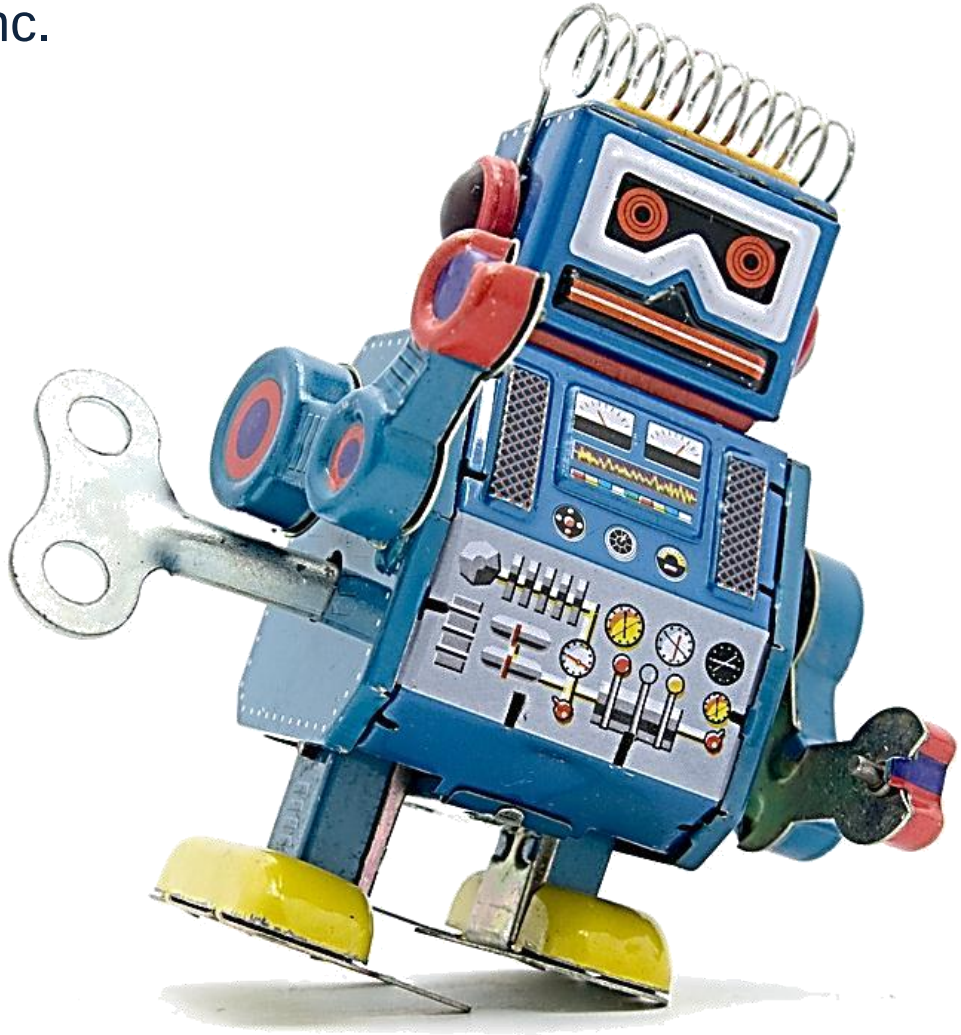
ROBOT POWER

Roger Hine, Co-Founder and CTO

Liquid Robotics Inc.



DON’T PLAN ON IT

Jupiter Foundation circa 2004


U.S. COAST GUARD
ASPEN

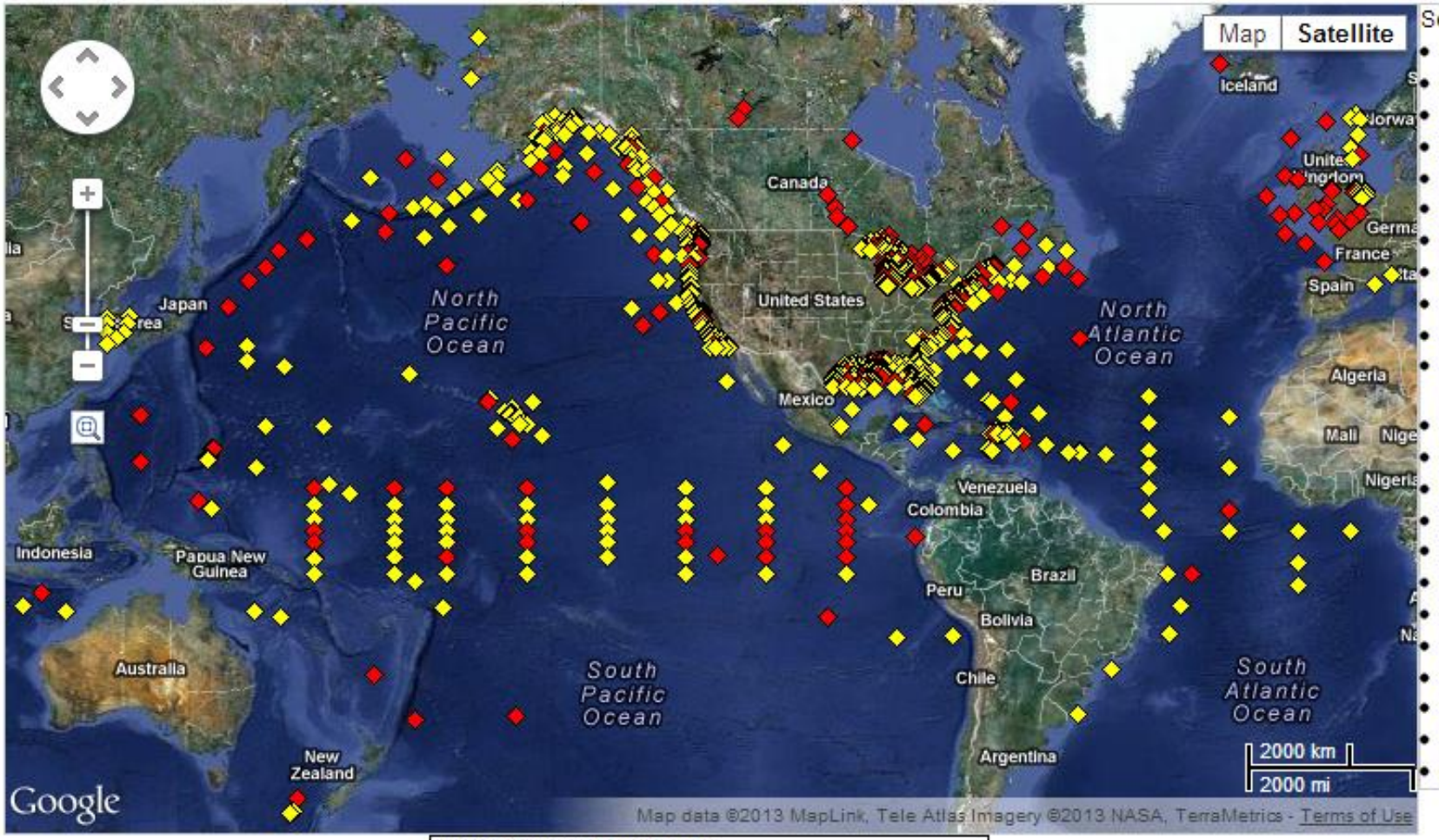

51003
NOAA
203


U.S.
COAST
GUARD
BEGG

National Oceanic and Atmospheric Administration's

National Data Buoy Center

Center of Excellence in Marine Technology



Select a region:

- Atlantic (Tropical)
- Atlantic (West)
- Australia
- Bay of Bengal
- Caribbean Sea
- Central America
- Chile
- Europe
- Gulf of Alaska
- Gulf of Mexico (West)
- Gulf of Mexico (East)/Florida
- Nova Scotia
- Pacific (North)
- Pacific (West)
- USA-Alaska
- USA-Hawaii
- USA-Great Lakes (Ea
- USA-Lake Superior
- USA-Northeast
- USA-Northwest
- USA-Southeast
- USA-Southwest
- World

Mouse Cursor Coordinates:

- Stations with recent data
- Stations with historical data only
- Stations with no data in last 8 hours (24 hours for tsunami stations)
- Tsunami station in event mode (within previous 24 hours)

1170 stations deployed
850 have reported in the past 8 hours

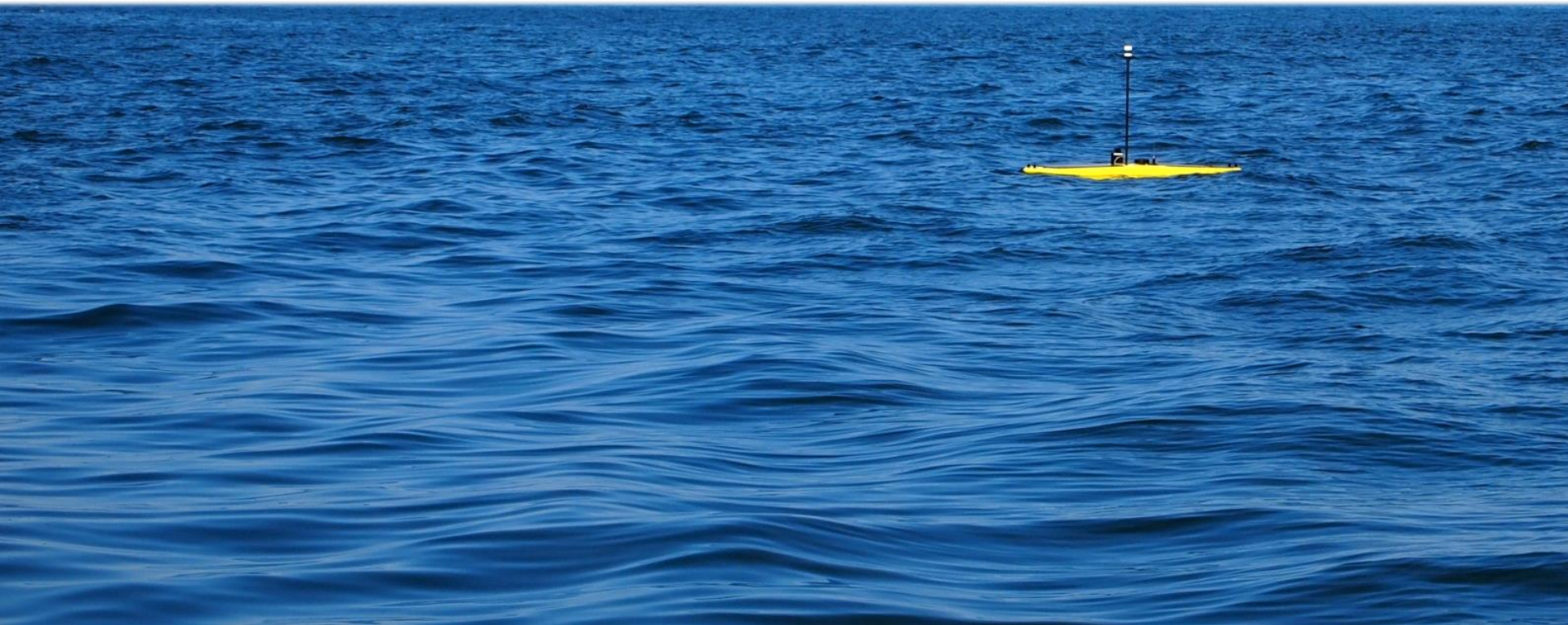
Disclaimer

Get Observations by Program as KML

Get Observations by Owner as KML

How do I use KML?

Solar and wave powered ocean robots



3 Primary Business Areas

Commercial

liquid robotics OIL+GAS

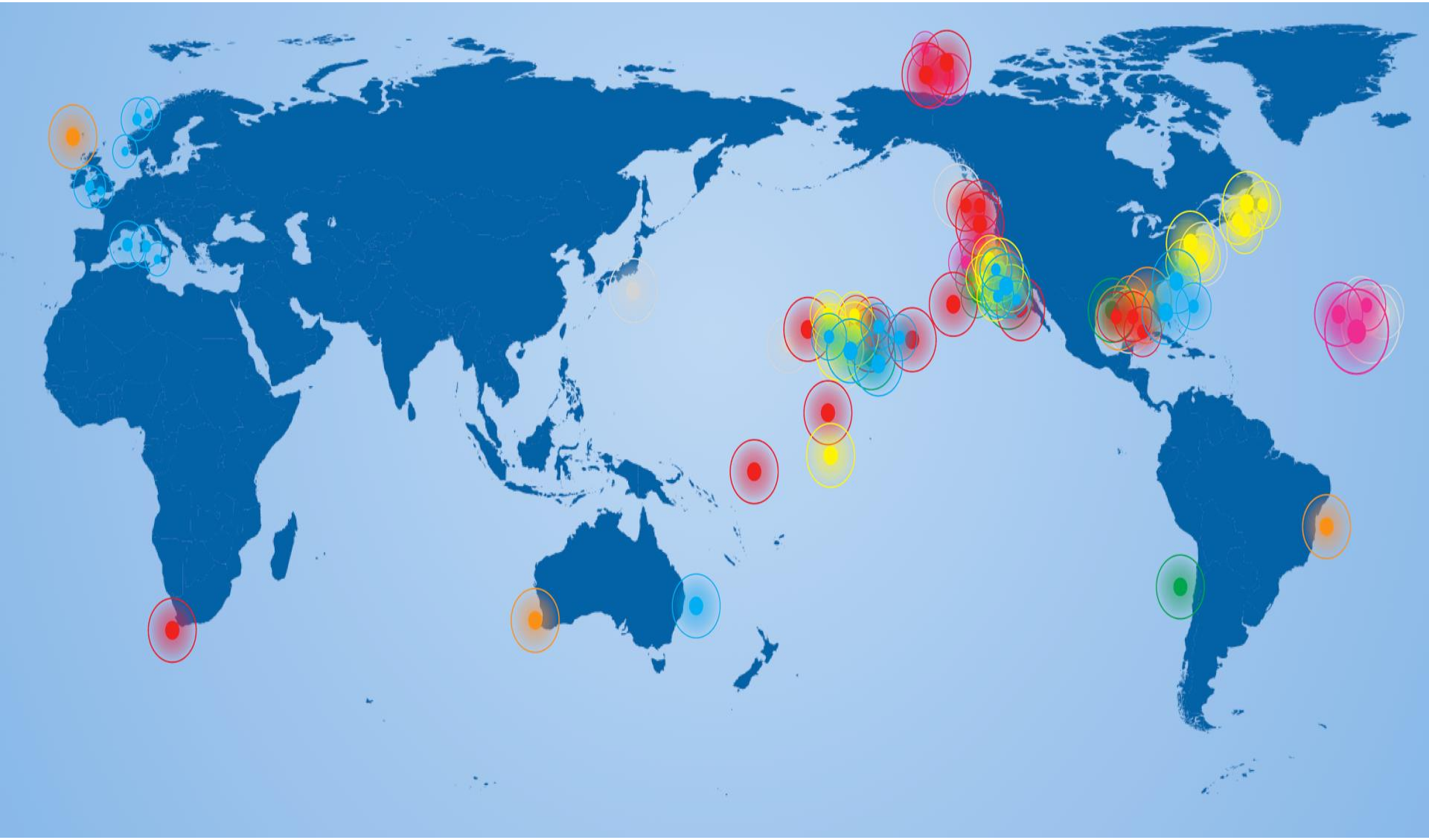
A joint venture with Schlumberger

Science &

Environment

Security

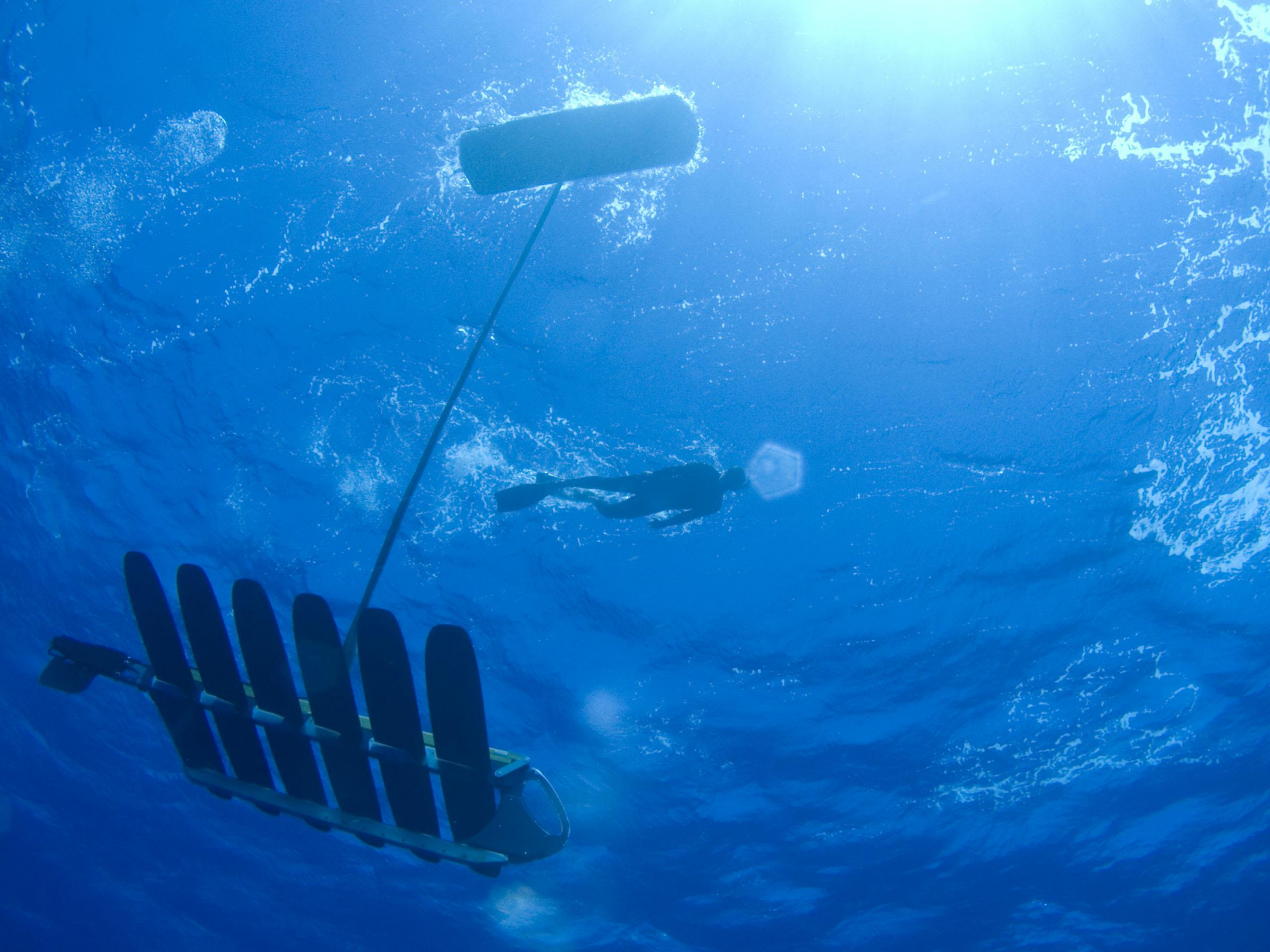
WAVE GLIDER OPERATIONS THROUGH 2012



MARINE ROBOT ENERGY OPTIONS

1. Carry it with you, in batteries or tanks
2. Dock & recharge
3. Sun
4. Wind
5. Waves
6. Thermal gradients
7. Soil microbes
8. Graze?
9. Other…?

liquid robotics

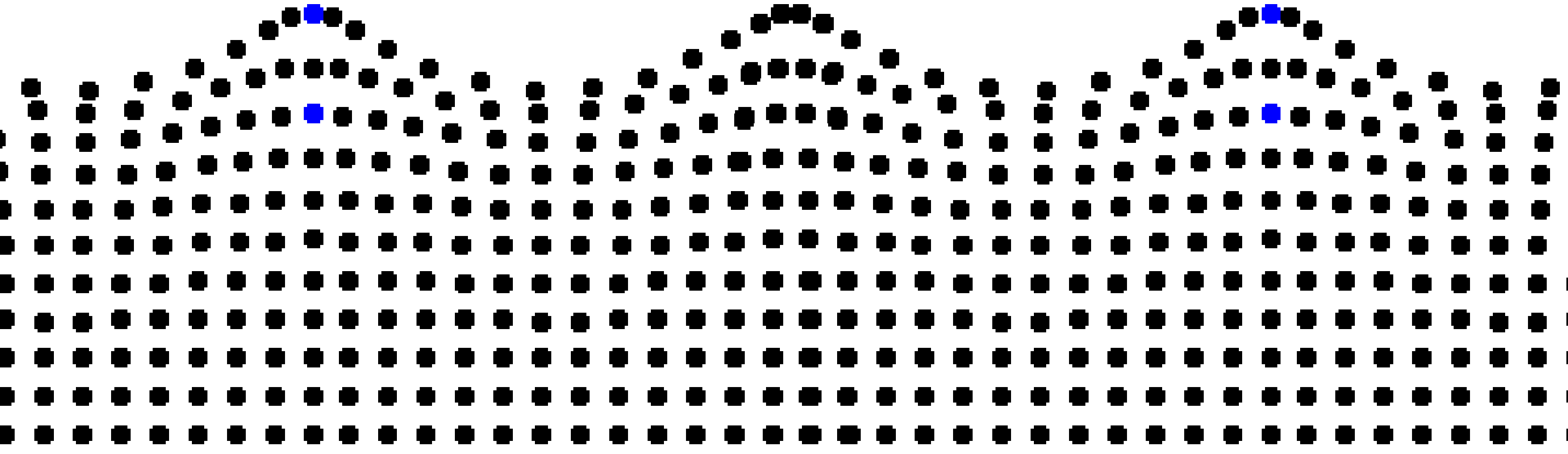


Ocean Waves

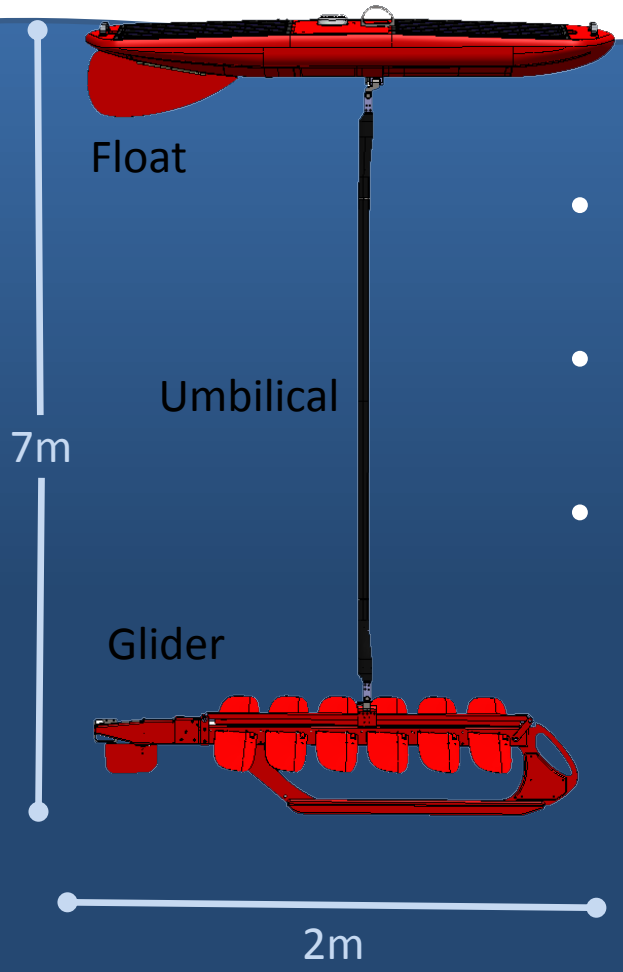
Wave amplitude decreases rapidly with depth: $A_y = A_s e^{y*L/2pi}$

