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

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Background

- Evolved from a private initiative to study Humpback Whale songs in 2003-2007 to maritime monitoring (for weekly to seasonal periods)
- Field programs for:
  - Algal blooms
  - Satellite ground truth
  - Mammals and fisheries surveillance
  - Carbon cycle studies
  - Geodosy
  - Magnetics
  - Hydrocarbon mapping
  - Oceanography and meteorology data, including tropical cyclones
- 24-h operating center, with an operational GUI known as the Wave Glider Management System (WGMS). Local boat traffic monitored with AIS.

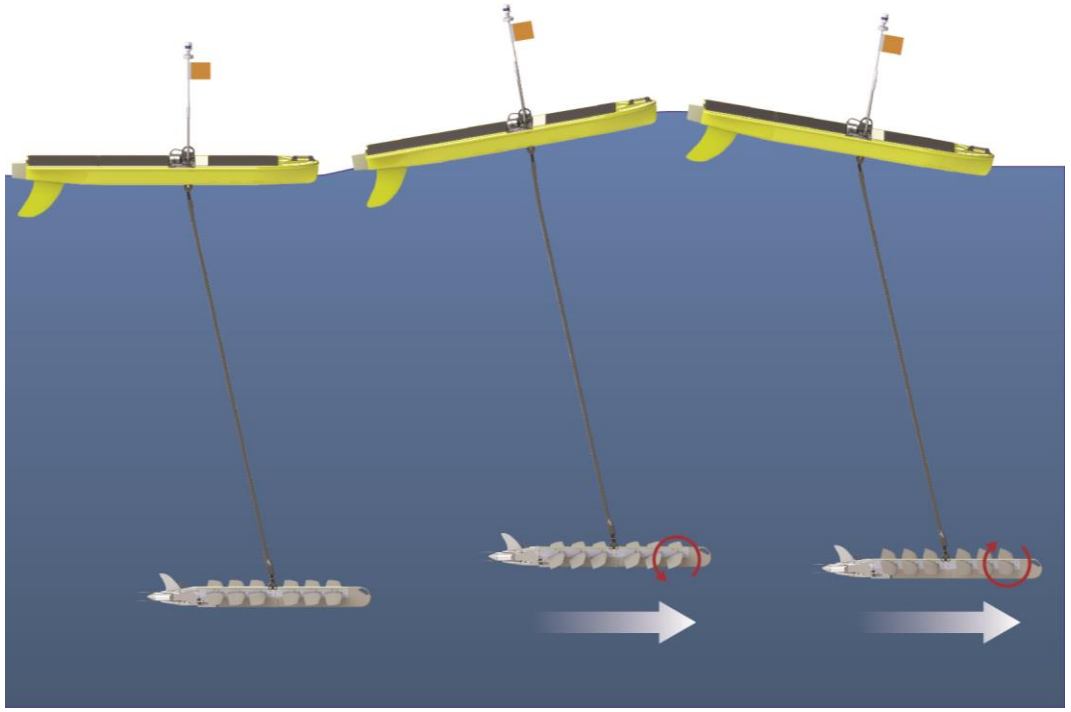
Instrumentation

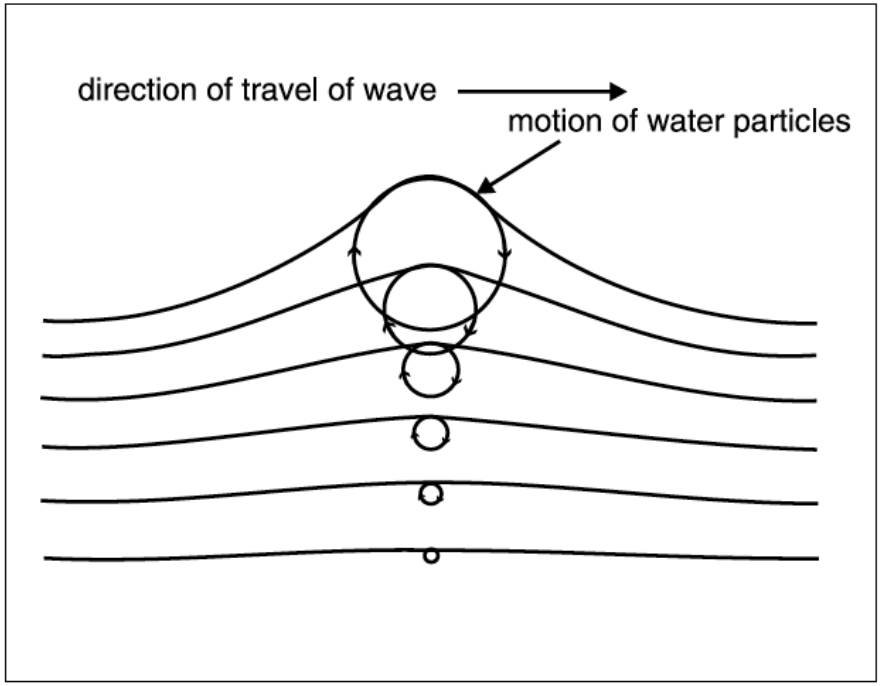
- Payloads are on the float and the glider 6 m below
- Possible instruments (red used in GOM field program):
  - Meteorology – wind, temperature, pressure (1-m height)
  - Directional wave sensor - sig wave height, avg period, peak period, peak direction, spectra
  - ADCP – profile of ocean currents
  - CTD-DO (conductivity/salinity, temperature, depth, dissolved oxygen)
  - Acoustic modems and acoustic recorders
  - Bathymetry sensors
  - Fluorometer (oil, turbidity, chlorophyll)
  - Magnetometer
  - Cameras
- Some data transmitted real-time by Iridium satellite link, some archived onboard and retrieved after missions. Data transmission depends on a balance of priorities, power, data resolution, data types, and transmission limits.
- All plots in this presentation show real-time data for the Gulf of Mexico field program

Previous O&M field programs

- Pacific Crossing (PacX) project with 4 WGs, including one in cat 3 TC Freda (2012). Documented by Lenain and Melville (2014) in Oct. issue *J. Atmos. Oceanic Technol.*
- Salinity Processes in the Upper Ocean Regional Study (SPURS)
- Robotic Exploration of Ocean Fronts
- Other private enterprise, NDBC, and University of Southern Mississippi ventures
- WGs have traversed 16 TCs, including Isaac (2012), Sandy (2012), and cat 5 Supertyphoon Rammasun (2014)
- Youtube video in Hurricane Isselle (2014) at https://www.youtube.com/watch?v=e5RhkjzYbCU&feature=youtu.be

Propulsion mechanism



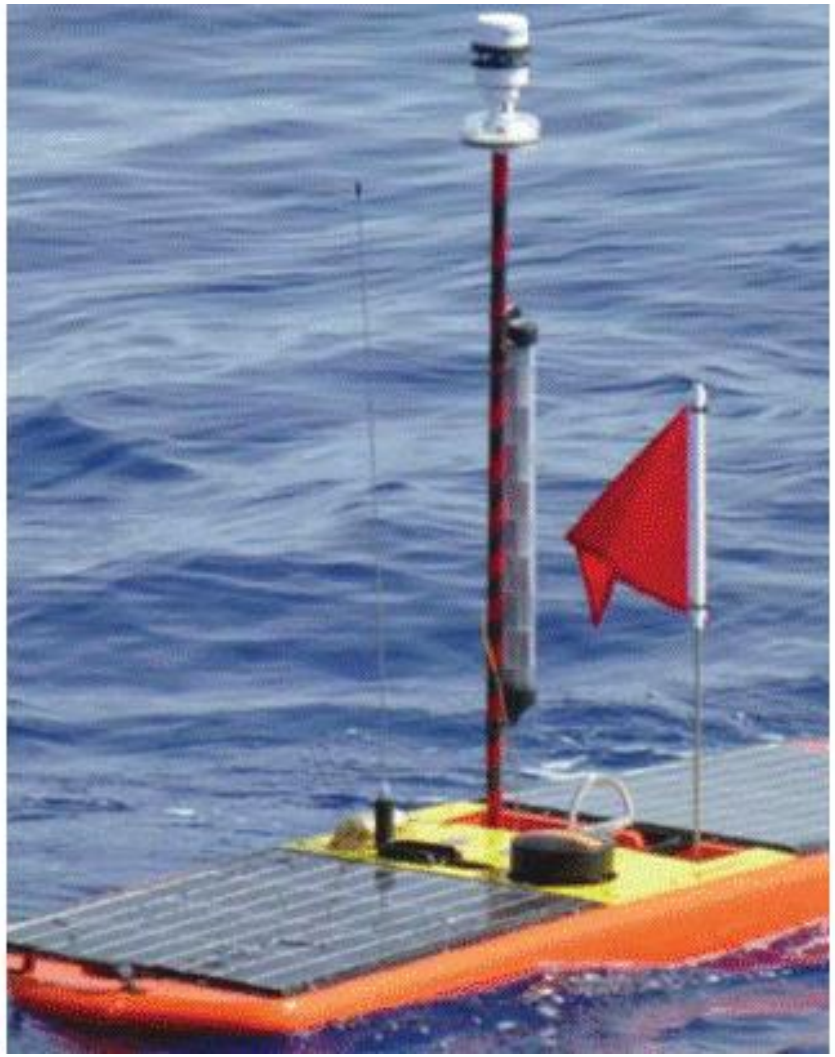


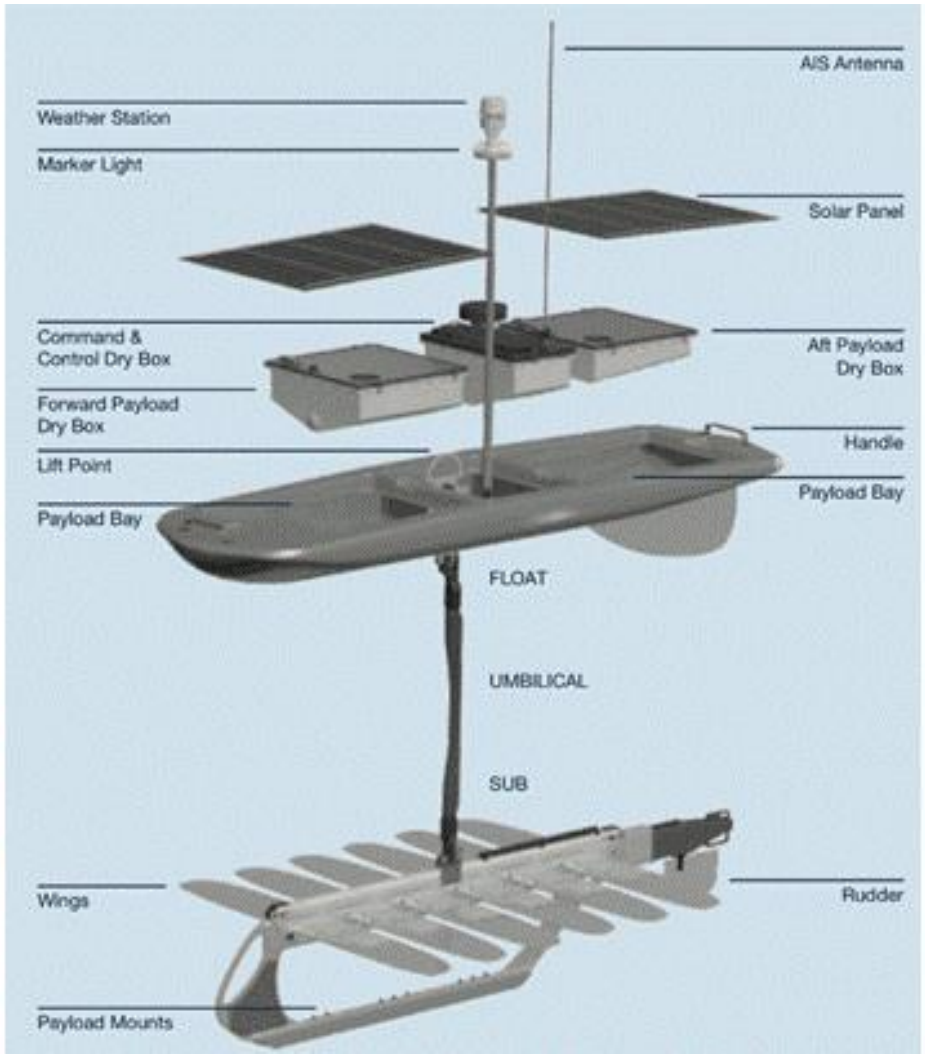
The propulsion works off of the buoyancy of a surface float tethered to a wing rack, the smaller amplitude of the wave motion 6 m below, and a switch on the wings from the wave crests rising and falling. The up and down motion of the wing system creates propulsion, pulling the float by its tether, in a synergistic feedback.

Typical translation speed range was 0.25-1 ms^{-1}, with an average of 0.5 ms^{-1} . Proportional to buoyancy force, generally faster for higher waves. Propulsion of 0.25 ms^{-1} happens even with low-wind “ripples”, but drifting can occur if calm.

Also need to consider and monitor currents, because forward motion can be challenging around currents faster than 1 ms^{-1}

Wave Glider SV2





One of three WGs on R/V Tommy Munro

Pre-deployment, Biloxi, MS

Aug. 25, 2014

Launched 37 km offshore

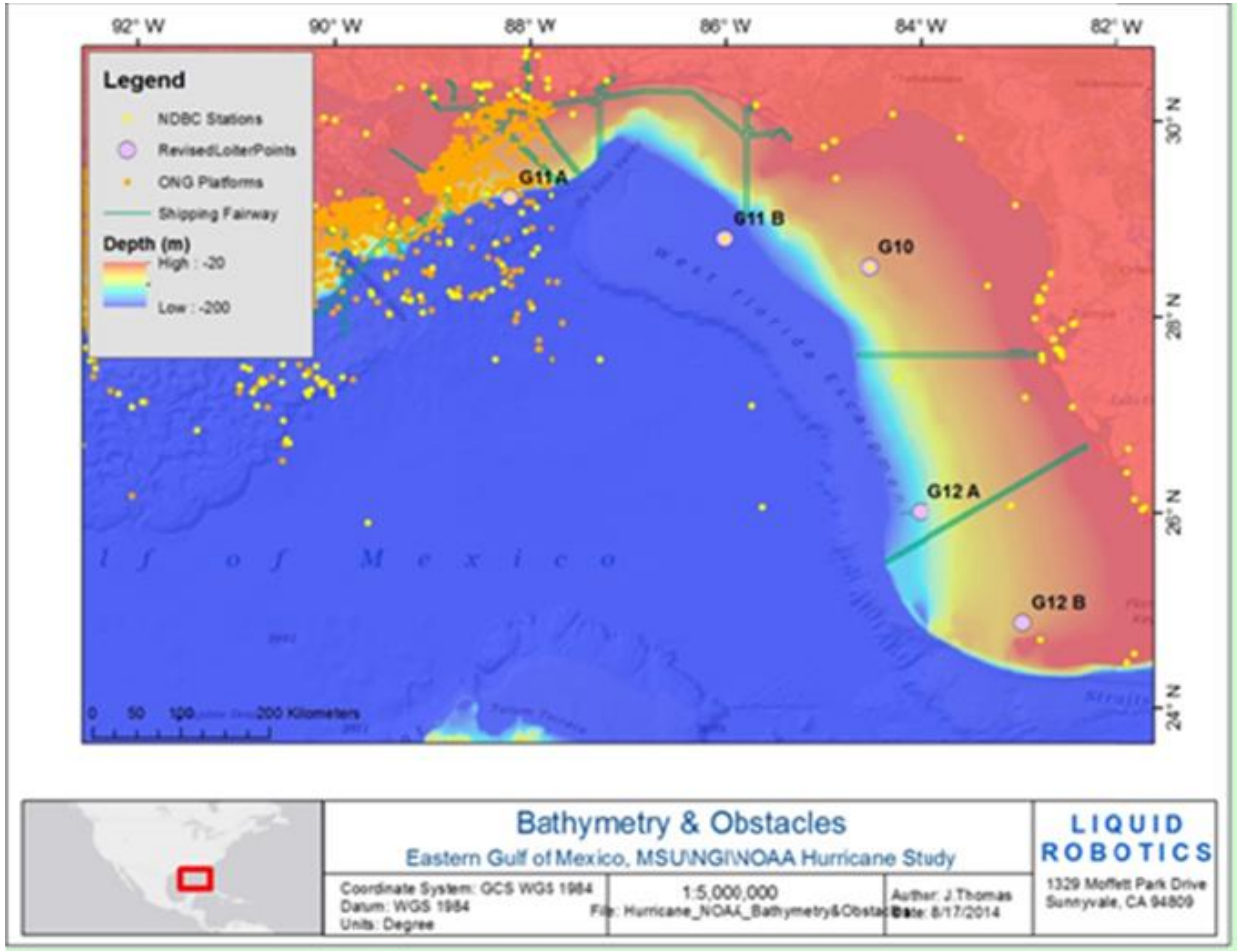
A WG about to be launched

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

Initial plan and loitering waypoints

Must consider currents, oil rig locations, shipping lanes, political boundaries, model guidance, and tropical cyclone climatology. The team agreed to an eastern Gulf of Mexico surveillance with a spread of WGs off N. Gulf (G11), off Tampa (G10), and off SW FL (G12)



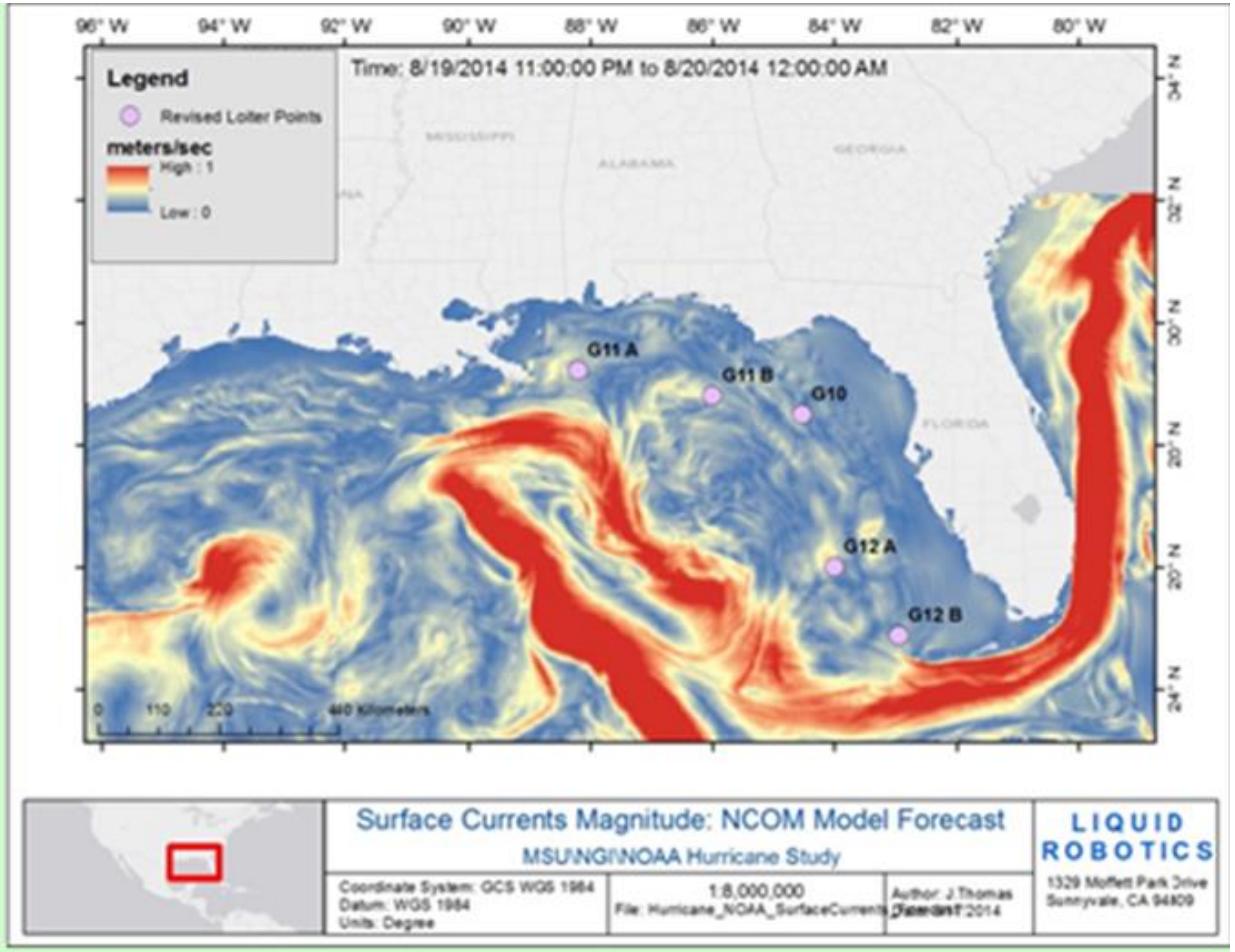


Figure 5. (Left) Location of Wave Glider loitering points relative to bathymetry, shipping fairways, and structures. Waypoint G11A is Buoy 42040, G11B is Buoy 42039, G10 is Buoy 42036, and G12B is CMAN PLSF1. G11 is 26°N 84°W. (Right) Same, but relative to the Loop Current on August 19, 2014, 11 UTC.

