A "Game Changing" Technology

Oceanographic Results from Wave Gliders & Measuring Currents with an ADCP from Wave Glider

Presented to the 5th EGO Meeting

Neil Trenaman, Liquid Robotics Inc.

March 16, 2011

liquid robotics

Kawaihae

Founded: January 2007

50 staff

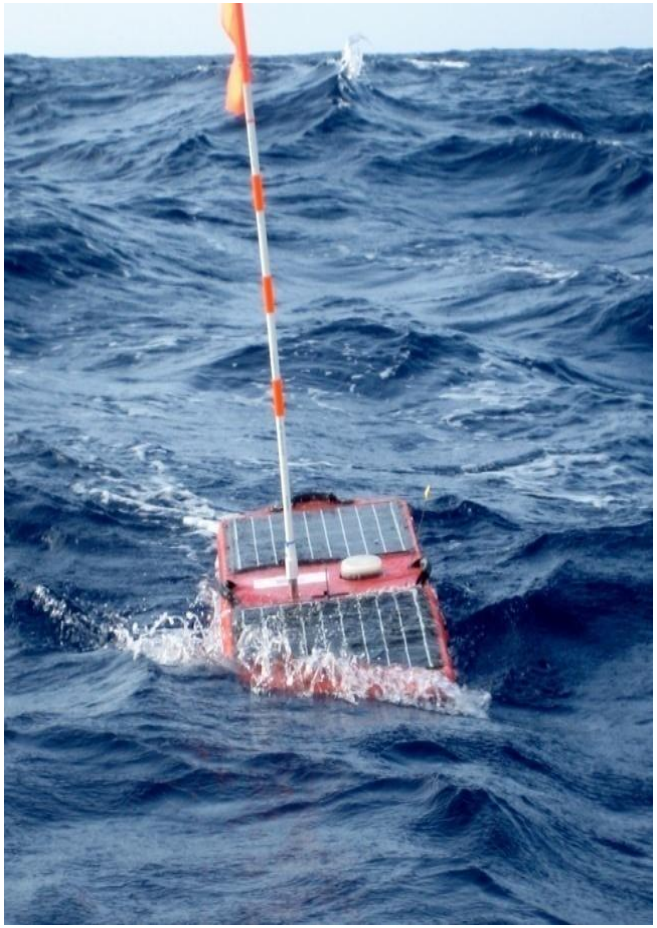
Headquarters: Sunnyvale, California

Test & Development: Big Island of Hawaii

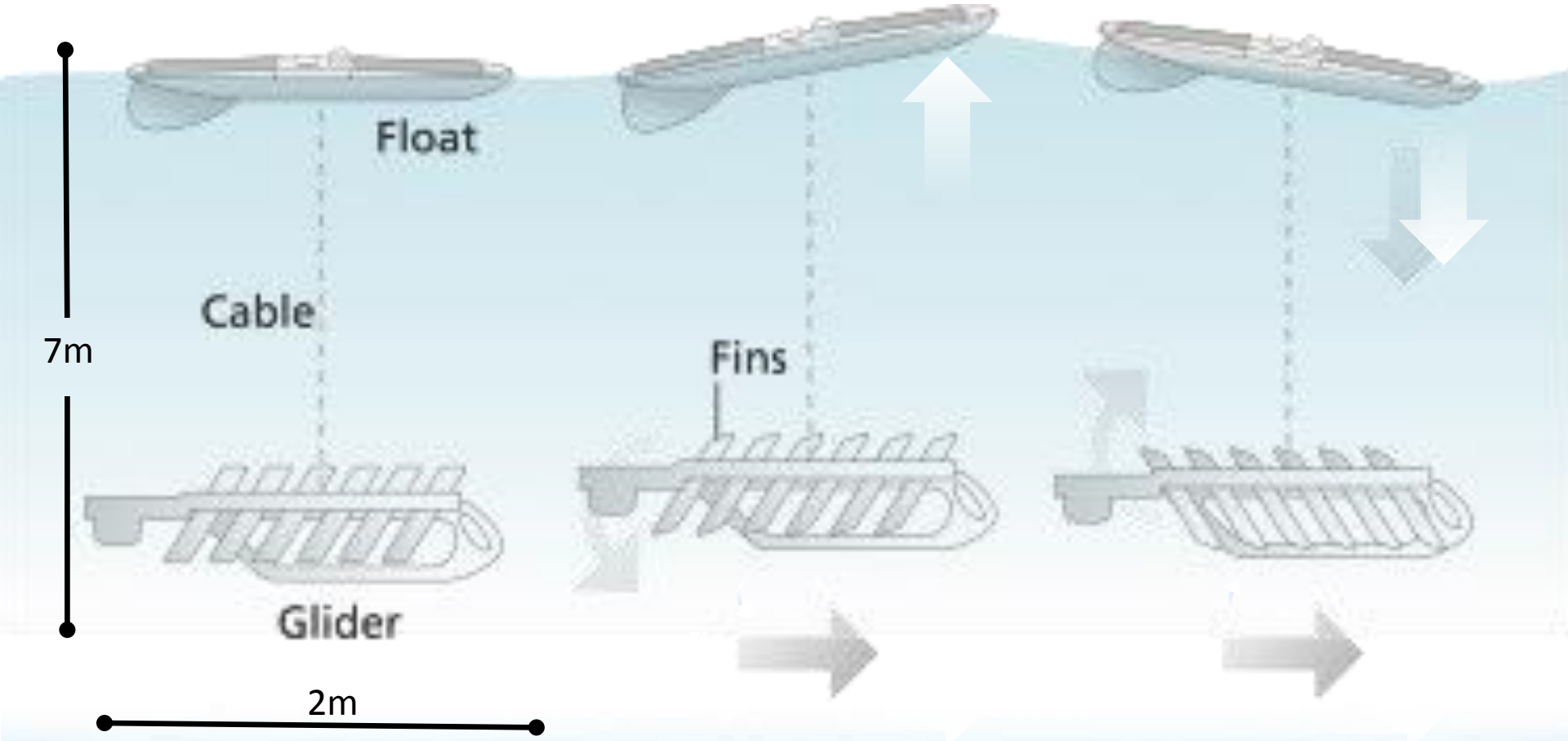
Customers & Collaborators: Globally

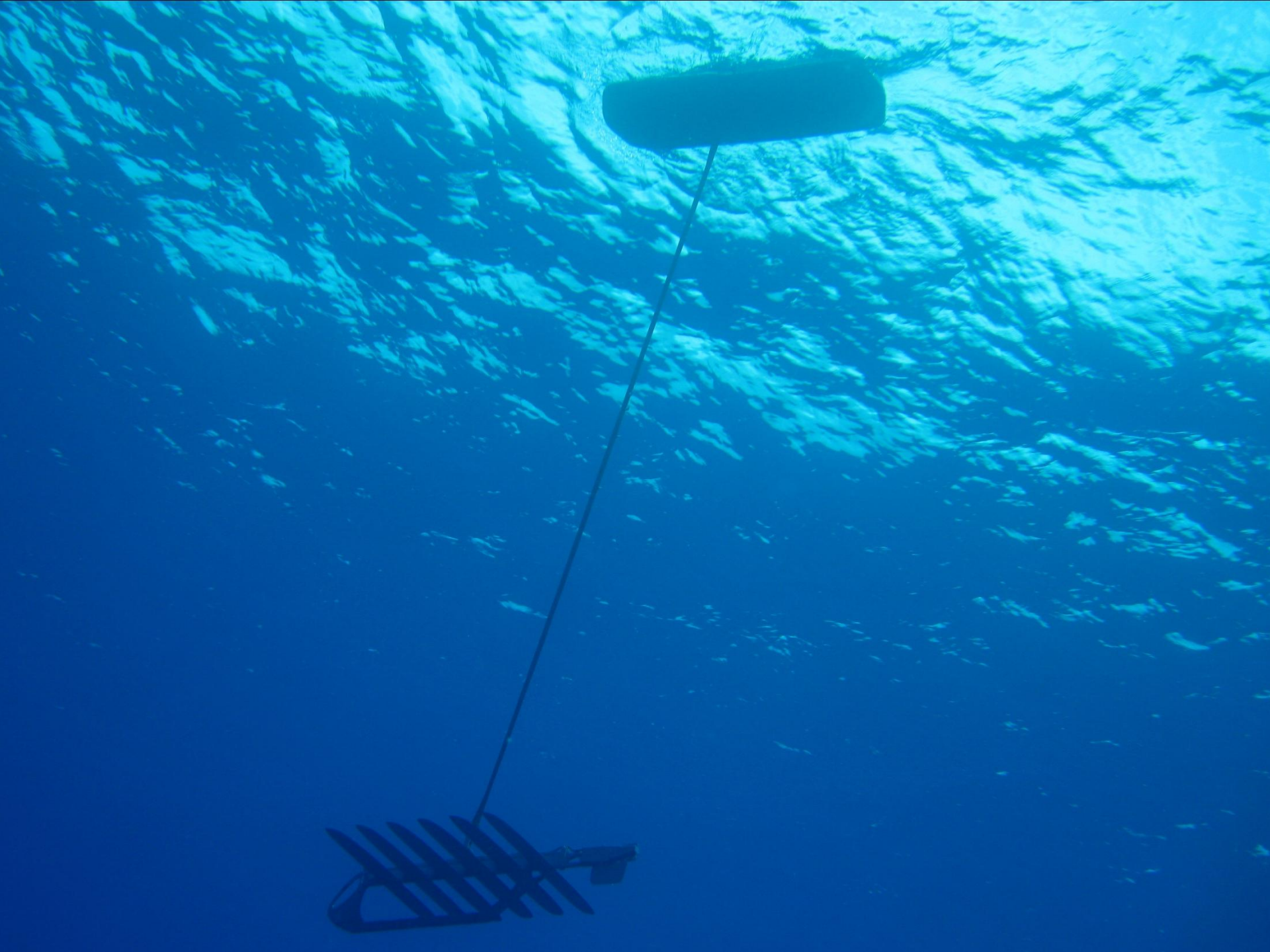
The Wave Glider
a “game changing” technology

- Unique Two Part Vehicle:
  - Converts wave motion into thrust
  - Calm and rough seas
  - Thrust generation increases with sea state
  - Long mission durations possible
- Both a Buoy and a Vehicle
  - Travel to operation area
  - Return for maintenance
  - Patrol, survey or hold station
- Proven Performance:
  - Existing fleet has traveled over 100,000 nmi
  - Long Distance Missions
  - “Iron Man” vehicle in water operations now exceeds two years continuous service

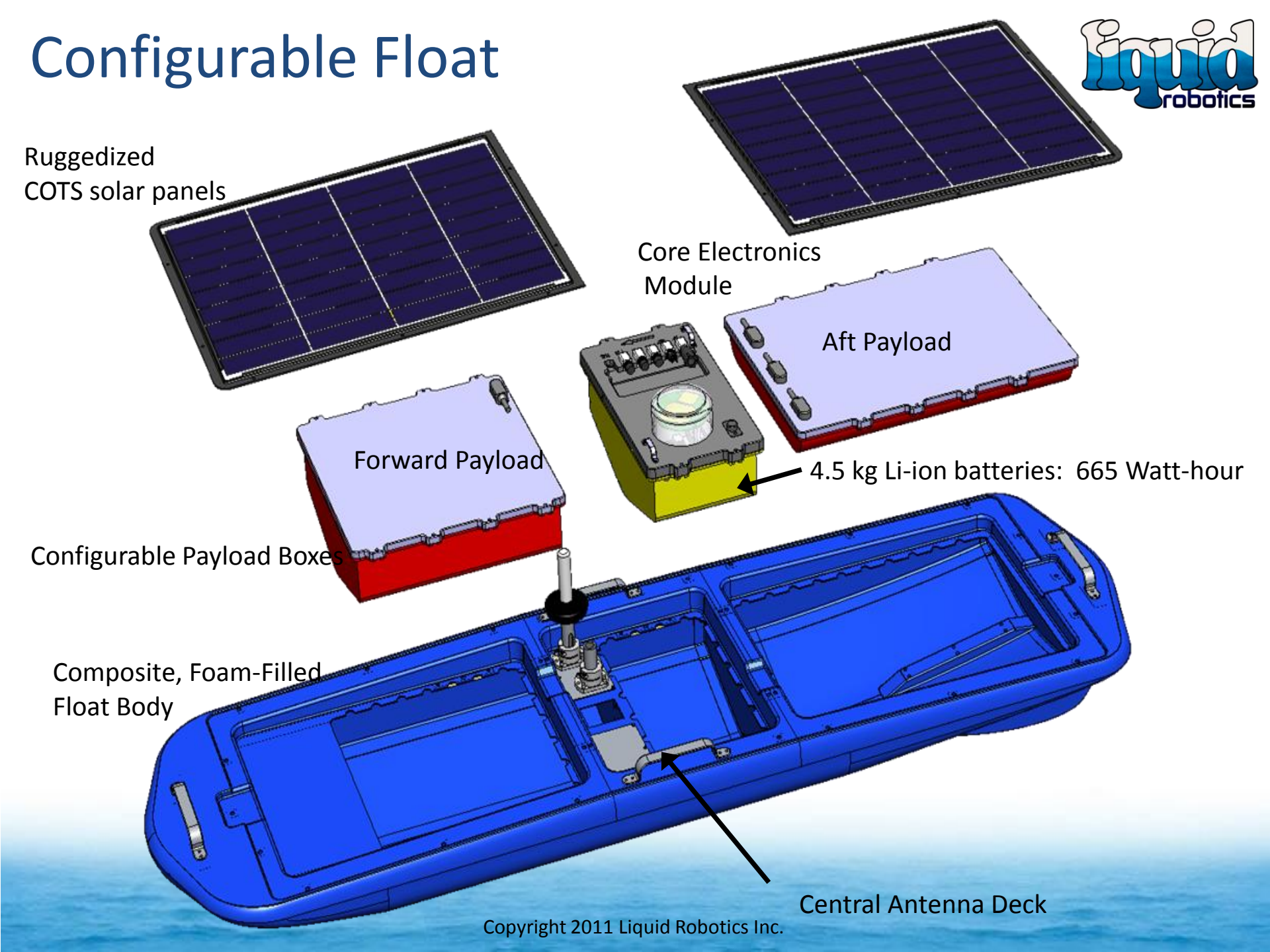


Wave Glider Concept
Submerged glider converts vertical motion into forward thrust

