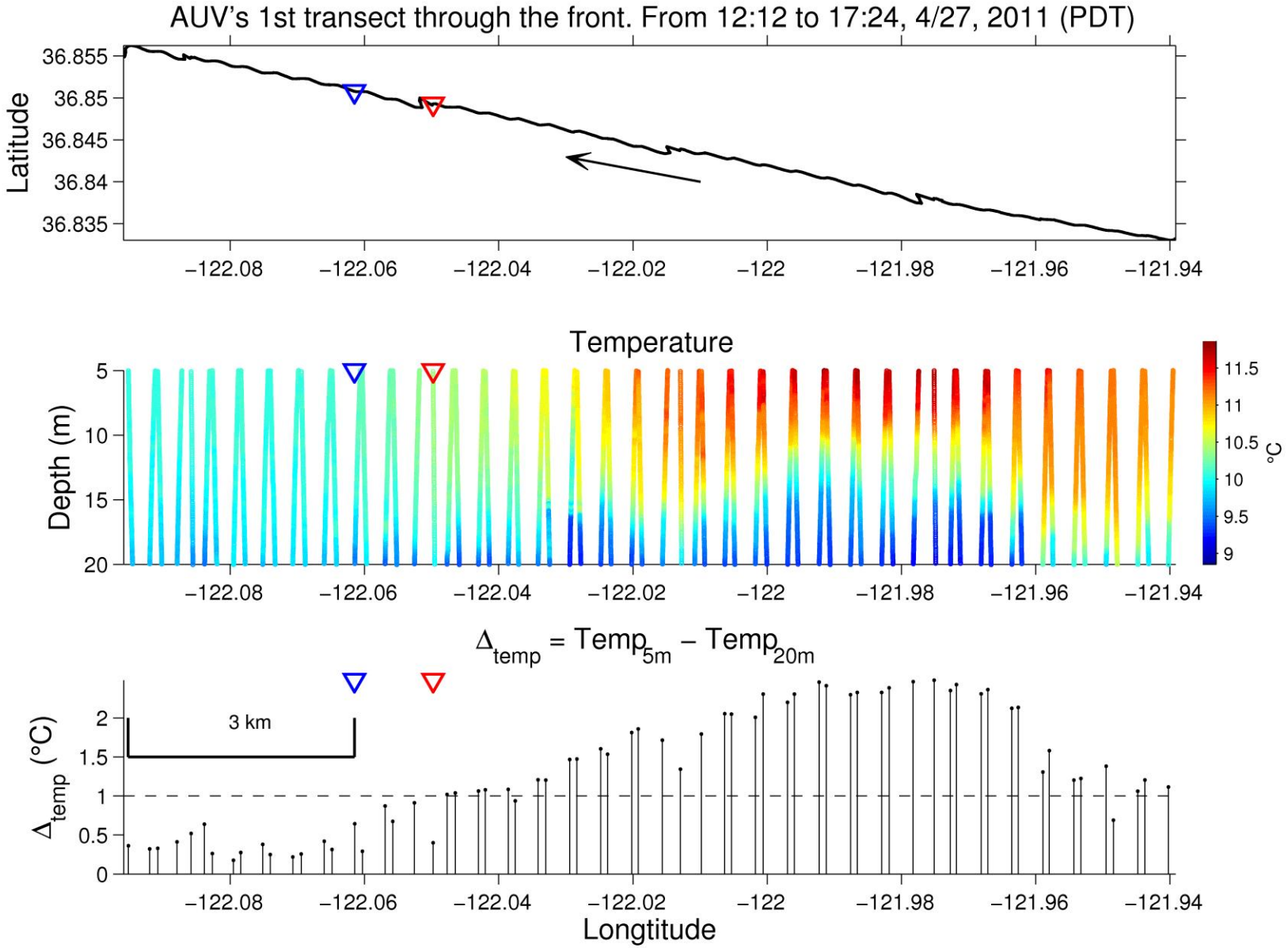
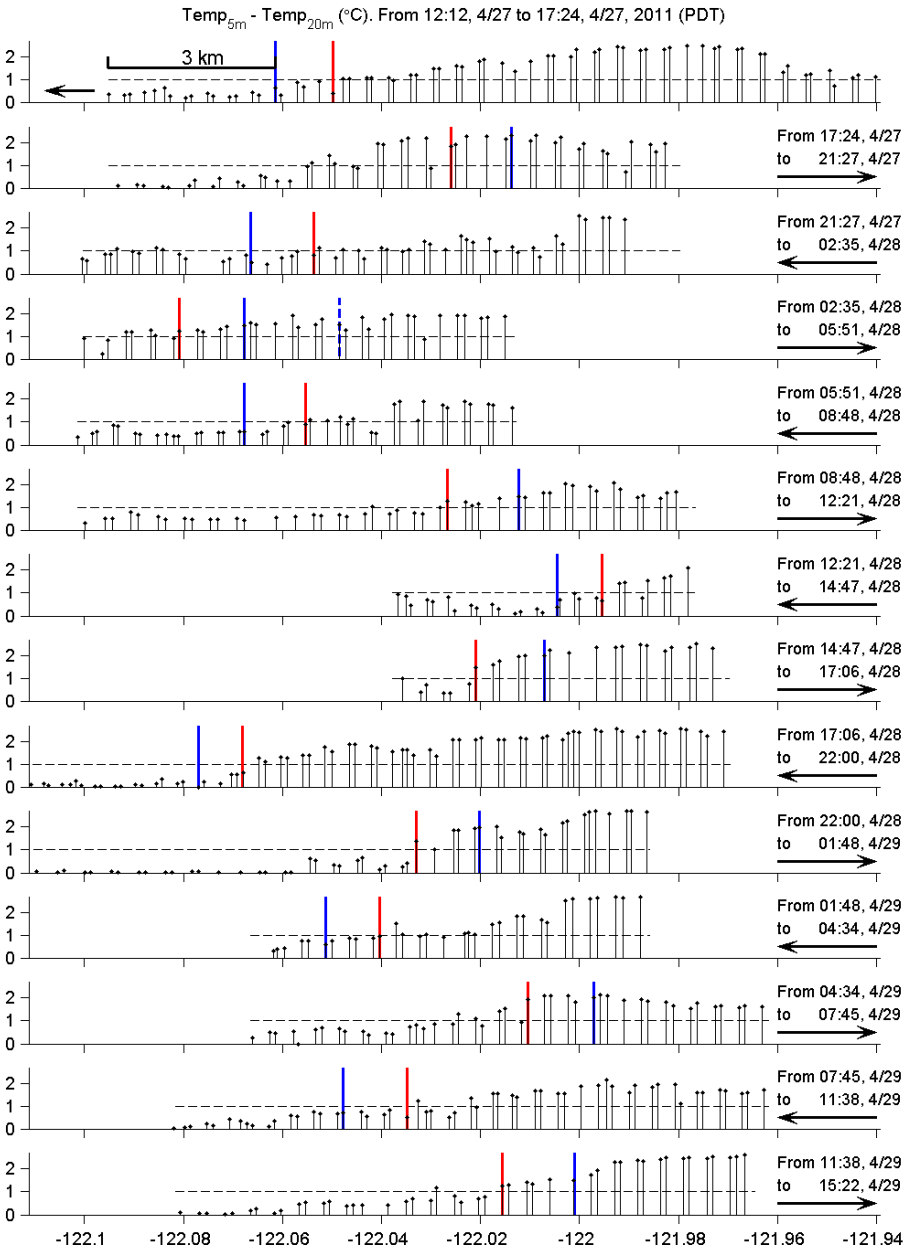
