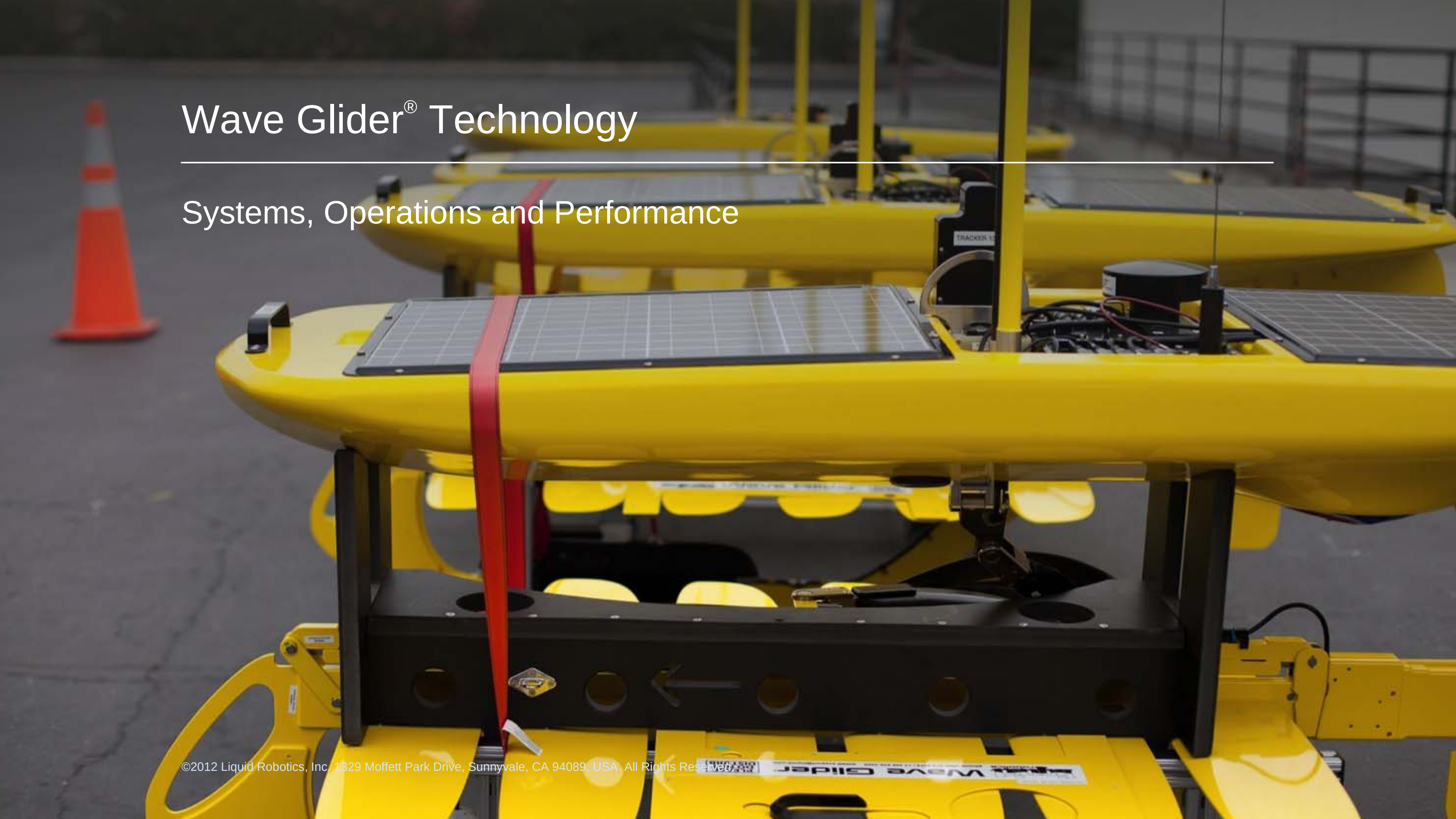
Liquid Robotics, Inc.

Long Term Autonomous Ocean Remote Sensing Utilizing the Wave Glider

Liquid Robotics

Mission	Change the economics of ocean data gathering and revolutionize how the world accesses our oceans
Business focus	Ocean data services provider and developer of the Wave Glider®
Market traction	Over 130 Wave Glider systems shipped globally
Target markets	DoD, Oil & Gas, Science & Oceanography
Oil & Gas	Joint venture with Schlumberger
Employees	90+
Investors	VantagePoint Capital Partners and Schlumberger
Incorporated	2007
Locations	California, Hawai’i, Washington DC

Awards



Wave Glider® Technology

Systems, Operations and Performance

The Wave Glider

Float

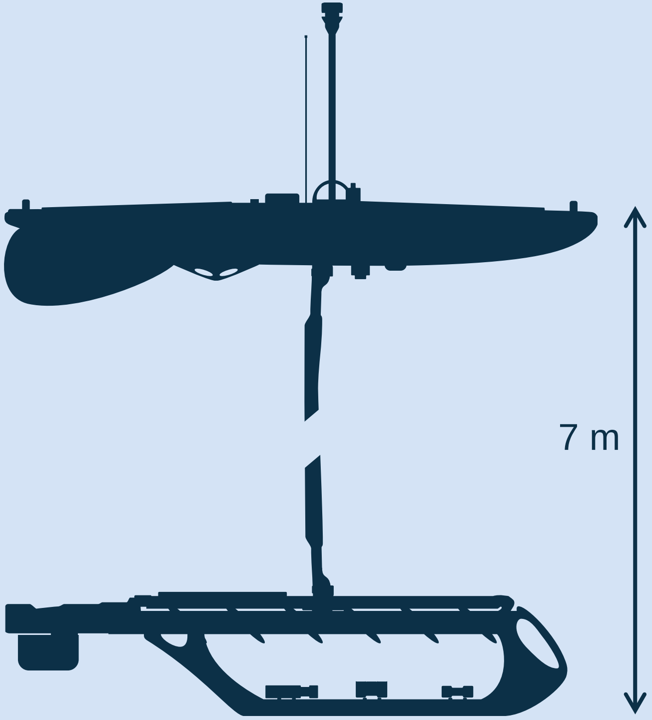
- Solar Panels
- Navigation
- Communications – Iridium or cellular
- Payloads

Sub

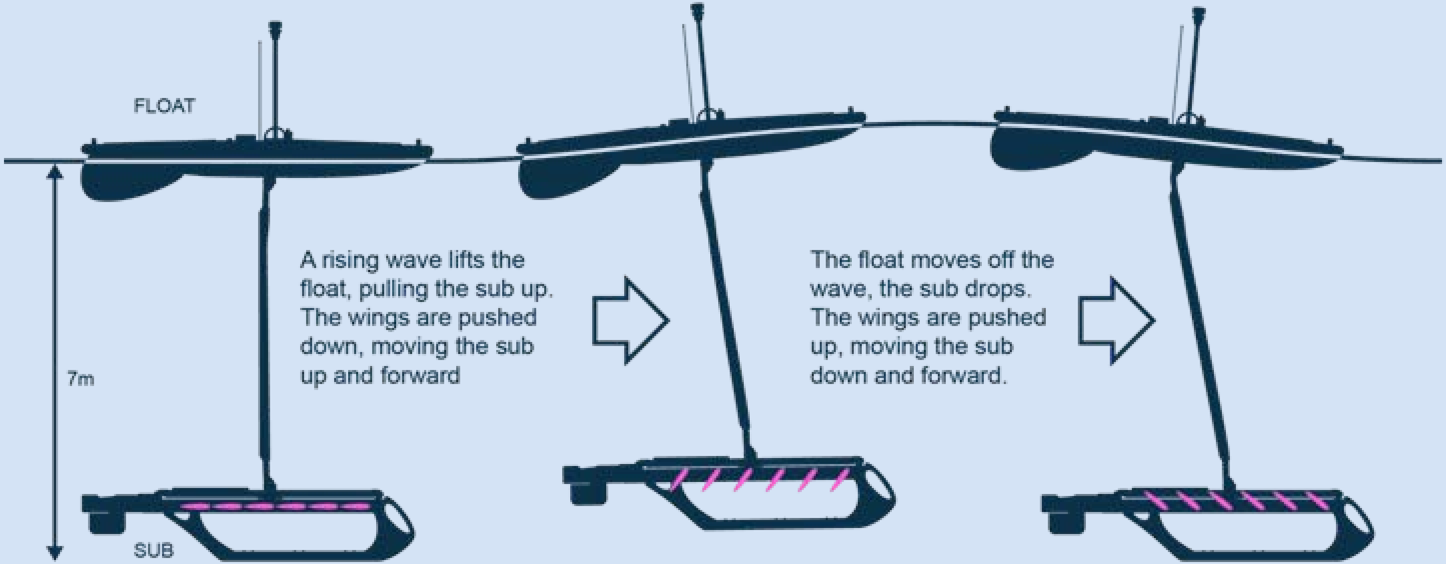
- Wave Powered
- Forward Thrust
- Rudder Control
- Payloads