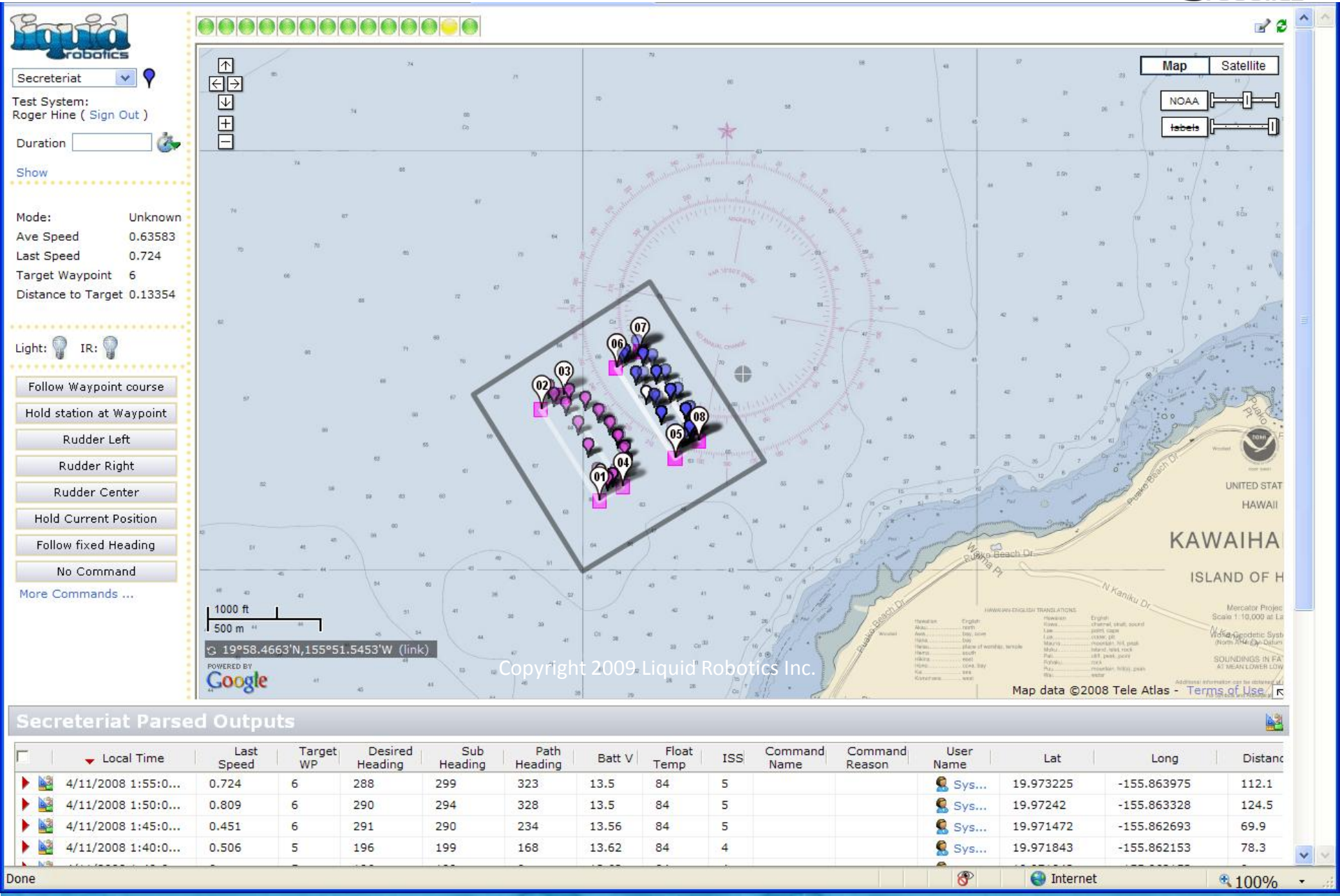




Configurable Float



Web Based User Interface



WG Command and Control : different modes

Programmed

Mission Planning

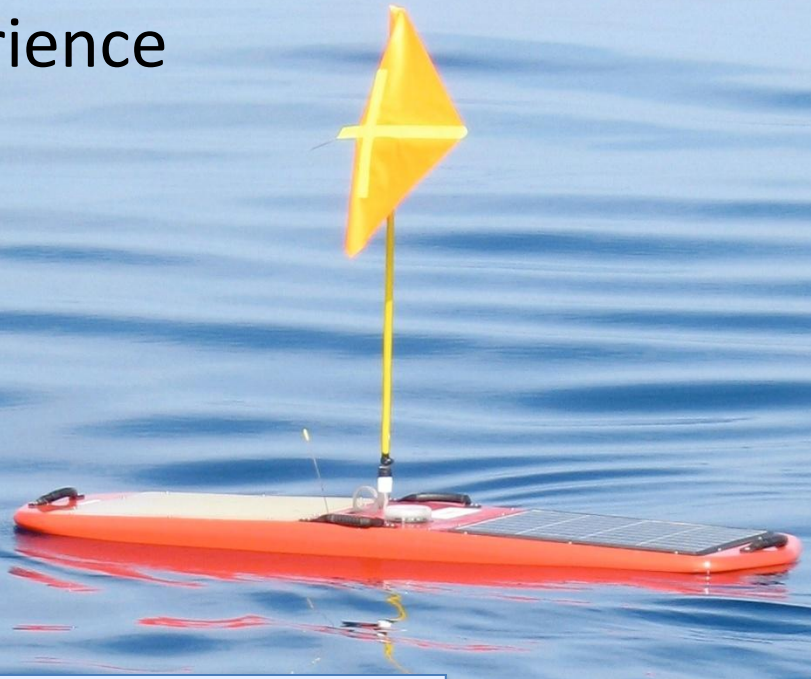
Semi Automatic

Real-time way point or pattern setting

Remote Control

Real-time direct rudder operations

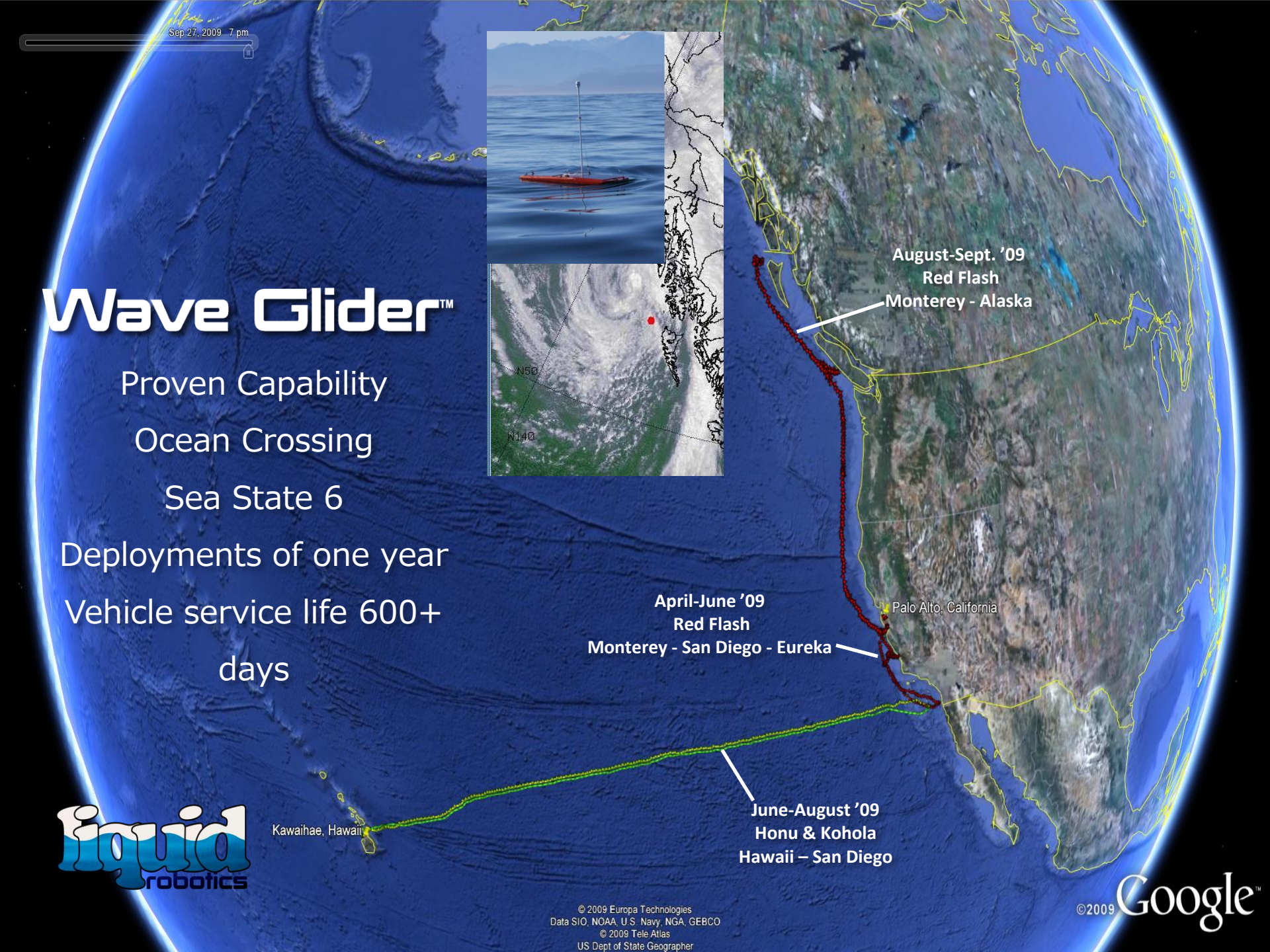
Wave Glider Speed Performance
Qualitative Experience



Propulsion Speed Performance	
Flat Calm	0 kts
Sea State 0	0.25 to 0.50 kts
Sea State 1	0.50 to 1.50 kts
Sea State 2	1.25 to 2.00 kts
Sea State 3+	1.50 to 2.25 kts
Average	1.50 kts

Under typical sea conditions, Wave Glider advances at 1.5 kts, independent of wave direction.

Wave Glider maintains 0.25 to 0.50 kt headway, even under very calm conditions.


Sep 27, 2009 7 pm
Wave Glider™
Proven Capability
Ocean Crossing
Sea State 6
Deployments of one year
Vehicle service life 600+ days
N50
N140
August-Sept. '09
Red Flash
Monterey - Alaska
April-June '09
Red Flash
Monterey - San Diego - Eureka
Palo Alto, California
June-August '09
Honu & Kohola
Hawaii – San Diego
Kawaihae, Hawaii
liquid robotics
© 2009 Europa Technologies
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2009 Tele Atlas
US Dept of State Geographer
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Airmar PB200
- Wind Speed
- Wind Direction
- Air Temp
- Barometric Pressure

Liquid Robotics Wave Glider "Red Flash"

MBARI M1

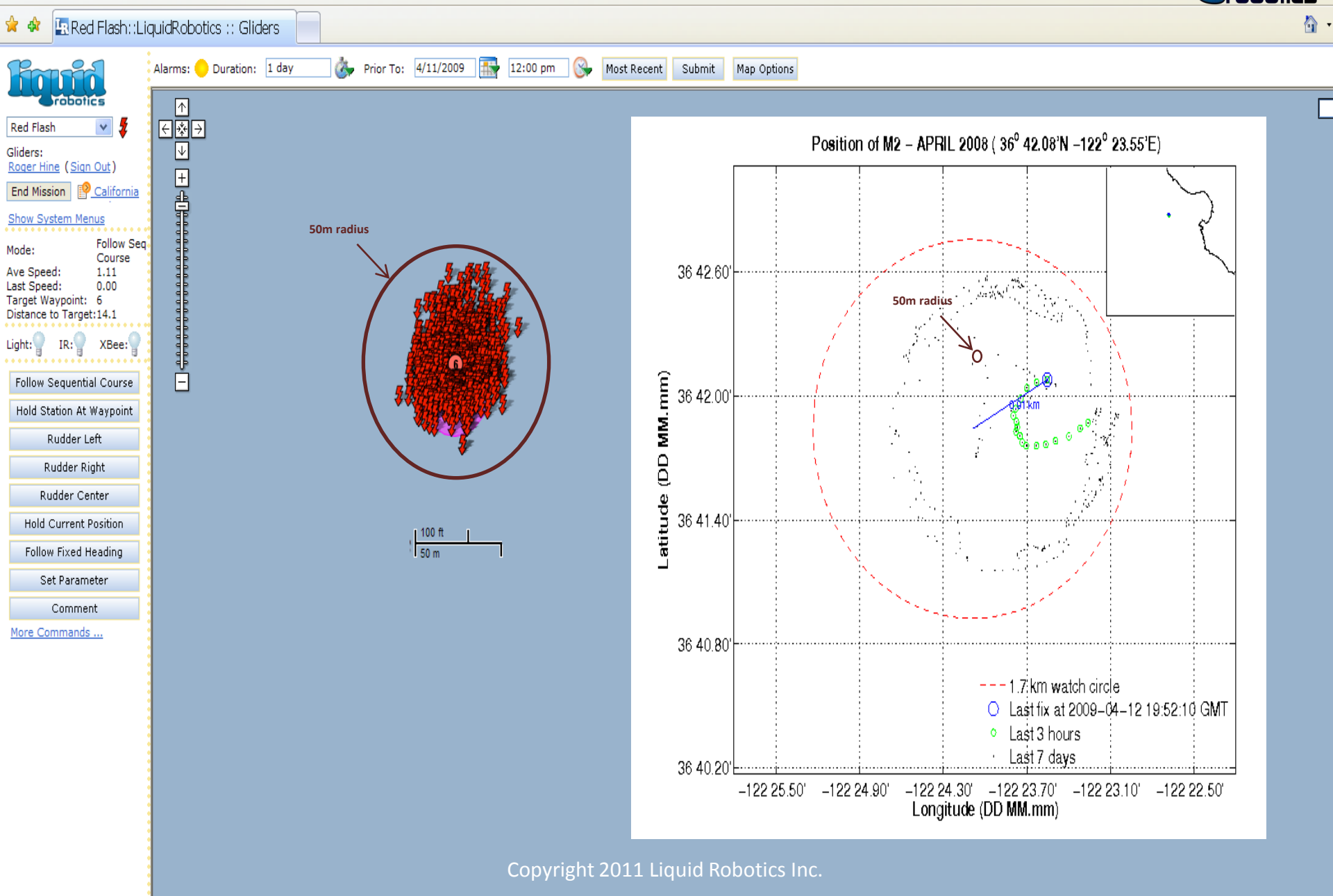
SCRIPPS 46236

MBARI M2

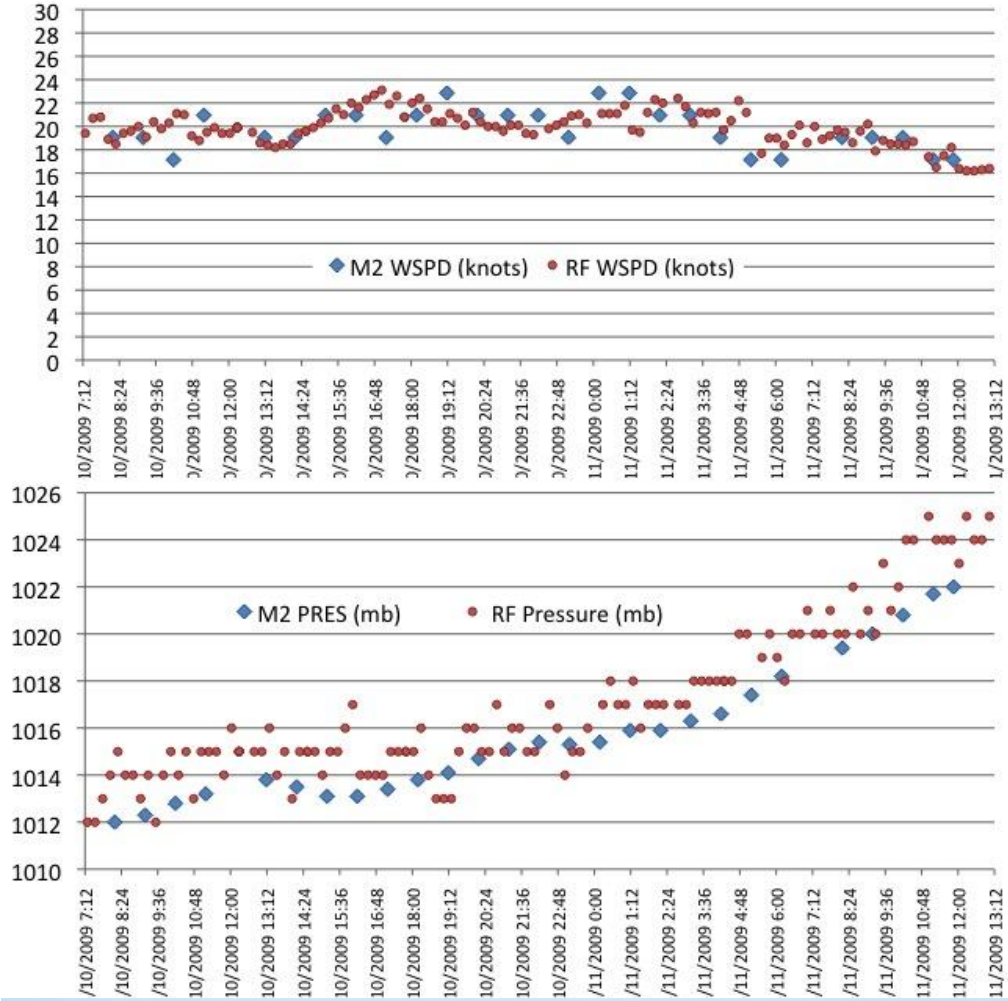
Wave Glider Testing in Monterey Bay

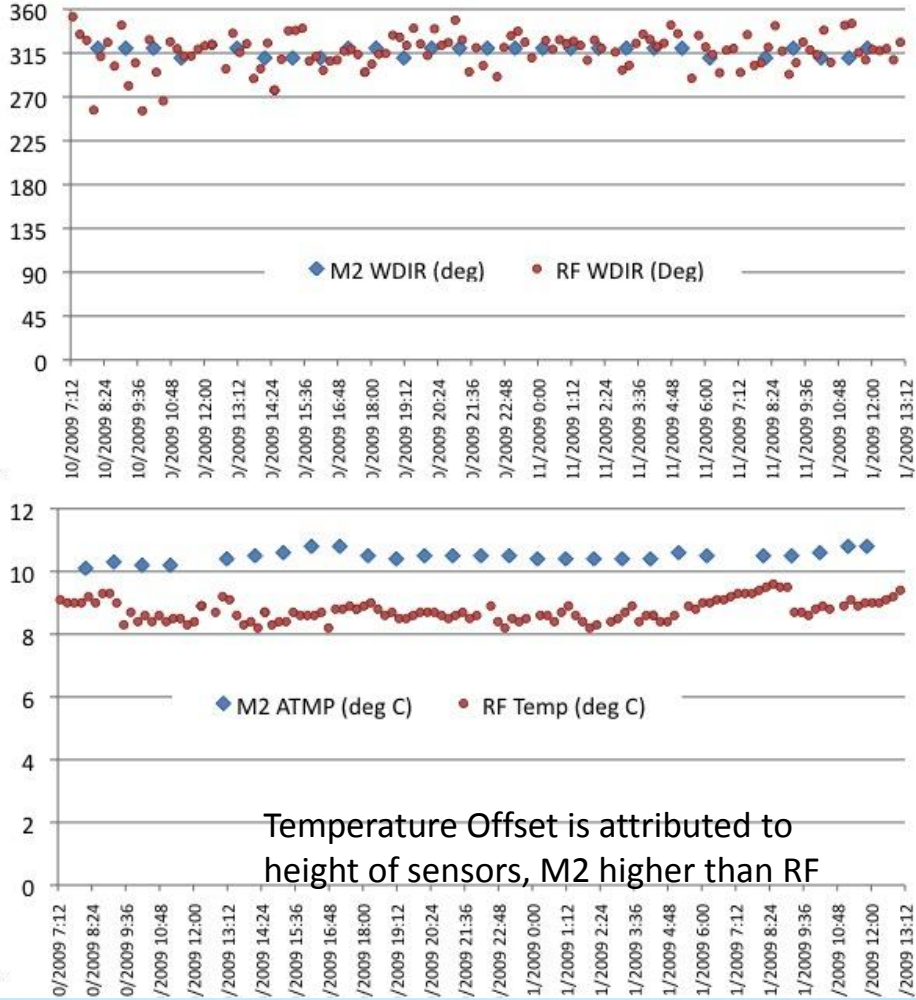
Wave Glider vs. Typical Mooring

Station Keeping Comparison – WG: 50m M2 1700m



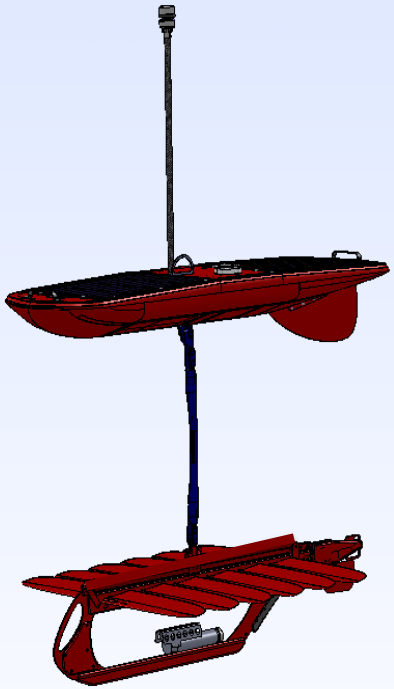
Wave Glider (RF) Data compared favorably to M2 Mooring (April 2009)