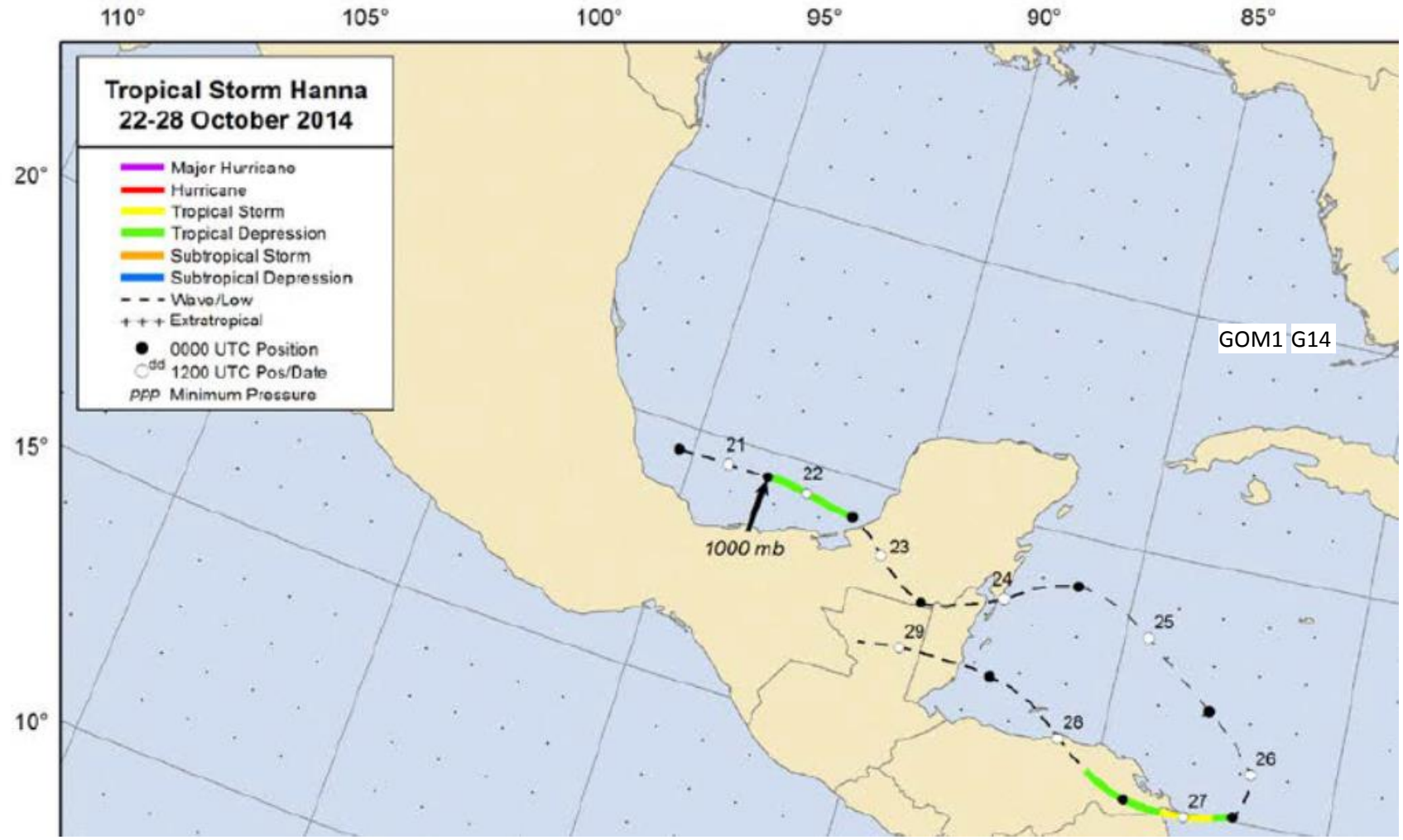
Initial loitering plan

- 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
- At end of mission in late Nov., G10, G14, and GOM1 all loitered around buoy 42099

- G14 loitered west of Keys 10/25-11/18
- GOM1 loitered west of Keys 10/23-11/3



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)

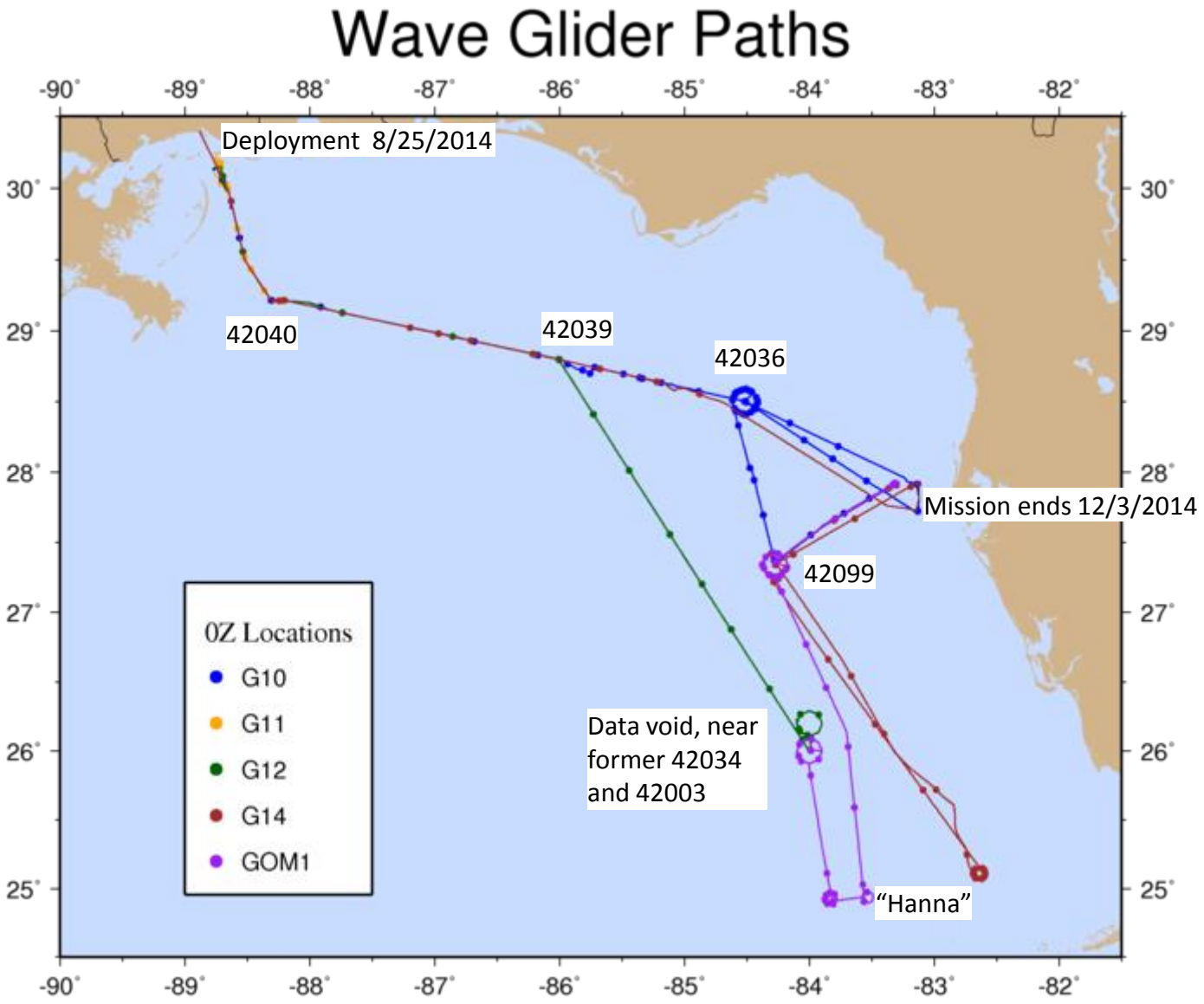
42039: 9/1-9/2
84W, 26N: 9/9-10/23

G14

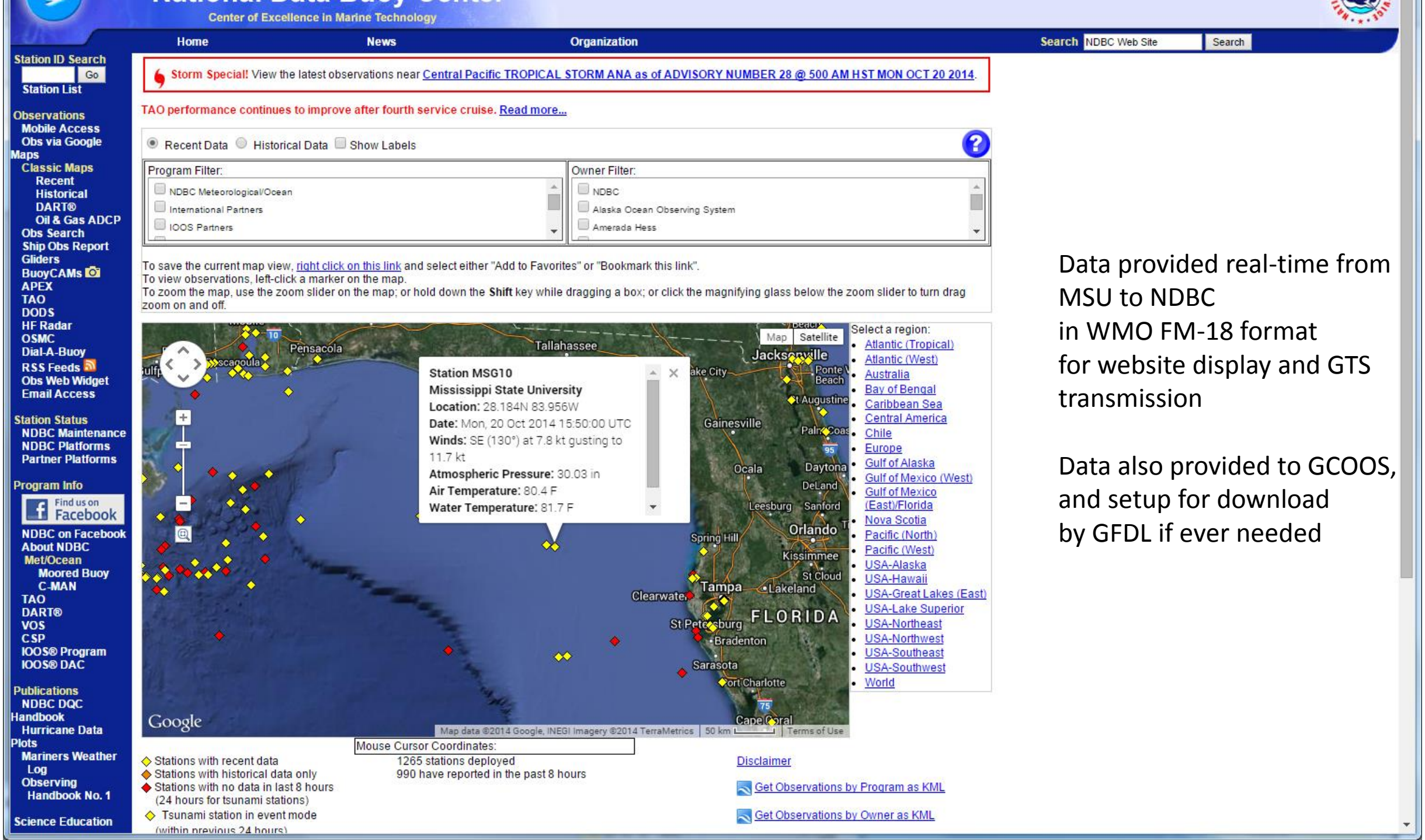
42040: 9/14-9/19
42099: 10/10-10/21
“Hanna” 82.6W 25.1N: 10/25-11/18
42099: 11/28-11/29

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

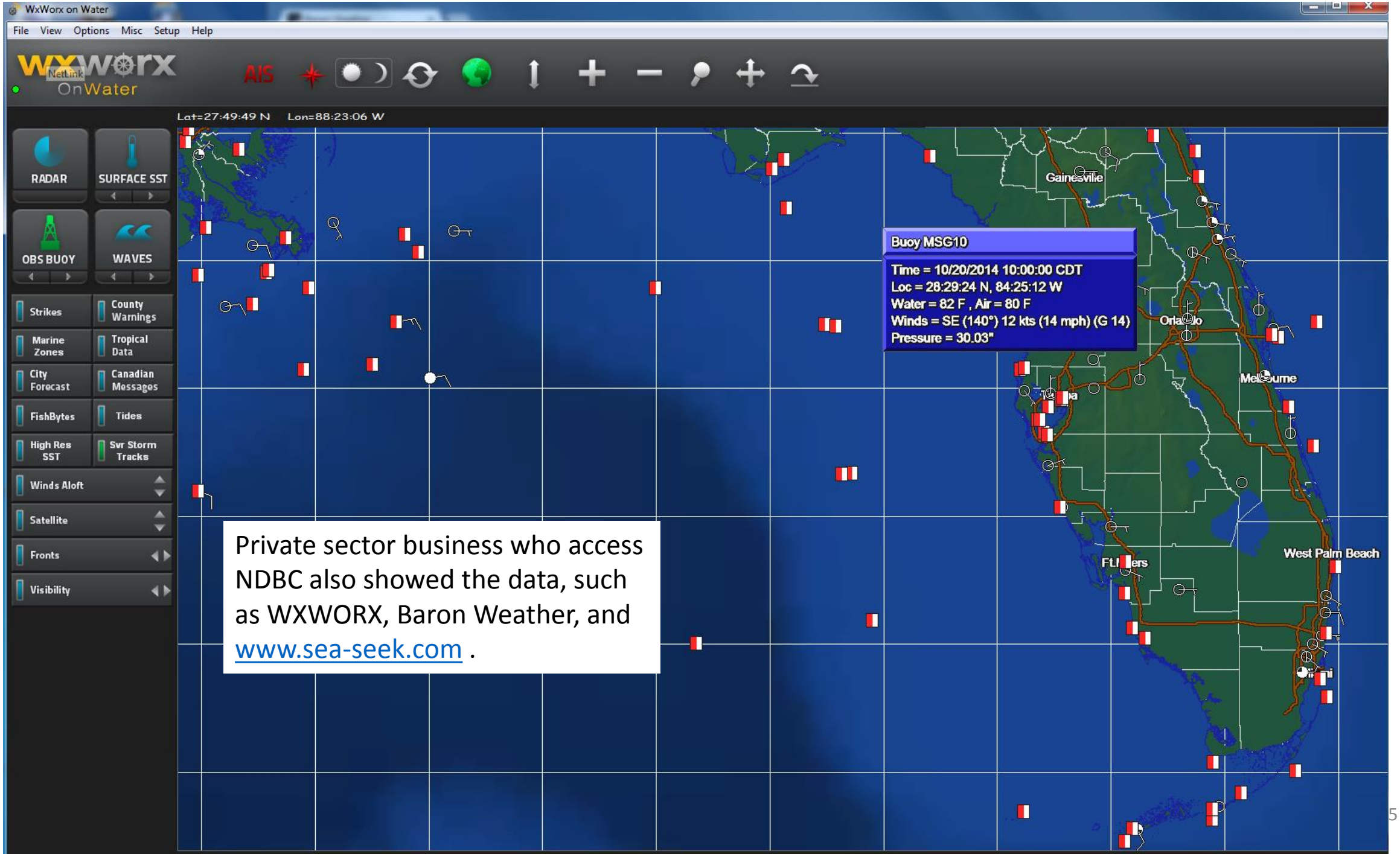


“Hanna” connotes northern fringe of tropical system



Data provided real-time from MSU to NDBC
in WMO FM-18 format
for website display and GTS transmission

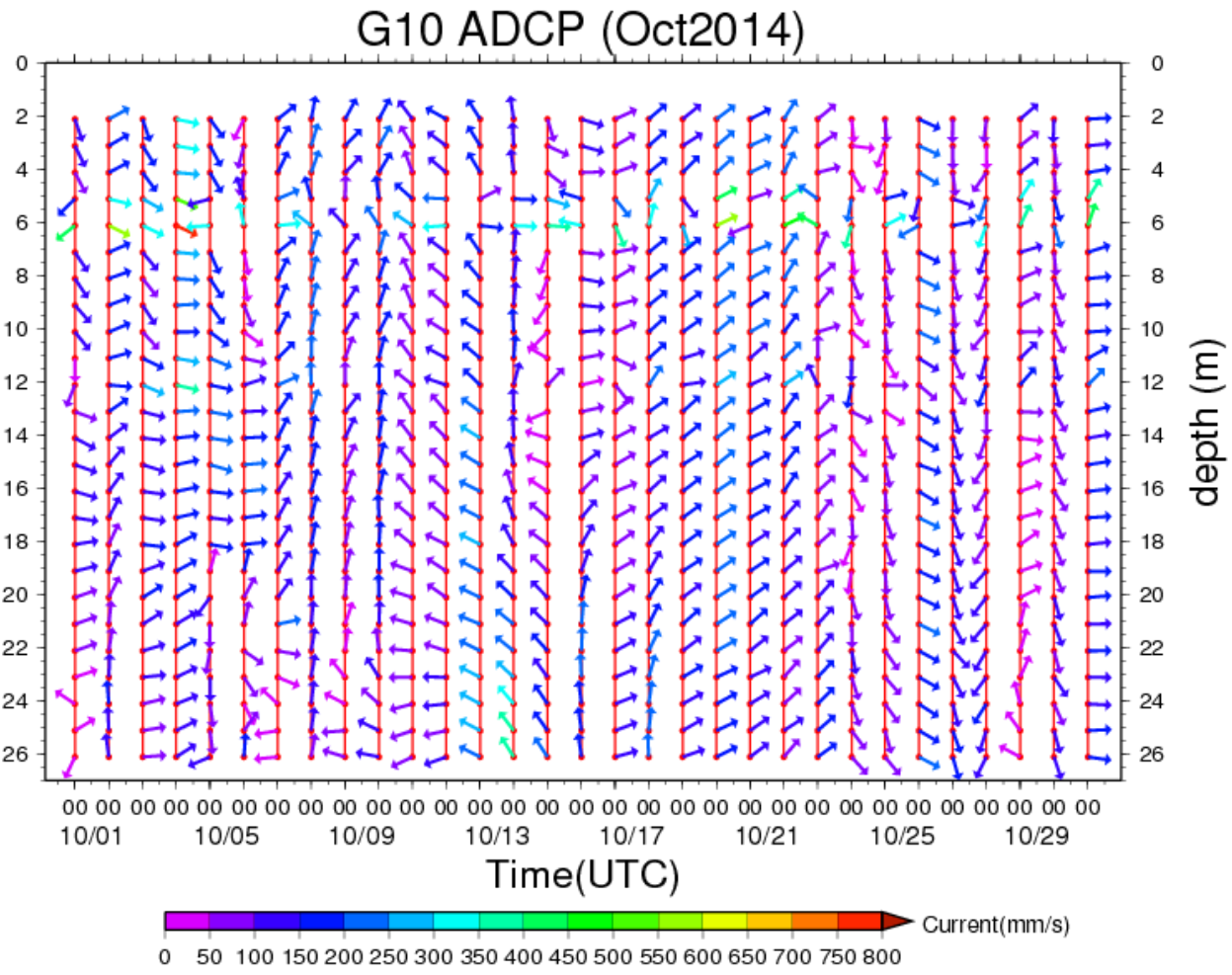
Data also provided to GCOOS, and setup for download by GFDL if ever needed

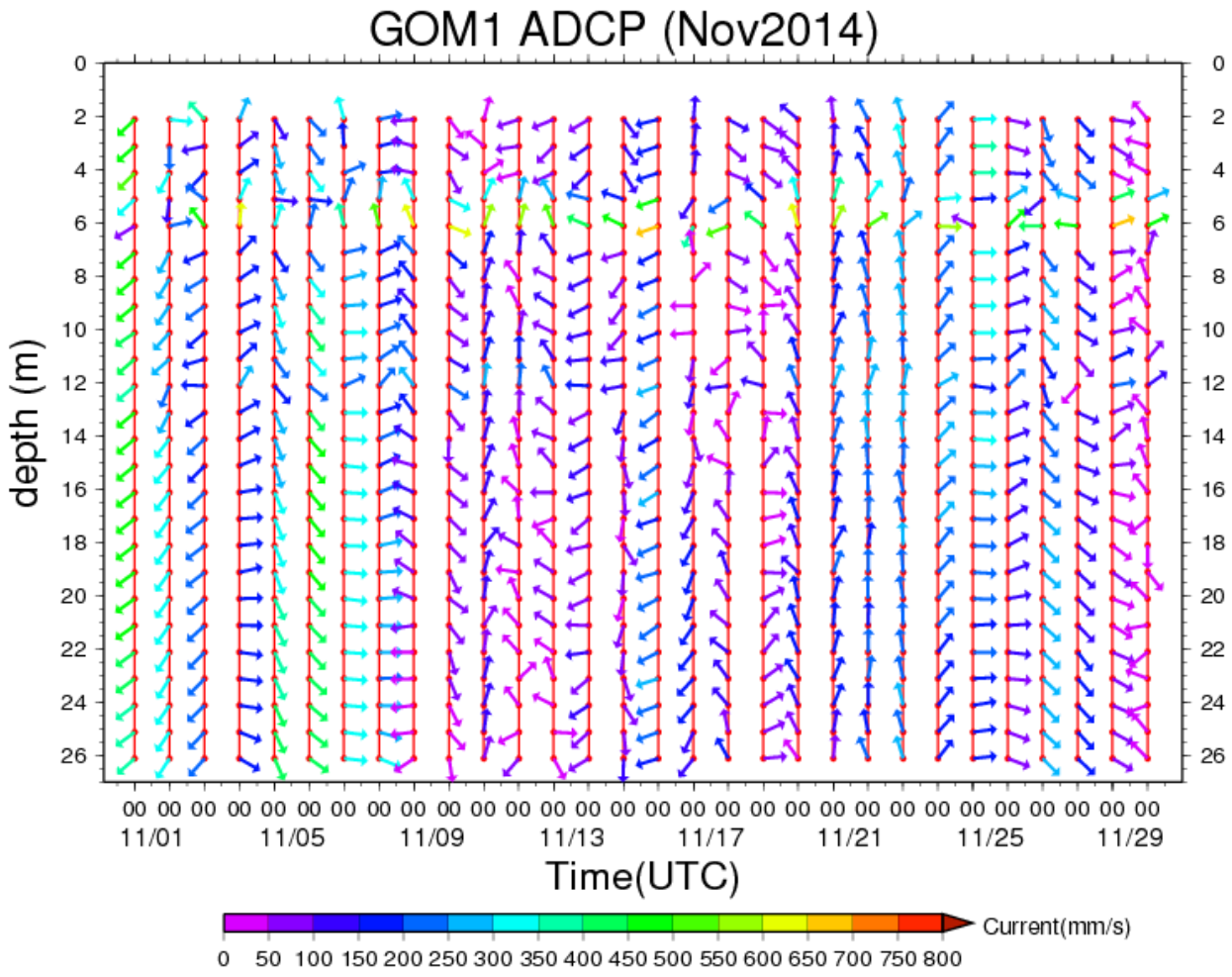


Private sector business who access NDBC also showed the data, such as WXWORX, Baron Weather, and www.sea-seek.com .

Example data plots

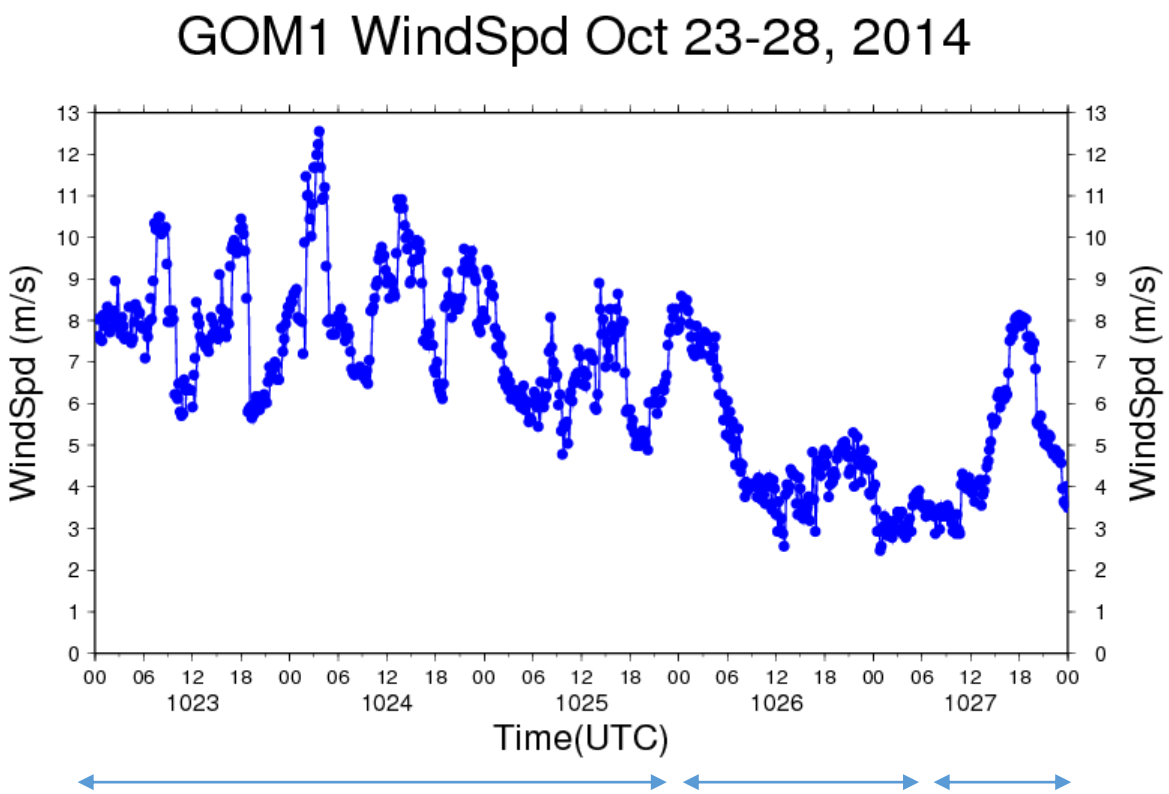
Example monthly plots of ADCP at 00Z – no validation possible