We use the difference to extract power

Wave Period :	3 seconds	6 seconds	9 seconds
Wave Length :	14m	56m	126m
Relative amplitude at 6.5m depth:	95%	52%	28%

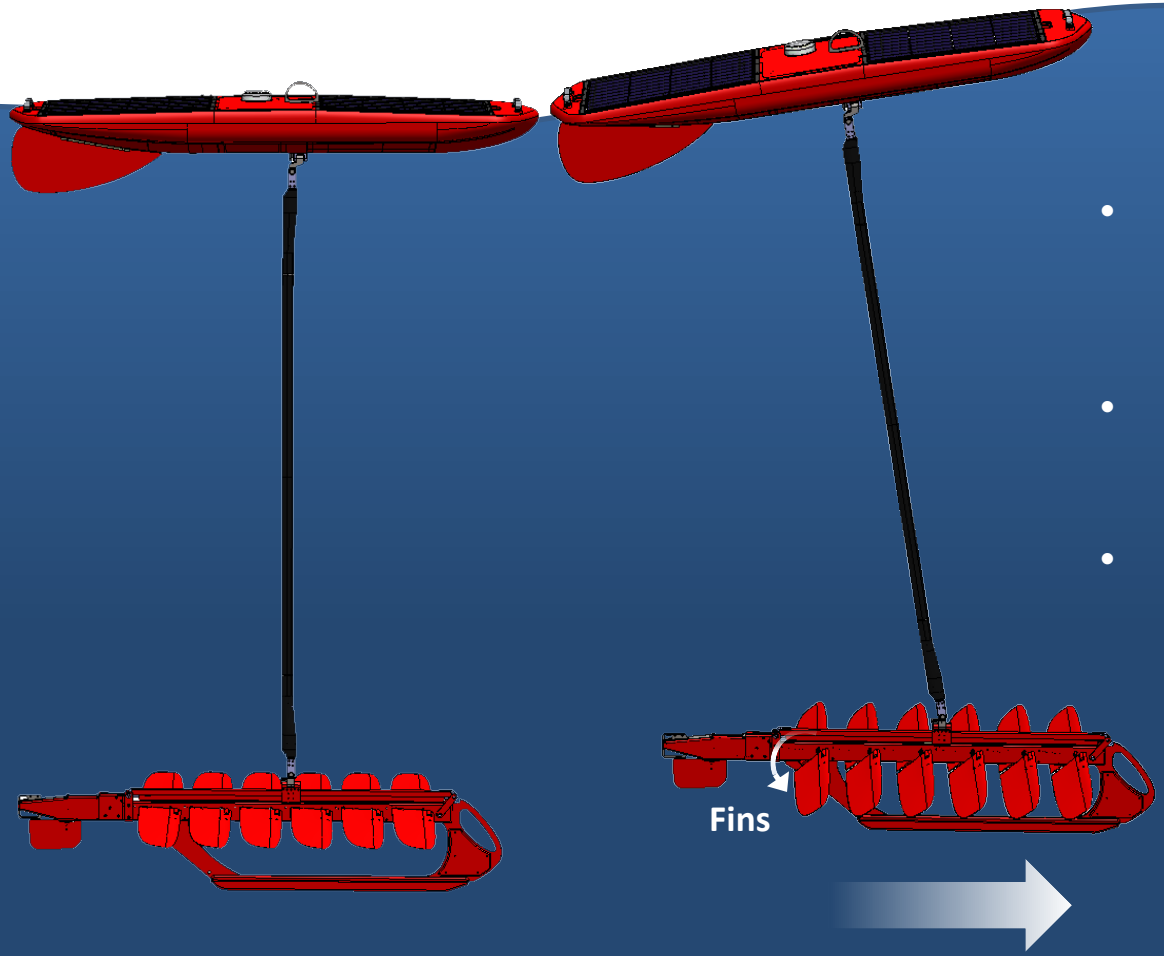


Wave Glider™ Autonomous Ocean Vehicle



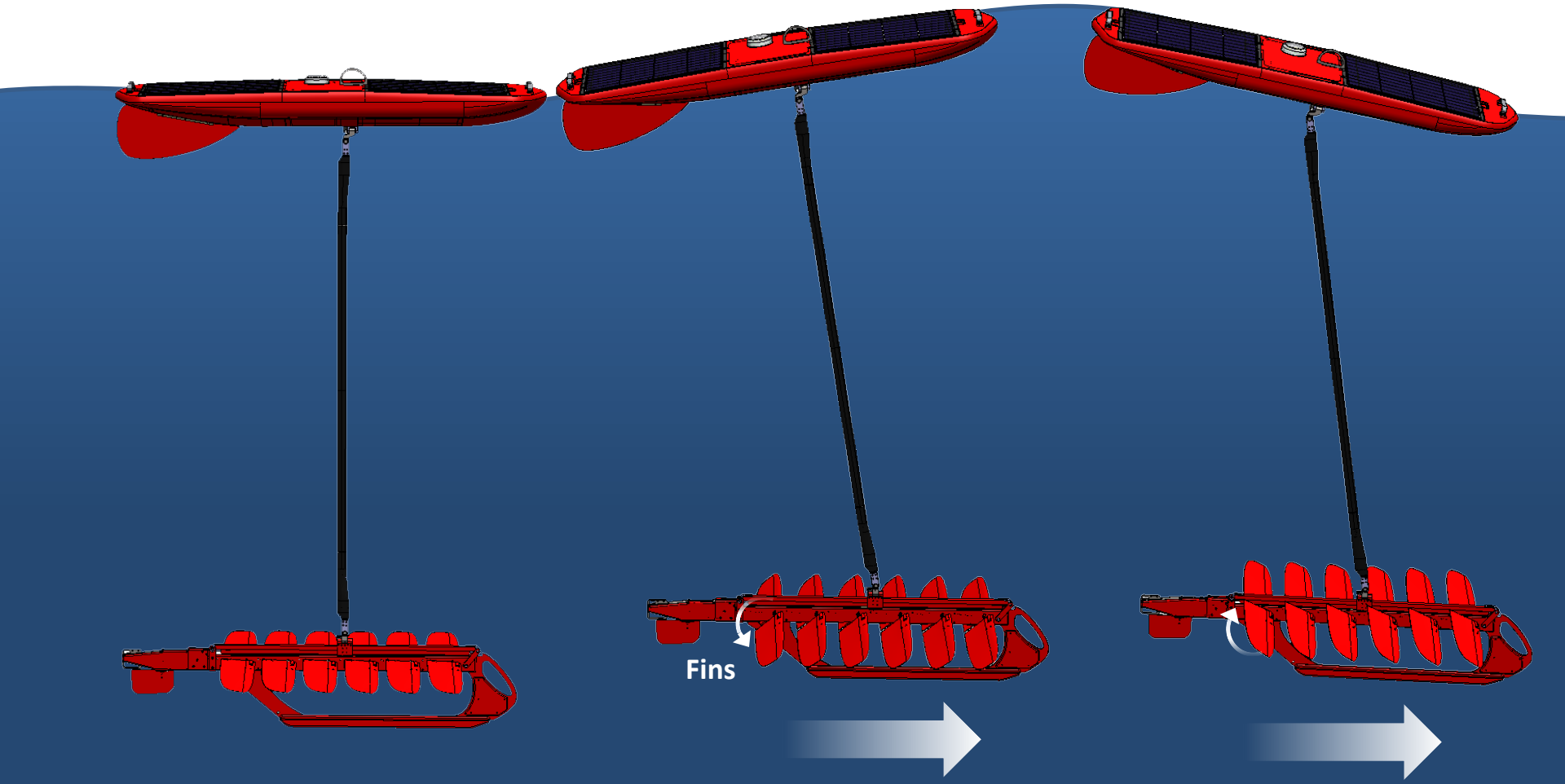
- Two part vehicle converts wave motion to thrust
- Solar panels provide power for navigation and payloads
- Satellites provide constant, global communication and control

Gliding on the way up…

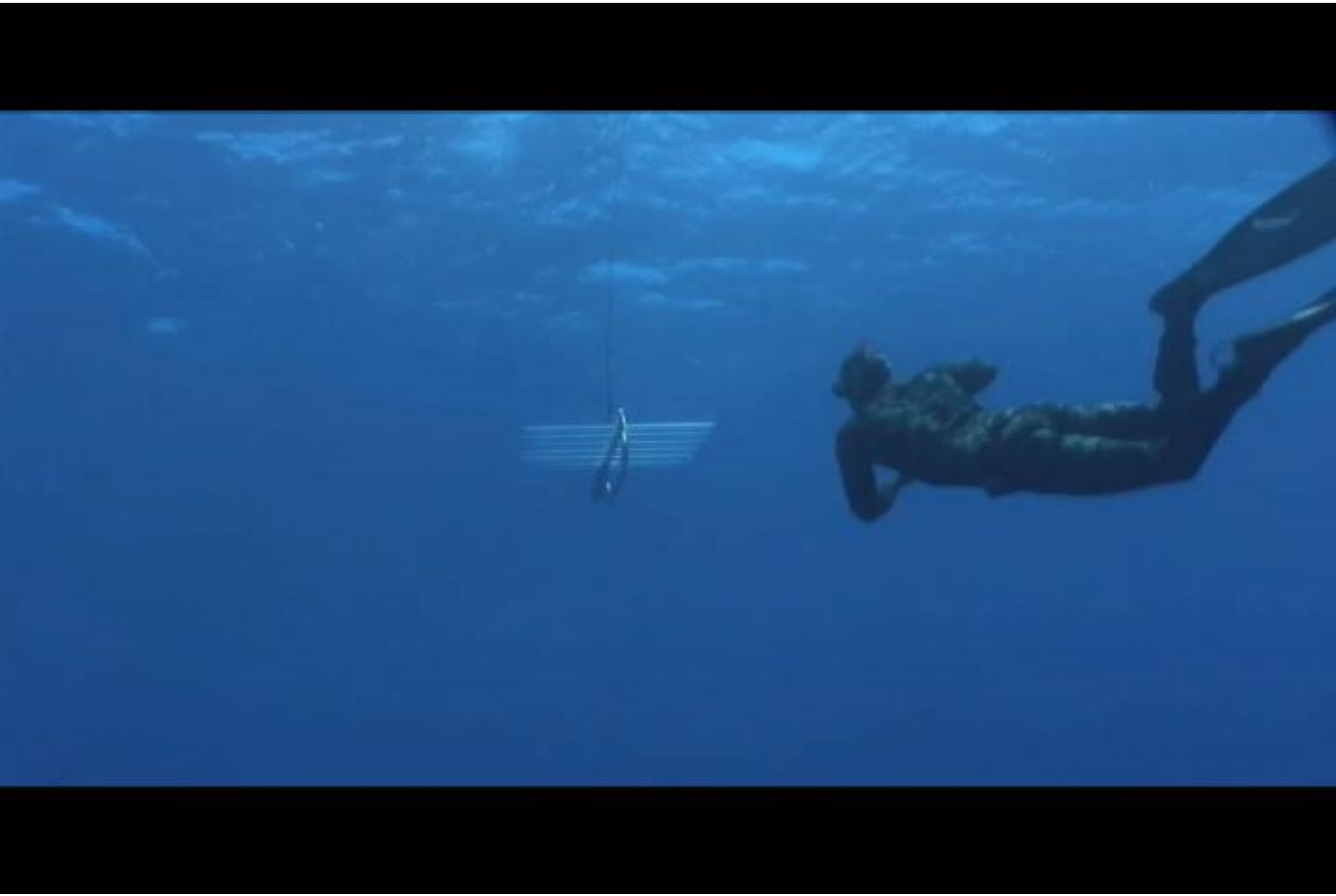


- A passing wave lifts the float and pulls the glider upward
- Passive fins on the glider are pushed downward
- As the glider moves up, the fins generate thrust to pull the vehicle forward

… and gliding on the way down



- Both upward and downward motions produce thrust
- A rudder at the tail of the glider steers the vehicle in any direction



Kaimana::LiquidRoboti ×

gliders.wgms.com/home/vehiclepage.aspx?orgid=1&entitytype=85

Apps | Liquid Robotics Li... | MISUMI, the catal... | Advanced Patent... | MITCalc - Mecha... | Electric Car Batte... | Kurt Hughes Mult... | Electric Motorspo... | Aspen Power Cat... | Sail-World.com : ... | Marine Hybrid | V...

liquid robotics

Kaimana

Auto Evasion

Mode: Follow Fixed Heading
Ave Speed(kts): 0.00
Last Speed(kts): 0.00
Desired Heading: 0
Path Heading: 0
Ave Water Speed(kts): 0

Light: IR: XBee:
P/L1: P/L2: Sub:
P/L3: PEP:

Follow Sequential Course
Hold Station At Waypoint
Follow Custom Course
Hold Current Position
Follow Fixed Heading
Set Parameter
Comment
More Commands ...

Begin Mission

Show System Menus

Gliders:
Roger Hine (Sign Out)

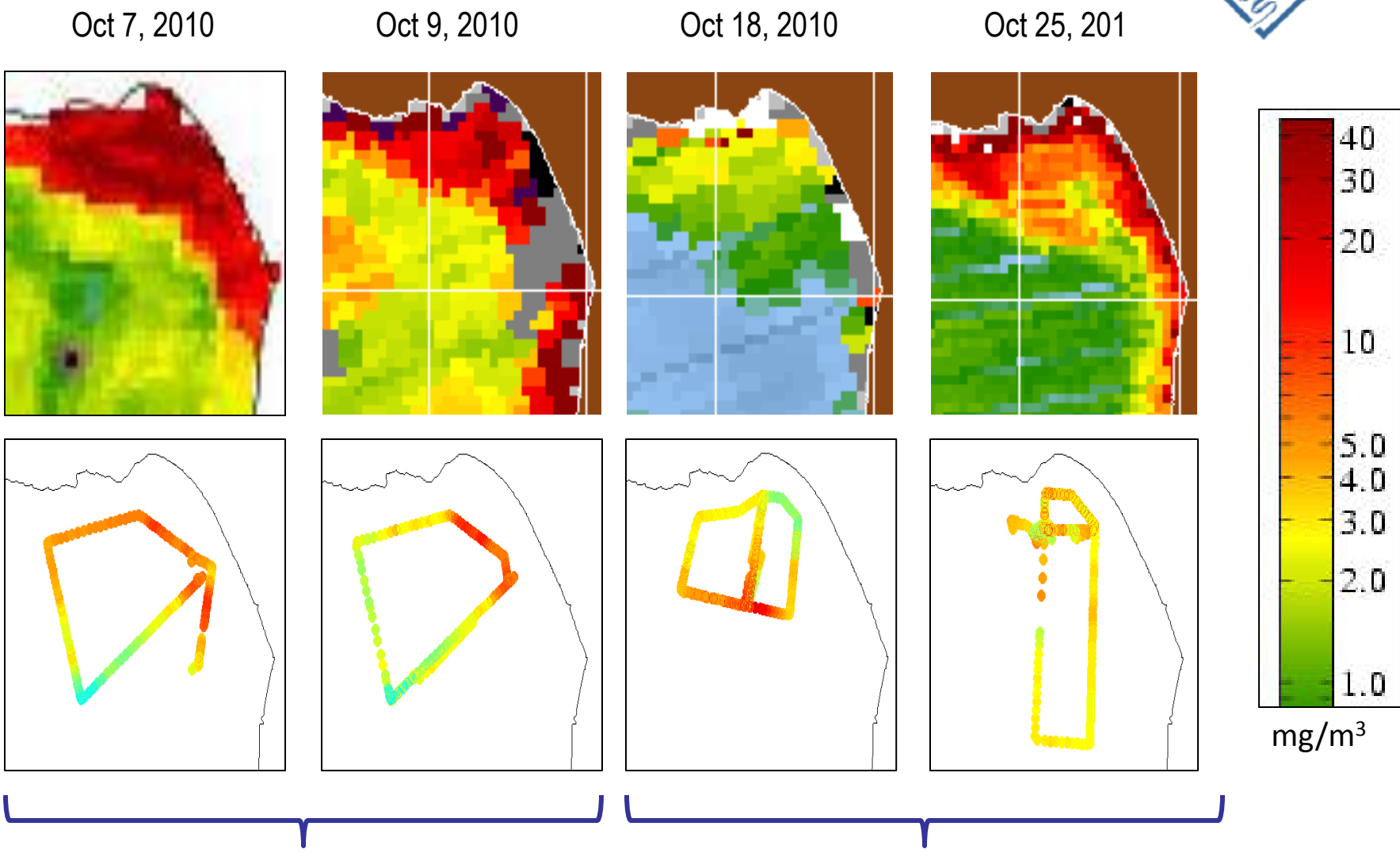
Alarms: Last refresh: Wed-Oct-9-2013 5:26:46 (Hawaiian Standard Time) Autorefresh

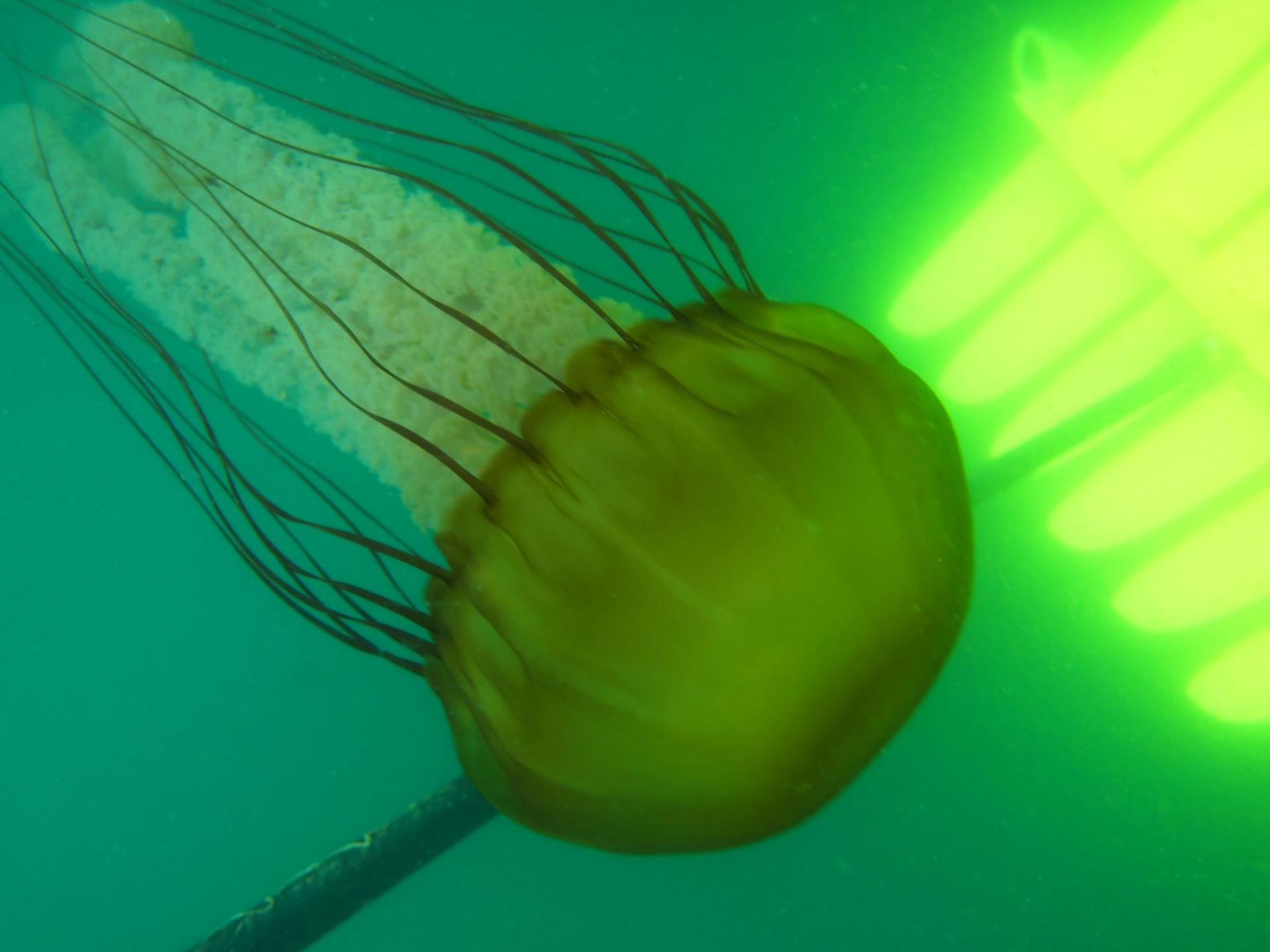
Duration: 30 minutes Prior To: **Now**, Switch To: Date Range Submit

4 WG Array Pattern Test, Jan 2011

- Approx 20km x 10km area
- 87km course for each glider
- 37.5 hour lap time
- 0.64m/s (1.25knots)
- 9 channels of flourometer data at surface and 7m