Speed

- Averages 1 to 1.5 knots - STW

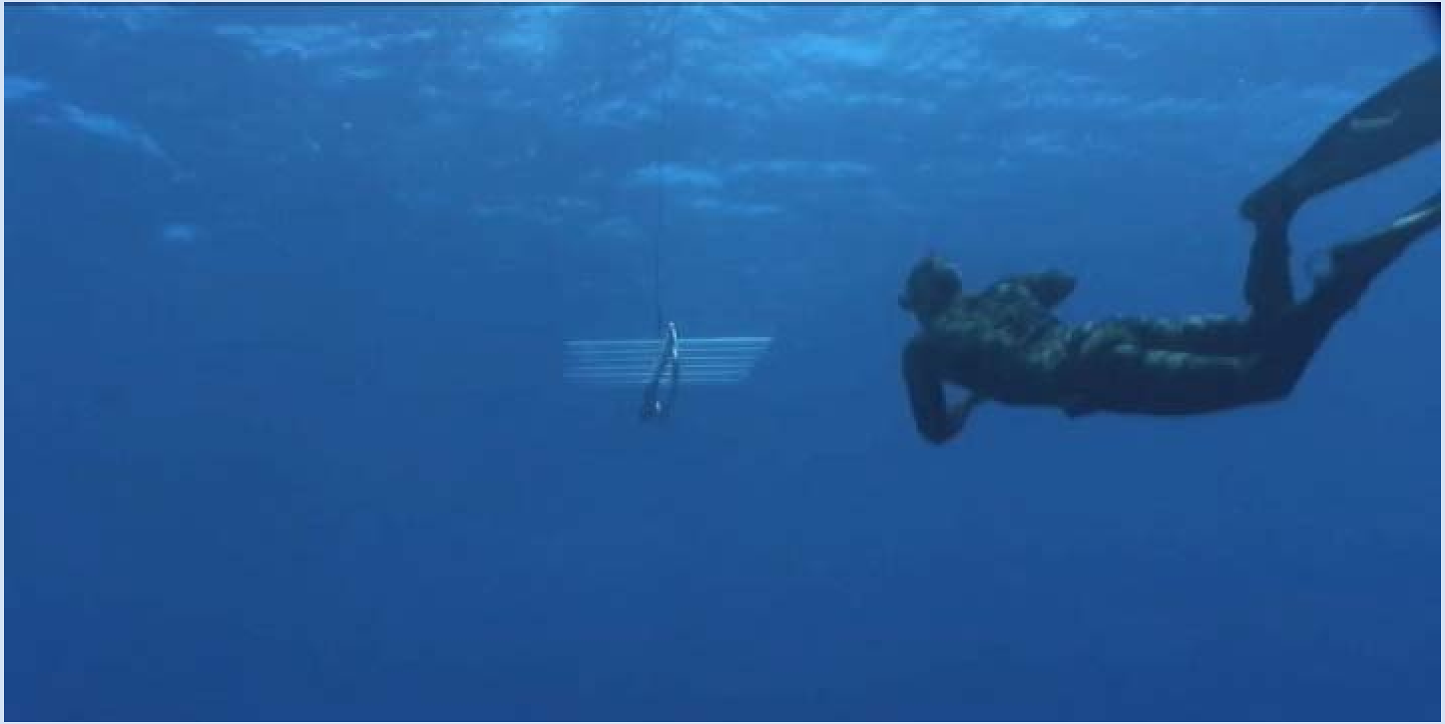


How It Works



3 U.S. and 9 foreign patents issued. 20 U.S. Provisional applications, 42 foreign applications.

How It Works



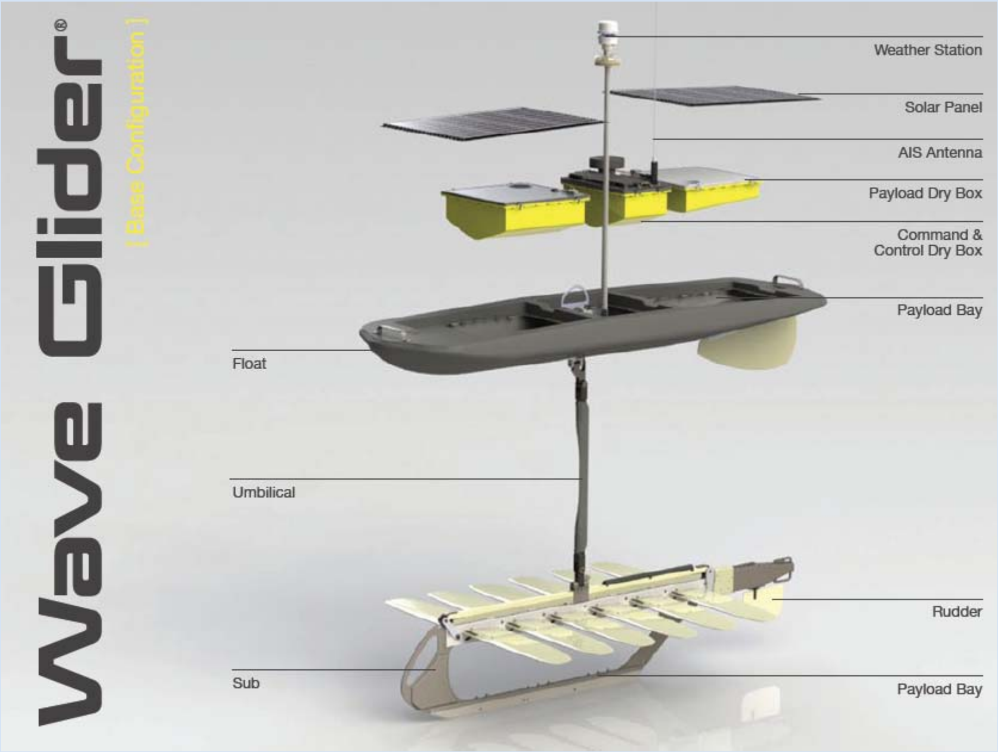
System Architecture - Modular

Modular design

•encourage sensor integrations

•simple maintenance

•Custom algorithm development



Available Sensors

Surface Sensors

•Camera

•Weather Station

•Wave Sensor

Subsea Sensors

•ADCP

•Fluorometer

•Hydrophone

•CTD

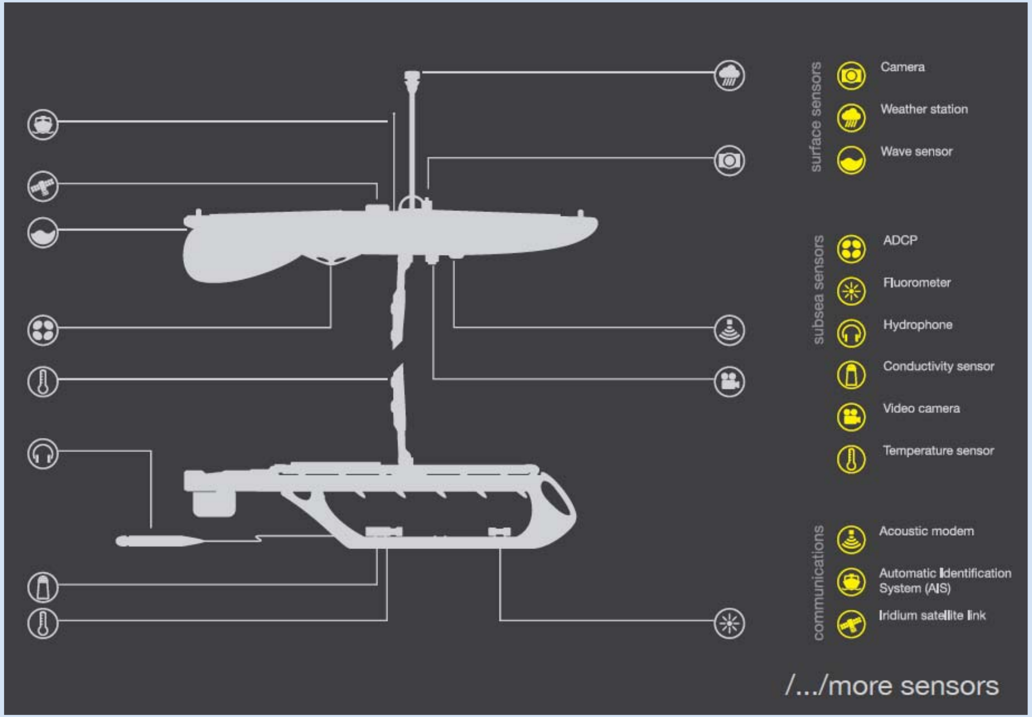
•Echosounder

Communications

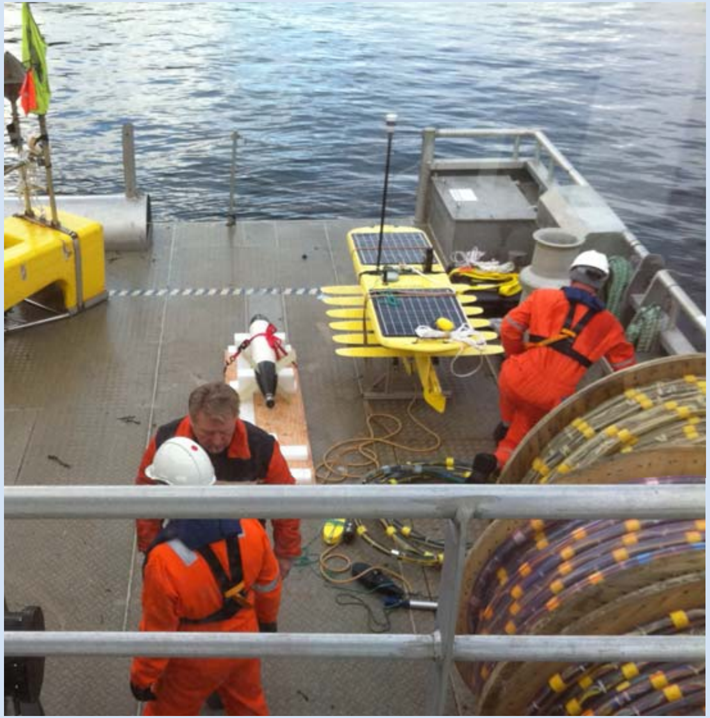
•Acoustic Modem

•Automatic Identification System (AIS)

