A Review of the 2014 Gulf of Mexico Wave Glider® Field Program

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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

A WG about to be launched

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

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

Loitering periods

G10

42040: 8/28-8/29
42039: 9/2-9/5
42036: 9/15-9/23; 10/11-11/21
42099: 11/28-11/29

G11 (renamed G14 on 9/11)

42040: 9/1-9/5

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

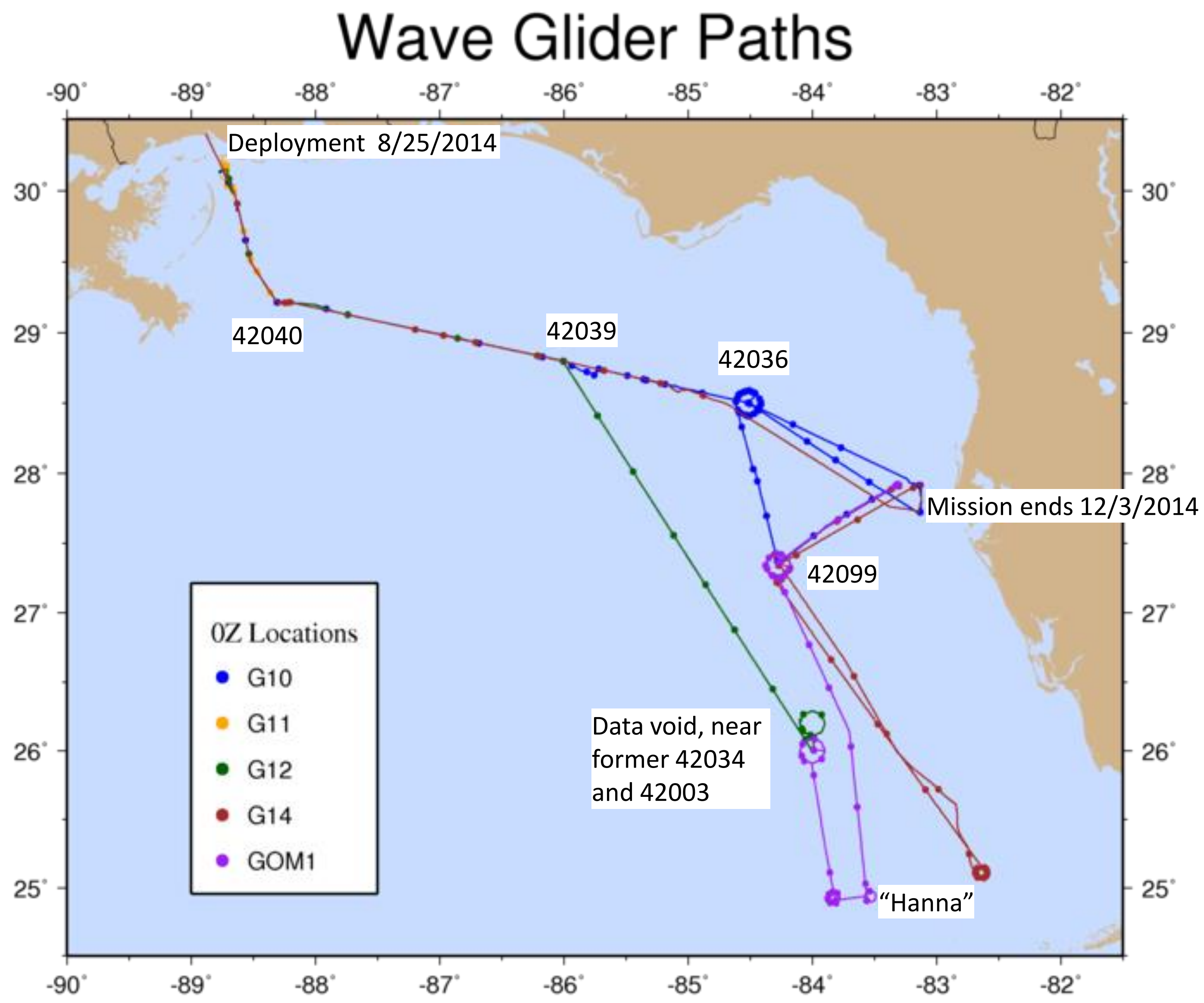
42039: 9/1-9/2
84W, 26N: 9/9-10/23

G14

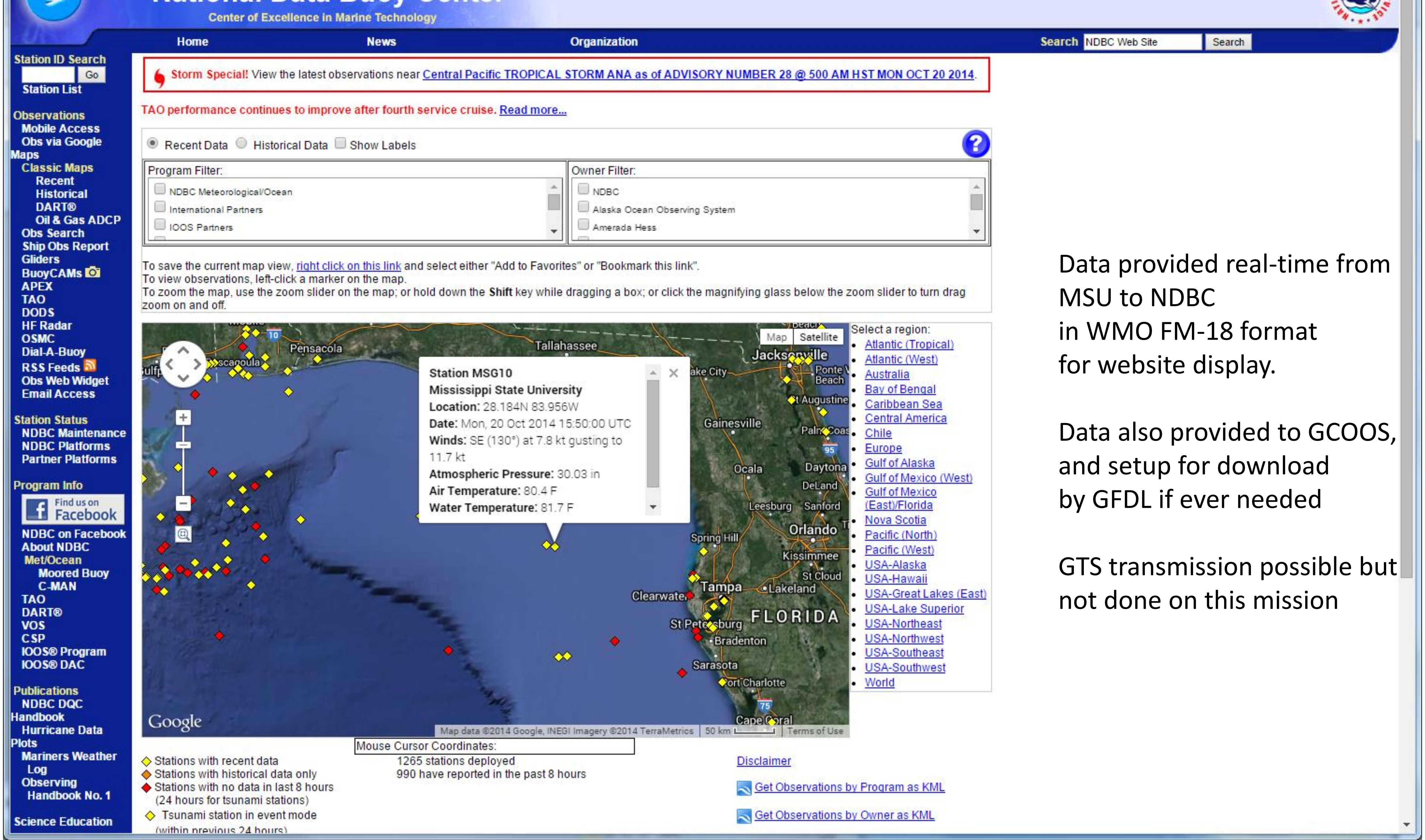
42040: 9/14-9/19
42099: 10/10-10/21
"Hanna" 82.6W 25.1N: 10/25-11/18
42099: 11/28-11/29

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.

