

# Wave Glider™

Autonomous Ocean Vehicle

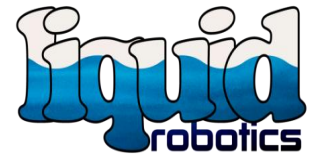


## The Wave Glider: A Mobile Buoy Concept for Ocean Science

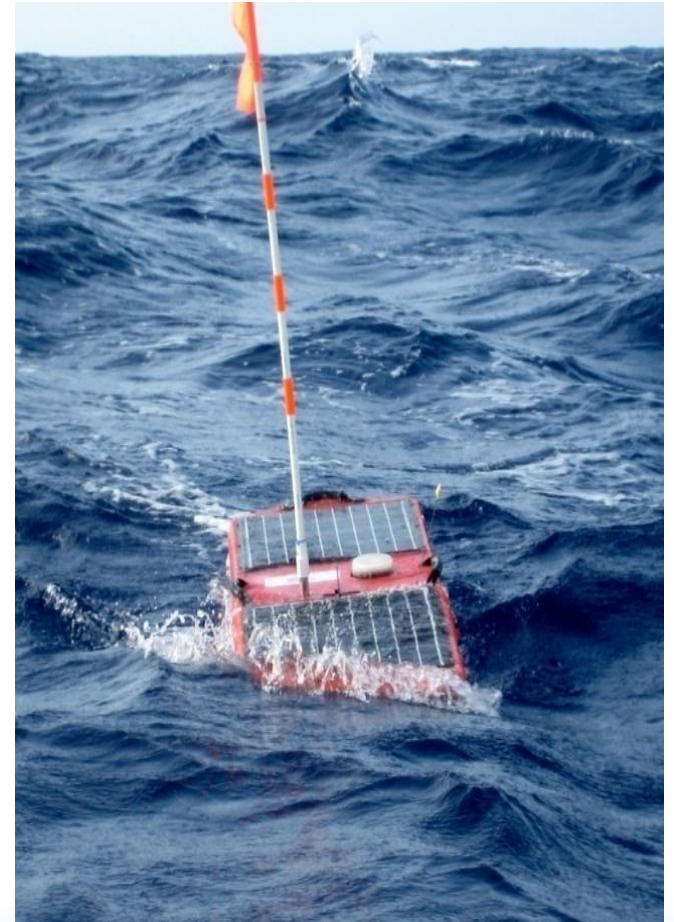
J. Manley & T. Richardson: Liquid Robotics Inc.  
DBCP XXV – Paris – September 28, 2009



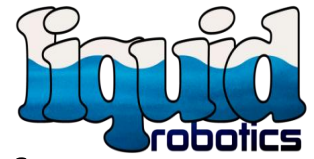
# Wave Glider Overview



- 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
- It's Real:
  - Existing fleet has traveled over 42,000 nmi
  - Duration of longest mission, over 9 months
  - Science applications demonstrated

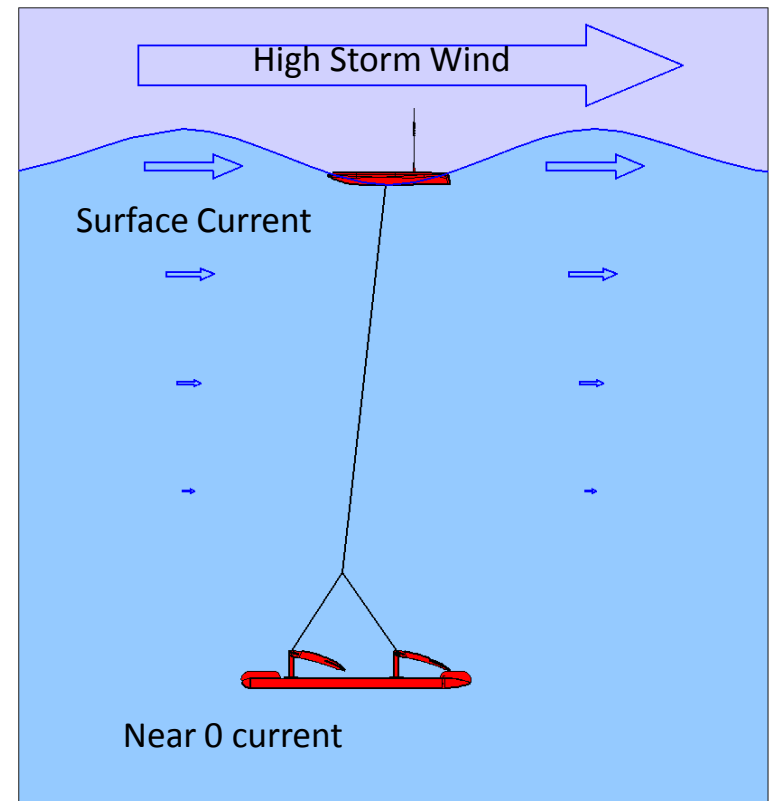
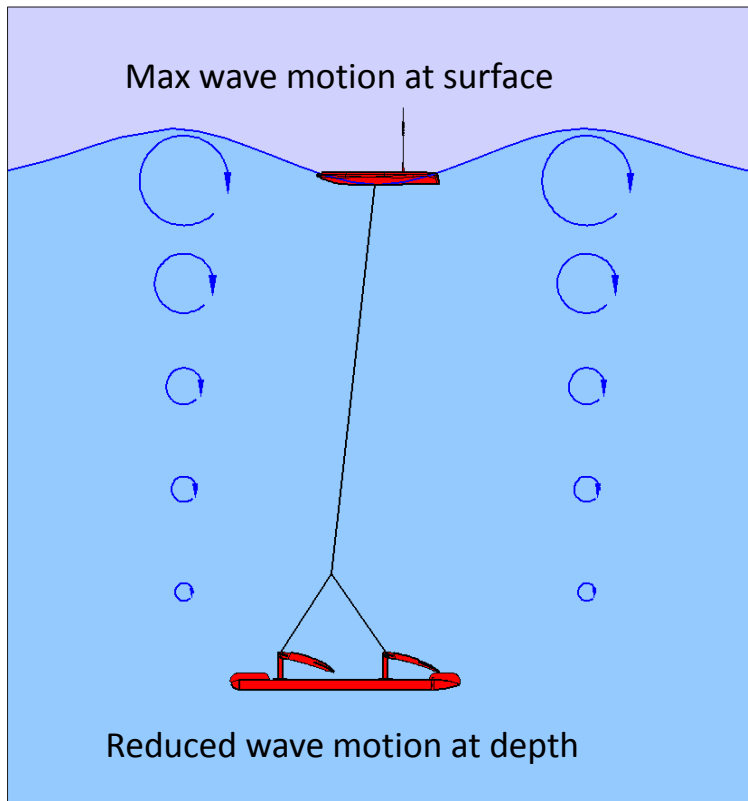


# Wave Glider Operating Principle



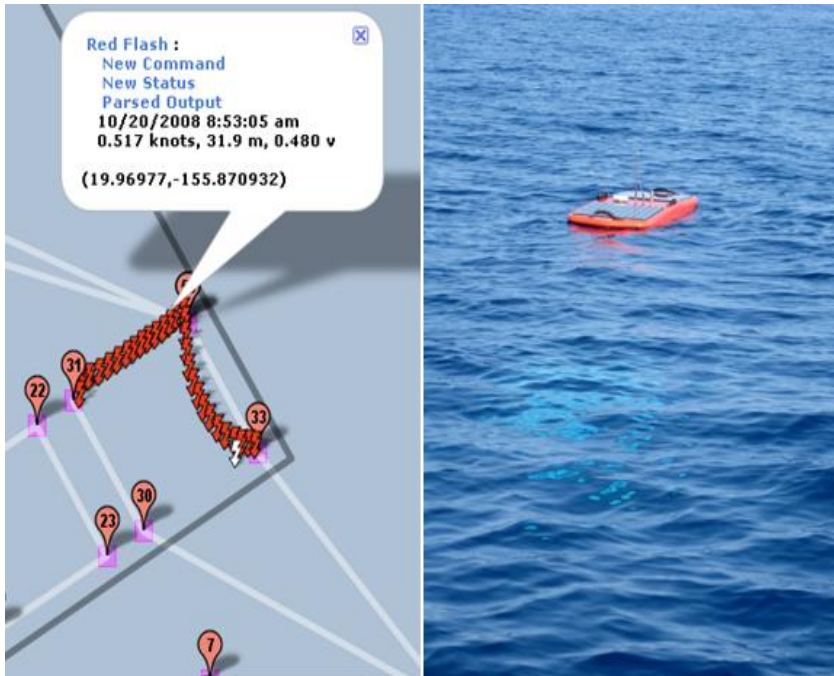
Glider Wings Convert Wave Motion To Thrust