•Iridium Satellite Link

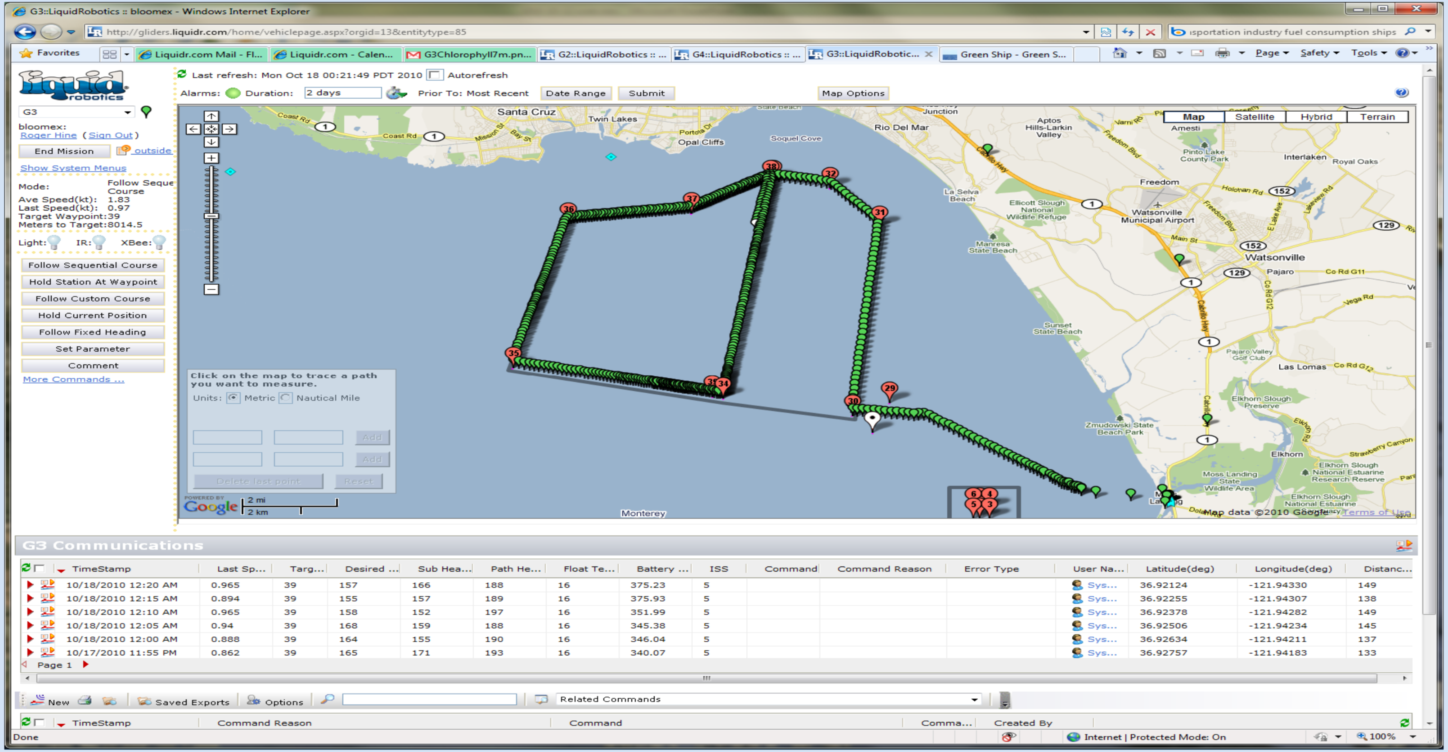


Marine Operations From Ships or Small Craft

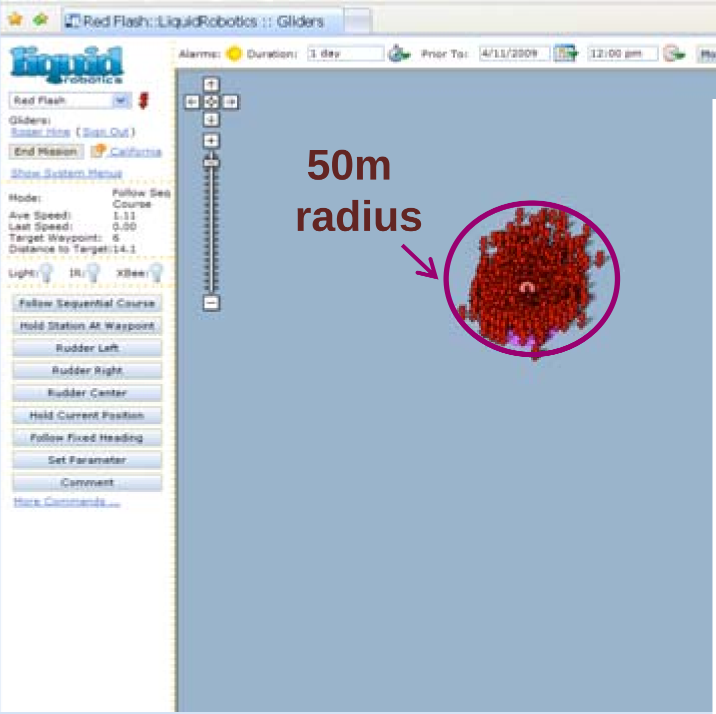


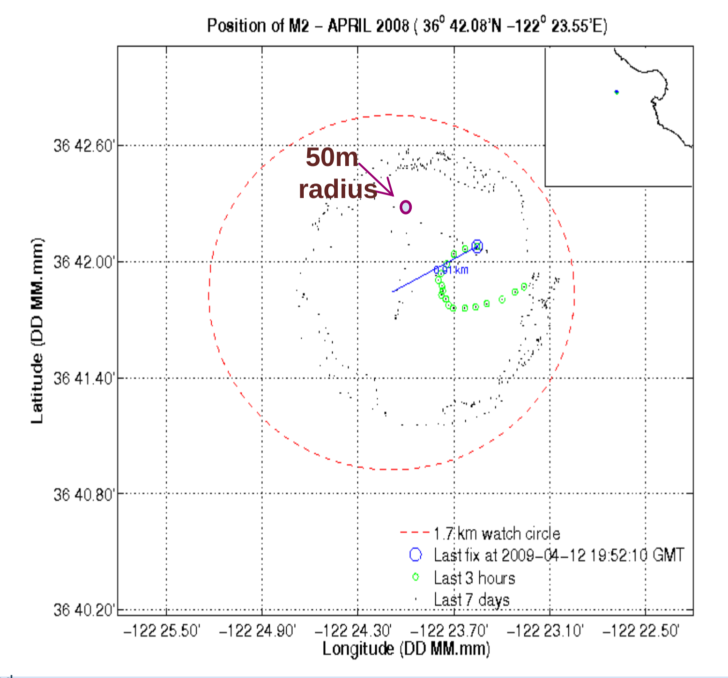
Launch and Recovery with Minimum Equipment

Wave Glider Management System (WGMS)