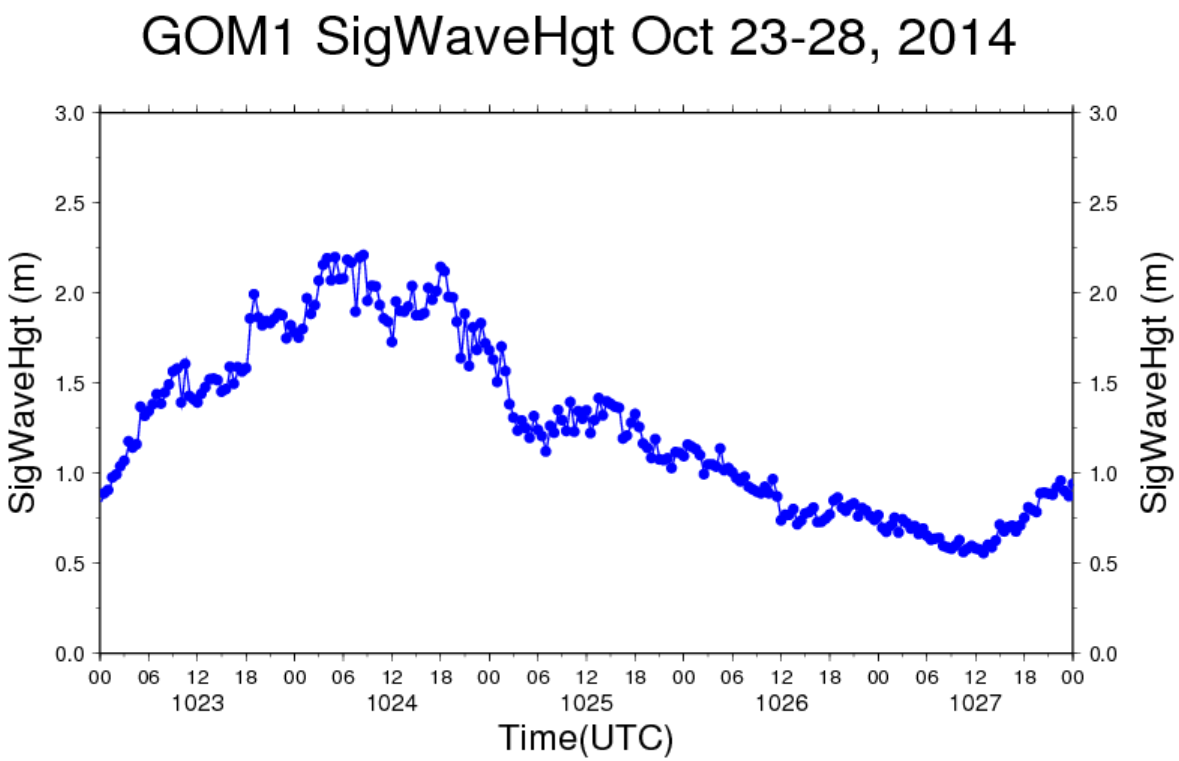




Real-time data available every 30 min

Northern fringe of Hanna lifecycle



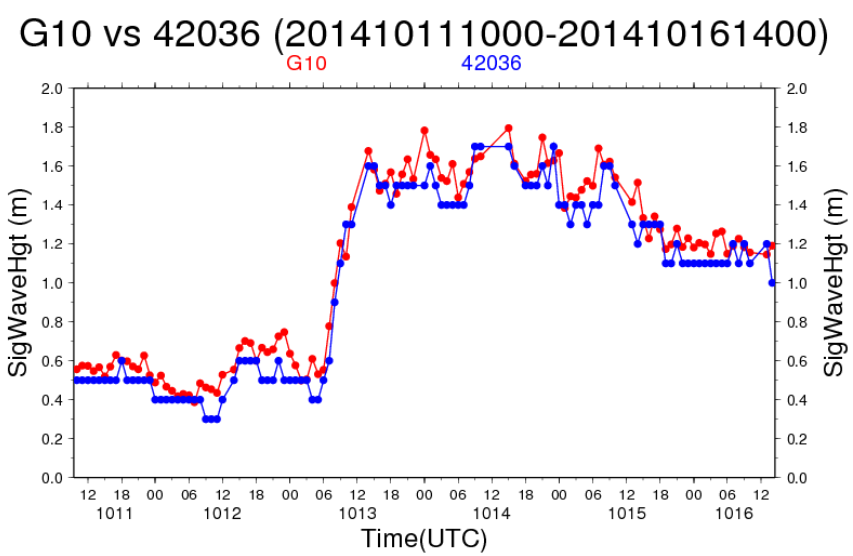


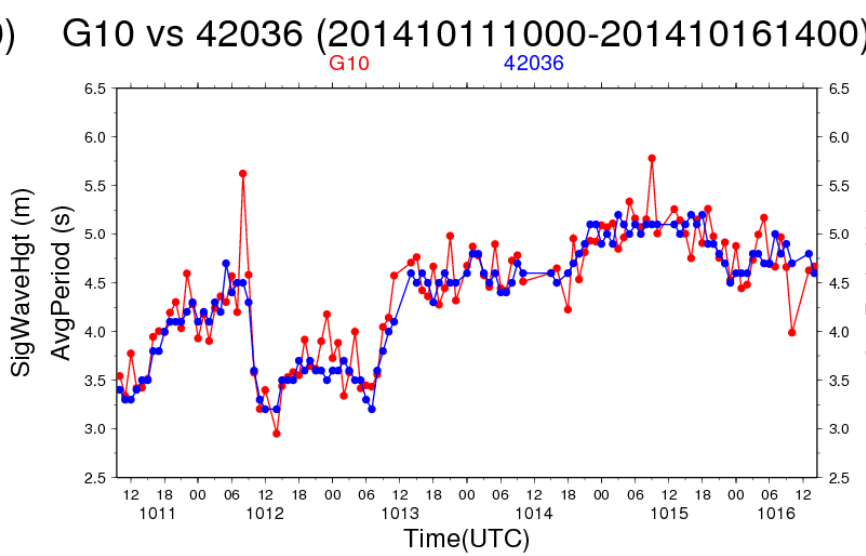
Front and circulation interaction

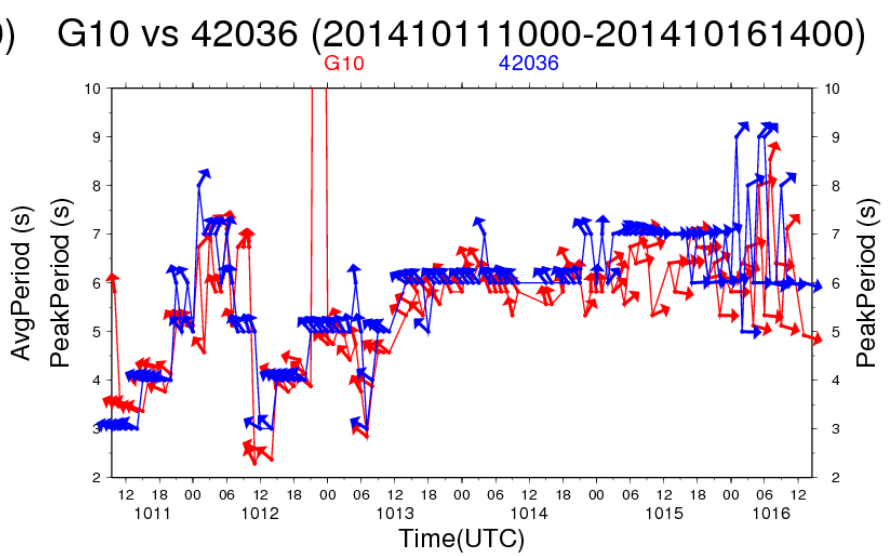
Front dissipates

Genesis then landfall

Loitering validation examples - wave data







Sig Wave Hgt
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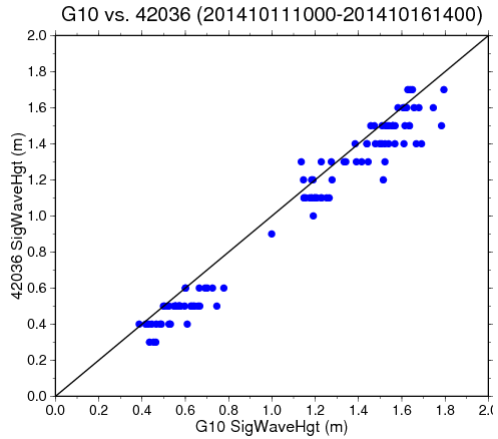
Abs Err = 0.09



Peak Period
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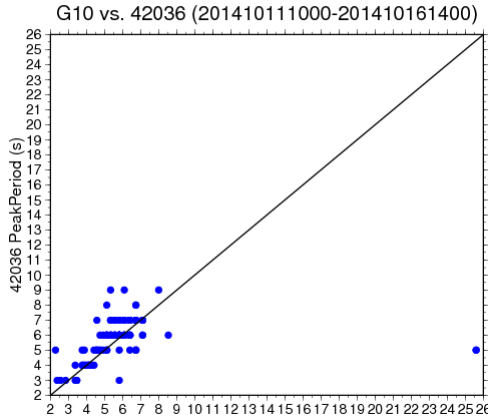
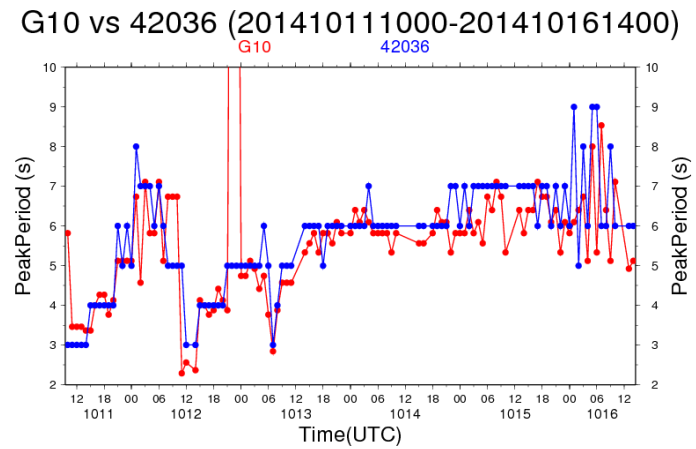
Abs Err = 1.06





Average Period
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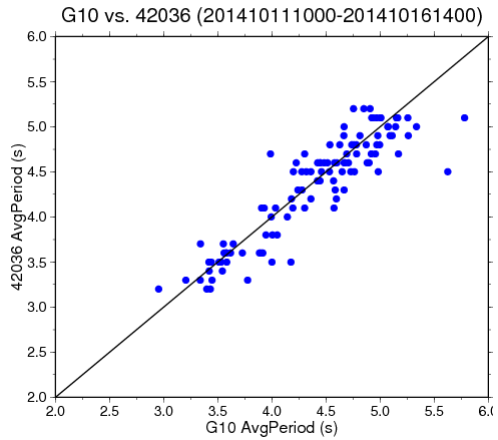
Abs Err = 0.19



Peak Direction
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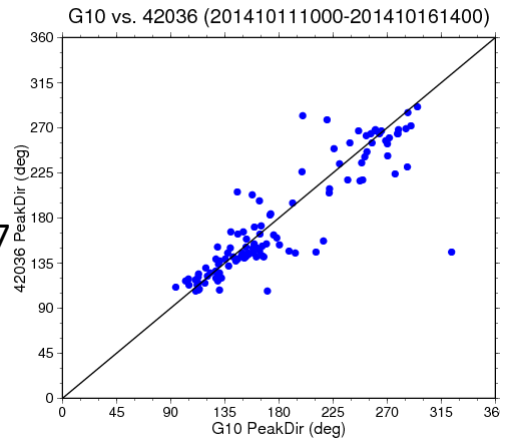
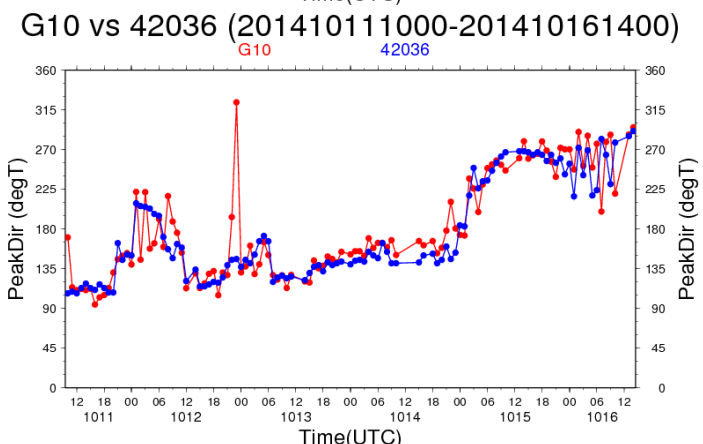
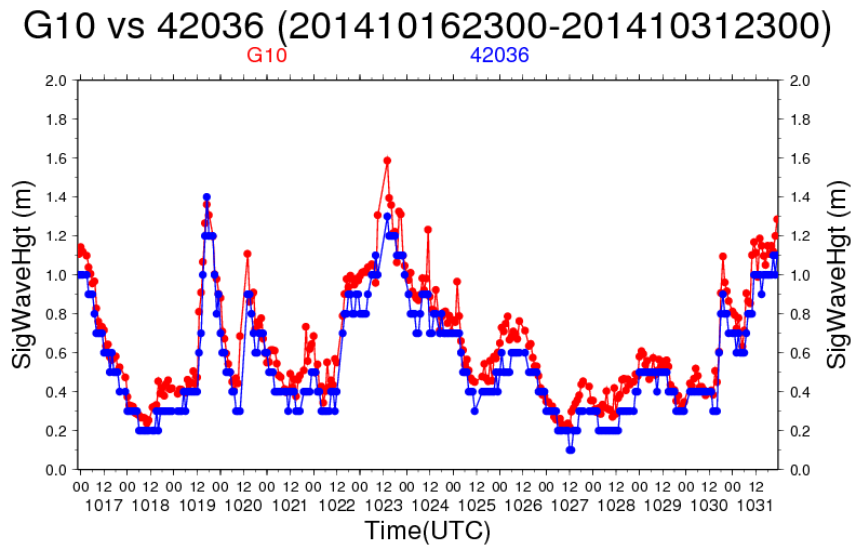
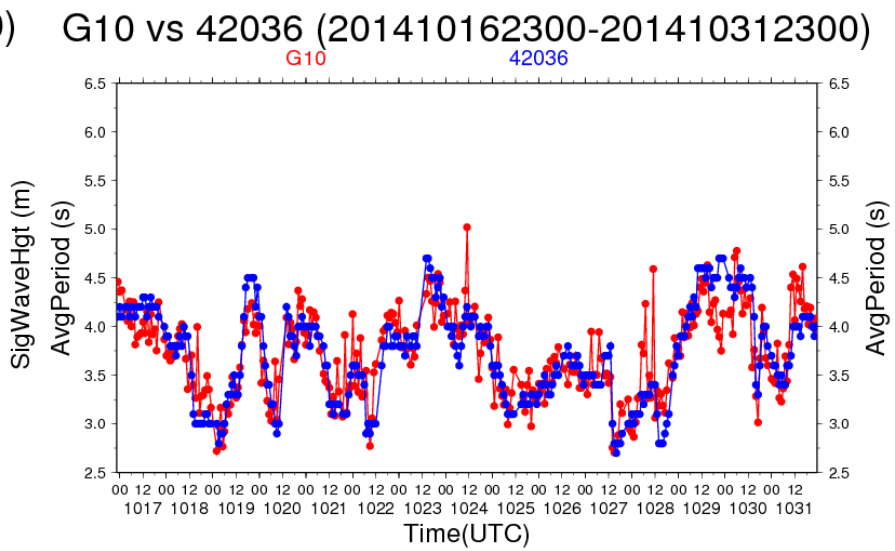
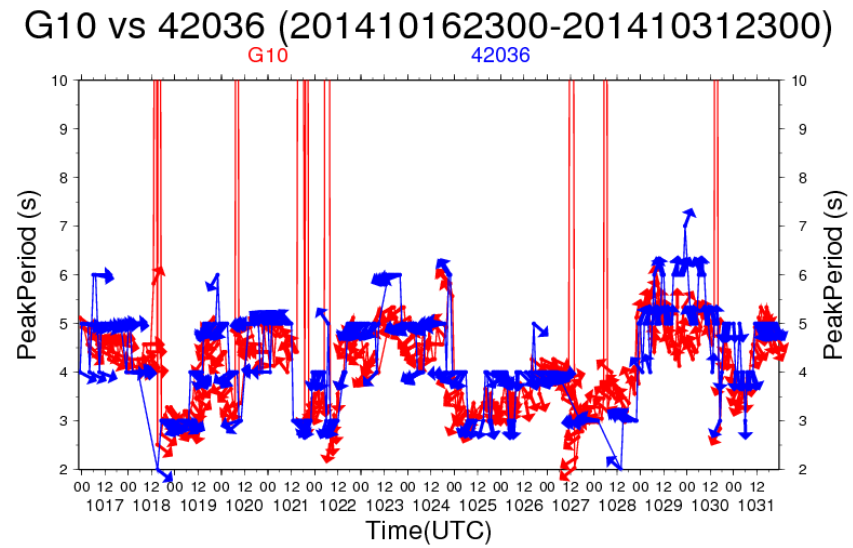
Abs Err = 17.27











Sig Wave Hgt
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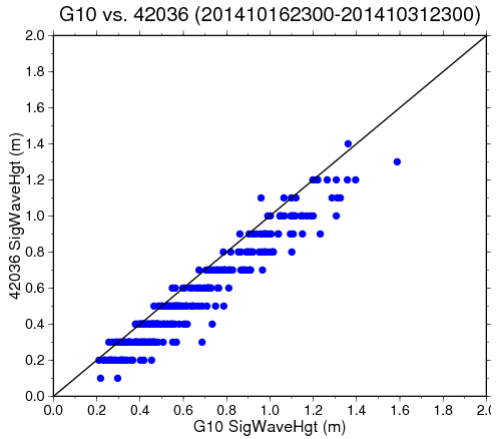
Abs Err = 0.10



Peak Period
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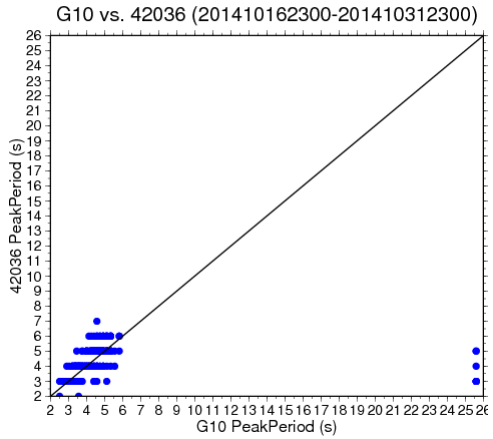

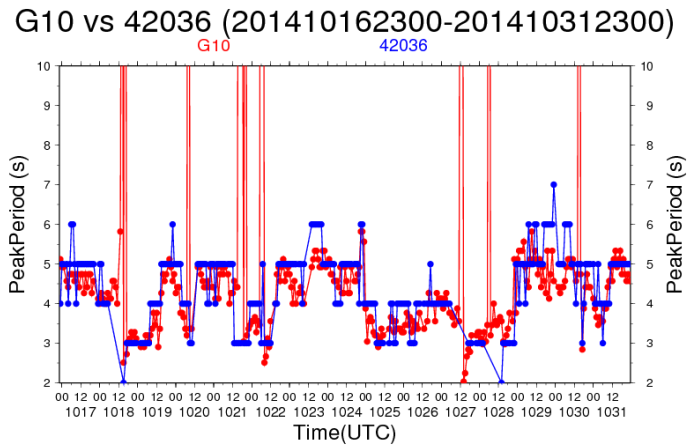

Average Period
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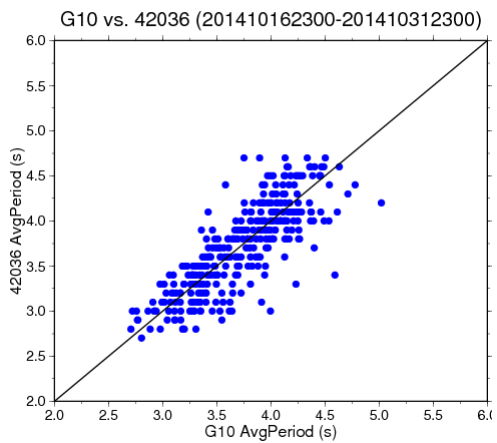

Peak Direction
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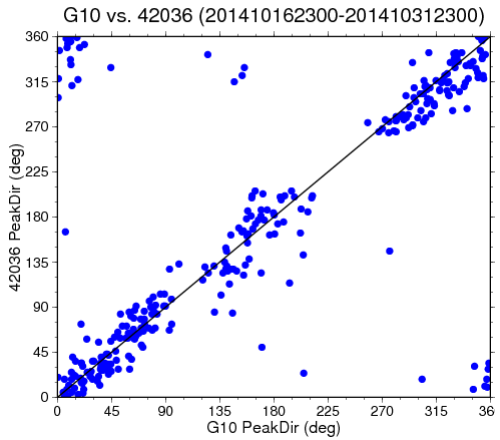

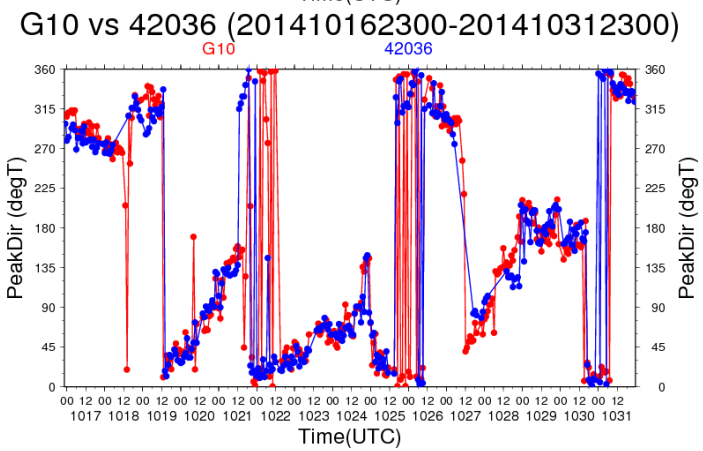

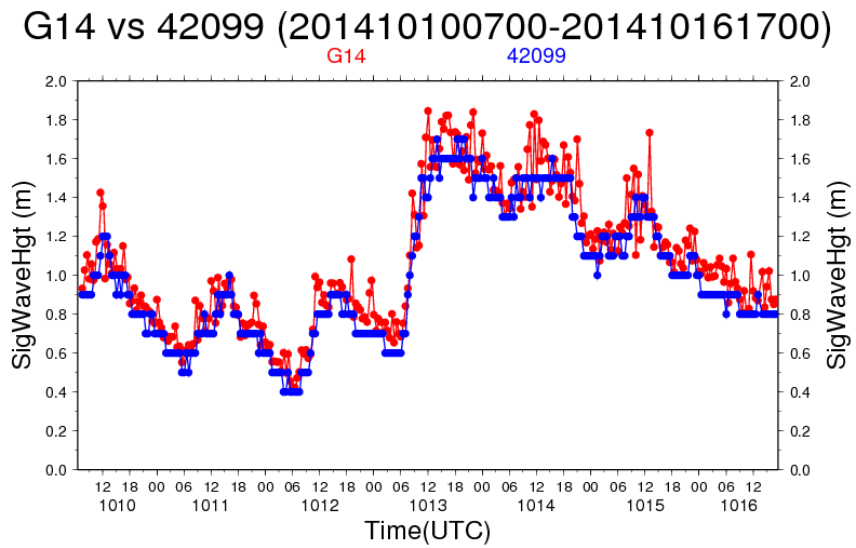

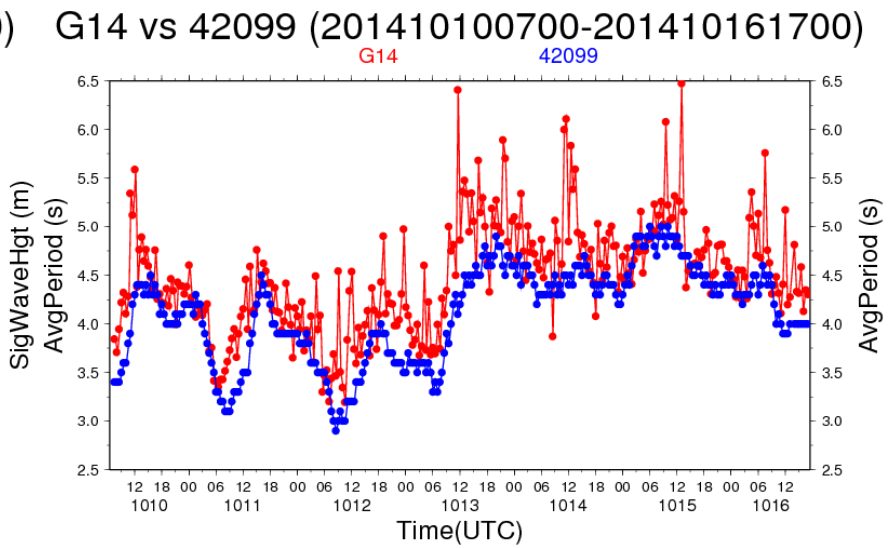

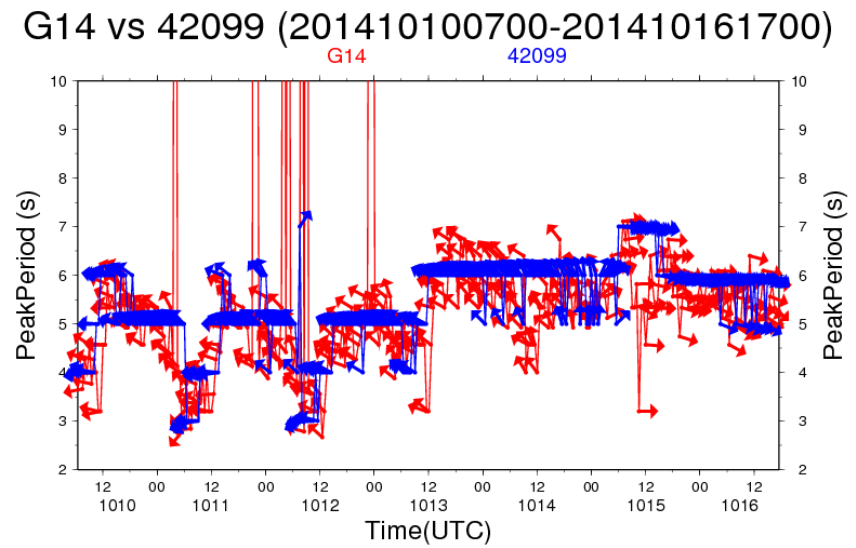

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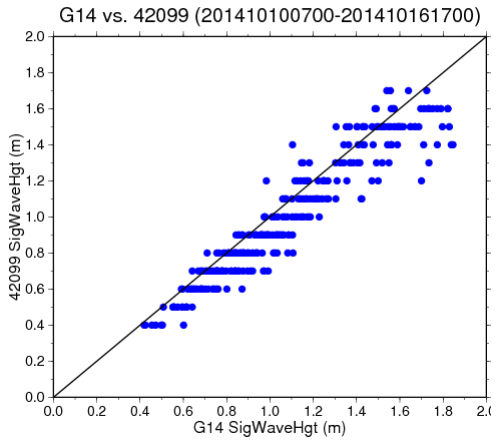

