liquid robotics

Wave Glider™
Autonomous Ocean Vehicle

The Wave Glider:
A Mobile Buoy Concept for Ocean Science

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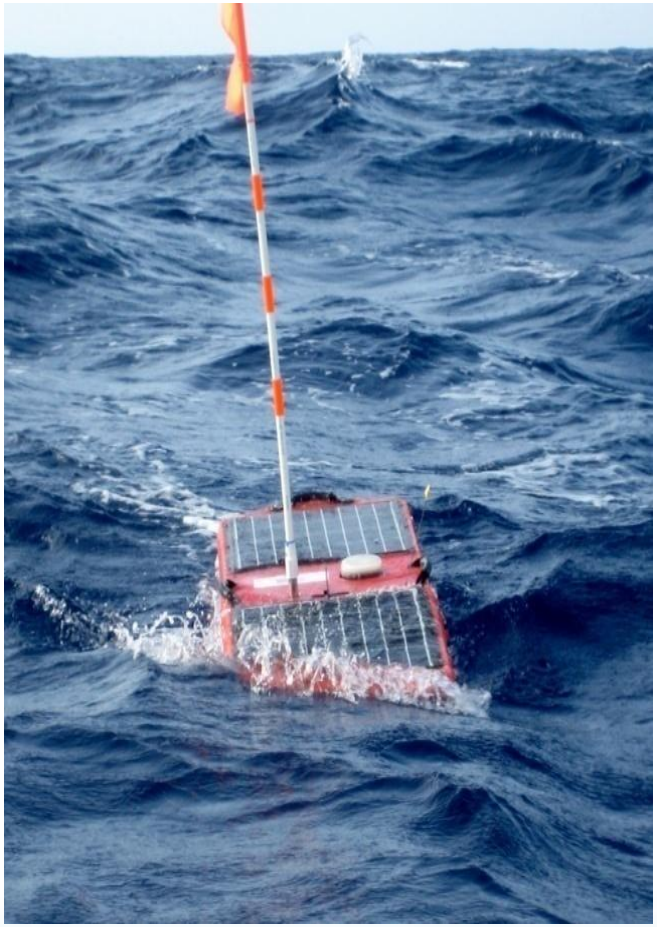
DBCP XXV – Paris – September 28, 2009