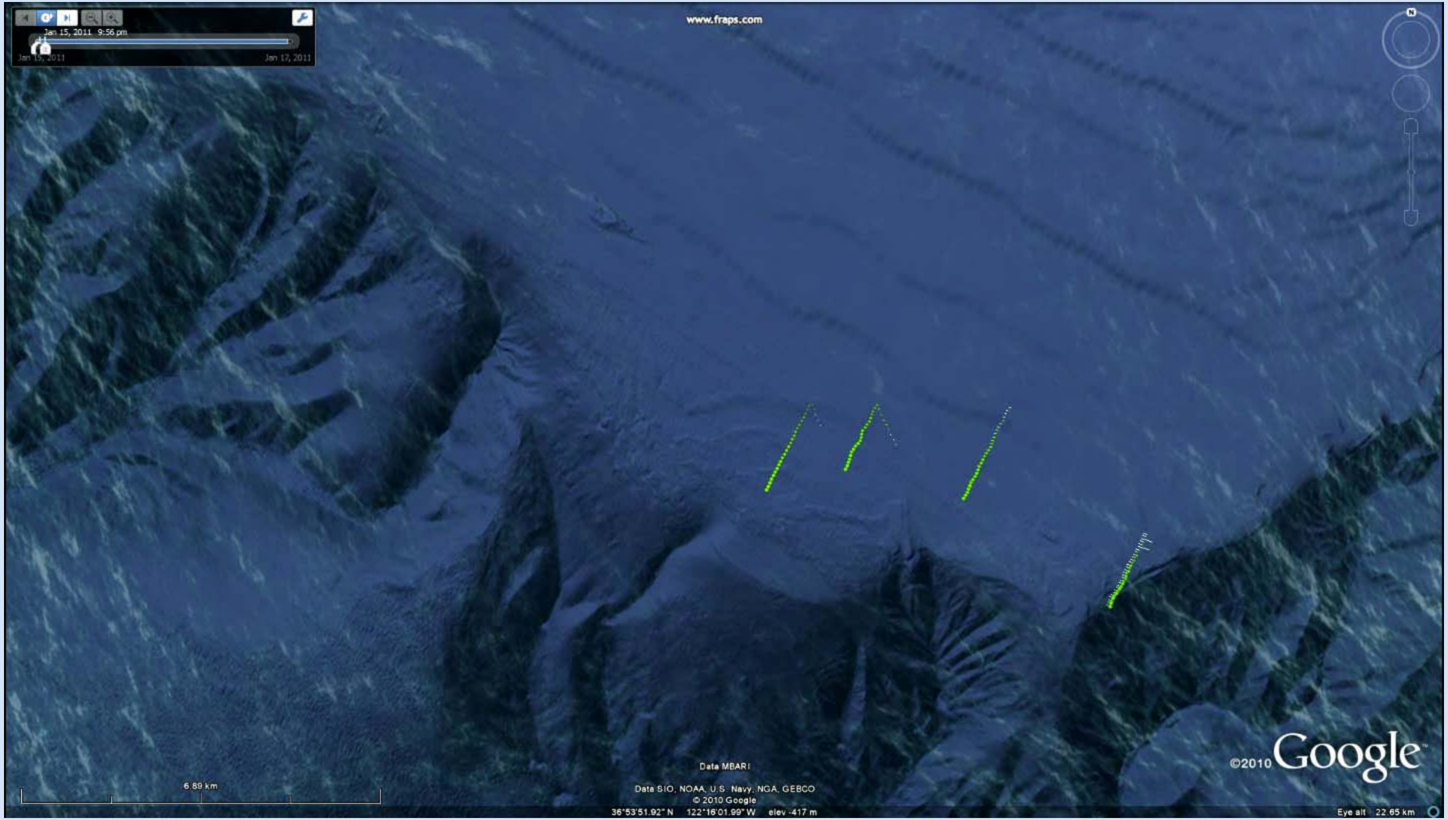


Station Keeping



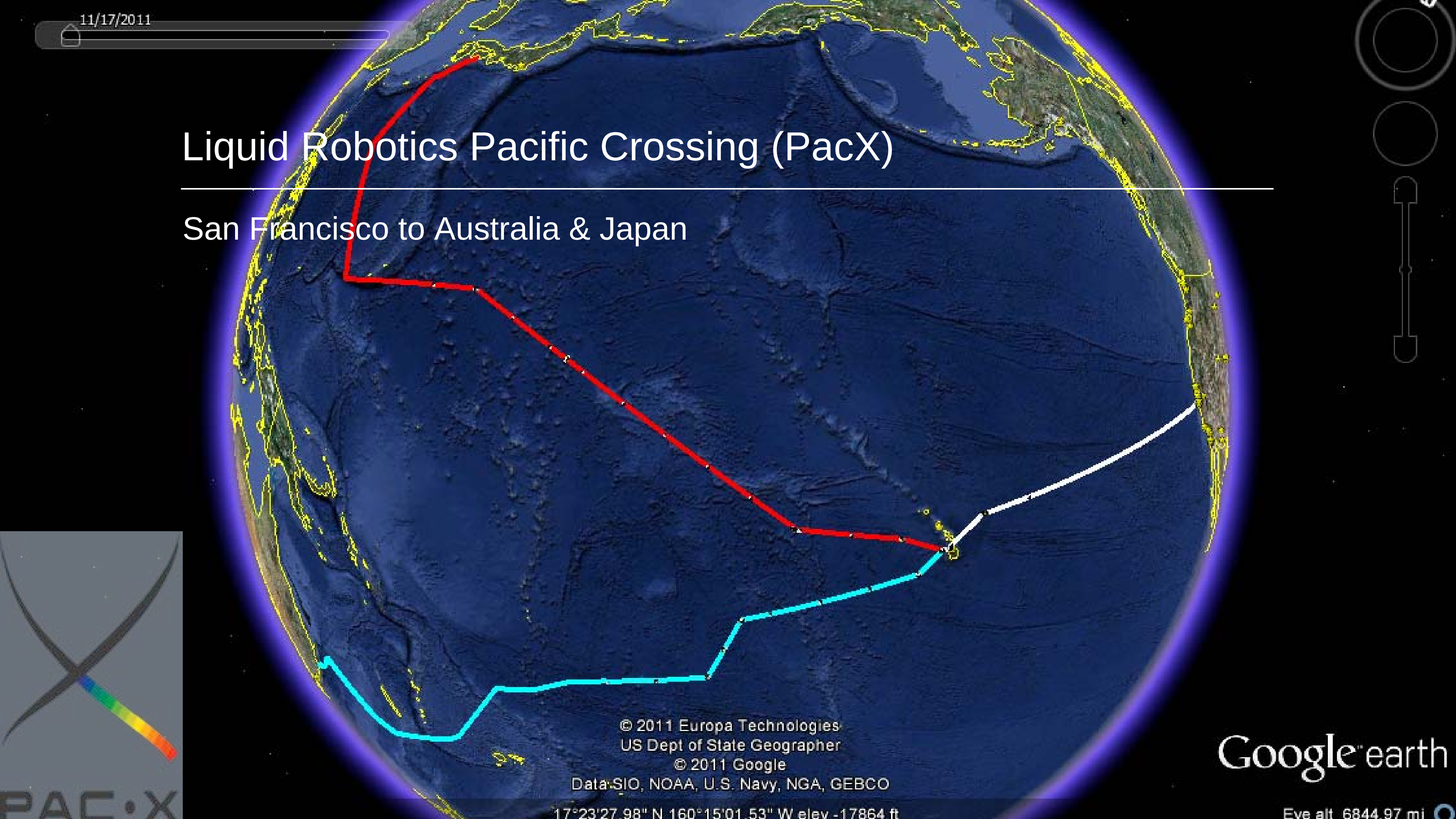


Line Following Array Demonstration

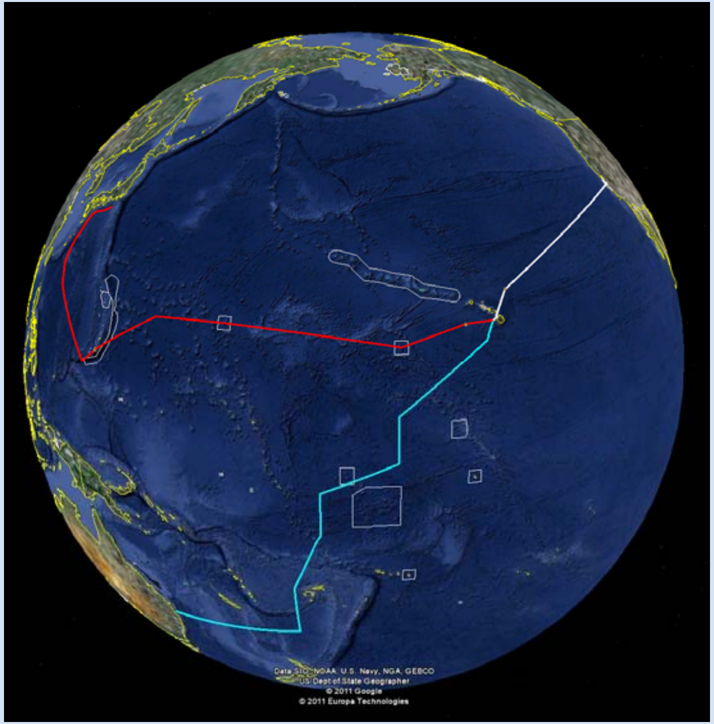


Liquid Robotics Pacific Crossing (PacX)

San Francisco to Australia & Japan



PacX Mission



The Challenge

- 4 Wave Gliders
- 330+ Days
- 2,250,000 Data Points
- 8,000+ Nautical Miles
- Launched November 17, 2011