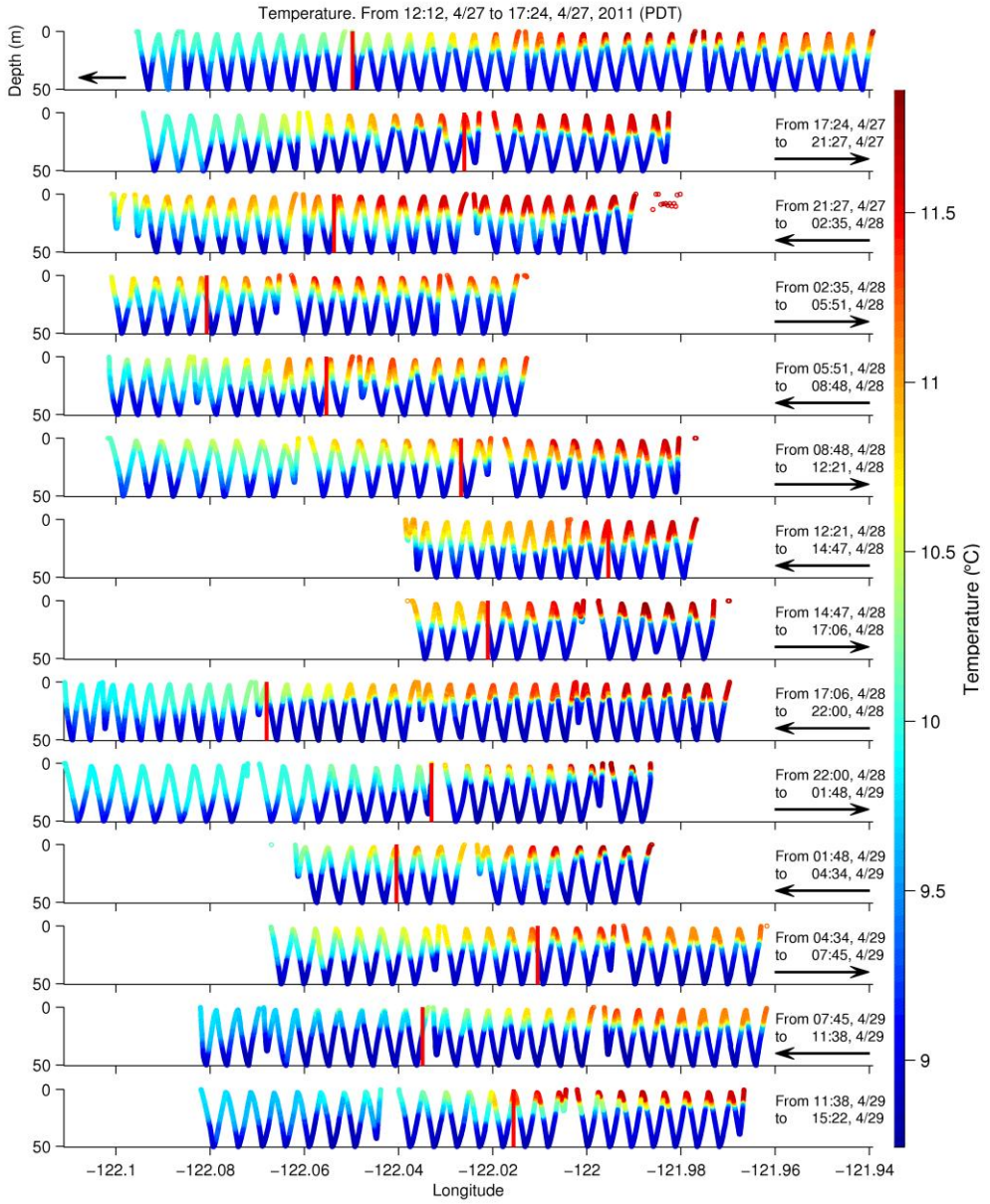
Front-Tracking by the Tethys AUV