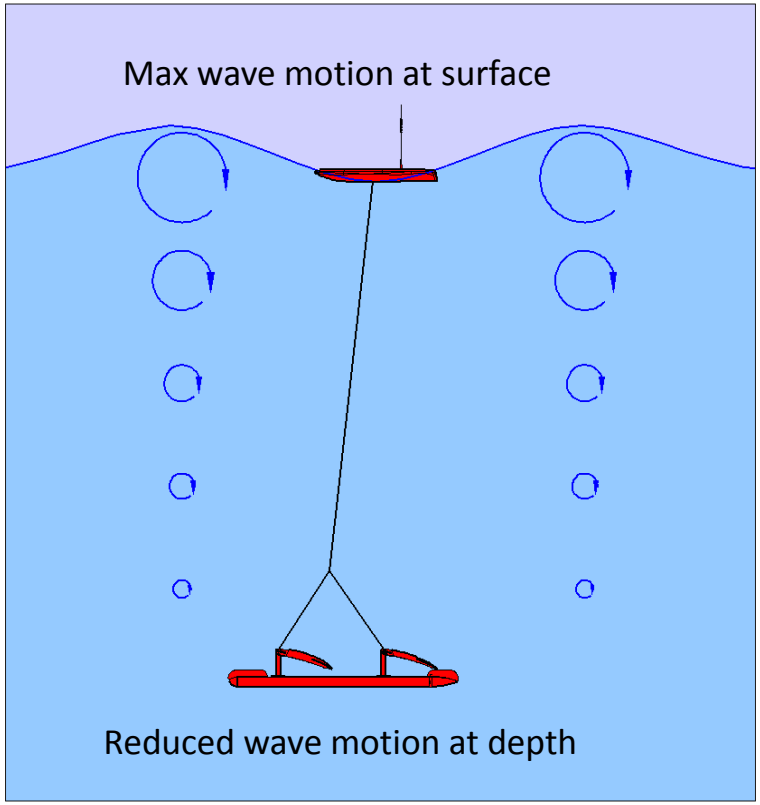
Wave Glider Overview

- 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

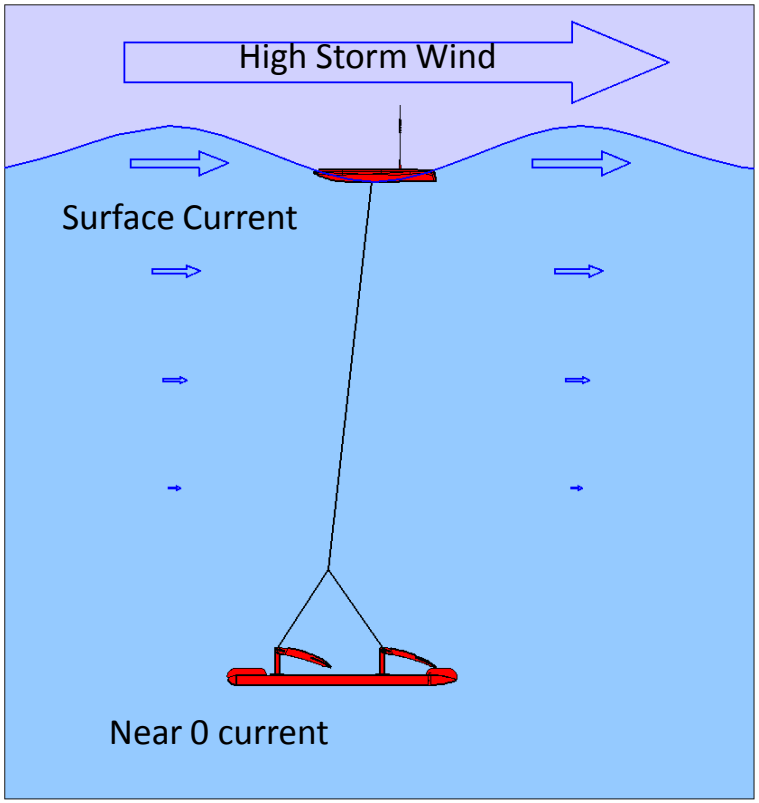


Wave Glider Operating Principle

Glider Wings Convert Wave Motion To Thrust

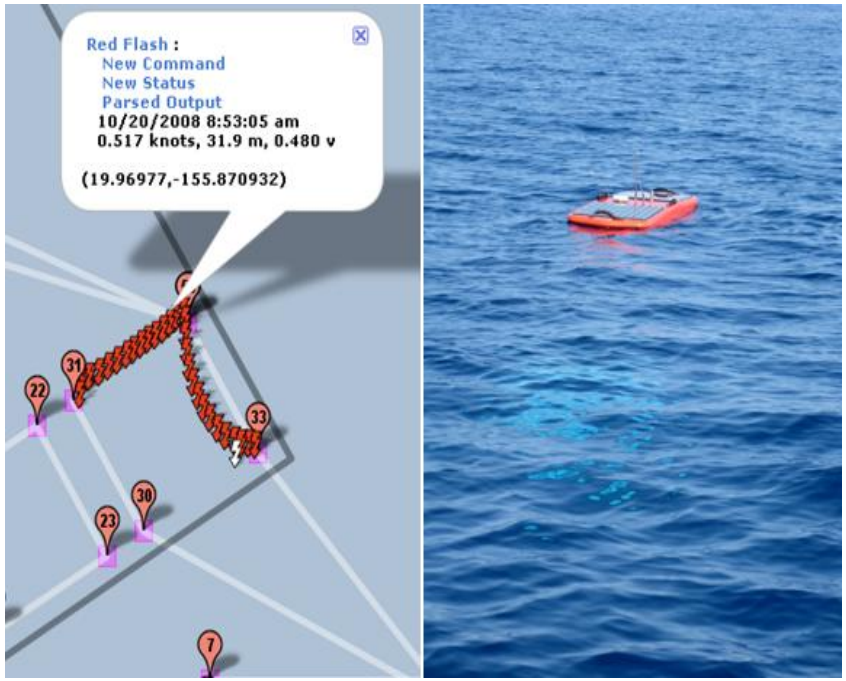