Glider is Protected from Surface Effects

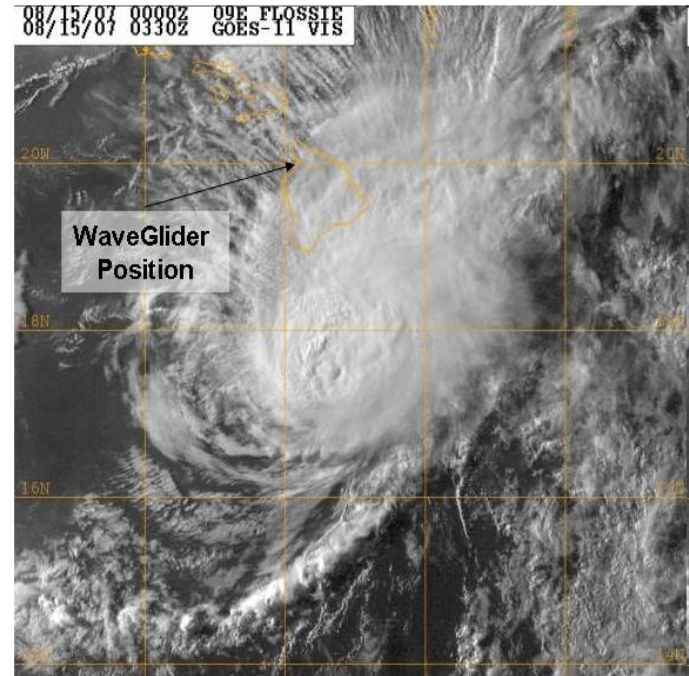


Passive float is towed by the submerged glider.

# Operational in range of conditions



Sea State 0: ½ knot speed



Edge of Hurricane Flossy:  
1 knot into 40-50 knot head winds

**In typical sea conditions, Wave Glider makes 1.0 to 1.5 knots, independent of wave direction. Wave Glider maintains 0.25 to 0.50 knot headway under very calm conditions.**

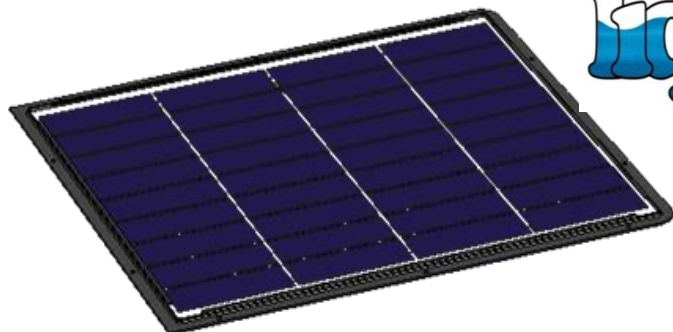
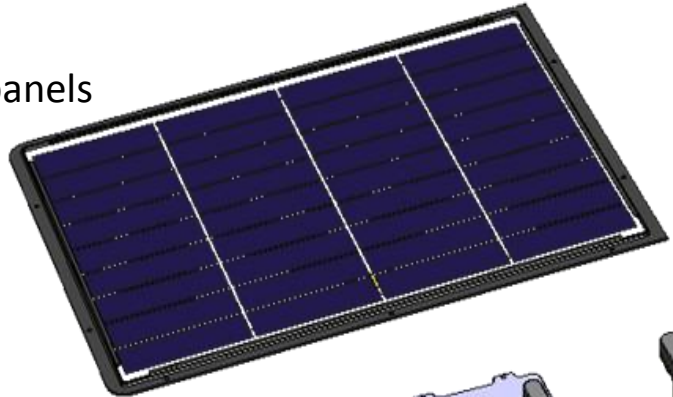
# Proven Capability

<b>Wave Glider Testing Milestones and Statistics</b>	
Cumulative Mission Time	1906 days (~5.2 years)
Cumulative Mission Miles	>42,100 nmi
Longest Single Mission Endurance (so far)	247 days, as of 8/21/09
Longest Single Mission Distance (so far)	2150 nmi, as of 8/21/09
Cumulative Miles on a Single Vehicle (so far)	6200 nmi, as of 8/21/09
Max. Sustained Sea State for Vehicle Operations	SS6: 15+ ft seas, 40+ kt winds