Comparison of satellite and WG data

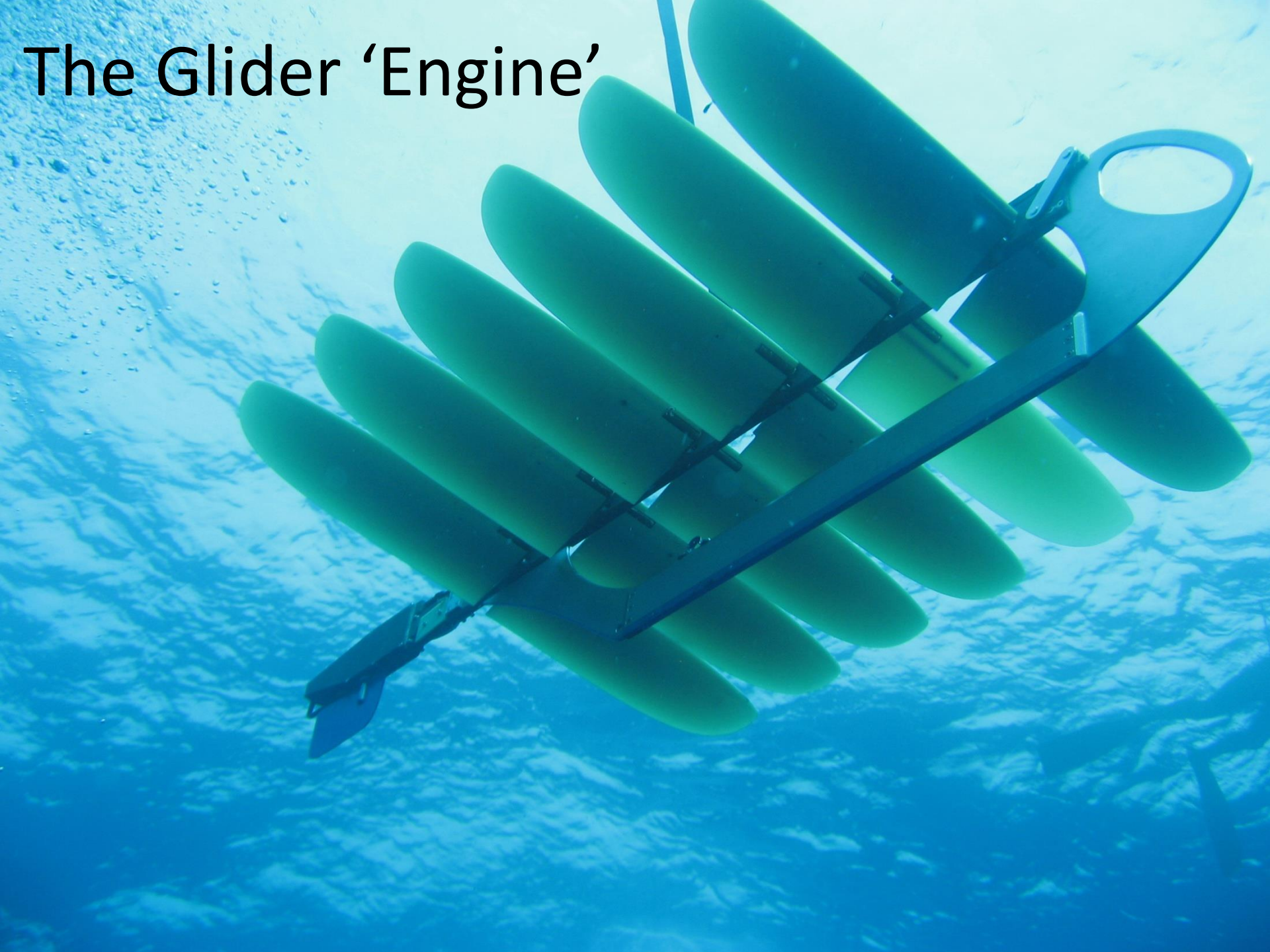


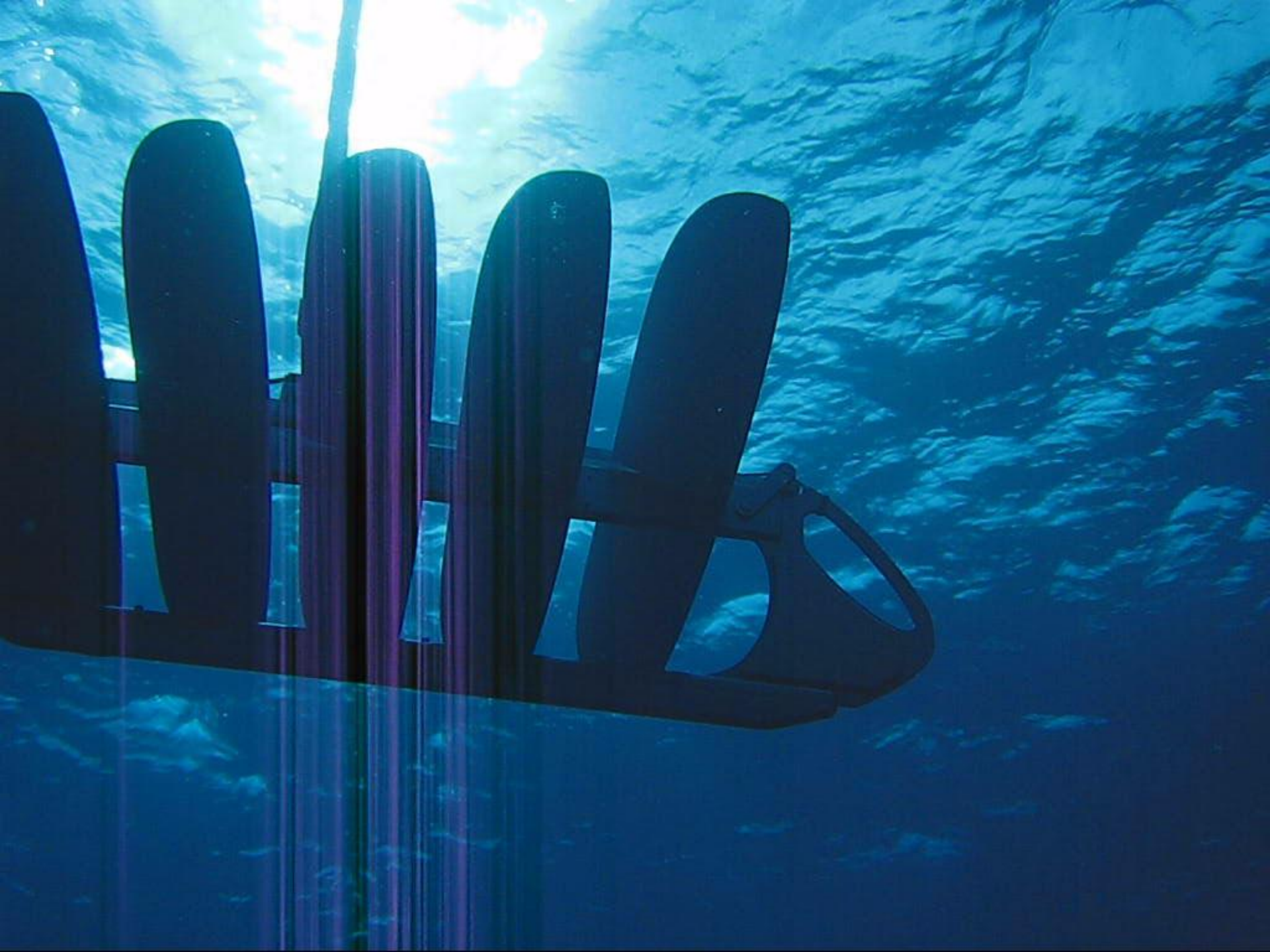


Postcard from a Wave Glider

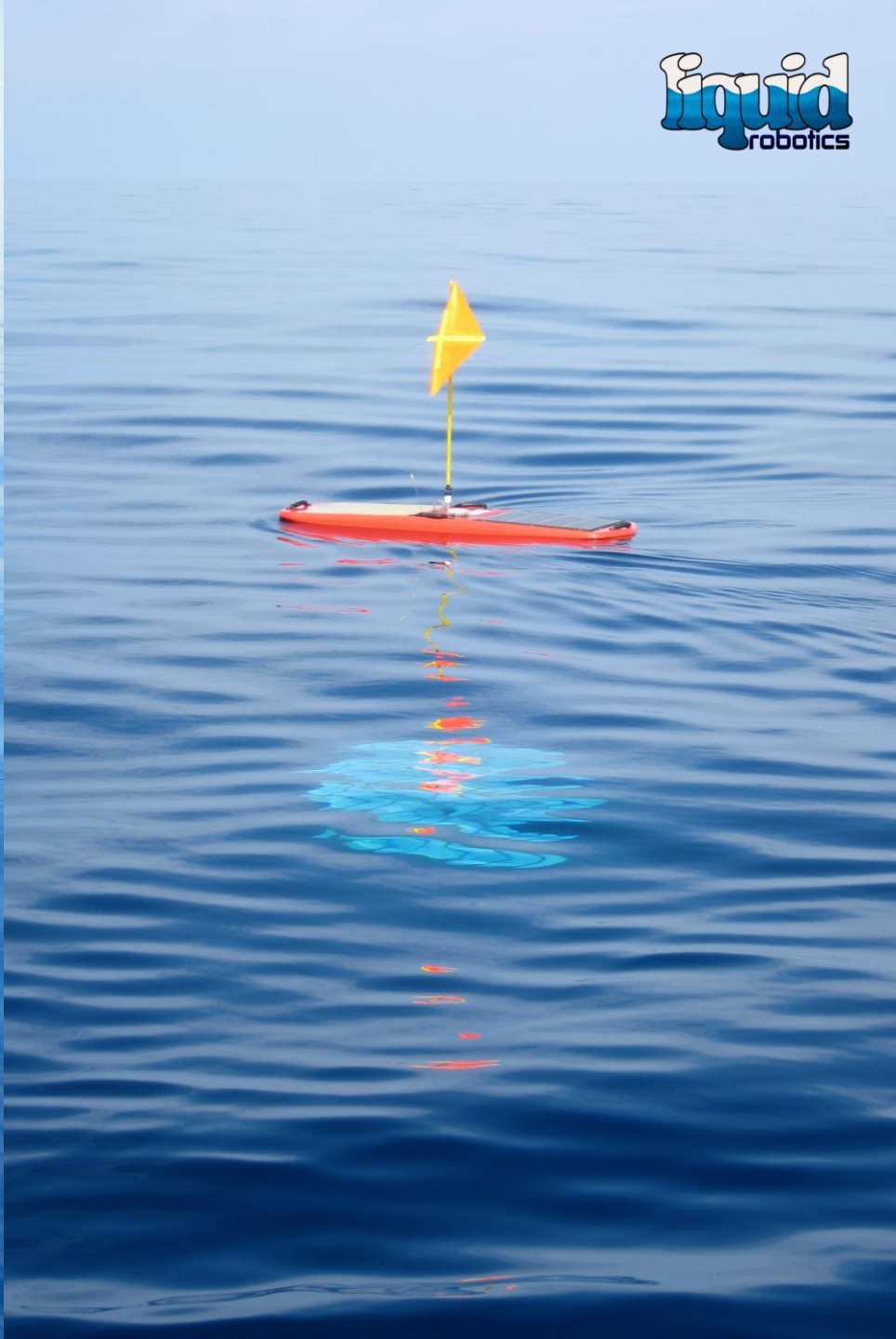
Gulf of Mexico, March 2011

The Glider ‘Engine’



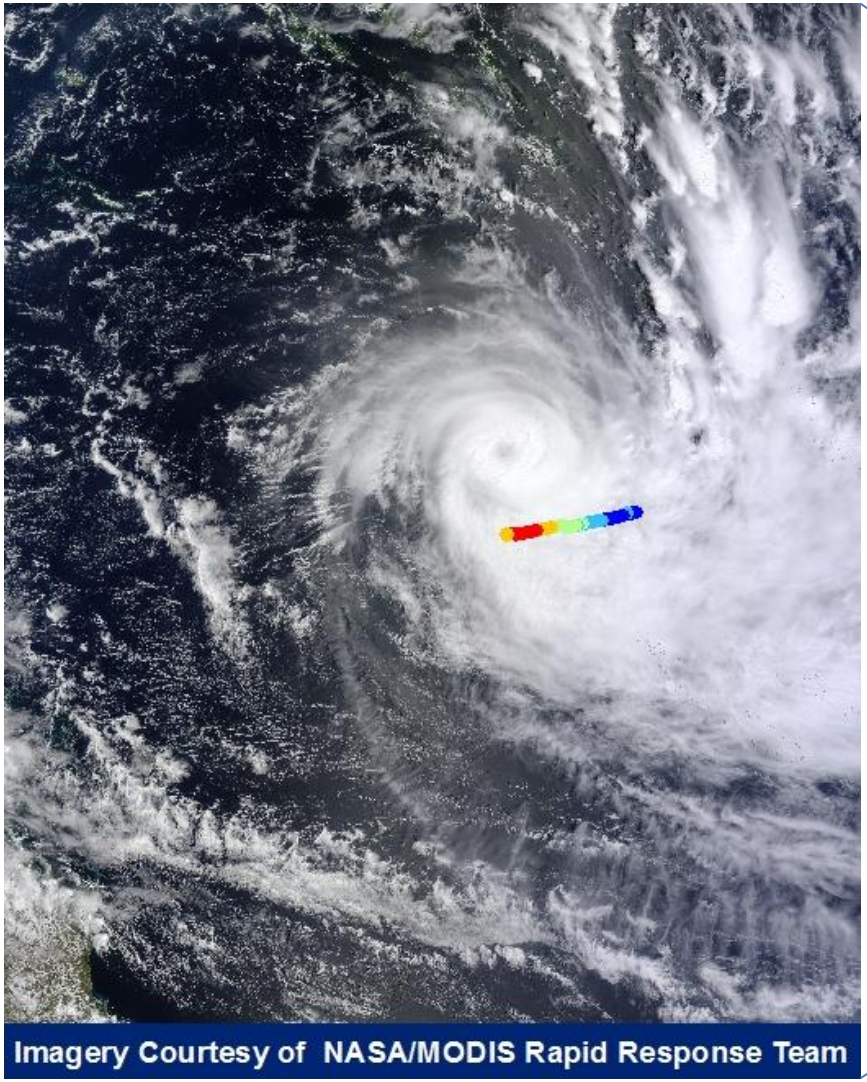


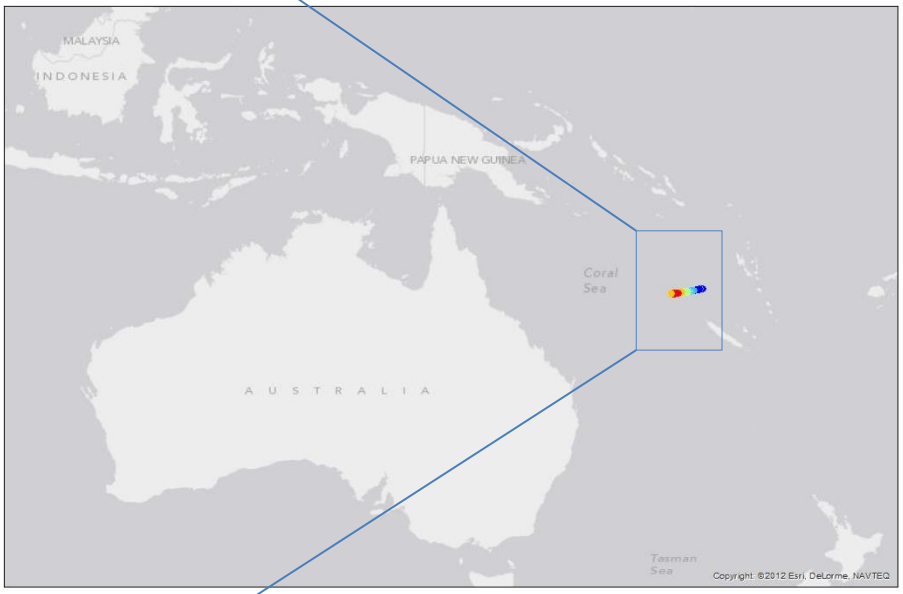
Calm Conditions…



… and rough

Wave Glider in Tropical Cyclone Freda





BBC NEWS

5 December 2012 Last updated at 10:27 ET

Share

Swimming robot reaches Australia after record-breaking trip

A self-controlled swimming robot has completed a journey from San Francisco to Australia.

The record-breaking 9,000 nautical mile (16,668km) trip took the PacX Wave Glider just over a year to achieve.

Liquid Robotics, the US company behind the

obot was fished out of the water in Hervey Bay completing its journey

NBCNEWS.com

G'day, mate! Ocean-crossing robot reaches Australia

Science robot ends Guinness record-breaking ocean journey

c|net

FAST COMPANY

POPULAR SCIENCE THE FUTURE NOW

Forbes CARS

GREEN TECH | 12/05/2012 @ 3:48PM | 4,023 views

Ocean Robot Completes Record-Setting 10,000 Mile Journey

SIGN UP FO

Take Note, Michael Phelps: Liquid Robotics' Wave Glider Swims 9,000 Miles To Australia, Breaks Record

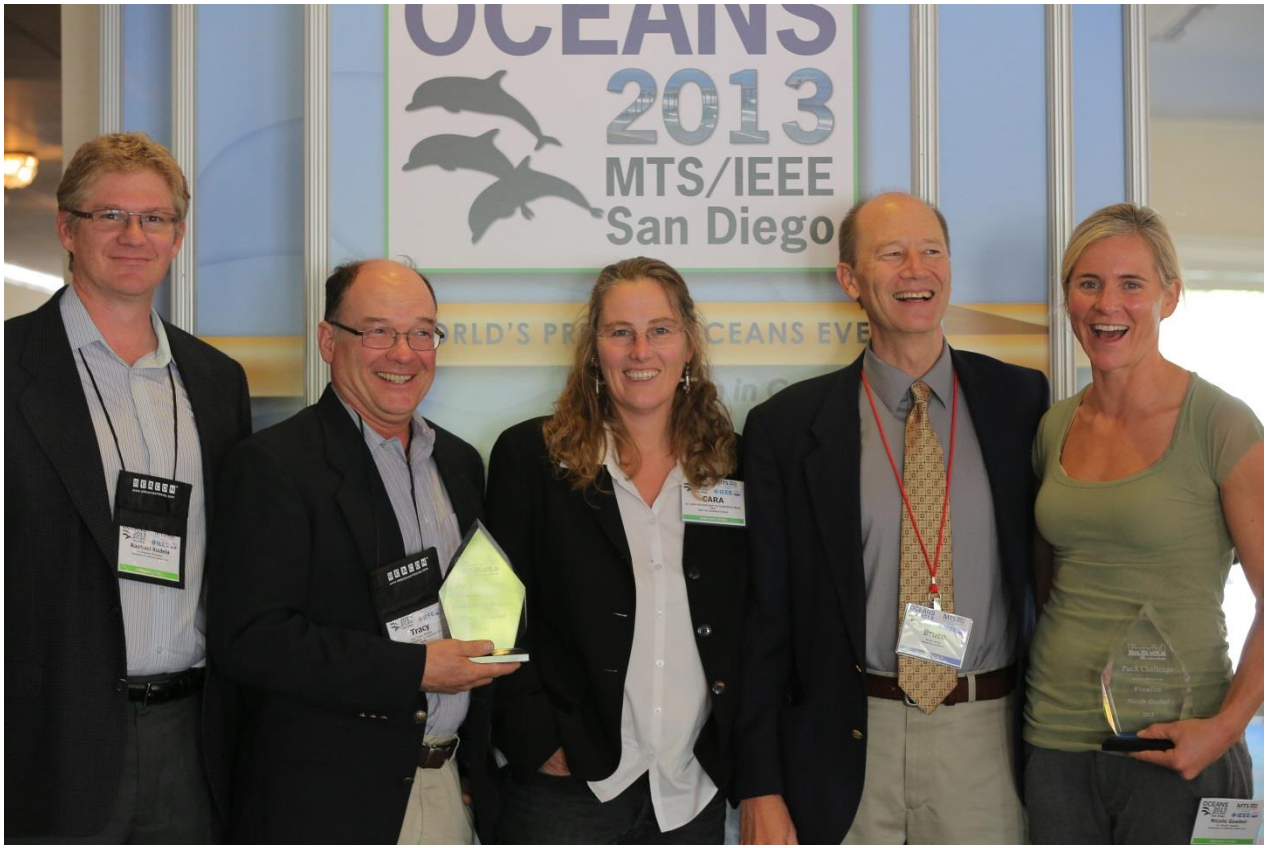
BY KIT EATON | DECEMBER 5, 2012

Papa Mau, 9000 miles later


San Francisco to Sydney
PACIFIC CROSSING
WORLD RECORD
LIQUID ROBOTICS
+1 (888) 574-4574
PAPA MAU

PAC-X CHALLENGE

Papers at
http://www.liquidr.com/pacx/pacific-crossing.html



Dr. Tracy Villareal

University of Texas at Austin
"A Comparison of the PacX Trans-Pacific Wave Glider Data and Satellite Data."

Dr. Nicole Goebel

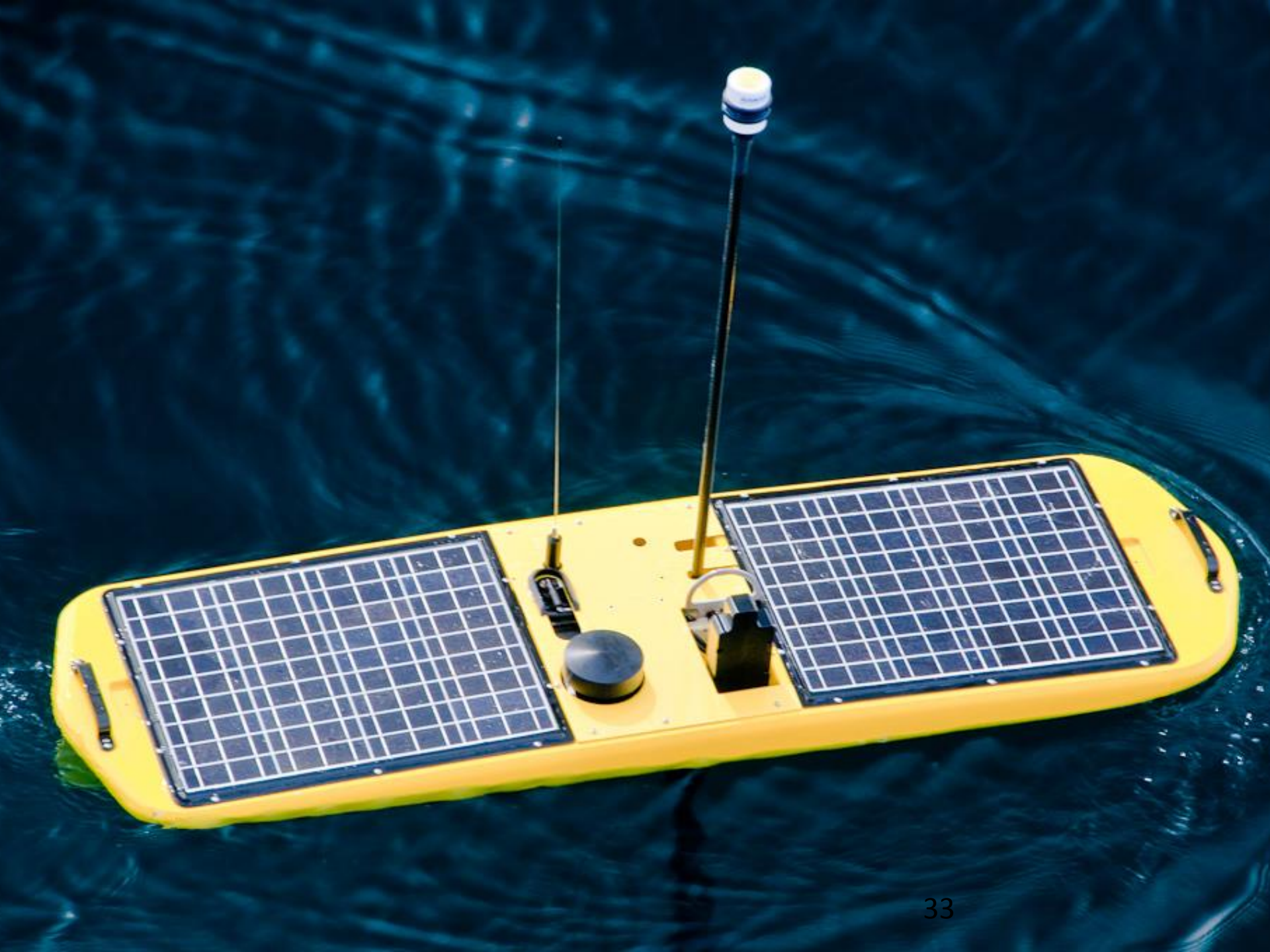
University of California Santa Cruz
"Using Replicate Wave Glider Sampling to Improve Estimates of Ocean Phytoplankton Biomass."