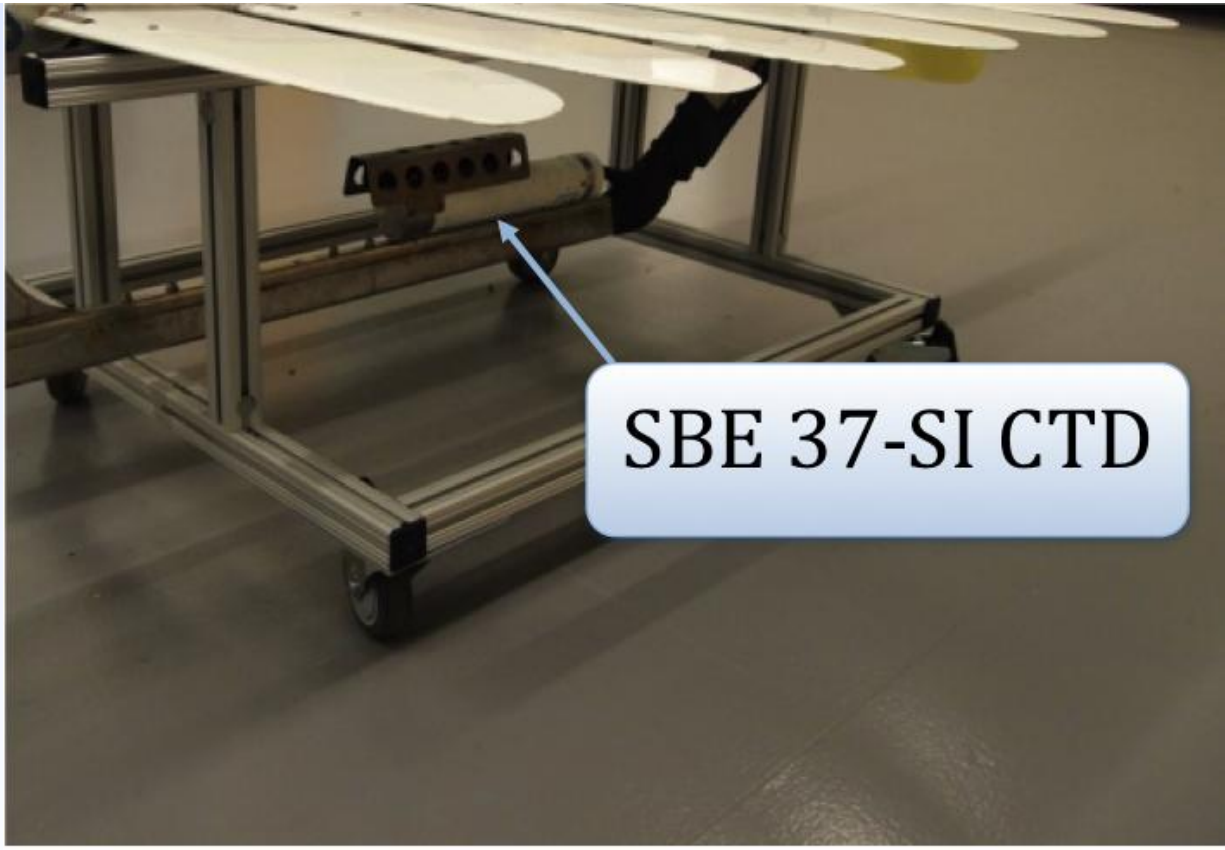




Temperature Offset is attributed to height of sensors, M2 higher than RF

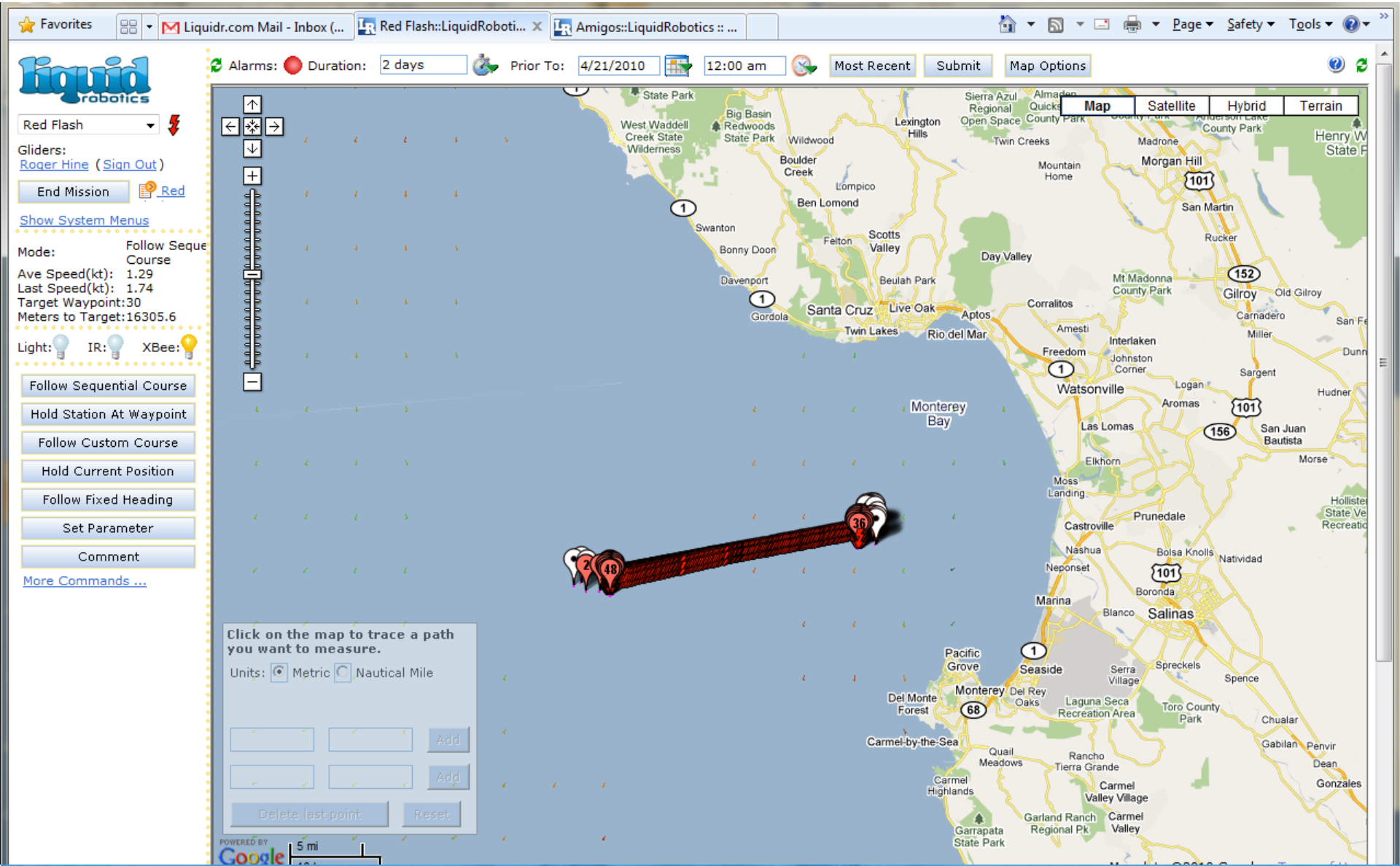
Red Flash CTD (April 2010)





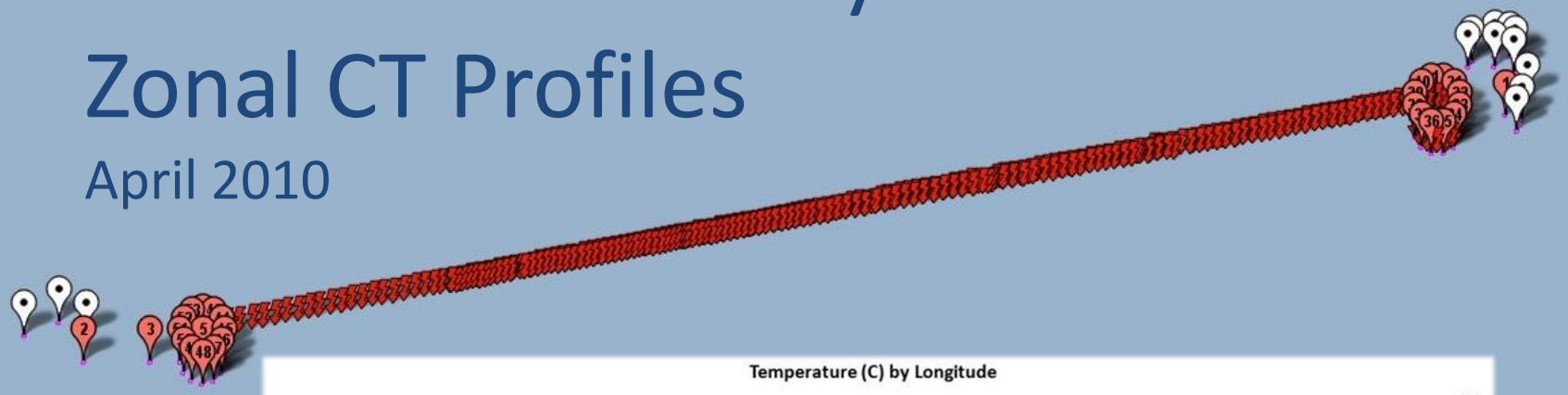
Red Flash Horizontal CT Profiles

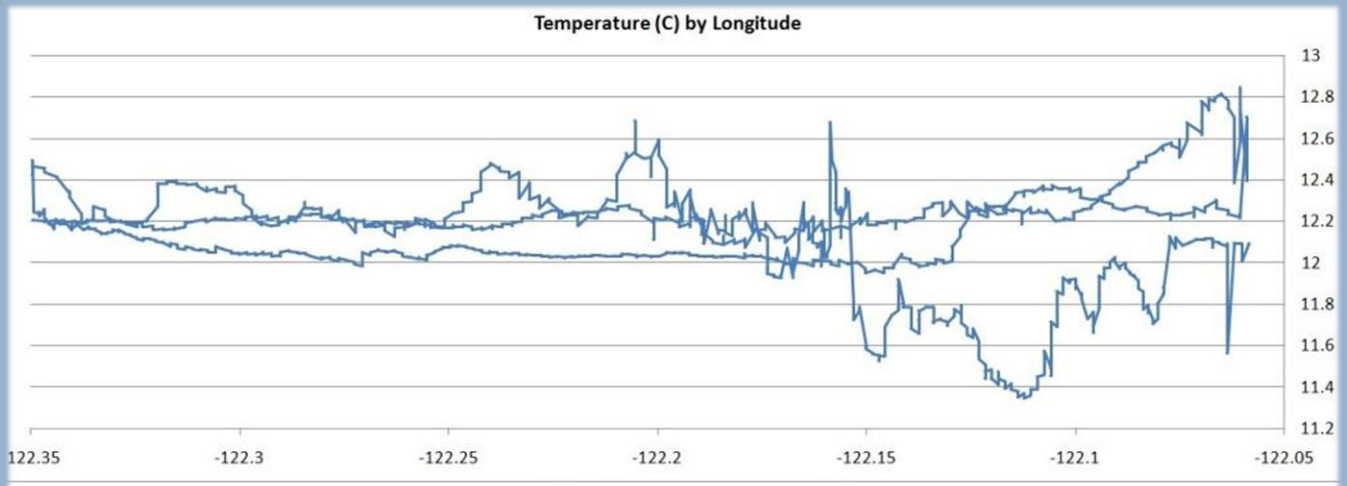
April 2010

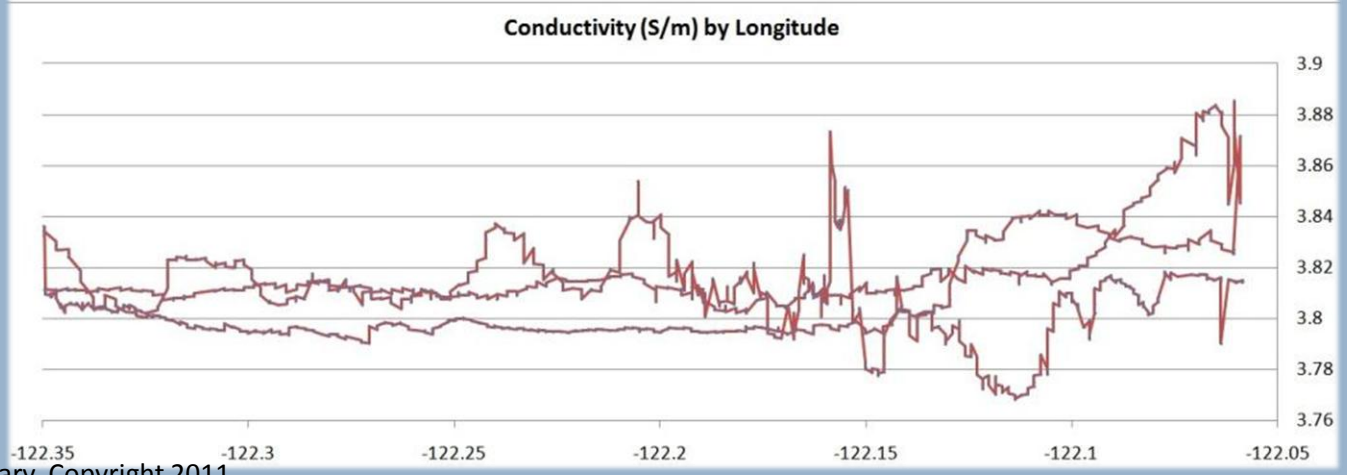


Red Flash Monterey Zonal CT Profiles

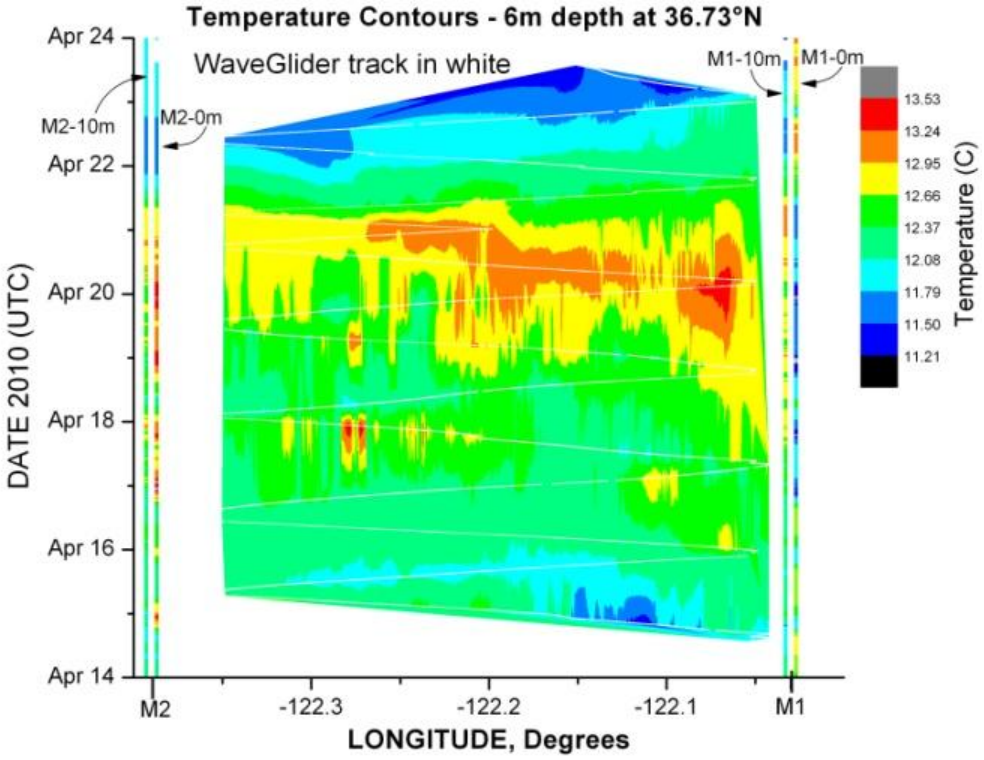
April 2010

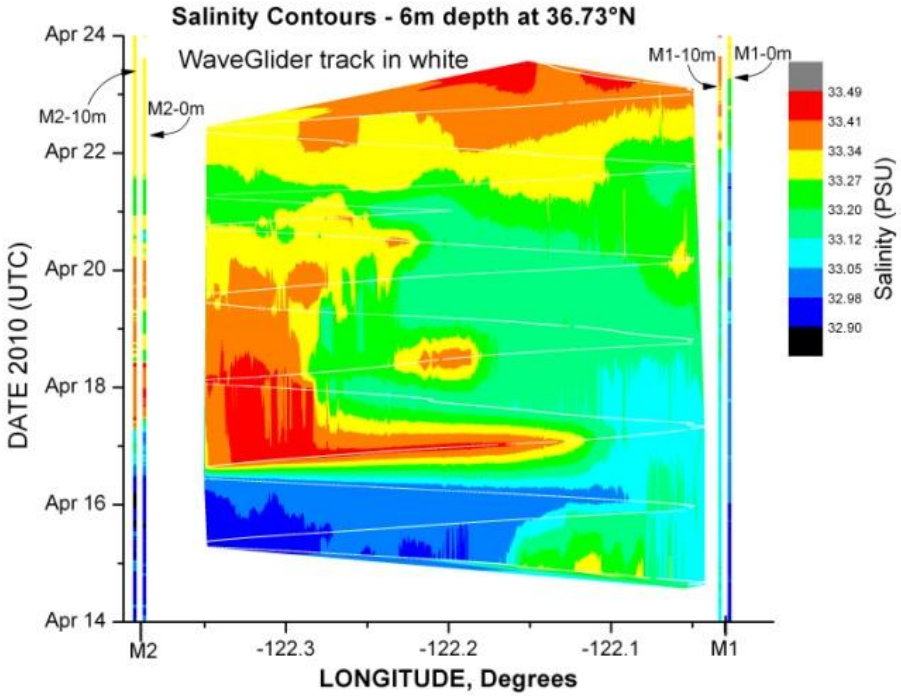






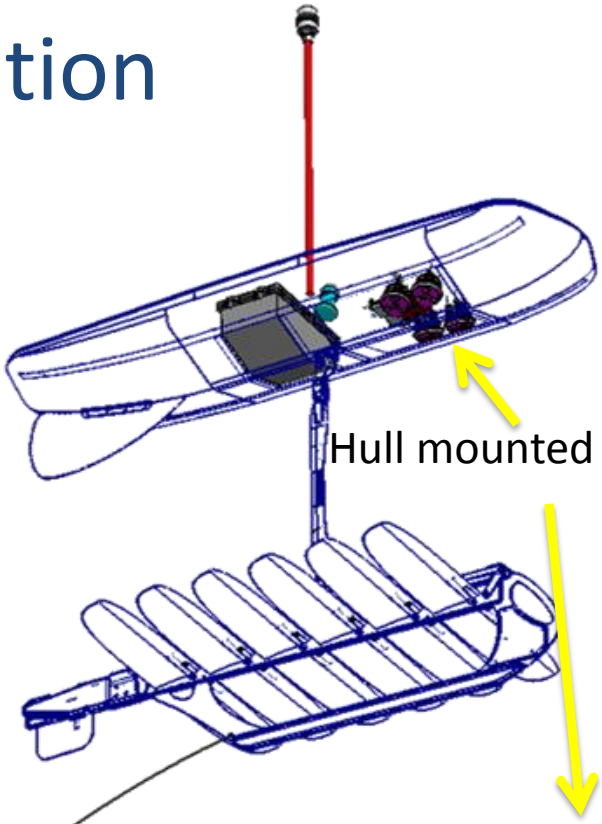
Red Flash Horizontal CT Profiles





Horizontal profiles proved interesting, paper accepted by the Journal of Ocean Dynamics.