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

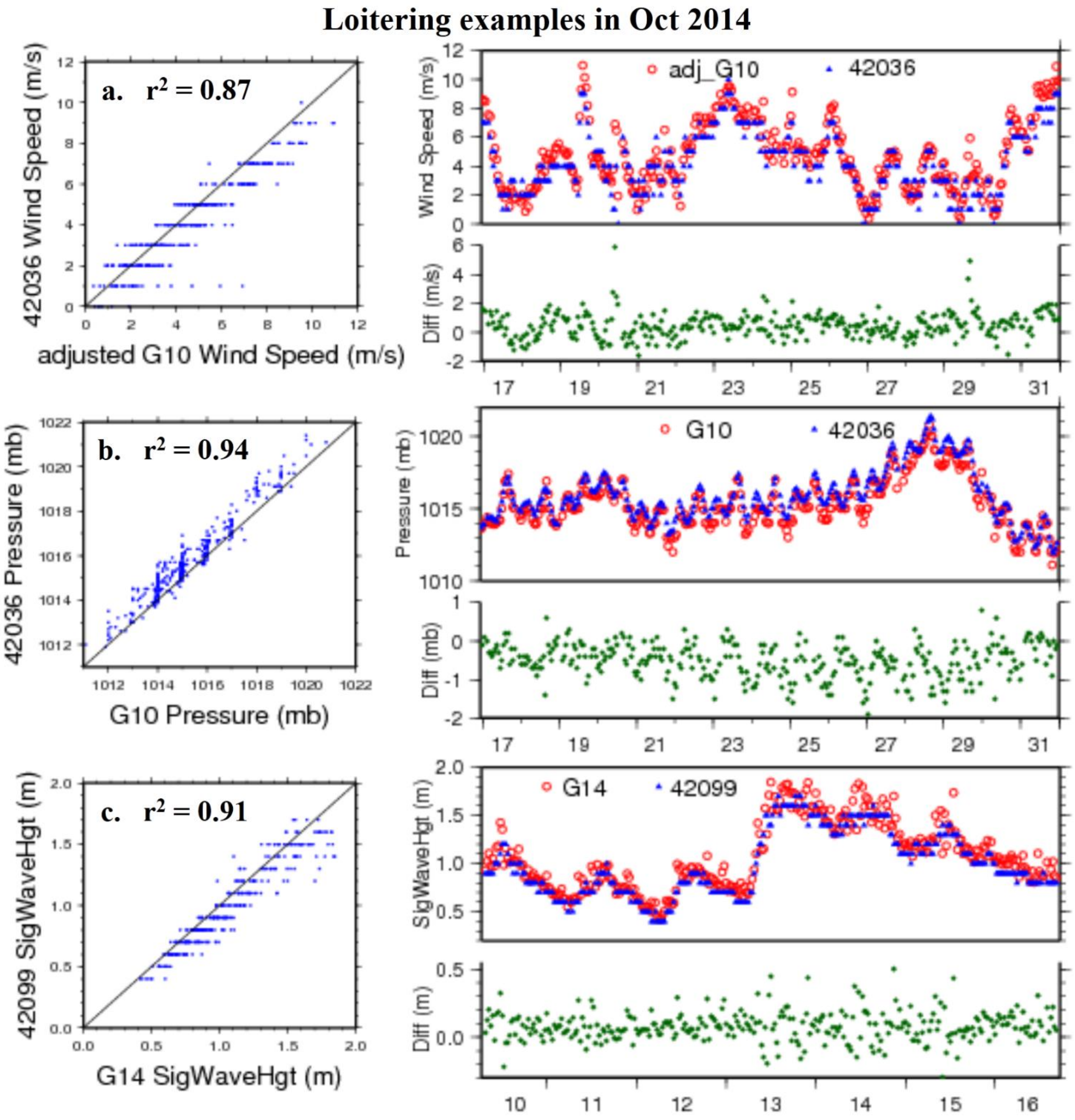
GTS transmission possible but not done on this mission

October validation

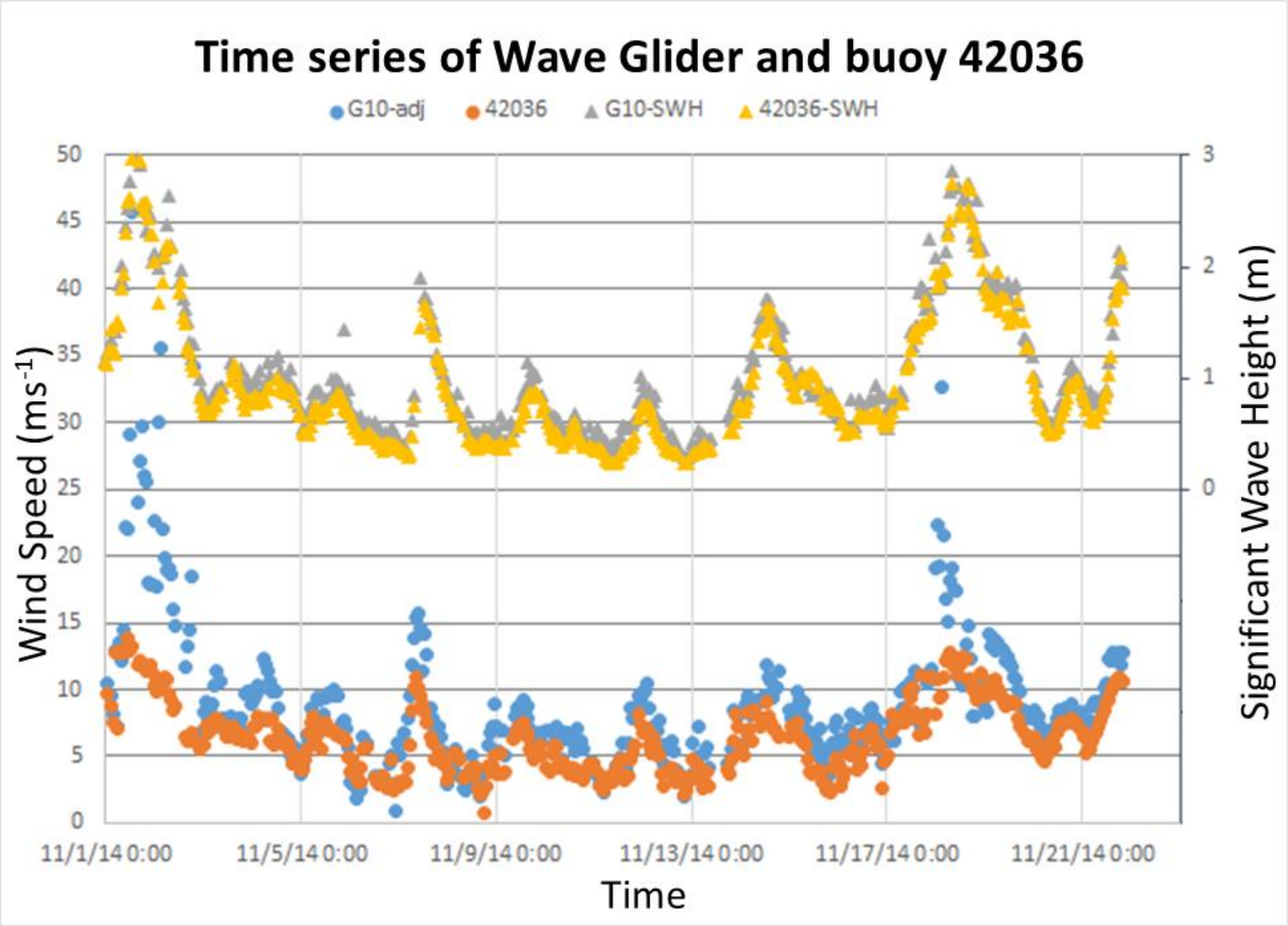
Bias Err = 0.48 m/s
Abs Err = 0.76 m/s

Bias Err = -0.51 mb
Abs Err = 0.55 mb

Bias Err = 0.08 m
Abs Err = 0.10 m



November validation


Time series of Wave Glider and buoy 42036
G10-adj
42036
G10-SWH
42036-SWH
Wind Speed (ms-1)
Significant Wave Height (m)
Time
50
45
40
35
30
25
20
15
10
5
0
3
2
1
0
11/1/14 0:00
11/5/14 0:00
11/9/14 0:00
11/13/14 0:00
11/17/14 0:00
11/21/14 0:00