Dr. J. Michael Beman

University of California Merced
"Quantifying respiration rates and their environmental controls across the Pacific Ocean using PacX data."

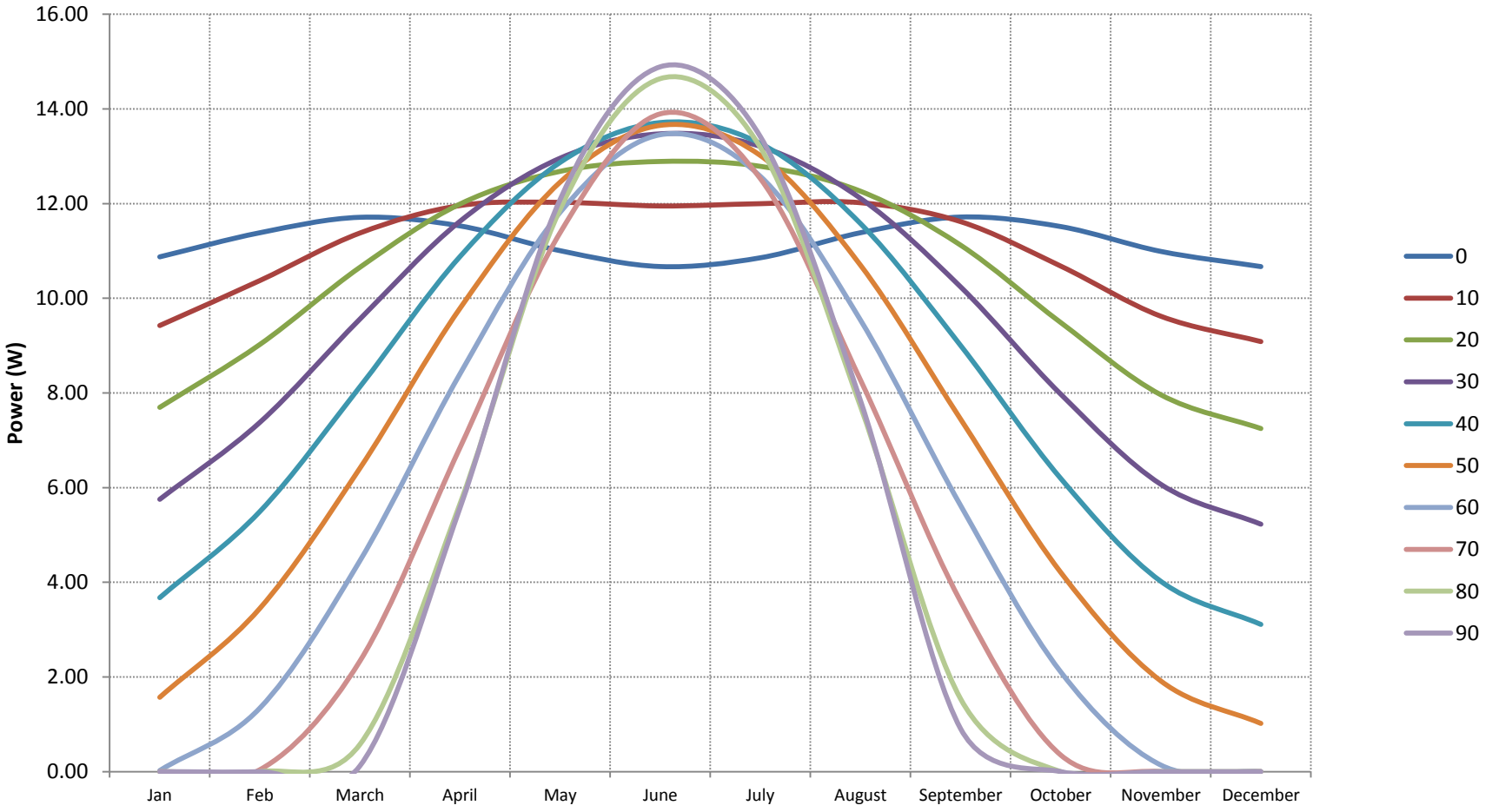
Dr. Elise Ralph

Independent Oceanographer, Boston, MA
"In Situ Observations of Finite Size Lyapunov Exponent Ridges in the Surface Pacific."



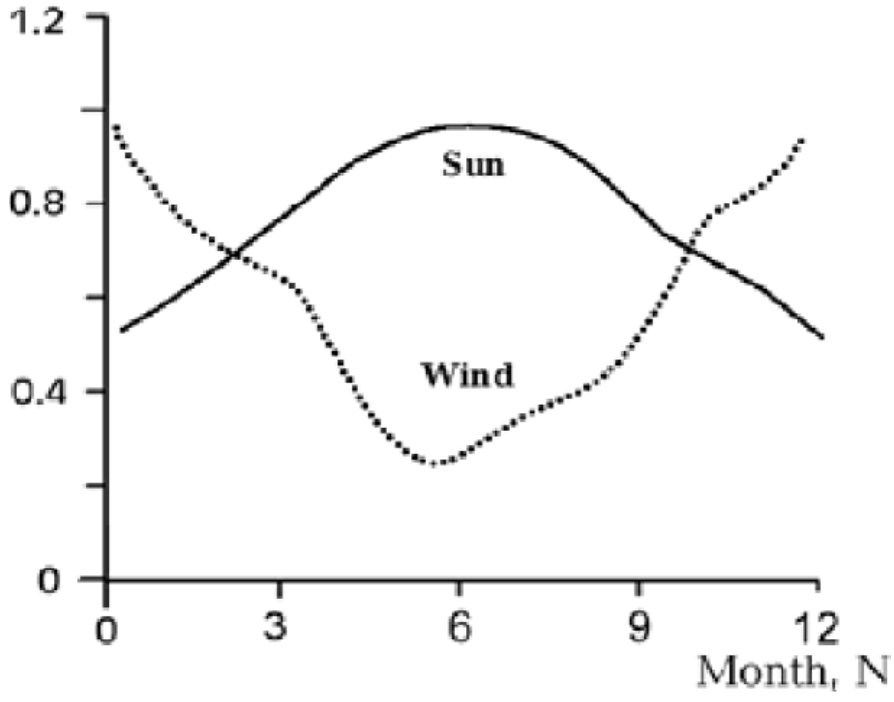
Maximum Sustainable Payload Power, SV2

By latitude, assuming 25% cloud cover

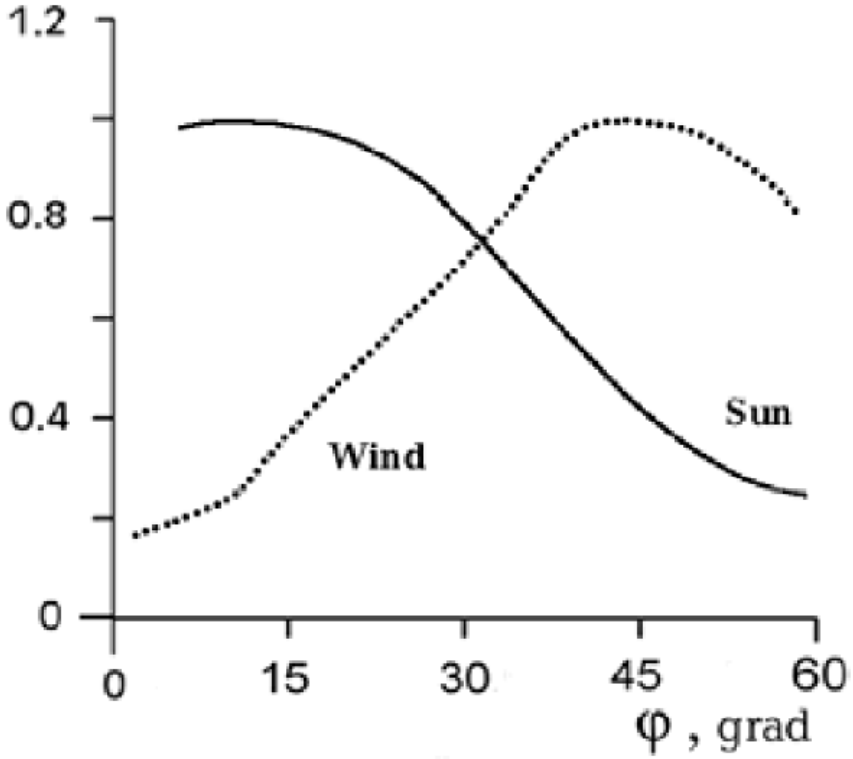


Solar and Wind Energy Distribution

By Month:

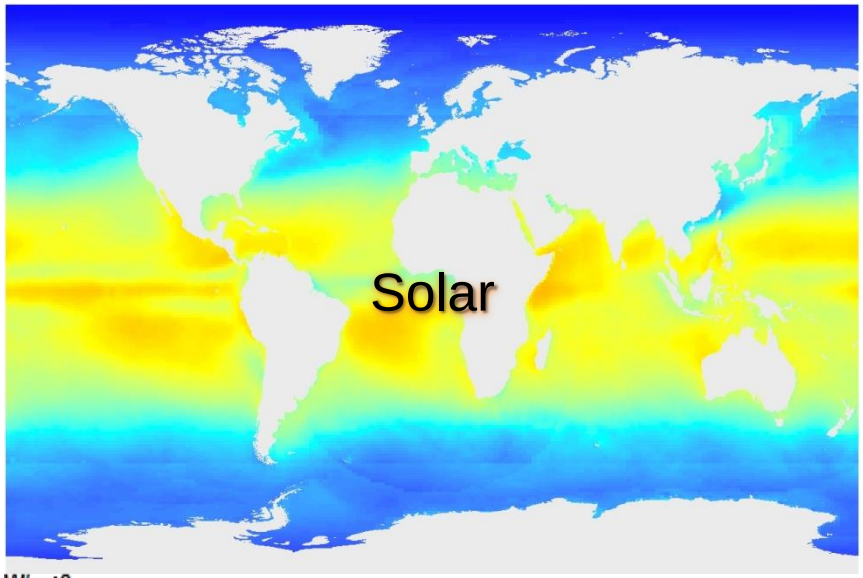


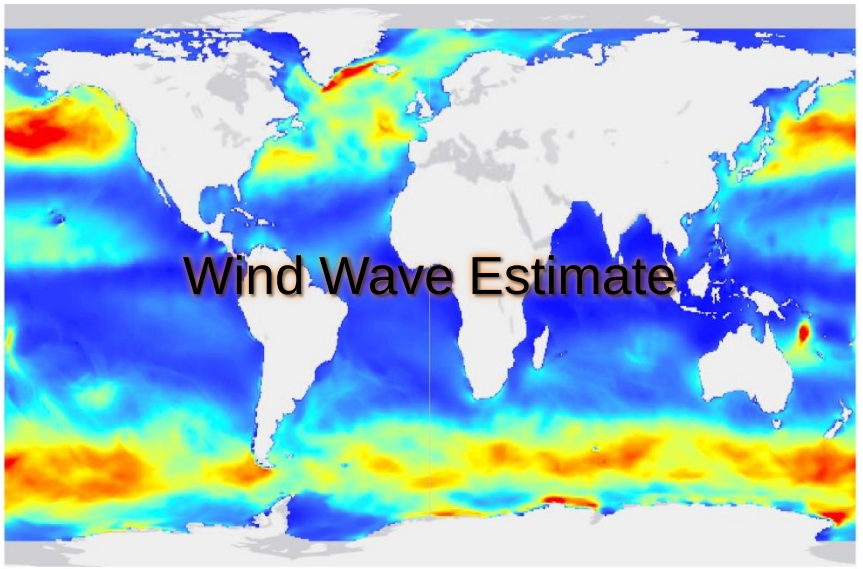
By Latitude:

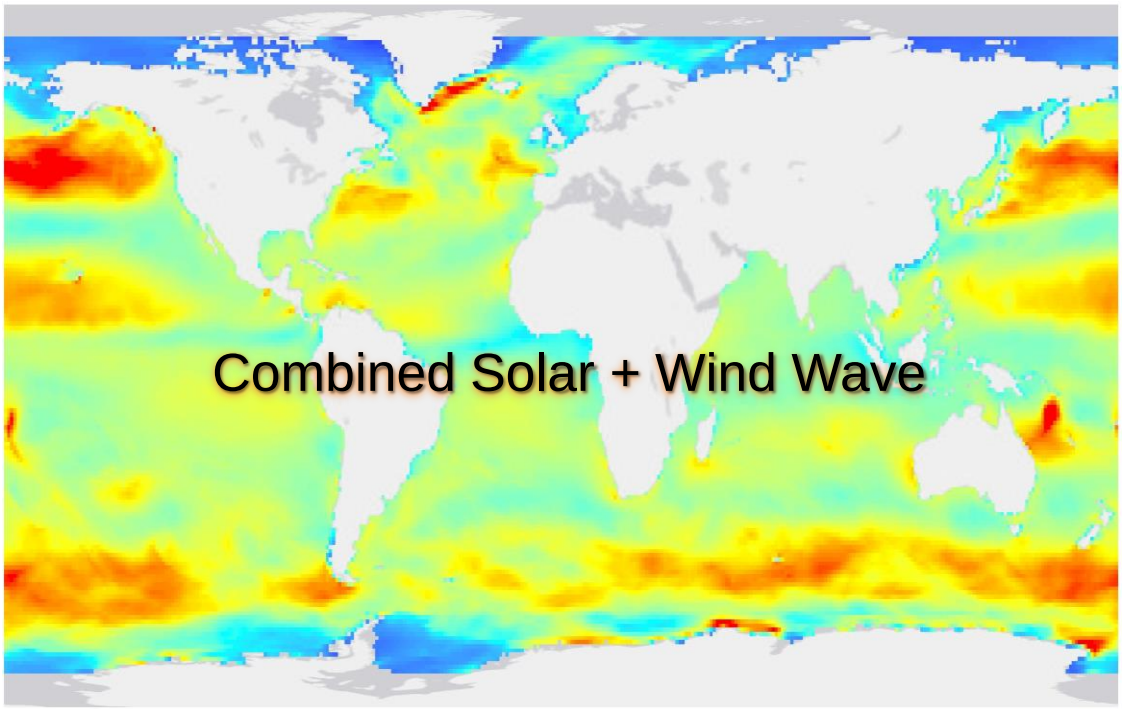


Source: M.D.Ageev "Application of solar and wave energies for long-range autonomous underwater vehicles." *Advanced Robotics,* Vol. 16, No. 1, pp.43-55 (2002)