Water Quality Configuration

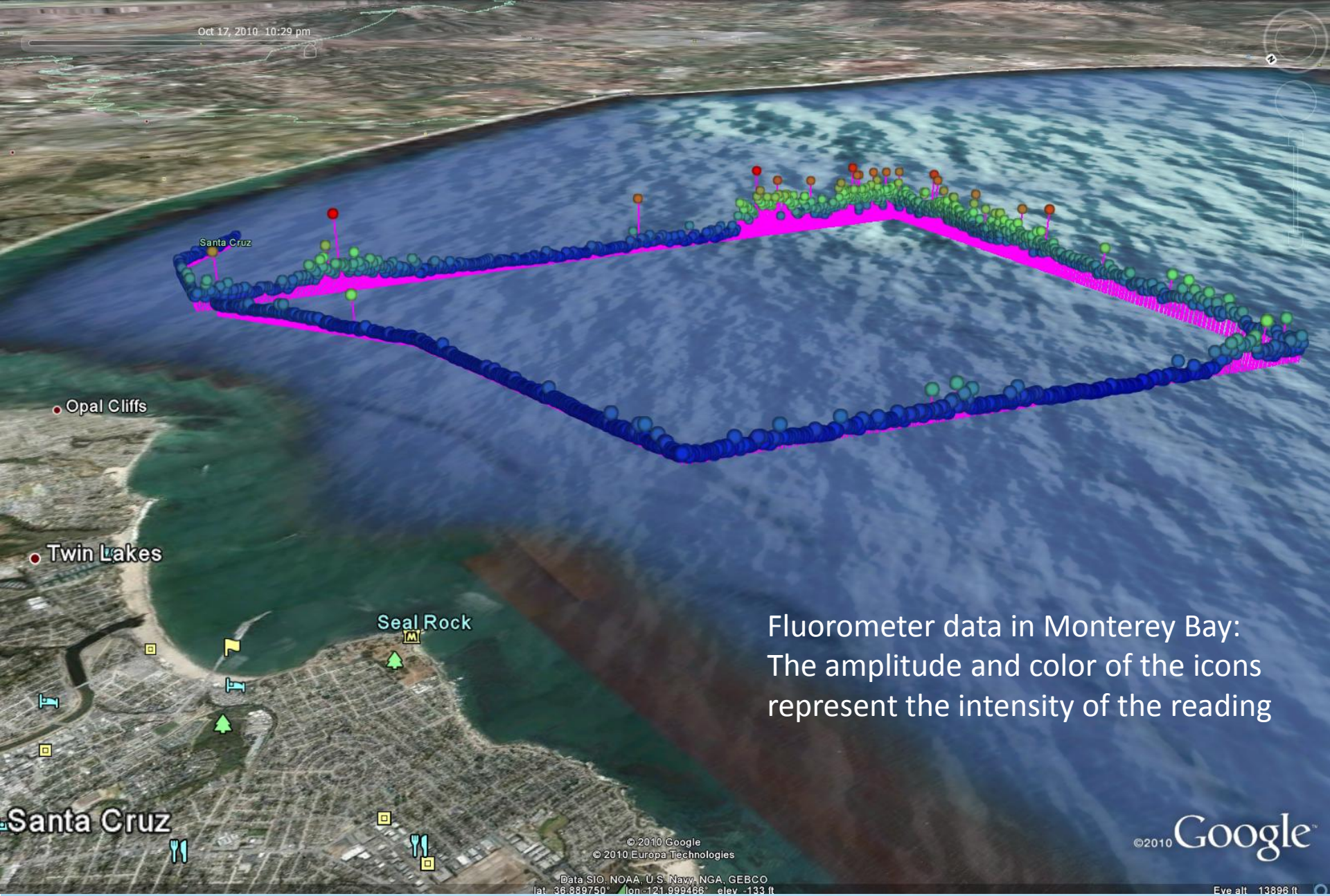


Hull mounted Fluorometers

Fluorometers on towbody
w/optional hydrophone array

Water Quality Payloads

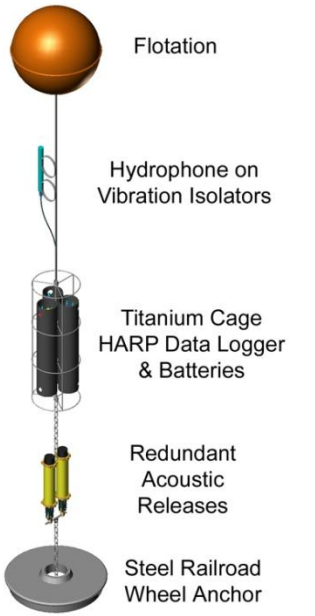
Sensor	Measurement	Sensor Location	Sample Rate	Telemetry Rate
Weather Station	Air Temp	1 m	1 Hz	15 min
	Barometric Press	1 m	1 Hz	15 min
	Wind Speed & Dir	1 m	1 Hz	15 min
C3 Fluorometer 1	Refined Fuels	0 m	1 min	7min
	CDOM	0 m	1 min	7min
	Turbidity	0 m	1 min	7min
	Water Temp	0 m	1 min	7min
C3 Fluorometer 2	Refined Fuels	0 m	1 min	7min
	Crude Oil	0 m	1 min	7min
	Chlorophyll A	0 m	1 min	7min
	Water Temp	0 m	1 min	7min
C3 Fluorometer 3	Refined Fuels	7 m depth	1 min	7min
	CDOM	7 m depth	1 min	7min
	Turbidity	7 m depth	1 min	7min
	Water Temp	7 m depth	1 min	7min

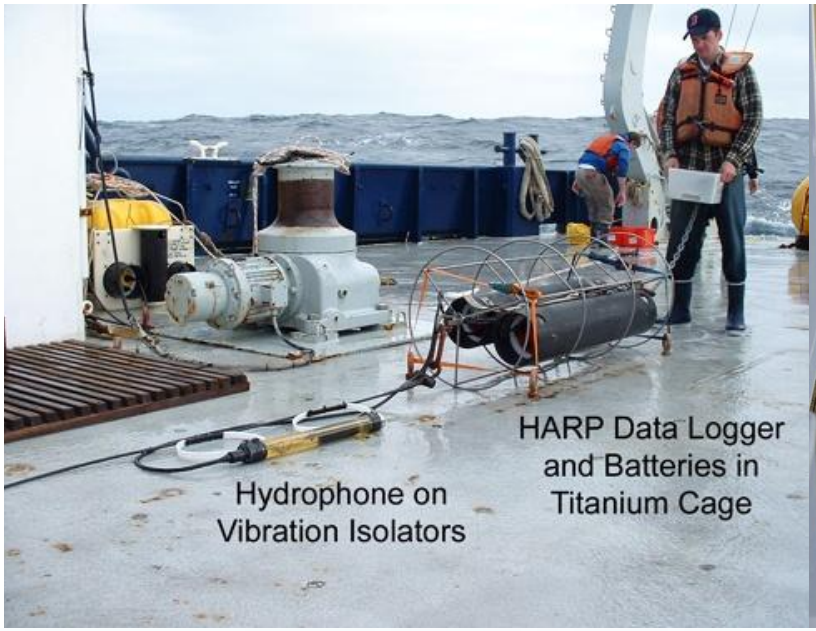


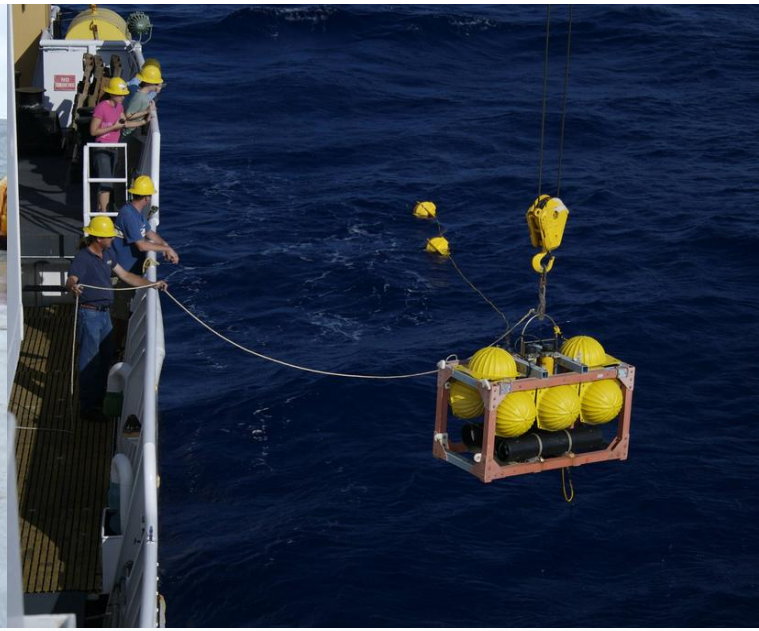
Fluorometer data in Monterey Bay:
The amplitude and color of the icons represent the intensity of the reading

Passive Acoustics

- Original inspiration for the Wave Glider
- Humpback Whales live online (JRF)
- Wave Glider deployed the Scripps High Frequency Acoustic Recorder (HARP)

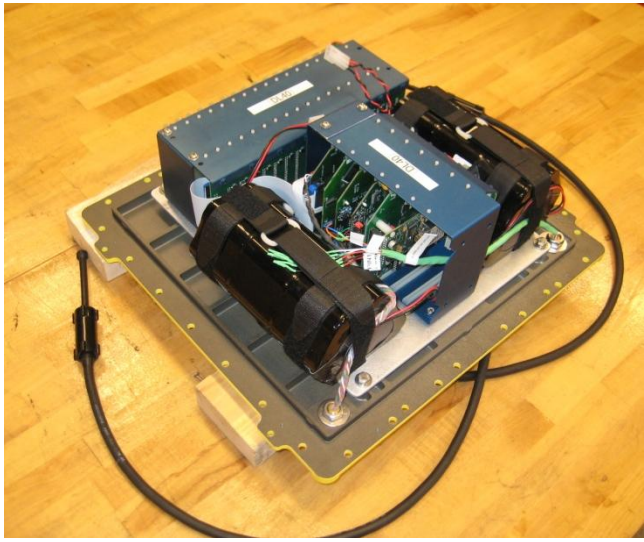


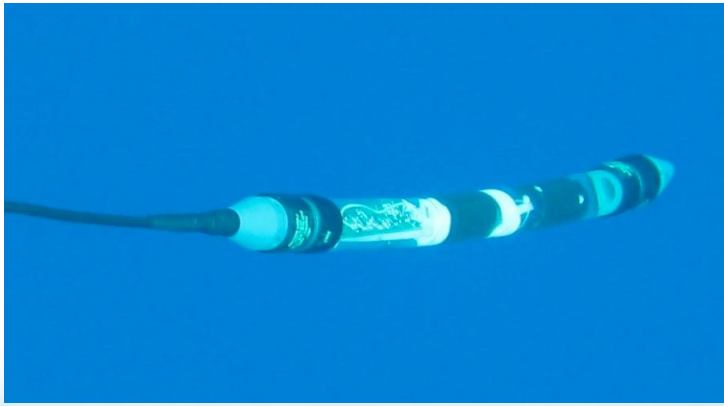




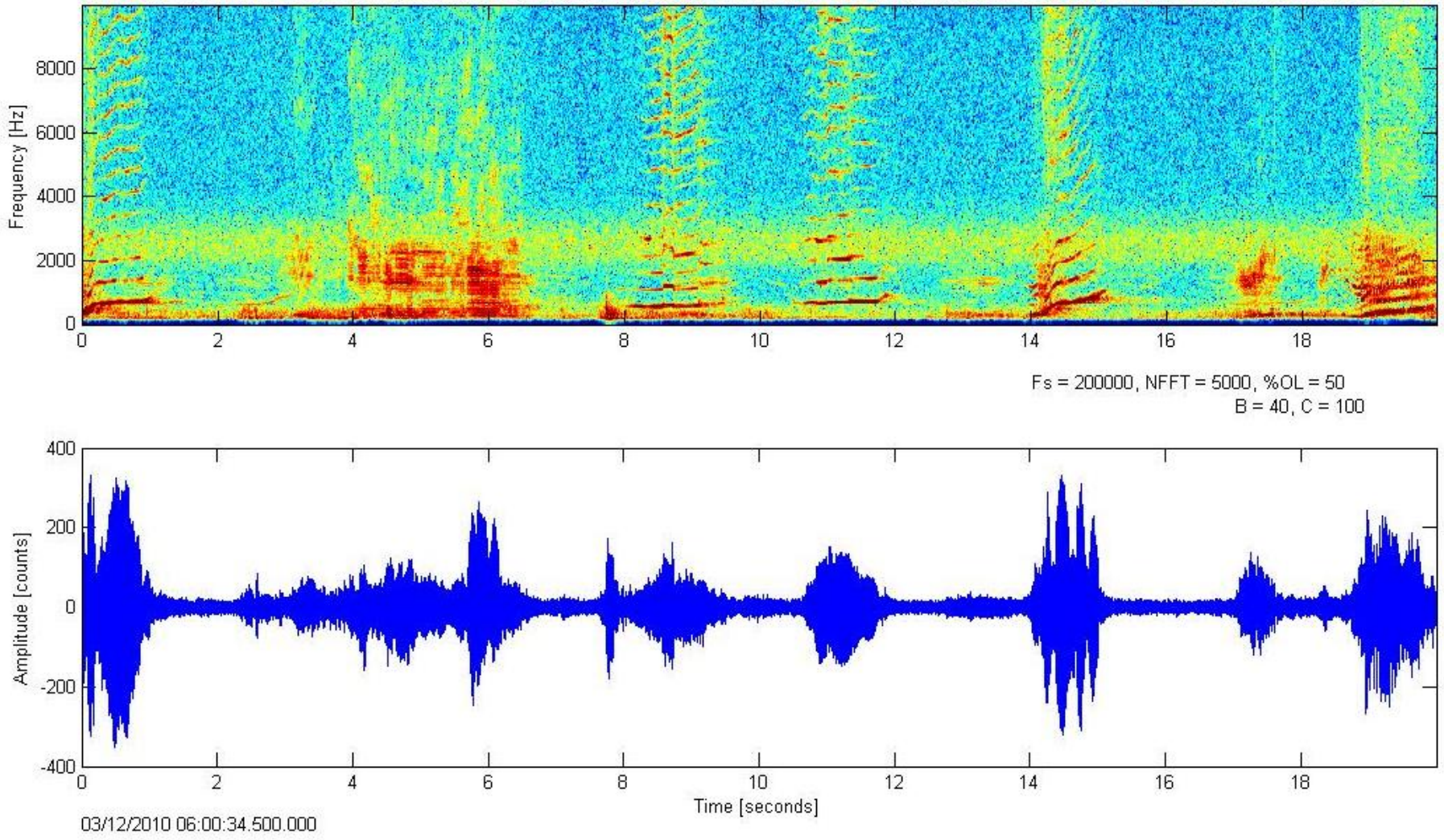
HARP Integration

- Electronics
  - low-power electronics (1/2W continuous data acquisition and 3W 20% duty cycle data storage),
  - high-speed data sampling (200 k Samples/s, 16-bit), 16 laptop disk drives (2TB),
  - and 12V batteries for self-contained power
  - repackaged the HARP electronics into a Wave Glider modular payload housing
- Hydrophone
  - Designed to be towed behind the Wave Glider: small cross-sectional area (25.4mm diameter) & small diameter (6.3mm) electro-mechanical cable
  - Consists of two transducers: Benthos AQ-1 cartridge for 10Hz - 2kHz &Sonar Research HS-150 for 2kHz - 100kHz.
  - Both are amplified and filtered with electronics inside the oil-filled hydrophone tube. Conditioned analog signals are digitized and stored to disk by the HARP data logger.