Peak Period
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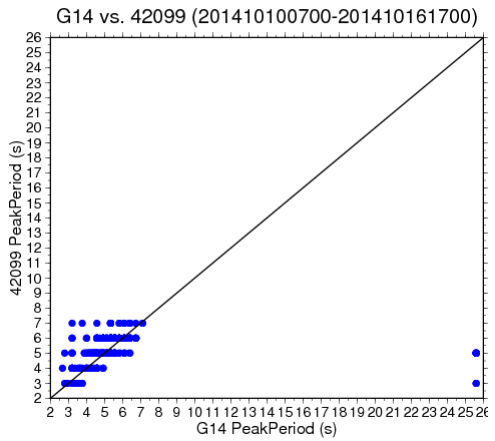
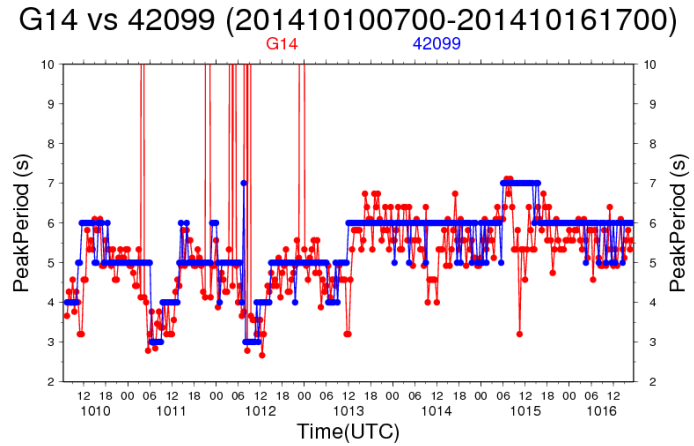
Abs Err = 1.21





Average Period
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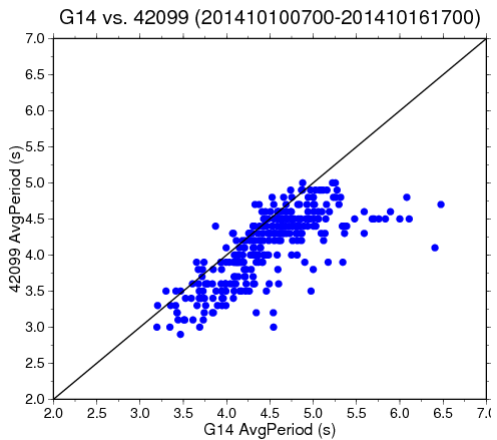
Abs Err = 0.40



Peak Direction
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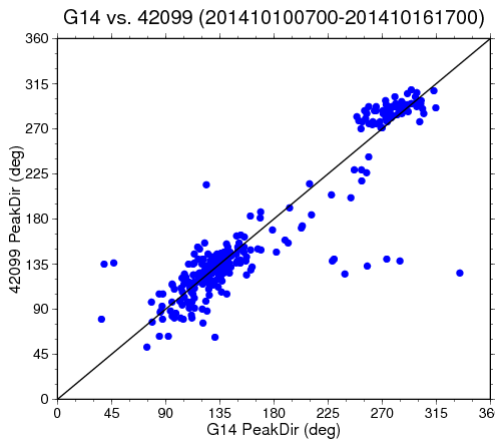
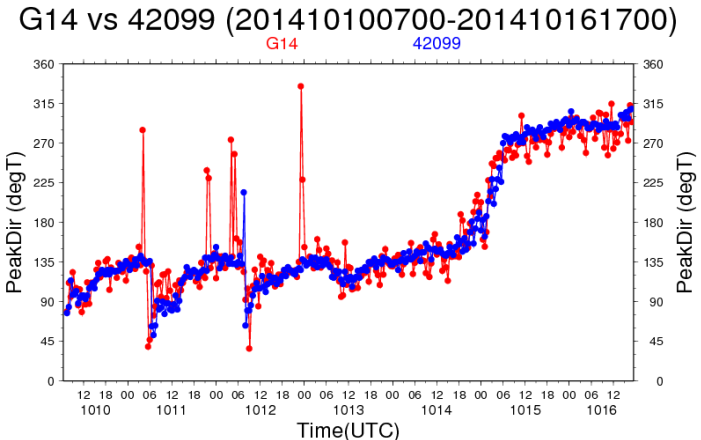
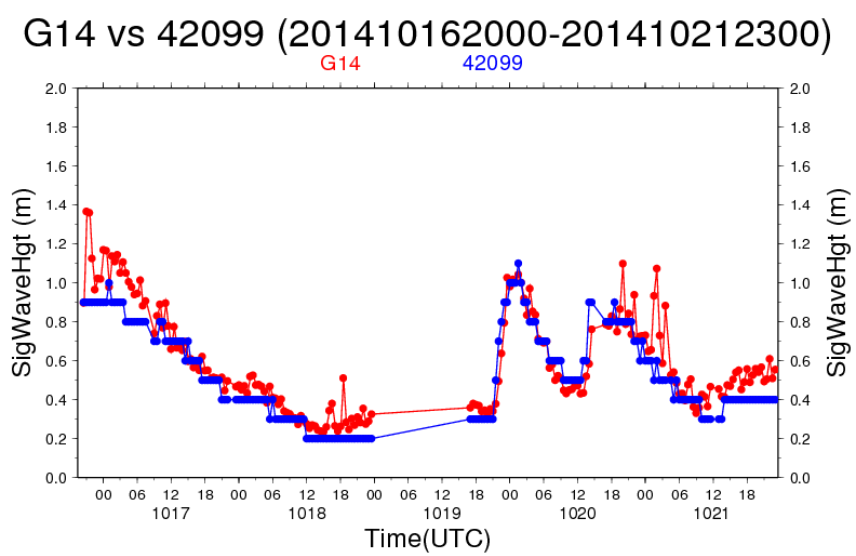
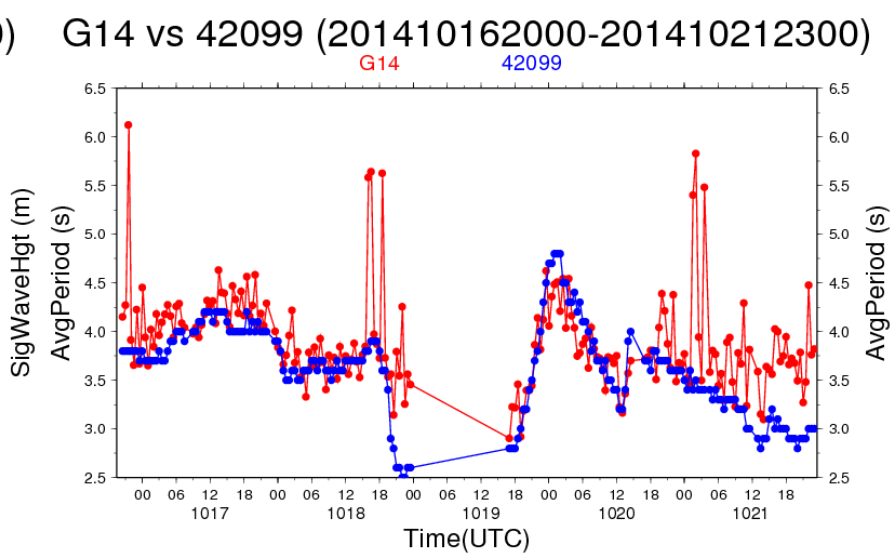
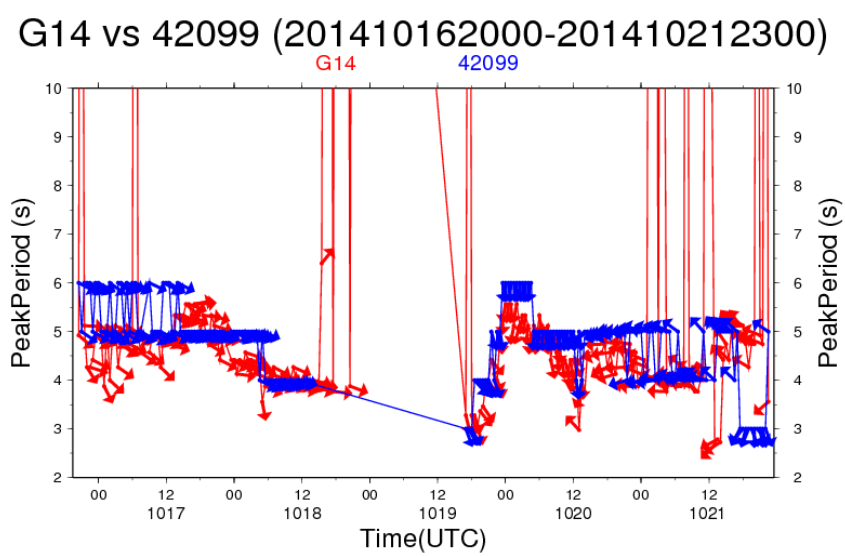
Abs Err = 15.17











Sig Wave Hgt
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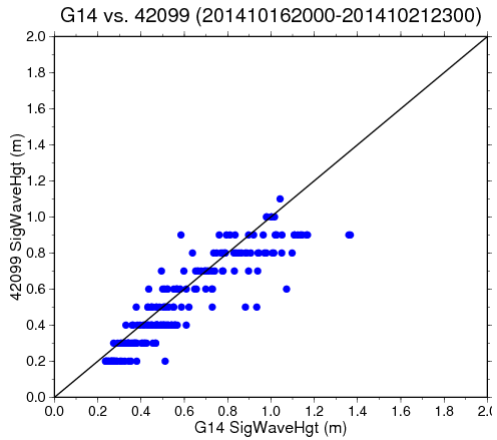
Abs Err = 0.10



Peak Period
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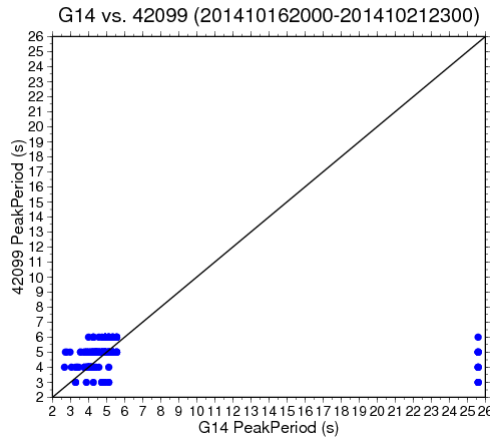
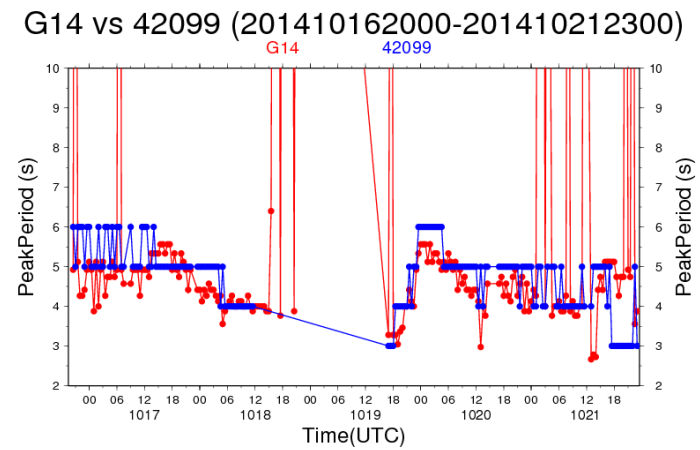
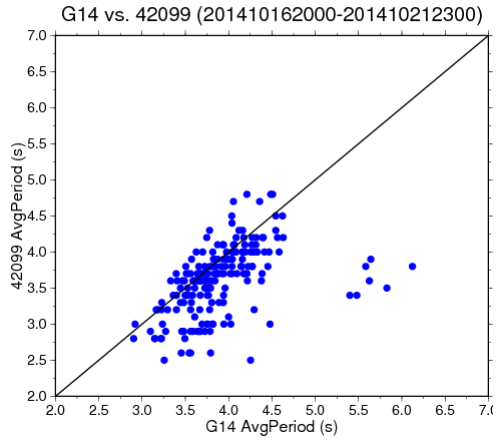
Abs Err = 1.90

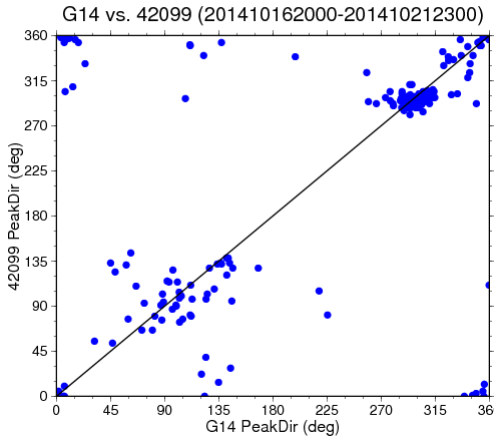


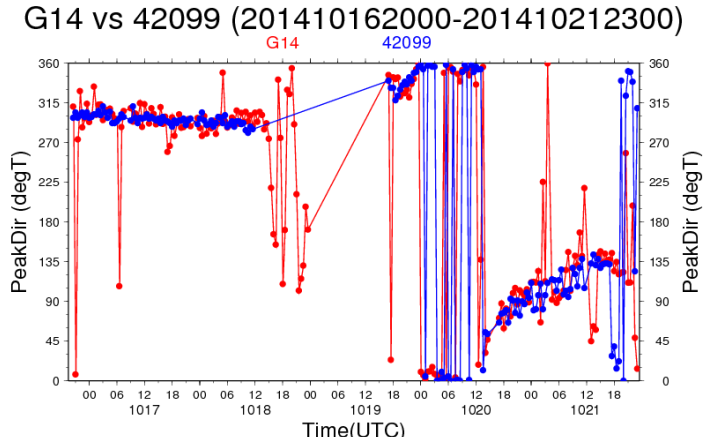


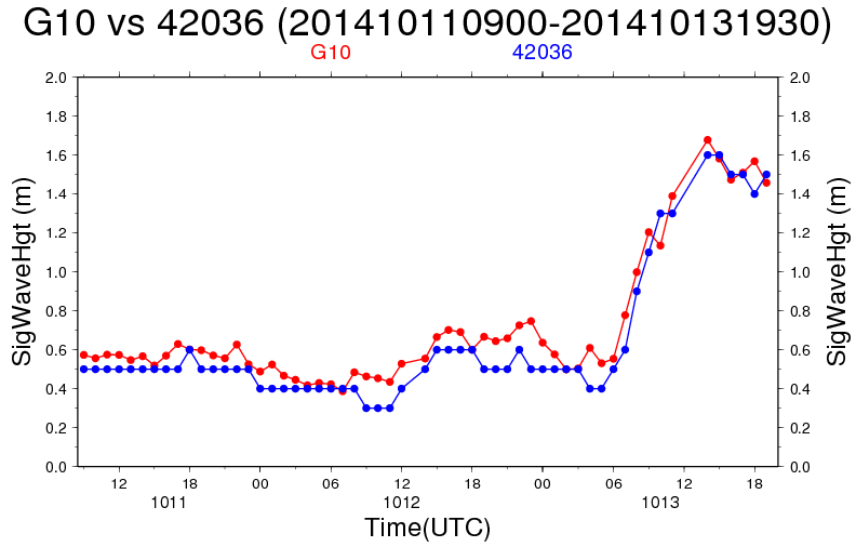
Average Period
Bias Err = 0.28
Abs Err = 0.37

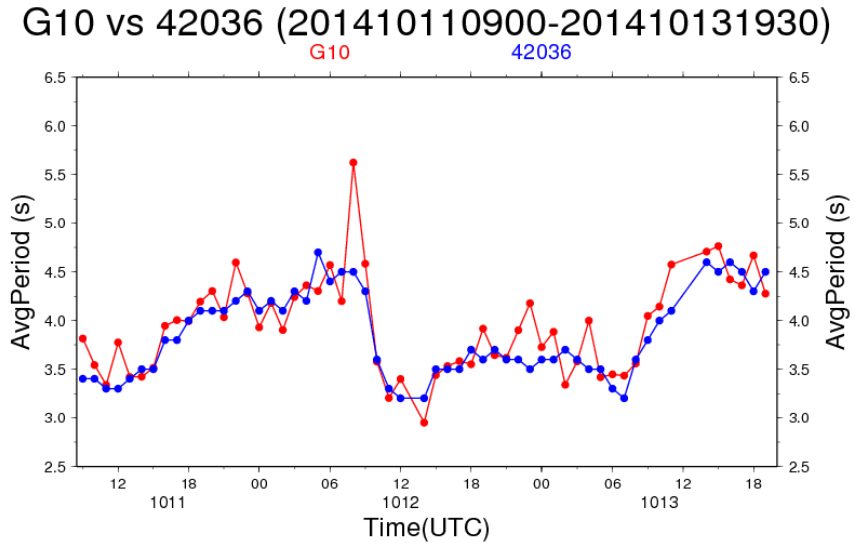


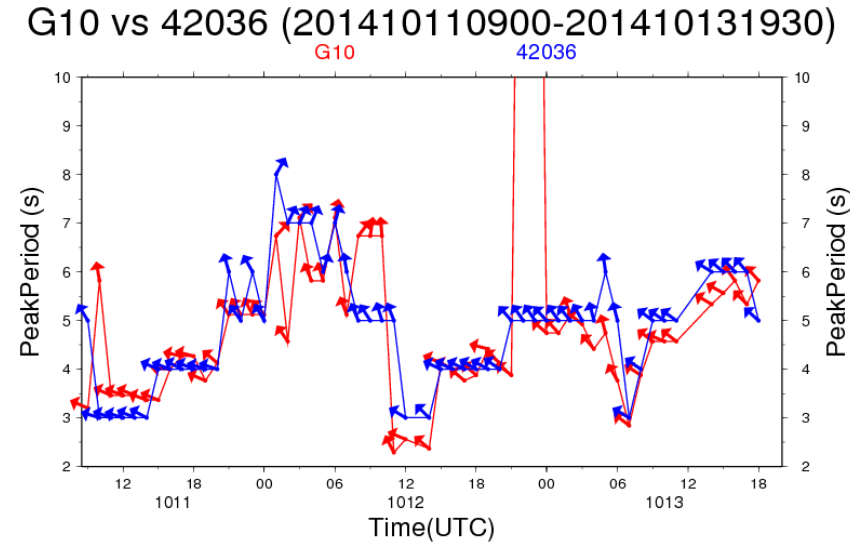
Peak Direction
Bias Err = -1.14
Abs Err = 23.24



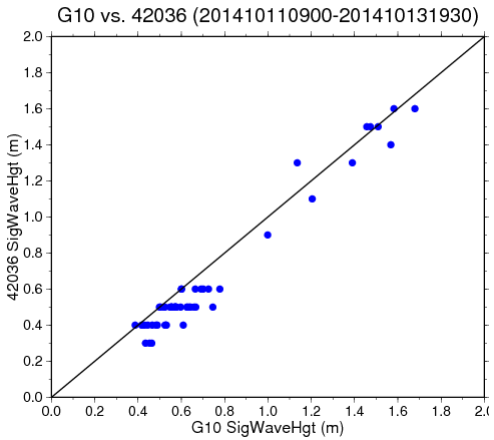




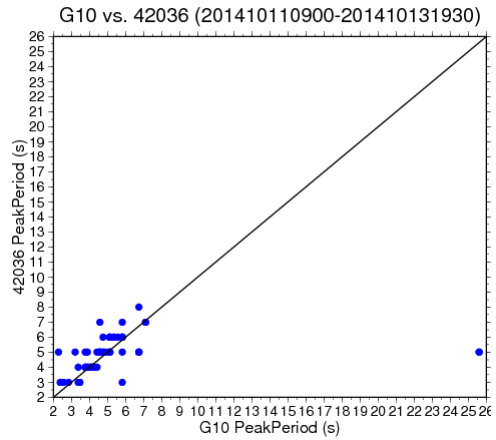


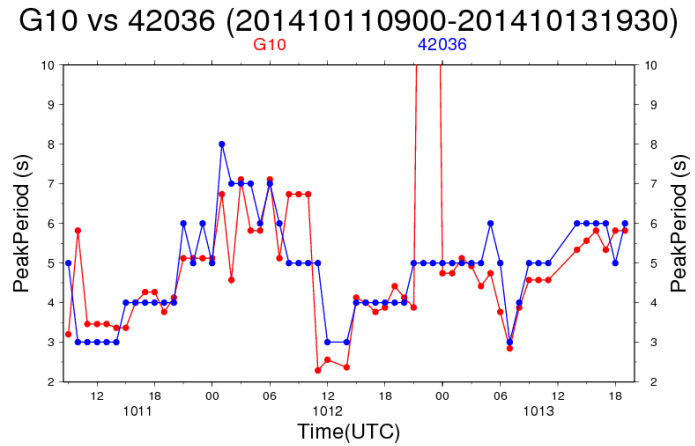


Sig Wave Hgt
Bias Err = 0.08
Abs Err = 0.09

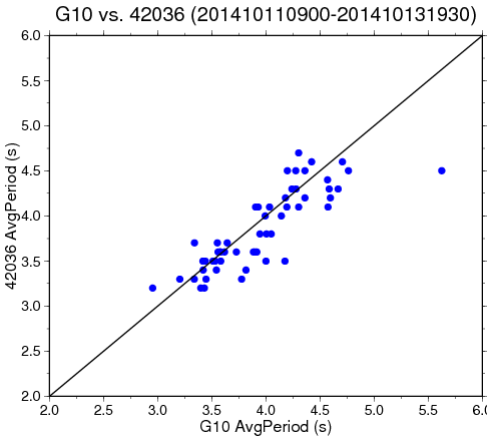


Peak Period
Bias Err = 0.55
Abs Err = 1.37

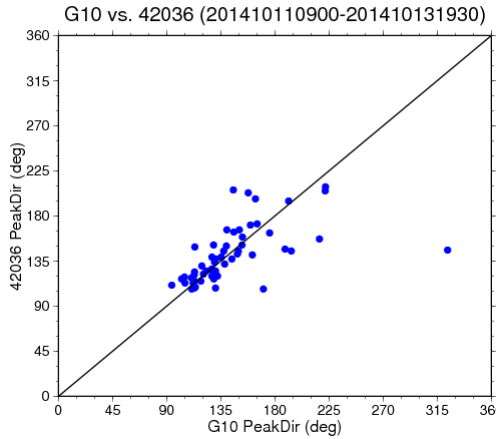


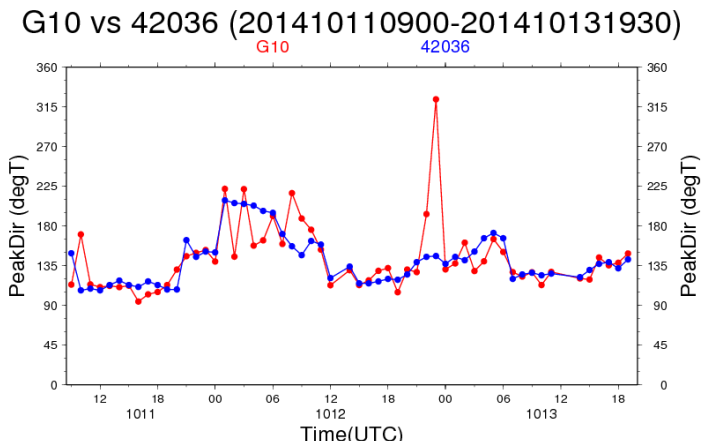


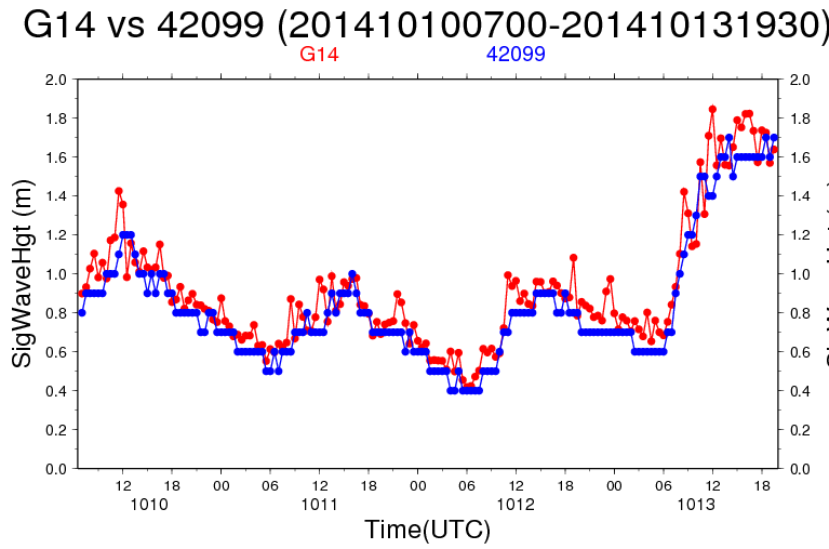
Average Period
Bias Err = 0.10
Abs Err = 0.20