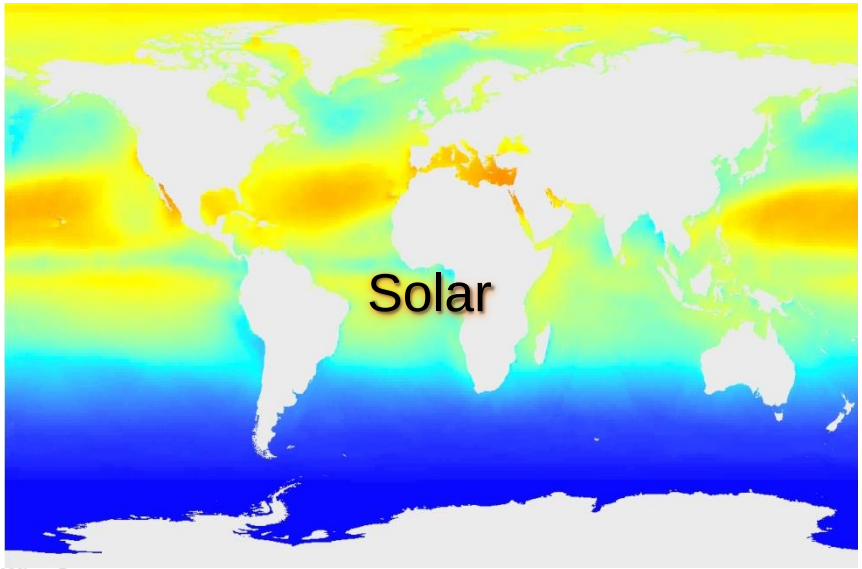
Power Density (W/m^2), March Average

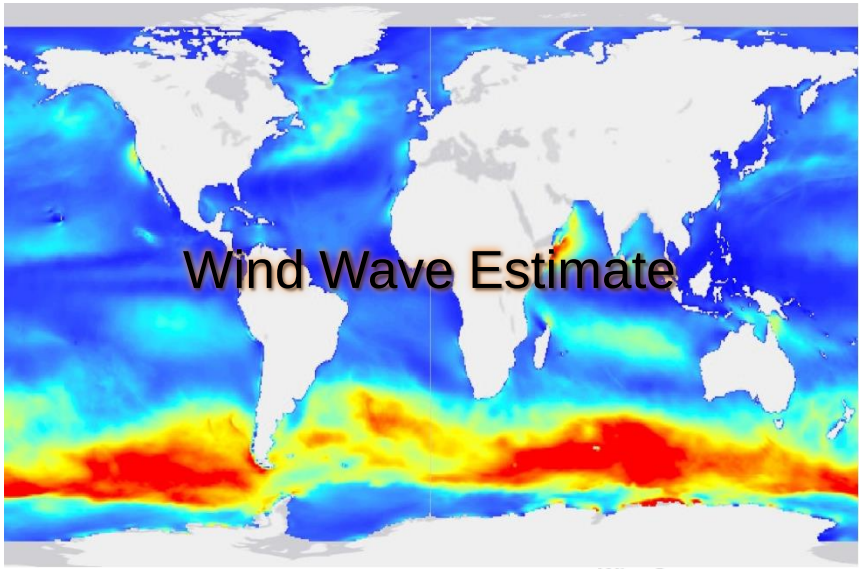


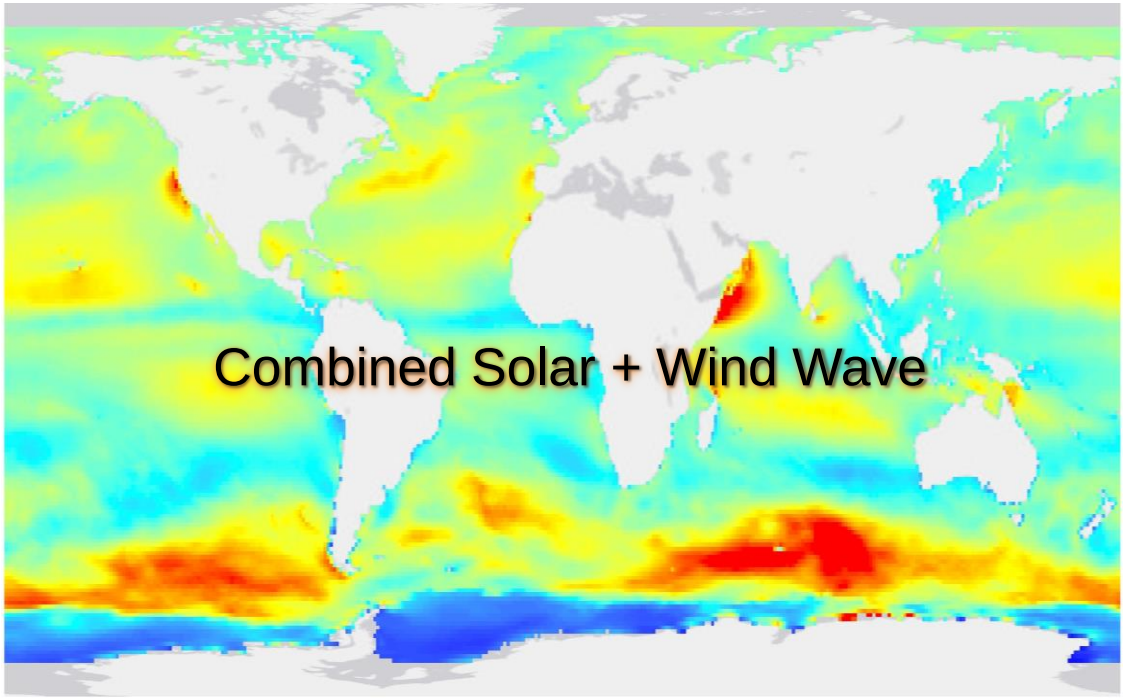




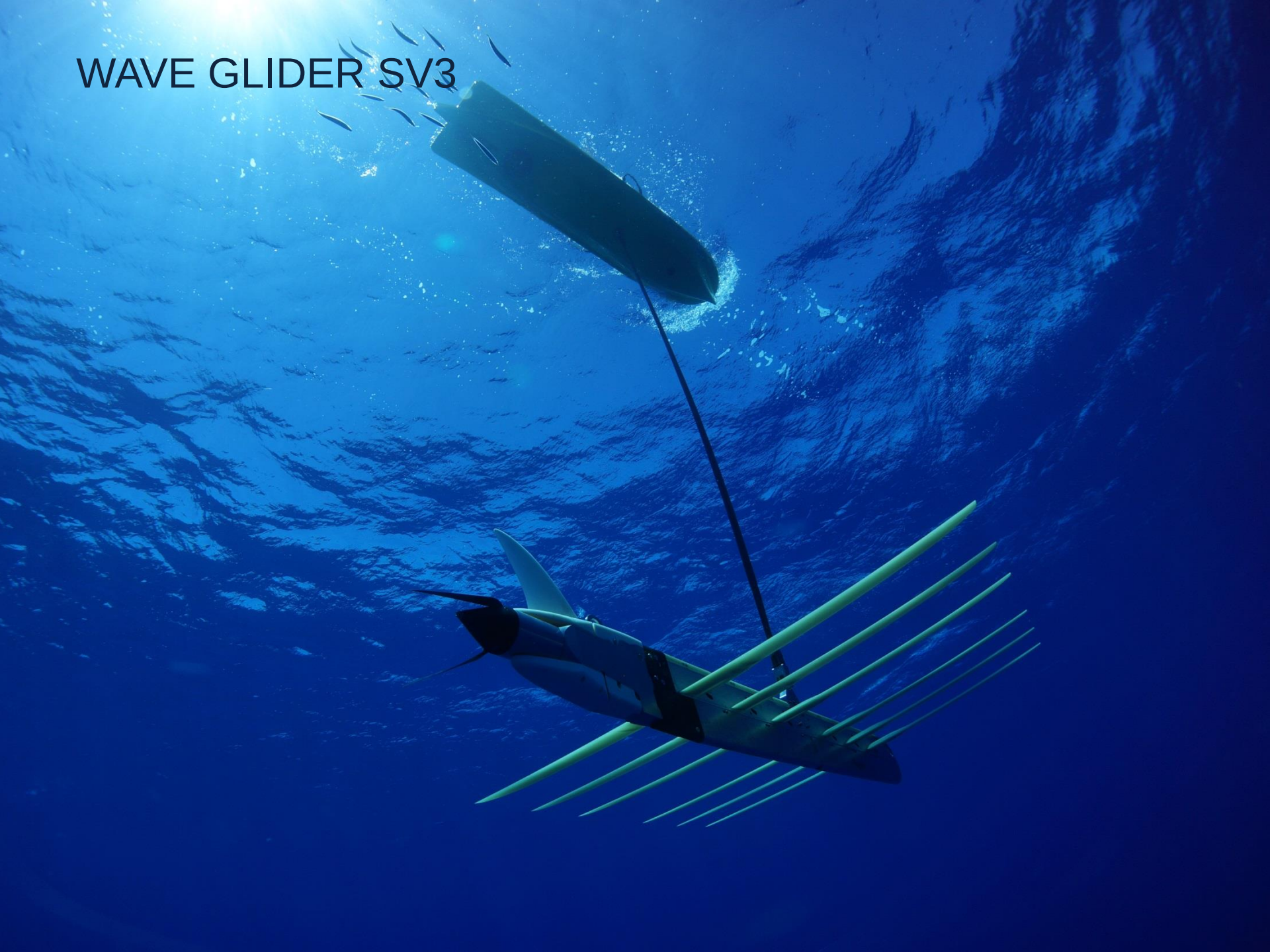
Power Density (W/m^2), June Average



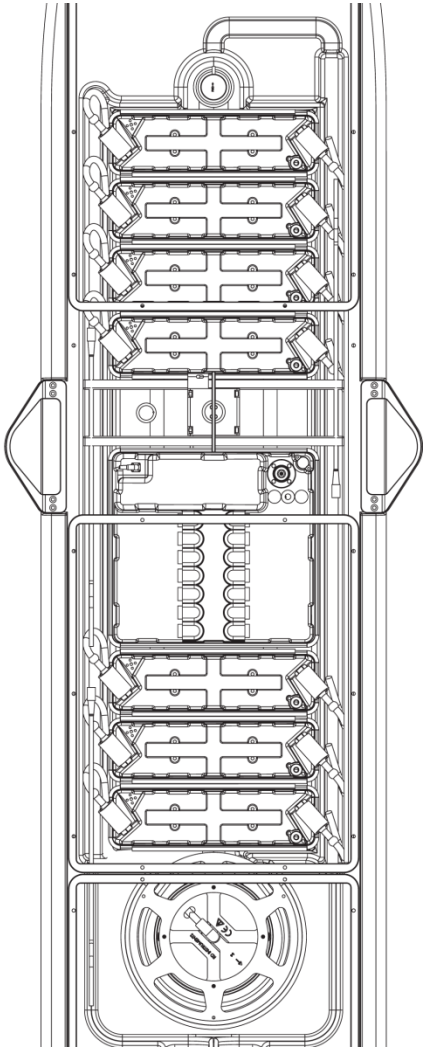


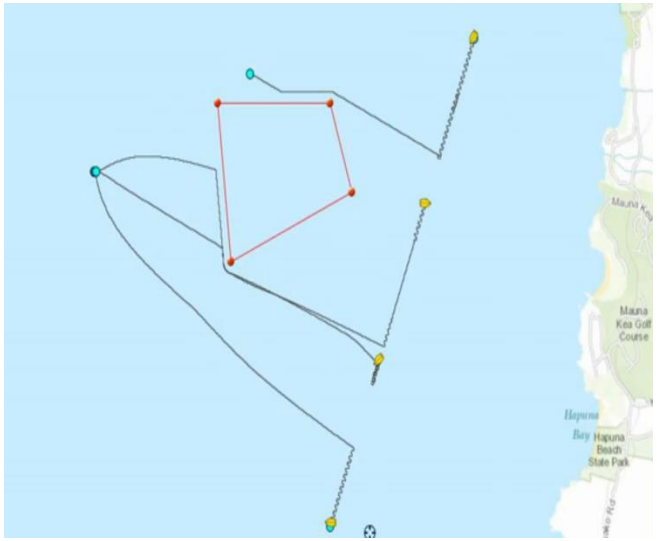


WAVE GLIDER SV3



WAVE GLIDER SV3





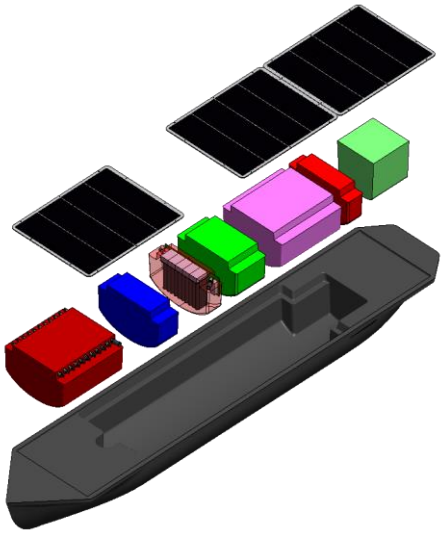
Regulus, configurable computing platform
- autonomy
- swarms, picket fences, formations
- data delivery & processing options

Hybrid propulsion, waves & solar with auxiliary folding prop thruster

AMPS (Adaptable Modular Power System)

A server rack at sea

SV3 ADAPTABLE MODULAR POWER SYSTEM (AMPS)

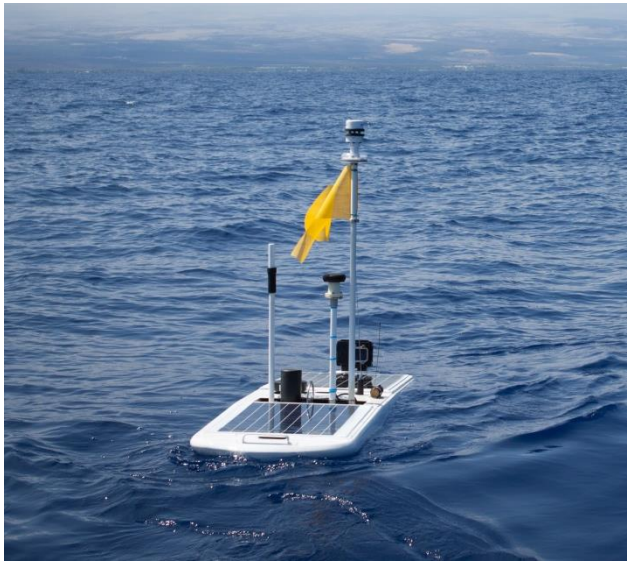


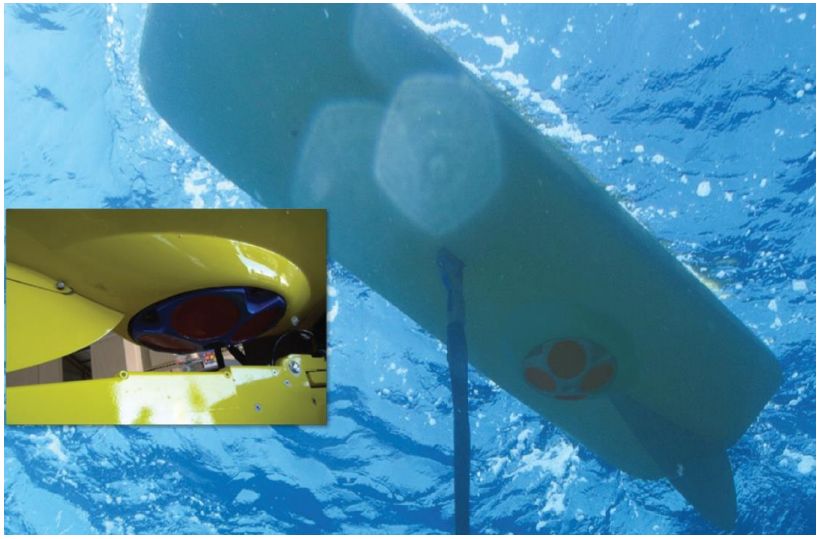
	Max Solar	Base Battery	Max Battery	Power Down Umbilical	Payload Peak Power
SV2	86 W*	0.65 kWh	0.65 kWh	13 W	80 W
SV3 w/AMPS	170 W	0.98 kWh	7.84 kWh	130 W	400 W

*112W panel upgrade available for SV2

WAVE GLIDER SV3

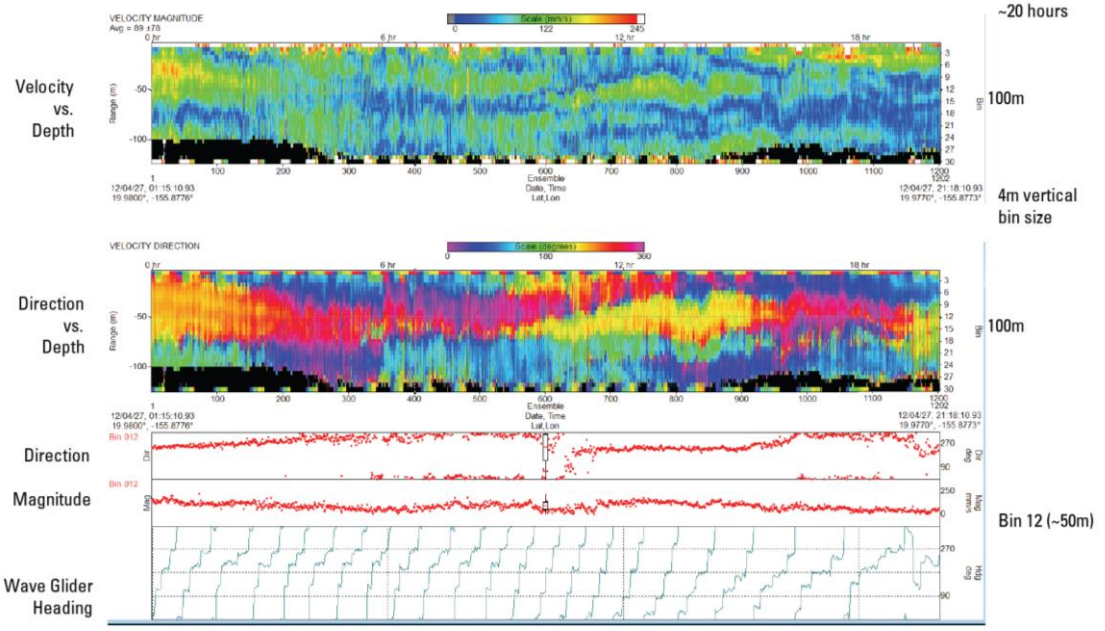
METOC WAVE GLIDER



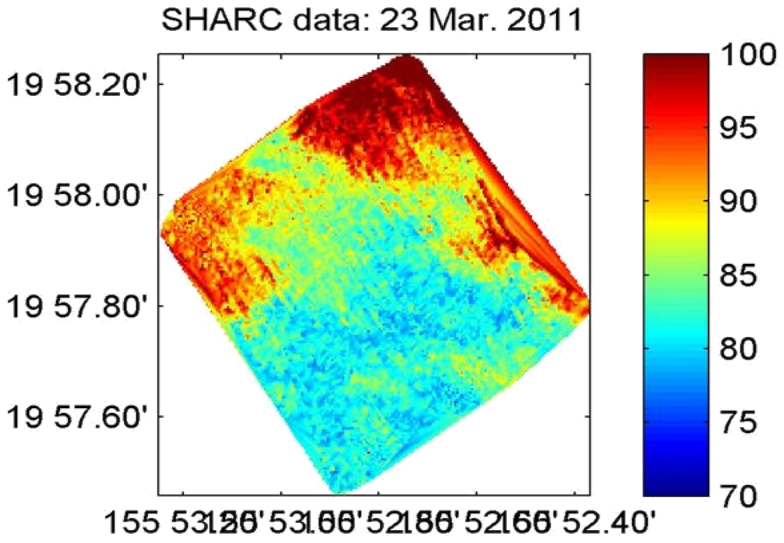


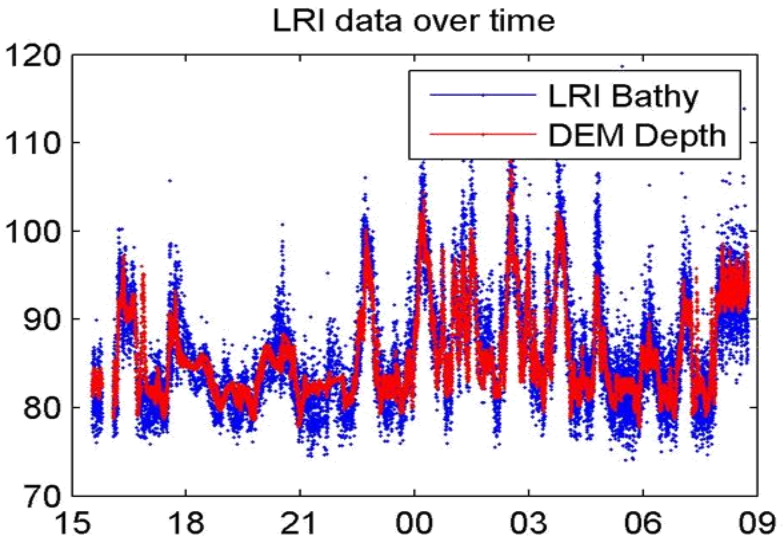
METOC Wave Glider Sensors:

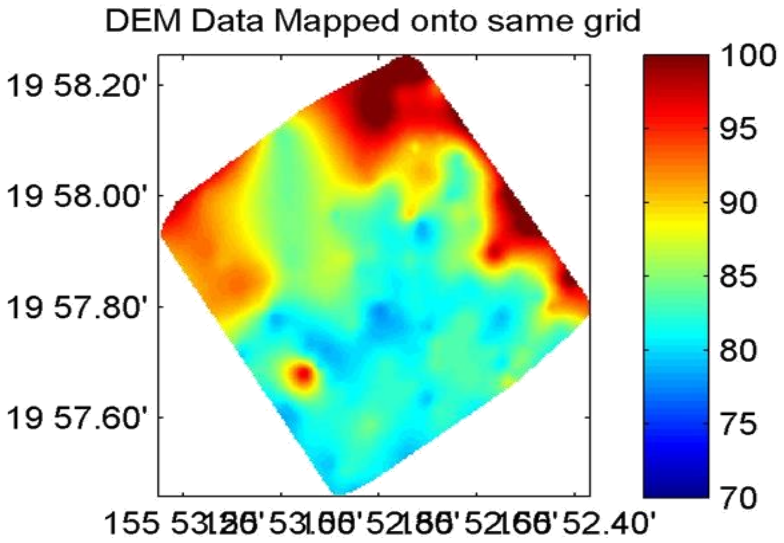
- Teledyne RDI Acoustic Doppler Current Profile (ADCP)
  - Surface temperature; current direction & speed in bins to 150m
- Datawell MOSE-G GPS-based Directional Wave Sensor
  - Wave height, period, direction
- Seabird GPCTD + DO
  - Water conductivity, temperature, density, salinity, dissolved oxygen
- Airmar PB200 Weather Station
  - Air temperature, wind speed & direction, barometric pressure



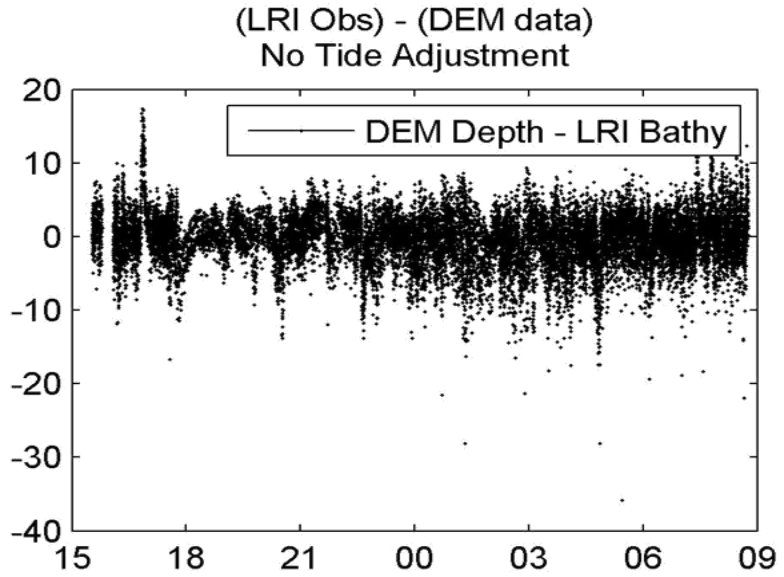
Navy Analysis of ADCP Bathymetry, LRI Hawaii Test Range







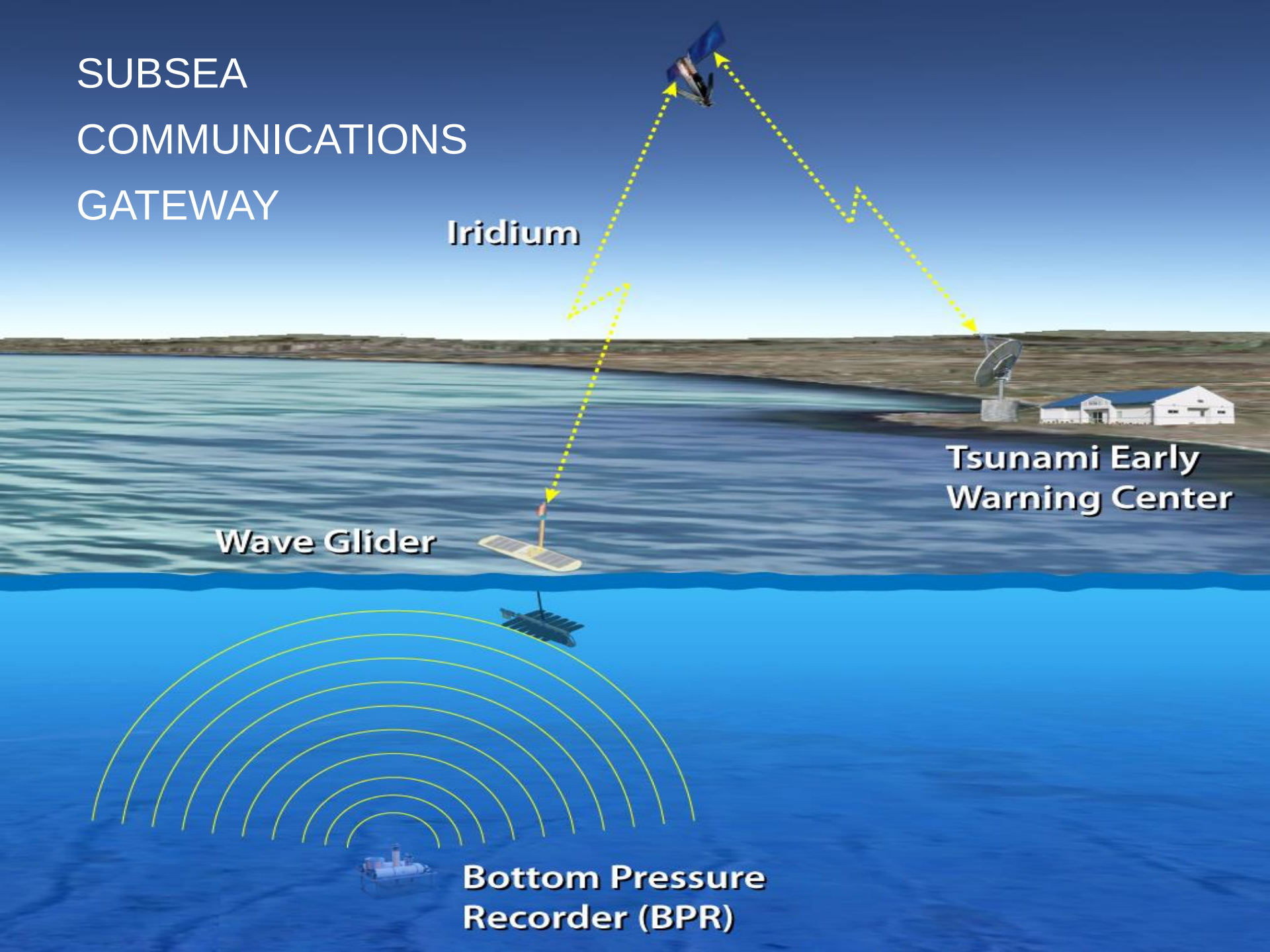
boundary whitened out to ease visual comparison



Mean Error: -0.30
Error Variance: 12.96

liquid robotics

SUBSEA COMMUNICATIONS GATEWAY

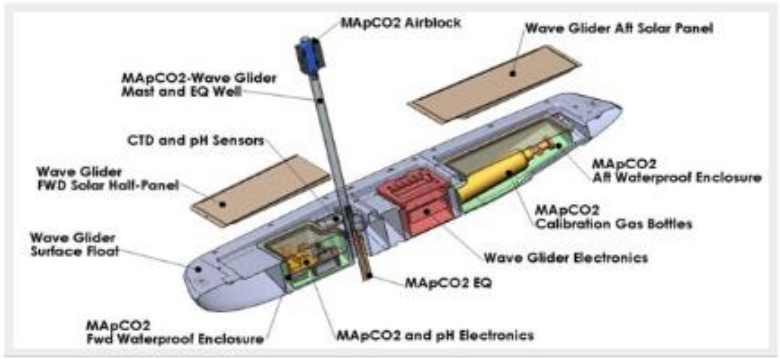


Carbon Wave Glider

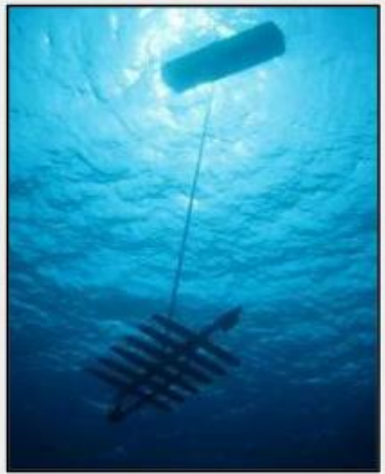
Developing new platforms for carbon measurements

The PMEL carbon group has teamed up with **Liquid Robotics Inc.** to integrate a $MAPCO_2$ system into a Wave Glider vehicle. The Wave Glider represents an innovative approach to ocean persistent presence; it harnesses ocean wave energy to provide essentially limitless propulsion while solar panels continually replenish the batteries used to power the Wave Glider's control electronics and payload systems. The Wave Glider vehicle is propelled by the purely mechanical conversion of ocean wave energy into forward thrust, independent of wave direction. Through extensive engineering trials and demonstrations, the Wave Glider's capability for long-term autonomous operation in the open and coastal oceans has been firmly established. The Wave Glider has successfully circumnavigated the Big Island of Hawaii, surveyed West Coast of the North American from Canada to Mexico, and crossed the Pacific Ocean from Hawaii to San Diego.