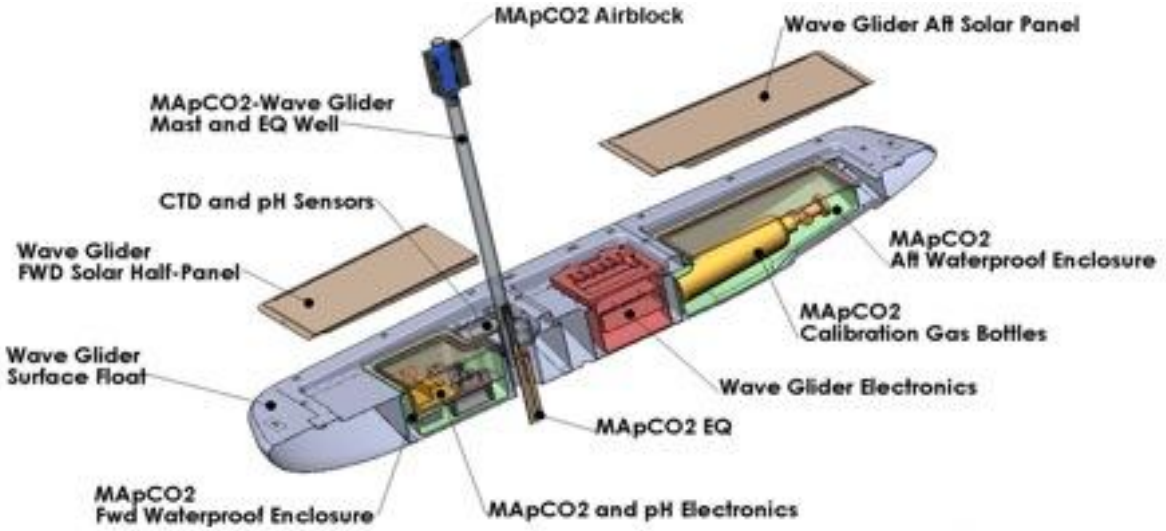


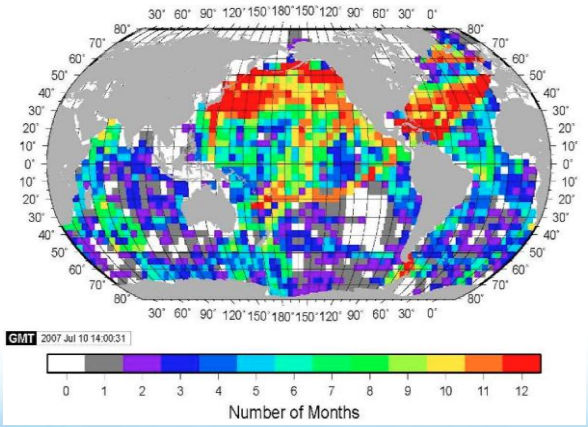
Humpback Recording



CO_2 Flux Monitoring (NOAA Sponsored Program)

- Collaboration with NOAA's Pacific Marine Environmental Laboratory
- Integrate bio-geo-chemical sensor suite on wave glider
- Deploy in Pacific Ocean
- Calibration and Evaluation
- Evaluate potential for long-term monitoring in South Pacific





Supplier	Sensor	Measurement	Calibrated Range & Accuracy
NOAA PMEL	$MAPCO_2$	pCO_2 SW & Air (ppm)	200 to 600 ± 3 (stable over ~year)
Scripps (Martz)	custom pH	SW Acidity (*p*H)	0 to 14 ± 0.01 (±0.005 stability ~wks)
Seabird Electronics	Glider Payload CTD	Conductivity (S/m)	0 to 6 ± 0.0003 (0 to 9 ± 0.0010)
		Temperature (°C)	1 to 32 ± 0.002 (-5 to +45 ± 0.010)
		Pressure (dbar)	0 to 100 ± 0.1% FS (same)
		Salinity (PSS 78)	0 to 35 ± 0.005 (0 to 45 ± 0.015)
WETLabs	ECO Triplet	Chlorophyll (µg/l)	0.01 to 50 (0.01) (470/695 nm)
		CDOM (ppb)	0.18 to 375 (0.18) (370/460 nm)
		Turbidity (NTU)	0 to 125 (0.02)

http://www.pmel.noaa.gov/co2/story/Carbon+Wave+Glider

Tsunami Warning Test Program

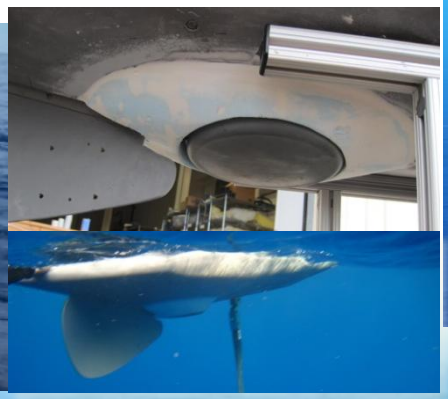
SAIC From Science to Solutions

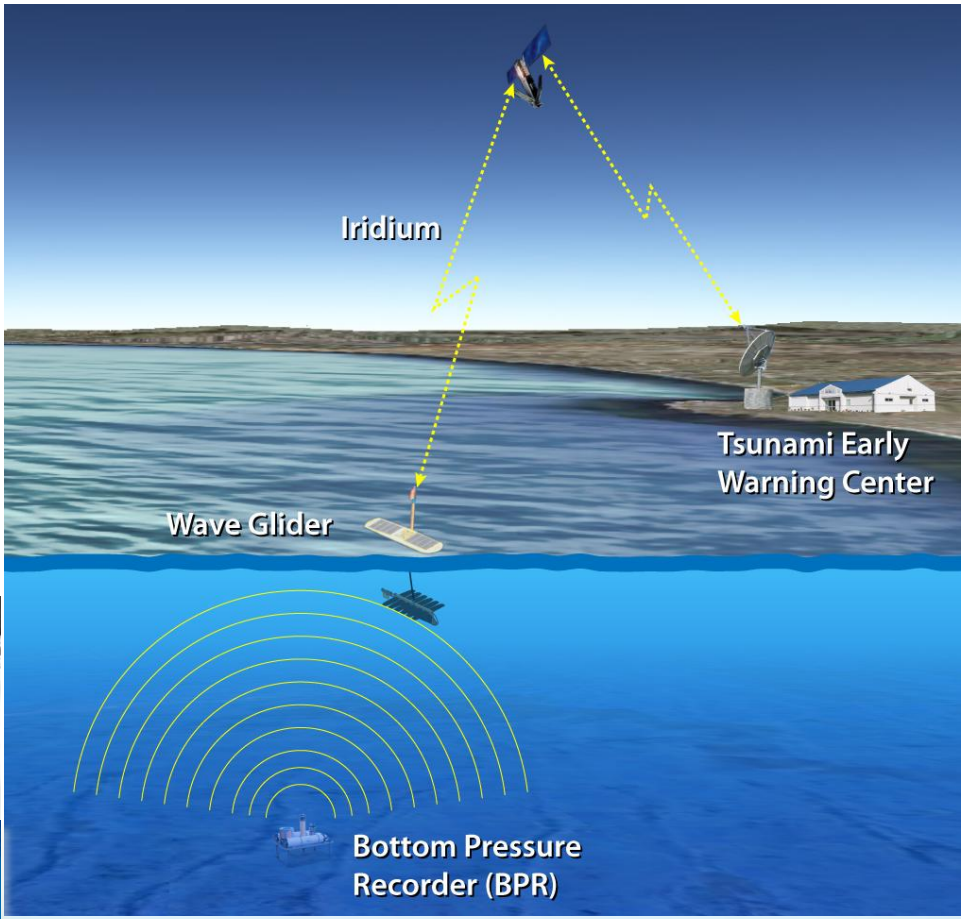
NOAA National Oceanic and Atmospheric Administration's National Data Buoy Center Center of Excellence in Marine Technology

liquid robotics

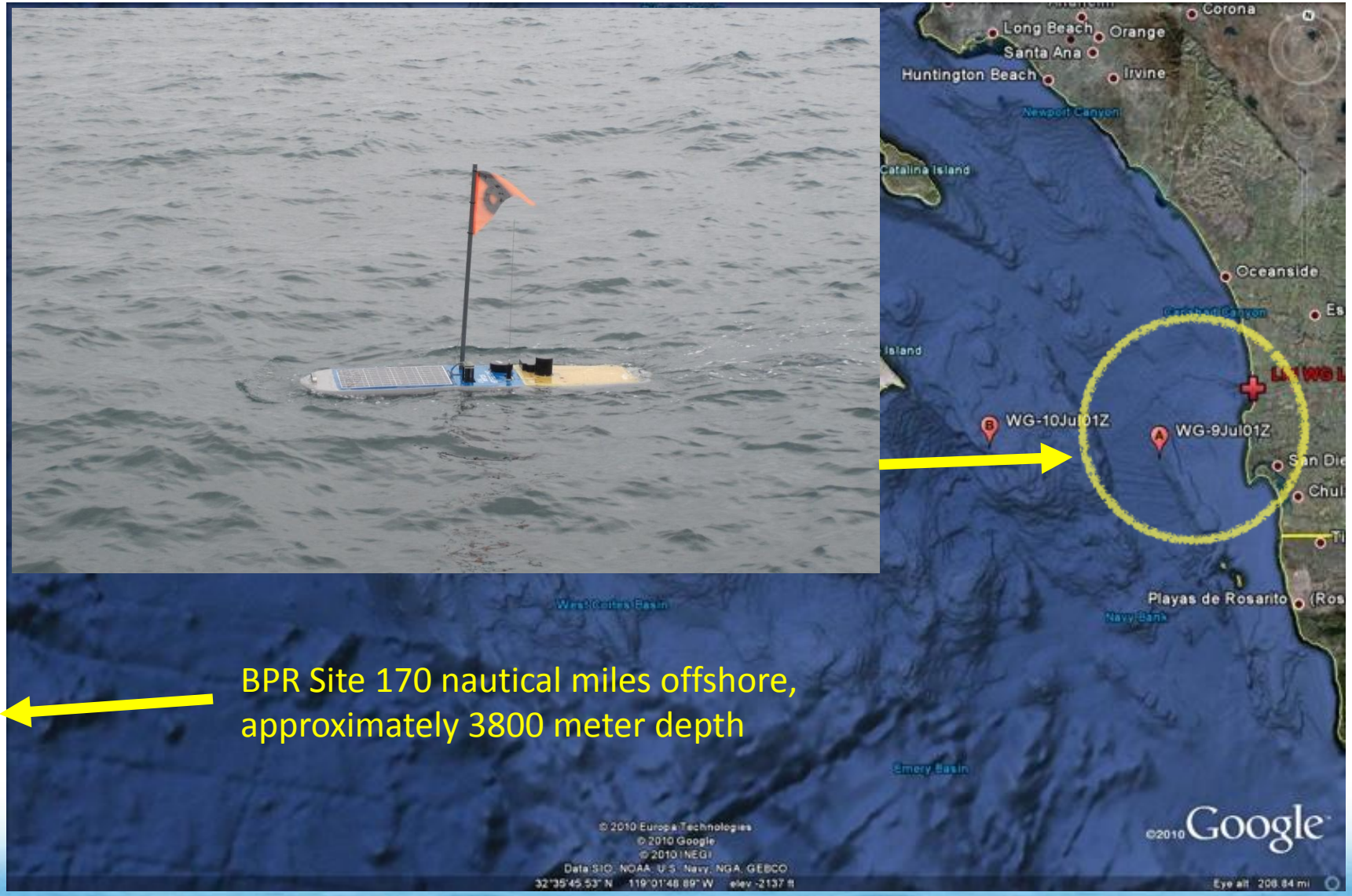
NOAA DART Buoy Test

- Provided redundant communications with bottom mounted sensor
- Trials off Kona, HI and San Diego, CA
- Station keeping functionality demonstrated
- Acoustic telemetry successfully demonstrated with 100% data return to DART servers ashore



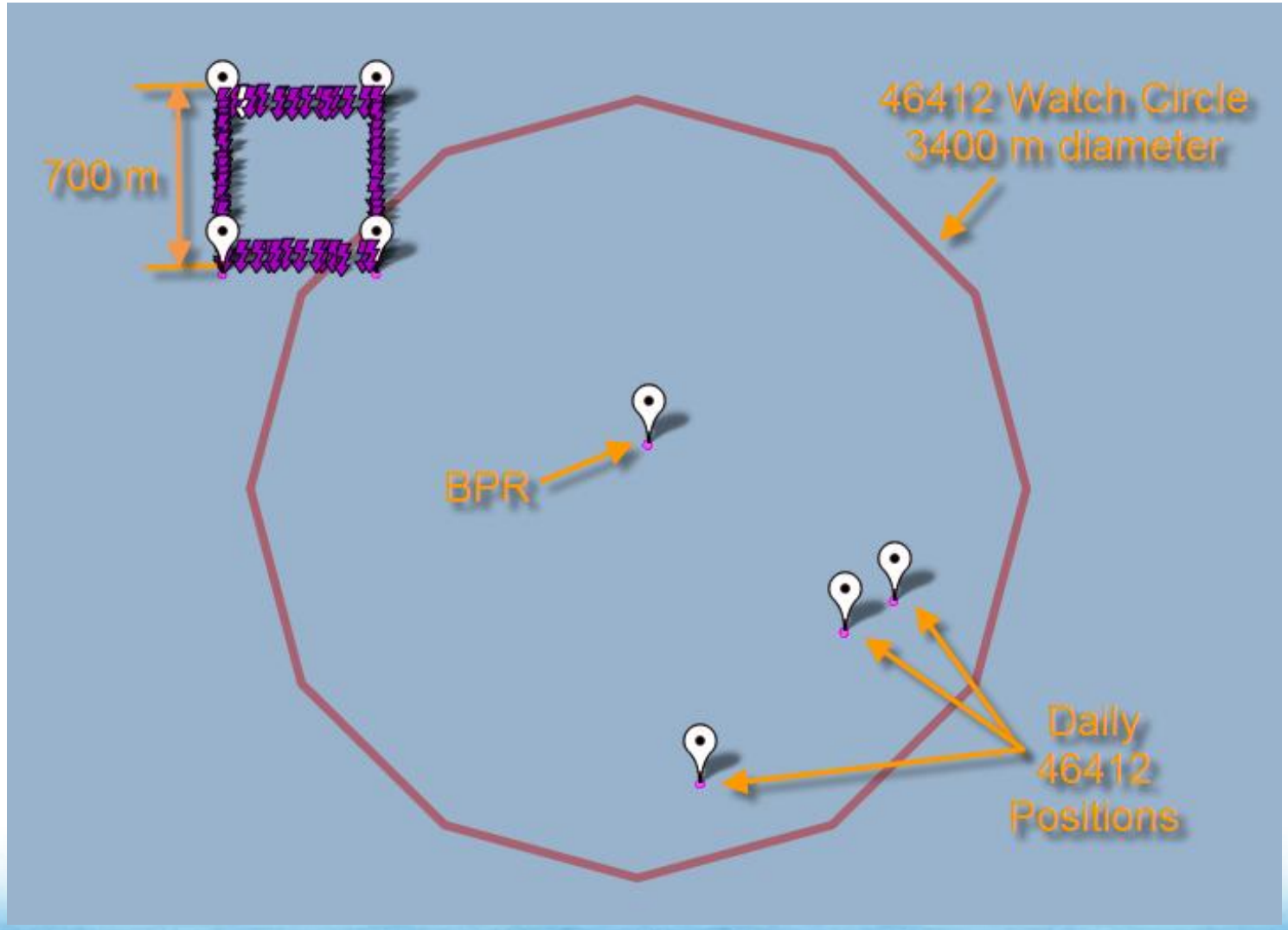


San Diego deployment, July 2010



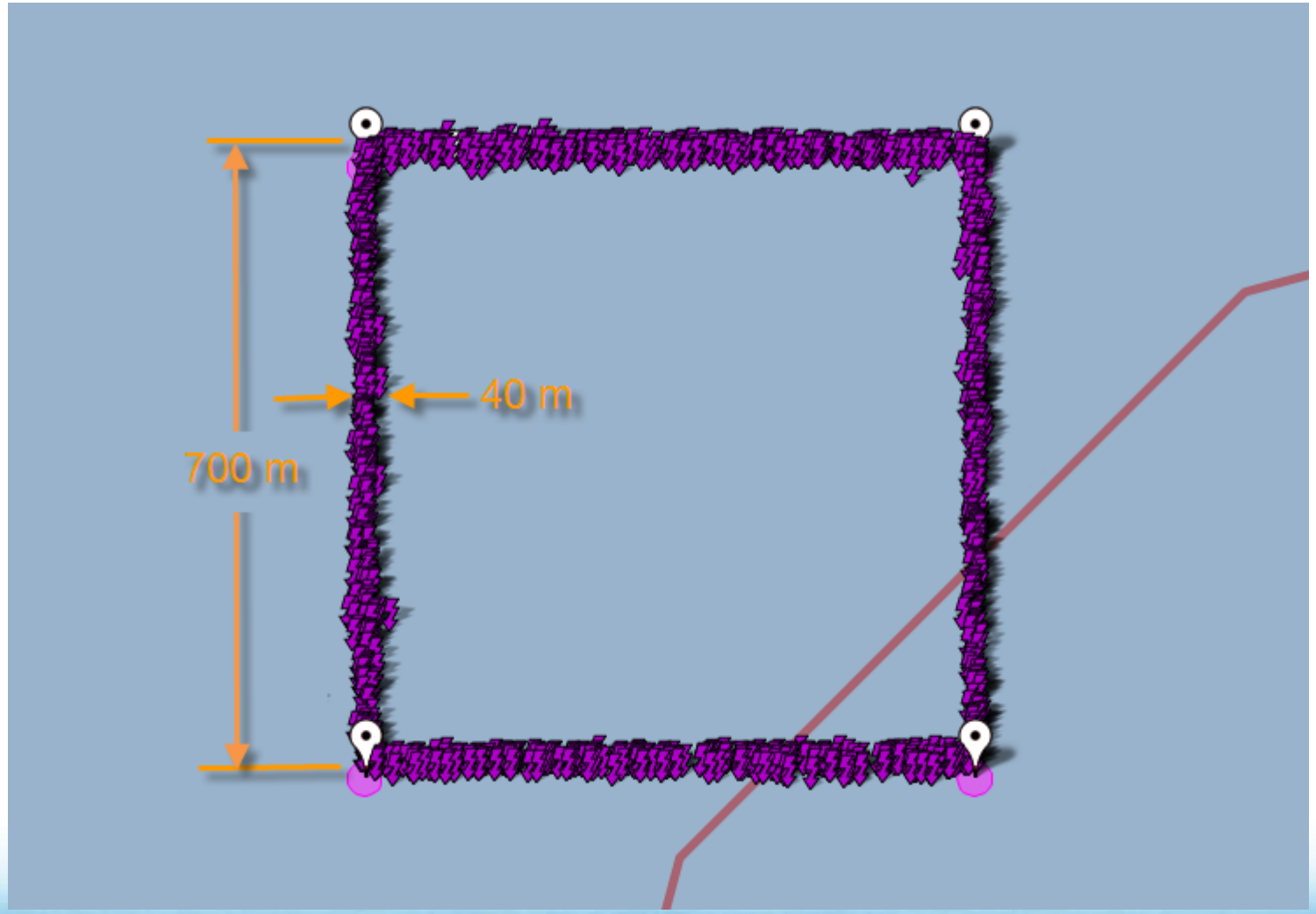
San Diego deployment, July 2010

Relative Positions, BPR, Buoy, Wave Glider



San Diego deployment, July 2010

Wave Glider Track (3 day sample)



San Diego deployment, July 2010

100% match buoy to Wave Glider over one week test period (sample data shown)

