Session 3 Presentation - An Overview of Recent Wave Glider® Field Program

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Pat Fitzpatrick, Yee Lau, Robert Moorhead, Adam Skarke, Daniel Merritt, Keith Kreider, Chris Brown, Ryan Carlon, Graham Hine, Teri Lampoudi, and Alan Leonardi

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An Overview of Recent Wave Glider® Field Program

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Liquid Robotics, Inc.

Alan Leonardi
NOAA/OAR/ Ocean Exploration and Research (formerly AOML)

Funded by the Sandy Supplemental Internal Competition for Instruments and Observing Systems under NOAA Grant NA14OAR4830128

Two papers published in MTS
One of three WGs on R/V Tommy Munro
Pre-deployment, Biloxi, MS
Aug. 25, 2014
Launched 37 km offshore
Research goal

- Primary goal - Intercept of Gulf of Mexico tropical cyclone by one or more WGs in 2014
- Other goals –
  - Validation of instruments by loitering around buoys
  - Proof of concept for providing data in regions lacking buoys
  - Understanding maneuverability capabilities and limitations
- No tropical cyclones in Gulf of Mexico in 2014, but demonstrated maneuverability and pre-deployment capabilities on northern fringe of Tropical Storm Hanna when it formed in Caribbean Sea
**Instrumentation**

- Payloads are on the float and the glider 6 m below

- Instruments used in field program
  - Meteorology – wind, temperature, pressure (1-m height, every 10 min)
  - SST (archived, from ADCP; can be done realtime with surface CTD on SV3)
  - Directional wave sensor – sig wave height, avg period, peak period (every 30 min), spectra (archived)
  - ADCP – profile of ocean currents (1-25 m, every 30 min), raw data (archived)
  - CTD-DO – conductivity/salinity, temperature, dissolved oxygen (6-m depth, every 10 min)

- Some data transmitted real-time by Iridium satellite link, some archived onboard and retrieved after mission. Data transmission depends on a balance of priorities, power, data resolution, data types, and transmission limits
Loitering periods

**G10**

42040: 8/28-8/29
42039: 9/2-9/5
42099: 11/28-11/29

**G11 (renamed G14 on 9/11)**

42040: 9/1-9/5

**G12 (discontinued 10/24, duties assumed by GOM1)**

42039: 9/1-9/2
84W, 26N: 9/9-10/23

**G14**

42040: 9/14-9/19
42099: 10/10-10/21
“Hanna” 82.6W 25.1N: 10/25-11/18
42099: 11/28-11/29

**GOM1**

84N, 26W: 10/14-10/21
“Hanna” 83.8W 24.9N: 10/23-10/31
“Hanna” 83.5W 24.9N: 11/1-11/3
42099: 11/9-11/29

“Hanna” connotes northern fringe of tropical system
Data provided real-time from MSU to NDBC in WMO FM-18 format for website display.

Provided to weather broadcast vendor Barons

Data provided to GCOOS, and setup for download by GFDL if ever needed

GTS transmission possible but not done on this mission
October and November time series
Bias Err = 0.48 m/s
Abs Err = 0.76 m/s