Sensors

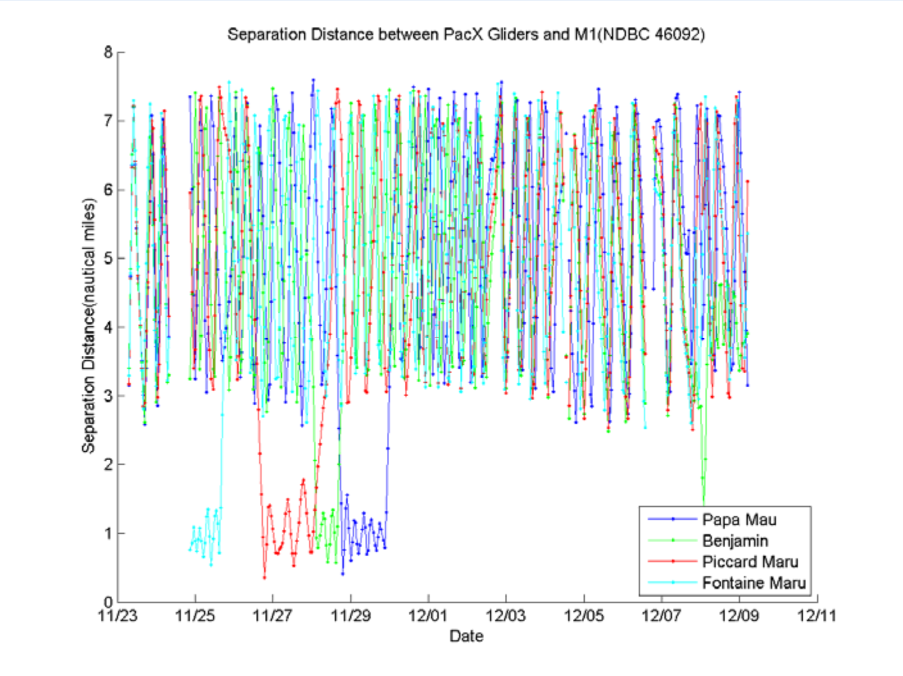
- Seabird GPCTD/DO
- Airmar PB200 Weather Station
- Datawell MOSE-G Wave Sensor
- Turner C3 Fluorometer

MBARI M1 (NDBC 46092)

- All 4 vehicles circumnavigated M1 for two weeks
- Nov. 23 to Dec. 9, 2011
- Also compared wave data to NDBC 46236 (Scripps)

M1 Circumnavigation

- Ideally, Wave Gliders & M1 would be collocated
- Operation Considerations result in average 4.7 nmi separation
- High spatial variability
- wind speed
- wind direction
- Lesser spatial variability
- water temperature
- air temperature

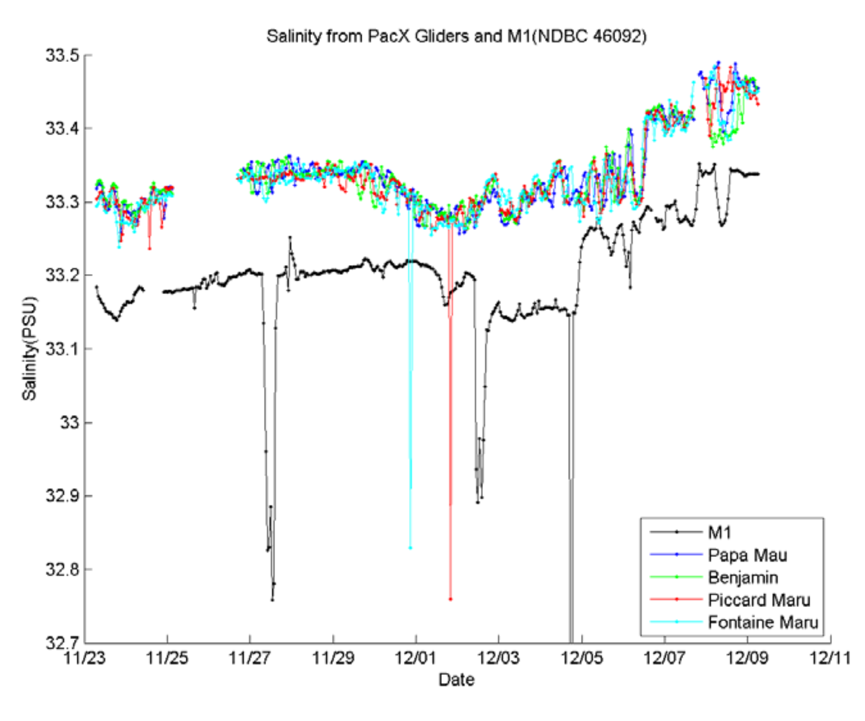


Seabird GPCTD/DO

- Conductivity, Temperature, Depth, and Dissolved Oxygen
- Mounted in Wave Glider Float
- 8 sample average returned every 10 minutes

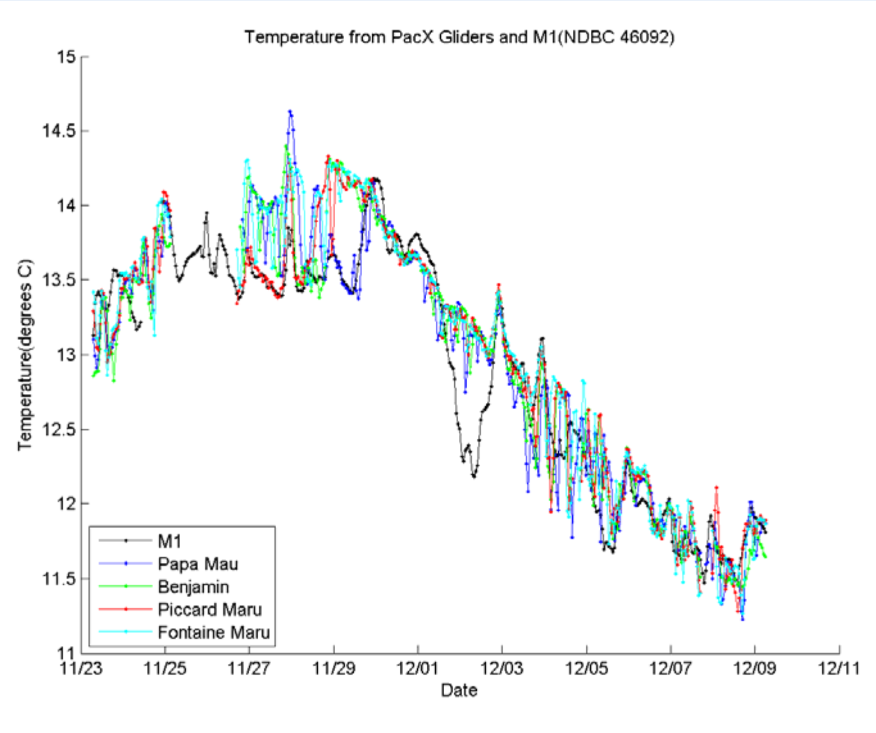
Salinity

- Salinity within the bay is expected to be uniform
- Agreement between gliders is excellent
- Confirmed that the CTD on M1 was not cleaned since July of 2011.
- Percent difference for the majority of the measurements is less than 0.5.



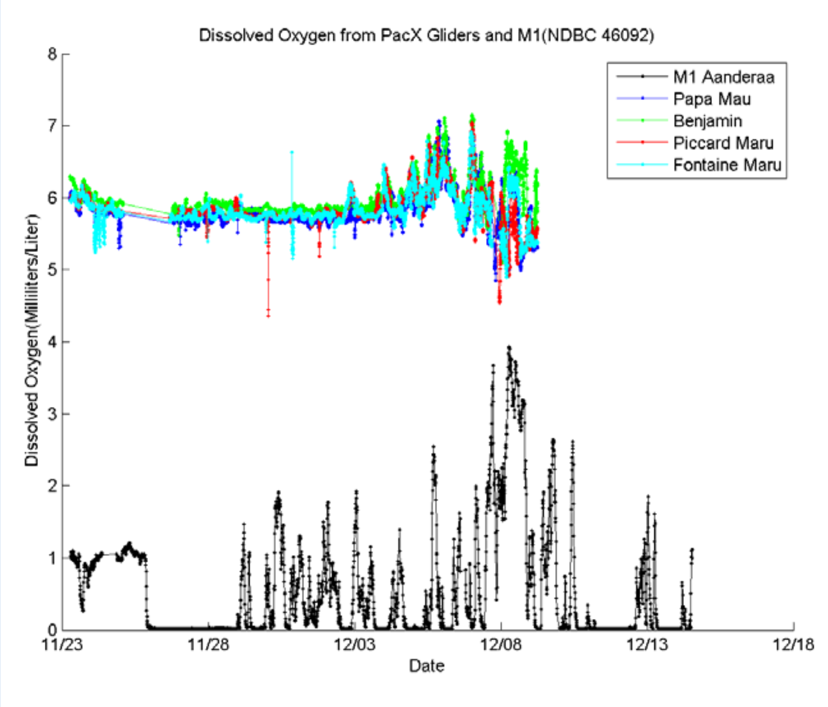
Water Temperature

- Temperature variability in Monterey Bay is greater than that of salinity
- Temperature spread of about 4 degrees C.
- Average percent difference of 2.5%