Wave Glider DART Payload

```
D$1I 07/24/2010 18:15:00 1444143 3717778 3717754 3717726 3717695  1* 32
D$1I 07/24/2010 19:15:00 1444143 3717665 3717628 3717597 3717565  1* 30
D$1I 07/24/2010 20:15:00 1444143 3717535 3717508 3717482 3717463  1* 3F
D$1I 07/24/2010 21:15:00 1444143 3717453 3717446 3717441 3717442  1* 38
D$1I 07/24/2010 22:15:00 1444143 3717453 3717469 3717494 3717524  1* 3F
D$1I 07/24/2010 23:15:00 1444143 3717559 3717601 3717650 3717700  1* 37

        D$0 07/25/2010 01:13:40 3227.7332 N 12034.5313 W 071* 40

D$1I 07/25/2010 00:15:00 1444143 3717754 3717812 3717875 3717943  1* 34
D$1I 07/25/2010 01:15:00 1444143 3718007 3718074 3718136 3718197  1* 33
D$1I 07/25/2010 02:15:00 1444143 3718256 3718308 3718356 3718398  1* 37
D$1I 07/25/2010 03:15:00 1444143 3718431 3718455 3718470 3718477  1* 3B
D$1I 07/25/2010 04:15:00 1444143 3718473 3718457 3718433 3718395  1* 34
D$1I 07/25/2010 05:15:00 1444143 3718352 3718299 3718237 3718164  1* 3B
                                D$MI
                    BATT 07/25/2010 01:19:00 24:00:00
                            11.37 0.00 0.01 0


D$1I 07/25/2010 06:15:00 1444143 3718085 3718002 3717910 3717818  1* 3D
D$1I 07/25/2010 07:15:00 1444143 3717722 3717624 3717523 3717425  1* 3A
D$1I 07/25/2010 08:15:00 1444143 3717327 3717233 3717140 3717054  1* 35
D$1I 07/25/2010 09:15:00 1444143 3716978 3716906 3716841 3716786  1* 39
D$1I 07/25/2010 10:15:00 1444143 3716738 3716706 3716676 3716661  1* 37
D$1I 07/25/2010 11:15:00 1444143 3716653 3716655 3716668 3716691  1* 3D


D$1I 07/25/2010 12:15:00 1444143 3716721 3716761 3716805 3716857  1* 3D
D$1I 07/25/2010 13:15:00 1444143 3716913 3716980 3717050 3717124  1* 37
D$1I 07/25/2010 14:15:00 1444143 3717195 3717270 3717342 3717417  1* 37
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D$1I 07/25/2010 16:15:00 1444143 3717715 3717754 3717788 3717814  1* 35
D$1I 07/25/2010 17:15:00 1444143 3717832 3717843 3717848 3717845  1* 30
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DART Buoy 46412

```
D$1I 07/24/2010 18:15:00 1444143 3717778 3717754 3717726 3717695  1* 32
D$1I 07/24/2010 19:15:00 1444143 3717665 3717628 3717597 3717565  1* 30
D$1I 07/24/2010 20:15:00 1444143 3717535 3717508 3717482 3717463  1* 3F
D$1I 07/24/2010 21:15:00 1444143 3717453 3717446 3717441 3717442  1* 38
D$1I 07/24/2010 22:15:00 1444143 3717453 3717469 3717494 3717524  1* 3F
D$1I 07/24/2010 23:15:00 1444143 3717559 3717601 3717650 3717700  1* 37

        D$0 07/25/2010 01:13:11 3227.6065 N 12033.3008 W 041* 4F

D$1I 07/25/2010 00:15:00 1444143 3717754 3717812 3717875 3717943  1* 34
D$1I 07/25/2010 01:15:00 1444143 3718007 3718074 3718136 3718197  1* 33
D$1I 07/25/2010 02:15:00 1444143 3718256 3718308 3718356 3718398  1* 37
D$1I 07/25/2010 03:15:00 1444143 3718431 3718455 3718470 3718477  1* 3B
D$1I 07/25/2010 04:15:00 1444143 3718473 3718457 3718433 3718395  1* 34
D$1I 07/25/2010 05:15:00 1444143 3718352 3718299 3718237 3718164  1* 3B
                                D$MI
                    BATT 07/25/2010 01:19:00 24:00:00
                            15.69 10.29 44.98


D$1I 07/25/2010 06:15:00 1444143 3718085 3718002 3717910 3717818  1* 3D
D$1I 07/25/2010 07:15:00 1444143 3717722 3717624 3717523 3717425  1* 3A
D$1I 07/25/2010 08:15:00 1444143 3717327 3717233 3717140 3717054  1* 35
D$1I 07/25/2010 09:15:00 1444143 3716978 3716906 3716841 3716786  1* 39
D$1I 07/25/2010 10:15:00 1444143 3716738 3716706 3716676 3716661  1* 37
D$1I 07/25/2010 11:15:00 1444143 3716653 3716655 3716668 3716691  1* 3D