Bias Err = -0.51 mb
Abs Err = 0.55 mb

Bias Err = 0.08 m
Abs Err = 0.10 m
Time series of Wave Glider and buoy 42036

Wind Speed (ms⁻¹) vs. Time

Significant Wave Height (m) vs. Time
Validation
<table>
<thead>
<tr>
<th></th>
<th>G10 vs 42036 Nov 1-22, 2014</th>
<th>r</th>
<th>Bias (WG – buoy)</th>
<th>Mean absolute error</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
<td></td>
<td>0.98</td>
<td>0.1</td>
<td>0.5</td>
<td>436</td>
</tr>
<tr>
<td>Significant Wave Height (m)</td>
<td></td>
<td>0.98</td>
<td>0.1</td>
<td>0.1</td>
<td>430</td>
</tr>
<tr>
<td>Average Period (s)</td>
<td></td>
<td>0.91</td>
<td>0.0</td>
<td>0.2</td>
<td>430</td>
</tr>
<tr>
<td>Peak Period (s)</td>
<td></td>
<td>0.84</td>
<td>-0.2</td>
<td>0.4</td>
<td>414</td>
</tr>
<tr>
<td>Peak Direction (deg)</td>
<td></td>
<td>0.98</td>
<td>-1.5</td>
<td>14.7</td>
<td>414</td>
</tr>
<tr>
<td>Wind Speed (ms⁻¹) (filtered SWH ≤ 1.8 m)</td>
<td></td>
<td>0.85</td>
<td>1.5</td>
<td>1.7</td>
<td>341</td>
</tr>
<tr>
<td>Wind Gust (ms⁻¹) (filtered SWH ≤ 1.8 m)</td>
<td></td>
<td>0.87</td>
<td>2.2</td>
<td>2.3</td>
<td>338</td>
</tr>
<tr>
<td>Wind Direction (deg) (filtered SWH ≤ 1.8 m)</td>
<td></td>
<td>0.99</td>
<td>-1.1</td>
<td>10.8</td>
<td>341</td>
</tr>
<tr>
<td>Pressure (mb) (filtered SWH ≤ 1.8 m)</td>
<td></td>
<td>1.00</td>
<td>-0.2</td>
<td>0.4</td>
<td>336</td>
</tr>
</tbody>
</table>
# GOM1 vs 42099, November

## Wave data

<table>
<thead>
<tr>
<th>GOM1 vs 42099 Nov 9-29, 2014</th>
<th>( r )</th>
<th>Bias (WG – buoy)</th>
<th>Mean absolute error</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant Wave Height (m)</td>
<td>0.99</td>
<td>0.0</td>
<td>0.1</td>
<td>903</td>
</tr>
<tr>
<td>Average Period (s)</td>
<td>0.95</td>
<td>-0.1</td>
<td>0.3</td>
<td>903</td>
</tr>
<tr>
<td>Peak Period (s)</td>
<td>0.92</td>
<td>-0.3</td>
<td>0.5</td>
<td>892</td>
</tr>
<tr>
<td>Peak Direction (deg)</td>
<td>0.99</td>
<td>1.3</td>
<td>10.7</td>
<td>892</td>
</tr>
<tr>
<td>Loitering platform, radii proximity, and dates</td>
<td>r</td>
<td>Bias (WG - buoy)</td>
<td>Mean absolute error</td>
<td>Sample size</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>------</td>
<td>------------------</td>
<td>---------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>G10 vs 42036 (Large radius) 10/16-11/22</td>
<td>0.98</td>
<td>0.12</td>
<td>0.13</td>
<td>861</td>
</tr>
<tr>
<td>G10 vs 42036 (Small radius) 10/11-10/16</td>
<td>0.97</td>
<td>0.15</td>
<td>0.15</td>
<td>126</td>
</tr>
<tr>
<td>G10 vs 42036 (Small radius) 9/15-9/23</td>
<td>0.98</td>
<td>0.18</td>
<td>0.18</td>
<td>192</td>
</tr>
<tr>
<td>G14 vs 42099 (Small radius) 11/25-11/28</td>
<td>0.94</td>
<td>-0.15</td>
<td>0.16</td>
<td>152</td>
</tr>
<tr>
<td>G14 vs 42099 (Large radius) 10/17-10/21</td>
<td>0.62</td>
<td>-0.03</td>
<td>0.23</td>
<td>243</td>
</tr>
<tr>
<td>G14 vs 42099 (Small radius) 10/10-10/16</td>
<td>0.99</td>
<td>-0.05</td>
<td>0.06</td>
<td>308</td>
</tr>
<tr>
<td>GOM1 vs 42099 (Small radius) 11/22-11/28</td>
<td>0.88</td>
<td>-0.24</td>
<td>0.27</td>
<td>315</td>
</tr>
<tr>
<td>GOM1 vs 42099 (Large radius) 11/9-11/22</td>
<td>0.84</td>
<td>-0.02</td>
<td>0.22</td>
<td>610</td>
</tr>
</tbody>
</table>

Large radii: 9250 m  
Small radii: 275 m

SST range 26.8-28.3°C. WG repeatedly circled in this gradient, contributing to a reduced correlation at larger radii to the stationary buoy.
Example monthly plots of ADCP at 00Z – no validation possible