G10 vs 42036, November
Atmos and wave data

G10 vs 42036 Nov 1-22, 2014	r	Bias (WG – buoy)	Mean absolute error	Sample Size
Air Temperature (°C)	0.98	0.1	0.5	436
Significant Wave Height (m)	0.98	0.1	0.1	430
Average Period (s)	0.91	0.0	0.2	430
Peak Period (s)	0.84	-0.2	0.4	414
Peak Direction (deg)	0.98	-1.5	14.7	414
Wind Speed (ms^{-1}) (filtered SWH ≤ 1.8 m)	0.85	1.5	1.7	341
Wind Gust (ms^{-1}) (filtered SWH ≤ 1.8 m)	0.87	2.2	2.3	338
Wind Direction (deg) (filtered SWH ≤ 1.8 m)	0.99	-1.1	10.8	341
Pressure (mb) (filtered SWH ≤ 1.8 m)	1.00	-0.2	0.4	336

GOM1 vs 42099, November
Wave data

GOM1 vs 42099 Nov 9-29, 2014	r	Bias (WG – buoy)	Mean absolute error	Sample Size
Significant Wave Height (m)	0.99	0.0	0.1	903
Average Period (s)	0.95	-0.1	0.3	903
Peak Period (s)	0.92	-0.3	0.5	892
Peak Direction (deg)	0.99	1.3	10.7	892

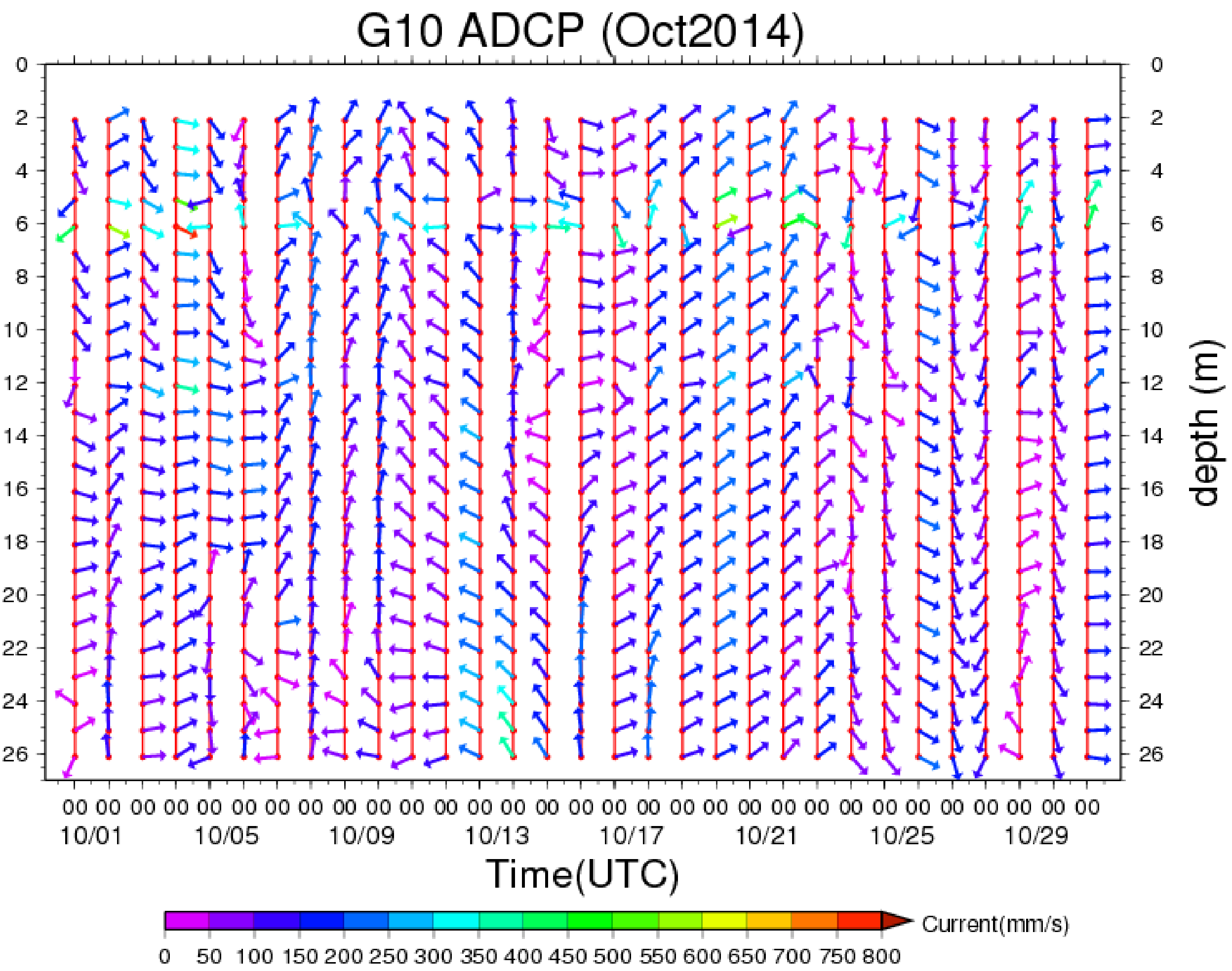
G10 vs 42036; G14 and GOM1 vs 42099
SST data