AUV's 1st transect through the front. From 12:12 to 17:24, 4/27, 2011 (PDT)
Latitude
36.855
36.85
36.845
36.84
36.835
−122.08
−122.06
−122.04
−122.02
−122
−121.98
−121.96
−121.94
Temperature
Depth (m)
5
10
15
20
11.5
11
10.5
10
9.5
9
°C
$\Delta_{temp} = Temp_{5m} - Temp_{20m}$
Δ_{temp} (°C)
3 km
2
1.5
1
0.5
0
Longtitude

r 2011


Temp5m - Temp20m (°C). From 12:12, 4/27 to 17:24, 4/27, 2011 (PDT)
3 km
From 17:24, 4/27 to 21:27, 4/27
From 21:27, 4/27 to 02:35, 4/28
From 02:35, 4/28 to 05:51, 4/28
From 05:51, 4/28 to 08:48, 4/28
From 08:48, 4/28 to 12:21, 4/28
From 12:21, 4/28 to 14:47, 4/28
From 14:47, 4/28 to 17:06, 4/28
From 17:06, 4/28 to 22:00, 4/28
From 22:00, 4/28 to 01:48, 4/29
From 01:48, 4/29 to 04:34, 4/29
From 04:34, 4/29 to 07:45, 4/29
From 07:45, 4/29 to 11:38, 4/29
From 11:38, 4/29 to 15:22, 4/29
0
1
2
-122.1
-122.08
-122.06
-122.04
-122.02
-122
-121.98
-121.96
-121.94



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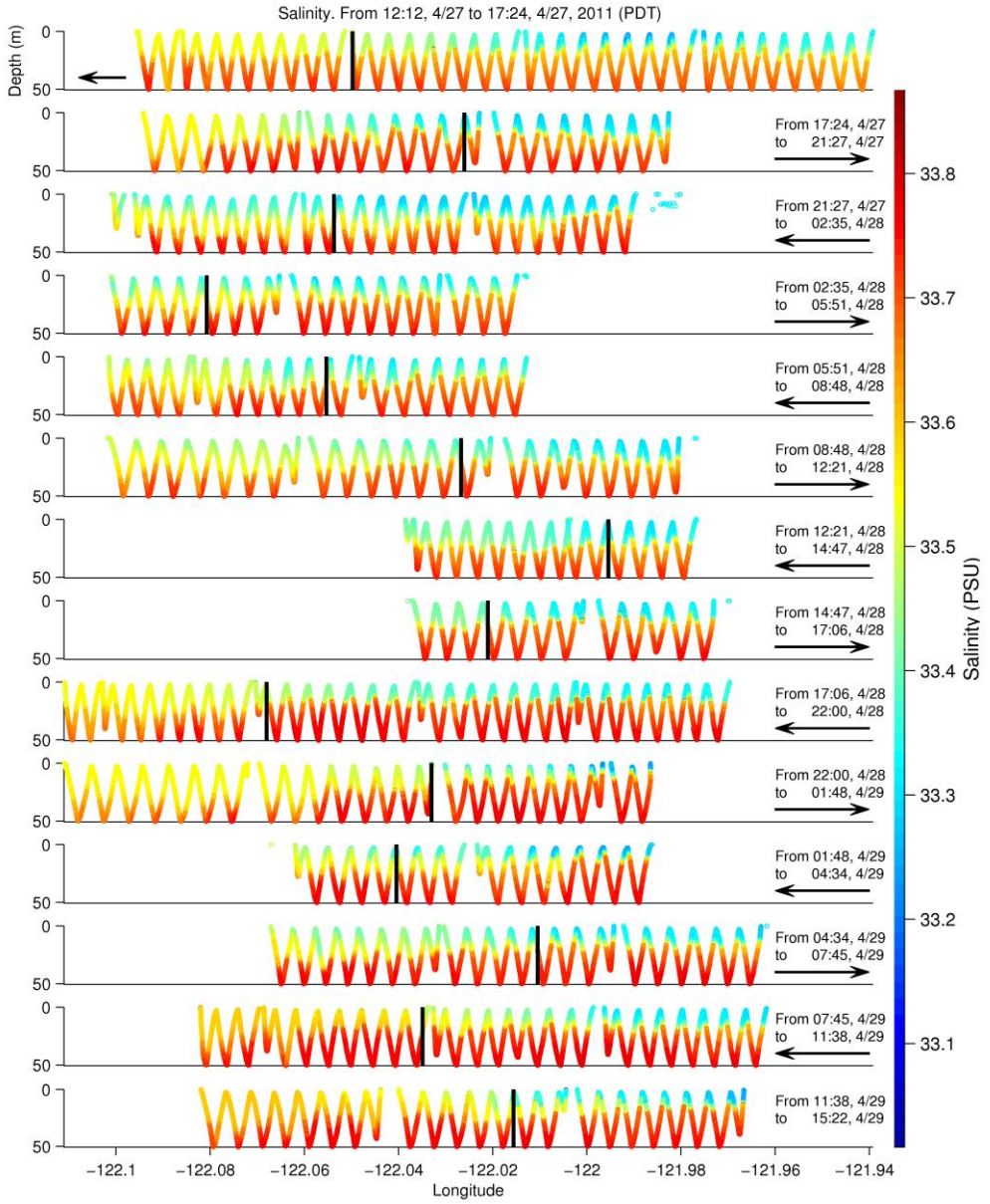

