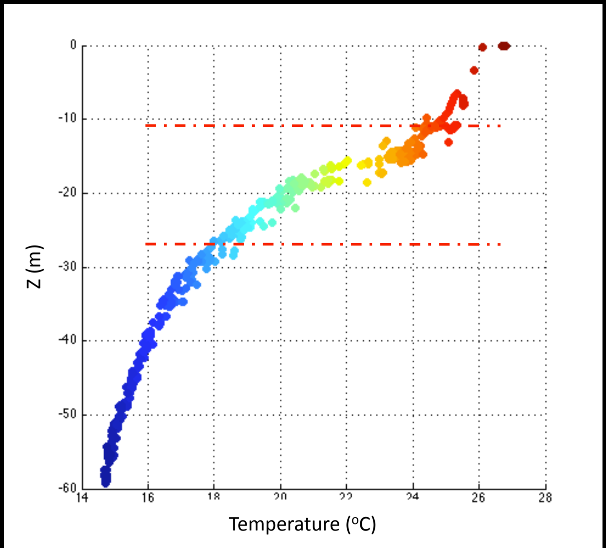
Autonomous Adaptive Environmental Feature Tracking via Autonomous Underwater Vehicles

- Tracking the Thermocline -



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MOOS-DAWG 2010

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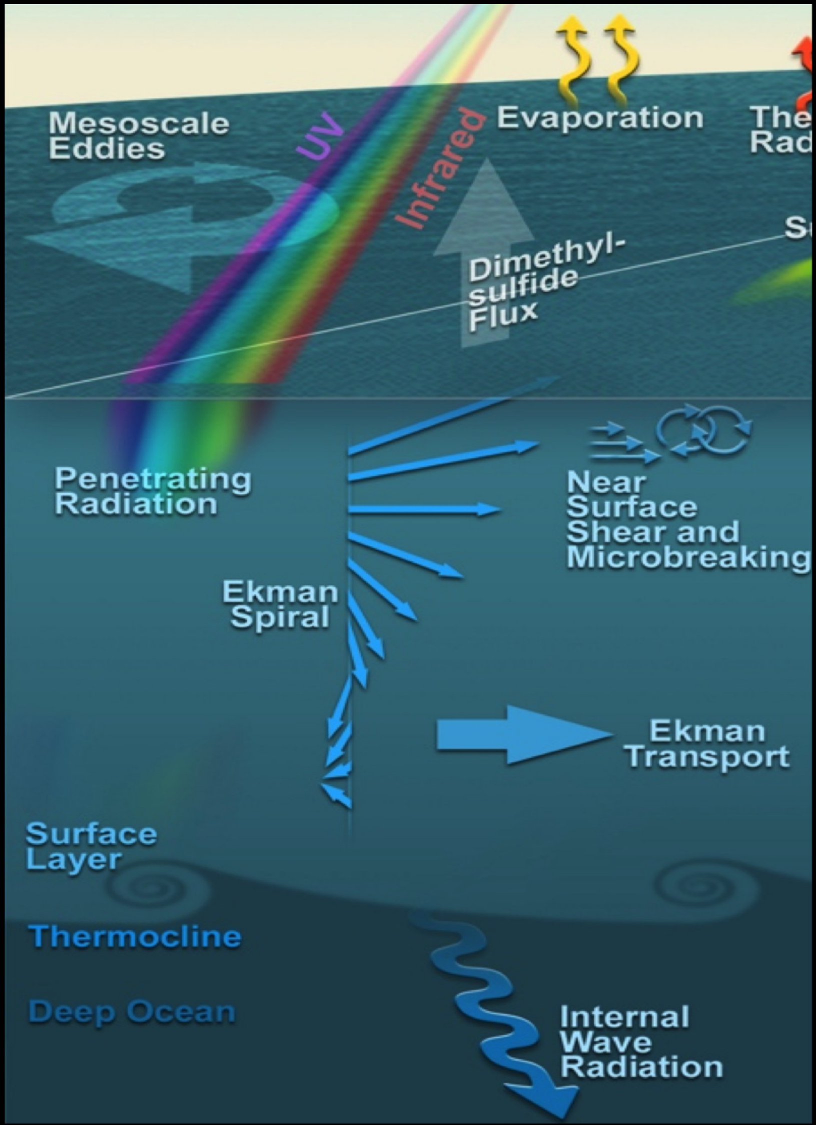
Background & Motivation: *The Missing Piece*

- Bridge Science and Engineering
- Incorporate real-time instrumental (e.g., CTD) data into adaptive sampling behaviors on board AUVs
  - Track oceanographic features
    - Thermoclines, haloclines, pycnoclines
    - Sound speed
    - O_2 & Cl concentrations, fluorescence
    - Light attenuation
    - Fronts
    - Currents