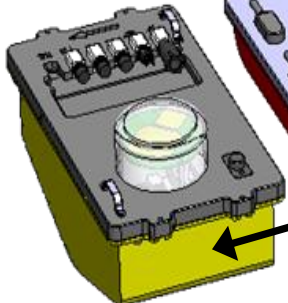


# Configurable Float (2.1 x 0.6m)

Ruggedized  
COTS solar panels



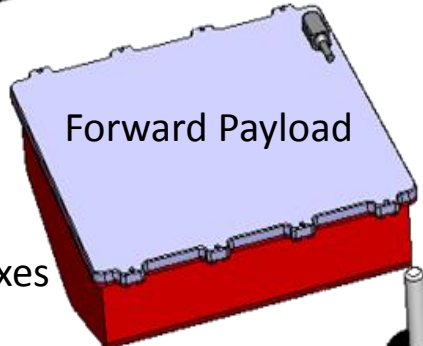
Core Electronics  
Module



Aft Payload



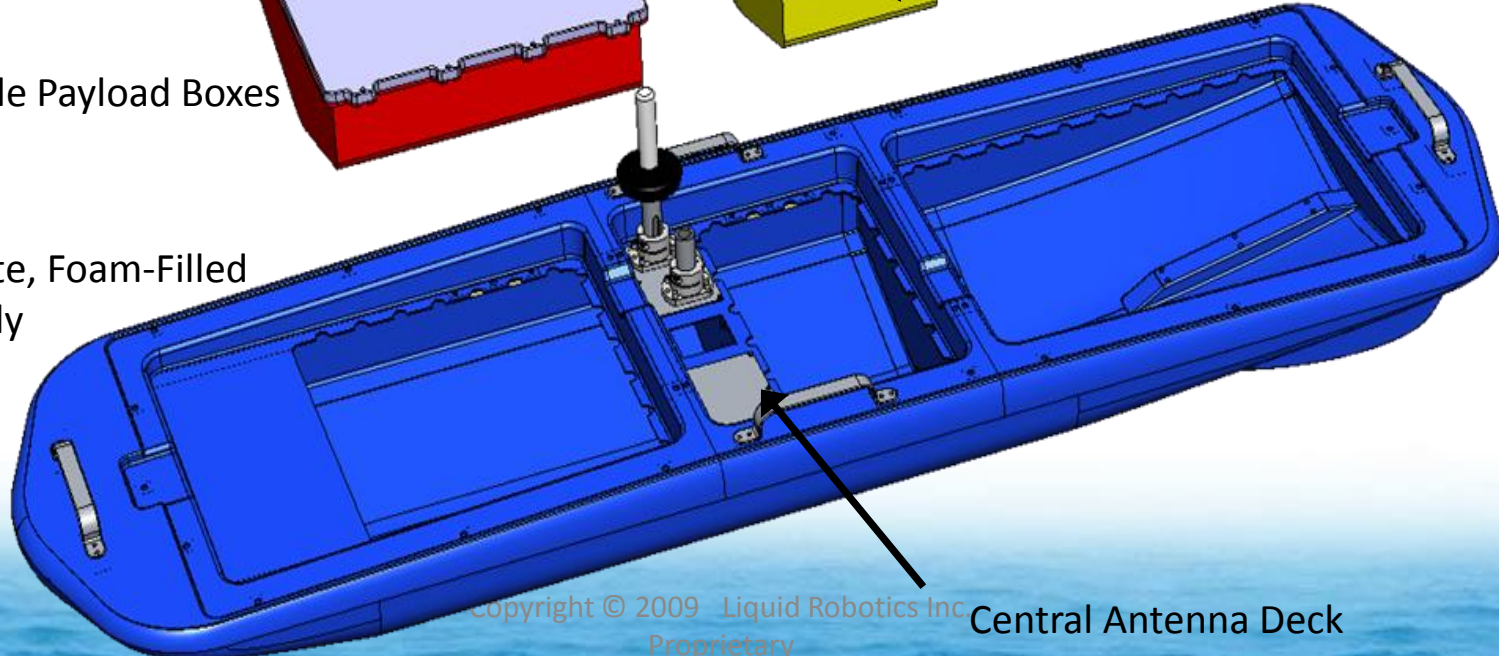
Forward Payload



4.5 kg Li-ion batteries: 665 Watt-hour

Configurable Payload Boxes


Composite, Foam-Filled  
Float Body



Central Antenna Deck

# Web Based User Interface





Secretariat ▼

Test System:  
Roger Hine ( Sign Out )

Duration

Show

---

Mode: Unknown

Ave Speed 0.63583

Last Speed 0.724

Target Waypoint 6

Distance to Target 0.13354

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Light:  IR:

Follow Waypoint course

Hold station at Waypoint

Rudder Left

Rudder Right

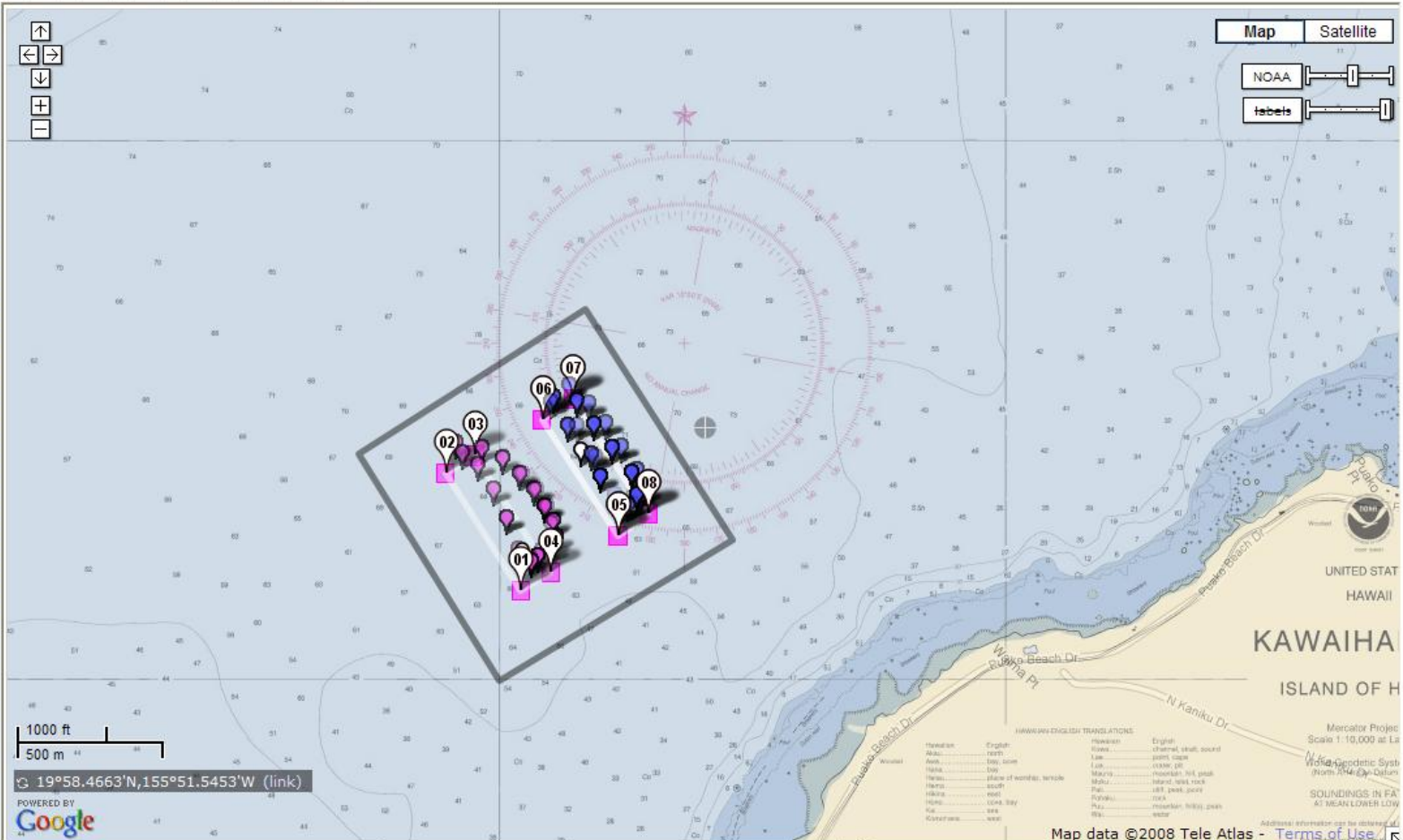
Rudder Center

Hold Current Position

Follow fixed Heading

No Command

More Commands ...



Map Satellite

NOAA

Labels

1000 ft

500 m

[19°58.4663'N,155°51.5453'W \(link\)](#)