Glider is Protected from Surface Effects

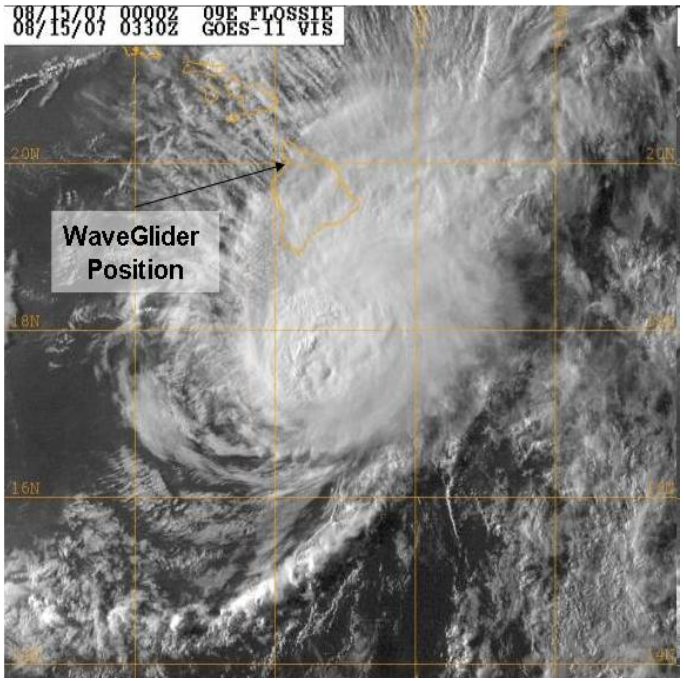


Passive float is towed by the submerged glider.

Operational in range of conditions



Sea State 0: ½ knot speed



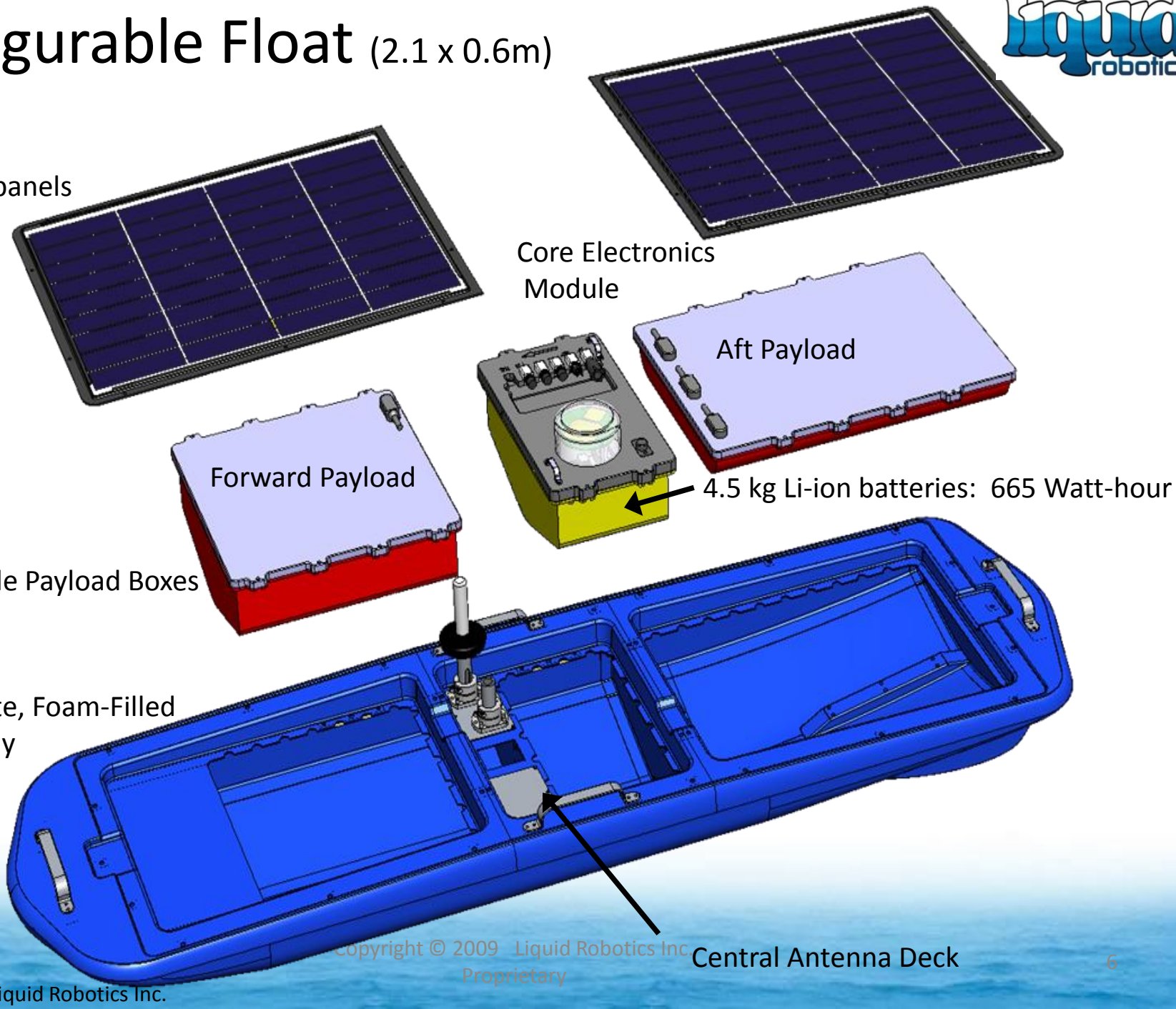
Edge of Hurricane Flossy:
1 knot into 40-50 knot head winds