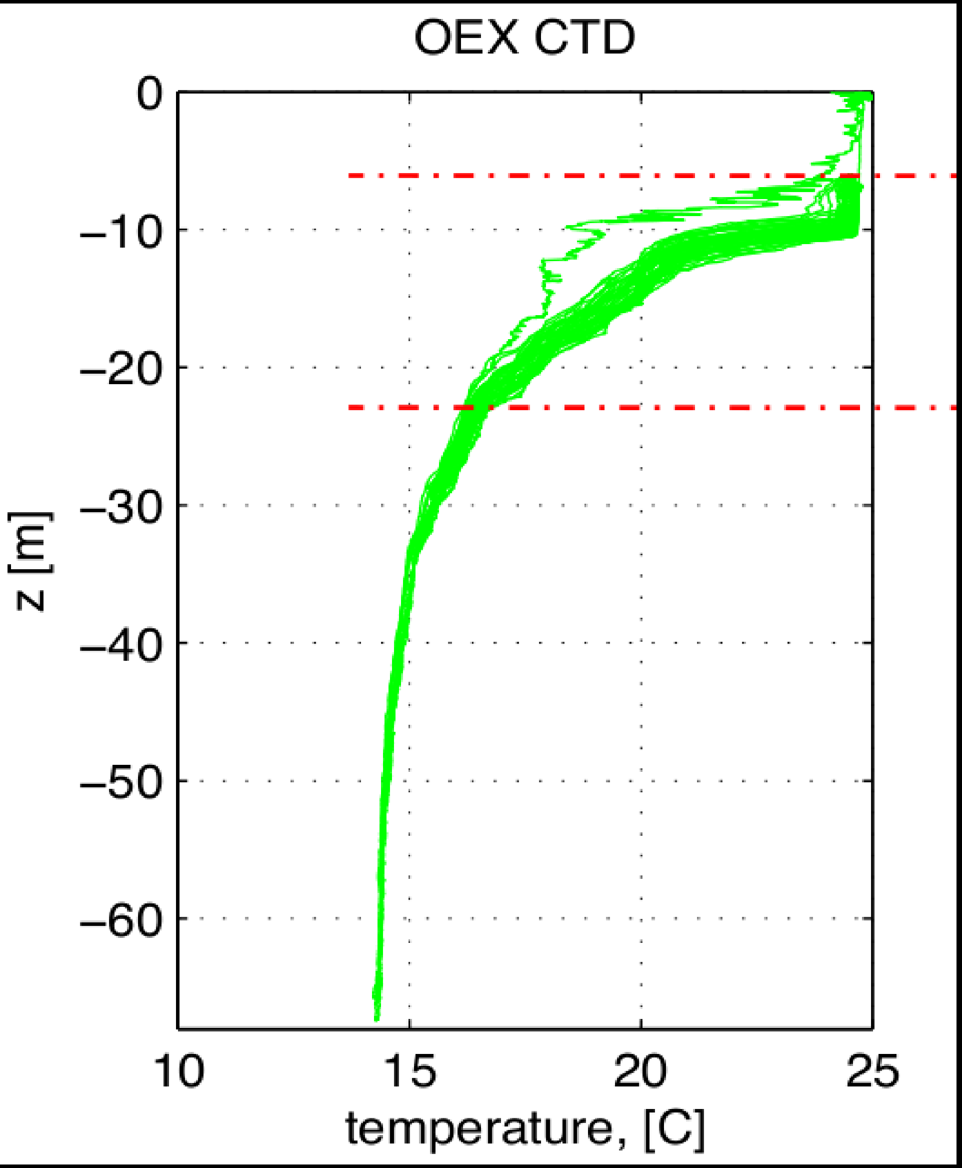


Oceanographic Features[1]

[1]John Delaney (concept) www.ooi.washington.edu/story/Oceans+and+Life

Background & Motivation:
What is a Thermocline?

- Thermally stratified body of water…
- Warmer surface water
- Middle layer in which temperature decreases rapidly with depth
- Cold deep water

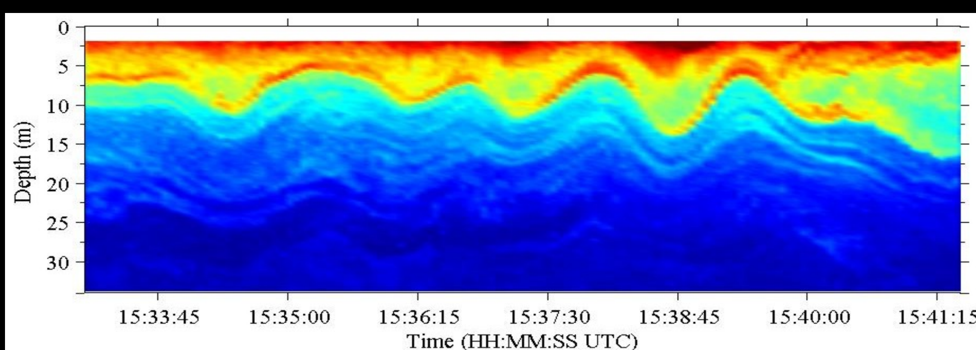


Thermocline region between dotted lines

Background & Motivation: *Thermocline Tracking*

- Example and proof-of-concept of autonomous adaptive environmental feature tracking
- Present in most large bodies of water
- Most AUVs are equipped with a CT or CTD sensor

- Widely studied in the oceanographic community
  - Acoustic communications
  - Biology - phytoplankton, plankton and plankton-eating fish
  - Physical oceanography - surface mixing, internal waves



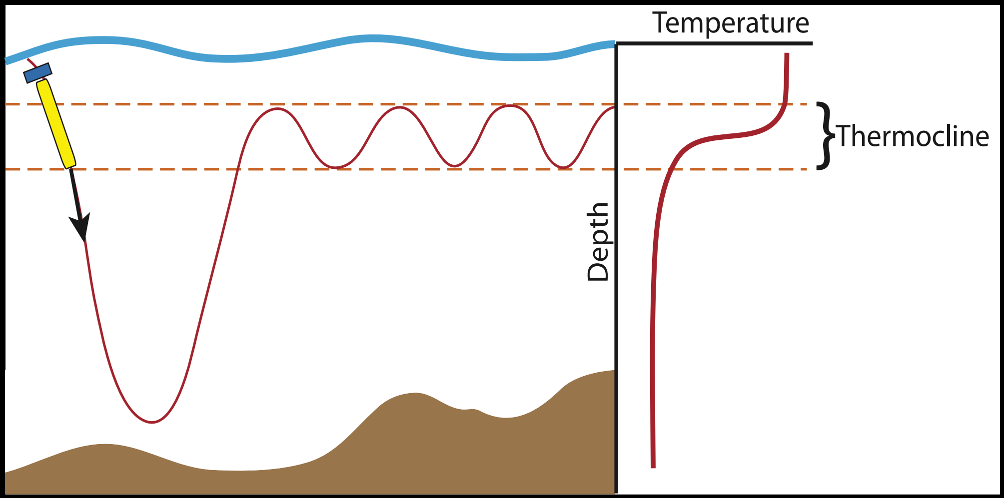
Internal Waves[2]

CTD[1]