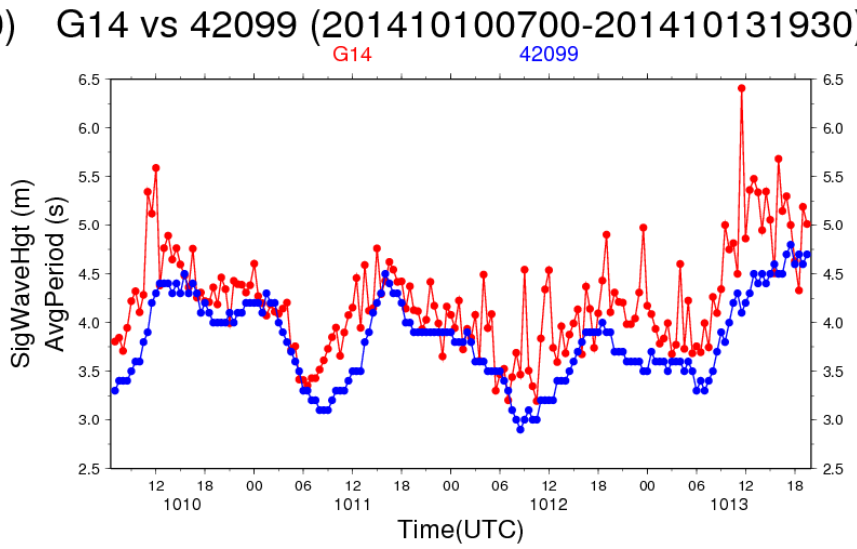


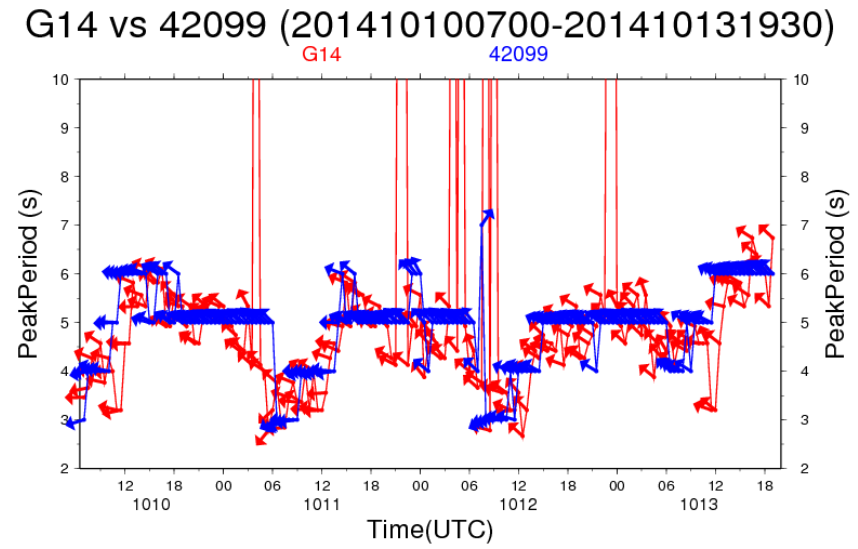
Peak Direction
Bias Err = 2.39
Abs Err = 17.59



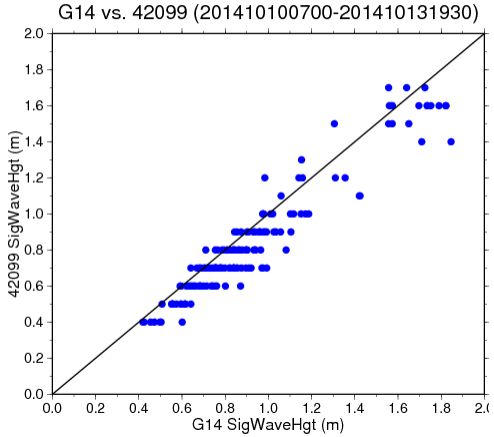




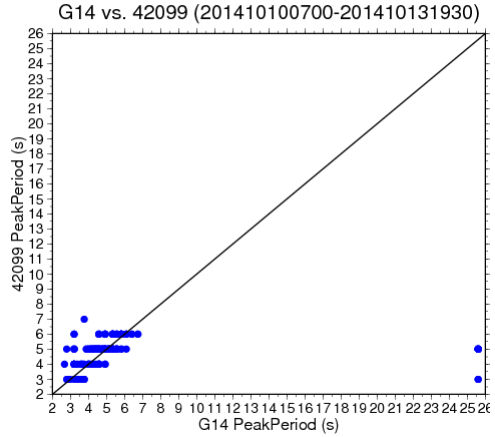


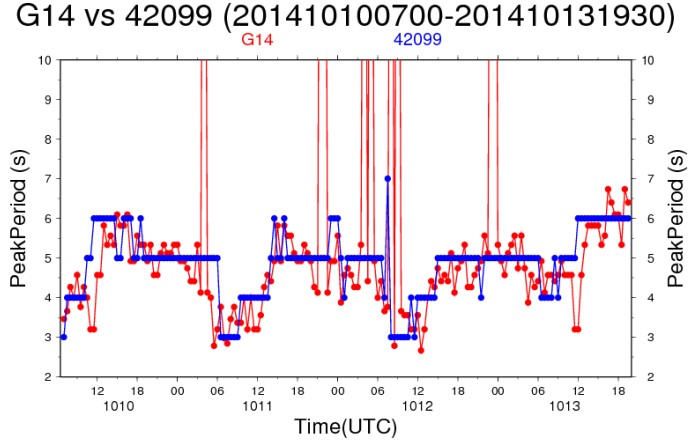


Sig Wave Hgt
Bias Err = 0.08
Abs Err = 0.10

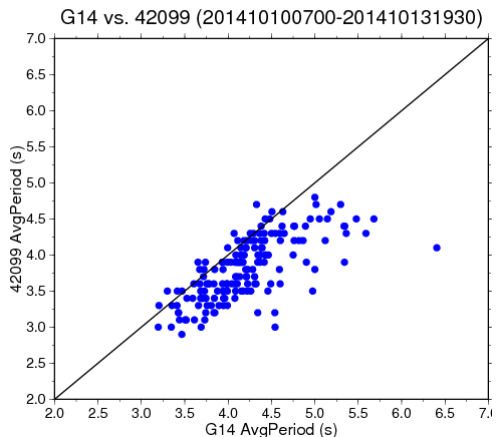


Peak Period
Bias Err = 0.87
Abs Err = 1.65

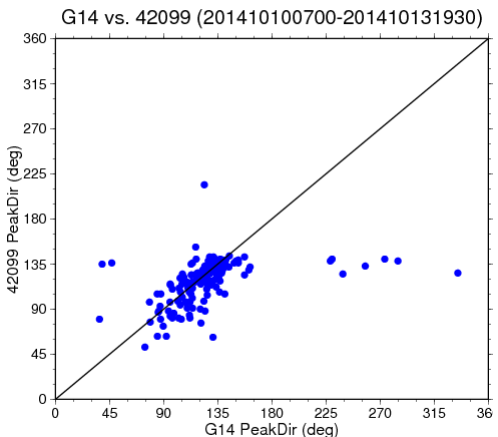


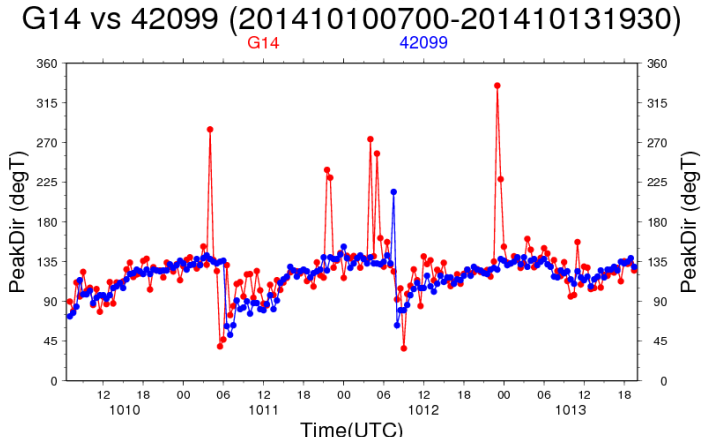


Average Period
Bias Err = 0.40
Abs Err = 0.42



Peak Direction
Bias Err = 6.79
Abs Err = 16.79

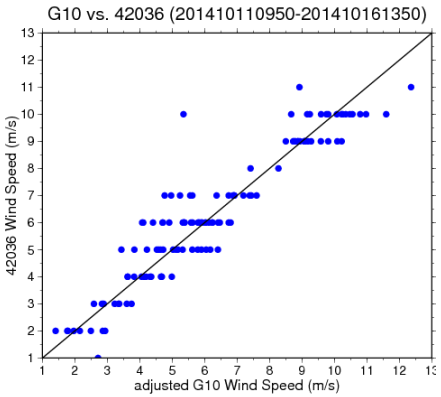




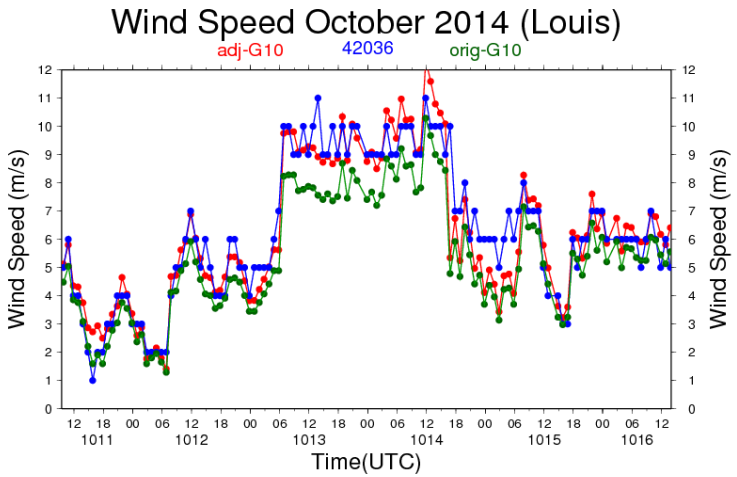
Loitering validation examples – meteorology data

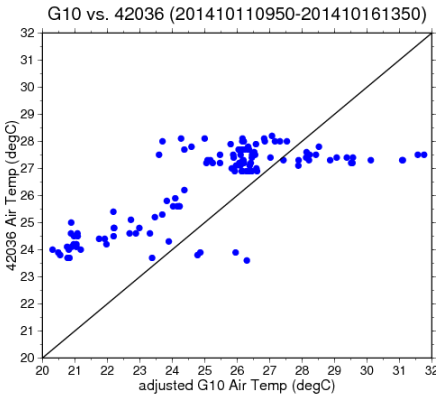
Results preliminary

G10 adjusted to 4m for AirTemp and 5m for WindSpd (42036) using 42036's water temperature in calculation

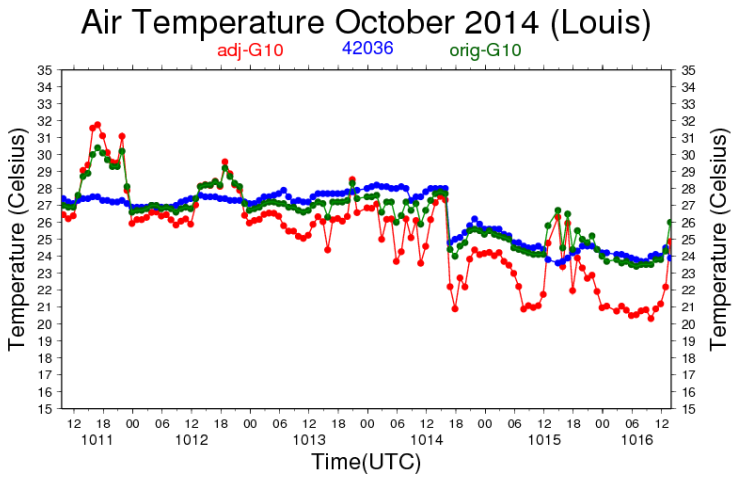


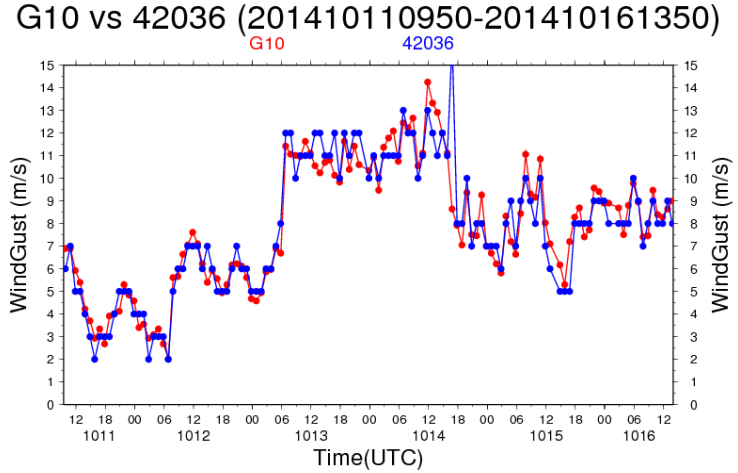
Bias Err = -0.09
Abs Err = 0.63

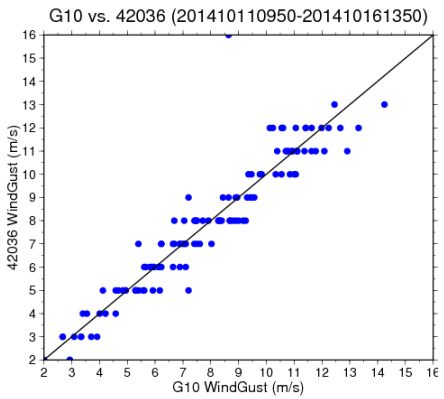




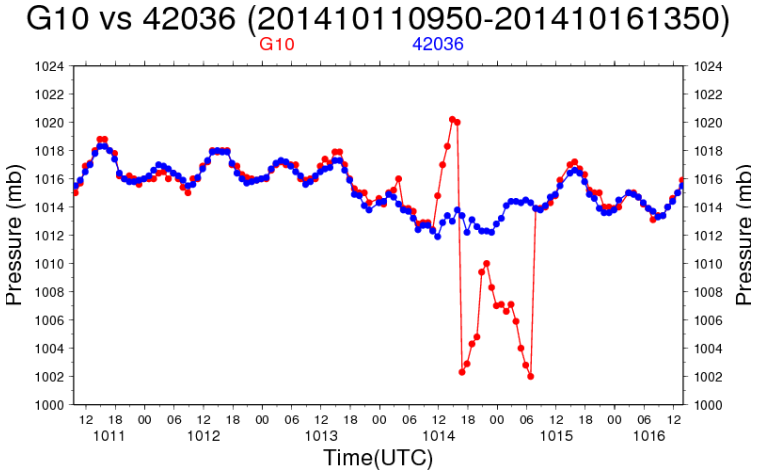
Bias Err = -1.14
Abs Err = 1.86

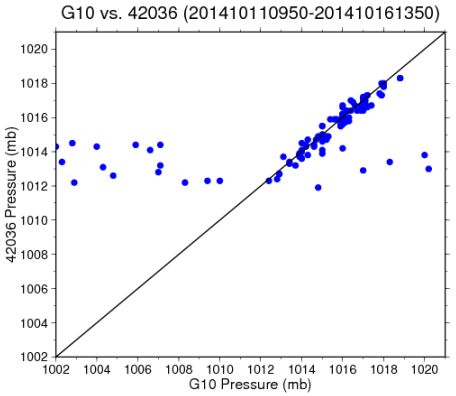




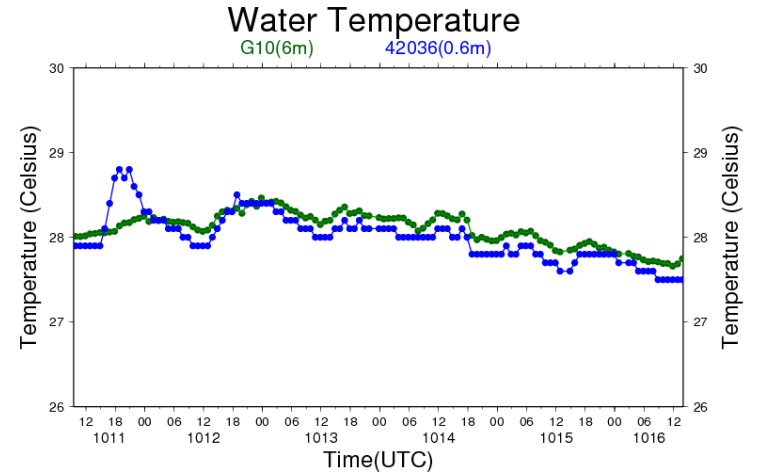


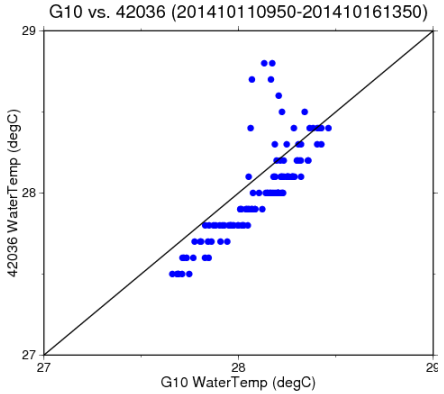
Bias Err = 0.03 Abs Err = 0.62





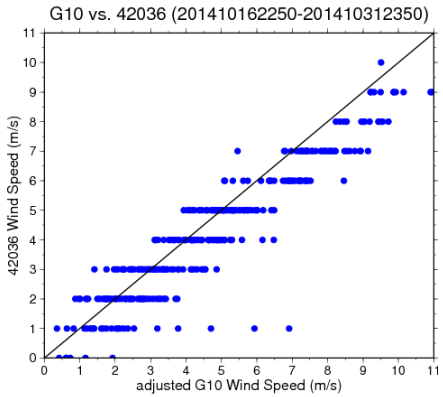
Bias Err = -0.63 Abs Err = 1.4



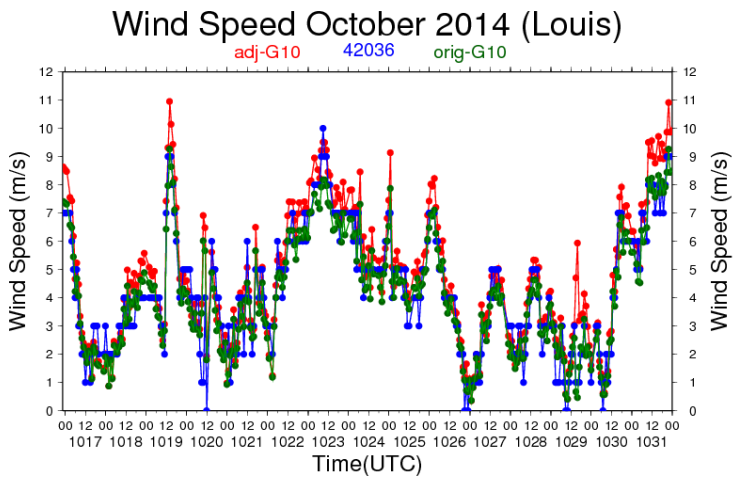


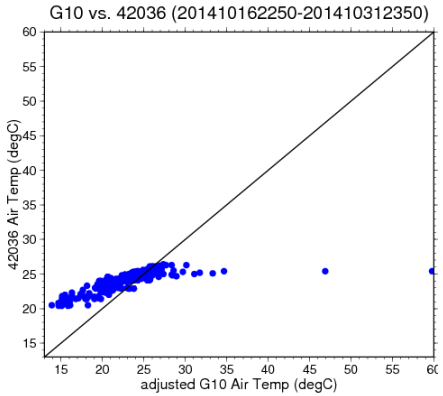
Bias Err = 0.10 Abs Err = 0.16

G10 adjusted to 4m for AirTemp and 5m for WindSpd (42036) using 42036's water temperature in calculation