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.

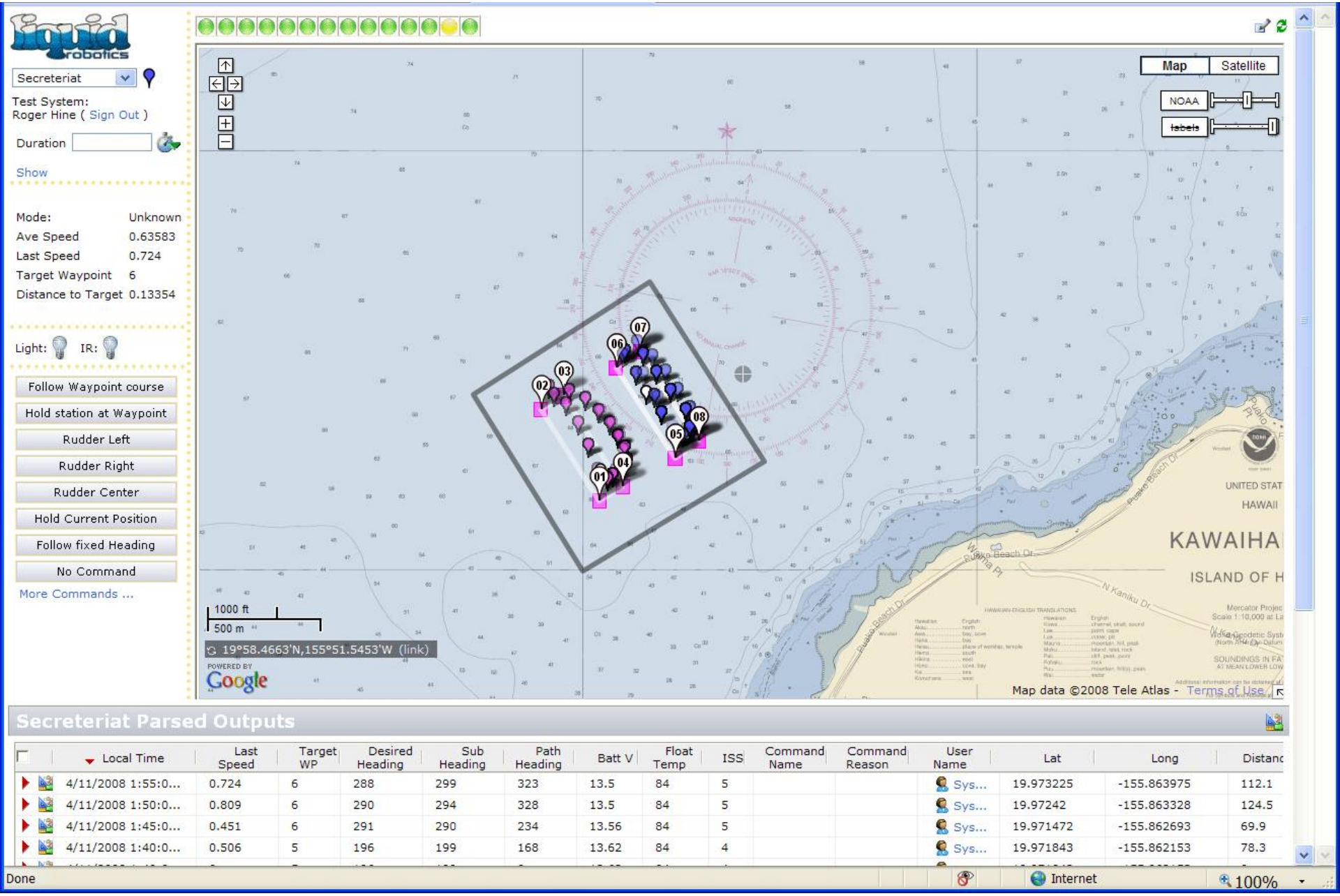
Proven Capability

Wave Glider Testing Milestones and Statistics	
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