[1]www.seabird.com
[2]myweb.dal.ca/kelley/SLEIWEX

Autonomous Adaptive Feature Tracking (AAFT): *Problem Definition*

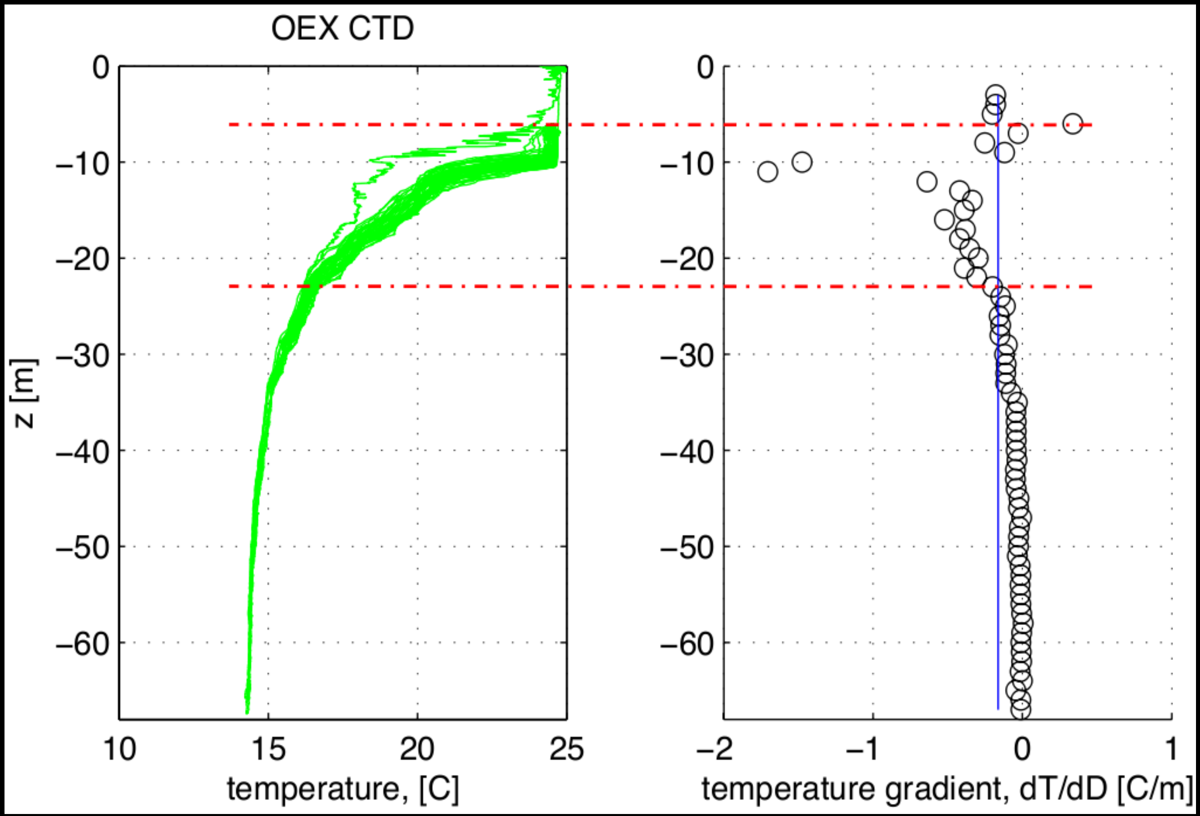
- Vehicle moving through the water column in time and space
- Where is the thermocline (or any feature)?
  - Based on *just* the environmental information the AUV collects and processes *on board*
- Completely autonomous (MOOS-IvP)
- Quantitatively define thermocline



Thermocline tracking by adapting yoyo motion.

Autonomous Adaptive Feature Tracking (AAFT): *Thermocline Definition*

- Quantitative
  - The depth range over which the vertical derivative of temperature, dT/dz, exceeds a threshold value

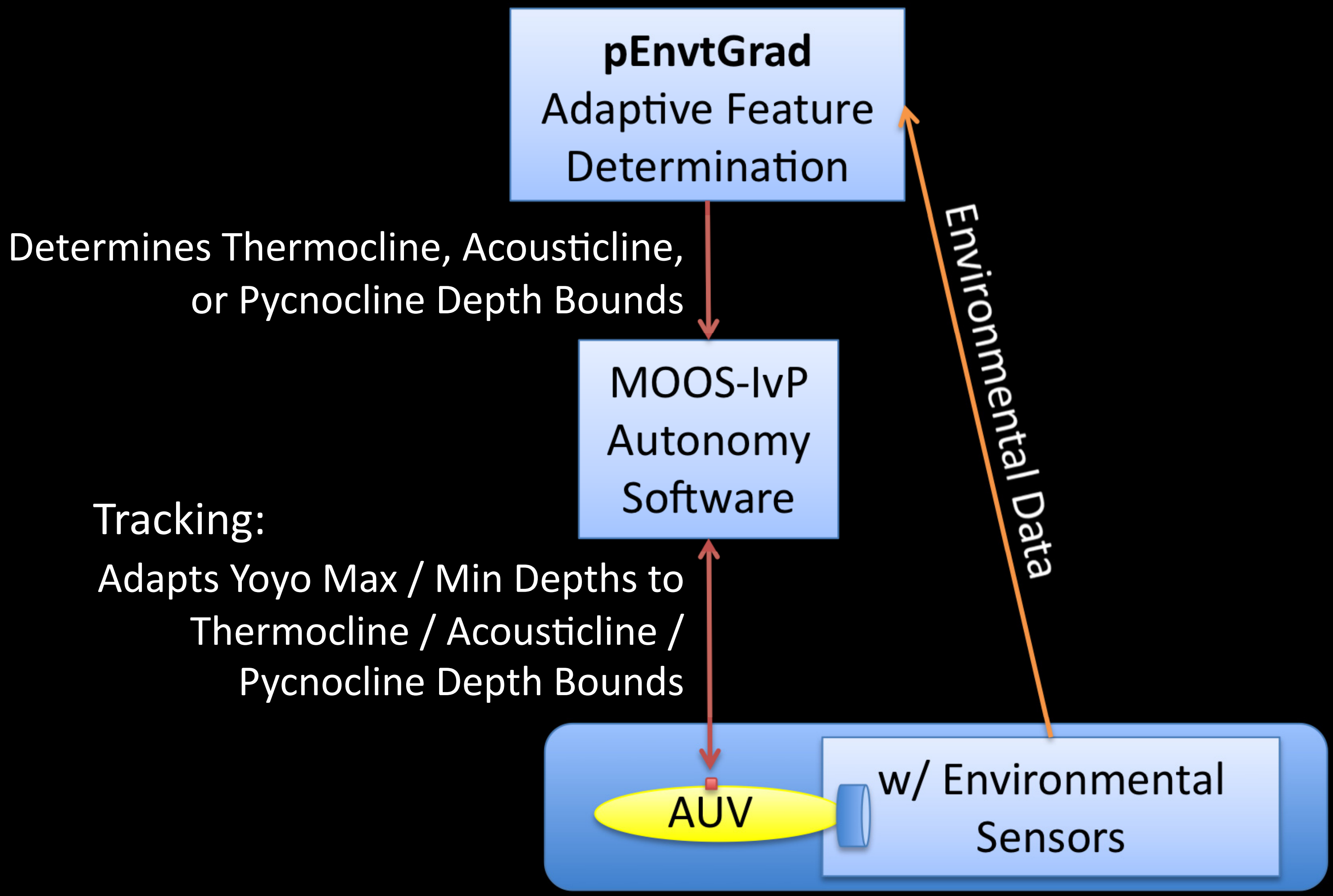


Thermocline region between dotted lines

AAFT:
MOOS Implementation

- pEnvtGrad (process: Environmental Gradient)
  - Environmental gradient determination process
    - used with adaptive yoyo (toggle depth) behavior
  - Quantitatively defines and detects
    - Thermocline
    - Acousticline
    - Pycnocline