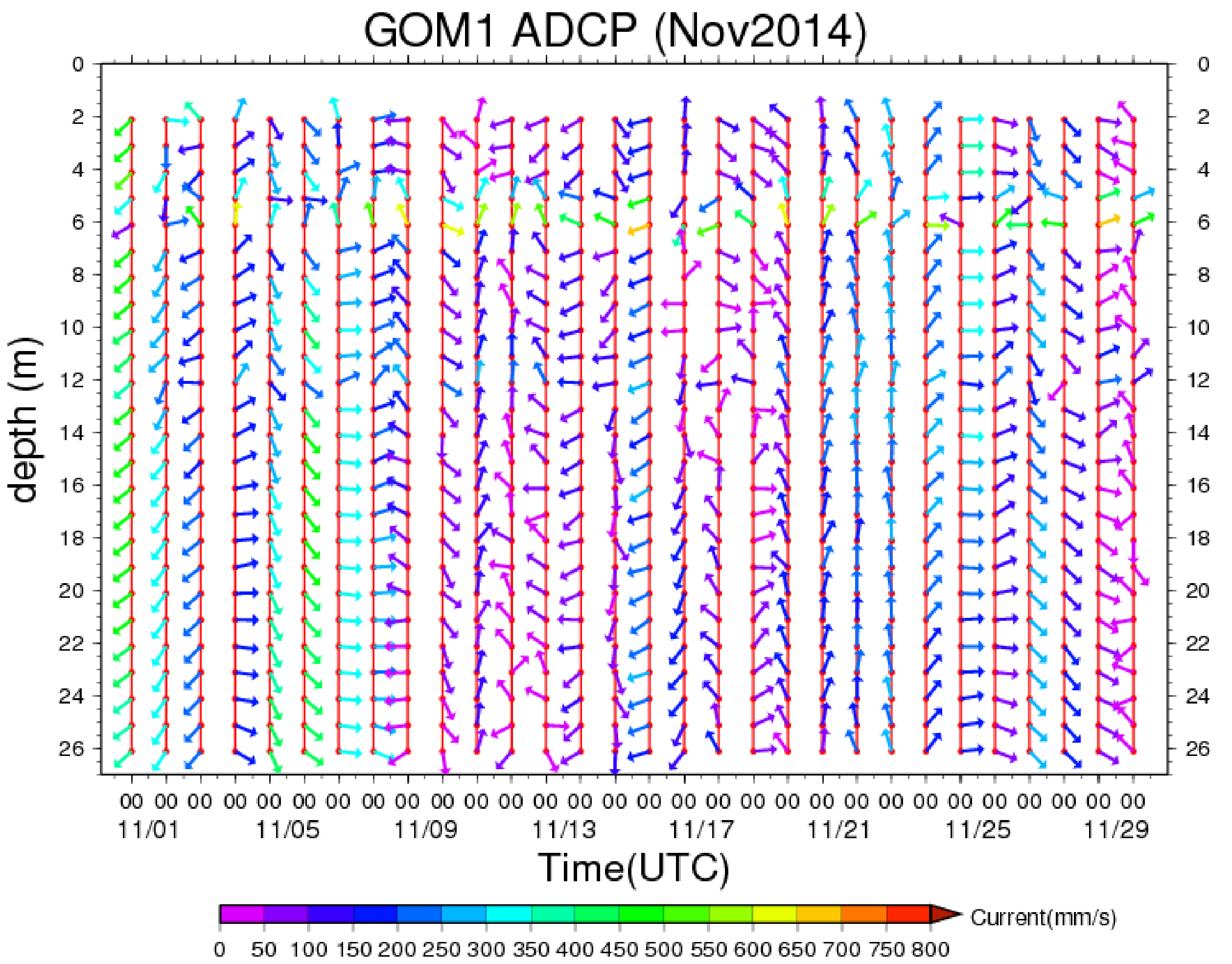
Large radii: 9250 m
Small radii: 275 m

Loitering platform, radii proximity, and dates	r	Bias (WG - buoy)	Mean absolute error	Sample size
G10 vs 42036 (Large radius) 10/16-11/22	0.98	0.12	0.13	861
G10 vs 42036 (Small radius) 10/11-10/16	0.97	0.15	0.15	126
G10 vs 42036 (Small radius) 9/15-9/23	0.98	0.18	0.18	192
G14 vs 42099 (Small radius) 11/25-11/28	0.94	-0.15	0.16	152
G14 vs 42099 (Large radius) 10/17-10/21	0.62	-0.03	0.23	243
G14 vs 42099 (Small radius) 10/10-10/16	0.99	-0.05	0.06	308
GOM1 vs 42099 (Small radius) 11/22-11/28	0.88	-0.24	0.27	315
GOM1 vs 42099 (Large radius) 11/9-11/22	0.84	-0.02	0.22	610

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





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

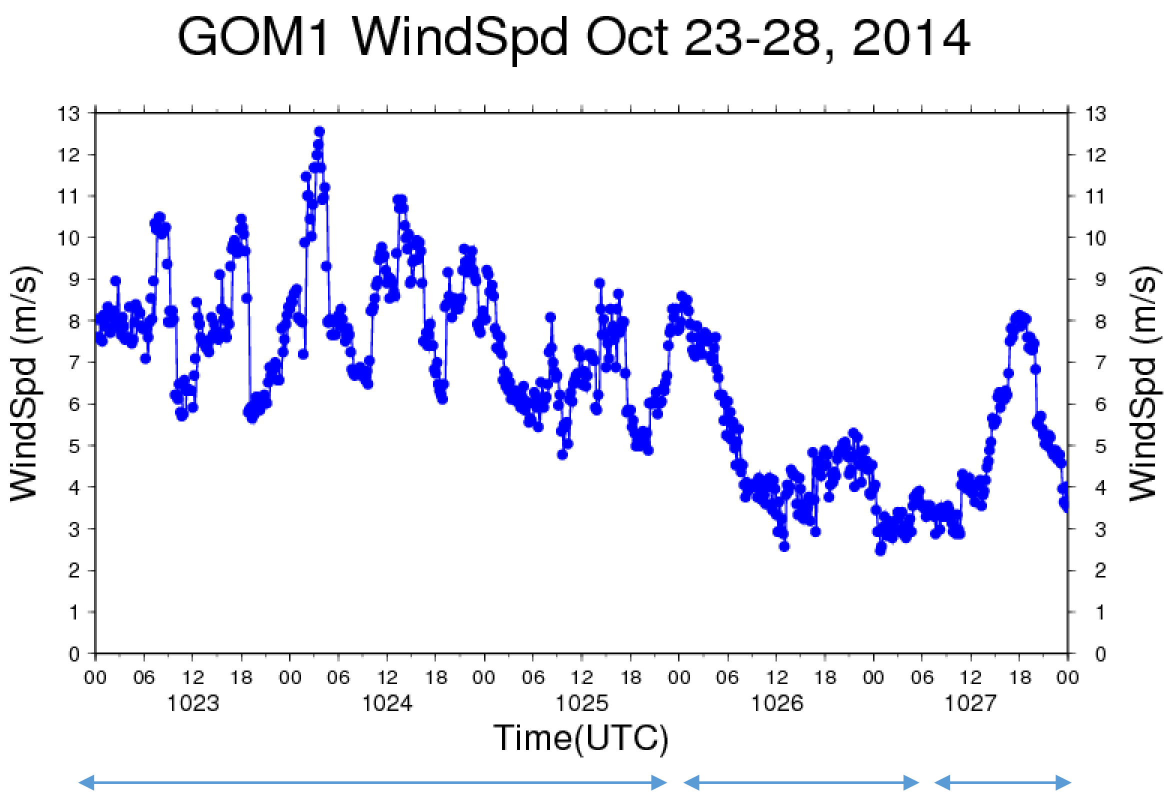
- Tampering or collisions need to be addressed by:
  - Better boater education and better signage
  - Increased distance from buoys during loitering. Buoys attract fish and fishermen.
- Tropical cyclone intercept studies needed to examine data impact and ocean evolution studies
- ADCP, salinity, wave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

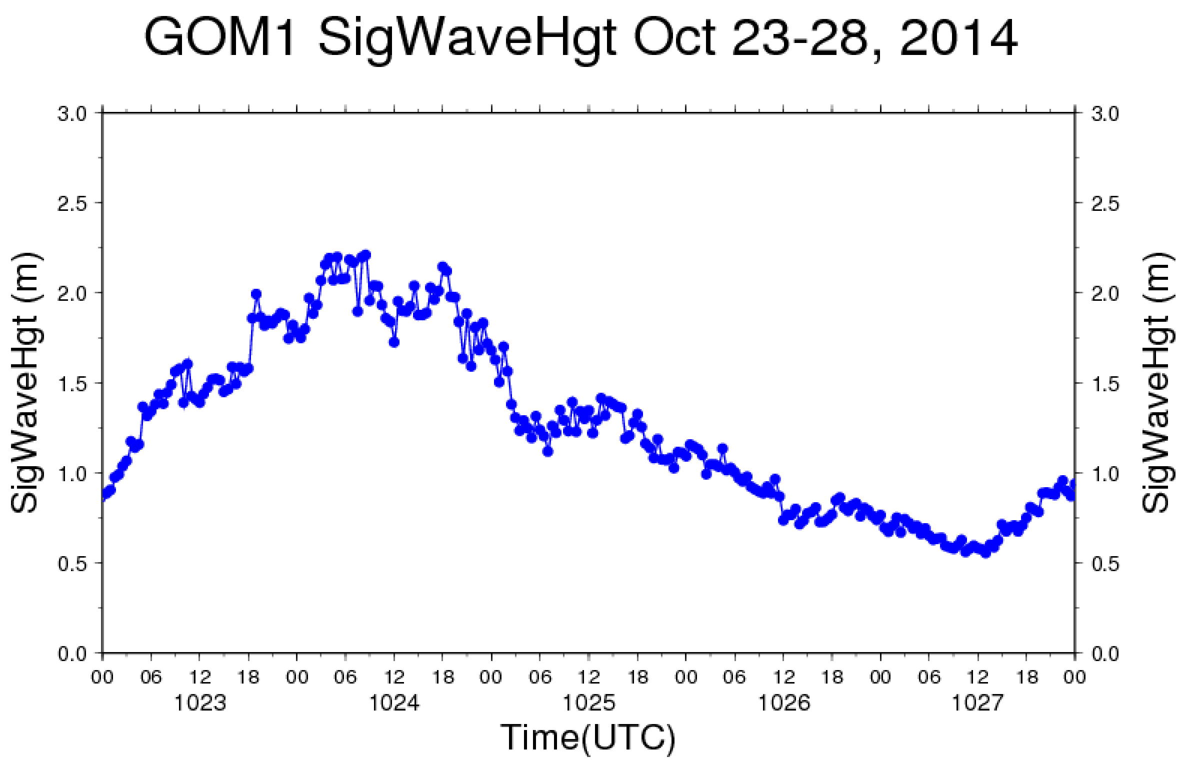
- Better quality atmospheric instrumentation needed; for example, Scripps and UW are using better anemometer