Use of this vehicle could lead to a new paradigm for economical underway surface observations that does not rely on expensive research ships and is not restricted to the standard shipping lanes of volunteer vessels.



The figure above shows a cut-away view of the integration of the $MAPCO_2$



RELATED STORIES

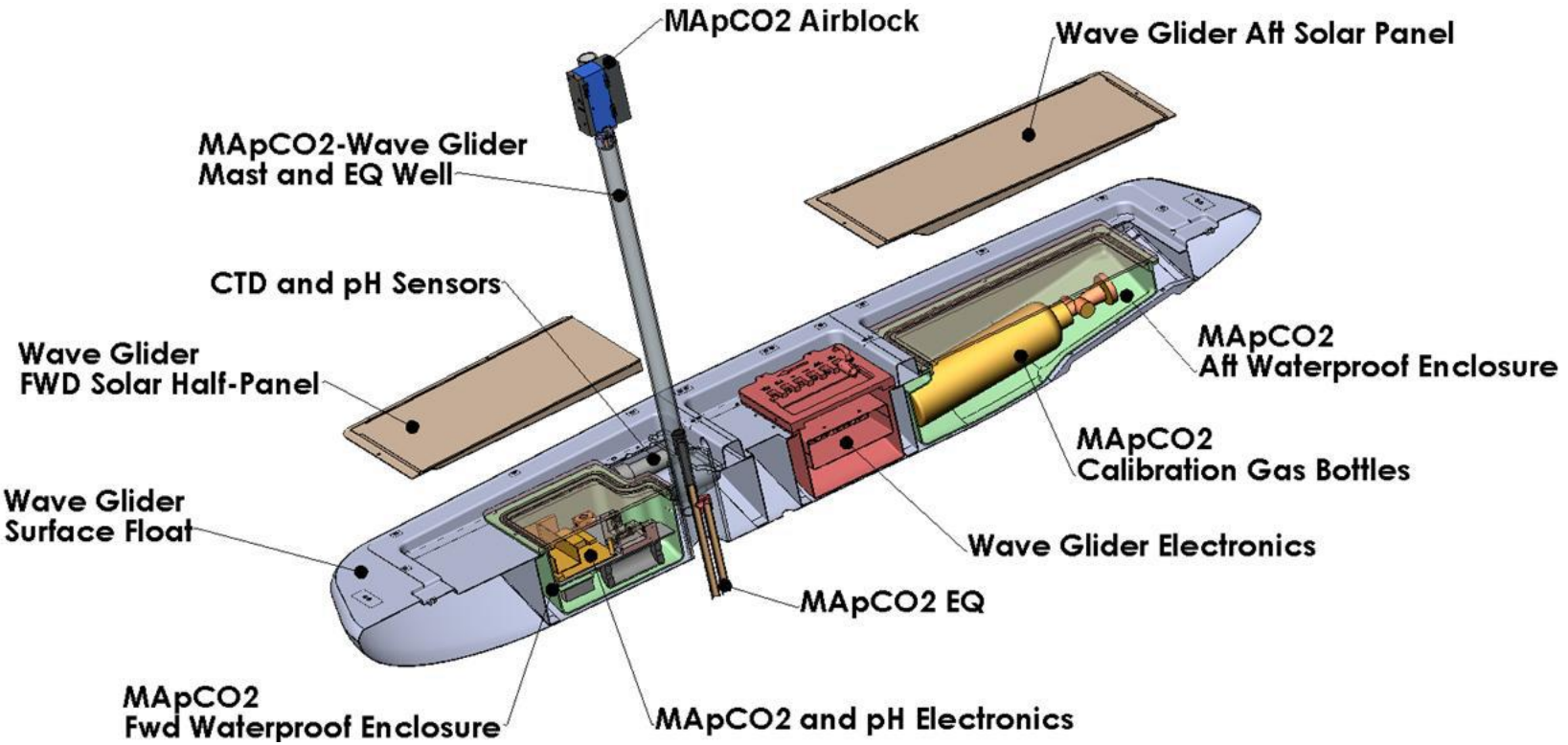
Coral Reef Moor ...
The PMEL carbon group is developing a network of carbon dioxi ...

Coastal Mooring ...
The PMEL carbon group is developing a network of carbon dioxi ...

Open Ocean Moor ...
The PMEL carbon group is developing a network of carbon dioxi ...

Buoys and Auton ...
PMEL is developing carbon dioxide systems for a variety of au ...

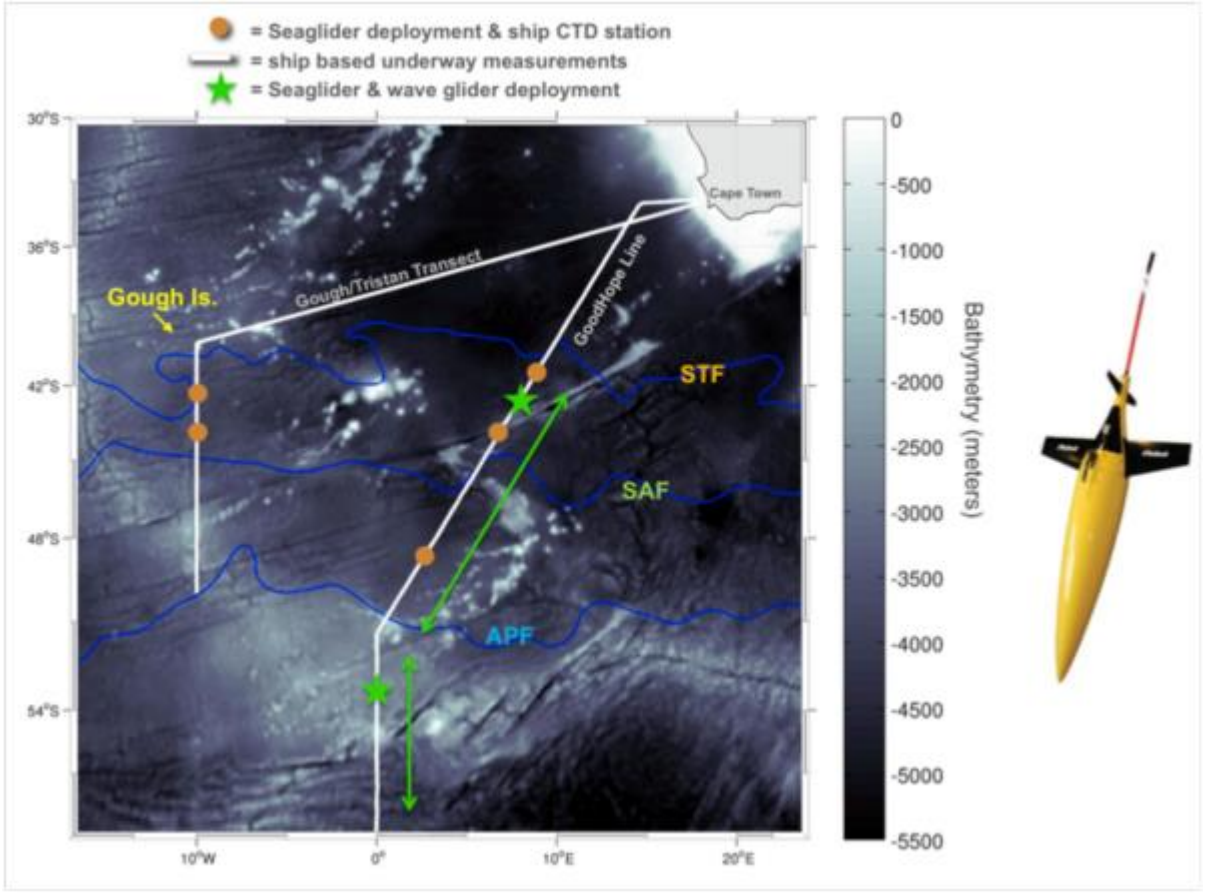
PMEL MAPCO2


MApCO2 Airblock
Wave Glider Aft Solar Panel
MApCO2-Wave Glider
Mast and EQ Well
CTD and pH Sensors
Wave Glider
FWD Solar Half-Panel
MApCO2
Aft Waterproof Enclosure
MApCO2
Calibration Gas Bottles
Wave Glider
Surface Float
Wave Glider Electronics
MApCO2 EQ
MApCO2
Fwd Waterproof Enclosure
MApCO2 and pH Electronics


CO_2
PMEL # 001
Carbon Wave Glider
WARNING: US Government Property
KEEP AWAY AND DO NOT RECOVER BEFORE:
OCTOBER 10 2011
If Found, Contact Noah Lawrence-Slavas

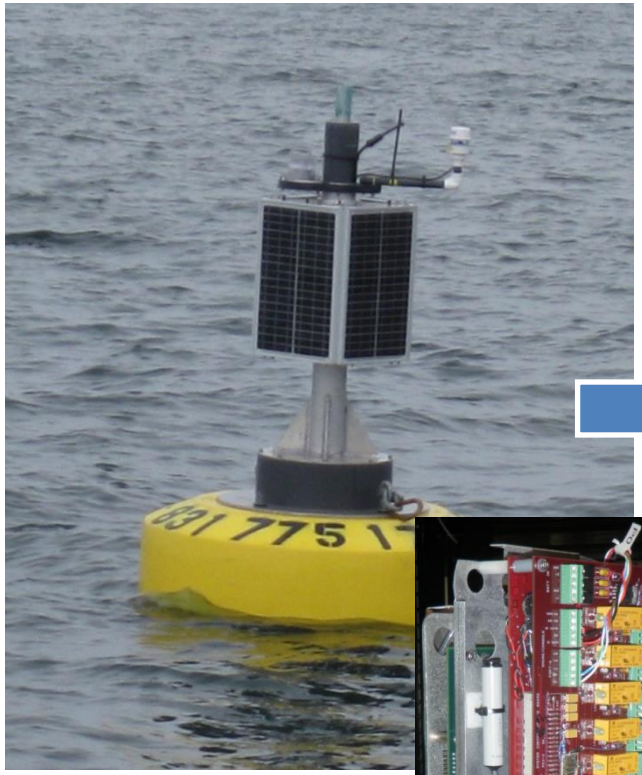
our future through science

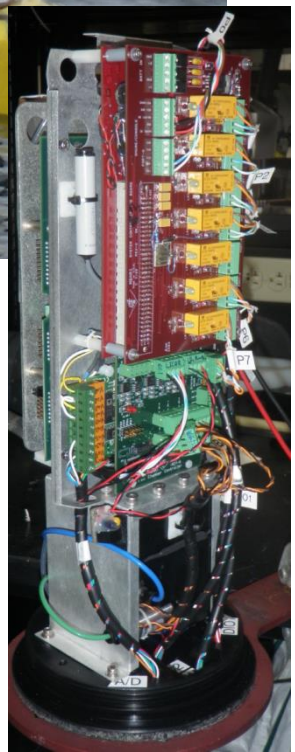
SOCCO



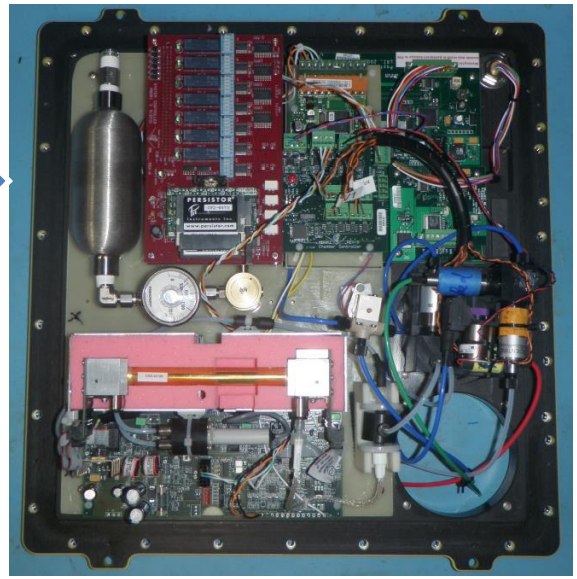
http://www.soos.aq/index.php/news/current-news/163-sagliders

MBARI Ocean Acidification (OA) mooring – NSF support





Wave Glider was equipped with the same OA sensors



This and following 11 slides originally authored by **Francisco Chavez (MBARI)**

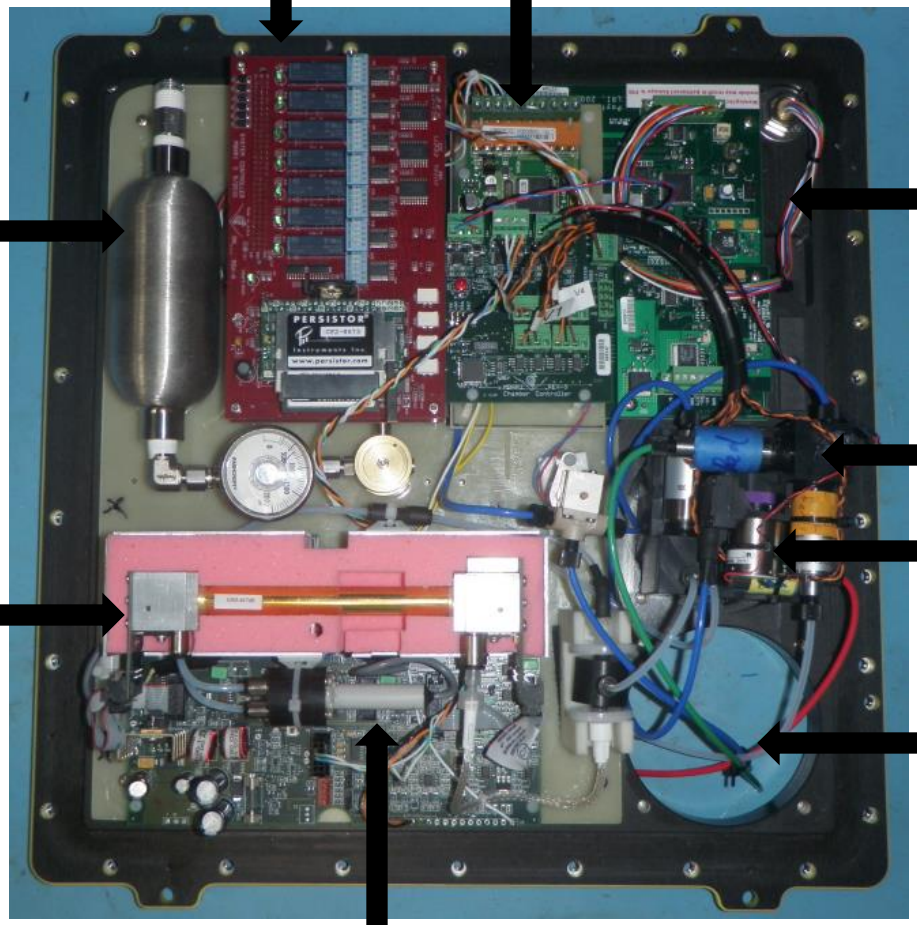
The system has been deployed in MBNMS and in the Gulf of Mexico and is now going back and forth between C1 and M2

MBARI OA SENSORS

- Licor LI-820 CO_2 Gas Analyzer, measures air, sea surface and standard
- Durafet II pH electrode
- Dissolved Oxygen (DO) Sensor SBE 43
- Seabird Payload Glider CTD

  Wet Labs ECO Puck
- Airmar PB-200 meteorological station

MBARI

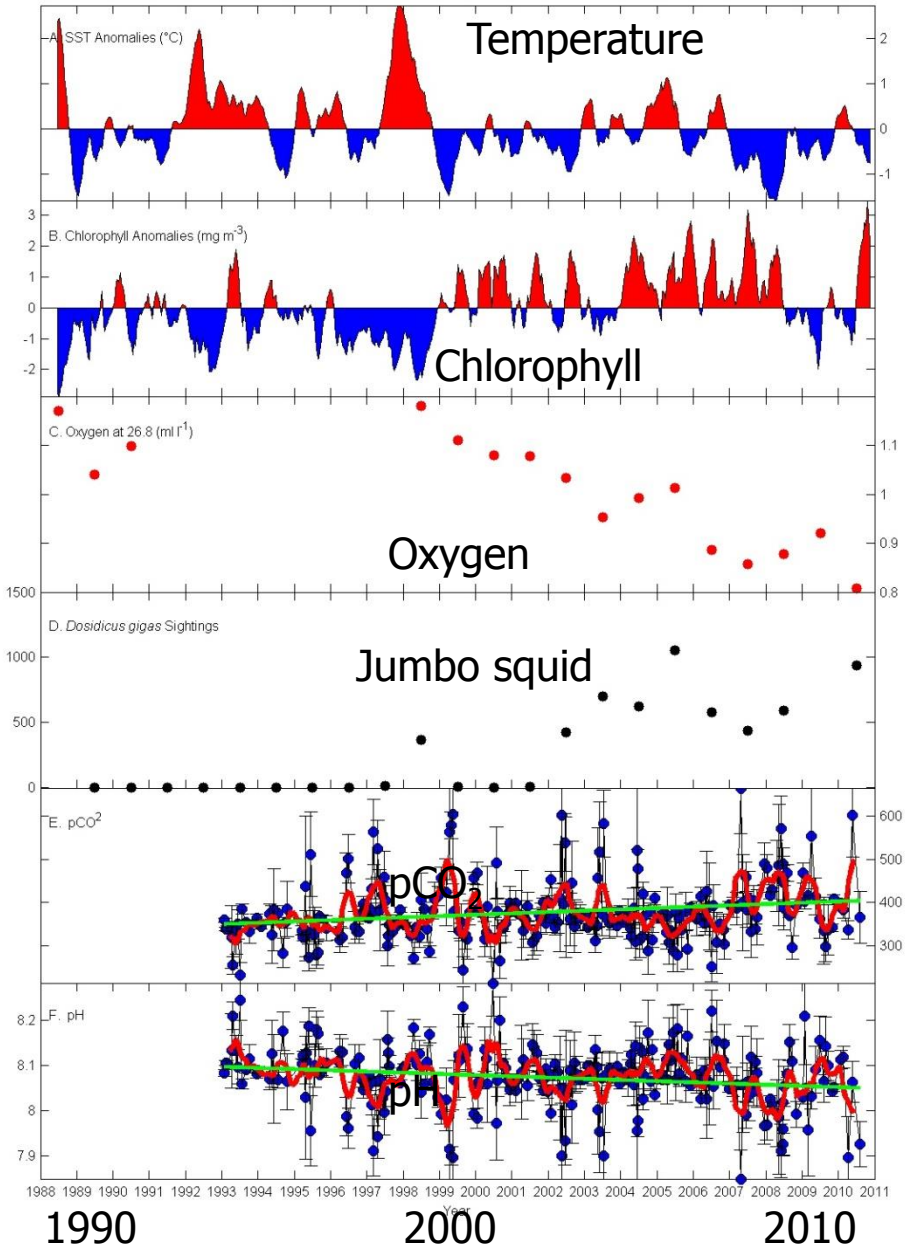

1. OASIS Control Board
2. A to D board and Chamber controller board
9. CO_2 Standard Tank
3. Wave Glider Personal Integration Board
4. Valve Block
5. Pump
8. LI-820 CO_2 Gas Analyzer
6. Controller Blank location once designed
7. Humidity Sensor

Why wave gliders: An example of an application

- For the past 20 years MBARI has been measuring the increase in pCO2 in California coastal waters
- Method has been to measure pCO2 on a ship transect from shore to ~ 50 km ~ every three weeks
- In 2013 we made close to 80 occupations of the same transect from March to October
- Wave glider data provides increased resolution and reliability at lower costs
- Exploring required resolution for model assimilation

MBARI

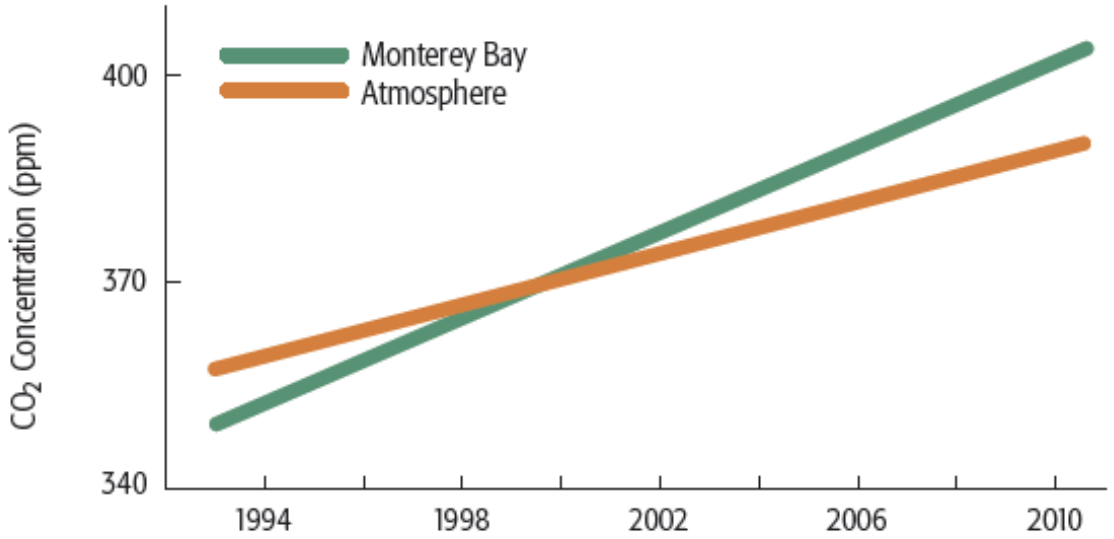
Monterey Bay Time Series showing increase changes in California coastal waters over 20 years



The Monterey Bay Time Series collected by MBARI is now almost 25 years long. The plots show that the recent period has been one of lower temperature, higher chlorophyll, decreasing oxygen at depth (on the 26.8 isopycnal (~200-300 m), and more abundant jumbo or giant squid. Also evident have been increasing concentrations of pCO2 and lower pH. More on these trends in the next few slides.