POWERED BY

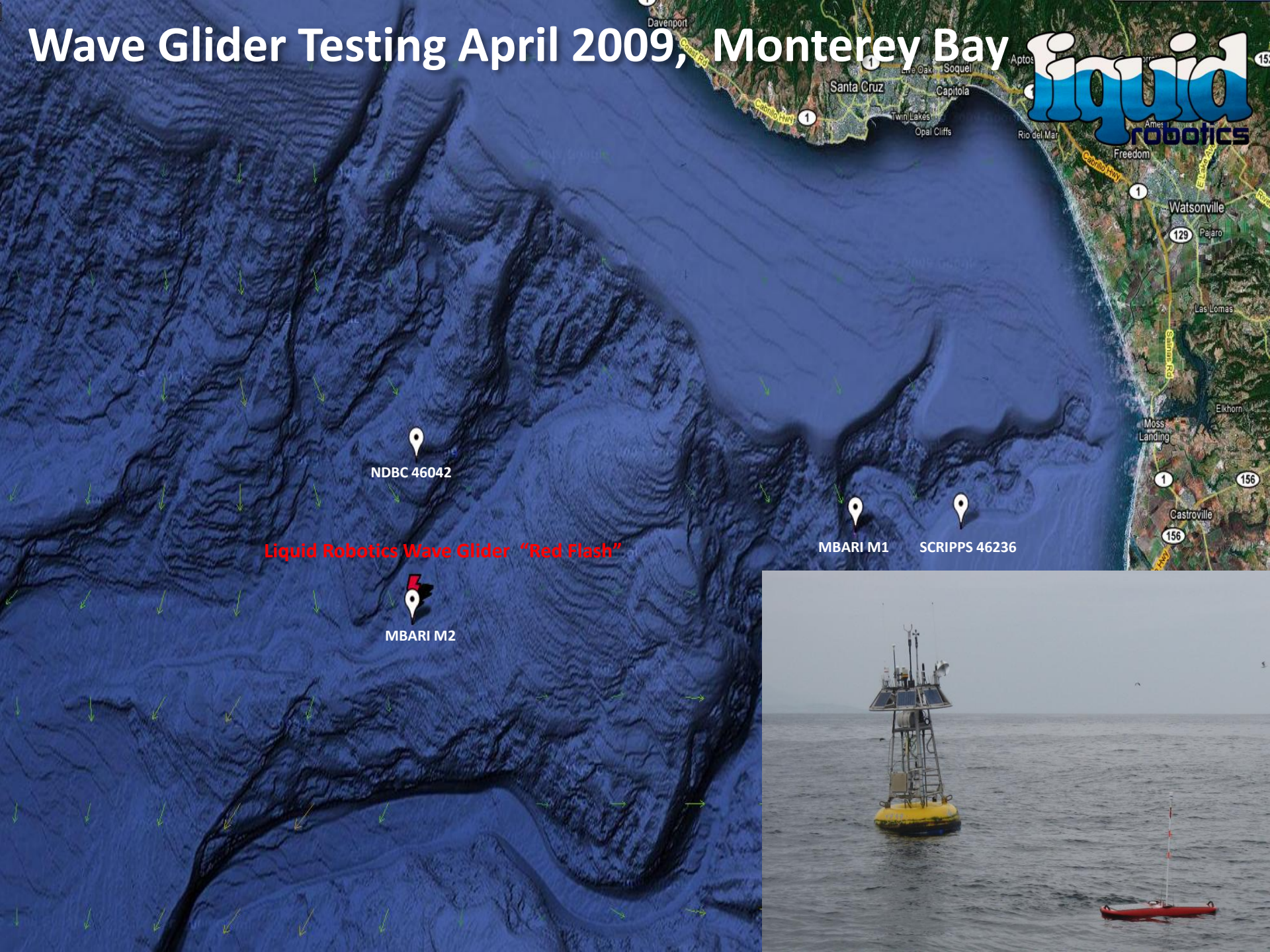
Map data ©2008 Tele Atlas - [Terms of Use](#)

## Secretariat Parsed Outputs

	Local Time	Last Speed	Target WP	Desired Heading	Sub Heading	Path Heading	Batt V	Float Temp	ISS	Command Name	Command Reason	User Name	Lat	Long	Distance
▶	4/11/2008 1:55:0...	0.724	6	288	299	323	13.5	84	5			Sys...	19.973225	-155.863975	112.1
▶	4/11/2008 1:50:0...	0.809	6	290	294	328	13.5	84	5			Sys...	19.97242	-155.863328	124.5
▶	4/11/2008 1:45:0...	0.451	6	291	290	234	13.56	84	5			Sys...	19.971472	-155.862693	69.9
▶	4/11/2008 1:40:0...	0.506	5	196	199	168	13.62	84	4			Sys...	19.971843	-155.862153	78.3



# Wave Glider Testing April 2009, Monterey Bay





# Station Keeping Comparison. WG: 50m M2: 1700m

Alarms: Duration: 1 day Prior To: 4/11/2009 12:00 pm Most Recent Submit Map Options

liquid robotics  
Red Flash  
Gliders: Roger Hine (Sign Out)  
End Mission California  
Show System Menus

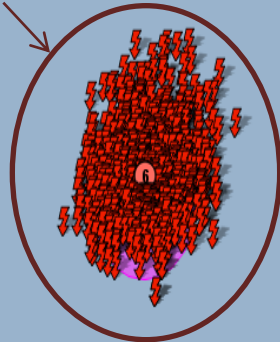
Mode: Follow Seq Course  
Ave Speed: 1.11  
Last Speed: 0.00  
Target Waypoint: 6  
Distance to Target: 14.1

Light: IR: XBee:   
Follow Sequential Course

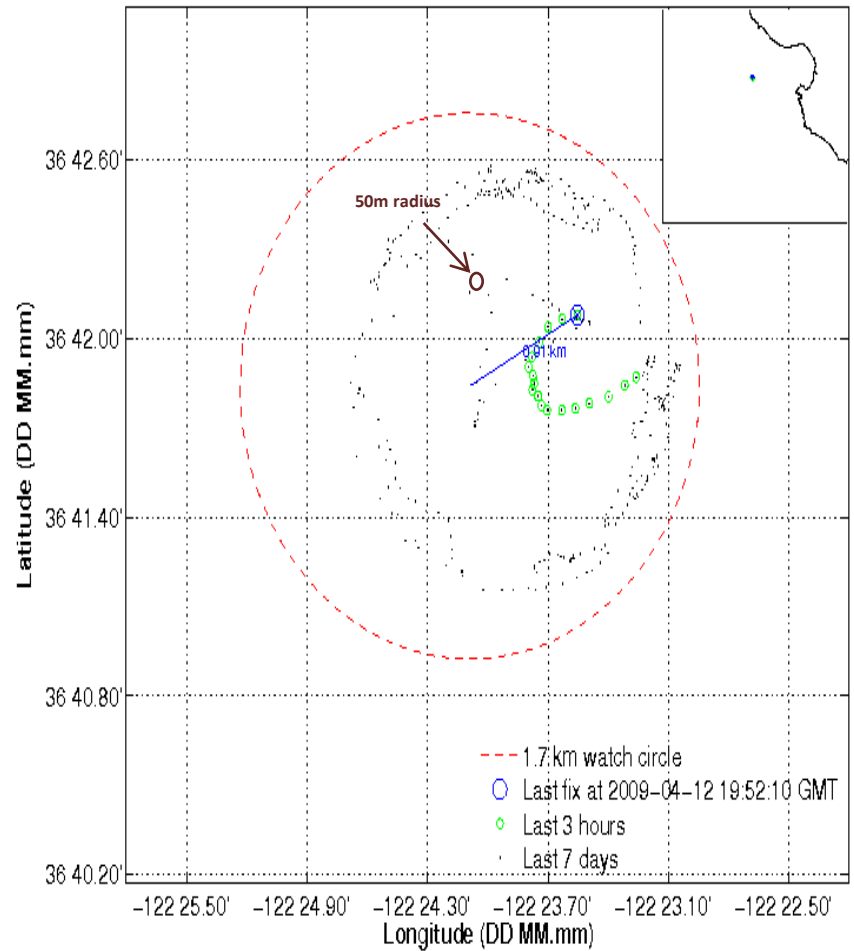
Hold Station At Waypoint  
Rudder Left  
Rudder Right  
Rudder Center  
Hold Current Position  
Follow Fixed Heading  
Set Parameter  
Comment

[More Commands ...](#)

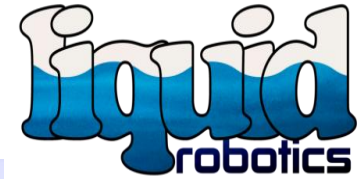
50m radius



Position of M2 - APRIL 2008 ( 36° 42.08'N -122° 23.55'E)