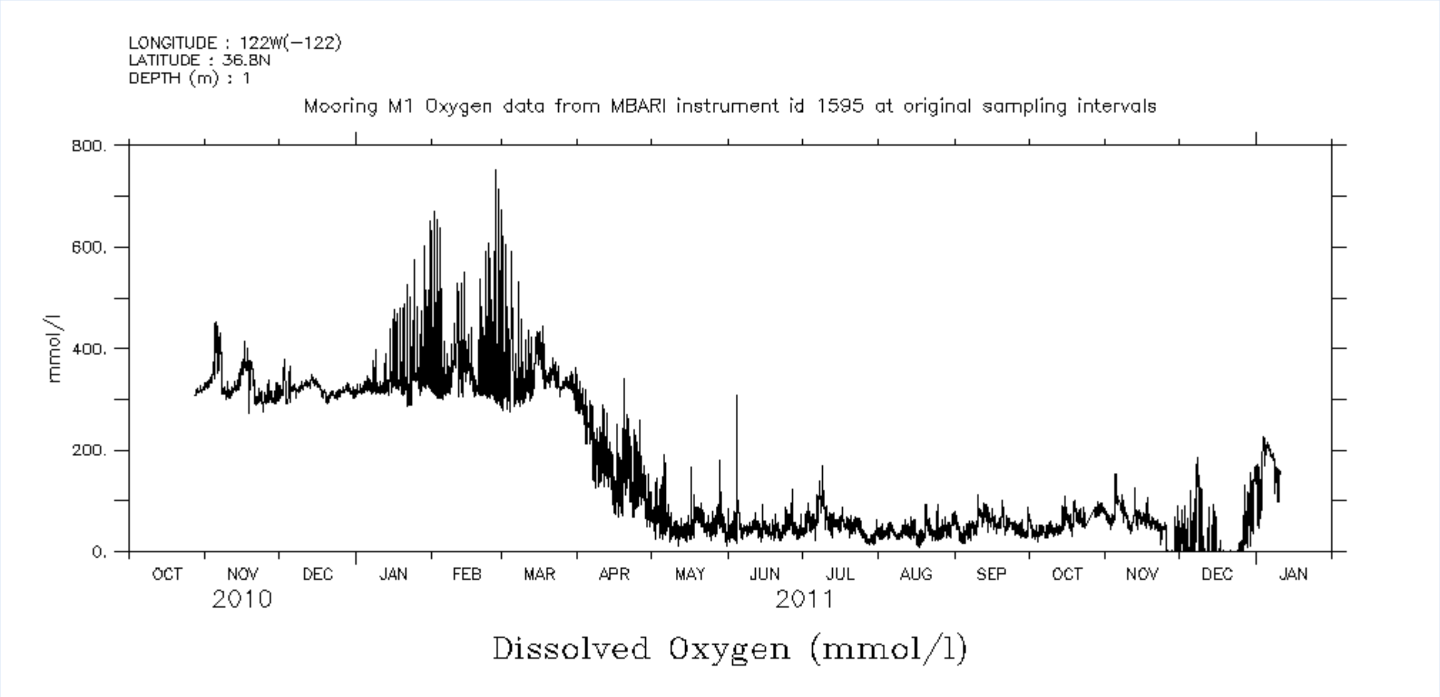


Dissolved Oxygen

- Wave Glider sensor agreement is excellent
- M1 O2 sensor - Aanderra Optode
- Sensor had not been cleaned for many months.
- The instrument started to foul in March of 2011



MBARI Dissolved Oxygen Sensor



GPCTD Conclusion

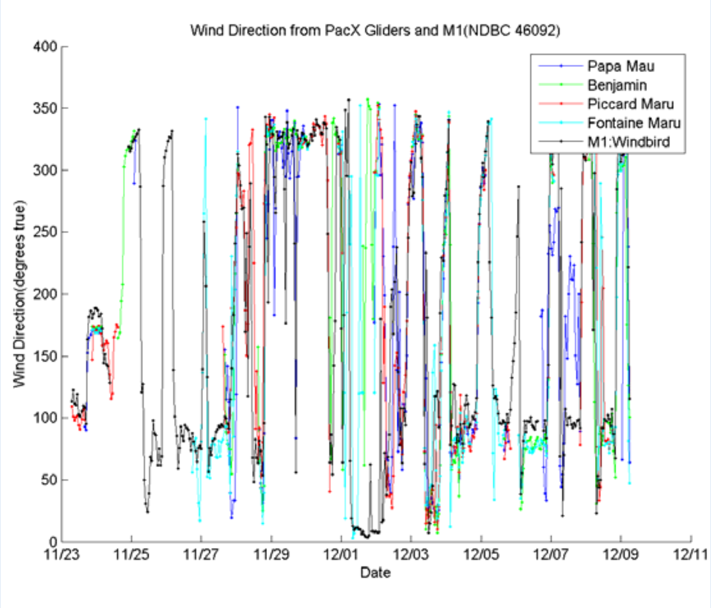
- The float mounted SeaBird GPCTDs exhibited excellent performance while in Monterey Bay.
- For the core variables of salinity and temperature, average percent differences relative to M1(NDBC 46092) were less than 0.5 and 3 respectively.
- The spatial variability of temperature and the positions of the Wave Gliders relative to M1 could explain these small differences.
- Without the measurements of dissolved oxygen at M1 as a reference, the agreement in dissolved oxygen among the gliders becomes the metric for evaluation of performance

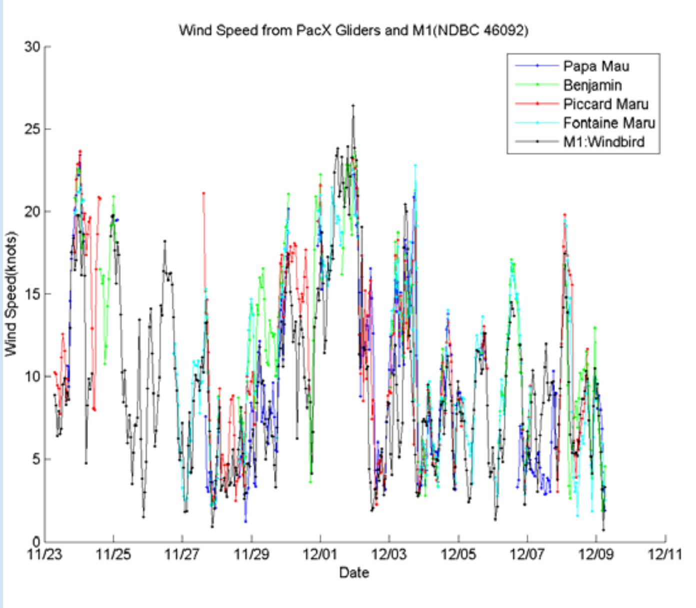
Airmar PB200 Met Station

- Ultrasonic transducer based measurement
- Measures
  - Air Temperature
  - Barometric Pressure
  - Wind speed & direction
- Mounted on 1m tall mast
- 1 Hz Sampling Rate
- 10 minute averages returned every 10 minutes

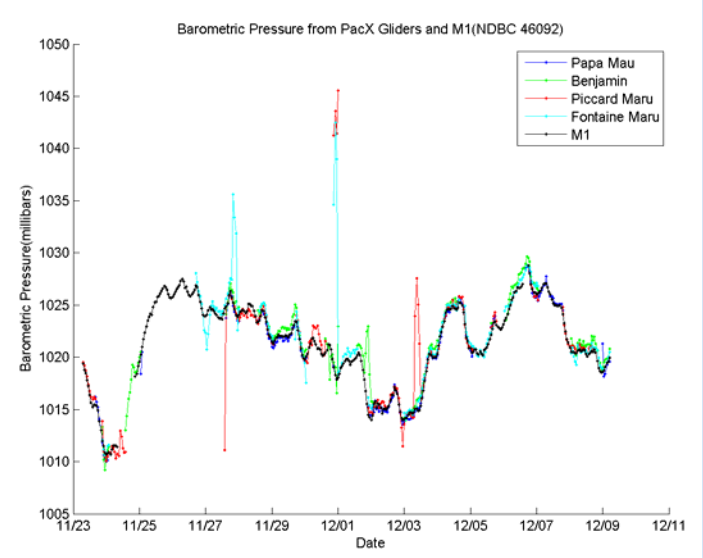
Wind Speed & Direction

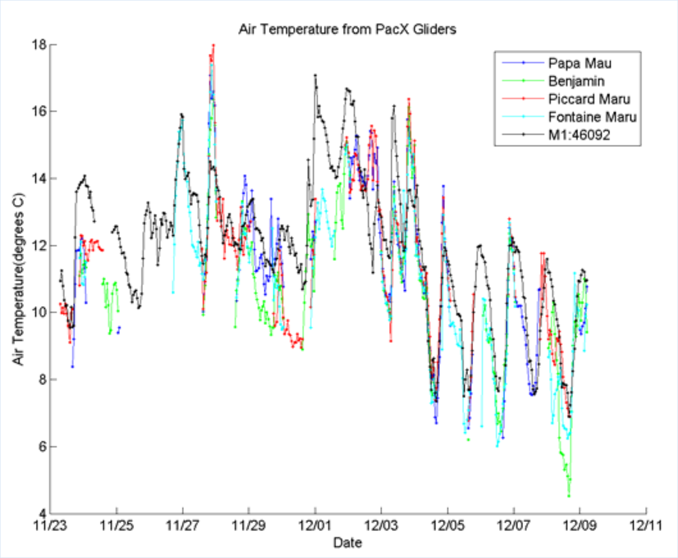
Wind speed and direction most affected by spatial variability