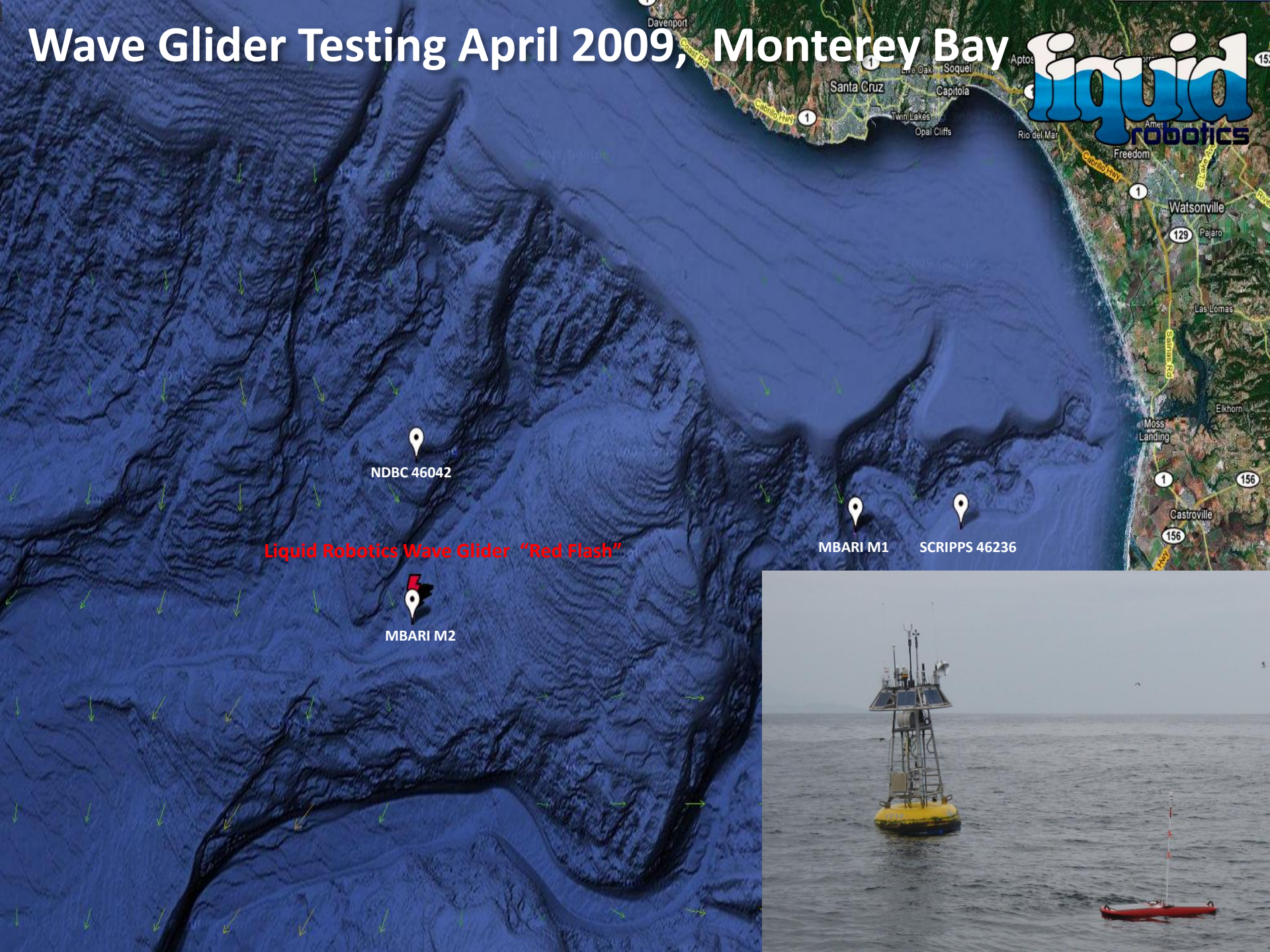
Configurable Float (2.1 x 0.6m)