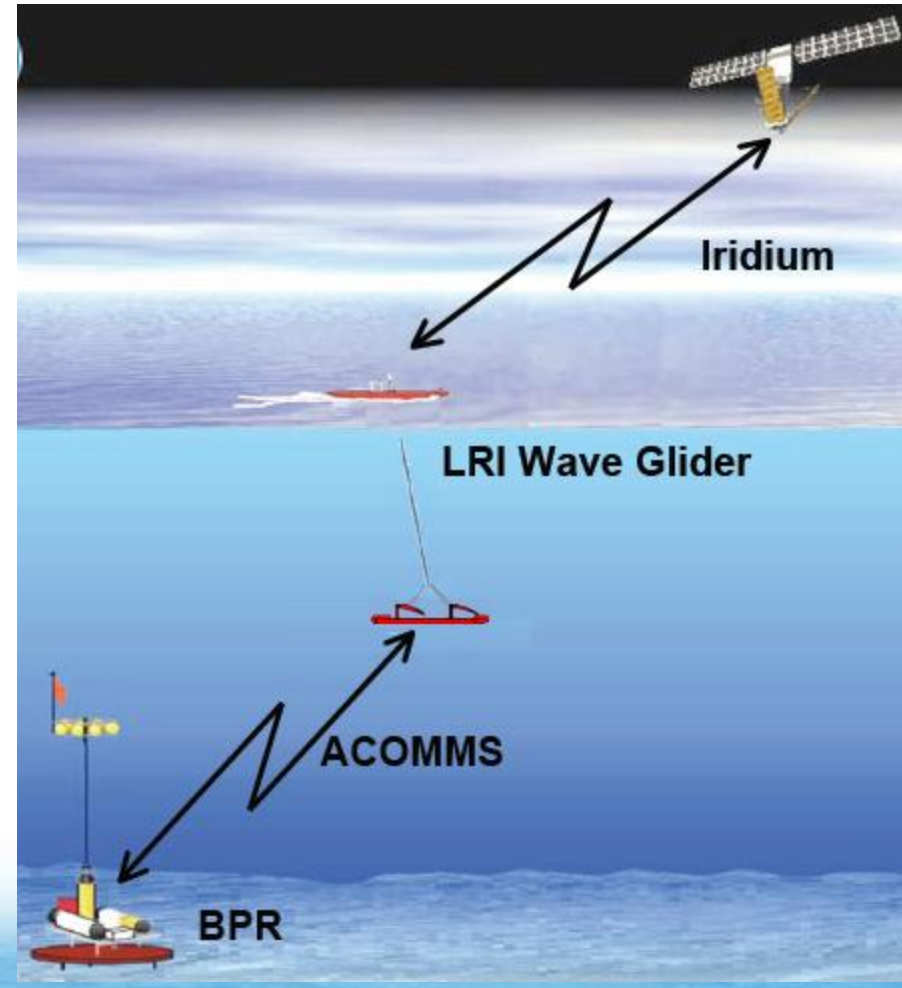
# WaveGlider Tsunami Warning



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

## NOAA DART Buoy Test

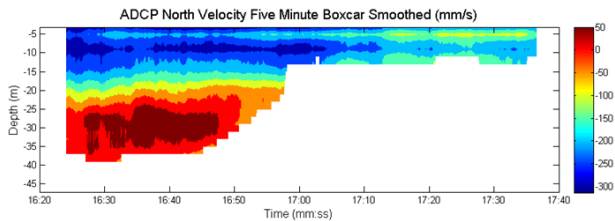
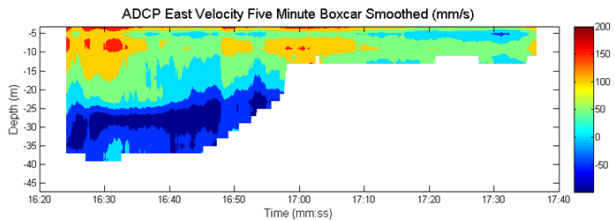
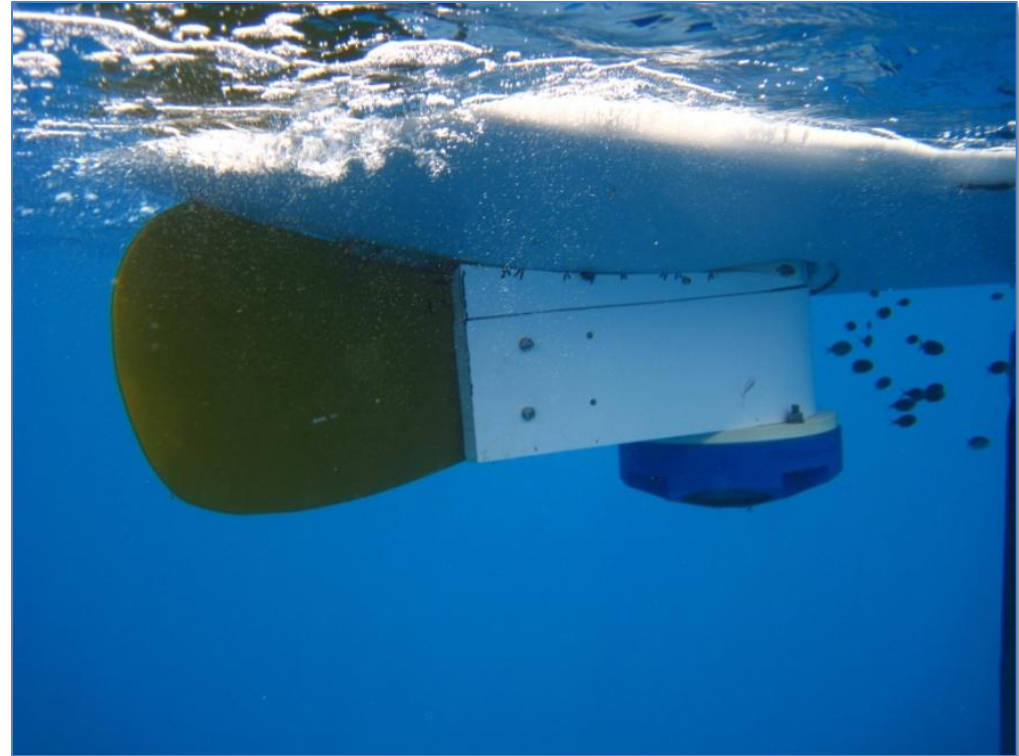
- Provided redundant communications with bottom mounted sensor
- DART buoy 51407 off Kona coast
- Glider on station 08/03/09 to 08/23/09
- Transited with glider based payload
- Supported acomms to BPR
- Station keeping functionality demonstrated



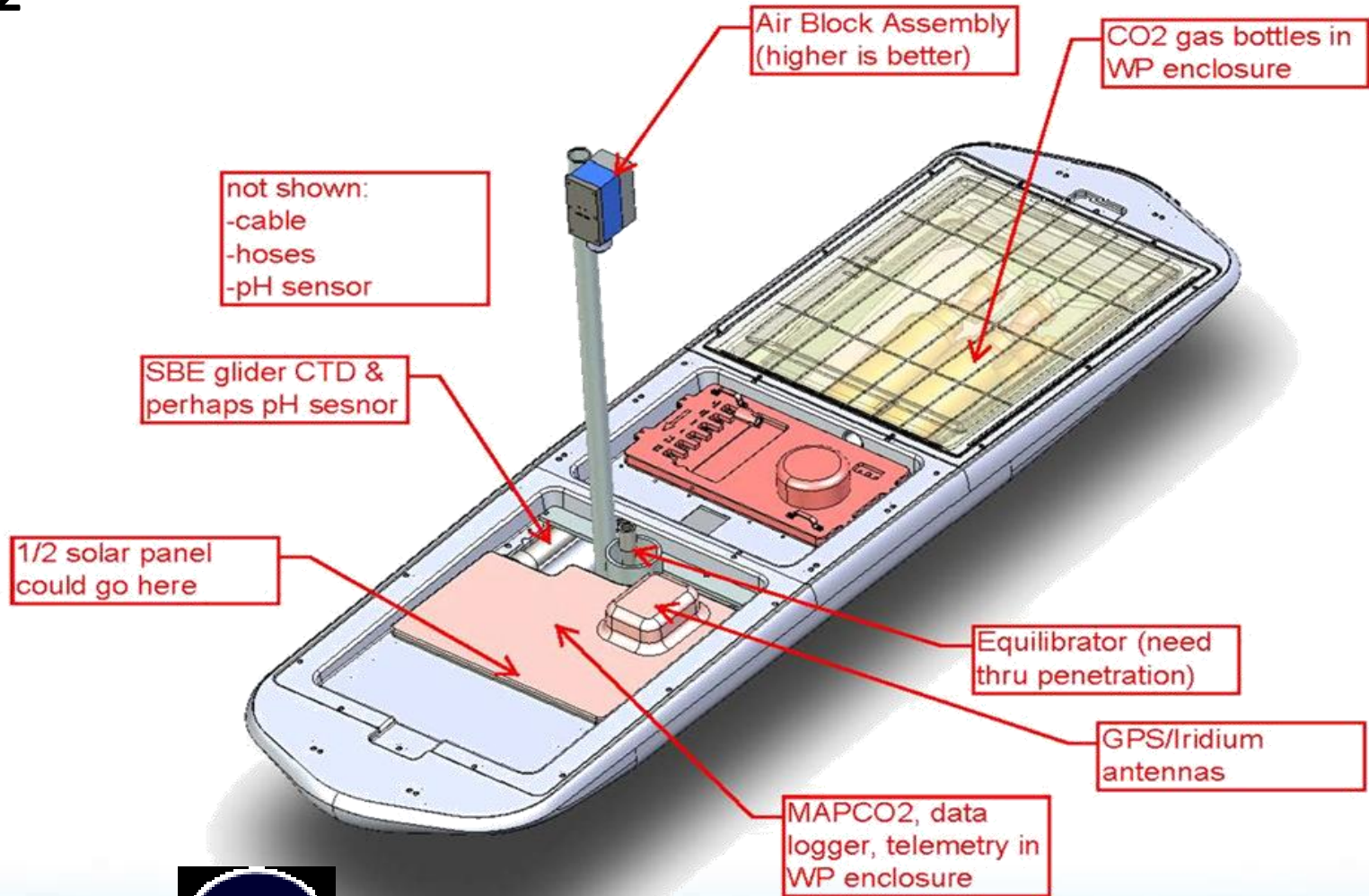
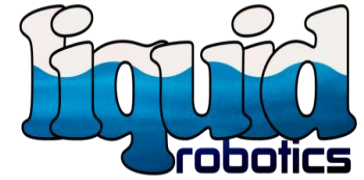