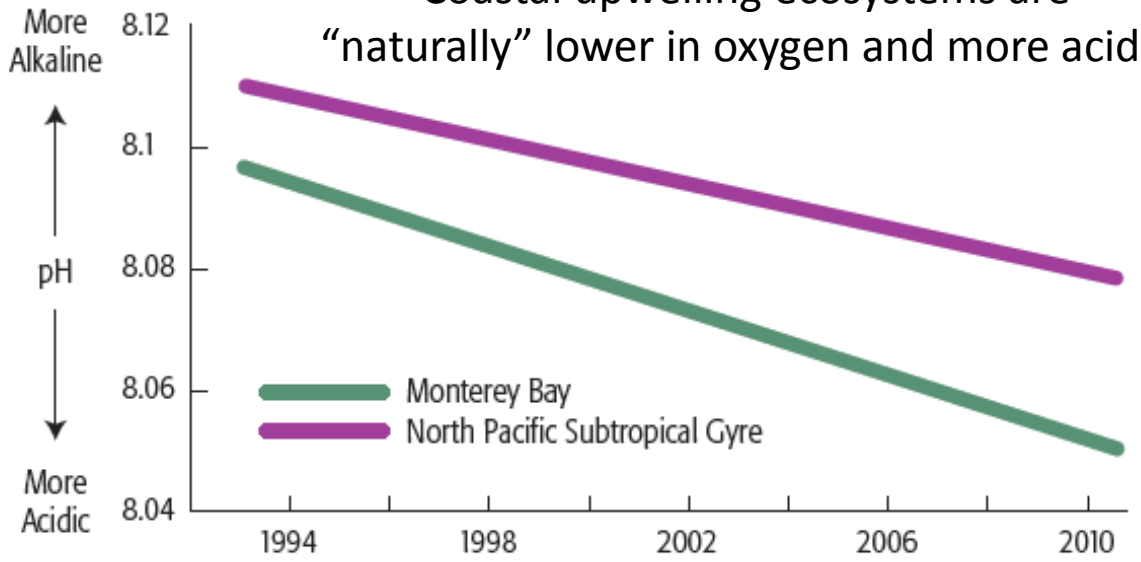
MBARI

Waters off California becoming higher in CO_2 and more acidic faster because of large scale changes in ventilation and increased productivity



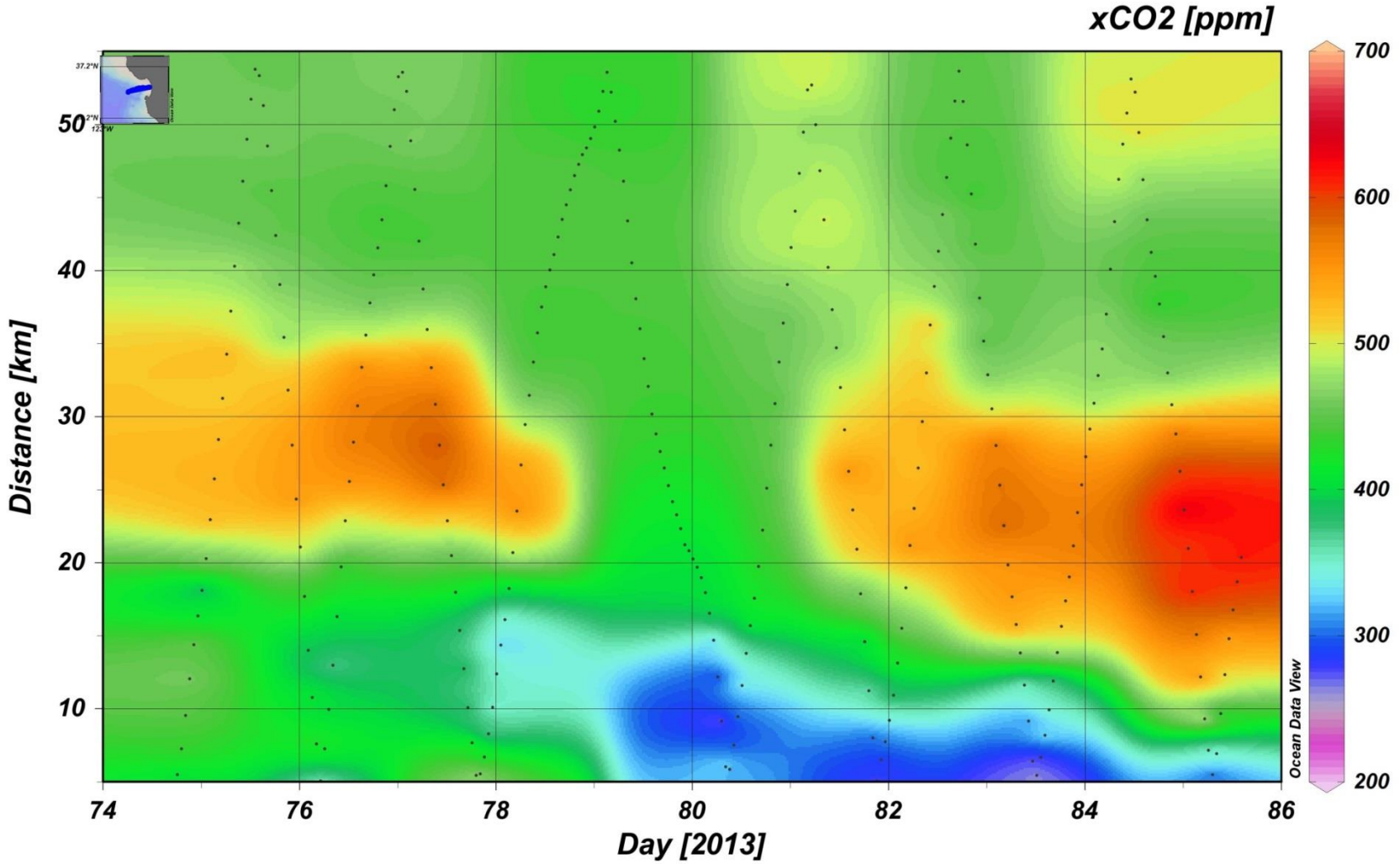
Declining pH

Coastal upwelling ecosystems are "naturally" lower in oxygen and more acidic



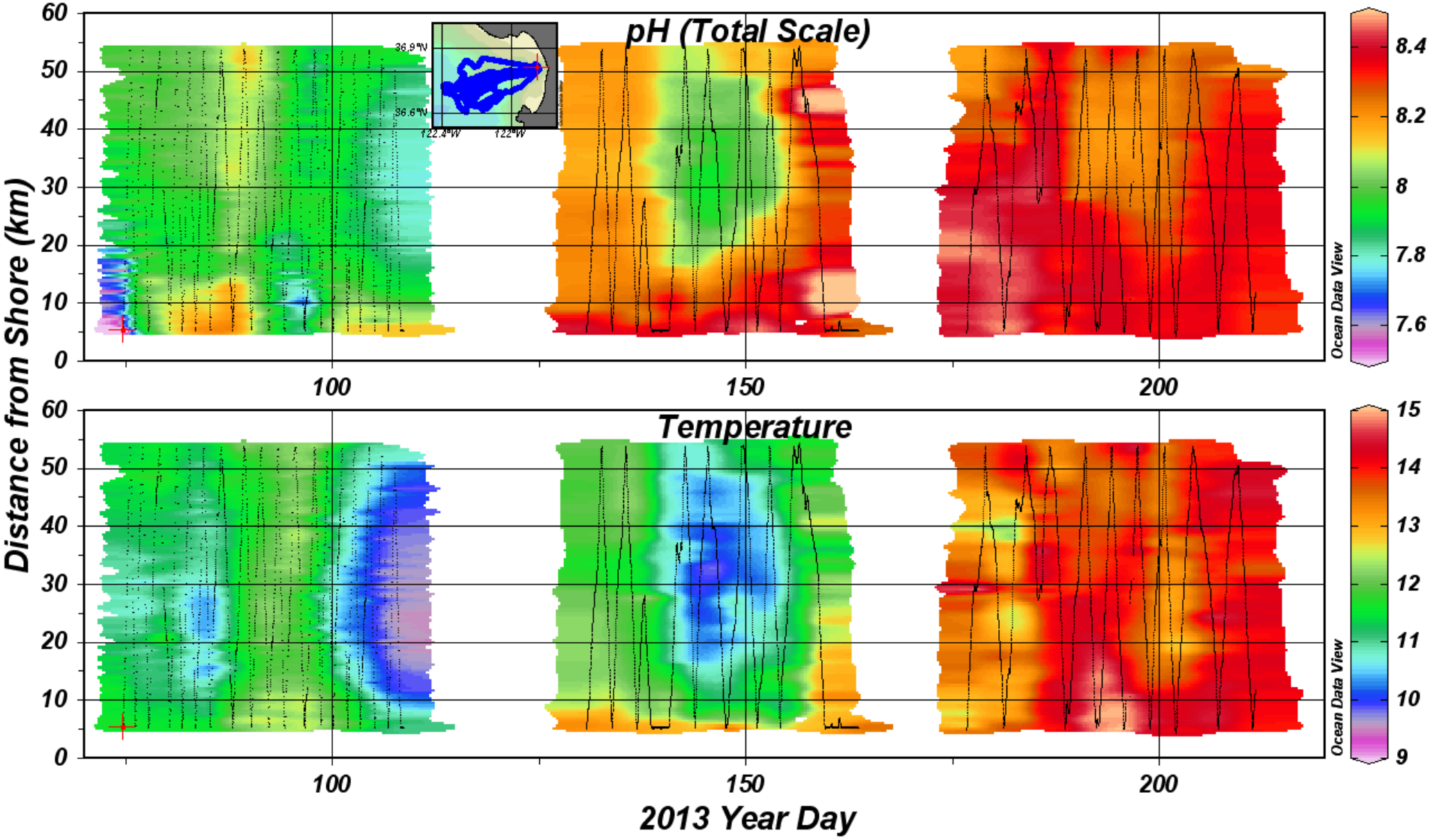
MBARI

Upwelling impact on the partial pressure of carbon dioxide across the mouth of Monterey Bay as observed from a wave glider

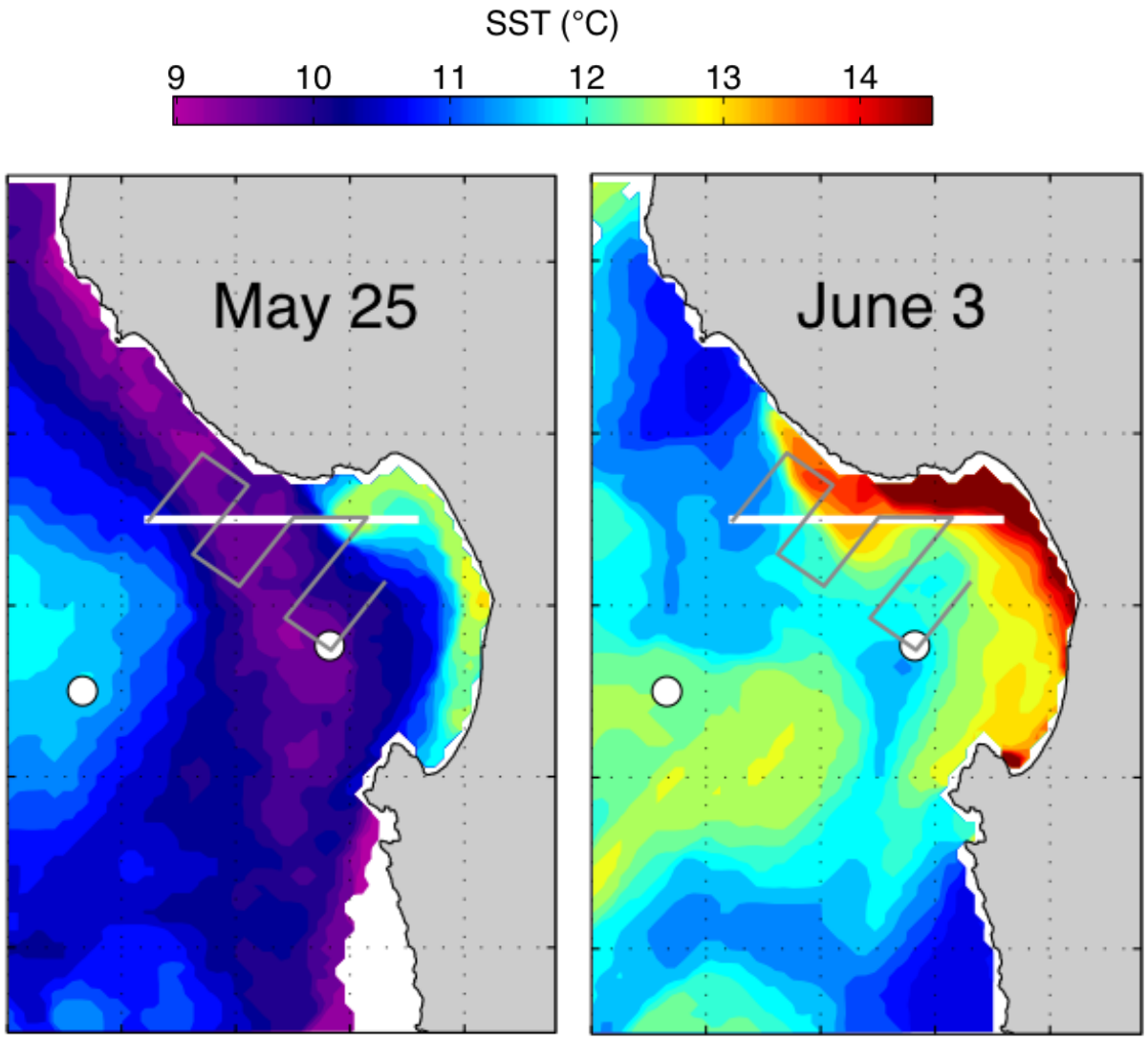


It takes a wave glider approximately 1 day to get from C1 (just outside of Moss Landing) to M2 or back. The figure shows the relatively low pCO2 (high pH) values inside the Bay increasing to a maximum around or just past M1 and then decreasing out M2. M2 can sometimes see the effects of upwelling further north (Point Arena, perhaps). Highest values, observed a few days ago are over 600 ppm. For reference atmosphere is now just under 400 ppm so in the high areas CO2 is being lost to the atmosphere. The wave glider speed depends on the waves and you can notice it slow down when winds weaken around day 78.

Upwelling impacts on pH across the mouth of Monterey Bay as observed from a wave glider



Satellite sea surface temperature



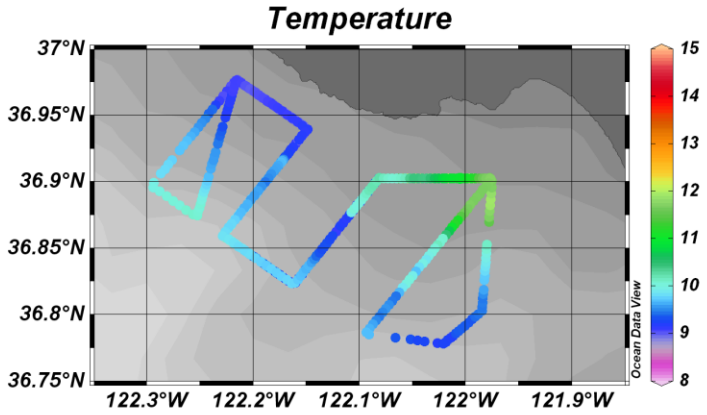
Upwelling

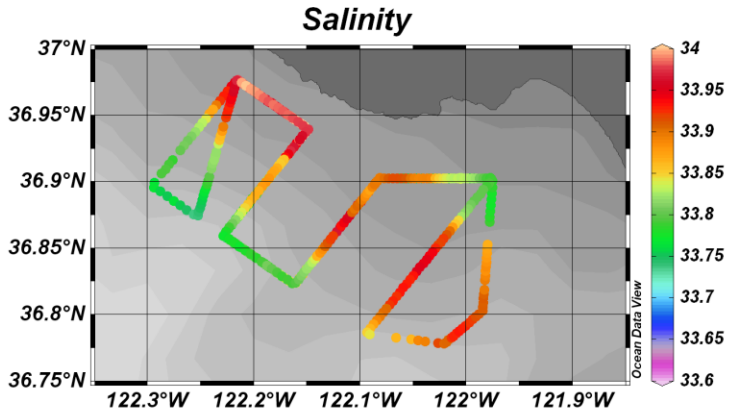
Relaxation

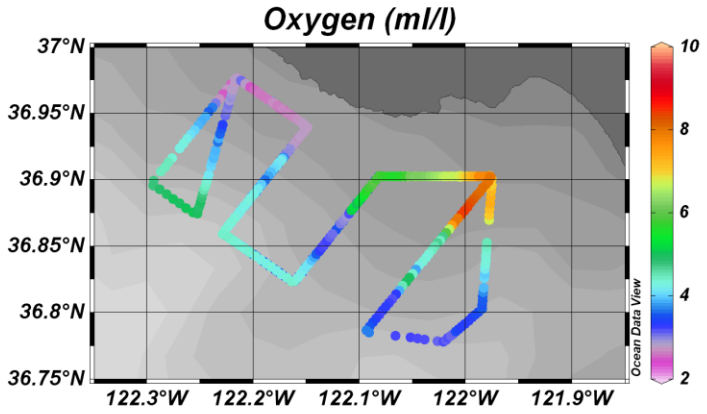
MBARI

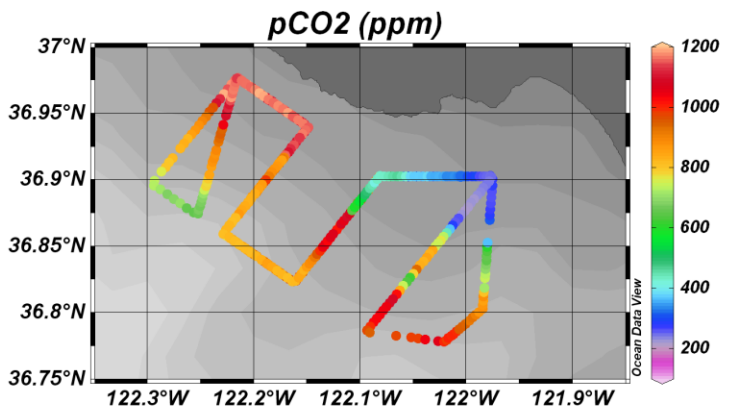
Upwelling as observed from wave glider during spring 2012