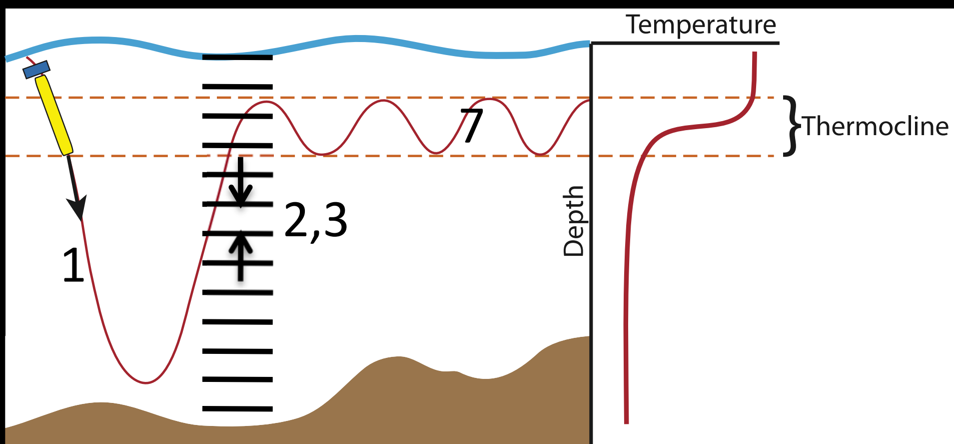
AAFT:
Implementation, cont.



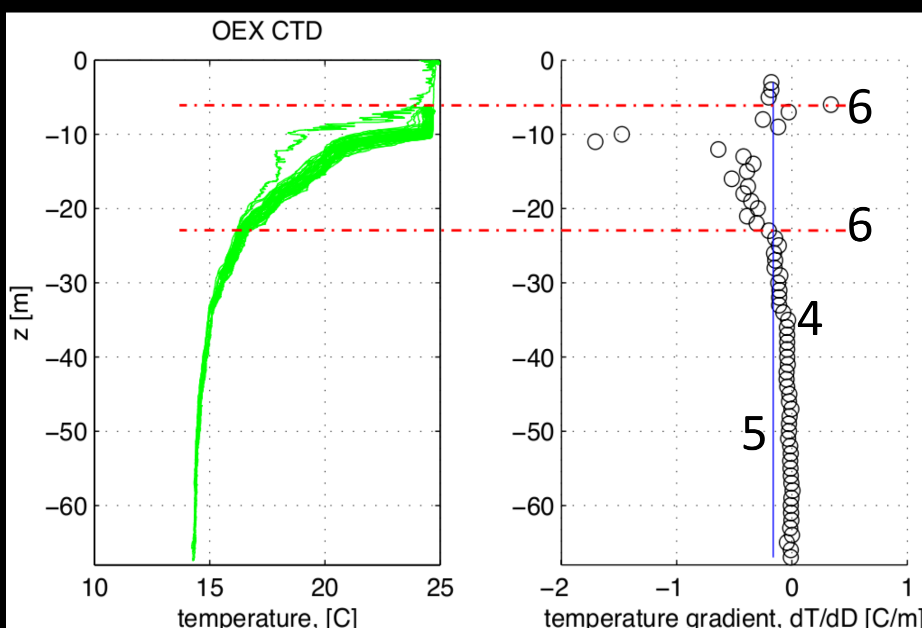
AAFT:

pEnvtGrad

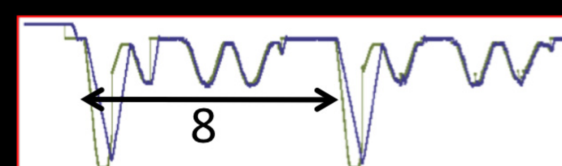
- Track Gradients: Temperature, Sound Speed, Density -



1) Initial yoyo
2) Create depth “bins”
3) Average T in bin
4) Vertical derivative (ΔT/Δz) over adjacent bins ‘o’



5) Threshold – Average ΔT/Δz over water column
6) Determine thermocline range (max|ΔT/Δz|) ‘- - - - - -’
7) Track! – adjust yoyo limits continuously
8) Periodic reset



Depth vs. Time

AAFT:
MOOS(-IvP) Interface

- Pros
  - Autonomy and Acomms interfaces already implemented, and continuously improving
  - Use a Toggle Depth behavior with pEnvtGrad to perform an adaptive yoyo through the water column
  - Multi-AUV collaboration possible
- Cons
  - Lack of a real database in MOOS
    - prevents incorporation of spatial and temporal scales into oceanographic feature determination

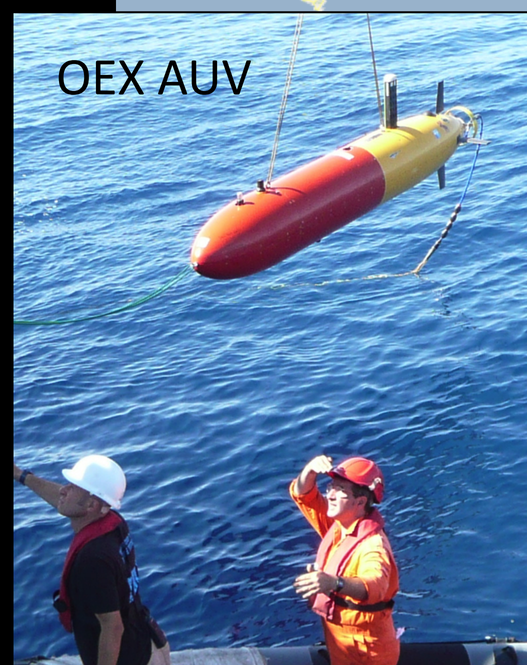
GLINT '09

Field Experiment

- 13-14 July, 2009
  Adaptive Env't. missions
  - MIT
  - NATO Undersea Research Centre (NURC), La Spezia, Italy
- NURC OEX AUV running MOOS & MOOS -IvP

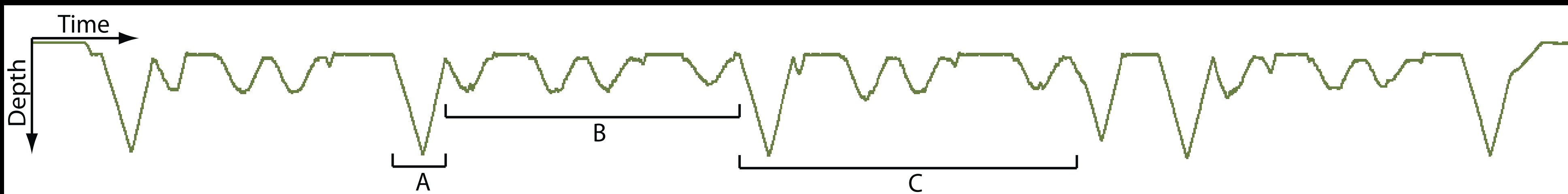
- Development, simulation & testing of pEnvtGrad
- Track acousticline

Tyrrhenian Sea, Italy



GLINT '09

Results (07/14/09)



Autonomy Behaviors:
Adaptive Yoyo (above) & Racetrack (1km x 200m oval)

Mission:
Track the acousticline.