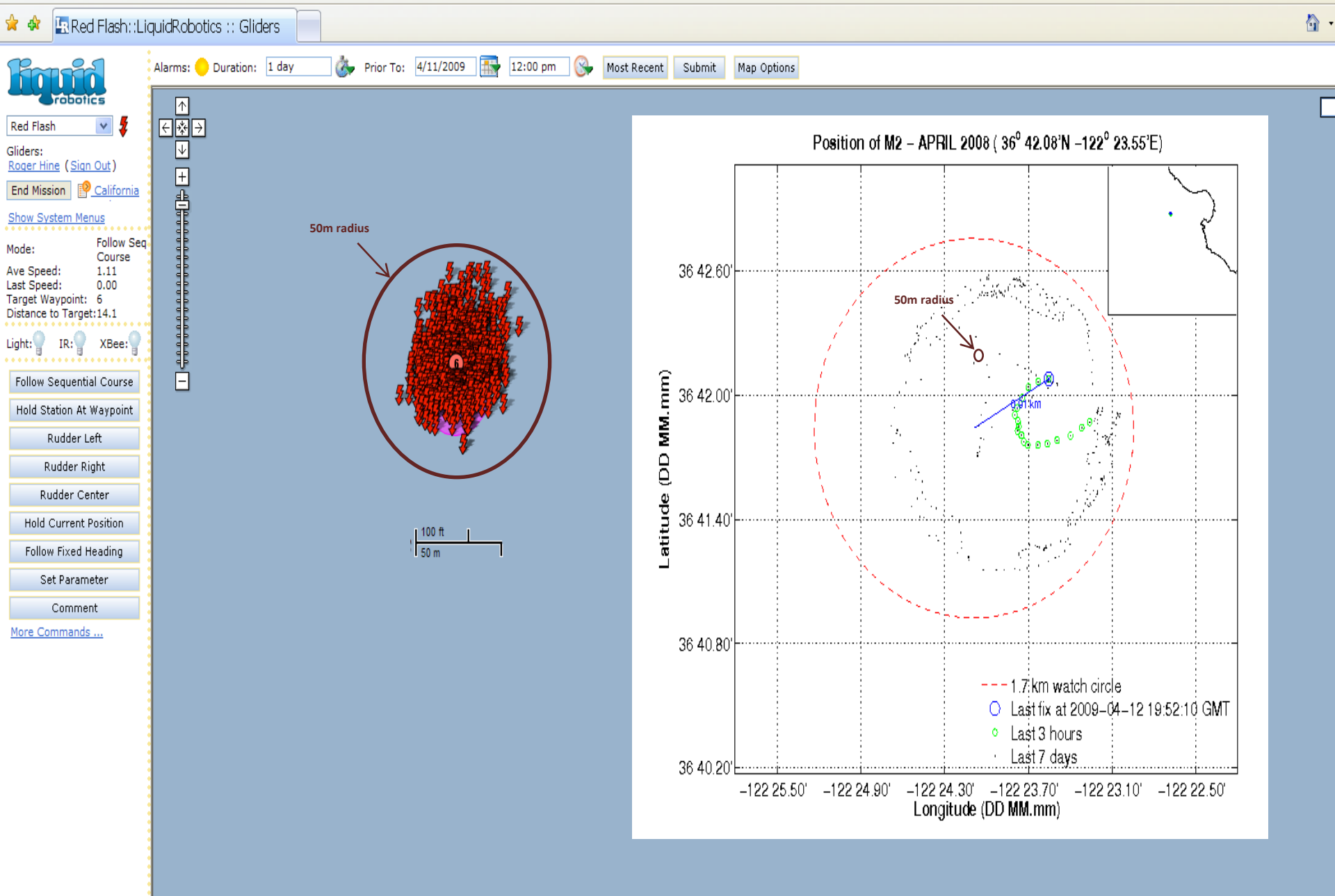
Web Based User Interface



Wave Glider Testing April 2009, Monterey Bay



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



WaveGlider
Tsunami Warning

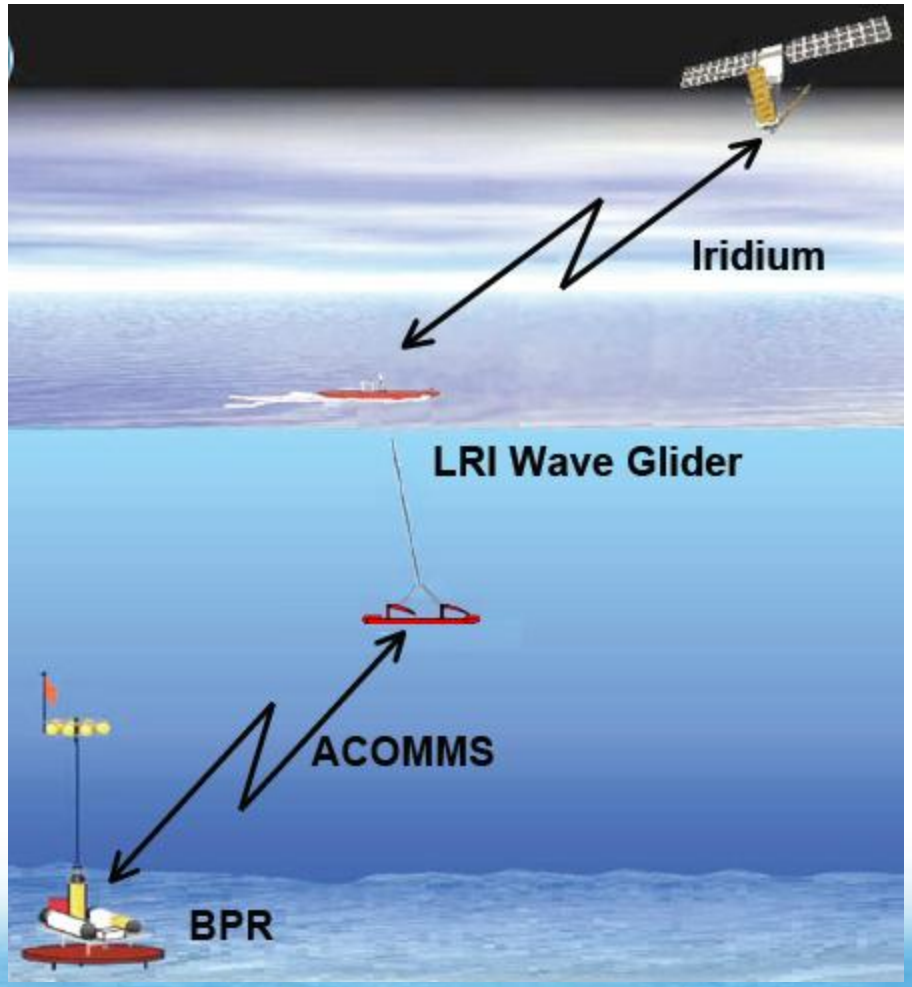
SAIC From Science to Solutions

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

liquid robotics

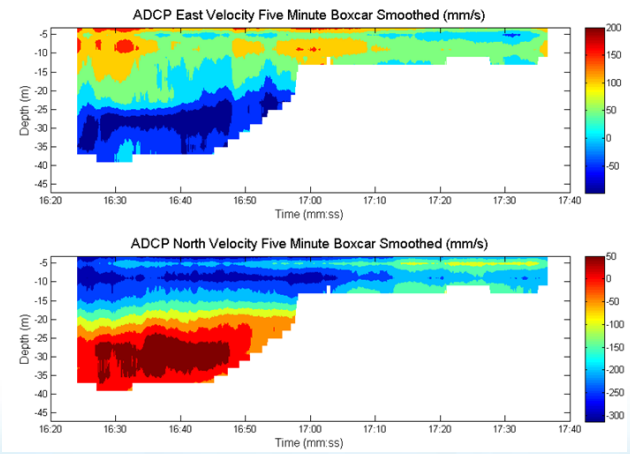
NOAA DART Buoy Test

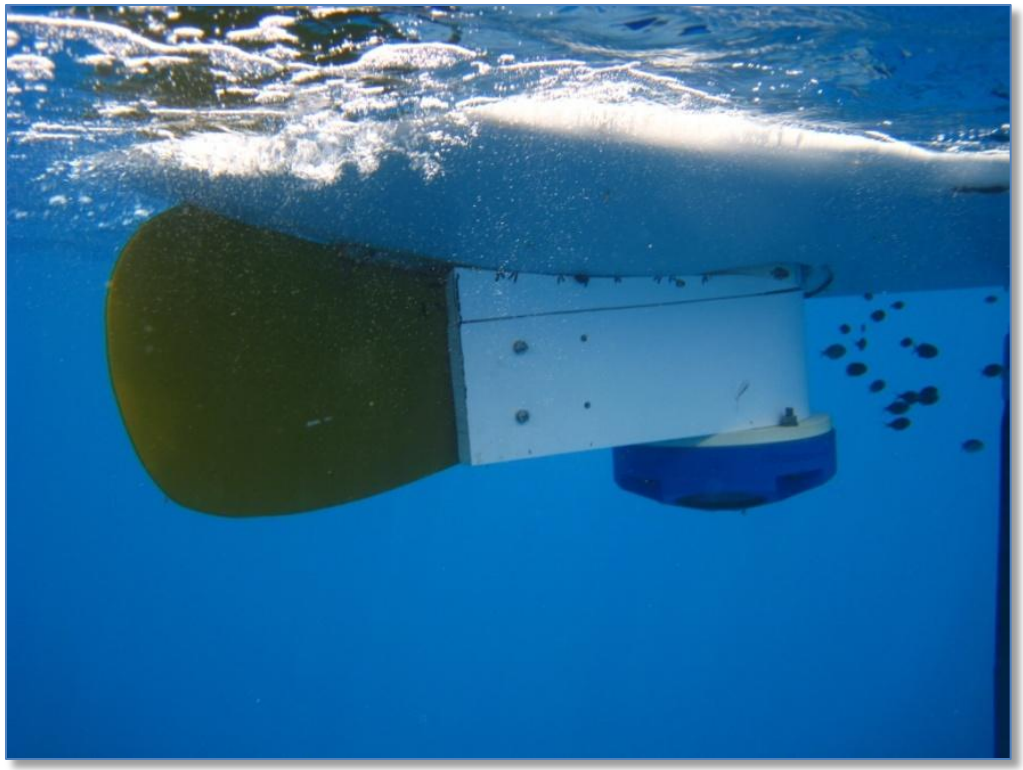
- Provided redundant communications with bottom mounted sensor
- DART buoy 51407 off Kona coast
- Glider on station 08/03/09 to 08/23/09
- Transited with glider based payload
- Supported acomms to BPR
- Station keeping functionality demonstrated