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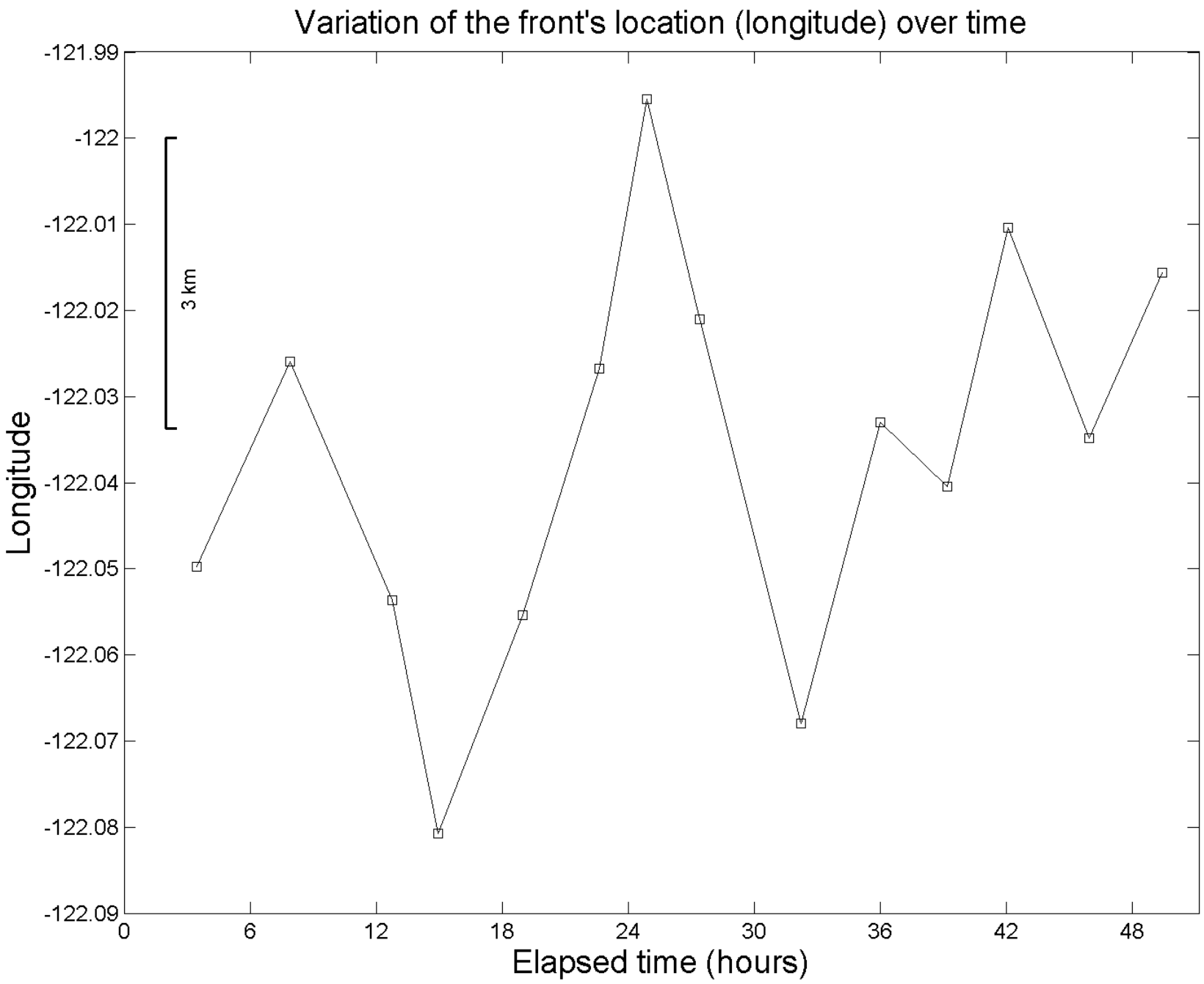