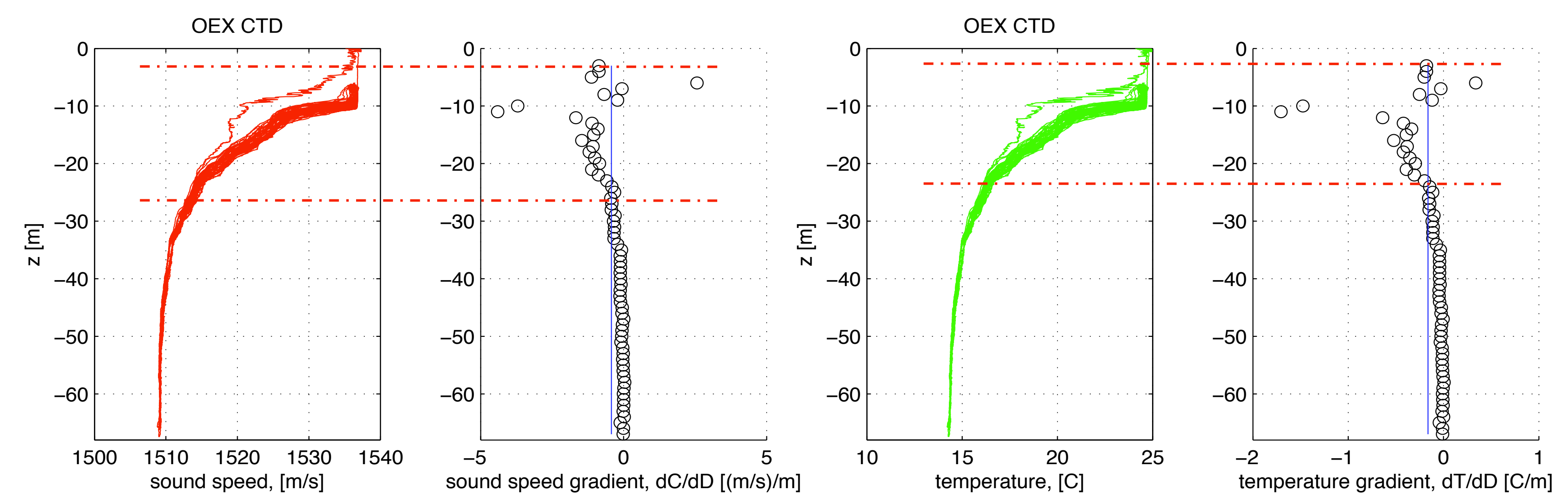
A: Initial yoyo, 7-70m
B: Tracking acousticline, 9-28m
C: Periodic timeout resets yoyo depth limits

Water Depth: ~105m

GLINT '09

Validation of pEnvtGrad Performance

- OEX CTD Gradient Determination -



Sound Speed (m/s)

$\left(\frac{\Delta c}{\Delta z}\right)_{avg}$ = -0.4269

Acousticline: 3 – 28m

Temperature (°C)

$\left(\frac{\Delta T}{\Delta z}\right)_{avg}$ = -0.1621

Thermocline: 3 – 23m

Tyrrhenian Sea – 14 July, 2009

Champlain '09
Field Experiment

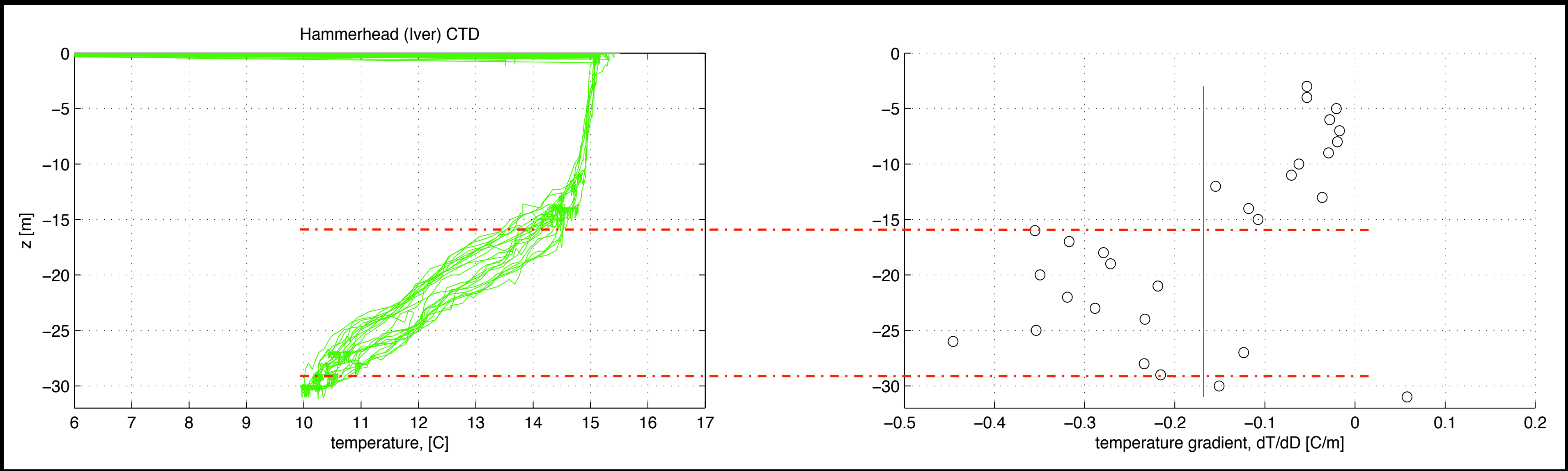
- 03-05 October, 2009
  - MIT
  - Naval Undersea Warfare Center (NUWC), Newport, RI
- Iver AUV running MOOS & MOOS-IvP
- Testing of pEnvtGrad
  - Track thermocline
- Fresh water!