G10 ADCP (Oct 2014)

GOM1 ADCP (Nov 2014)

Real-time data available every 30 min
Conclusion from validation exercise

- WGs show a capacity for short–term to seasonal targeted sustained observations in data-void regions and high-impact weather events.
- Demonstrated that SV2 WGs retain maneuverability in currents up to approximate 1 ms\(^{-1}\). SV3 has more thrust, and should be studied in fast currents.
- Surface SST, 6-m water temperature data, salinity, dissolved oxygen, and ADCP should facilitate mixed layer and wave studies. SST and wave data validates well against buoys.
- Airmar wind sensor performs well in moderate conditions.
- Airmar temperature sensor performs well in baroclinic conditions.
- Airmar wind sensor may have issues with wave heights > 1.8 m.
- Airmar temperature sensor in warm season suffers radiative heating in summer.

Issues

- Tampering or collisions need to be addressed by:
  - Better boater education and better signage
  - Increased distance from buoys during loitering. Buoys attract fish and fishermen.
- Tropical cyclone intercept studies needed to examine data impact and ocean evolution studies
- ADCP, salinity, wave spectra, and dissolved oxygen data require validation, but appear reasonable.
- Better quality atmospheric instrumentation needed; such as used by Scripps and UW.
Tropical cyclone intercepts

WG$s have traversed 16 TC$s, including Rasmussen, Isaac, and Sandy
Northern fringe of Hanna lifecycle during 2014 field program

GOM1 WindSpd Oct 23-28, 2014

GOM1 SigWaveHgt Oct 23-28, 2014

Front and circulation interaction

Front dissipates

Genesis then landfall
Pacific Crossing (PacX) experiment
Hurricane Freda (2012)

Luc Lenain and W. Kendall Melville
University of California, Scripps Institution of Oceanography

Published in J. Atmospheric and Oceanic Tech.

PacX sent 4 WGs across Pacific from San Francisco to Hawaii. Two then transited to Japan, the other two for Australia. One happened to pass poleward of Freda. Closest approach was 40 km.
Surface velocity sensor used for navigation turned off to reduce power consumption.

“Entrained” into Freda by currents.
Reduction in salinity (rainfall influence) and water temperature in TC wake
Sea surface displacement

Note rogue waves
Evolution wave directional spectrum

(a) 2012/12/28 14:00UTC, u = 6.07 m/s
(b) 2012/12/30 14:00UTC, u = 7.03 m/s
(c) 2012/12/31 09:00UTC, u = 19.41 m/s
(d) 2012/12/31 12:00UTC, u = 24.67 m/s
(e) 2012/12/31 16:00UTC, u = 26.24 m/s
(f) 2012/12/31 20:00UTC, u = 11.63 m/s
(g) 2013/01/01 21:00UTC, u = 7.79 m/s
(i) 2013/01/03 06:00UTC, u = 6.48 m/s


Application of Craik-Leibovich theory to Stokes depth scale

(a) Amplitude

(b) Direction

(c) Turbulent Langmuir number $L_{\lambda}$

(d) Stokes depth scale $D_{\lambda}$
Biophysical response

Chlorophyll and turbidity from a fluorometer
Validation near Hawaii against a Datawell directional wave buoy

Bulk wave parameter results similar to Fitzpatrick et al. (2016)
Initial loitering plan

- G10 targeted buoy 42036 (offshore Tampa), with stops at 42040 and 42039
- G11 targeted buoy 42039 and 42040 (N. Gulf)
- G12 targeted data void region around non-functioning buoys 42034 and 42003 (SW FL)

Modifications to loitering plan during mission

- Sabotage or “accidental intercept” occurred to G11 twice around Buoy 42040 off Mississippi River. G11 renamed G14 after first sabotage.
- G14 sent to buoy 42099 (wave and SST data only) off central FL.
- G10 weather instrument also damaged. Replaced
- G12 air temperature sensor failed. Another WG, dubbed GOM1, was in area from unrelated mission. GOM1 replaced G12.
- G14 and GOM1 moved west of Florida Keys before and during Tropical Storm Hanna