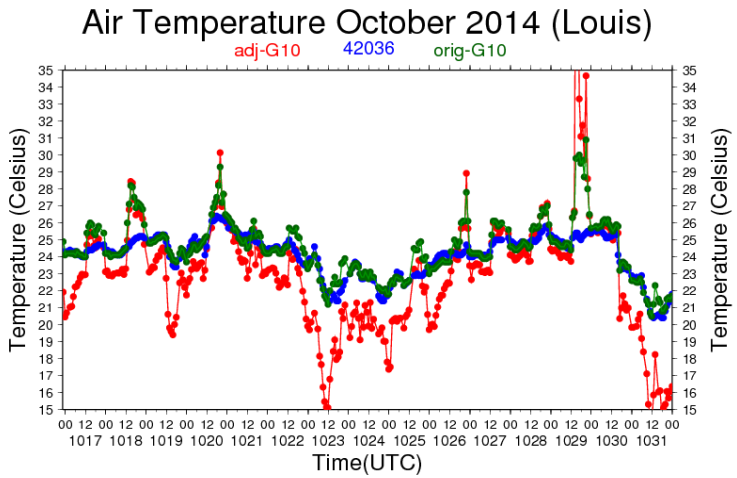


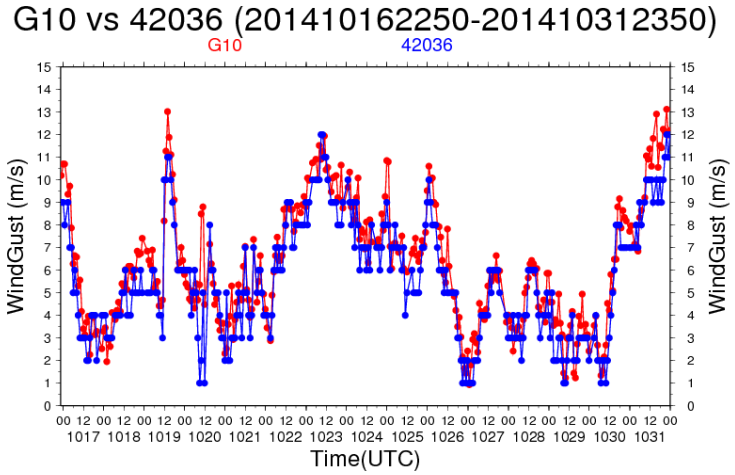
Bias Err = 0.48
Abs Err = 0.76

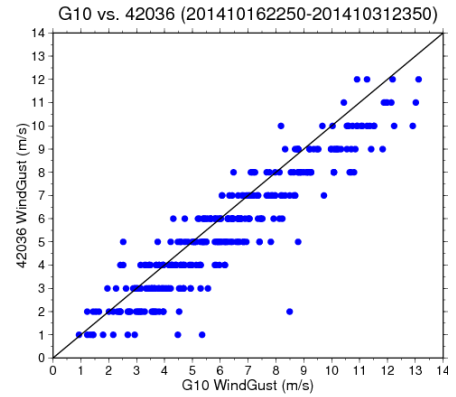




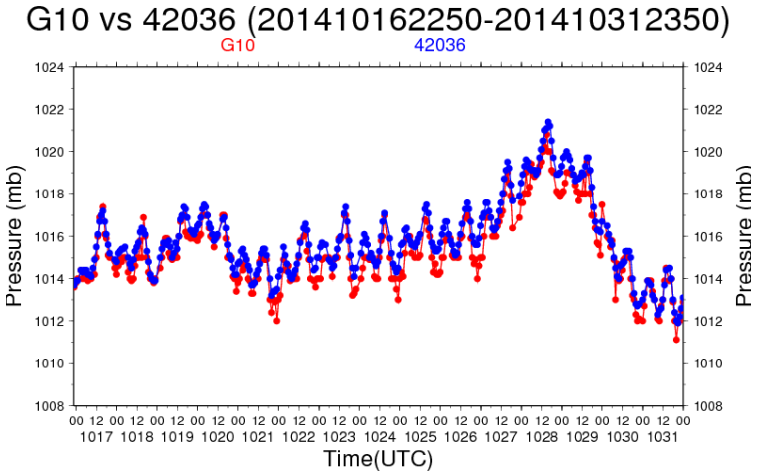
Bias Err = -1.08
Abs Err = 2.05

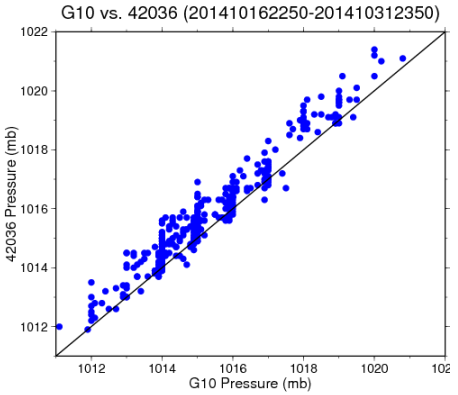




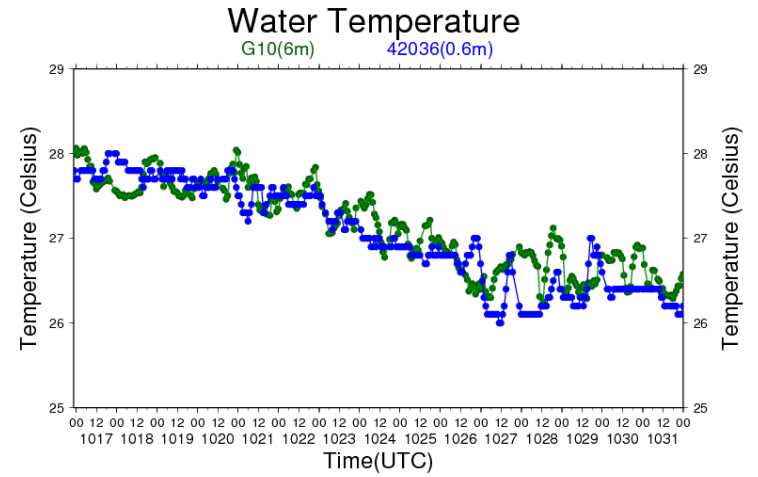


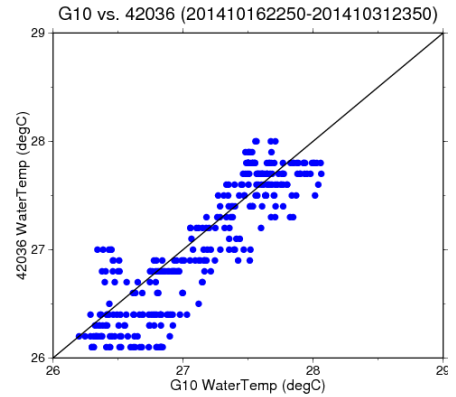
Bias Err = 0.67 Abs Err = 0.94





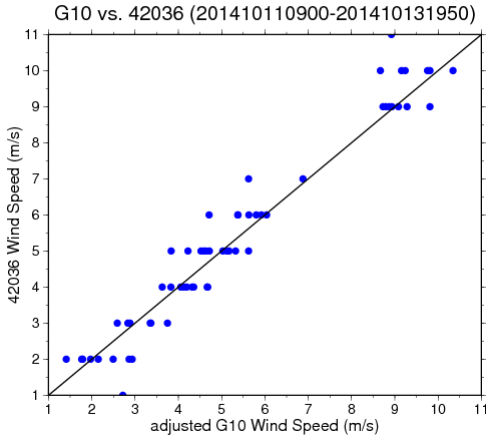
Bias Err = -0.51 Abs Err = 0.55



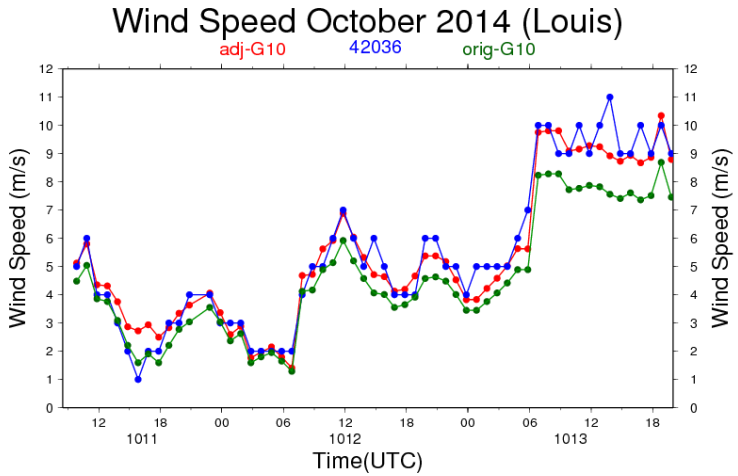


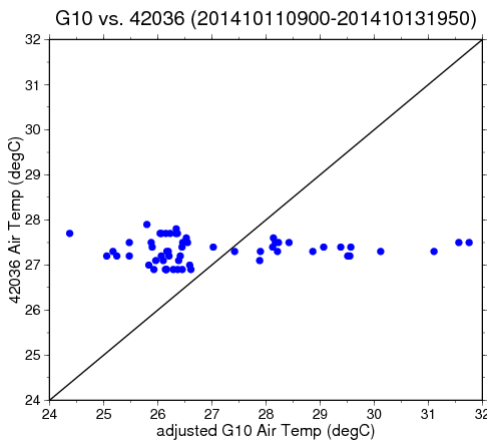
Bias Err = 0.11 Abs Err = 0.23

G10 adjusted to 4m for AirTemp and 5m for WindSpd (42036) using 42036's water temperature in calculation

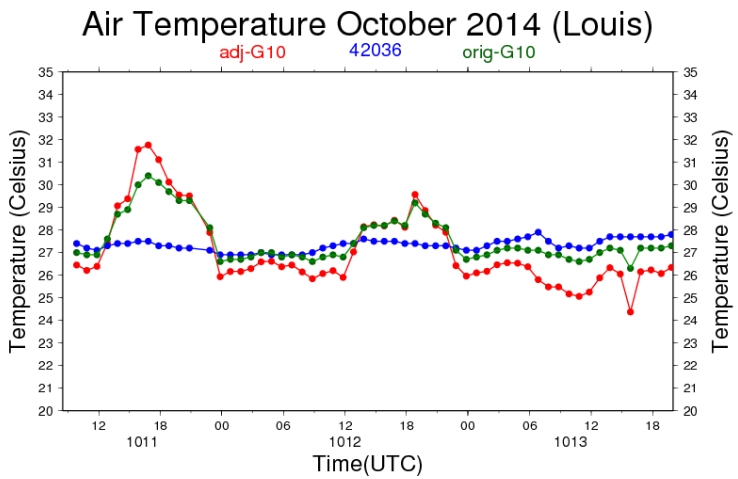


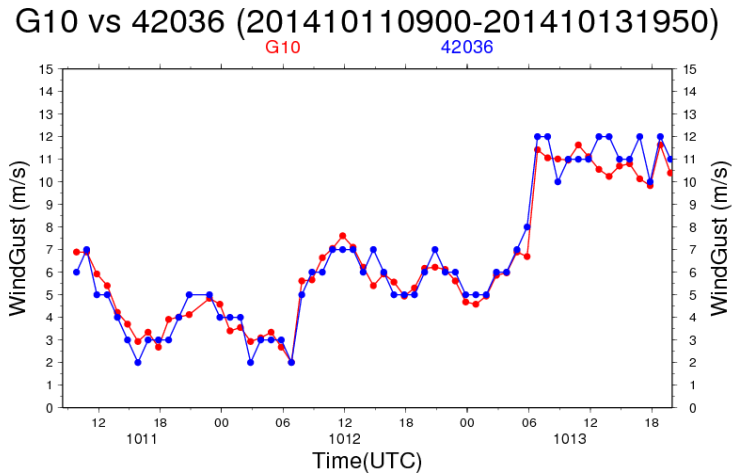
Bias Err = -0.10
Abs Err = 0.47

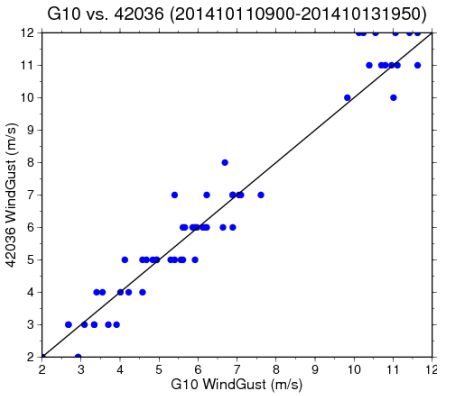




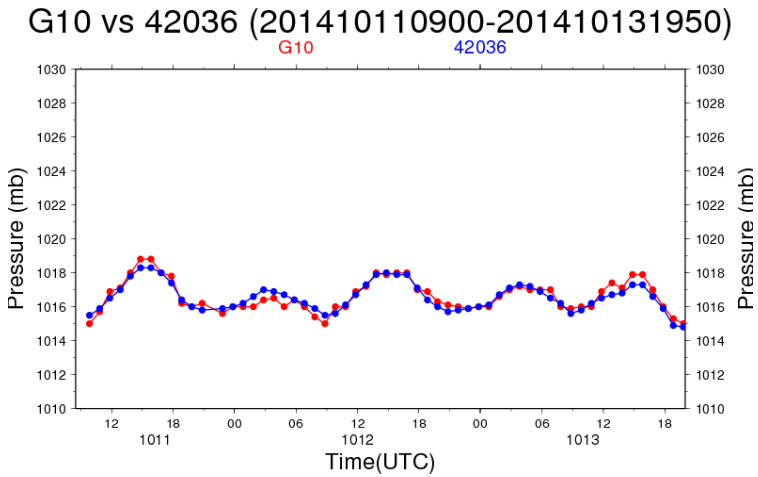
Bias Err = -0.26
Abs Err = 1.40

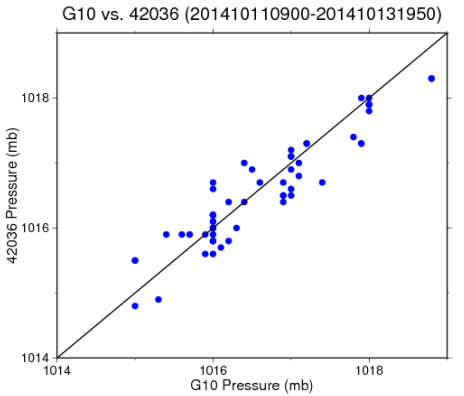




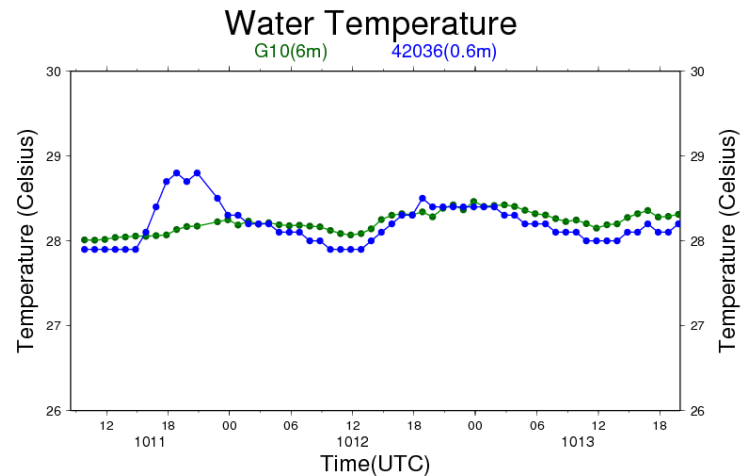


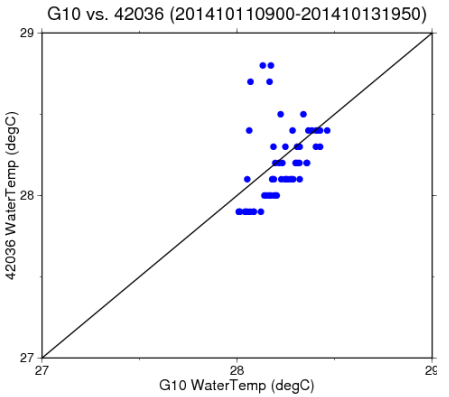
Bias Err = -0.08 Abs Err = 0.50





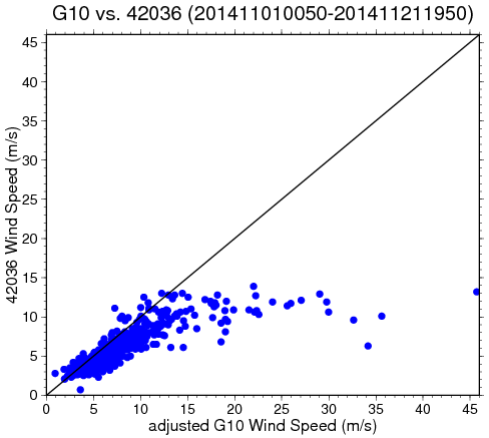
Bias Err = 0.06 Abs Err = 0.27



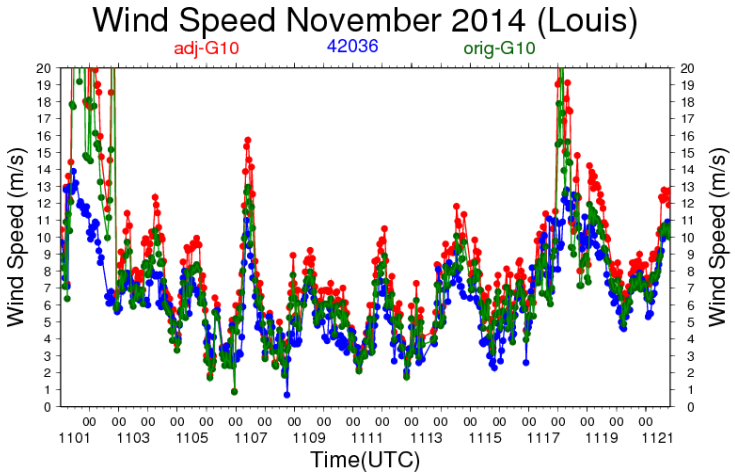


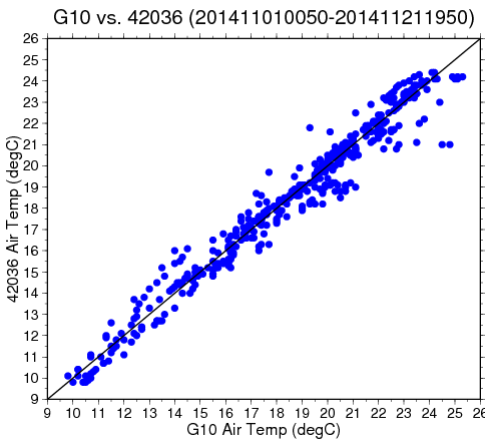
Bias Err = 0.03 Abs Err = 0.16

G10 adjusted to 5m for WindSpd (42036)
using G10's water temperature in calculation

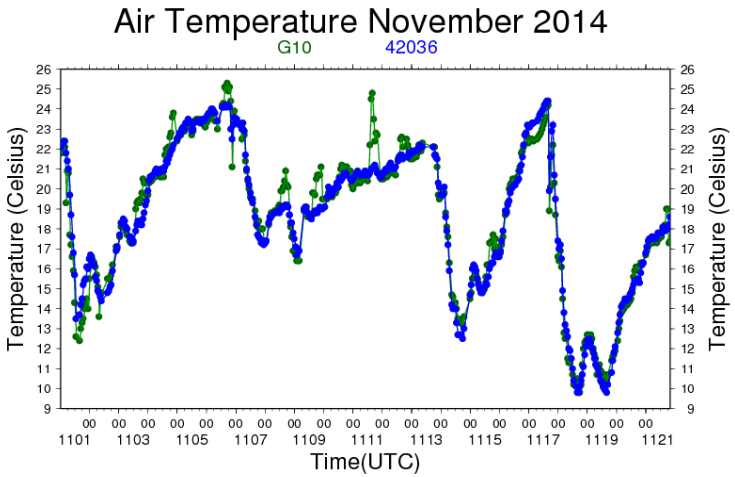


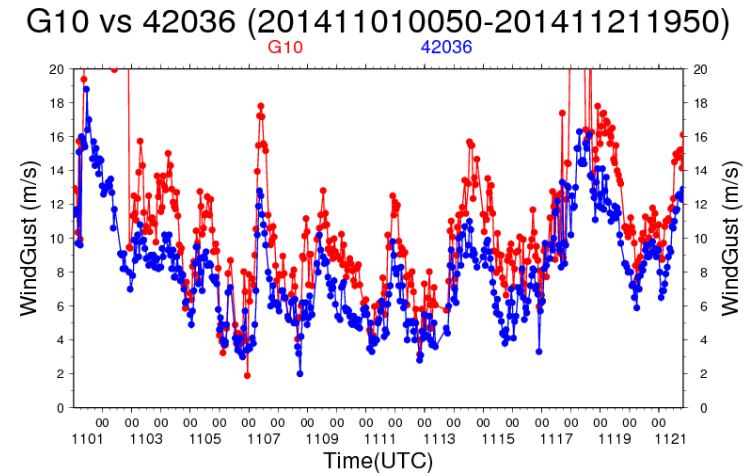
Bias Err = 2.32
Abs Err = 2.51

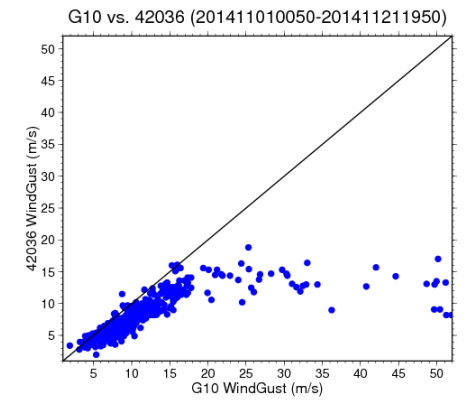




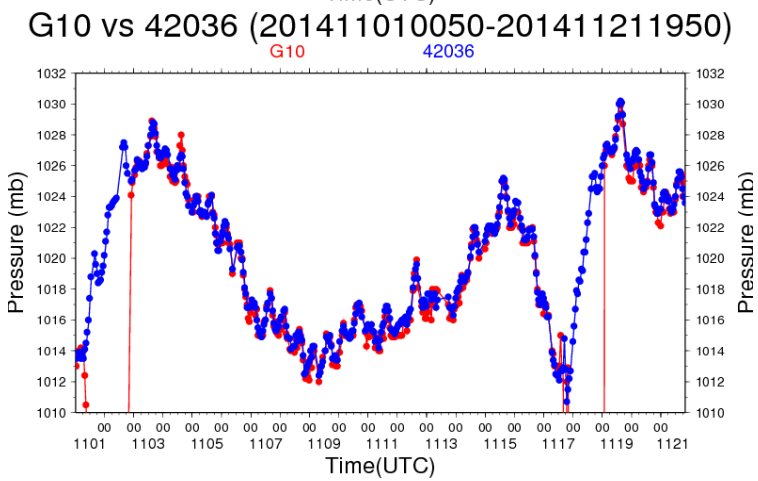
Bias Err = 0.05
Abs Err = 0.49

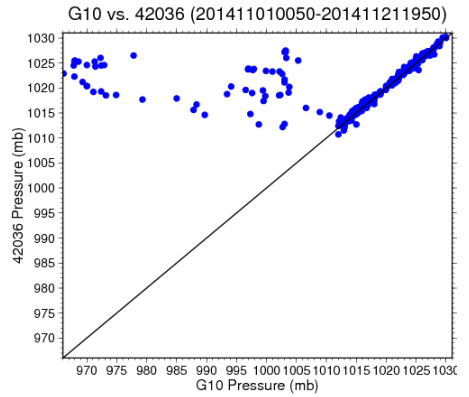




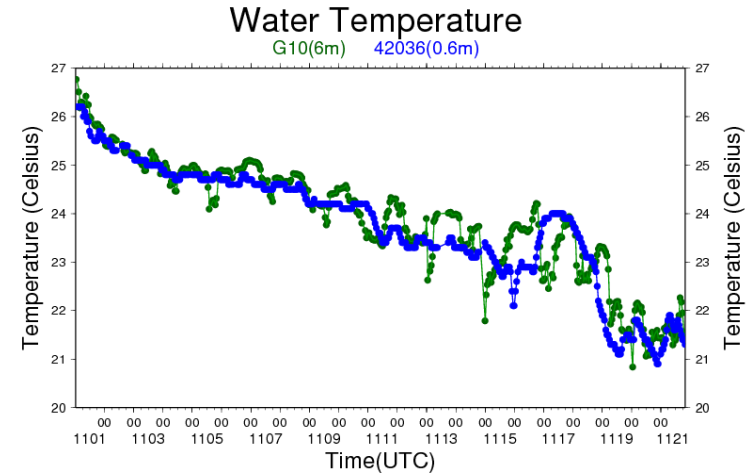


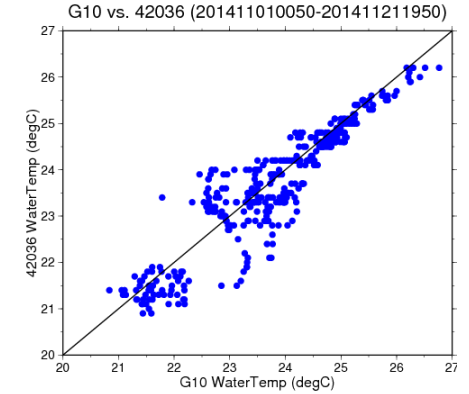
Bias Err = 3.93 Abs Err = 3.99





Bias Err = -4.35 Abs Err = 4.51





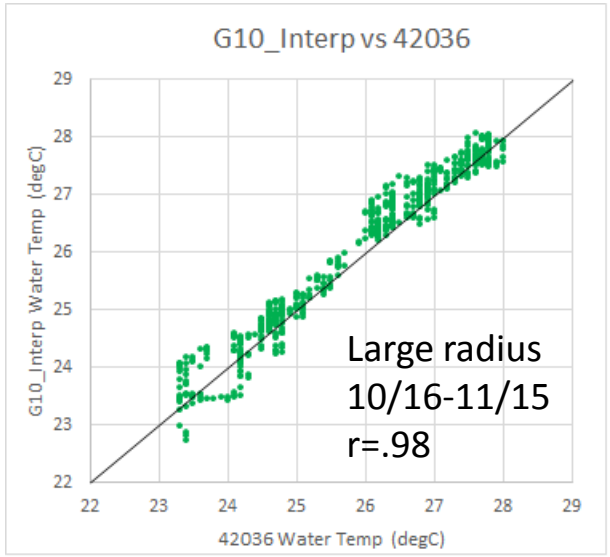
Bias Err = 0.14 Abs Err = 0.37

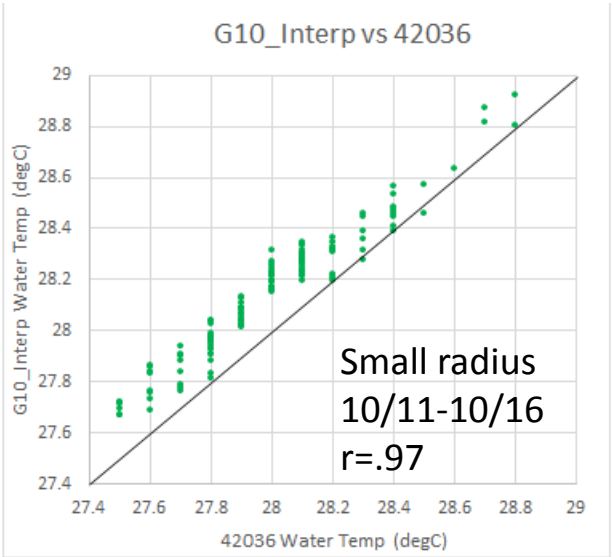
Loitering validation examples – surface water temperature data