Lake Champlain, VT

Hammerhead (Iver AUV)

Champlain '09

Thermocline Tracking, cont.



avg(dT/dz) = -0.1679 °C/m

Thermocline = [16   29] m

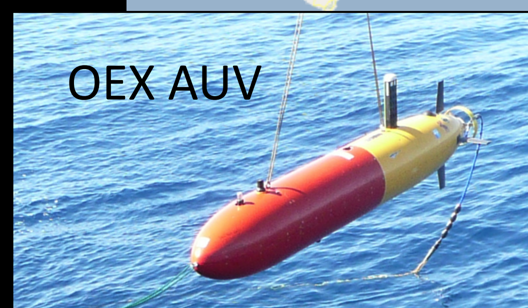
GLINT '10
Field Experiment

- 13 August, 2010
  Adaptive Env't. missions
  - MIT
  - NURC

- 2-AUV collaboration
- Unicorn (MIT Bluefin 21") & Harpo (NURC OEX) both running MOOS & MOOS-IvP

- Searching for internal waves
- Harpo – Swim at top of thermocline (~12m)
- Unicorn – Trail Harpo while tracking the thermocline

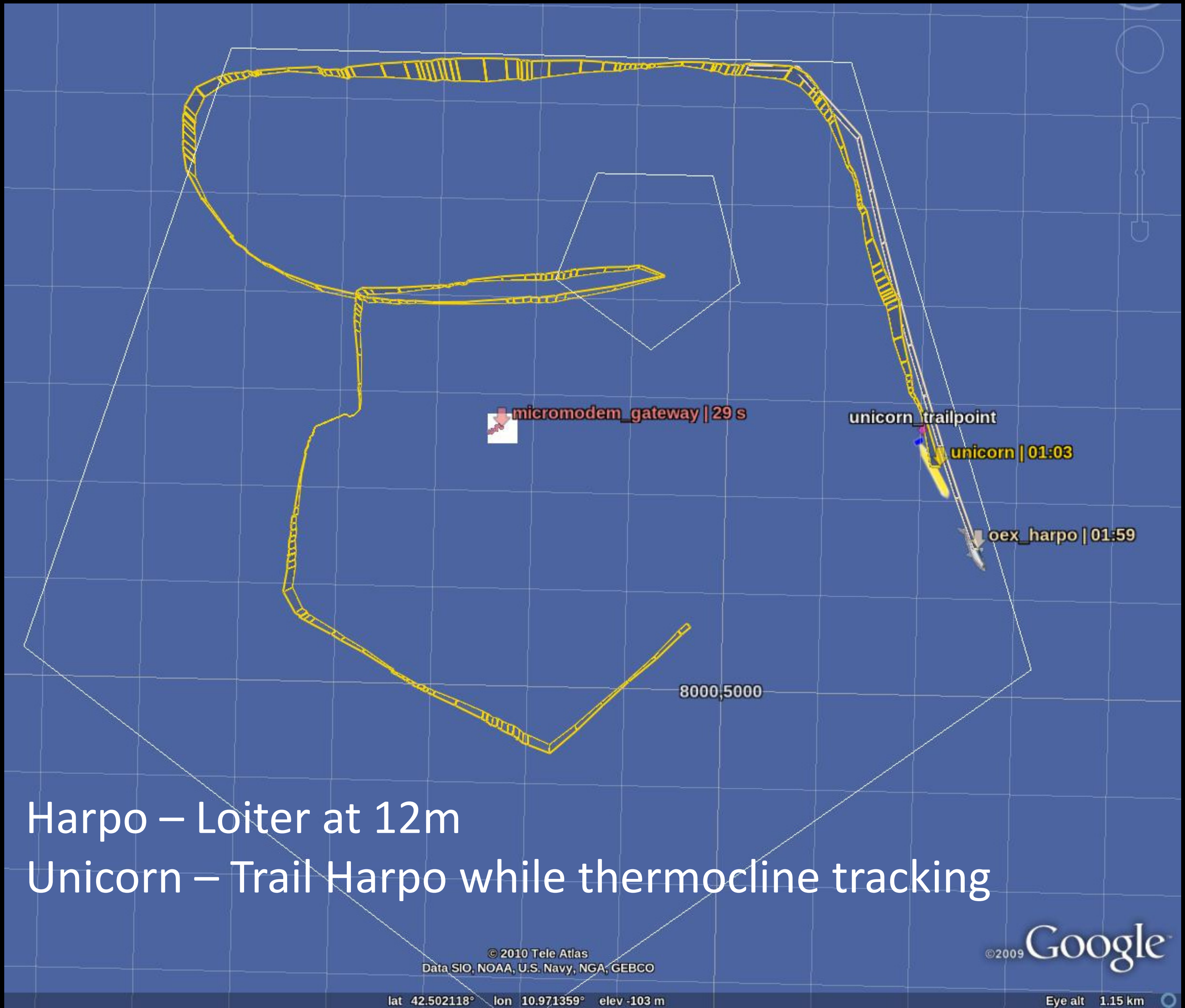
Tyrrhenian Sea, Italy



GLINT '10

Results (08/13/10)

GLINT '10
Results (08/13/10)