Air Temperature & Barometric Pressure





Airmar PB200 Conclusions

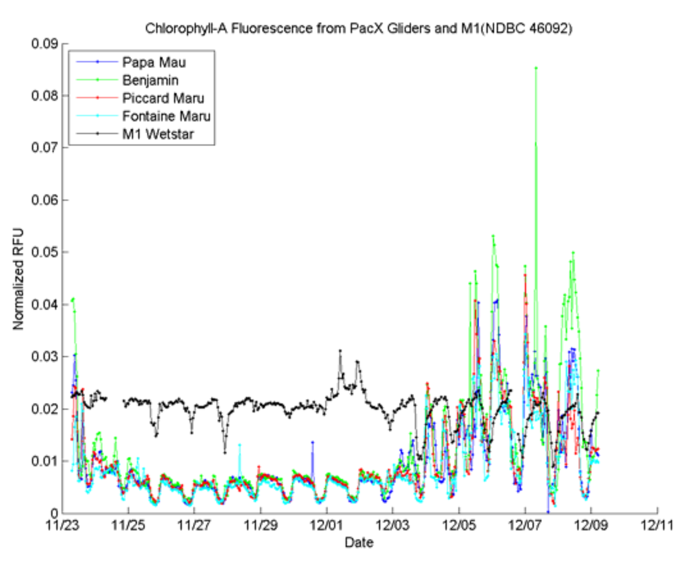
- The Airmar PB200 showed mixed results when compared to similar data at M1.
- The lack of agreement attributed to two factors:
- **Spatial Variability** - Monterey Bay wind speed and direction often show high spatial variability.
- **Instrument Height** - M1 anemometer: mounted 4 meters above sea level Airmar PB200: mounted 1m above sea level.
- Percent differences
- Wind speed and direction - between 0 and 200
- Air temperature measurements - less than 1 degree C
- Barometric pressure - less than 0.5% difference

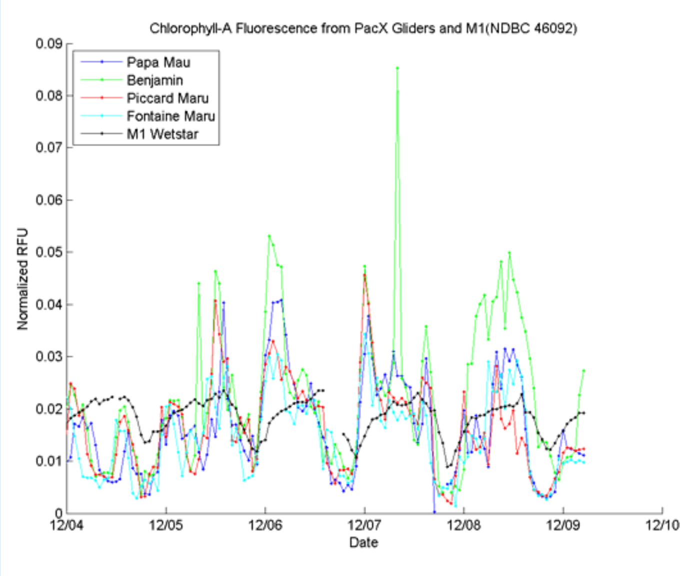
Turner C3 Fluorometer

- Three optical channels
  - Chlorophyll-A
  - Crude Oil
  - Turbidity
- Mounted in surface float
- 2 minute sampling rate
- Group of 7 samples returned every 14 minutes

Turner C3 Fluorometer

Notice the coincidental depression of the signal happening around midday. This presumably can be attributed to photo inhibition.





Turner C3 Conclusions

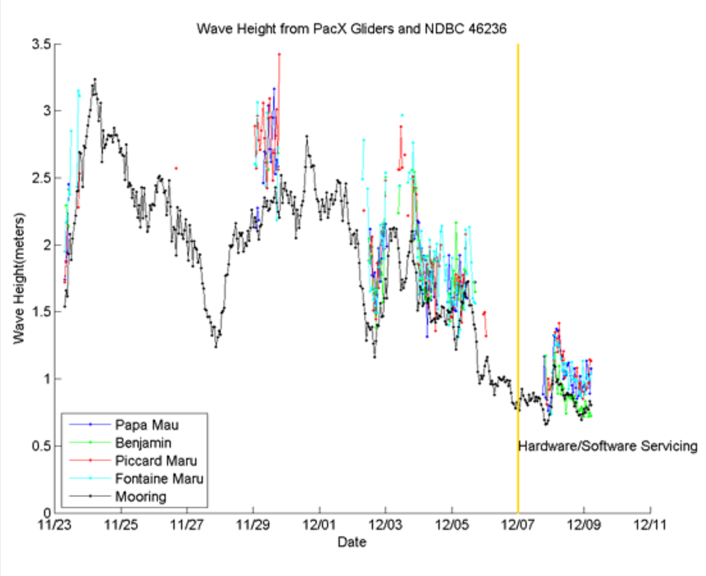
- Direct comparison of a fluorescence signal from the vehicles and M1 is not possible without a coincidental calibration
- Fluorscence signals were normalized by the maximum possible signal for the respective instrument
- Given the separation distances between M1 and the vehicles (3-8 km) as well as the spatial variability of chlorophyll in the bay, one would not expect the measurements to agree too closely.
- Strong agreement in known photoinhibition cycle between both sensors

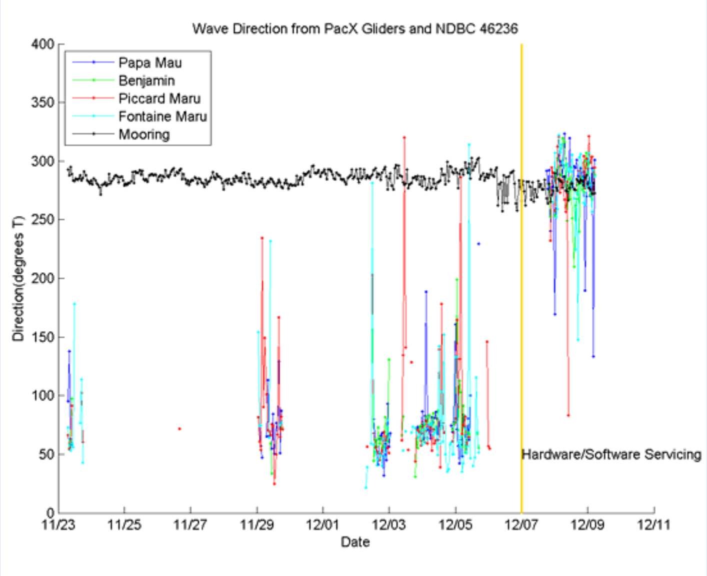
MOSE-G Wave Sensor – NDBC 46236

- GPS based wave motion sensor
- Measures
  - Significant wave height
  - Average period
  - Peak period
  - Peak direction
- 2 Hz sampling rate
- 512 point average every 30 minutes

MOSE-G Wave Sensor

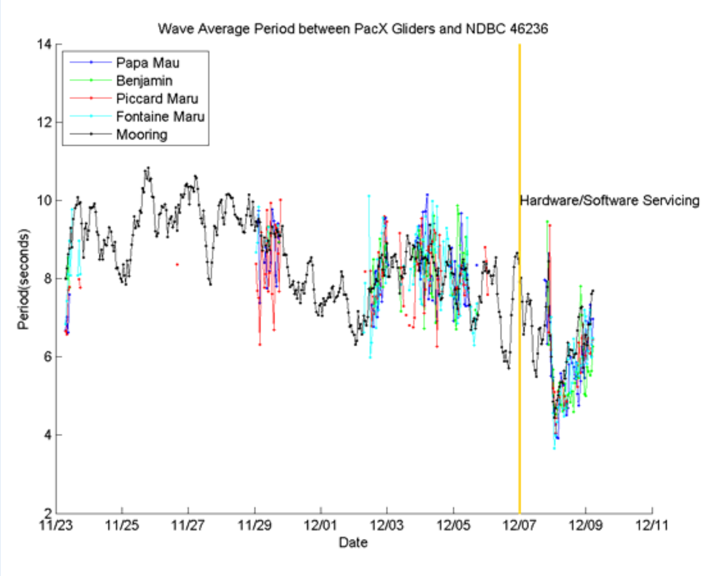
Note the improved agreement after remote firmware upgrade performed on December 7th