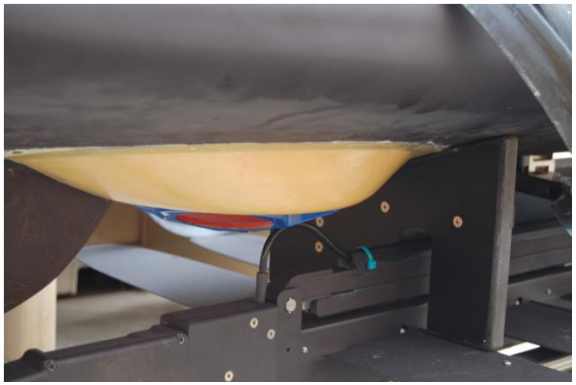

D$1I 07/25/2010 12:15:00 1444143 3716721 3716761 3716805 3716857  1* 3D
D$1I 07/25/2010 13:15:00 1444143 3716913 3716980 3717050 3717124  1* 37
D$1I 07/25/2010 14:15:00 1444143 3717195 3717270 3717342 3717417  1* 37
D$1I 07/25/2010 15:15:00 1444143 3717489 3717549 3717610 3717666  1* 35
D$1I 07/25/2010 16:15:00 1444143 3717715 3717754 3717788 3717814  1* 35
D$1I 07/25/2010 17:15:00 1444143 3717832 3717843 3717848 3717845  1* 30
```


From Science to Solutions

Measuring Currents with a Teledyne RDI Workhorse ADCP

- Standard COTS Teledyne RDI product
- Direct-Reading 1200, 600, 300 kHz ADCP
  - 18m, 60m, 110m typical current profiling range
- Custom physical integration with WG
- Power supplied by Wave Glider solar panel recharged core batteries
- Wave Glider motion compensation
- Ensembles delivered to shore in RDI PD0 format
- Persistent on-board storage of raw data
- Fully configurable while on mission
- Customizable on-board processing

Wave Glider ready for pier launch



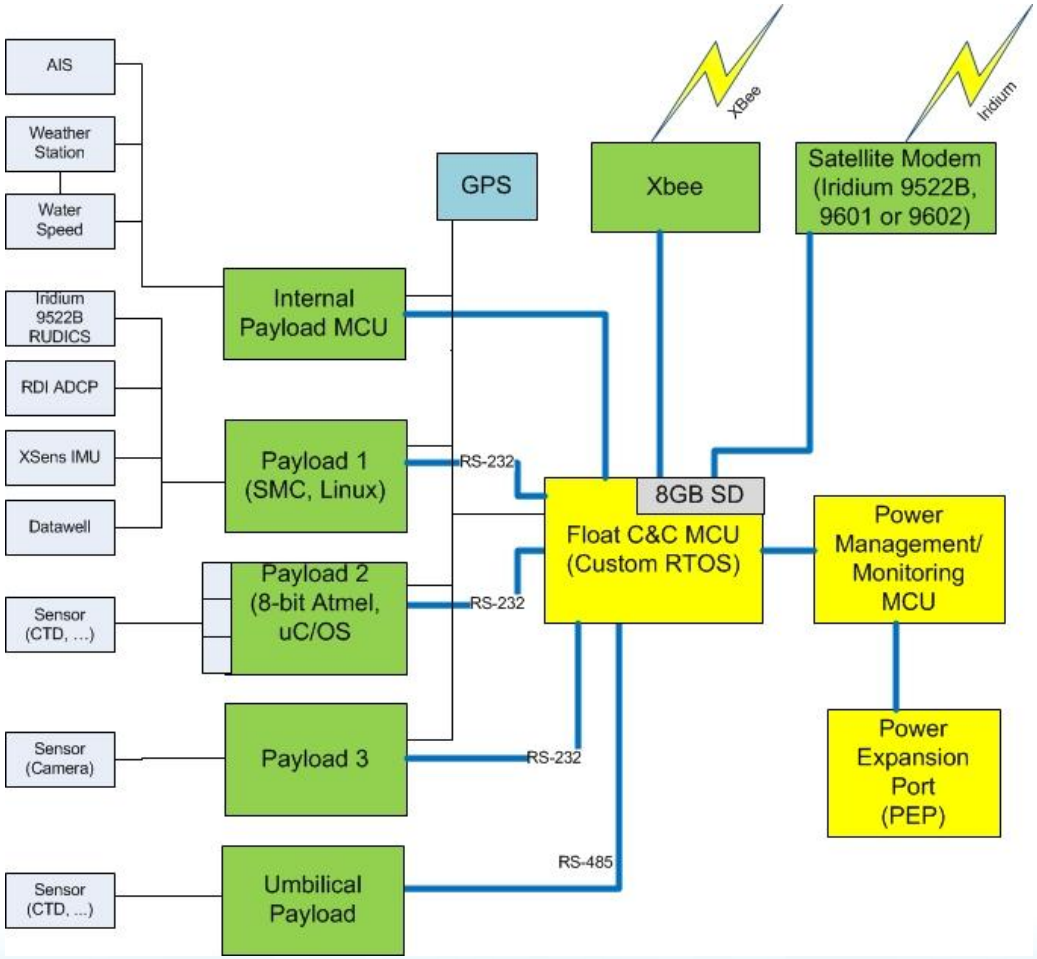
ADCP integrated into Wave Glider Float hull

In-Water

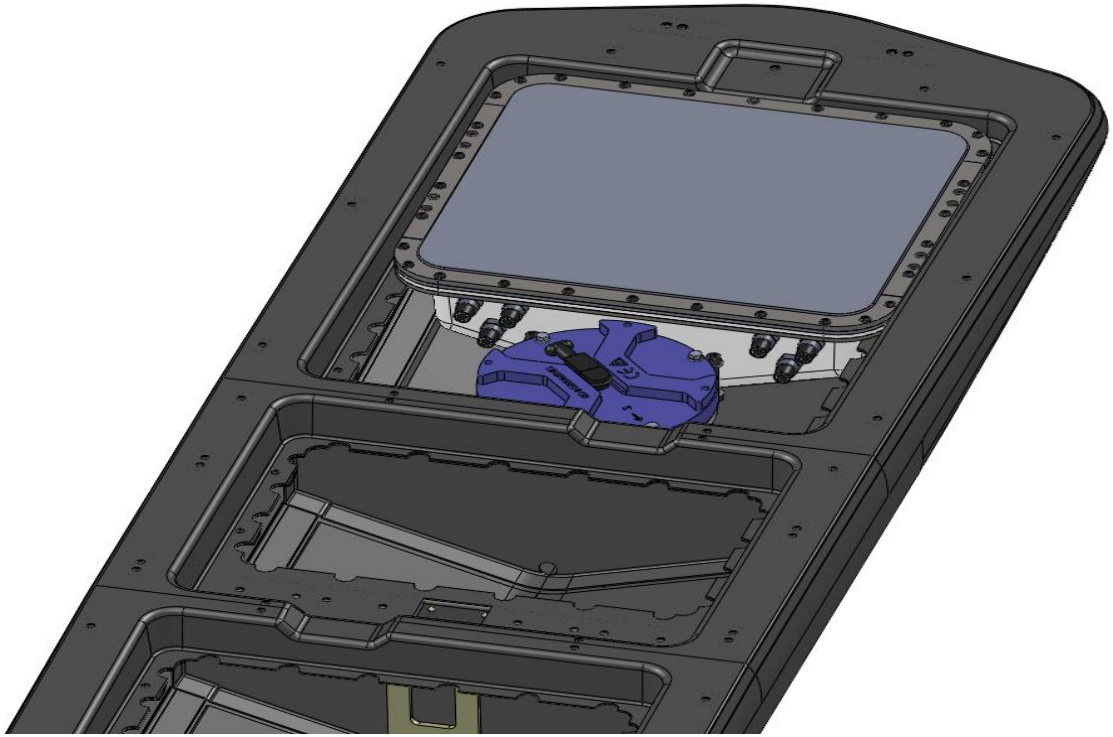
Recovery of Wave Glider at Scripps Pier

•Wave Glider with integrated Teledyne RDI Workhorse 600kHz ADCP deployed from Scripps Pier July 9th 2010

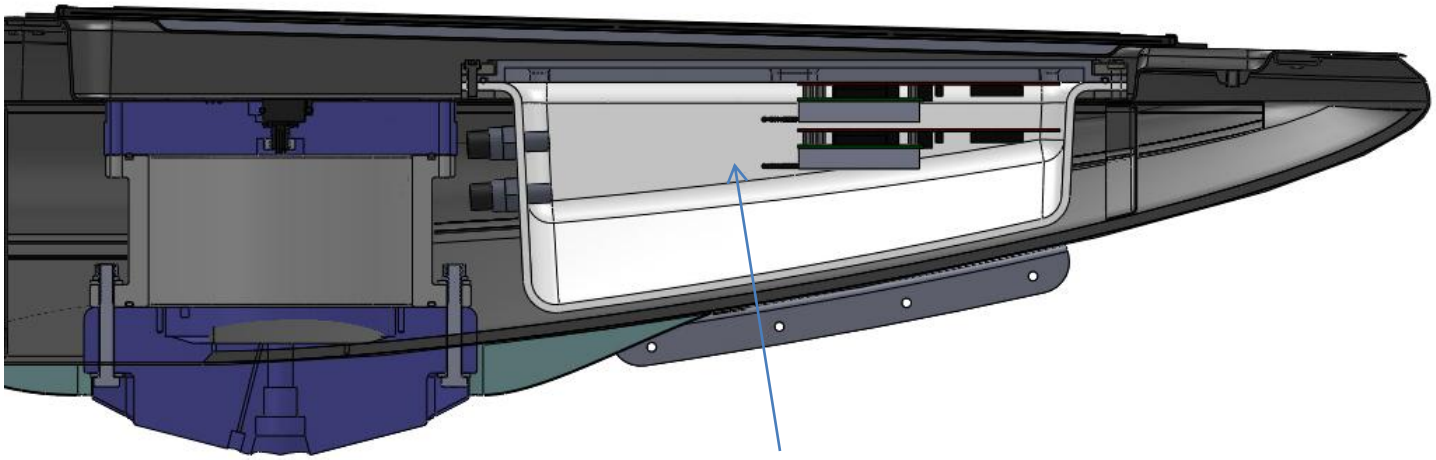
System Architecture



Float Layout



Cutaway Float Layout

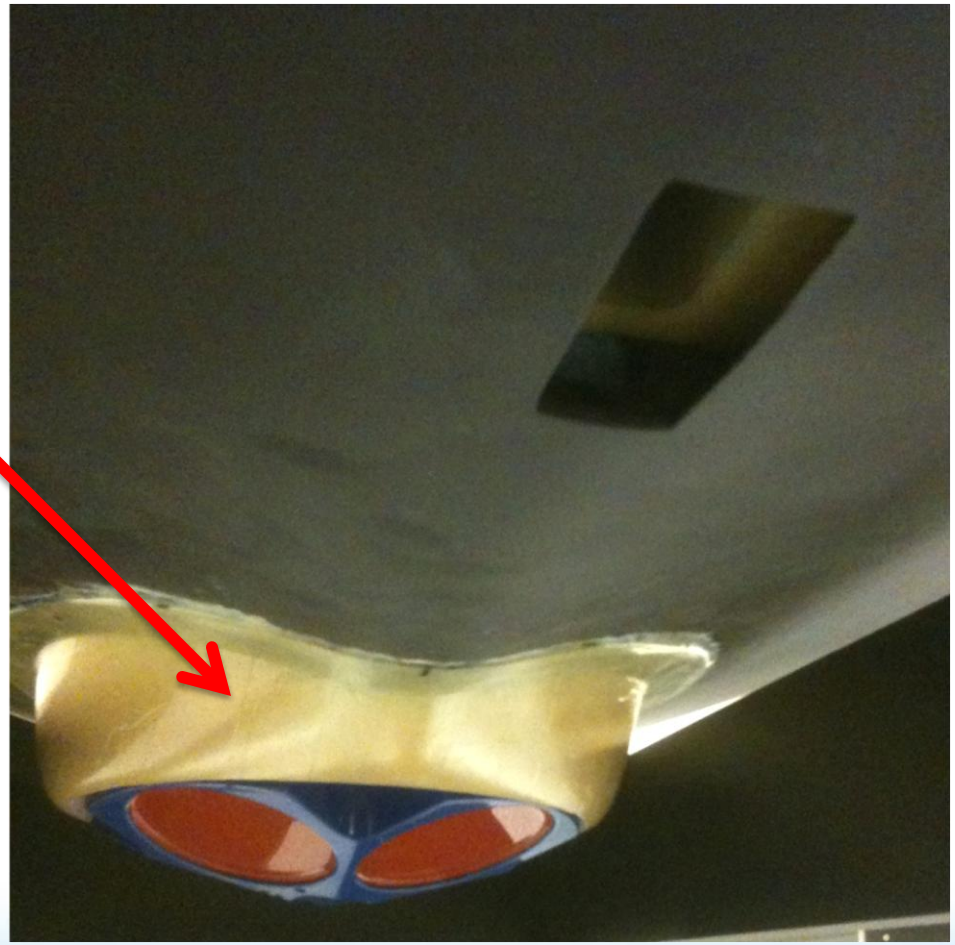


ADCP

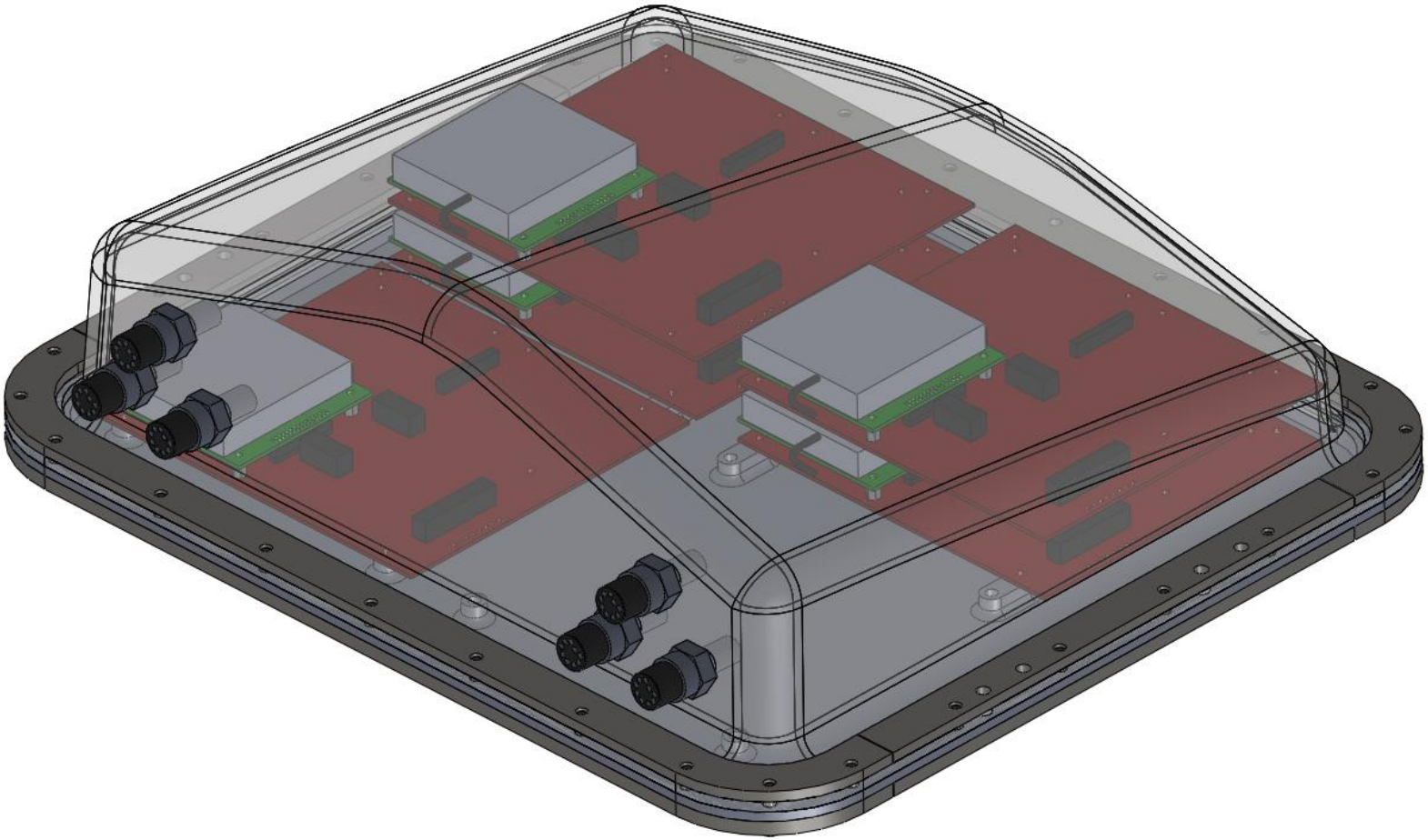
Aft Electronics
- SMC
- Iridium 9522B
- Other sensor electronics

Teledyne RDI Workhorse ADCP

Shows transducer mounted on bottom of float

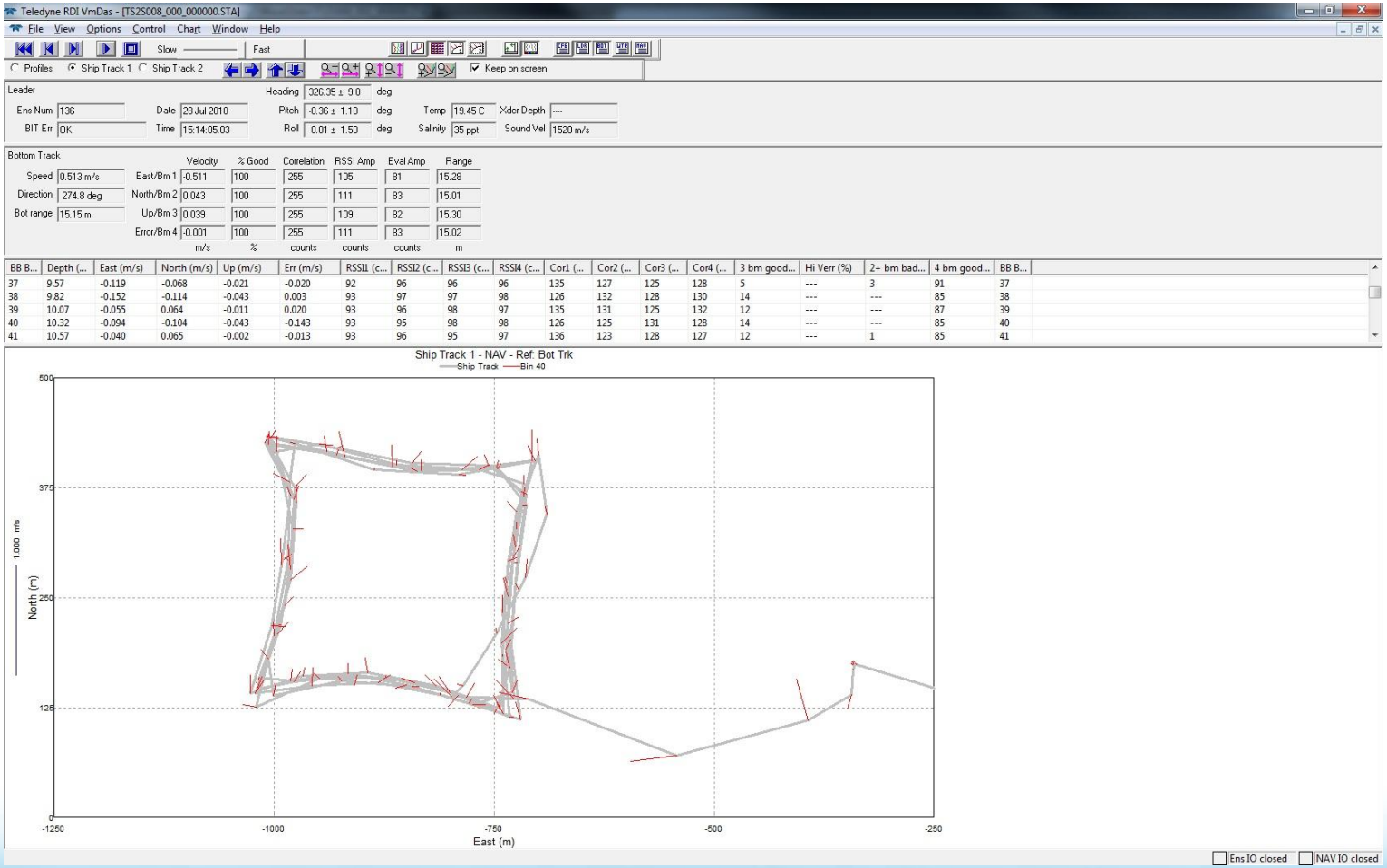


Sensor Electronics Bay



Inshore Wave Glider Track (A) & a co-located bottom mounted ADCP (B)

ADCP bottom track course