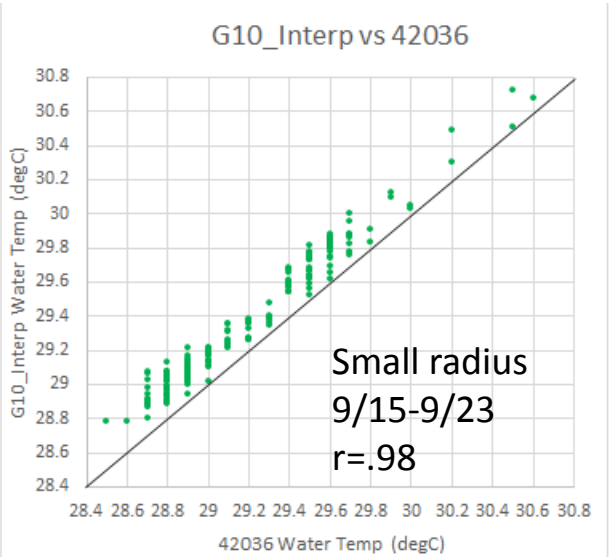
Validation of WG surface water temperature

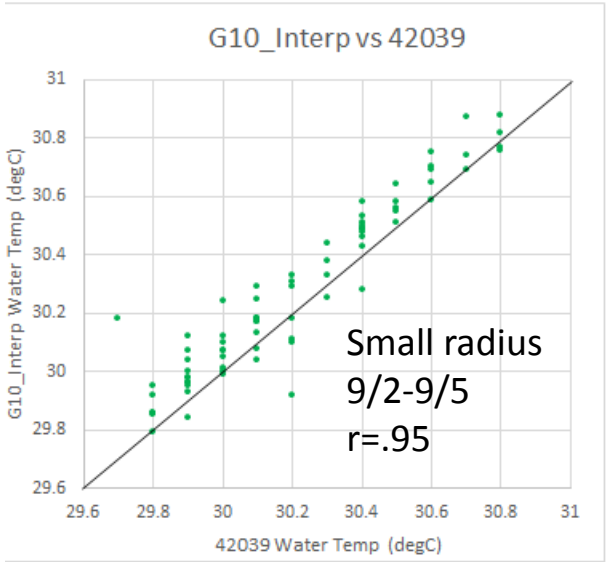
Loitering platform, radii proximity, and period	r	Bias (WG - buoy)	Absolute error	Bias σ	Absolute error σ	Sample size
G10 vs 42036 (Large radius) 10/16-11/15	.98	.14	.24	.27	.19	664
G10 vs 42036 (Small radius) 10/11-10/16	.97	.15	.15	.07	.07	126
G10 vs 42036 (Small radius) 9/15-9/23	.98	.18	.18	.07	.07	192
G10 vs 42039 (Small radius) 9/2-9/5	.95	.07	.09	.09	.07	76
G10 vs 42040 (Small radius) 8/28-8/29	.76	.12	.21	.20	.10	26
G11 vs 42040 (Small radius) 9/1-9/6	.94	.20	.28	.24	.14	64
G12 vs 42039 (Small radius) 9/1-9/2	.98	.12	.12	.06	.06	16
G14 vs 42099 (Small radius) 11/25-11/28	.94	-.15	.16	.08	.07	152
G14 vs 42099 (Large radius) 10/16-10/21	.62	-.03	.23	.30	.19	243
G14 vs 42099 (Small radius) 10/10-10/16	.99	-.05	.06	.04	.04	308
G14 vs 42040 (Small radius) 9/14-9/19	.91	.22	.30	.25	.14	133
GOM1 vs 42099 (Small radius) 11/22-11/28	.88	-.24	.27	.25	.21	315
GOM1 vs 42099 (Large radius) 11/9-11/22	.84	-.02	.22	.32	.23	610

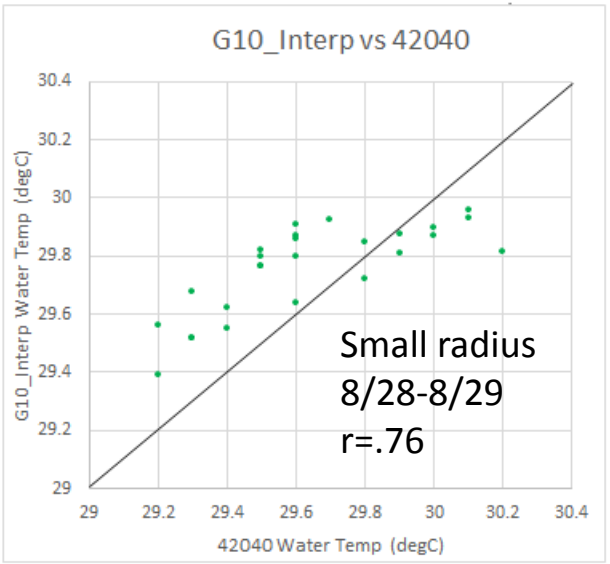
Buoy	Depth (m)
42036	0.6
42039	0.6
42040	1.0
42099	0.46

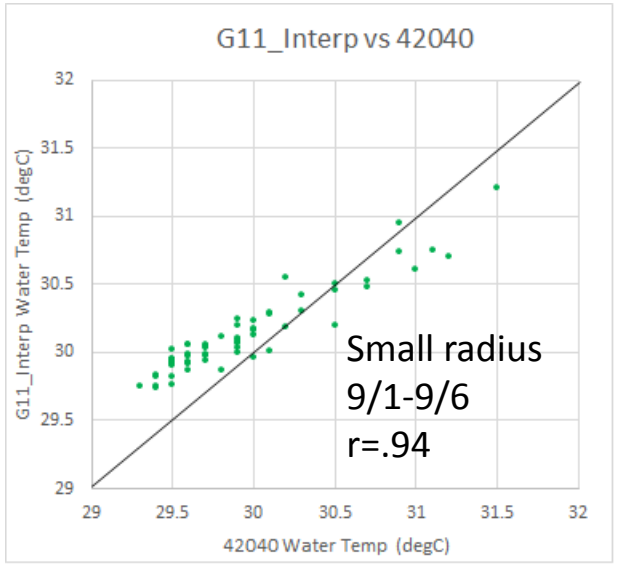

G10_Interp vs 42036
G10_Interp Water Temp (degC)
42036 Water Temp (degC)
Large radius
10/16-11/15
r=.98

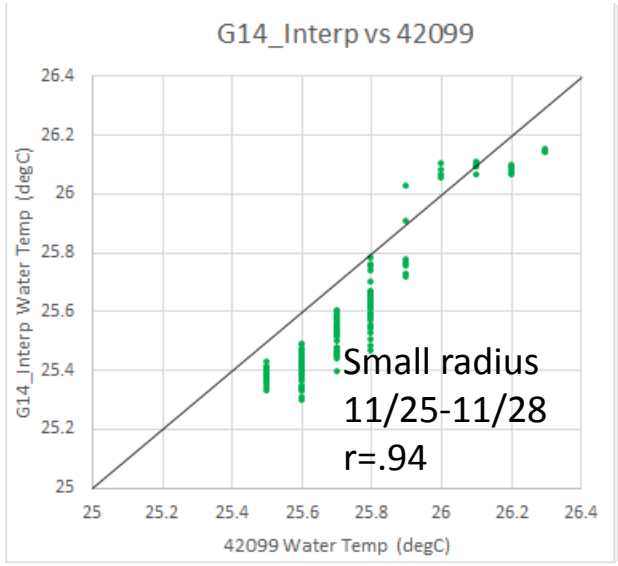

G10_Interp vs 42036
G10_Interp Water Temp (degC)
42036 Water Temp (degC)
Small radius
10/11-10/16
r=.97

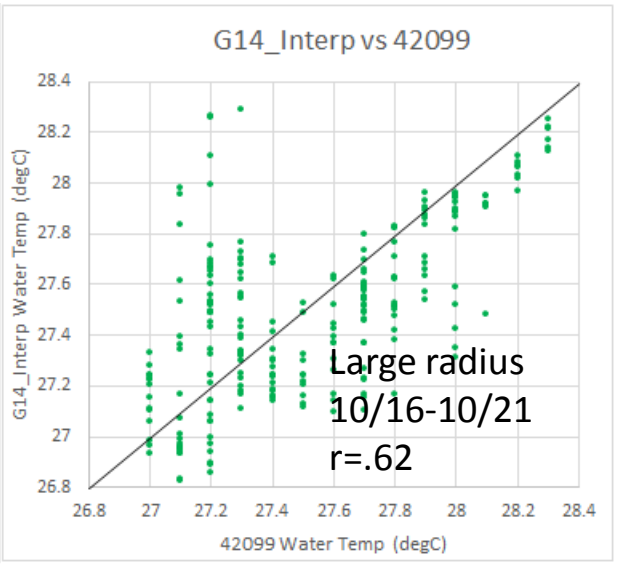

G10_Interp vs 42036
G10_Interp Water Temp (degC)
42036 Water Temp (degC)
Small radius
9/15-9/23
r=.98

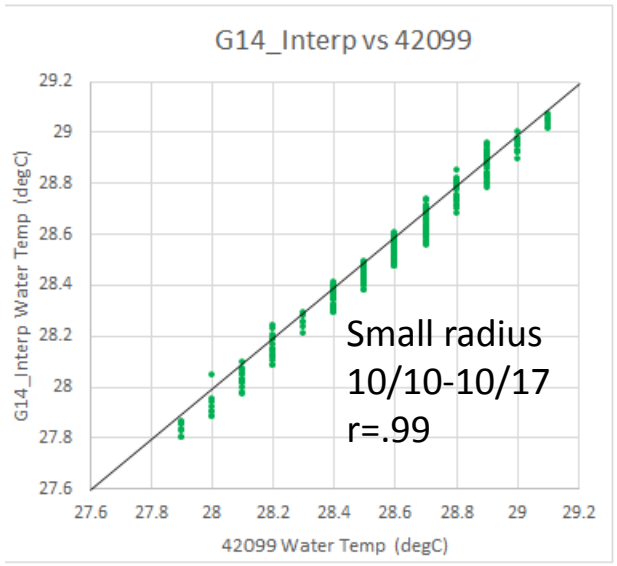

G10_Interp vs 42039
G10_Interp Water Temp (degC)
42039 Water Temp (degC)
Small radius
9/2-9/5
r=.95

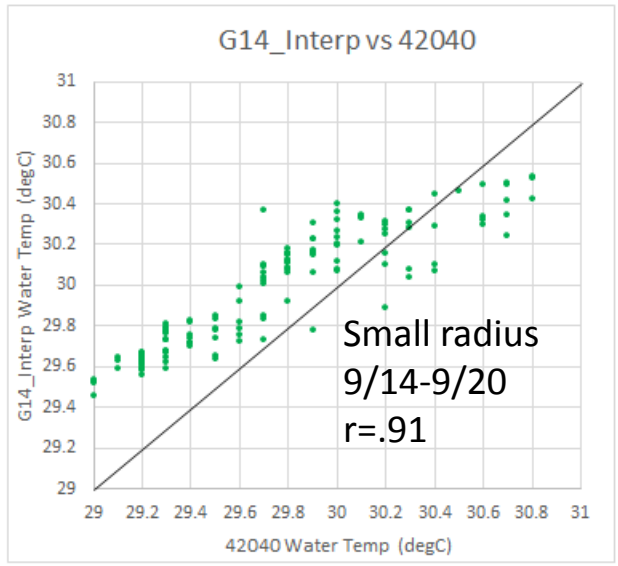

G10_Interp vs 42040
G10_Interp Water Temp (degC)
42040 Water Temp (degC)
Small radius
8/28-8/29
r=.76

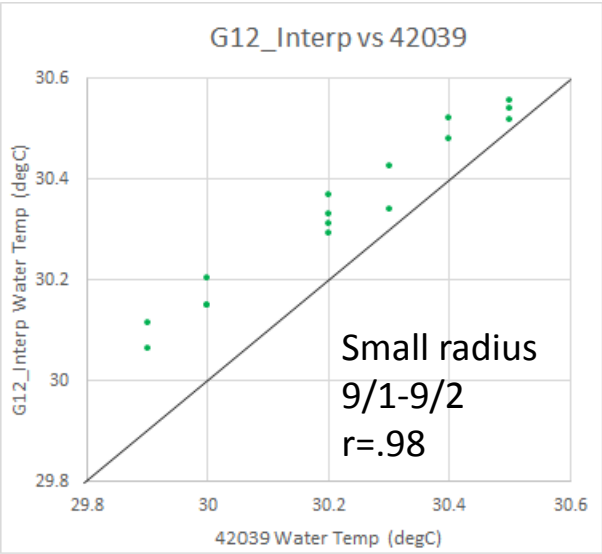

G11_Interp vs 42040
G11_Interp Water Temp (degC)
42040 Water Temp (degC)
Small radius
9/1-9/6
r=.94

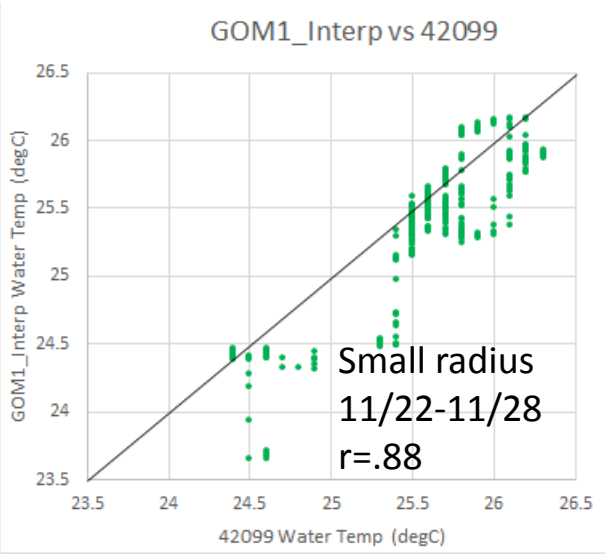

G14_Interp vs 42099
G14_Interp Water Temp (degC)
42099 Water Temp (degC)
Small radius
11/25-11/28
r=.94

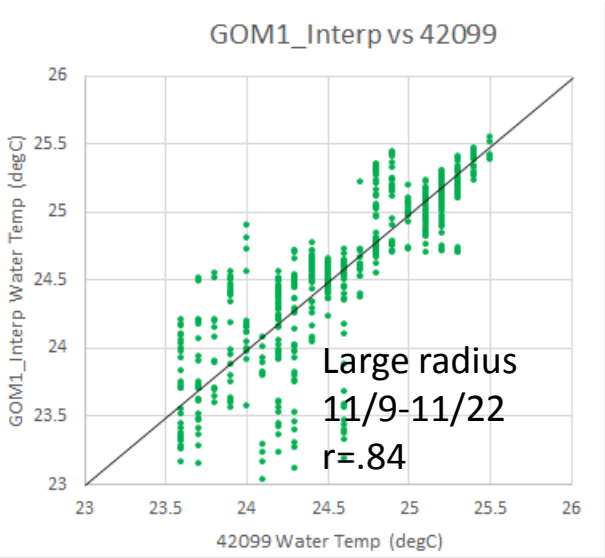

G14_Interp vs 42099
G14_Interp Water Temp (degC)
42099 Water Temp (degC)
Large radius
10/16-10/21
r=.62

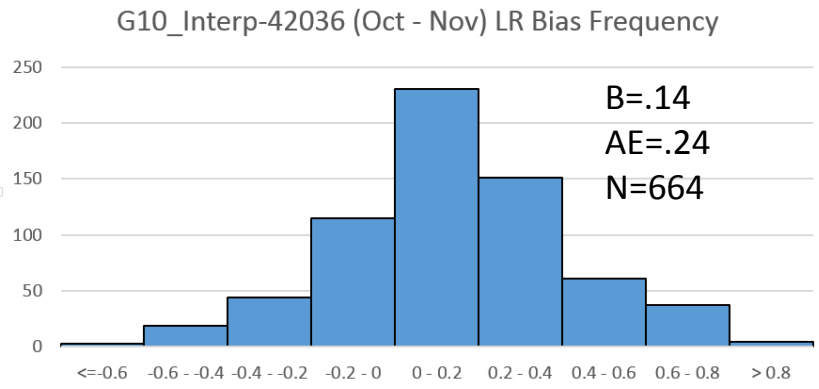

G14_Interp vs 42099
G14_Interp Water Temp (degC)
42099 Water Temp (degC)
Small radius
10/10-10/17
r=.99

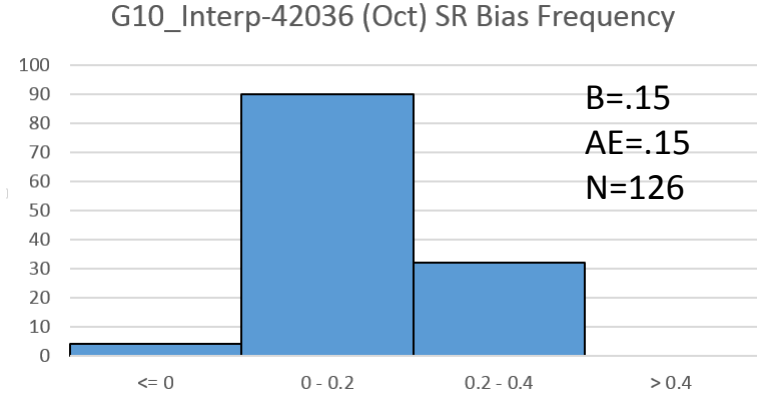

G14_Interp vs 42040
G14_Interp Water Temp (degC)
42040 Water Temp (degC)
Small radius
9/14-9/20
r=.91

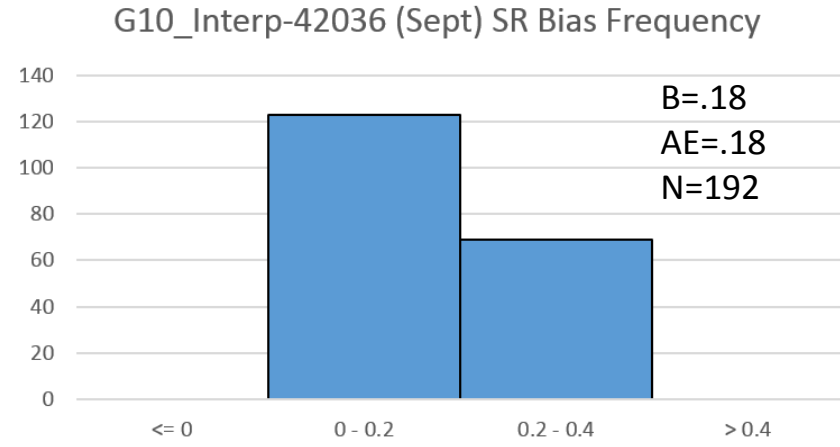

G12_Interp vs 42039
G12_Interp Water Temp (degC)
42039 Water Temp (degC)
30.6
30.4
30.2
30
29.8
29.8
30
30.2
30.4
30.6
Small radius
9/1-9/2
r=.98

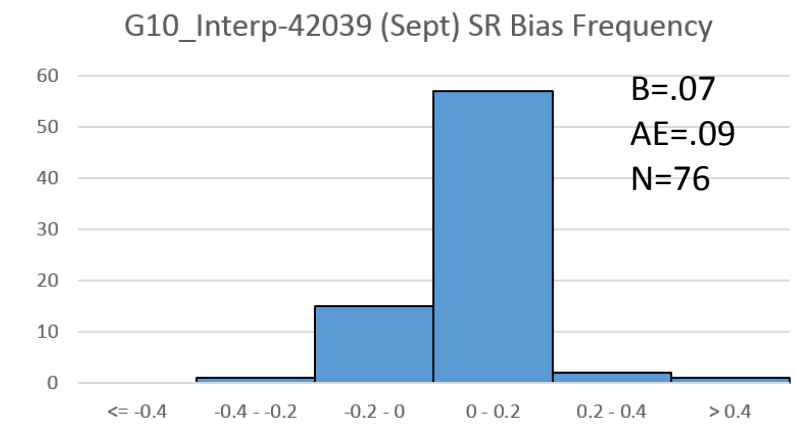

GOM1_Interp vs 42099
GOM1_Interp Water Temp (degC)
42099 Water Temp (degC)
26.5
26
25.5
25
24.5
24
23.5
23.5
24
24.5
25
25.5
26
26.5
Small radius
11/22-11/28
r=.88

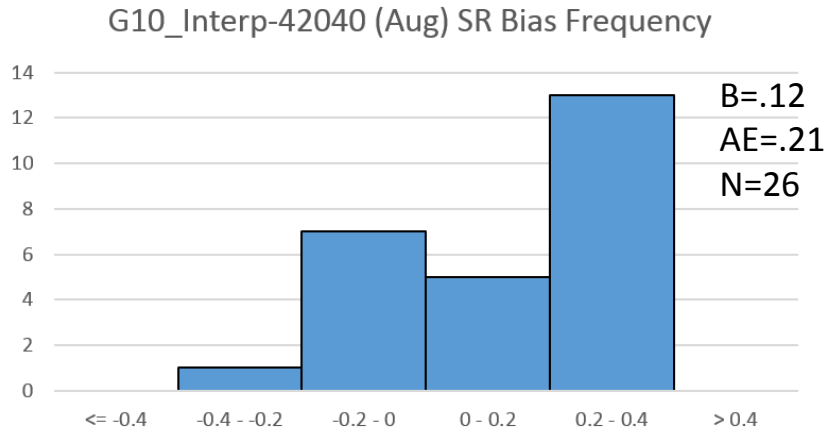

GOM1_Interp vs 42099
GOM1_Interp Water Temp (degC)
42099 Water Temp (degC)
26
25.5
25
24.5
24
23.5
23
23
23.5
24
24.5
25
25.5
26
Large radius
11/9-11/22
r=.84