# Wave Glider Trial ADCP Deployment

- Successful system integration, Teledyne RDI 600 kHz Sentinel
- Series of tests to evaluate the ADCP performance and data quality
- Data below the glider validated
- Surface layers between the float and glider thought to be good quality



# Wave Glider CO<sub>2</sub> Flux Monitor



**Pacific Marine Environmental Laboratory**

A leader in developing ocean observational systems to address NOAA's mission



# Compatible with typical instruments



- Water Column:
  - **ADCP**, *conductivity/temp*, **hydrophone**, *pH*, **velocity**
- Surface:
  - **Waves**, **meteorology**, *pCO<sub>2</sub>*, direct covariance flux,
- Shallow Water:
  - *Fluorometer*, *nutrients*, *DO*, spectral irradiance, photosynthetically available radiation, optical absorption, *zooplankton*
- Other:
  - *Mass Spectrometer*, **cameras**, chemical sampling

The photograph shows a presentation slide with a white background and a dark border. The slide is titled "OOI Sensors Deployed" and is divided into three columns: "Water Column", "Shallow Water", and "Bottom". Each column lists various sensors and their corresponding counts. Below the table, there is a paragraph of text explaining the purpose of the OOI sensor set.

OOI Sensors Deployed		Shallow Water	
<b>Water Column</b>		Fluorometer	81
		Nutrients	25
		Dissolved oxygen	82
		Spectral irradiance	22
		Photosynthetically available radiation	20
		Optical absorption	31
		Zooplankton sensor	13
<b>Surface</b>		<b>Bottom</b>	
Acoustic Doppler Current Profiler	39	Mass spectrometer	2
Conductivity/Temperature	210	Seafloor temperature	1
Hydrophone	10	Seismometer	13
Inverted echo sounder	5	Camera	13
pH	37	Benthic flow	1
Velocity, single point	53	Particulate DNA	1
		Vent chemistry	2
		Chemical sampling	3
		Seafloor pressure	15

The OOI will provide free and open access to a core set of multidisciplinary sensors chosen by the community. The core sensor set was selected to address both the needs of the different disciplines of ocean sciences and to provide the capability to sample the full water column from the sea floor to the sea surface. Sampling capabilities are designed to address the requirement to sample across a broad range of time and

## OOI Sensors Deployed

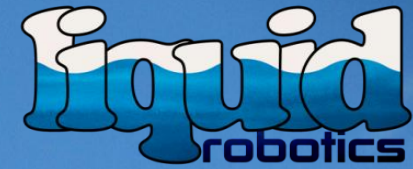
presented at OceanObs'09 - Venice, Sep 21-25 2009

## Wave Glider Status:

**Demonstrated**

*In Development*

# Wave Glider Recap

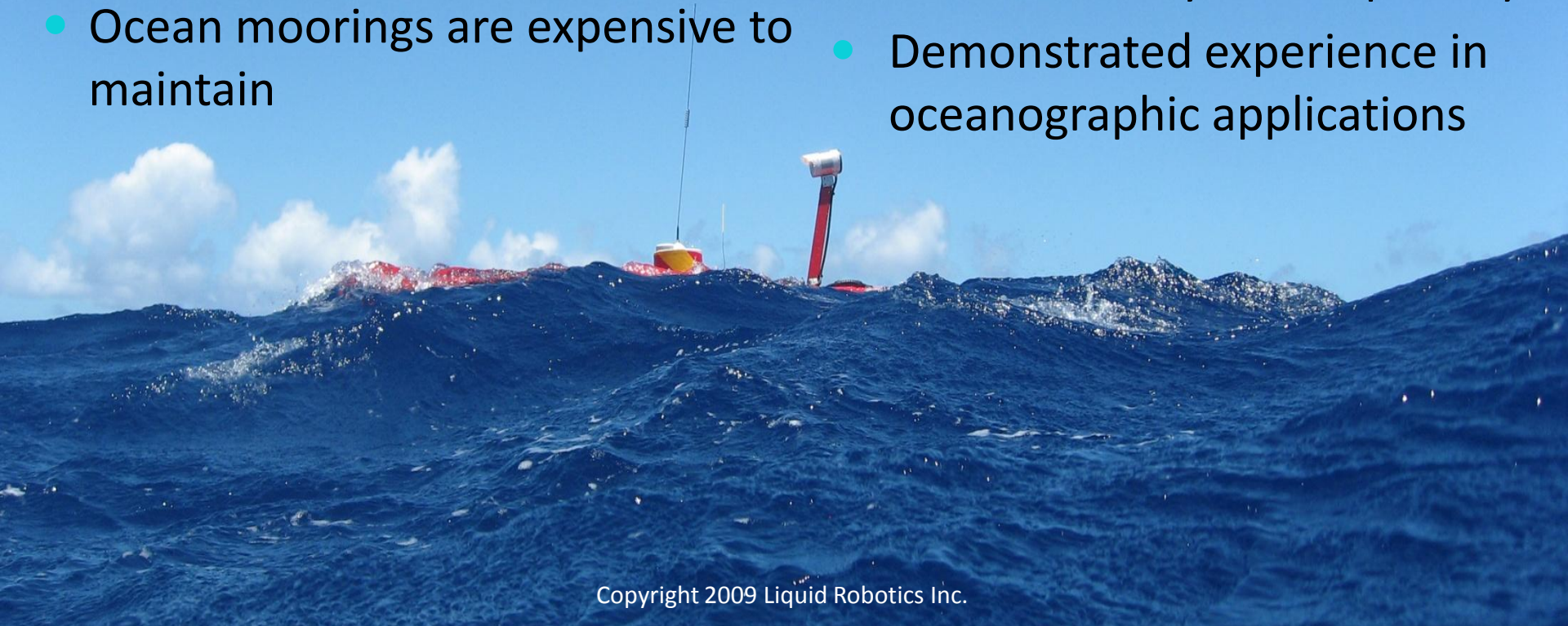


## Status Quo:

- Battery life limits autonomous vehicle range and payload
- Autonomous Marine Vehicles are mostly used near ships
- Ocean moorings are expensive to maintain