Tropical cyclone intercepts

WGs have traversed 16 TCs, including Rasmussen, Isaac, and Sandy

Northern fringe of Hanna lifecycle during 2014 field program





Front and circulation interaction

Front dissipates

Genesis then landfall

Pacific Crossing (PacX) experiment
Hurricane Freda (2012)

Luc Lenain and W. Kendall Melville

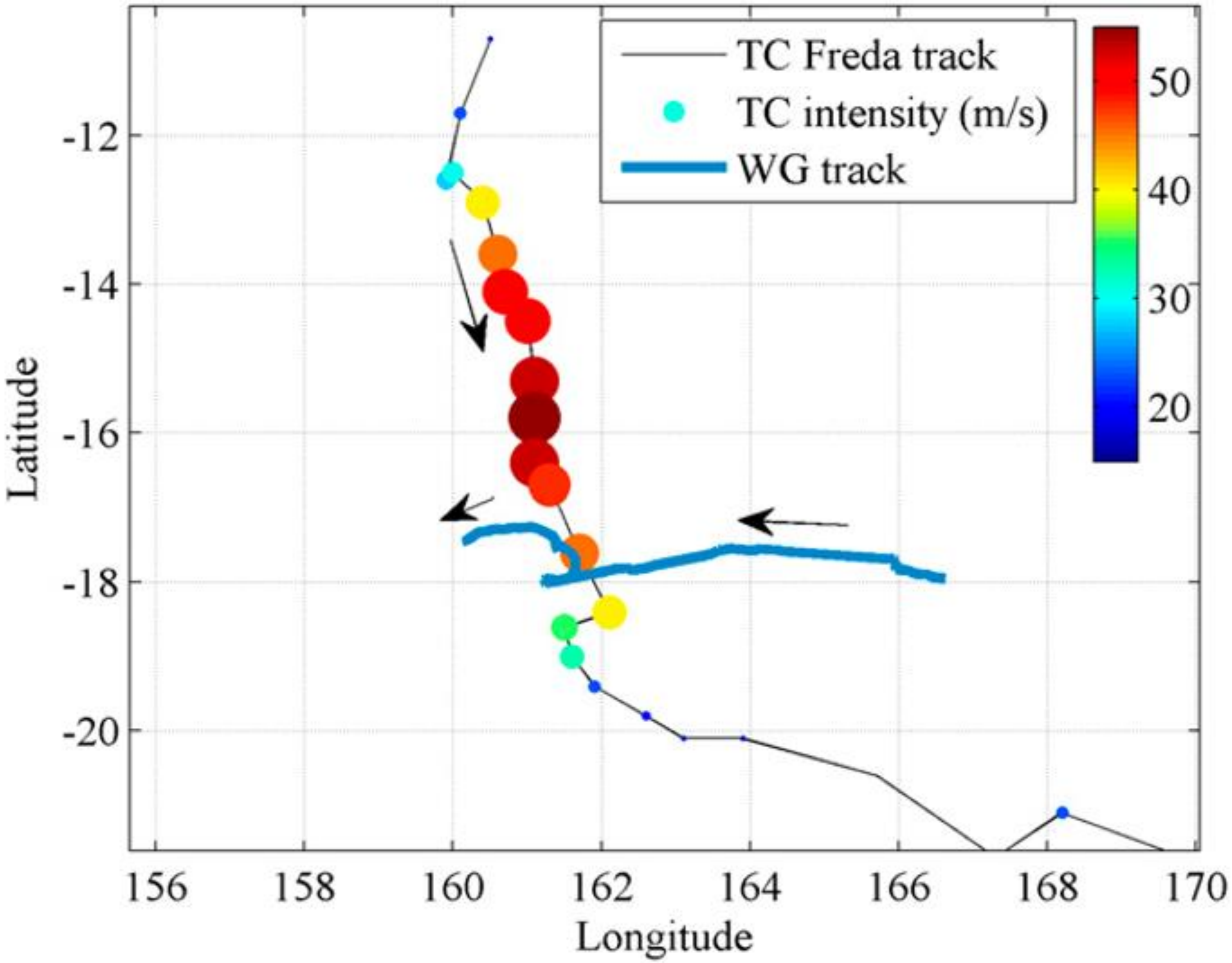
University of California, Scripps Institution of Oceanography

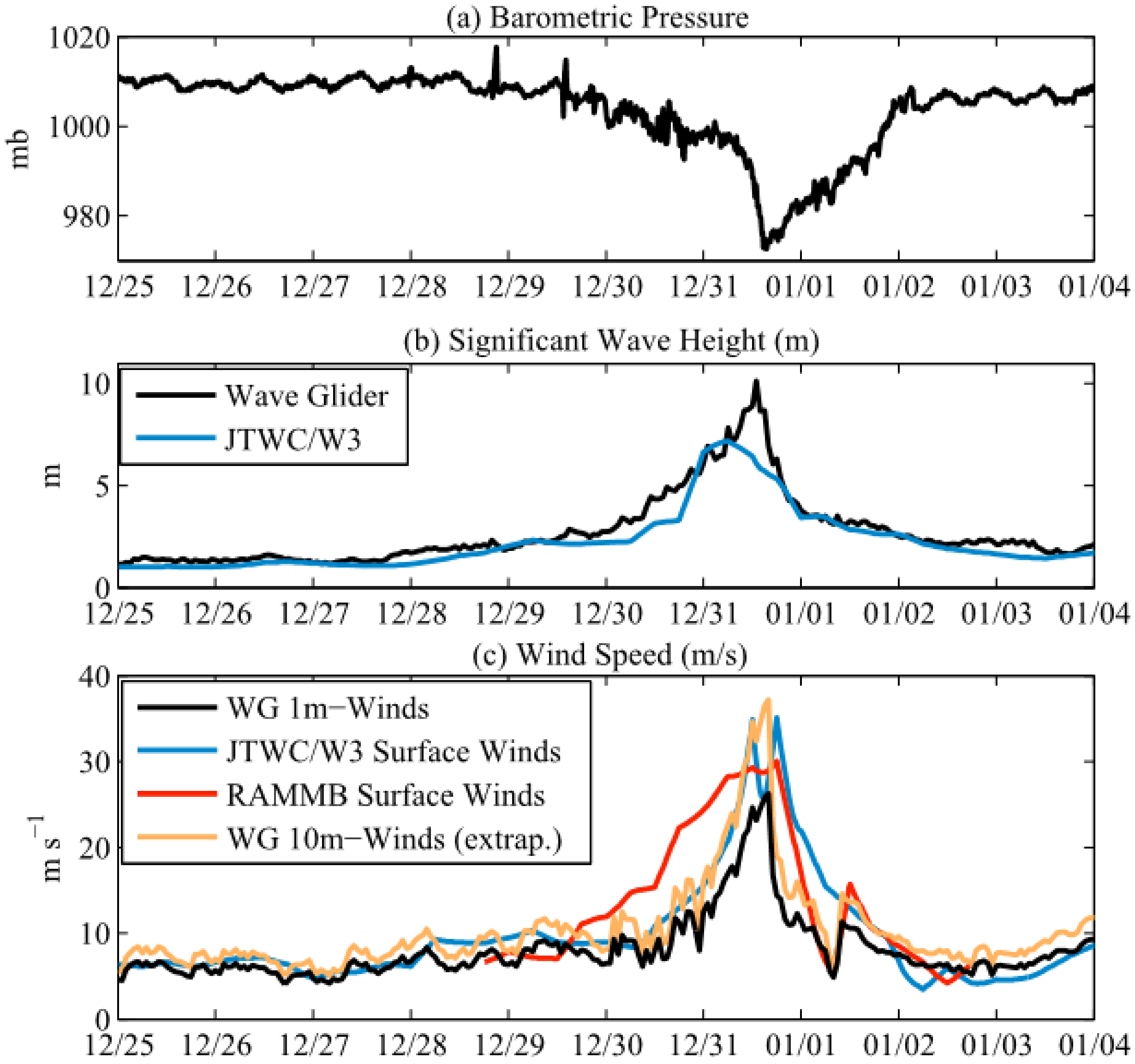
Published in *J. Atmospheric and Oceanic Tech.*

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.