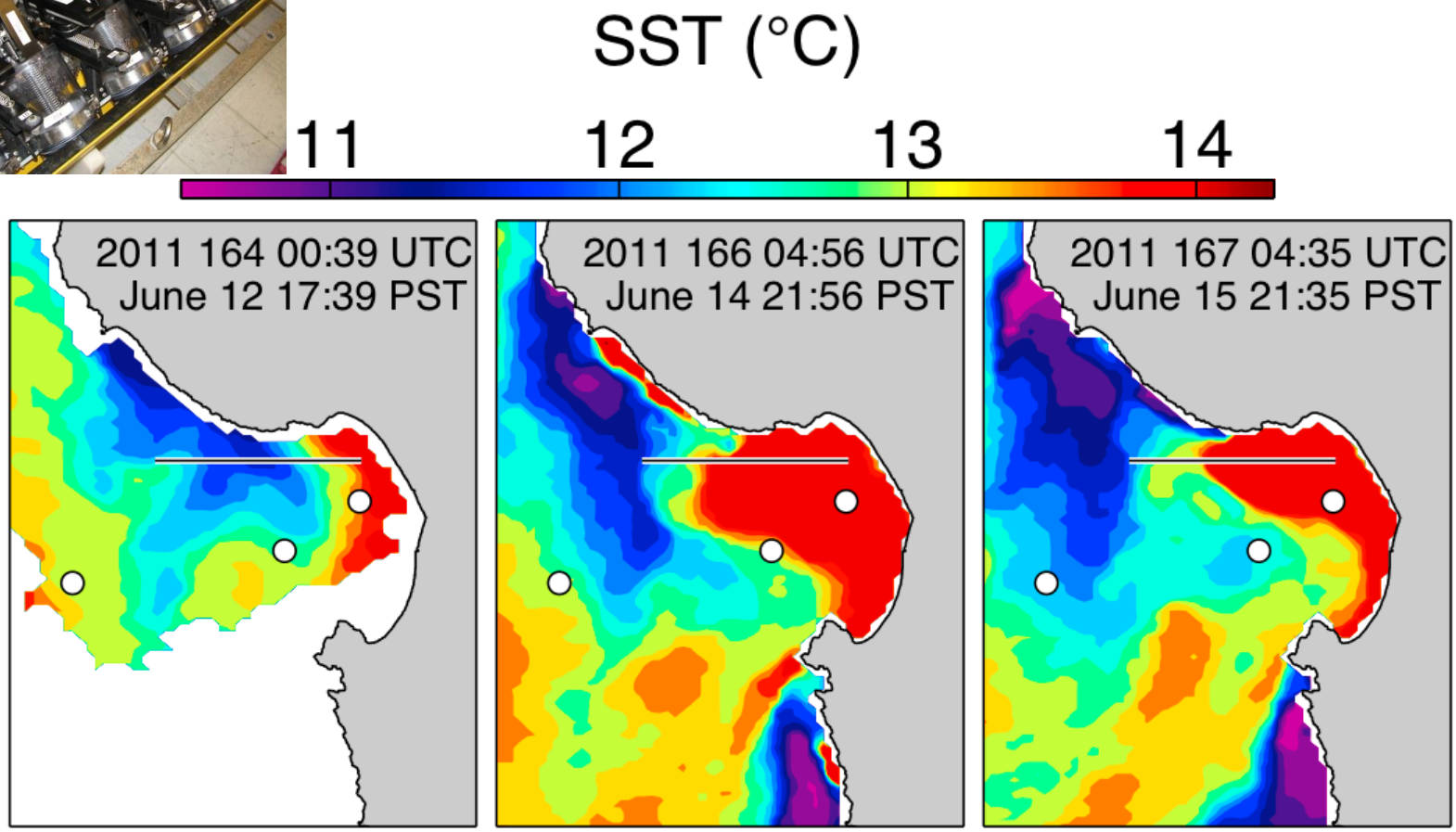
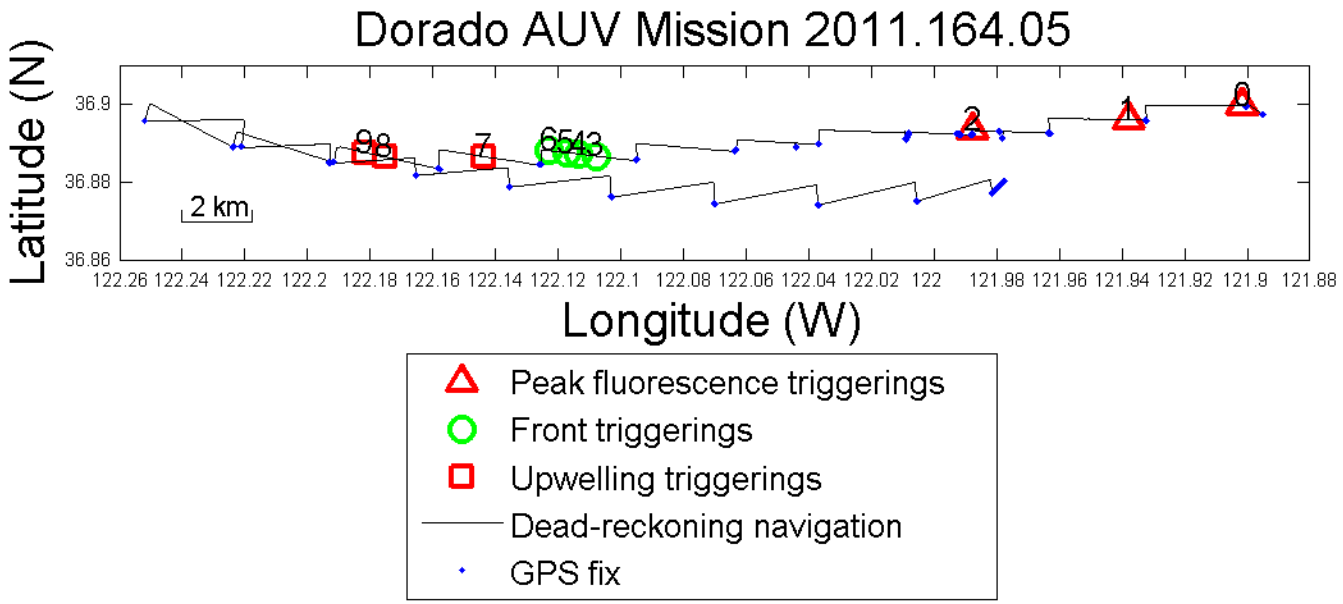