## Wave Glider:

- 100% energy harvesting
- Continuous communications
- Operational area: most of Earth
- Fundamentally new capability
- Demonstrated experience in oceanographic applications





Back Up

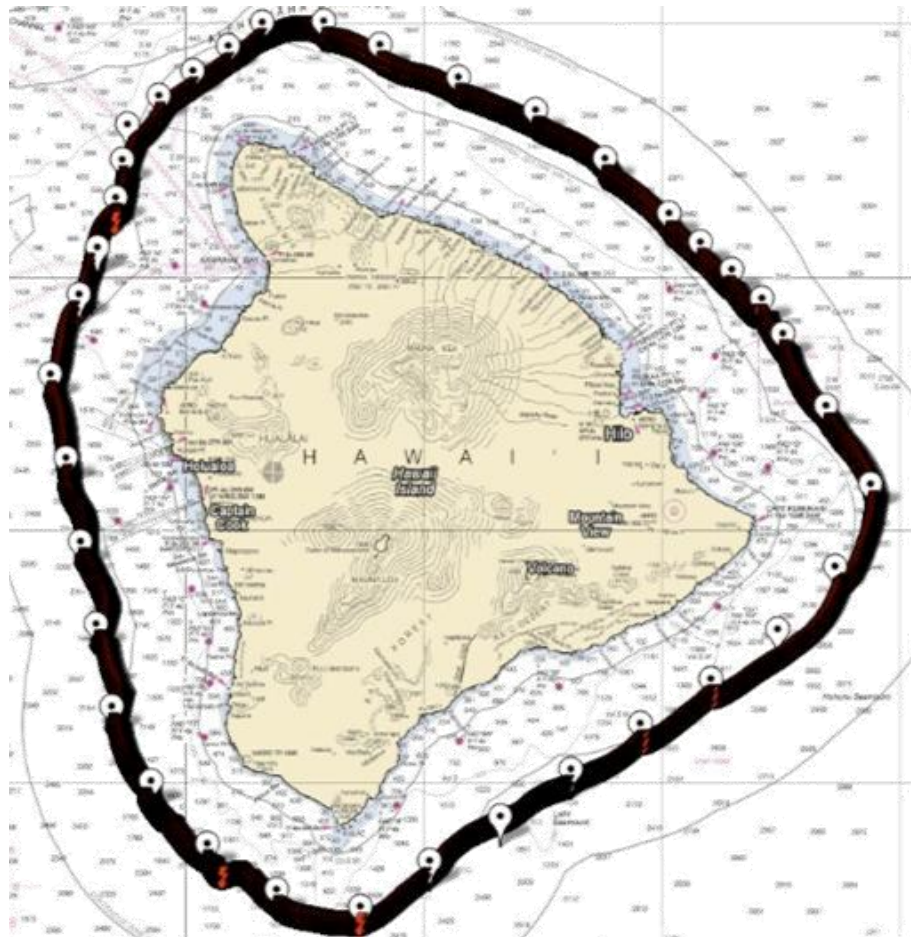
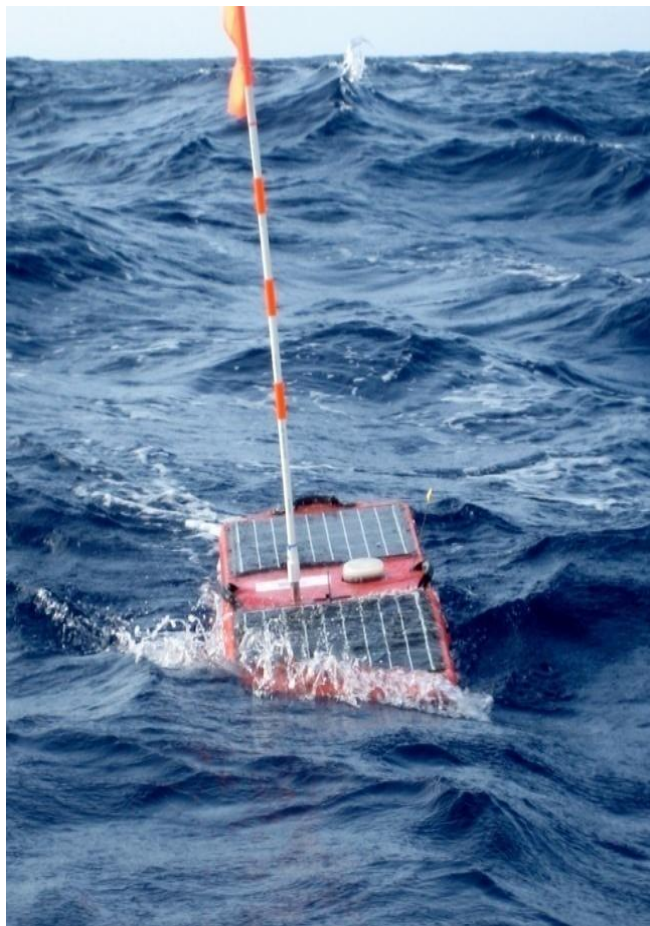
# Wave Glider Specifications

<b>Physical Characteristics</b>	
Vehicle Configuration	Submerged glider connected to a surface float by a tether.
Dimensions	Float: 2.1m x 0.6m; Glider: 0.4m x 1.9m; Wings: 1.1m wide
Weight and Buoyancy	75 kg mass, 150 kg displacement
Endurance	Up to 1 year
<b>Capabilities and Functionality</b>	
Propulsion Power	Mechanical conversion of wave energy into forward propulsion.
Speed through Water	>0.5 kt in Sea State 1 (SS1); >1.5 kt in Sea State 3 (SS3).
Battery	86W (peak) solar panel charging a 665 Wh Li-ion battery pack.
Payload Power Available	3-5 W continuous (typical), depending upon latitude, weather, etc.
Communications Systems	Iridium Satellite Modem. RF Modem
Navigation Systems	12 Channel, WAAS enabled GPS; Compass; Water Speed (Optional)
Control Interfaces	Web-based, GUI Chart interface, with location and status indicators.
Proven Survivability	SS6 (WMO) (14-18ft seas, 30-40kt winds)
Emergency Location Devices	Light and RF beacon. Optional acoustic beacon.



# Round-the-Island Mission

Circumnavigation of Hawaii, January 9<sup>th</sup> through 18<sup>th</sup> 2009

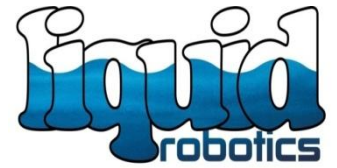


The mission was initiated as an engineering test. The Wave Glider was launched out of Kawaihae and circumnavigated the island in offshore waters.