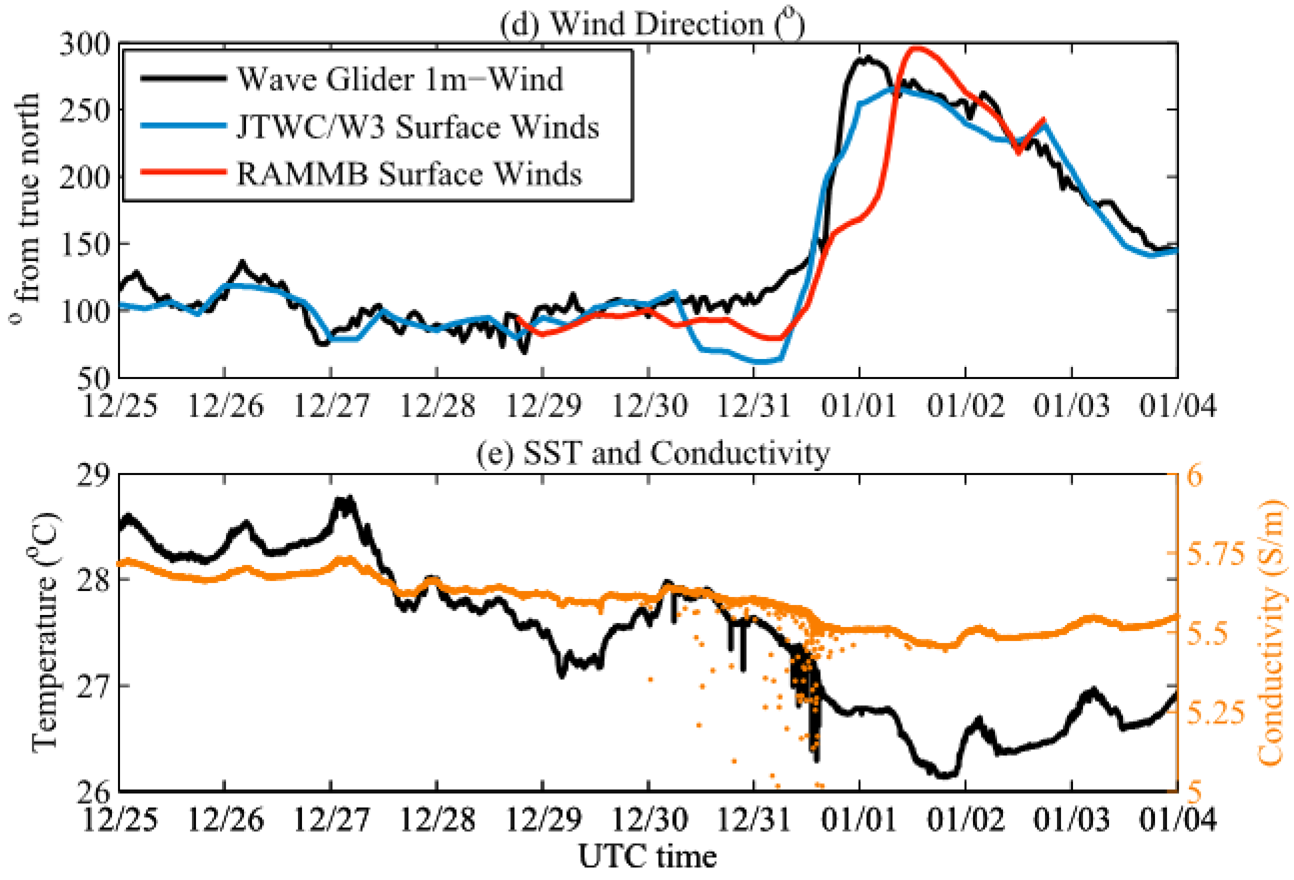
Surface velocity sensor used for navigation turned off to reduce power consumption.

“Entrained” into Freda by currents.



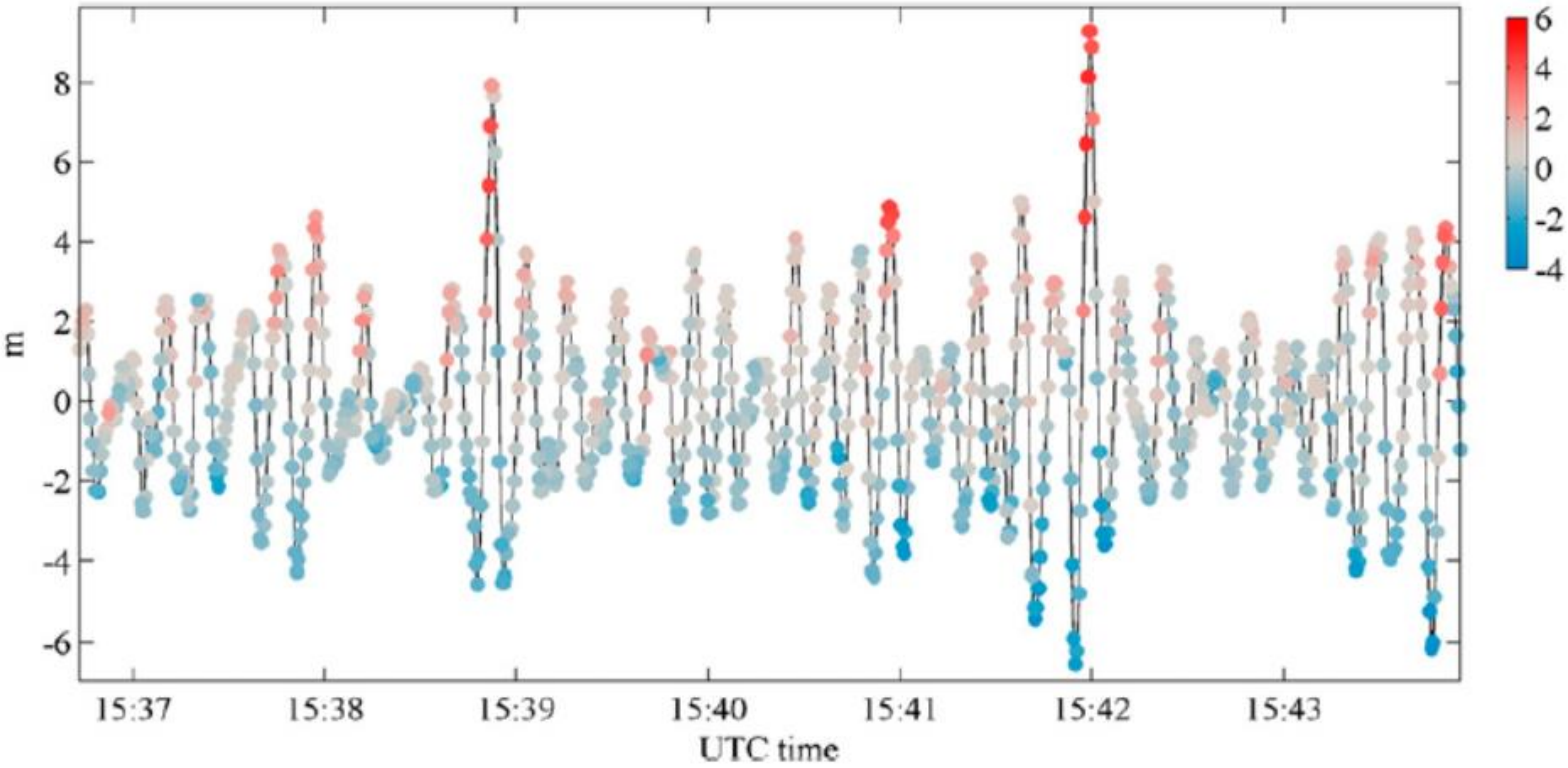

(a) Barometric Pressure
1020
1000
980
mb
12/25
12/26
12/27
12/28
12/29
12/30
12/31
01/01
01/02
01/03
01/04
(b) Significant Wave Height (m)
Wave Glider
JTWC/W3
10
5
0
m
12/25
12/26
12/27
12/28
12/29
12/30
12/31
01/01
01/02
01/03
01/04
(c) Wind Speed (m/s)
WG 1m−Winds
JTWC/W3 Surface Winds
RAMMB Surface Winds
WG 10m−Winds (extrap.)
40
30
20
10
0
m s−1
12/25
12/26
12/27
12/28
12/29
12/30
12/31
01/01
01/02
01/03
01/04