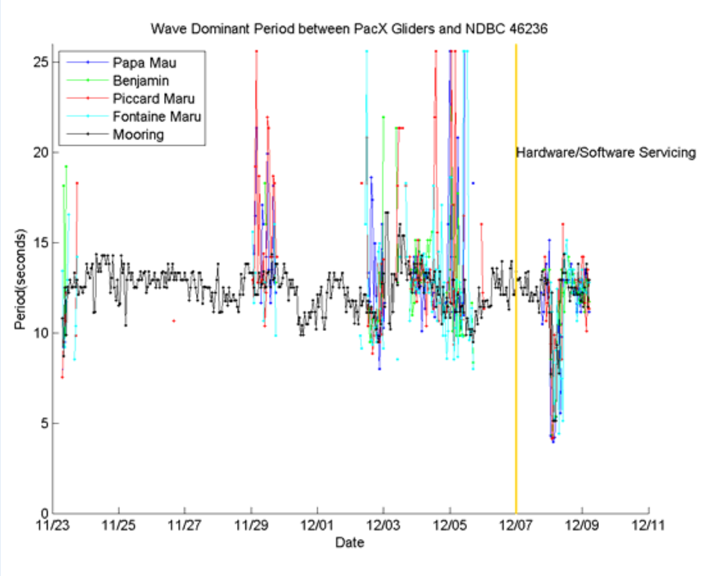




MOSE-G Wave Sensor

The mean percent difference in dominant and average period between the Wave Gliders and NDBC 46236 was 18 and 10 respectively.





MOSE-G Conclusions

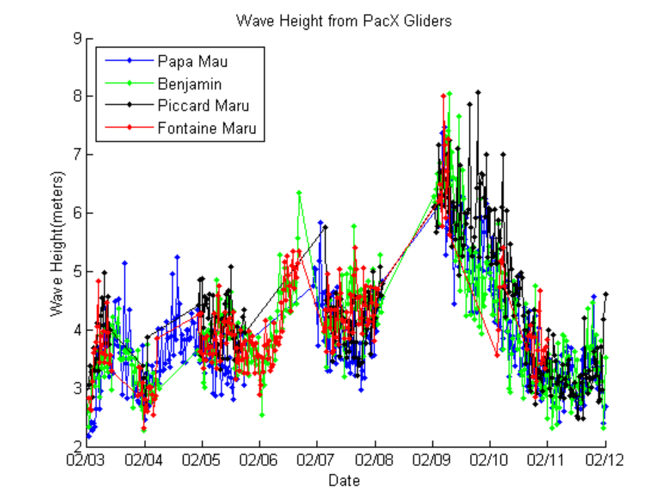
- The Datawell MOSE-G waves sensor showed mixed results when compared to NDBC 46236.
- Wave direction initially determined to be 90 degrees from NDBC 46236.
- This prompted corrective modification of the firmware on the instrument.
- Average percent differences in wave direction decreased from 118 to 11 percent.
- Future comparisons showed improved performance of the MOSE-G sensor

Severe Storm Assessment

Sea Storm Assessment

PAC·X

3-10 Feb 2012 - Lat. = 28.3011 ° N Lon. = 145.2055 ° W



The trio from Edmonton, Canada hit a series of storms while sailing from Mexico to Hawaii and high winds snapped their mast about 300 miles from their destination

Wave Heights as high as 8m

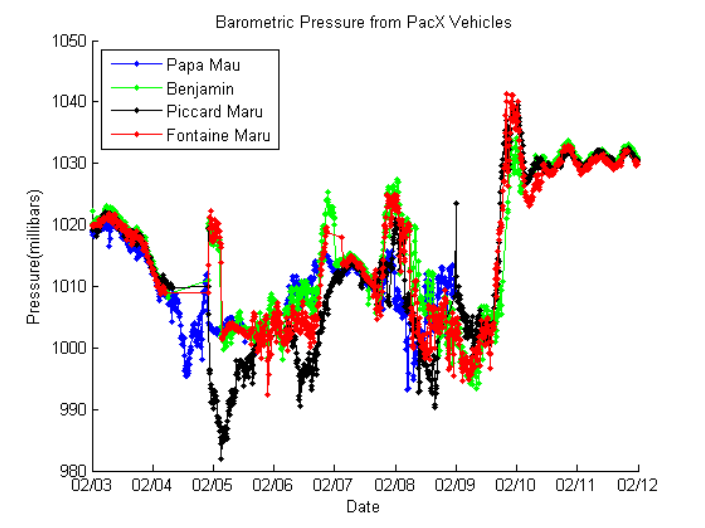
Dominant Wave Periods 10-14 seconds

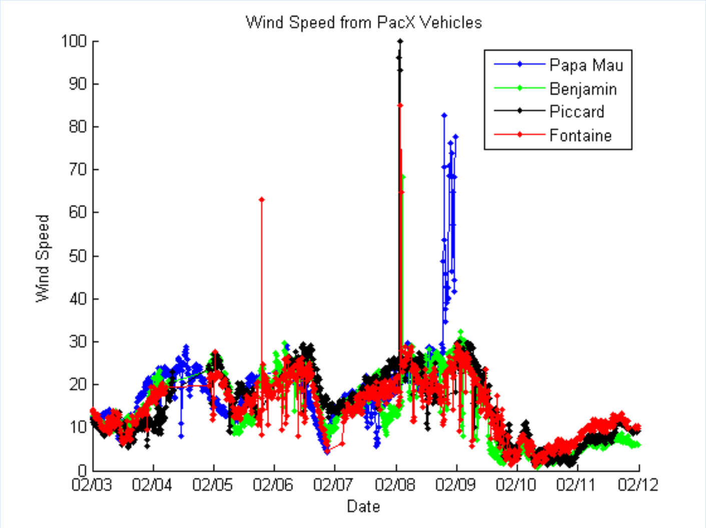
A container ship in the area was diverted by USCG to rescue a stricken sailing family

"Wind blowing 50 knots and the seas rolling at 20-25 feet"

PacX Results – Severe Pacific Storm

3-10 Feb 2012 - Lat. = 28.3011 ° N Lon. = 145.2055 ° W





Pressures as low as 980 mb

Category 2 Hurricane = 965-979 mb

Verified against SSV Robert C Seamans

Sustained Wind Speeds up to 30 knots

Gusts = 60+ Knots

Verified against ASCAT satellite

Conclusions

- Wave Glider is a suitable and highly efficient platform for the observation of sea surface and lower atmospheric conditions over extended sampling periods.
- The Wave Glider could quickly and efficiently increase the operational density of ocean observations.
- While additional surveys are necessary to understand reasons for the disagreement among certain variables, the results of these comparisons are quite encouraging.
- Due to the inability to sample the same waters as the reference mooring it is nearly impossible to determine what percentage of the differences are due to spatial variability.

What's Next for PacX Wave Gliders?

- Papa Mau should arrive in Australia around middle of October, 2012
- The Japanese Team should arrive in January, 2012
- Then? Should we circumnavigate Antarctica?

Wave Glider

Persistent

•Year long missions without fuel or maintenance

Mobile

•Travel to op area, patrol, and return

•Capture spatial and temporal dynamics

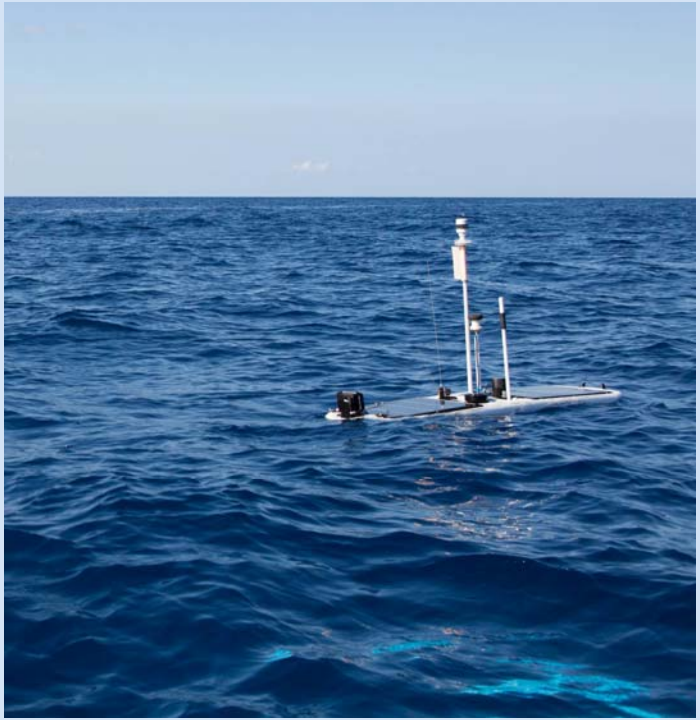
Real-Time

•Data transmitted via satellite connection

Proven

•More than 130 systems shipped

•Over 250,000 operational miles



Questions?