<b>Duration:</b>	<b>9 days, 2 hours</b>
<b>Total Distance:</b>	<b>343nm</b>
<b>Average Speed:</b>	<b>1.57kts (SOG)</b>
<b>Max Speed:</b>	<b>3.84kts (SOG) w/ current</b>
<b>Sea State (WMO):</b>	<b>SS5 [est. 10ft, 15kts]</b>

# California Coast Mission

Monterey to San Diego, April 17 - 28



- Red Flash was launched out of Monterey and sent on an offshore course for San Diego.
- Onboard weather sensor data compared favorably against existing weather buoys

**Distance:**

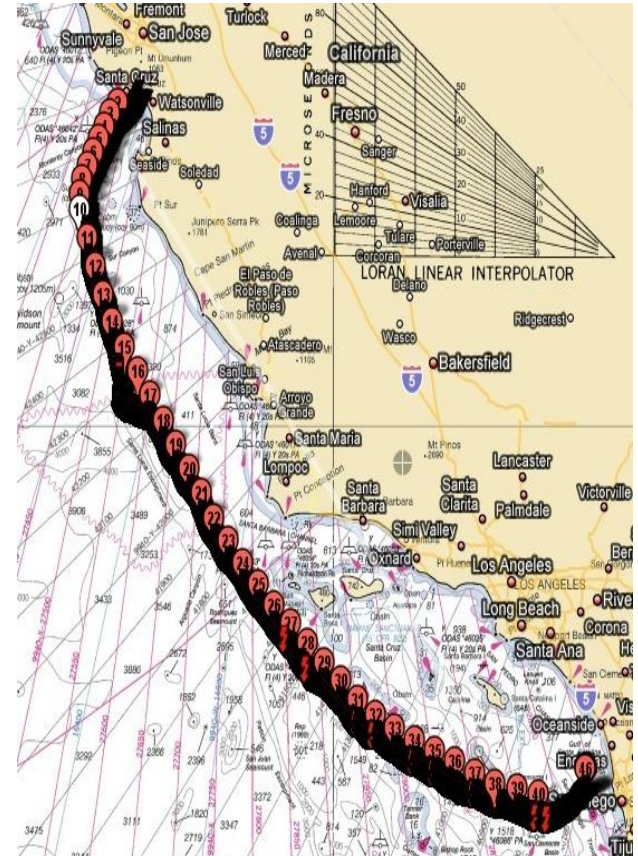
**406nm**

**Duration:**

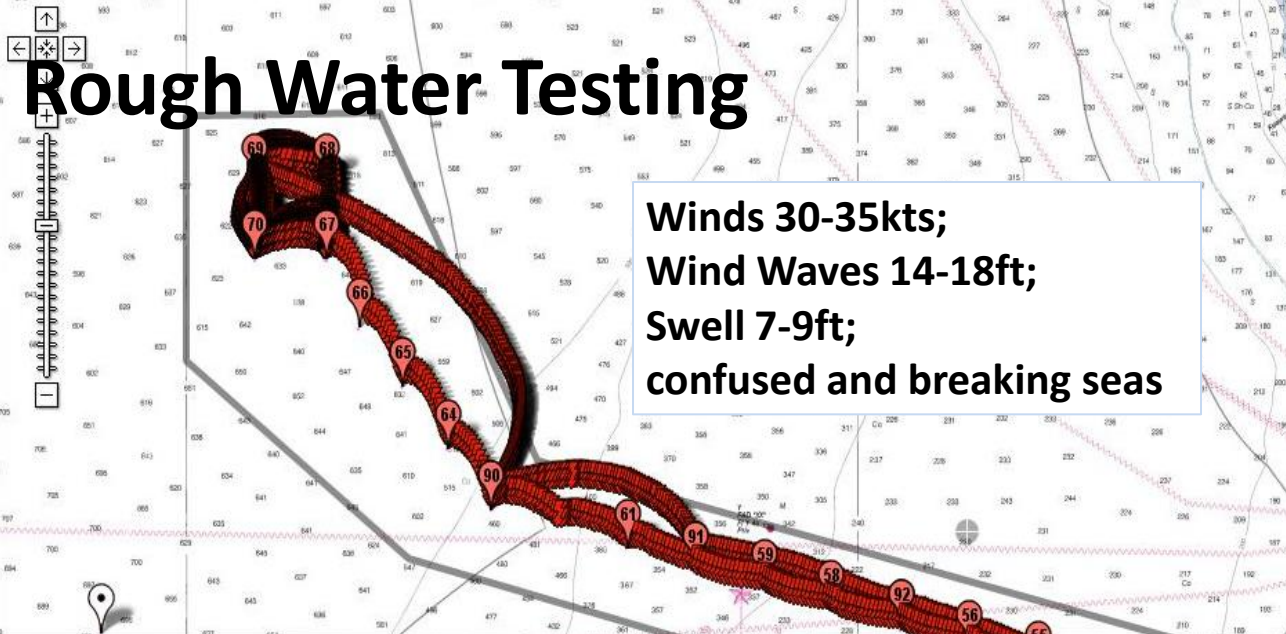
**11 days, 2 hours**

**Average Speed:**

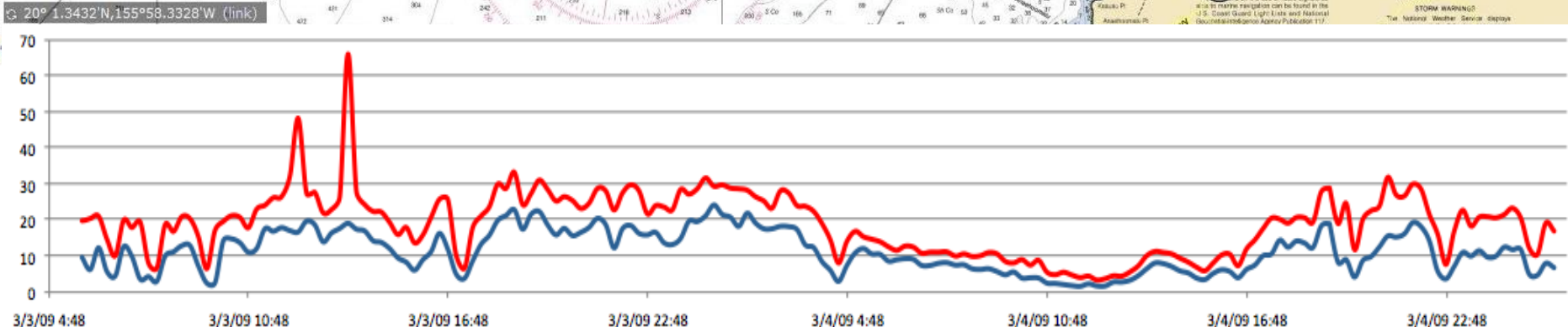
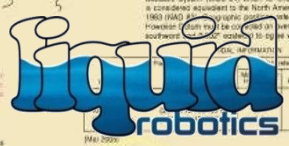
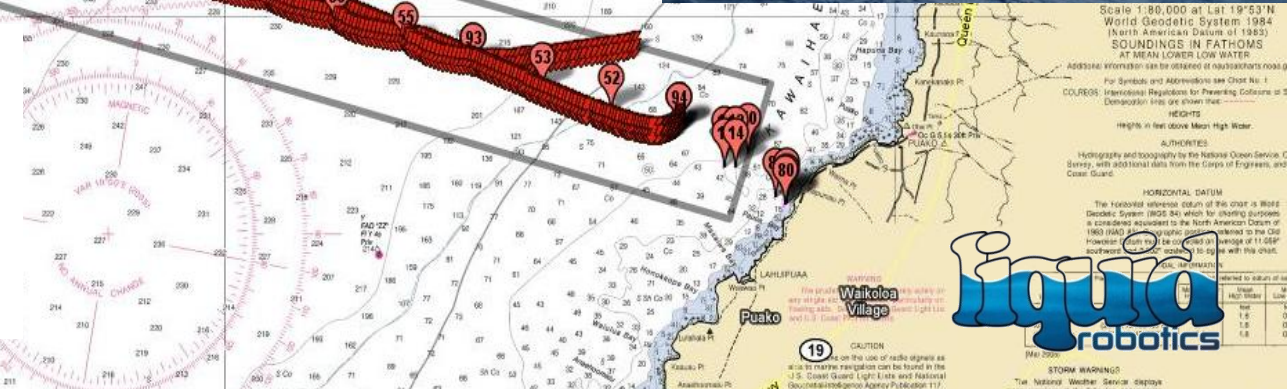
**1.53kts**







**Test Initiated: 3/28 1100HST**  
**Test Concluded: 4/5 0100HST**  
**Test Duration: 134 hours**  
**Average Speed 1.44 kts**  
**Distance Covered: 193nm**



# Wave Glider Comms & Control