Variation of the front's location (longitude) over time
Longitude
Elapsed time (hours)
3 km
-121.99
-122
-122.01
-122.02
-122.03
-122.04
-122.05
-122.06
-122.07
-122.08
-122.09
0
6
12
18
24
30
36
42
48

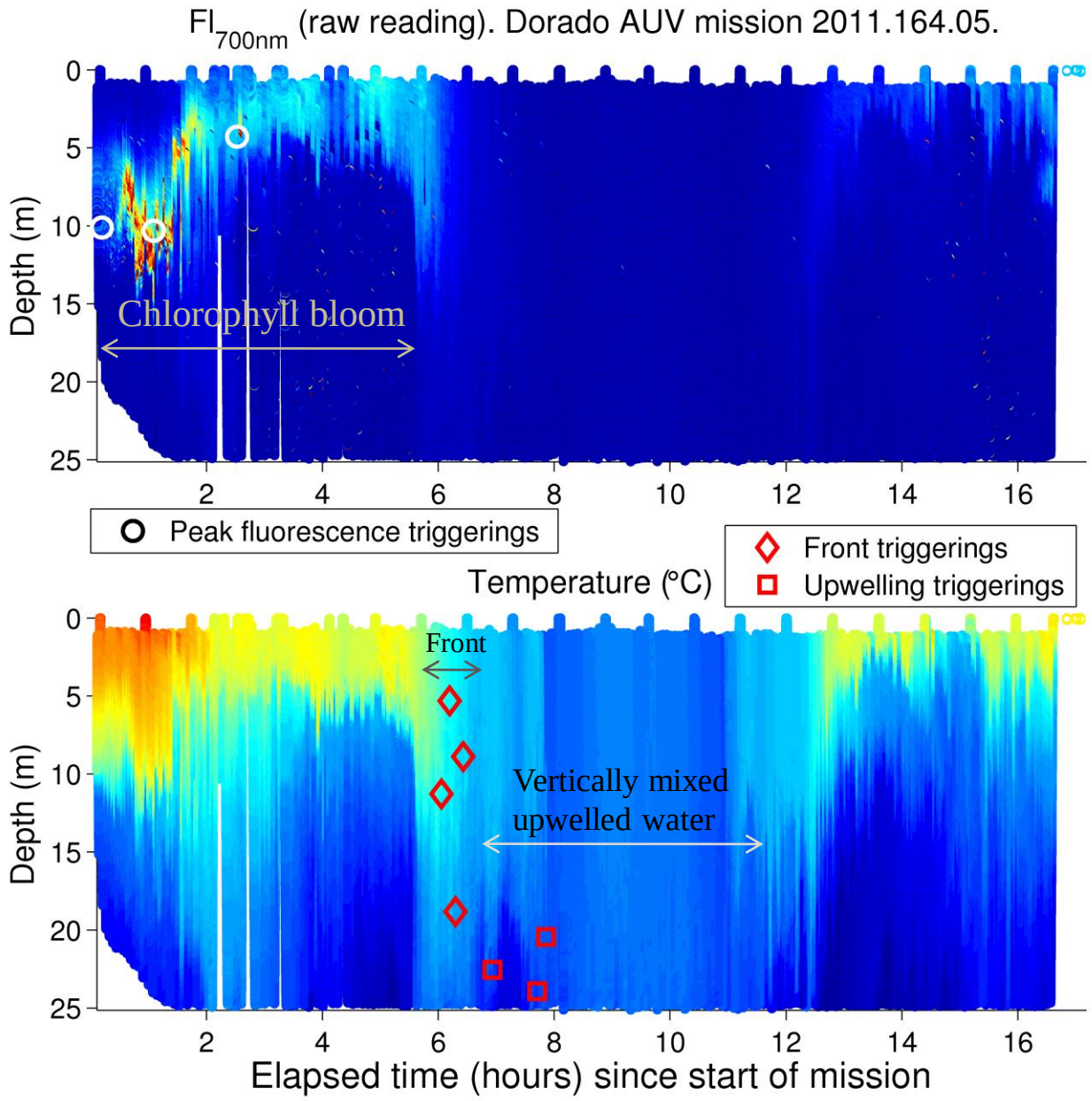
Targeted Sampling when Yo-yoing through Three Distinct Water Columns (Dorado AUV)



AVHRR data courtesy of Kudela Lab (UCSC) and NOAA CoastWatch

Targeted Sampling when Yo-yoing through Three Distinct Water Columns (Dorado AUV)