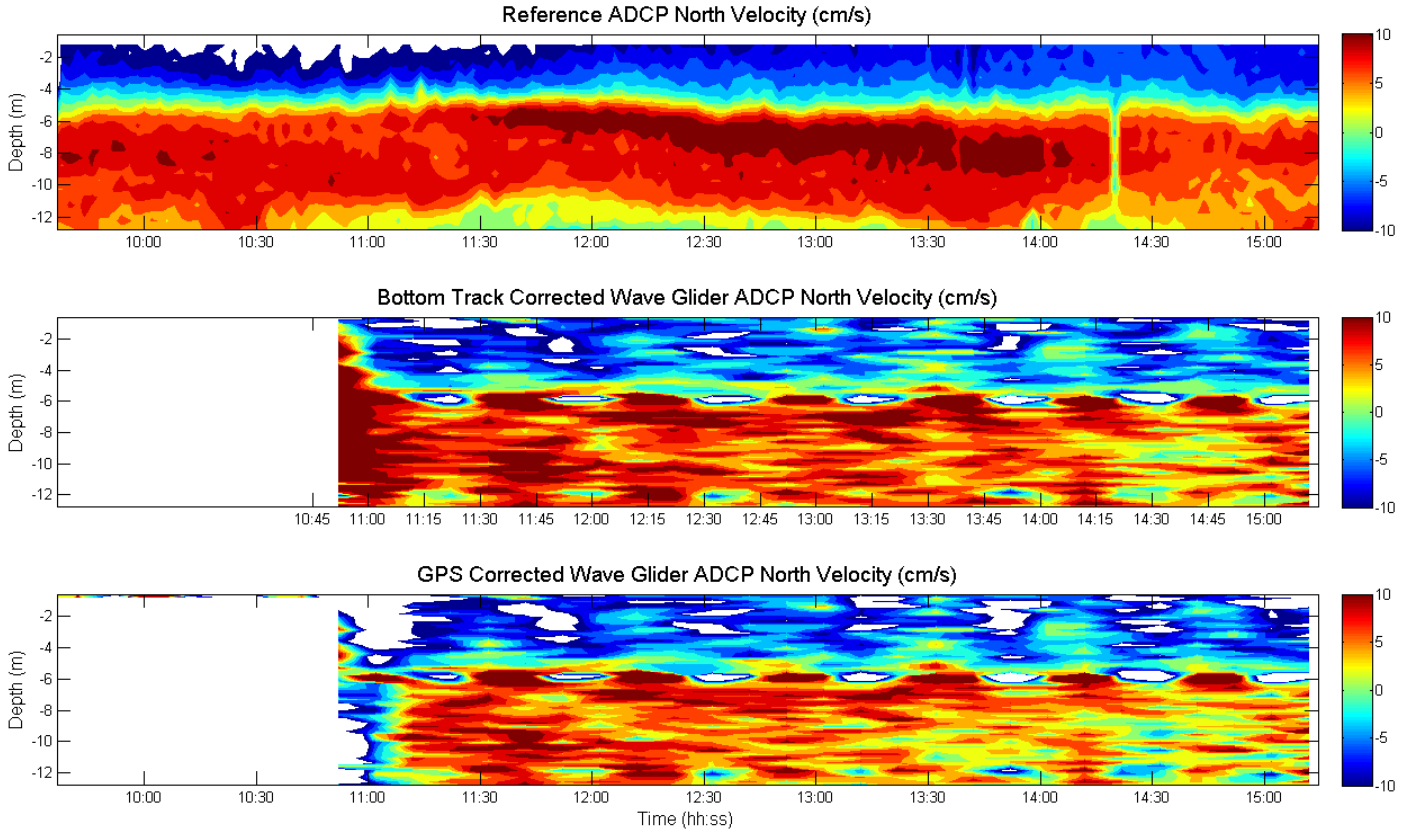


Comparison of the bottom mounted ADCP current profile (A) and the Wave Glider ADCP current profiles – (B) ADCP Bottom Track reference & (C) ADCP GPS reference

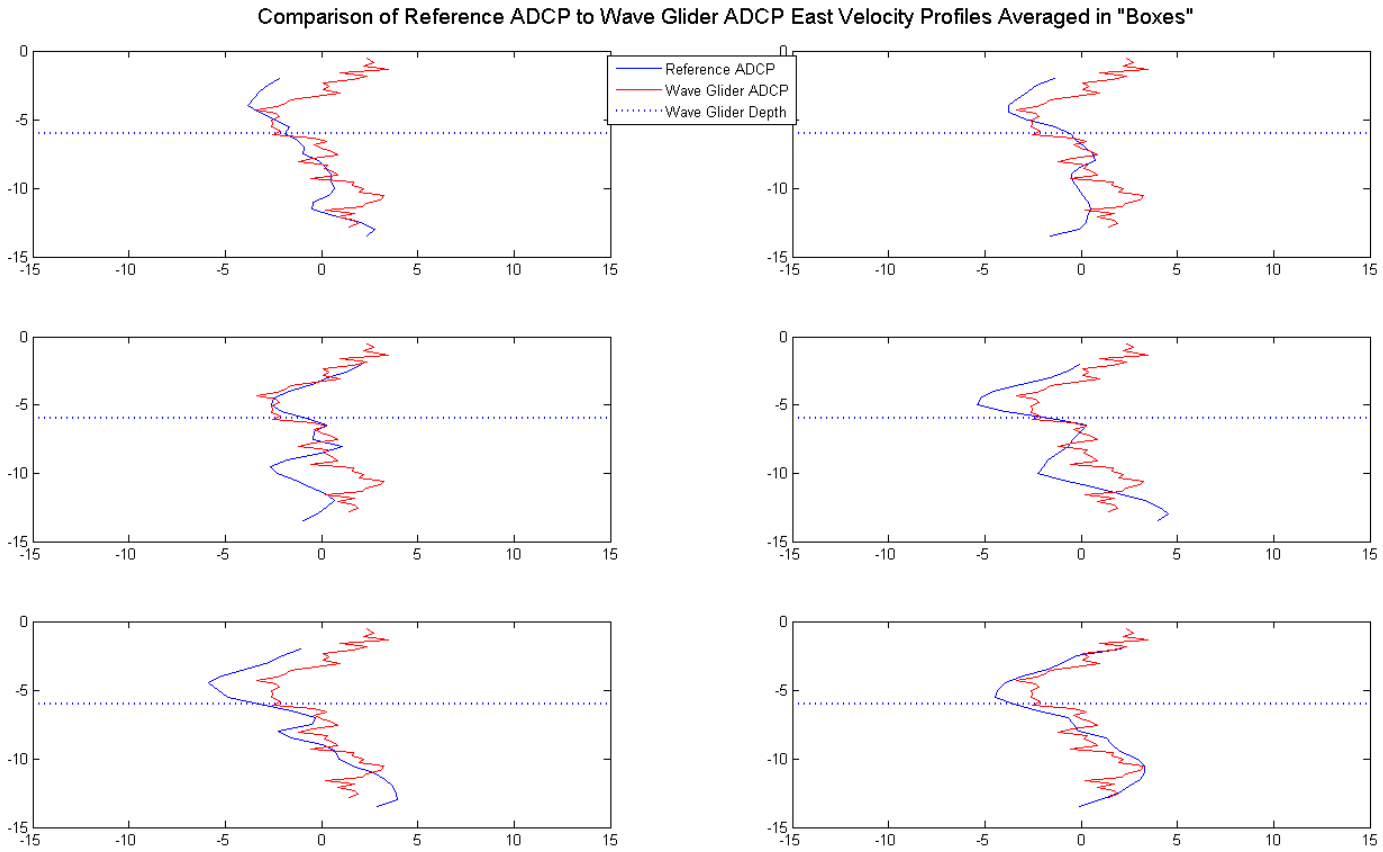
(A)

(B)

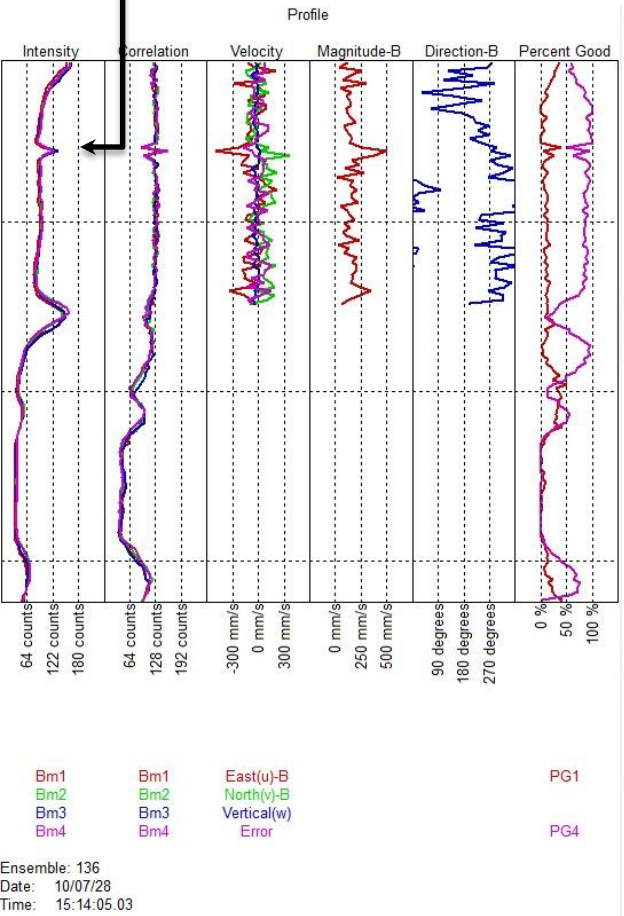
(C)

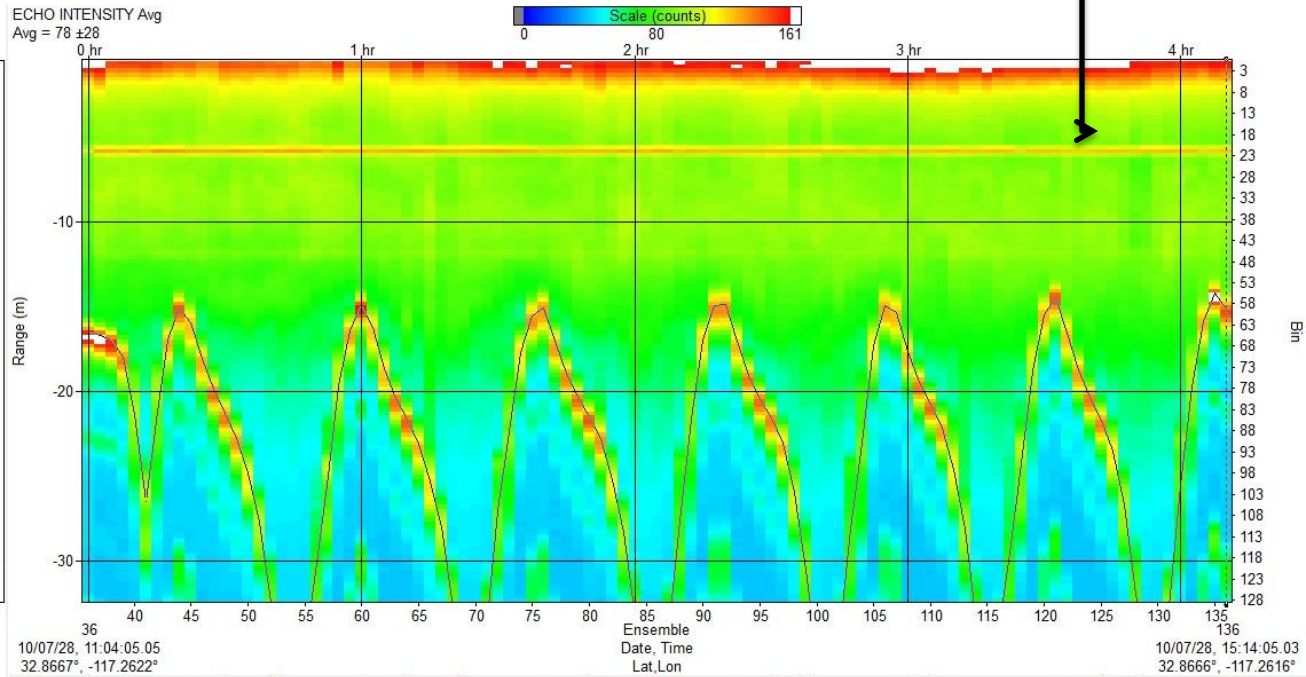


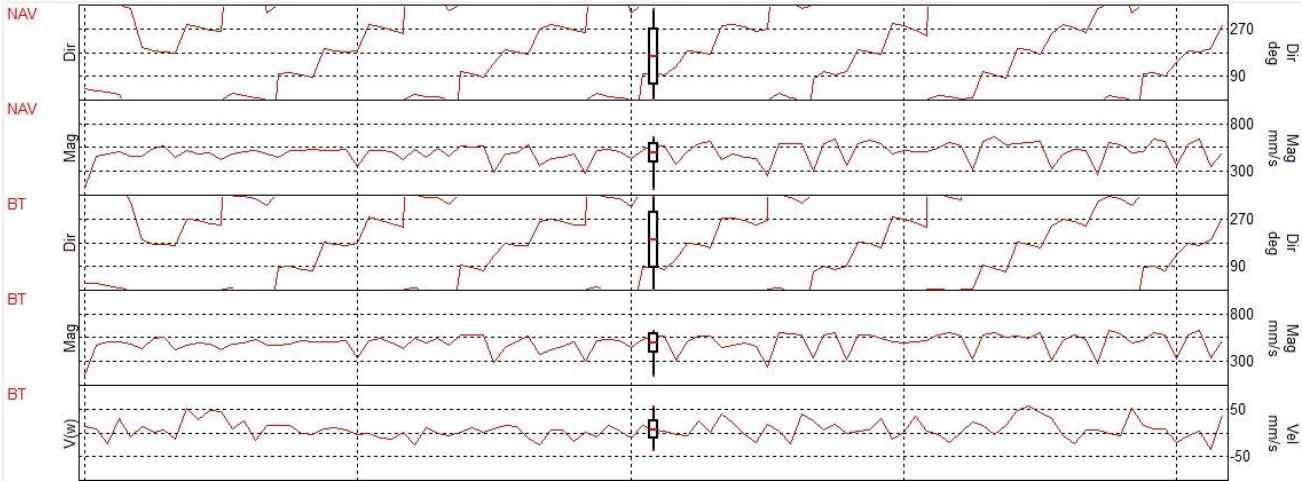
Comparison of Reference ADCP E-W profiles (blue) to Wave Glider ADCP E-W profiles (red)



Wave Glider ADCP Echo Intensity profile.
Note the effect of the Wave Glider Wing at the 7M depth

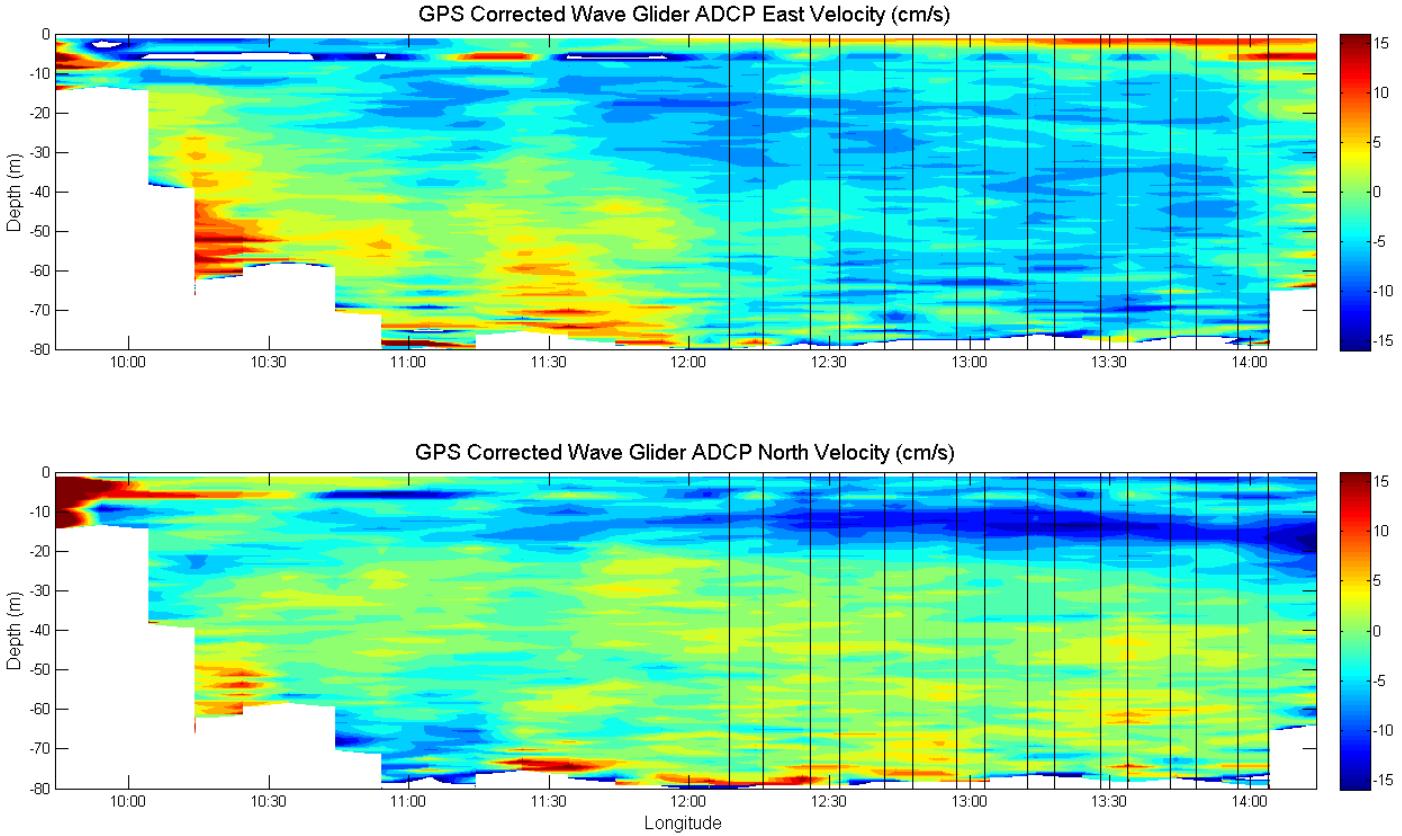




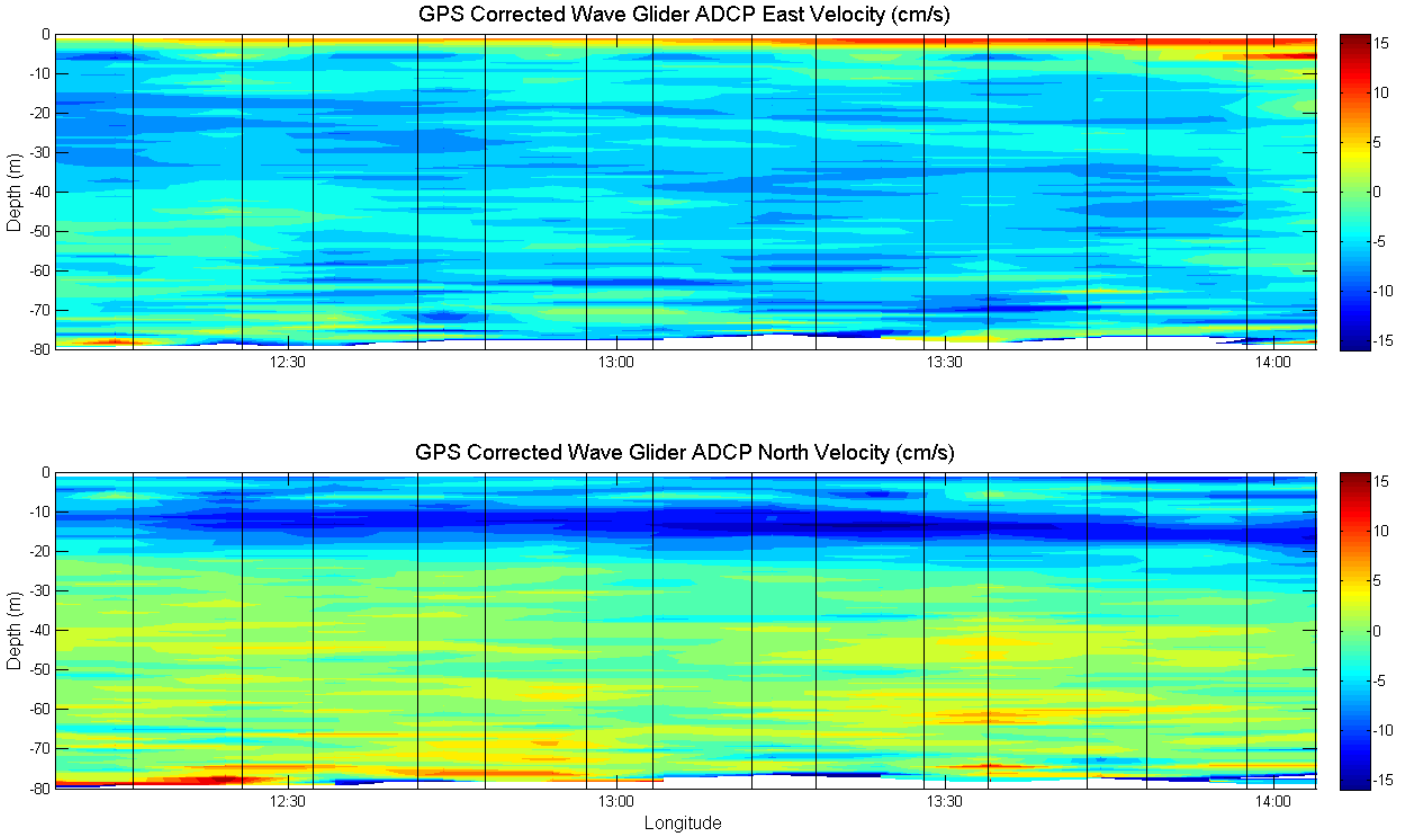


Deep water track to trial the ADCP performance outside of bottom track range – the Wave Glider GPS is the default reference used to resolve the ADCP measurements.

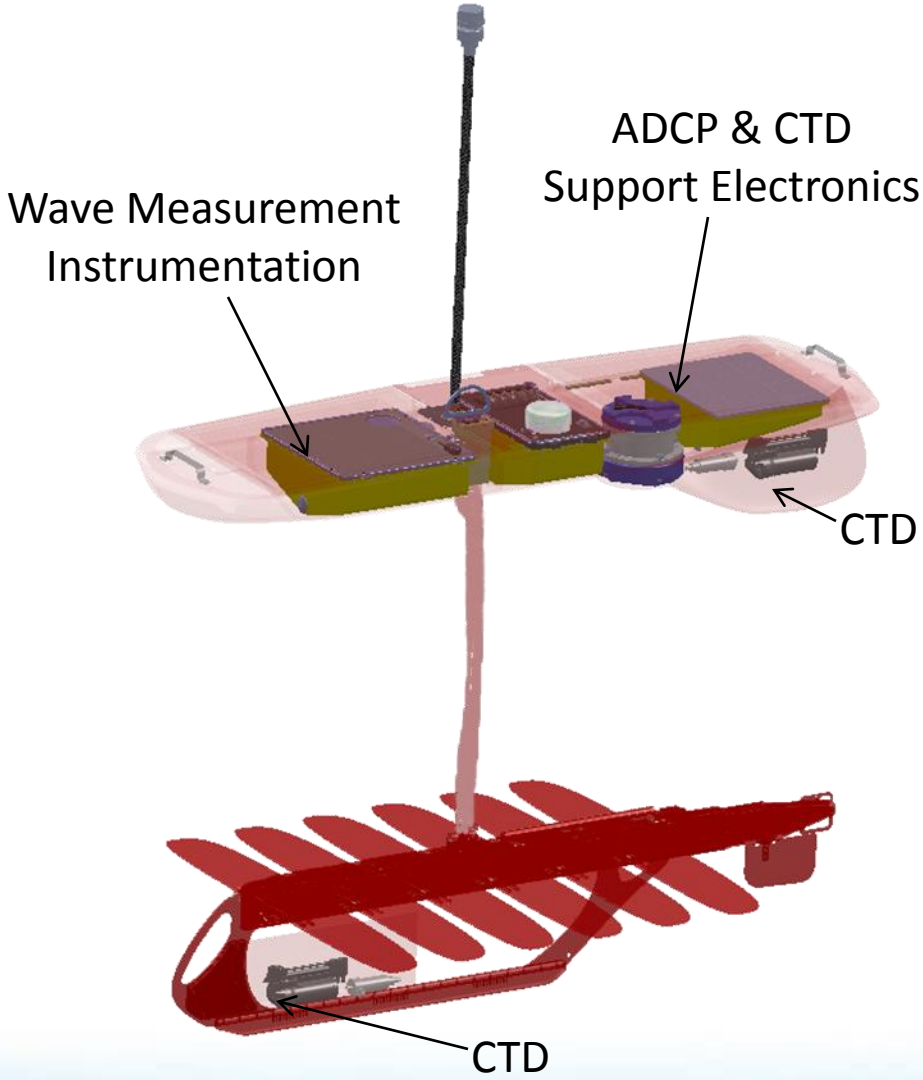
Transition from Bottom Tracking reference to GPS reference

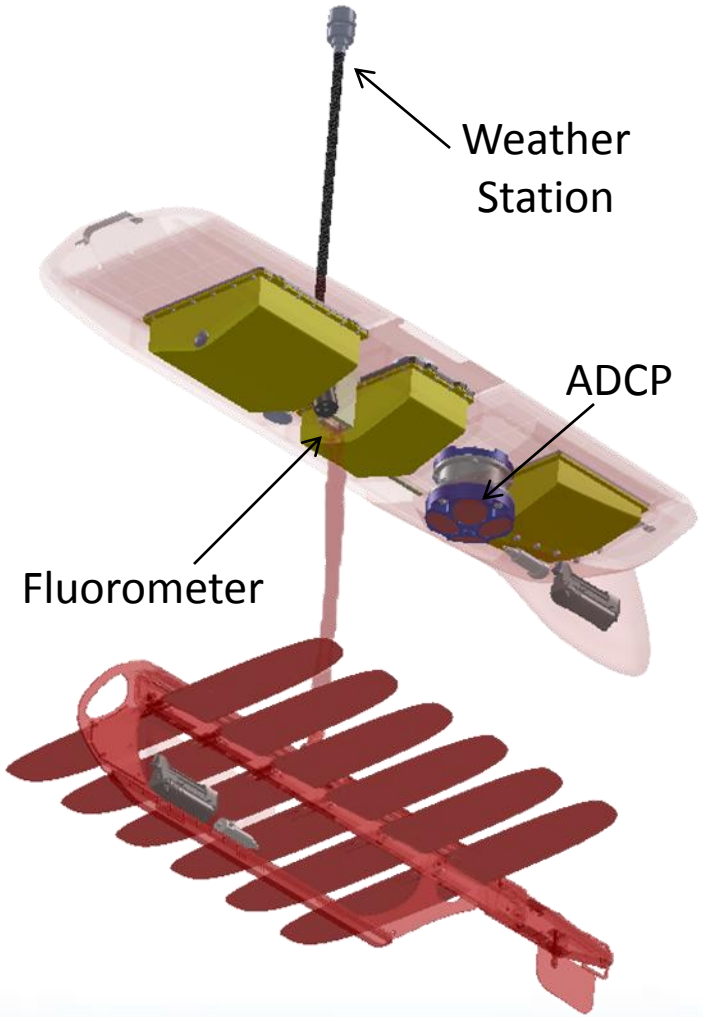


Transition from Bottom Tracking reference to GPS reference



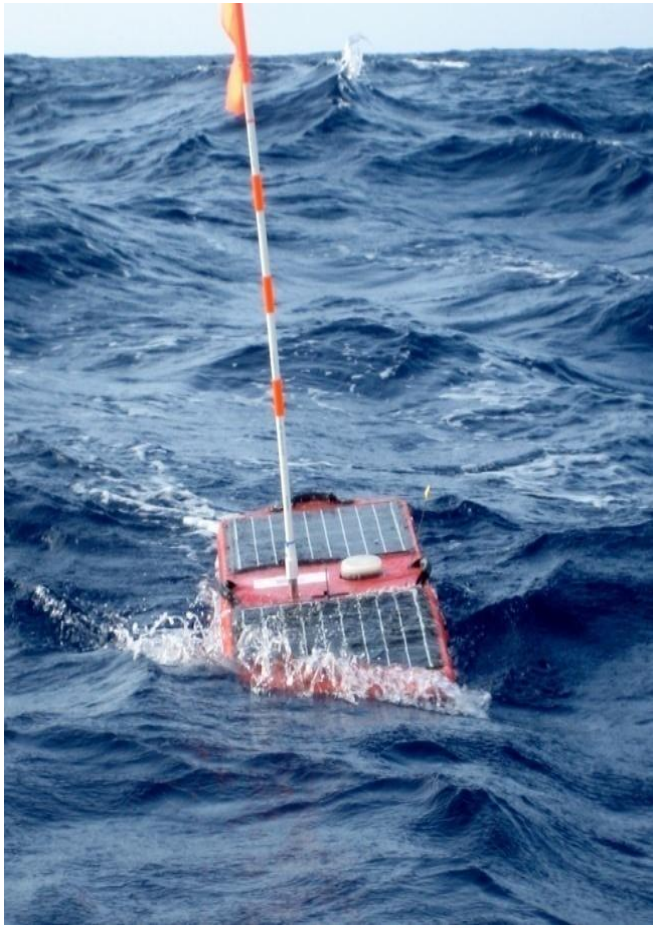
METOC Wave Glider, in development as a standard offering





The Wave Glider
a “game changing” technology

- Unique Two Part Vehicle:
  - Converts wave motion into thrust
  - Calm and rough seas
  - Thrust generation increases with sea state
  - Long mission durations possible
- Both a Buoy and a Vehicle
  - Travel to operation area
  - Return for maintenance
  - Patrol, survey or hold station
- Sensor integration to date
  - Meteorology
  - Water Quality (CTD, Fluorometry)
  - Passive Acoustic & Acoustic “Gateway”
  - Current Profiling & Bathymetry



Thank You

Looking forward to feedback, discussions and collaboration . . .

Contact: Neil Trenaman, Vice President of International Business
+1-760-484-3670, neil.trenaman@liquidr.com