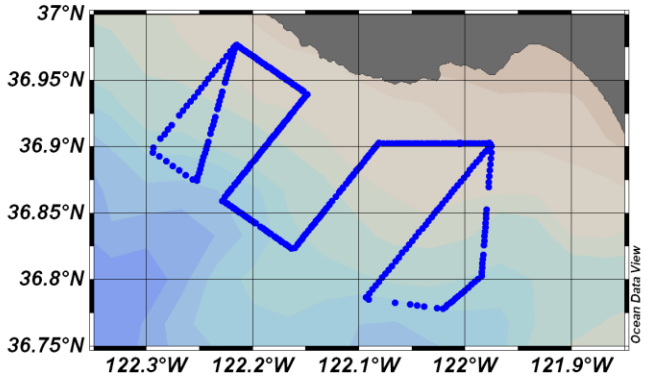
May 25-27 2012

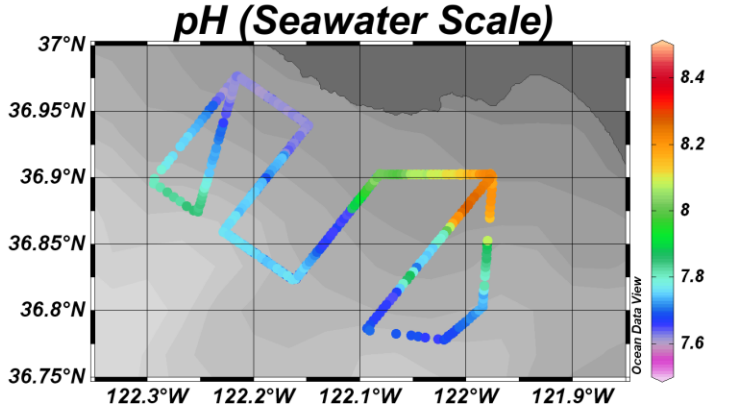






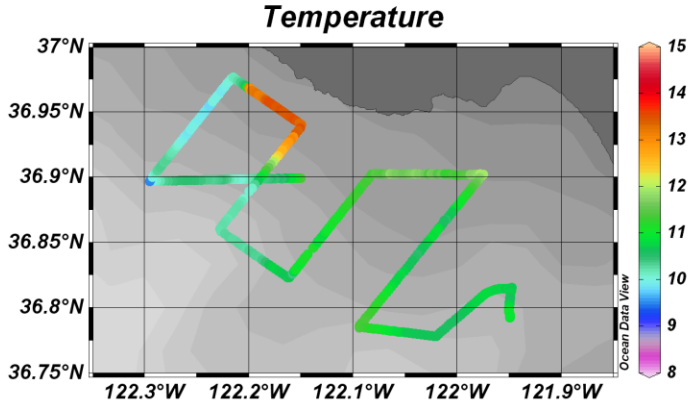


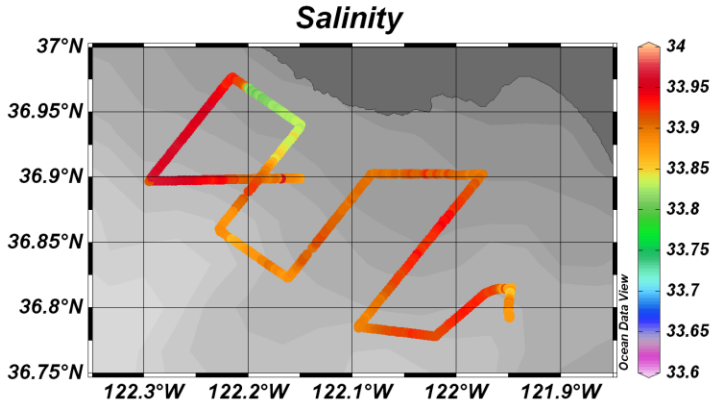


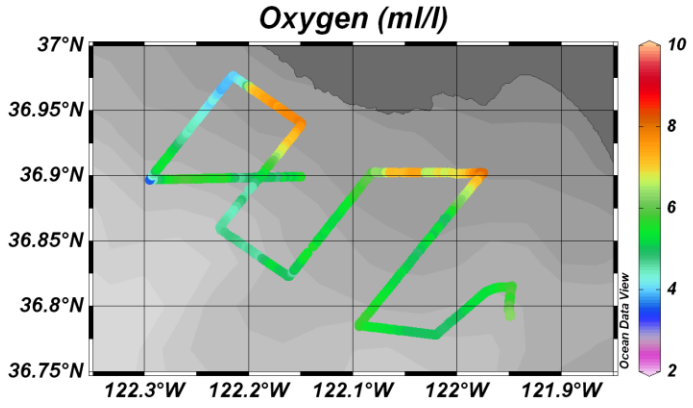


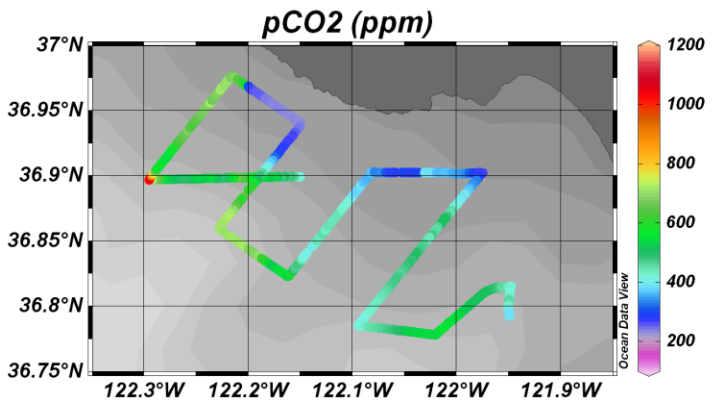
Relaxation as observed from wave glider

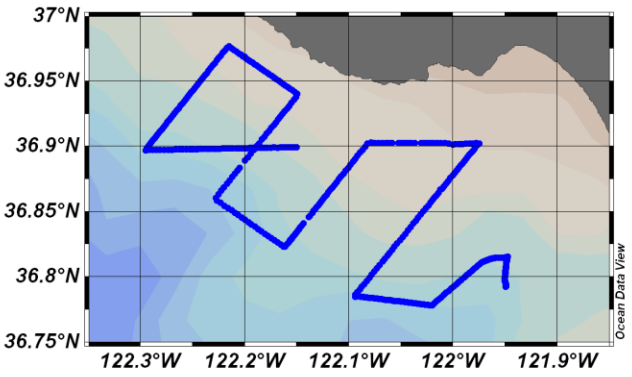
June 2-4 2012

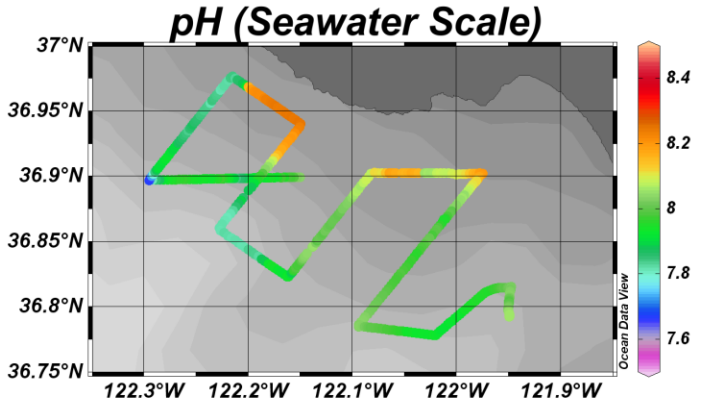




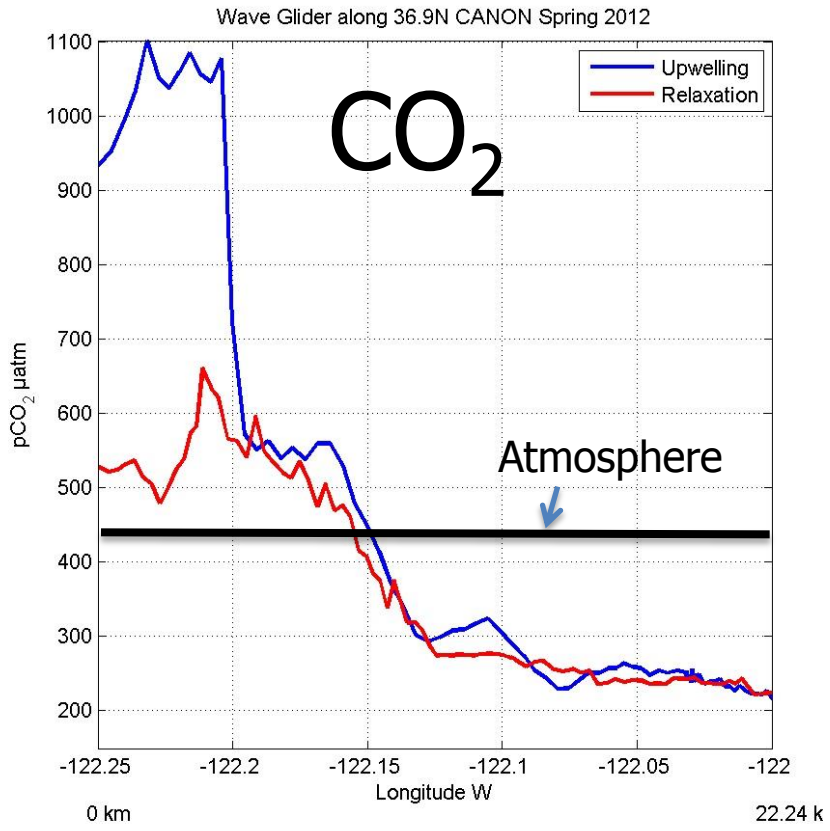


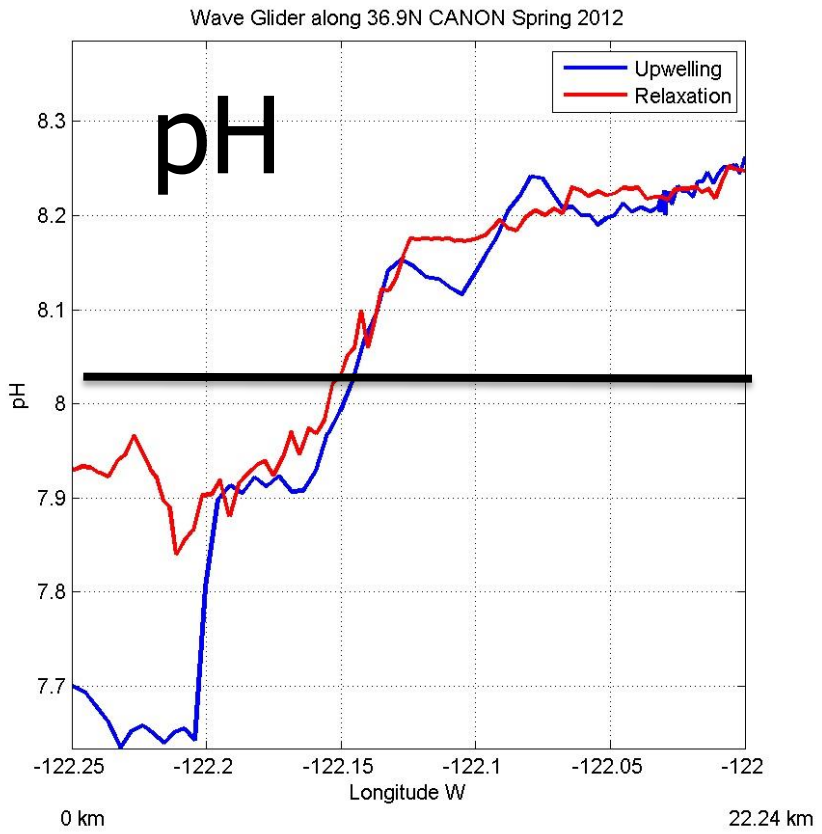






Very large gradients (as large as global means) observed on order of a kilometer





Wave glider observations of pCO_2 and pH

MBARI

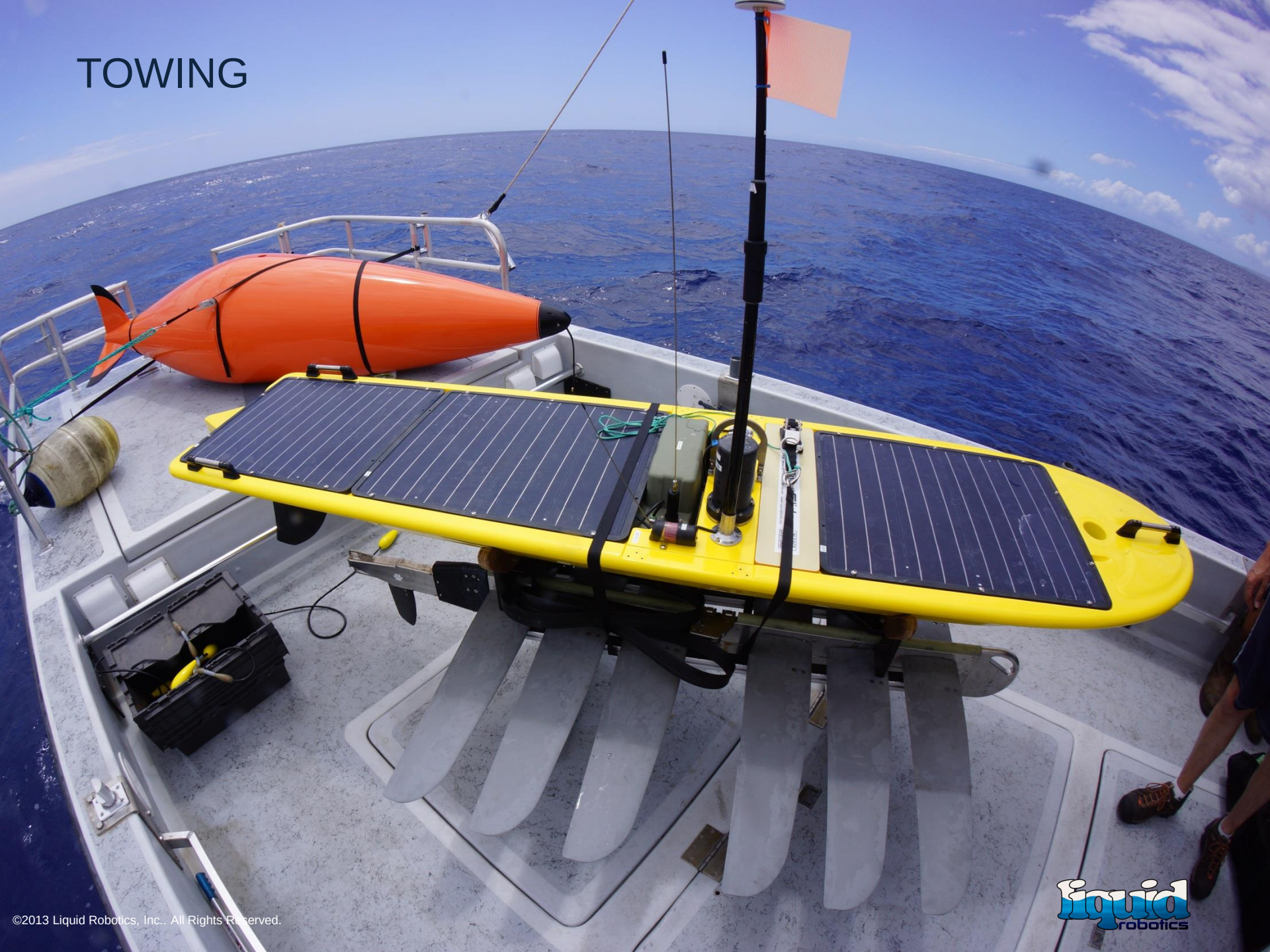
TOPP
TAGGING OF PACIFIC PREDATORS

Shark Net Ap
on iTunes

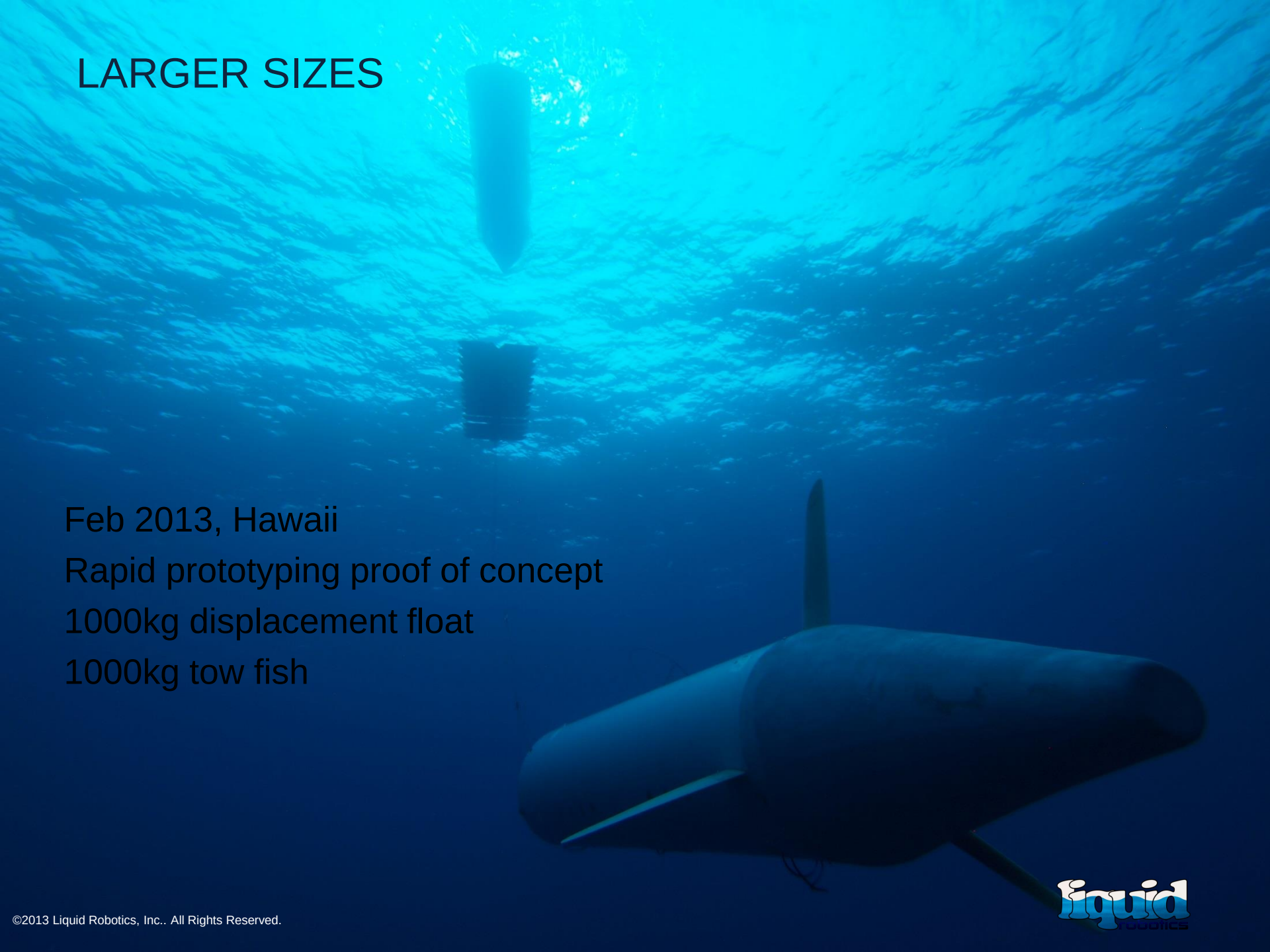
"The California Current is like having Yellowstone in our backyard. Our goal is to increase protection of this rich predator region."

— Barbara Block, Marine Sciences Professor, Stanford Univ.

TOWING



LARGER SIZES



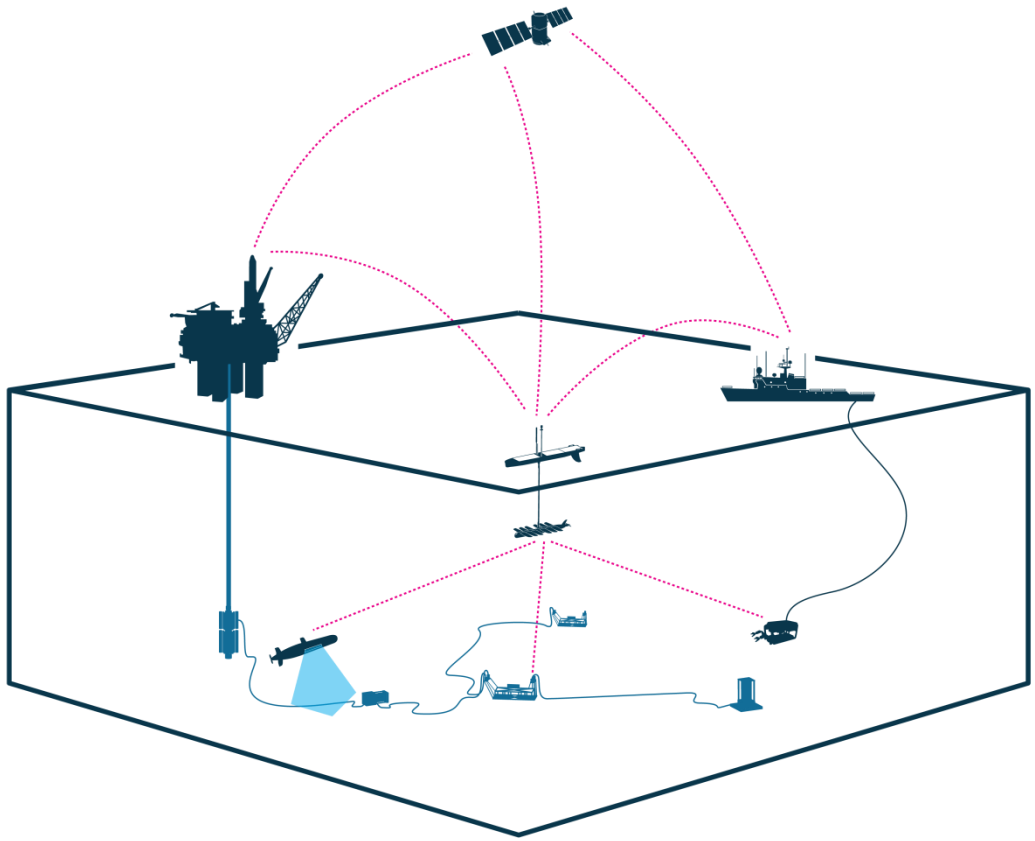
Feb 2013, Hawaii

Rapid prototyping proof of concept

1000kg displacement float

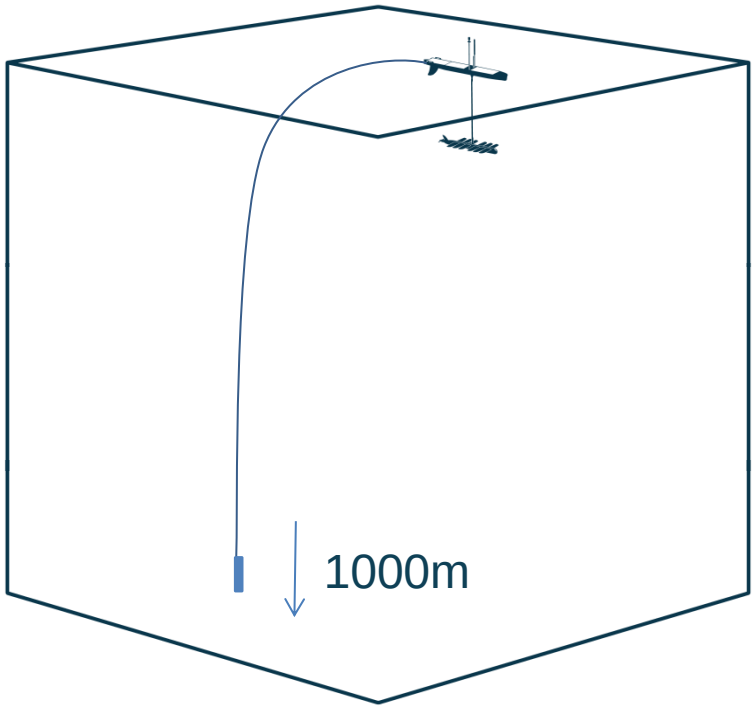
1000kg tow fish

SUBSEA SUPPORT



SV3 VERTICAL PROFILING PROJECTS

Deep Profiler

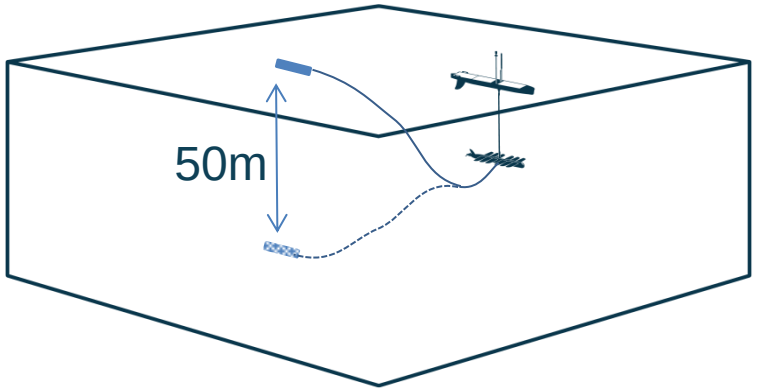


Rapid, brief profiles.

Small probe docks & recharges on float.

2 profilers per Wave Glider.

Surface Profiler



Buoyancy modulated tow fish.

Large sensor volume and continuous sensor power and communications.

Shallow depths only.

SPURS UPDATE

“all 3 recovered in good condition. second 6 months almost perfect -- no known data loss except for a few related to fetch (which are probably recoverable). nothing available online immediately from my site as we haven't been able to access for the past 3 weeks. in the water for 3 platform-years, almost 100% data recovery in second six months, but probably in the 75% range for total data recovery (largely due to loss of all met stations, iridium on one vehicle, couple of ctd's during the first 6 months).”

Dave Fratantoni

r/v endeavor

24N, 52W

Oct 27, 2013

Photo credit: Dave Fratantoni

Photo credit: Dave Fratantoni

Photo credit: Dave Fratantoni