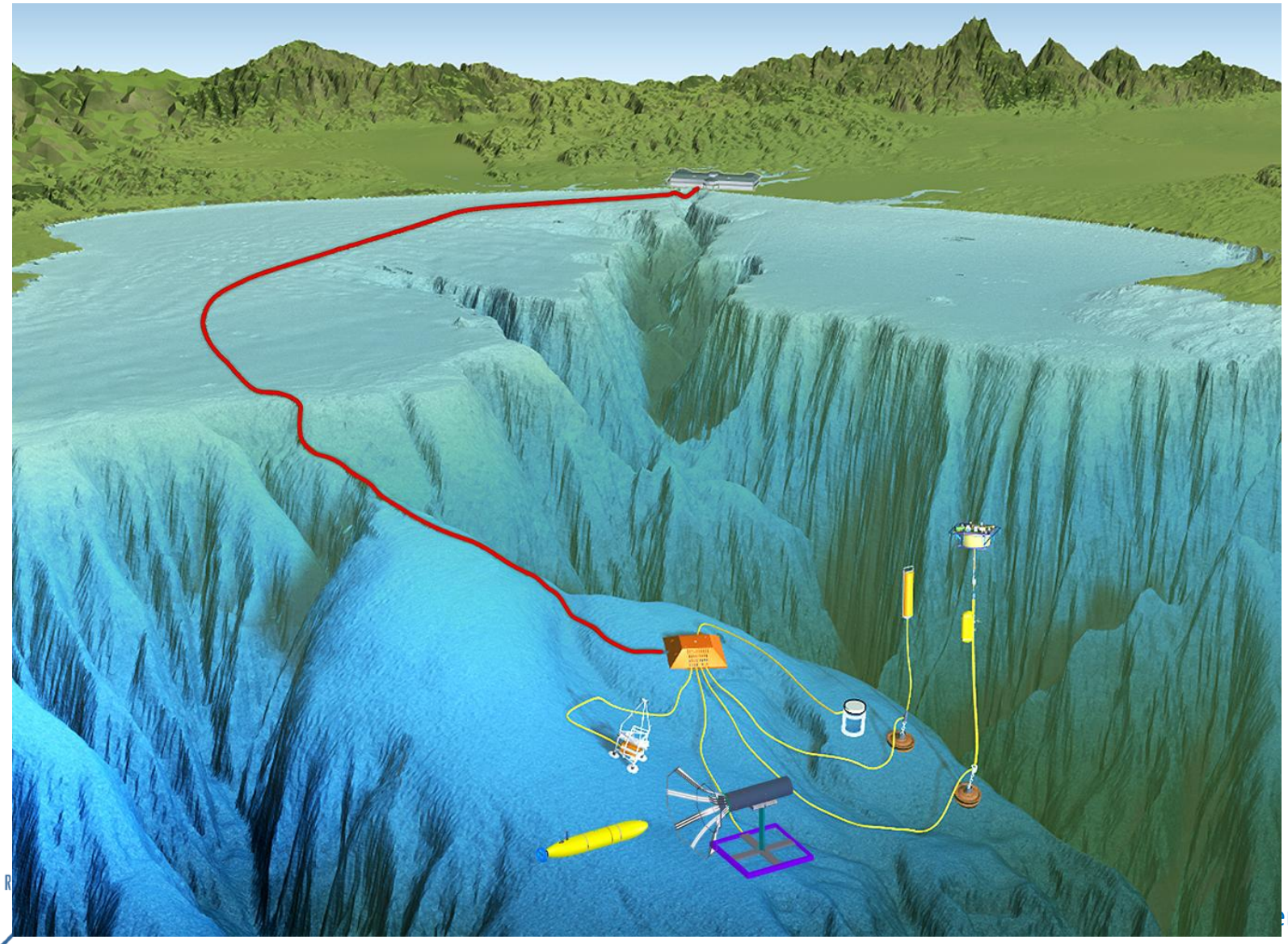


Peak-capture algorithm: [Zhang, McEwen, Ryan, and Bellingham, *IEEE JOE*, 2010]

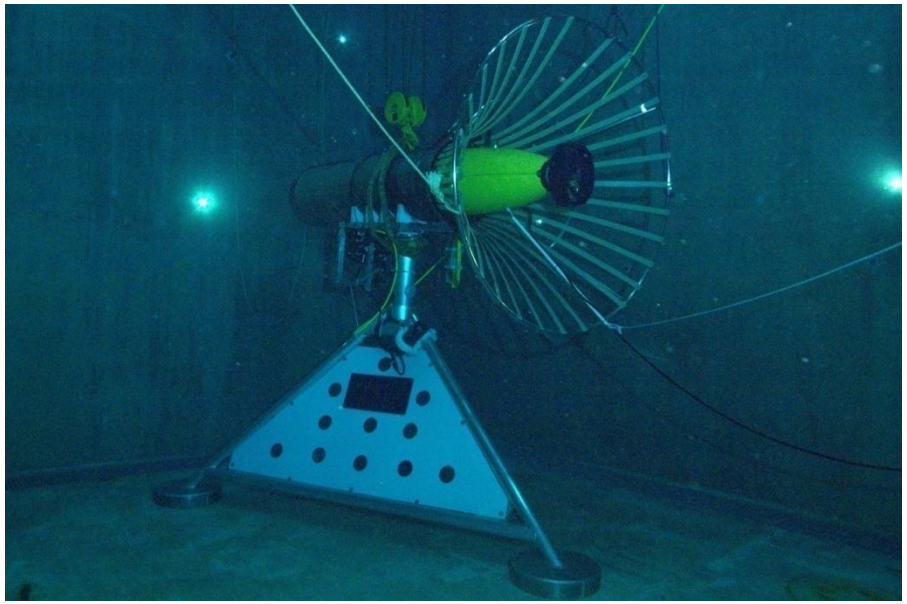
Front detection: when horizontal gradient of (T_{5m}-T_{20m}) exceeds a threshold.

Upwelling detection: when (T_{5m}-T_{20m}) < 1°C lasting for a number of AUV yo-yo profiles.

Towards Synergistic Adaptive Ocean Observation: Cabled Observatory + AUVs



AUV Docking



- Autonomous homing and docking
- Batteries recharge
- Data download
- Mission upload
- Vehicle sleep/wakeup
- Code modification & recompile

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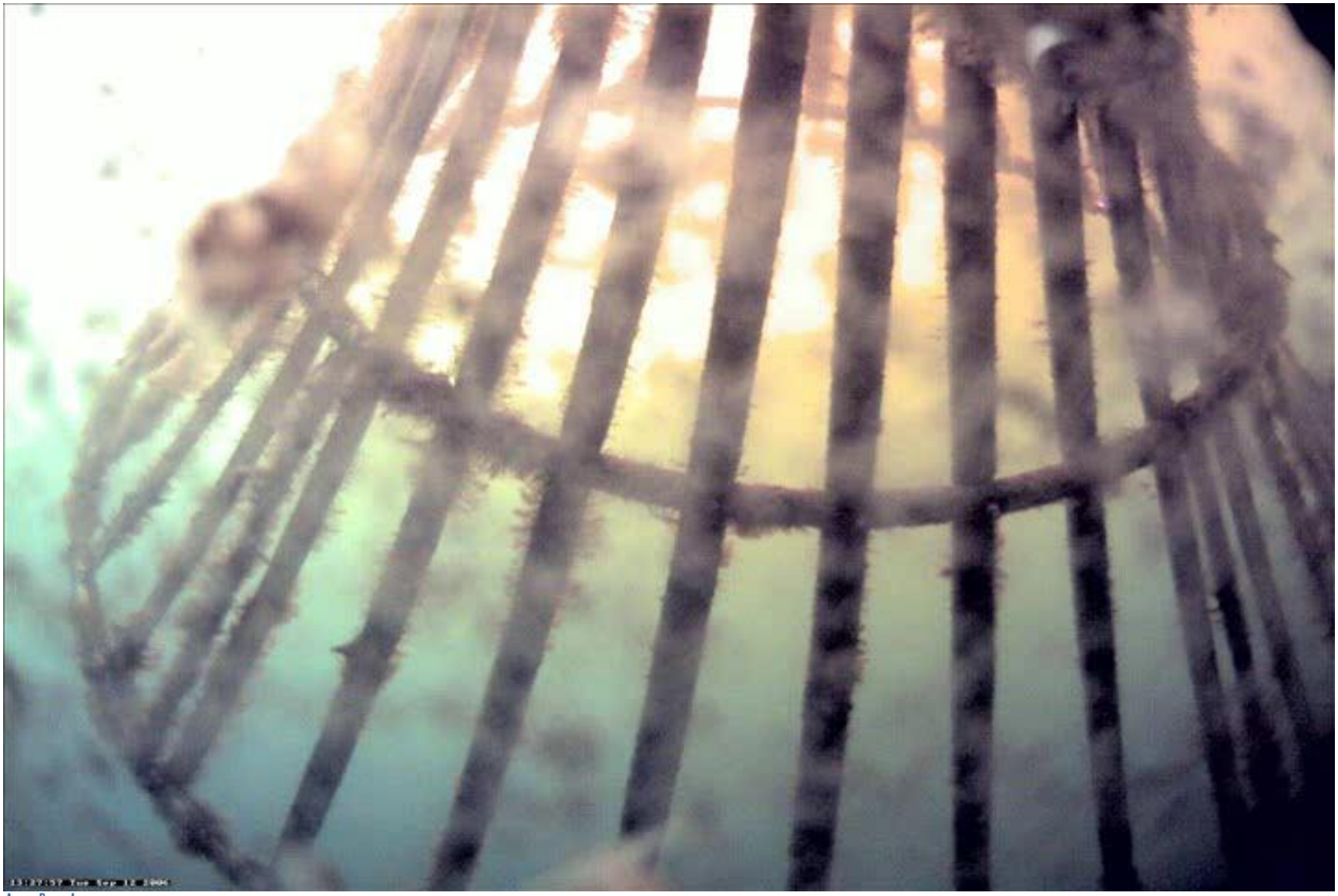
AUV Docking