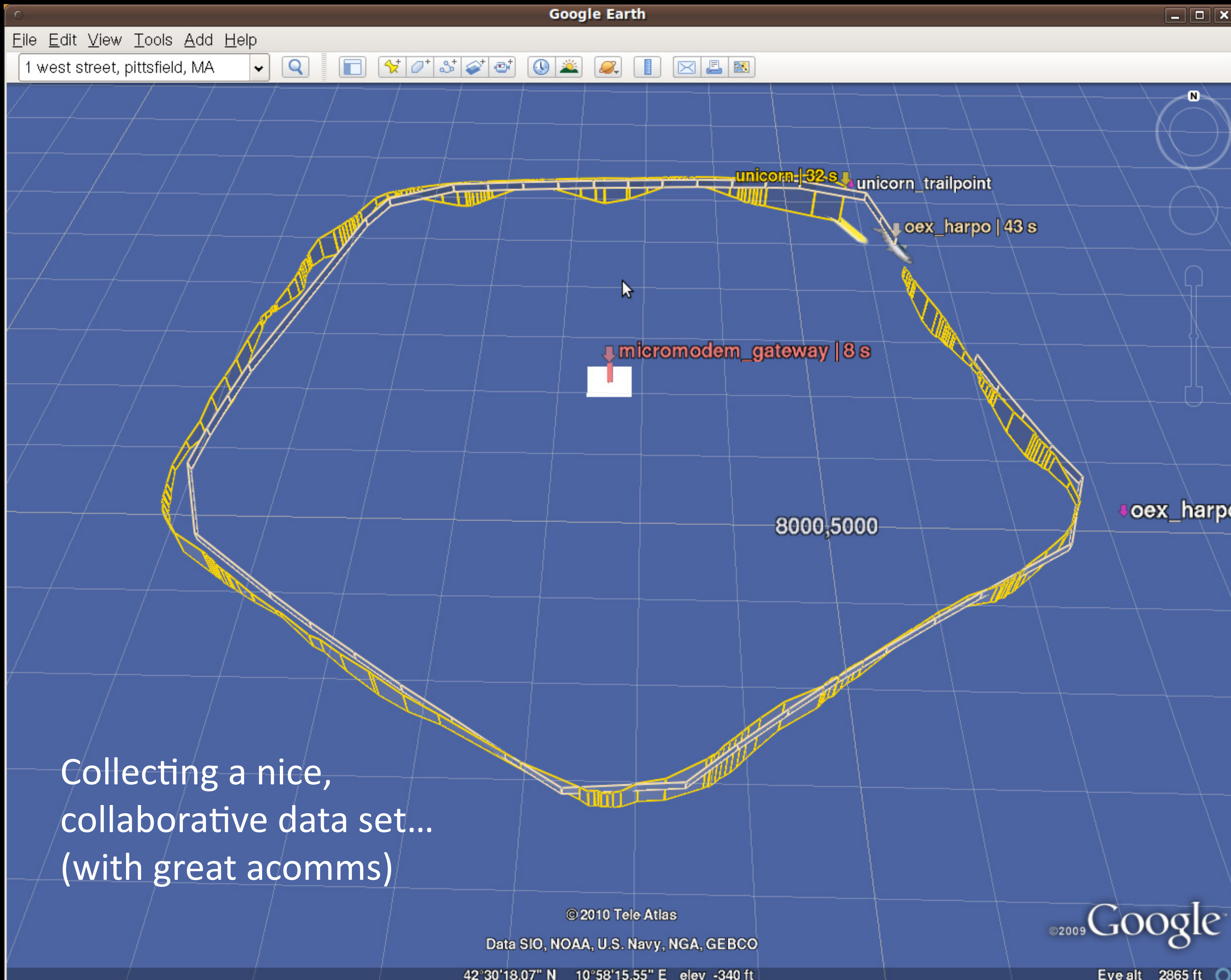


Harpo – Loiter at 12m

Unicorn – Trail Harpo while thermocline tracking

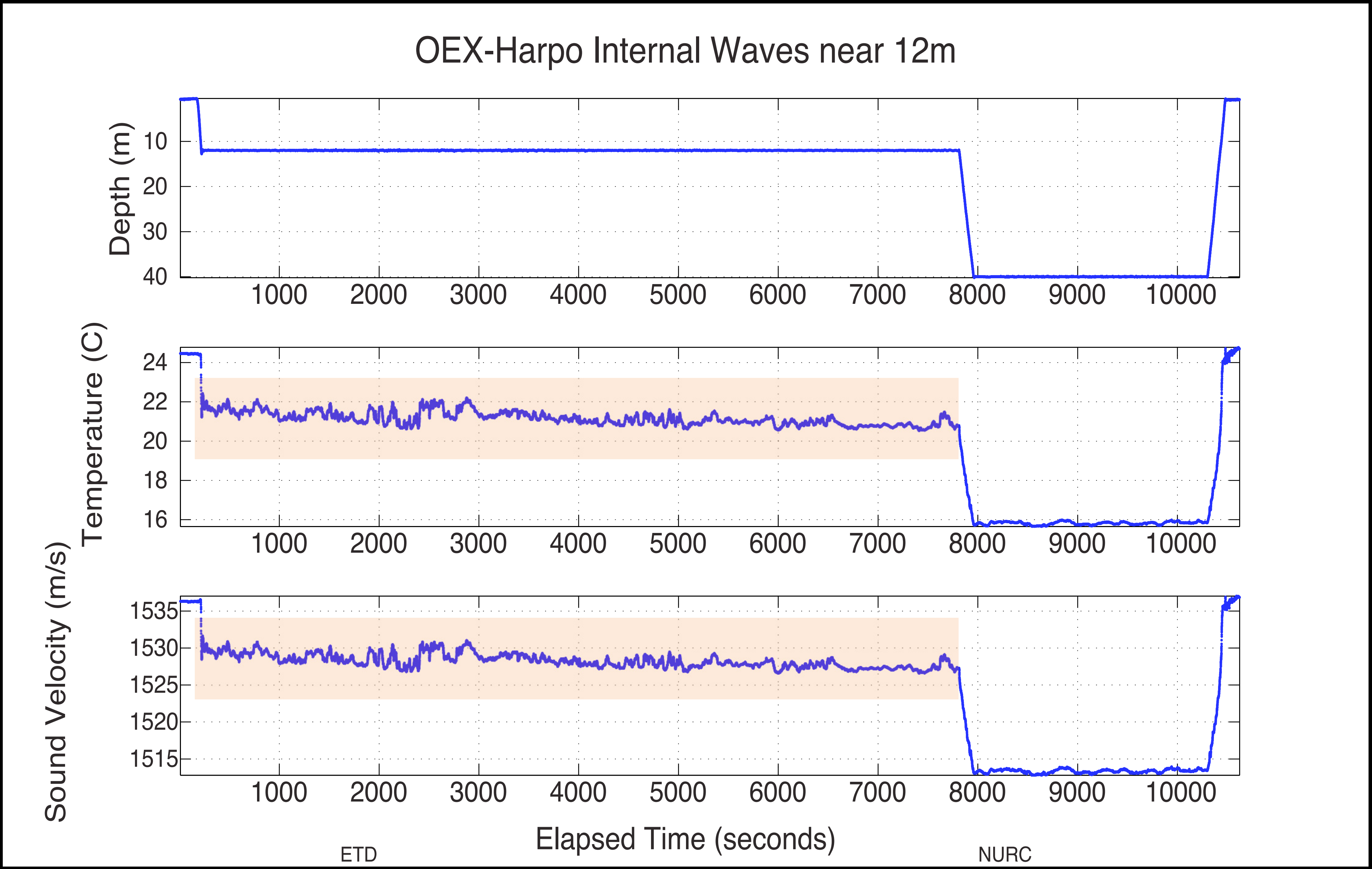
GLINT '10

Results (08/13/10)



Collecting a nice, collaborative data set… (with great acomms)