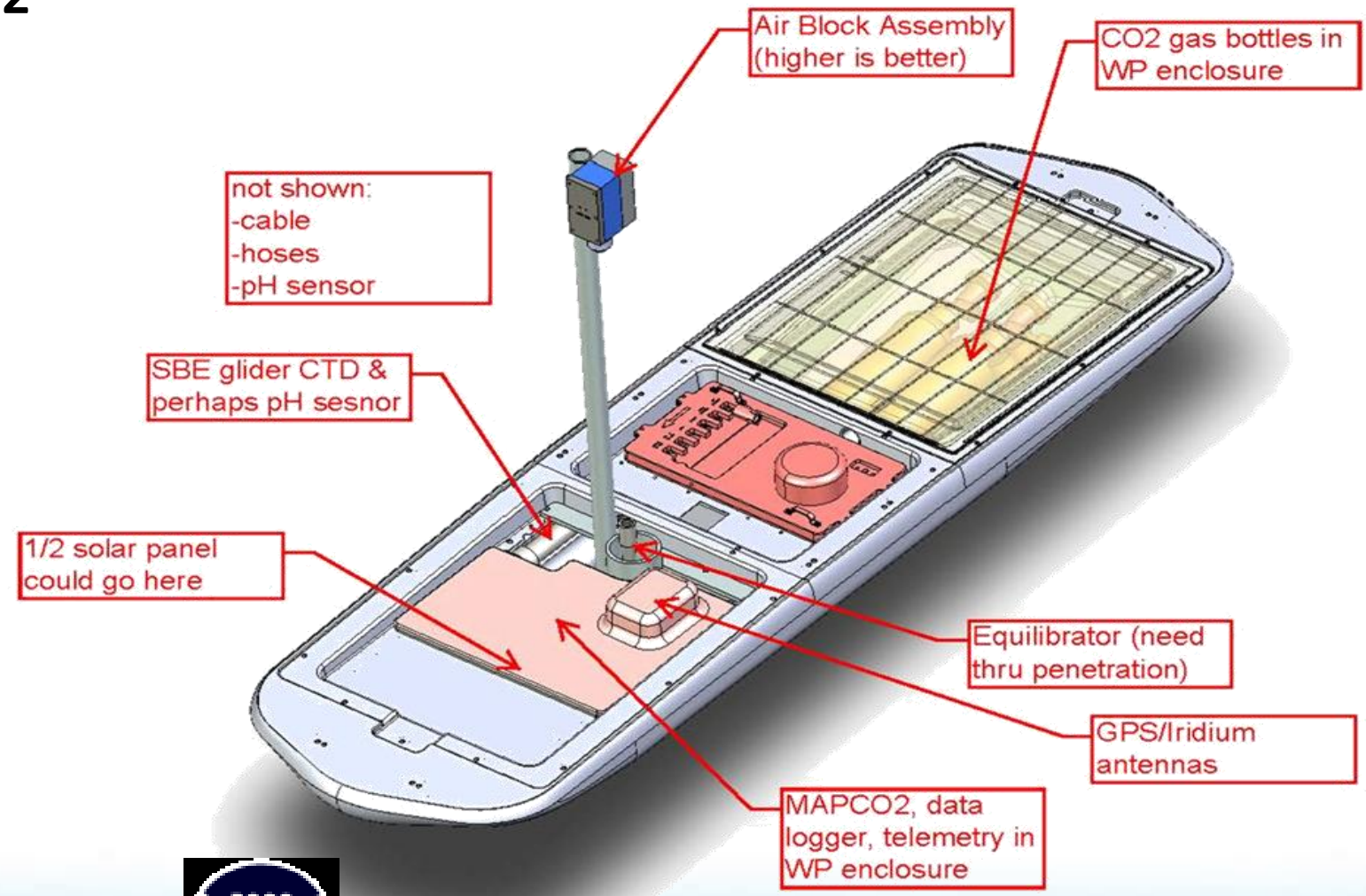
Wave Glider
Trial ADCP Deployment

- 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_2 Flux Monitor

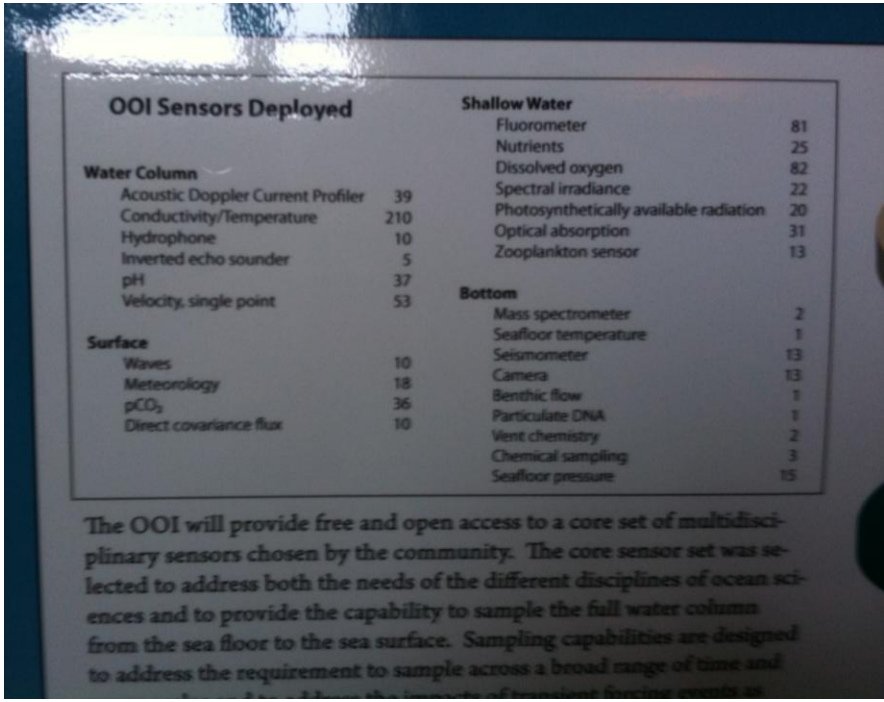


Pacific Marine Environmental Laboratory

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**, *pCO2*, direct covariance flux,
- Shallow Water:
  - *Flourometer, nutrients, DO,* spectral irradiance, photosynthetically available radiation, optical absorption*, zooplankton*
- Other:
  - *Mass Spectrometer*, **cameras**, chemical sampling



OOI Sensors Deployed

Water Column		**Shallow Water**	
Acoustic Doppler Current Profiler	39	Fluorometer	81
Conductivity/Temperature	210	Nutrients	25
Hydrophone	10	Dissolved oxygen	82
Inverted echo sounder	5	Spectral irradiance	22
pH	37	Photosynthetically available radiation	20
Velocity, single point	53	Optical absorption	31
Surface		Zooplankton sensor	13
Waves	10	**Bottom**	
Meteorology	18	Mass spectrometer	2
pCO_2	36	Seafloor temperature	1
Direct covariance flux	10	Seismometer	13
		Camera	13
		Benthic flow	1
		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