Reduction in salinity (rainfall influence) and water temperature in TC wake

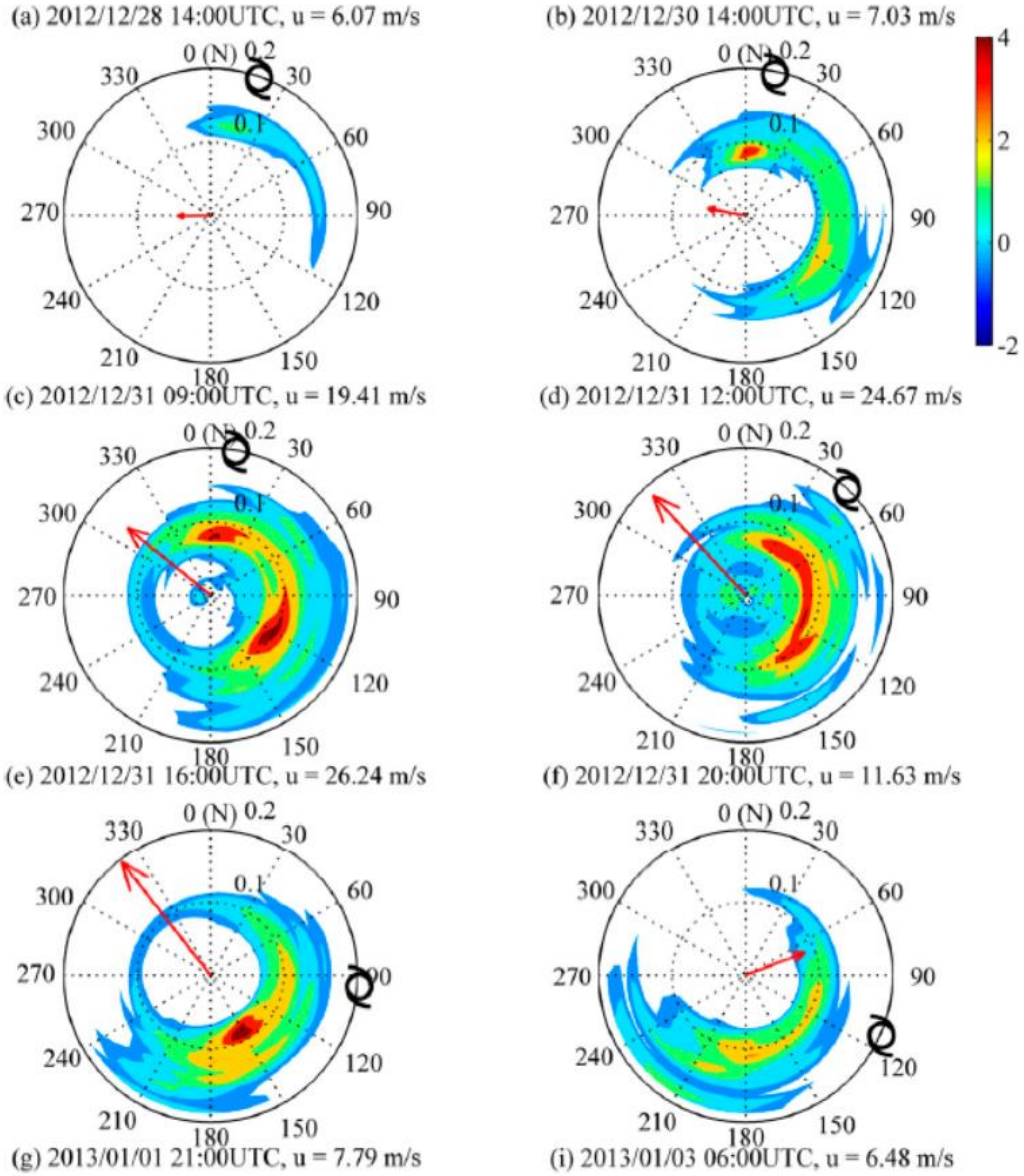


Sea surface displacement

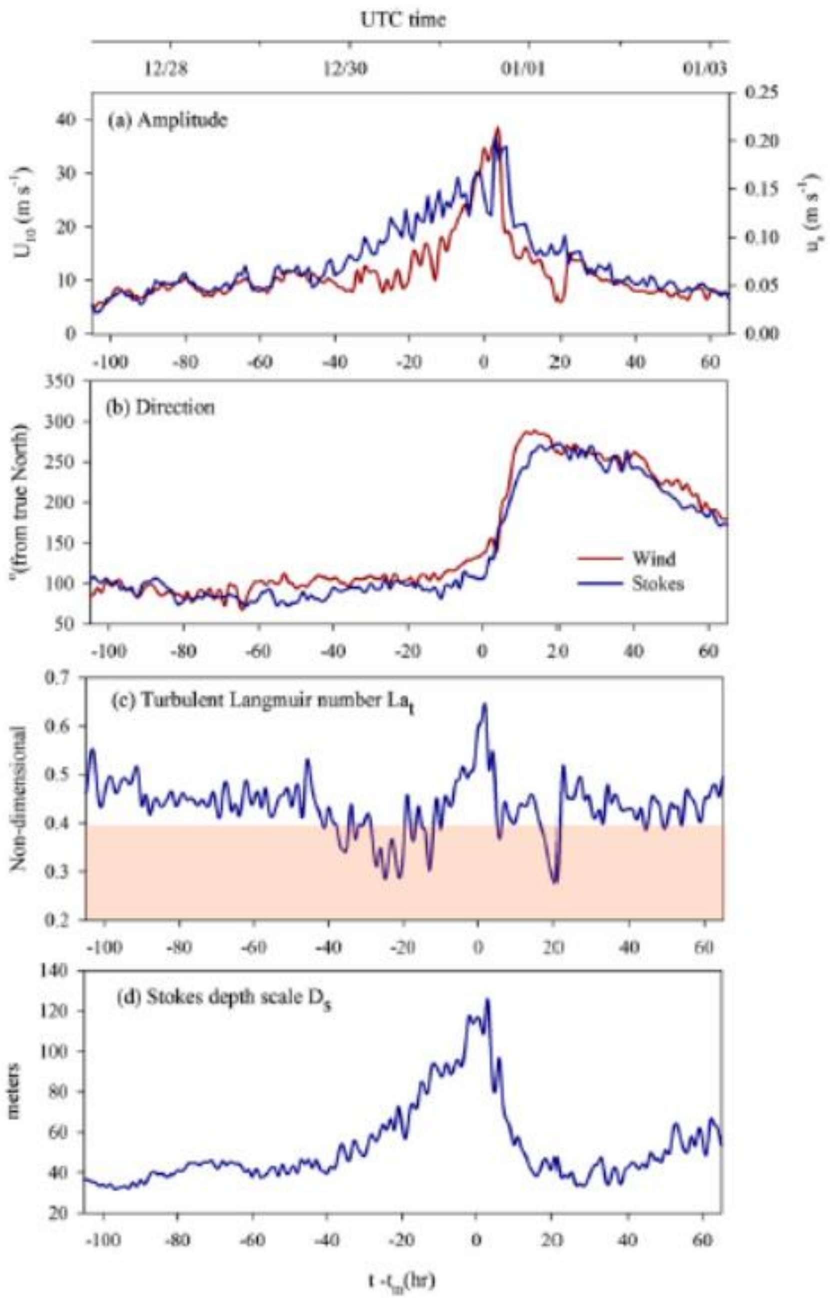
Note rogue waves



Evolution wave directional spectrum

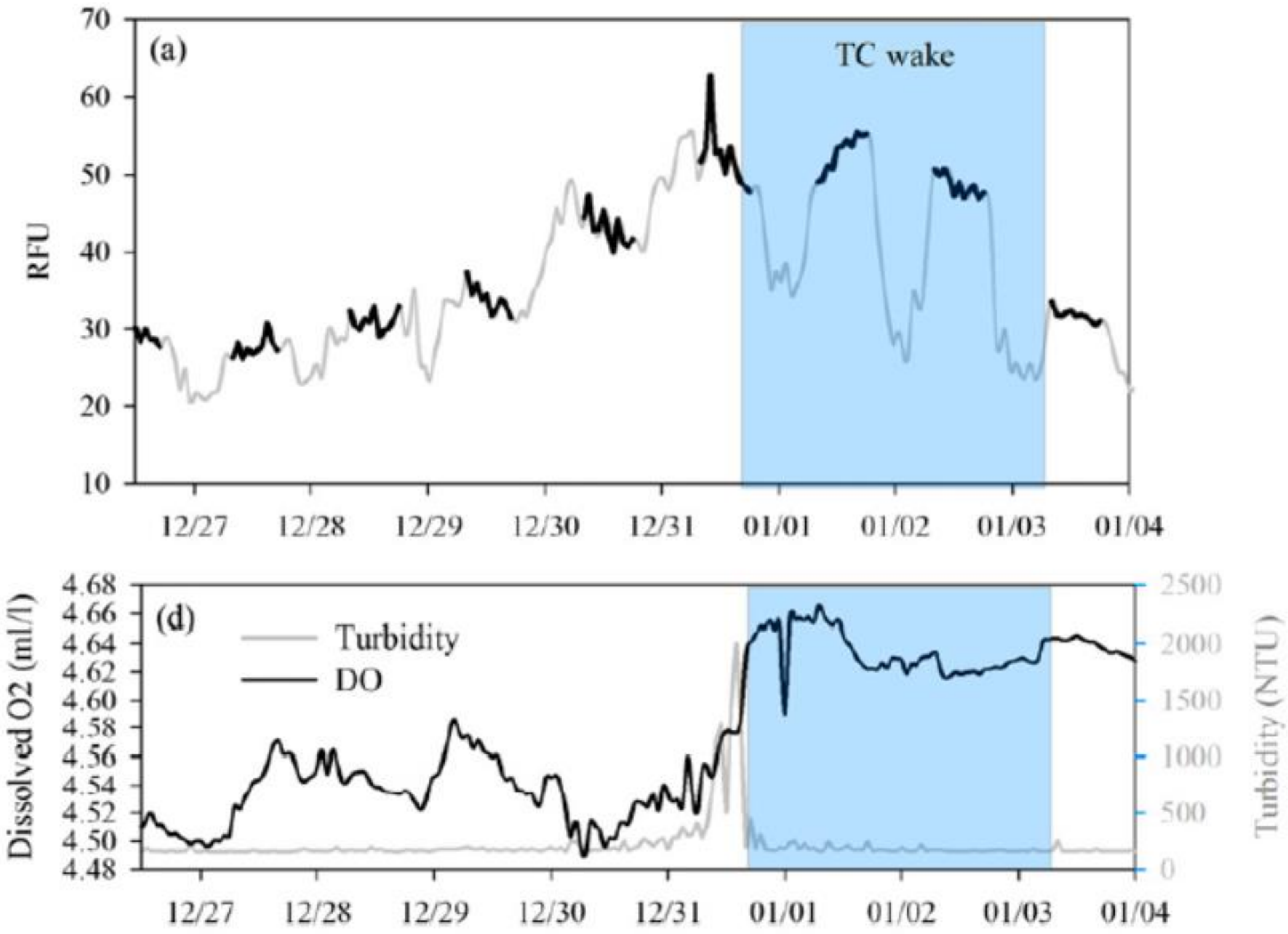


Application of Craik-Leibovich theory to Stokes depth scale



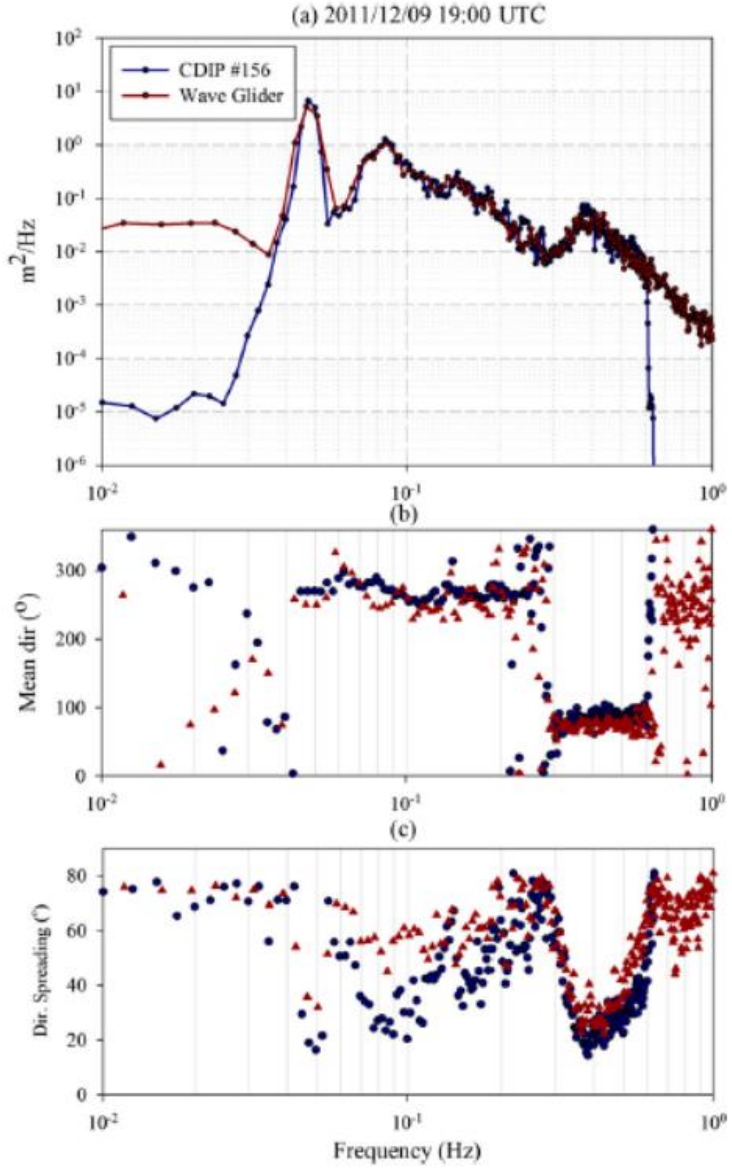
Biophysical response

Chlorophyl and turbidity from a fluorometer



Validation near Hawaii against a Datawell directional wave buoy

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



References

Fitzpatrick, P. J., Y. Lau, D. Merritt, R. Moorhead, A. Skarke, K. Kreider, C. Brown, R. Carlon, G. Hine, T. Lampoudi, and A. Leonardi, 2015: A review of the 2014 Gulf of Mexico Wave Glider® field program. *Marine Technology Society Journal*, **49**, 64-71.

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Lenain, L., and W. K. Melville, 2016: Autonomous surface vehicle measurements of the ocean's response to Tropical Cyclone Freda. *J. Atmos. Oceanic Tech.,* **31**, 2169-2190.