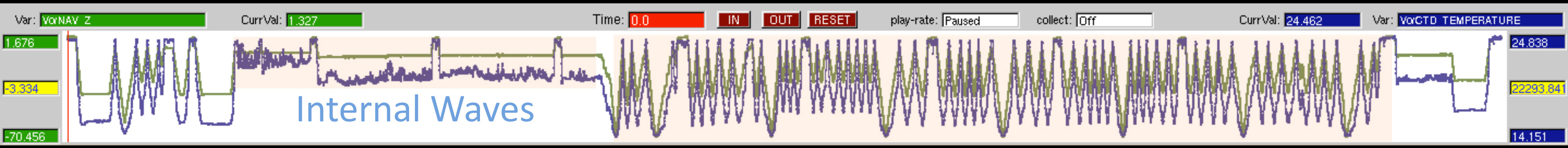
GLINT '10
Results - Harpo



GLINT '10

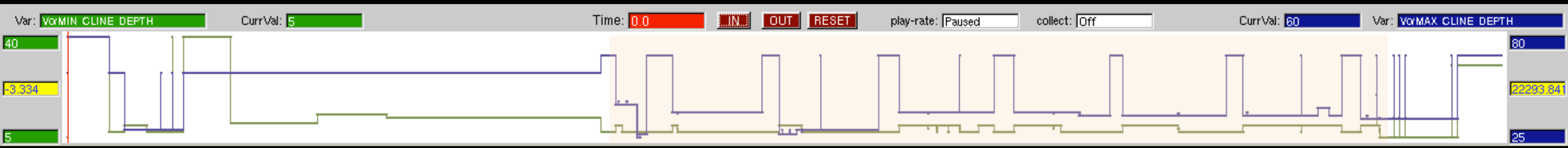
Results - Unicorn

Depth of Unicorn, Temperature at Unicorn's Location



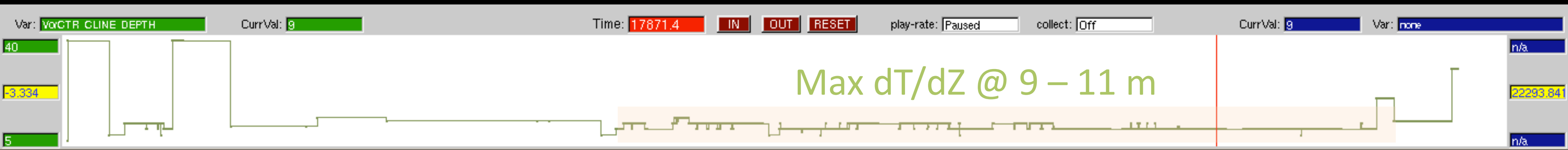
Adaptive Yoyo

Min & Max depth bounds of thermocline



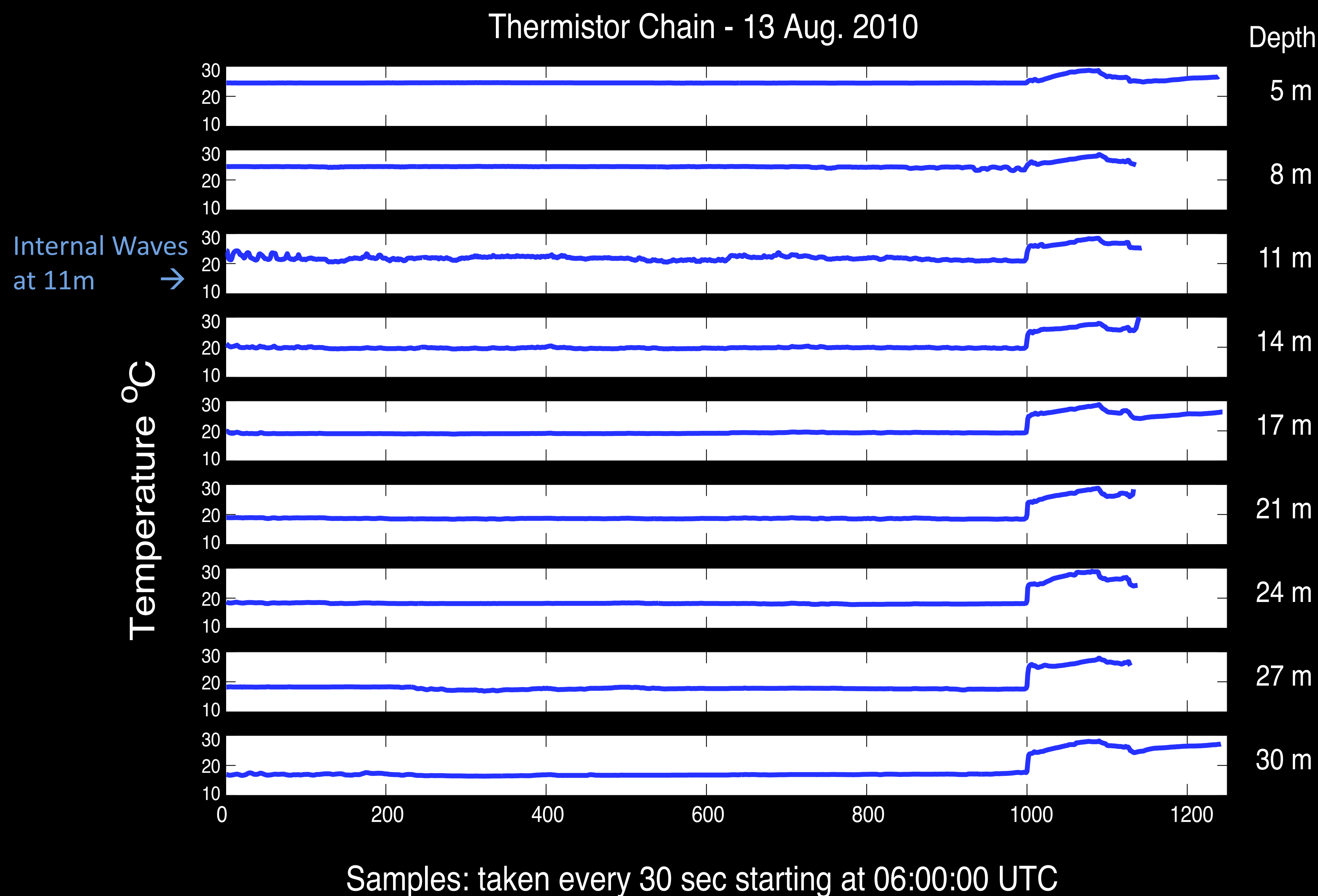
Thermocline Depth Range: 9 – 39 m

Depth of Max Temperature Gradient



GLINT '10

Did it work? – Yes!



Summary

- Successful proof-of-concept for AAFT
- Widely applicable in the dynamic ocean environment, for single and collaborating AUVs
- MOOS & MOOS-IvP allow us to bring our technology advances into use in the oceanographic community
  – Good, but we need a real database for onboard dynamic data processing!

Acknowledgements

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Questions / comments?

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