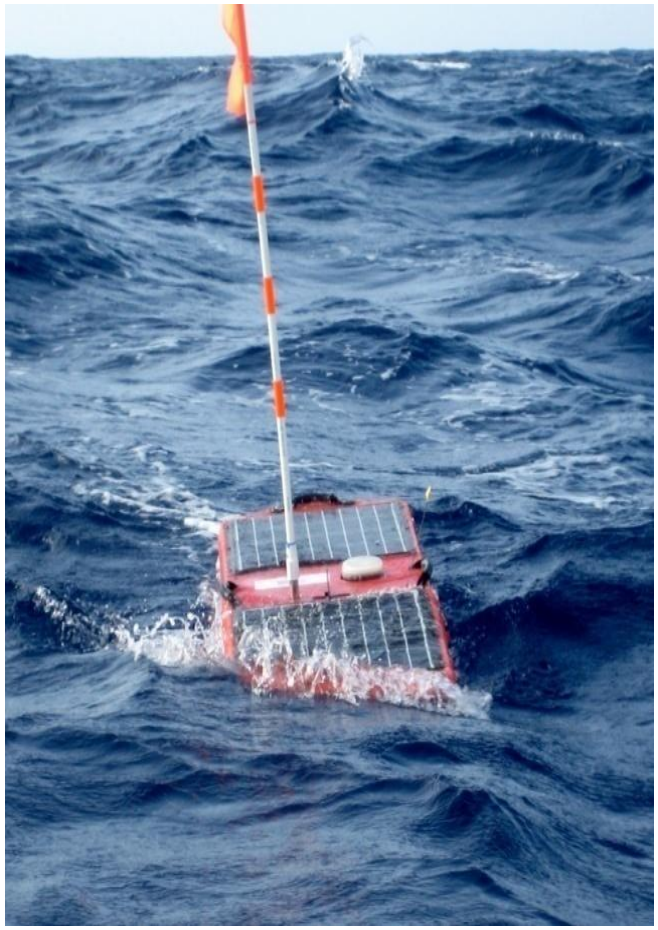
Back Up

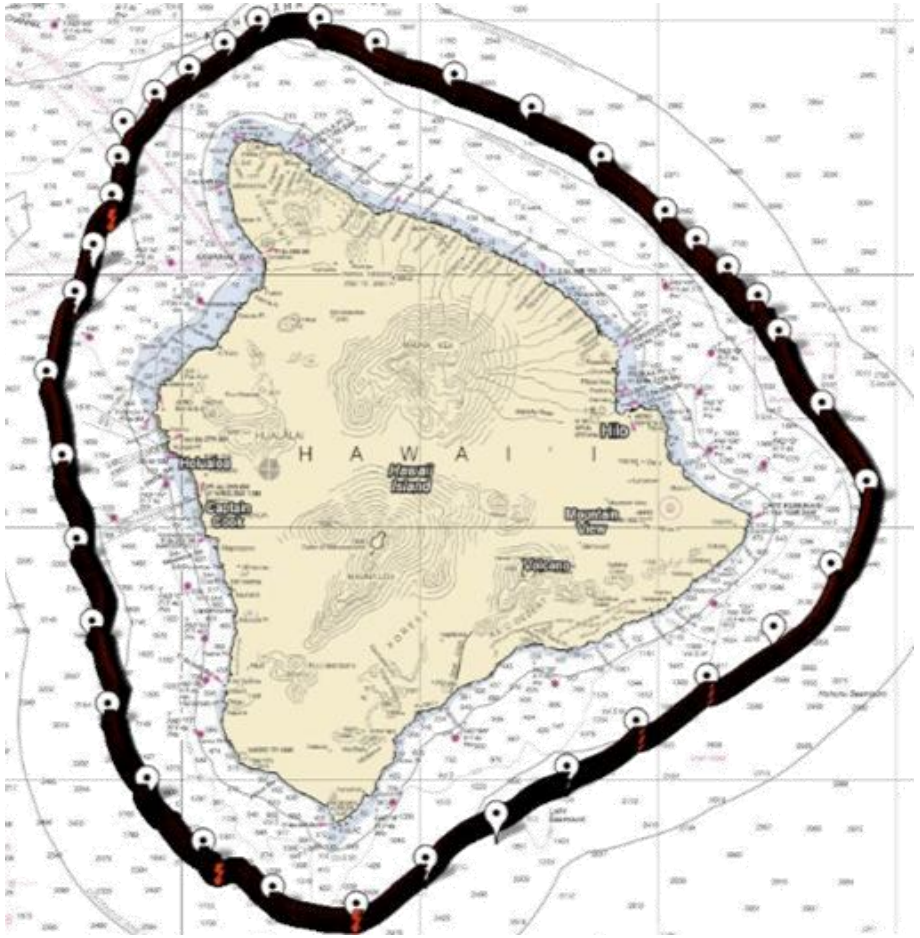
Wave Glider Specifications

Physical Characteristics	
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
Capabilities and Functionality	
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 9th through 18th 2009





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

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

California Coast Mission

Montery to San Diego, April 17 - 28

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

Distance:

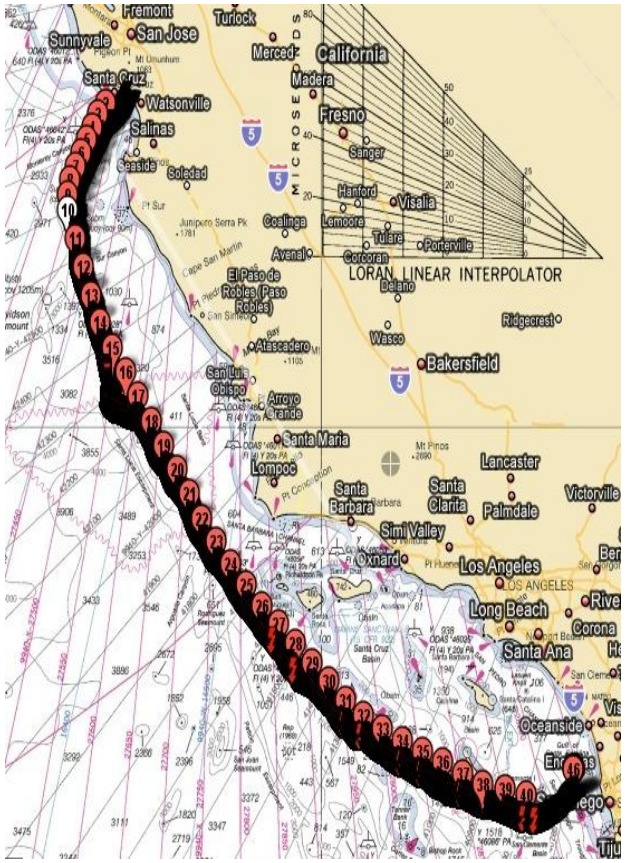
406nm

Duration:

11 days, 2 hours

Average Speed:

1.53kts



Rough Water Testing

Winds 30-35kts;
Wind Waves 14-18ft;
Swell 7-9ft;
confused and breaking seas

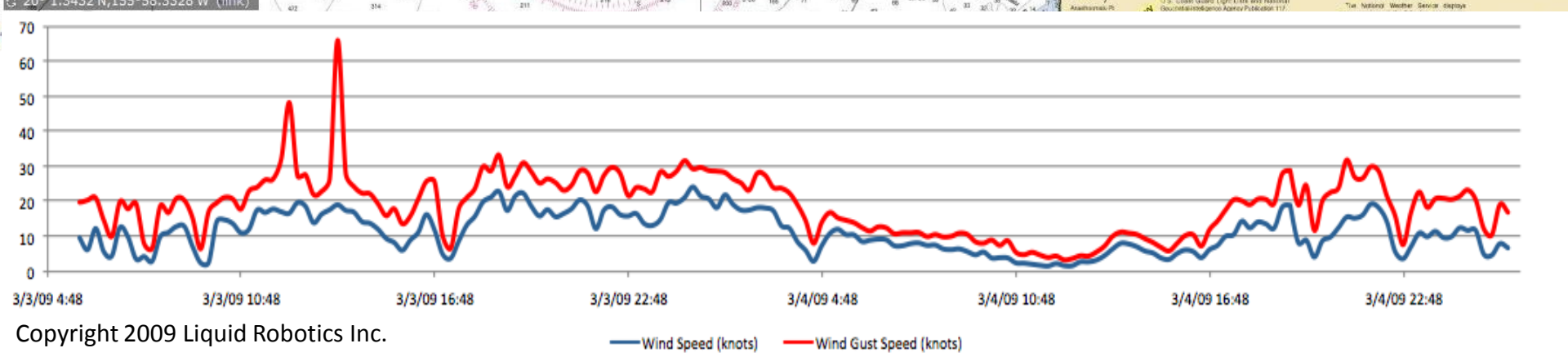
Test Initiated: 3/28 1100HST

Test Concluded: 4/5 0100HST

Test Duration: 134 hours

Average Speed 1.44 kts

Distance Covered: 193nm



Wave Glider Comms& Control