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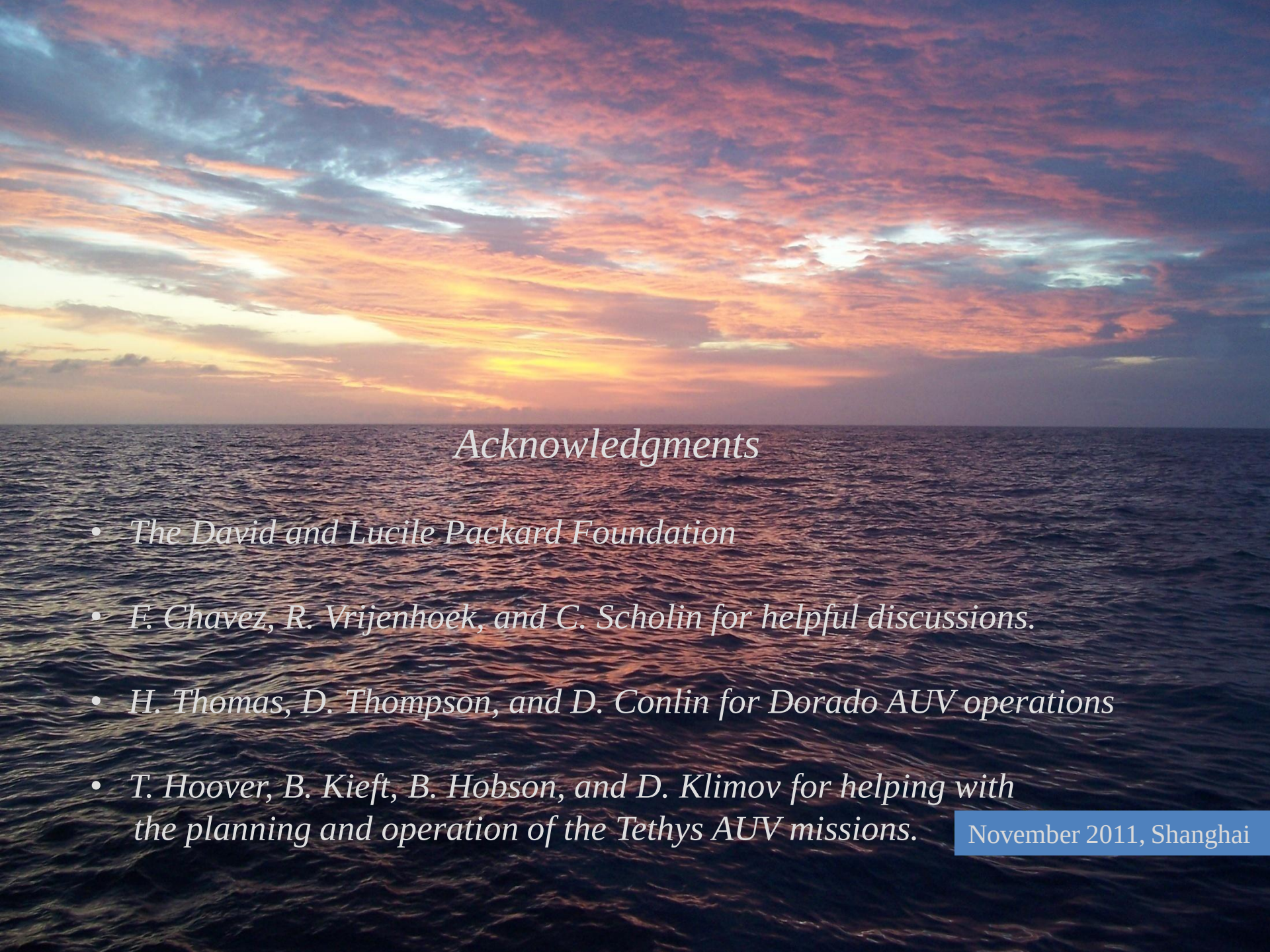
Summary

- Adaptive sampling techniques are important for both moored instruments and mobile platforms.
- Adaptive sampling algorithms we developed for AUVs have enabled accurately targeted samplings in different water columns.
- On a cabled observatory that incorporates docked AUVs, adaptive triggering/sampling techniques are key to efficient use of the system.



Acknowledgments

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