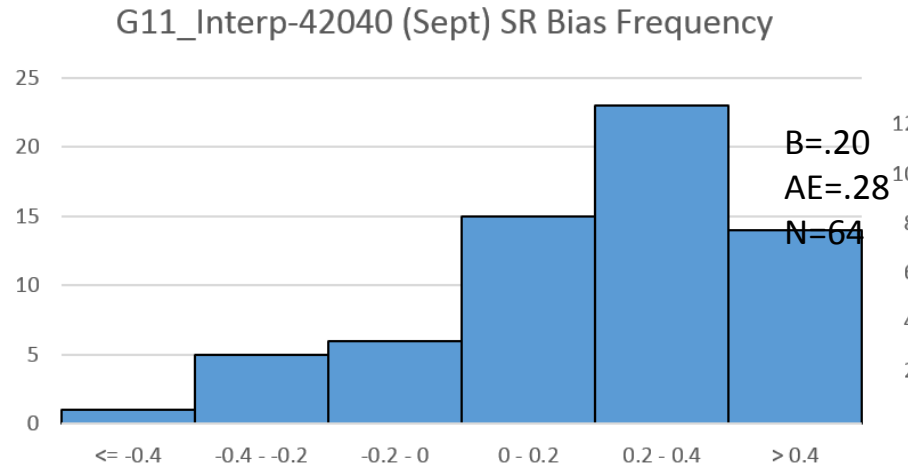

G10_Interp-42036 (Oct - Nov) LR Bias Frequency
B=.14
AE=.24
N=664
250
200
150
100
50
0
<=-0.6
-0.6 - -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
> 0.8

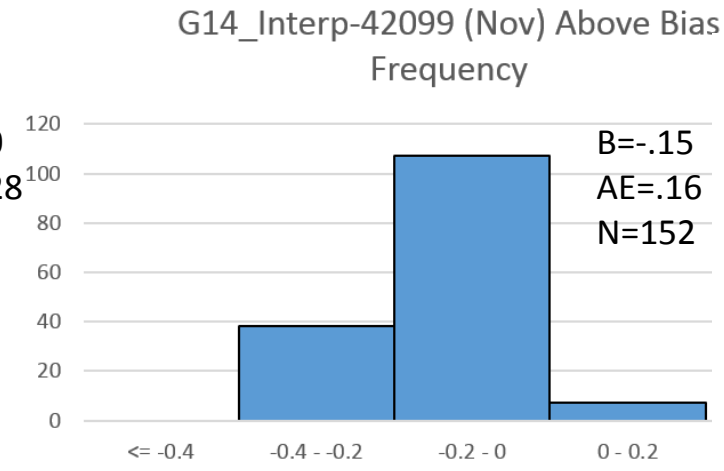

G10_Interp-42036 (Oct) SR Bias Frequency
B=.15
AE=.15
N=126
100
90
80
70
60
50
40
30
20
10
0
<= 0
0 - 0.2
0.2 - 0.4
> 0.4

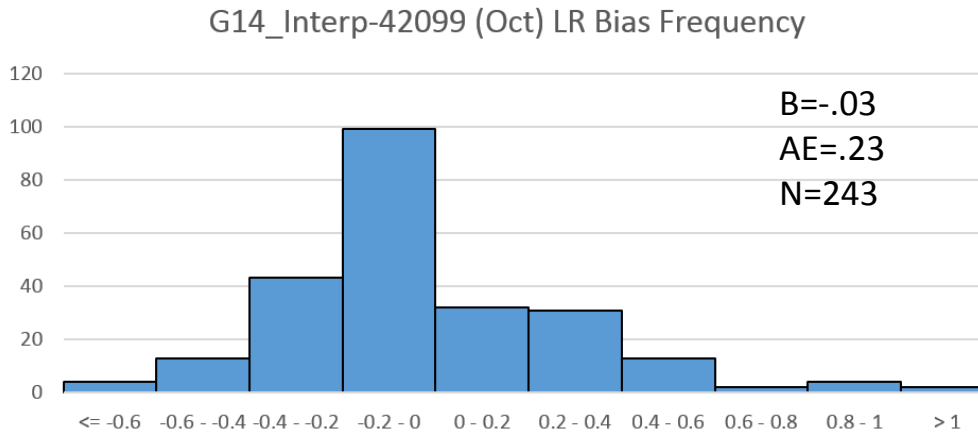

G10_Interp-42036 (Sept) SR Bias Frequency
B=.18
AE=.18
N=192
140
120
100
80
60
40
20
0
<= 0
0 - 0.2
0.2 - 0.4
> 0.4

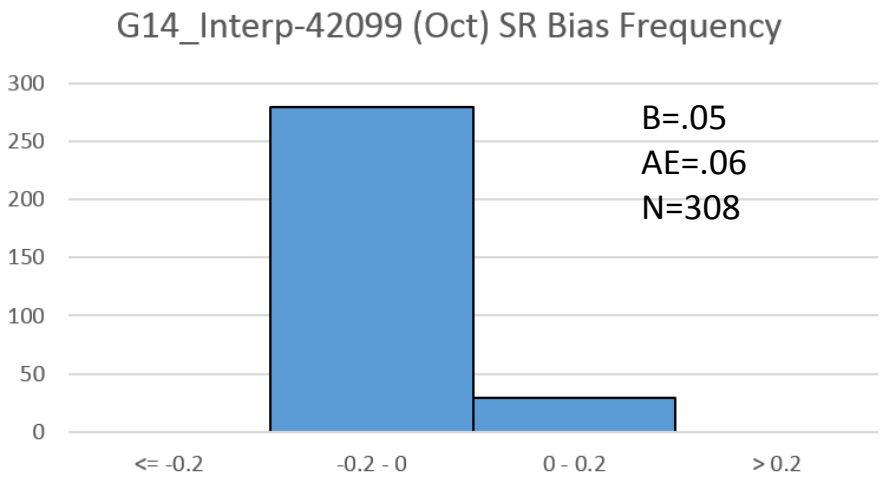

G10_Interp-42039 (Sept) SR Bias Frequency
B=.07
AE=.09
N=76
60
50
40
30
20
10
0
<= -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
> 0.4

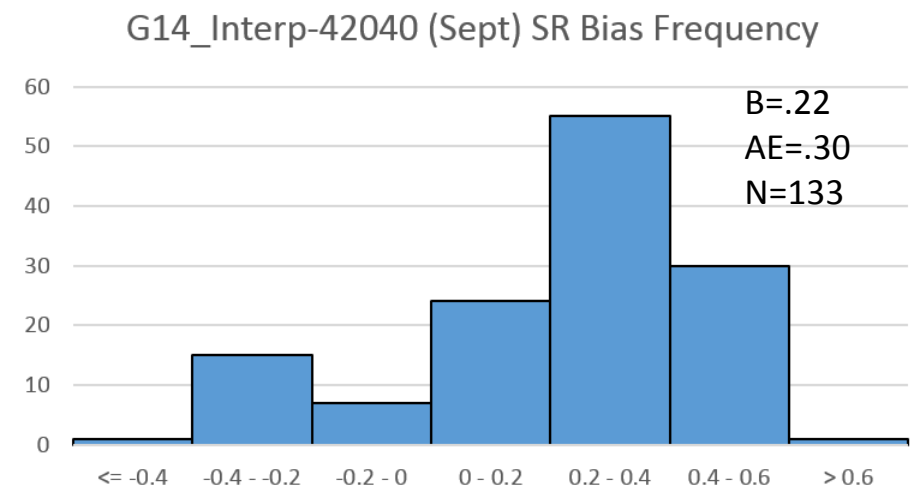

G10_Interp-42040 (Aug) SR Bias Frequency
B=.12
AE=.21
N=26
14
12
10
8
6
4
2
0
<= -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
> 0.4

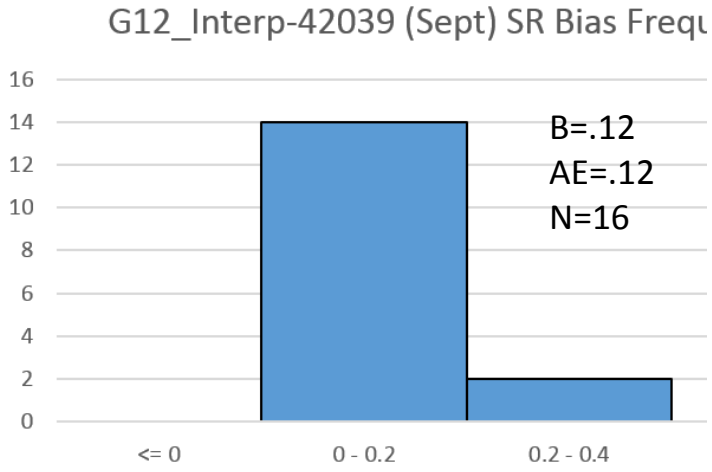

G11_Interp-42040 (Sept) SR Bias Frequency
25
20
15
10
5
0
<= -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
> 0.4
B=.20
AE=.28
N=64

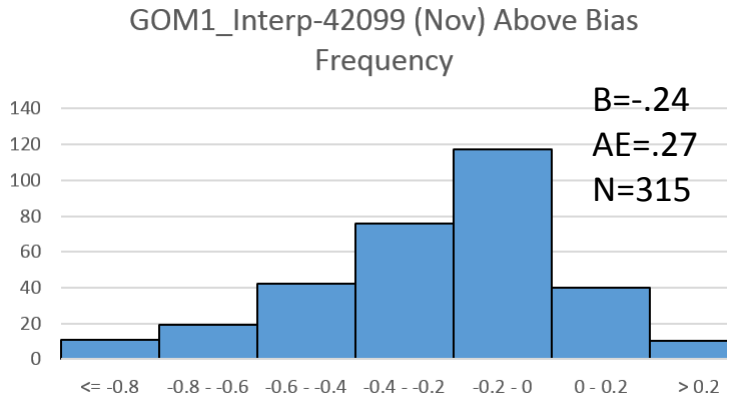

G14_Interp-42099 (Nov) Above Bias Frequency
120
100
80
60
40
20
0
<= -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
B=-.15
AE=.16
N=152

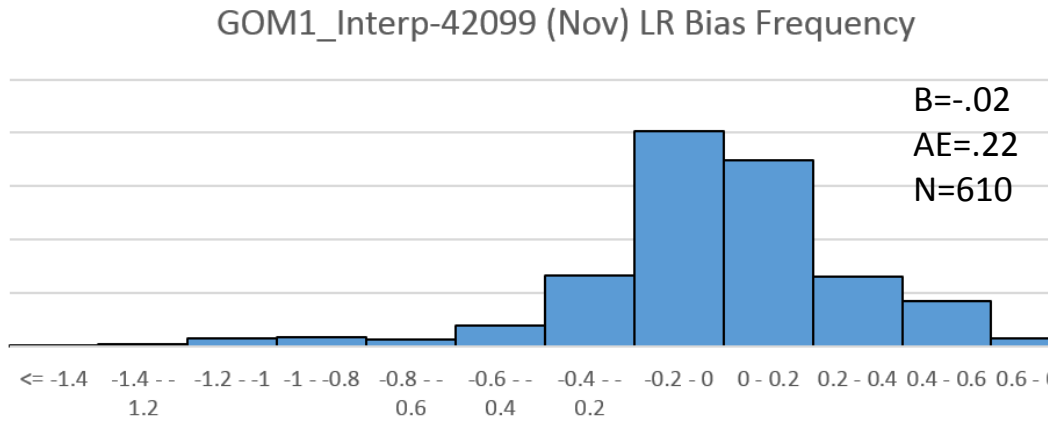

G14_Interp-42099 (Oct) LR Bias Frequency
120
100
80
60
40
20
0
<= -0.6
-0.6 - -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
> 1
B=-.03
AE=.23
N=243


G14_Interp-42099 (Oct) SR Bias Frequency
300
250
200
150
100
50
0
<= -0.2
-0.2 - 0
0 - 0.2
> 0.2
B=.05
AE=.06
N=308


G14_Interp-42040 (Sept) SR Bias Frequency
60
50
40
30
20
10
0
<= -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
> 0.6
B=.22
AE=.30
N=133


G12_Interp-42039 (Sept) SR Bias Frequ
16
14
12
10
8
6
4
2
0
B=.12
AE=.12
N=16
<= 0
0 - 0.2
0.2 - 0.4


GOM1_Interp-42099 (Nov) Above Bias Frequency
140
120
100
80
60
40
20
0
B=-.24
AE=.27
N=315
<= -0.8
-0.8 - -0.6
-0.6 - -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
> 0.2


GOM1_Interp-42099 (Nov) LR Bias Frequency
250
200
150
100
50
0
B=-.02
AE=.22
N=610
<= -1.4
-1.4 - -1.2
-1.2 - -1
-1 - -0.8
-0.8 - -0.6
-0.6 - -0.4
-0.4 - -0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6

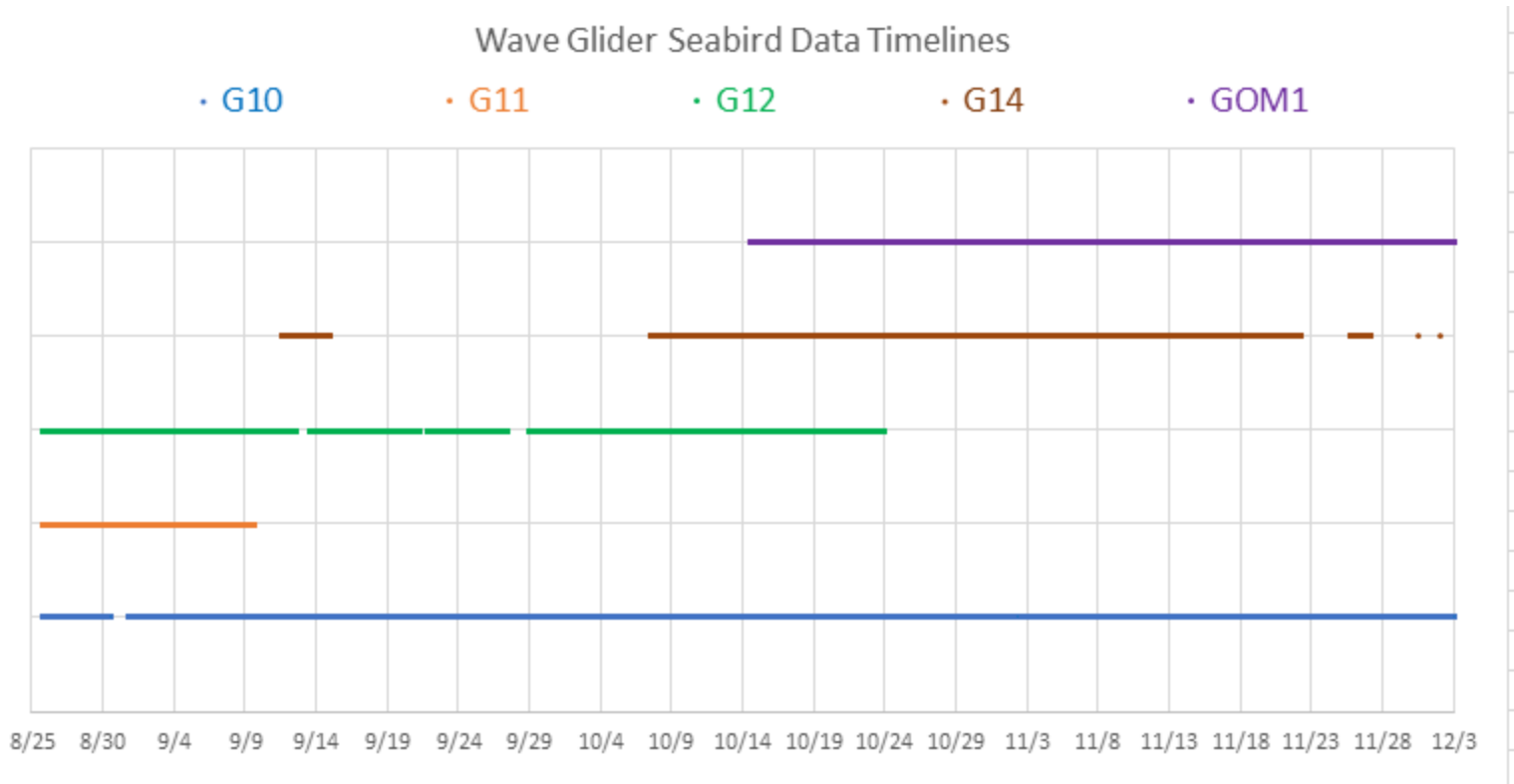
Conclusion

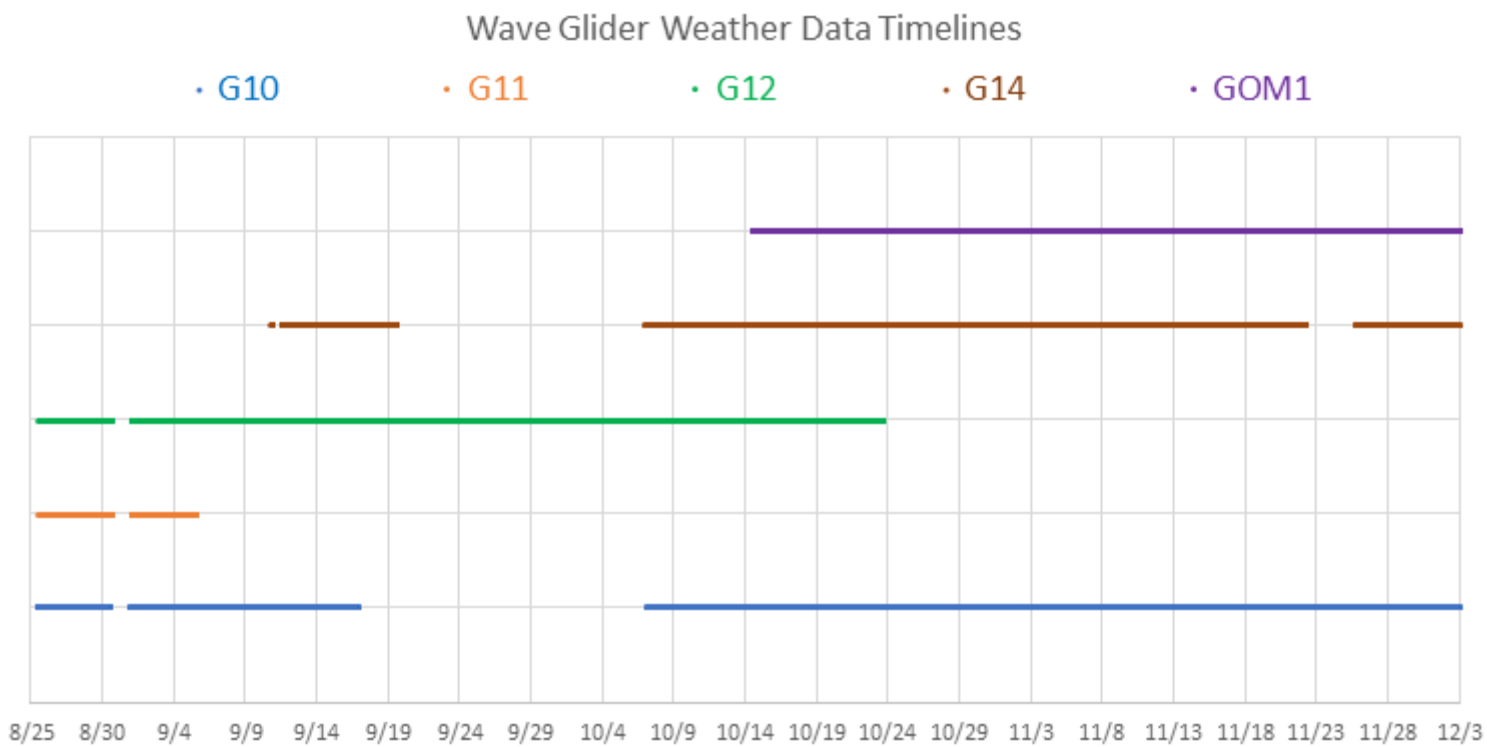
- WGs show a capacity for short–term to seasonal targeted sustained observations in data-void regions and possibly tropical cyclones.
- Demonstrated that SV2 WGs retain maneuverability in currents up to approximate 1 ms^{-1} .
- Preliminary results indicate reasonable buoy agreement with wave, pressure, and SST. Height-adjusted wind promising but have outliers that require more study. Instruments may also deteriorate with time (under study).
- Needs an improved air temperature sensor in warm season.
- Validation of WGs against each other planned.
- Surface (float), 6-m water temperature data (glider), salinity, dissolved oxygen, and ADCP will facilitate excellent mixing layer studies.
- Paper in upcoming May/June MTS journal

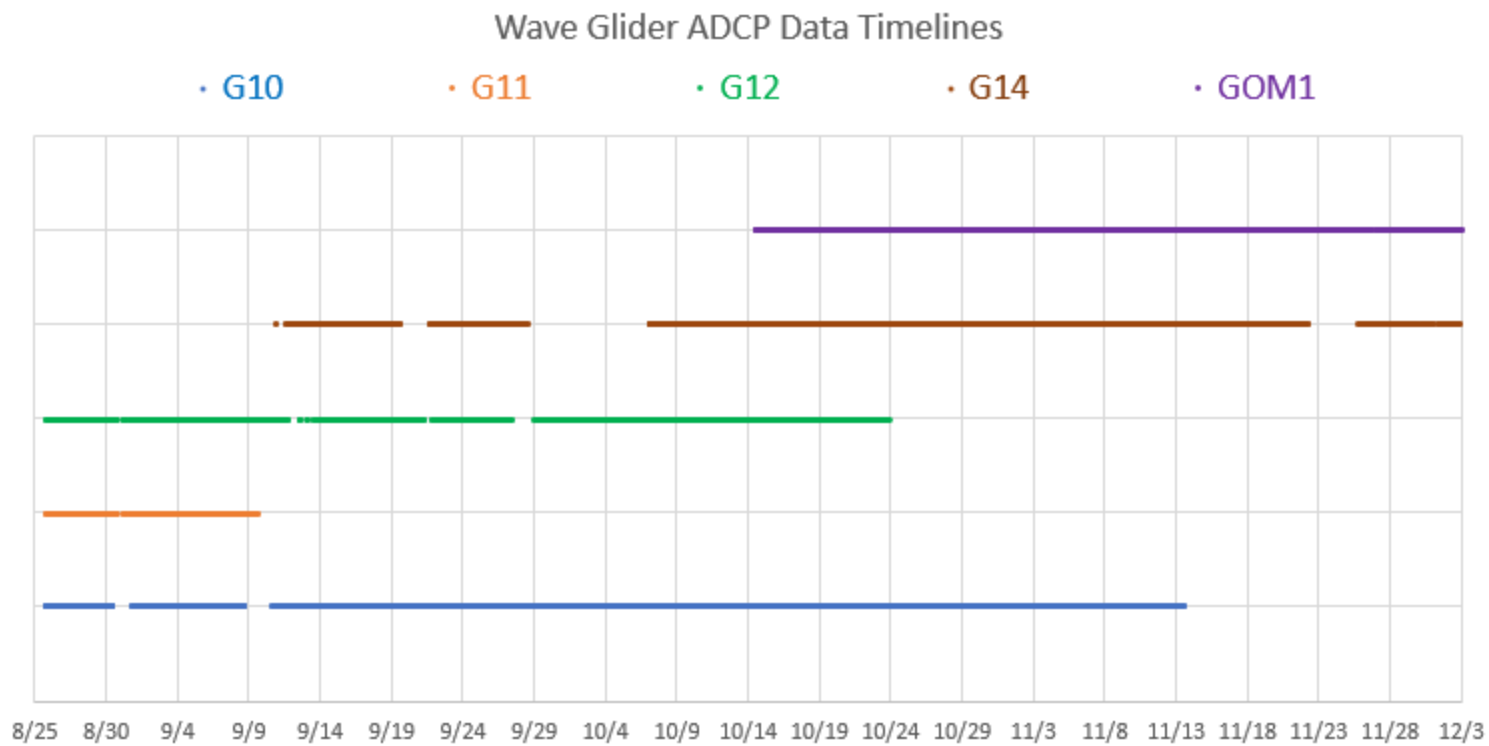
Issues

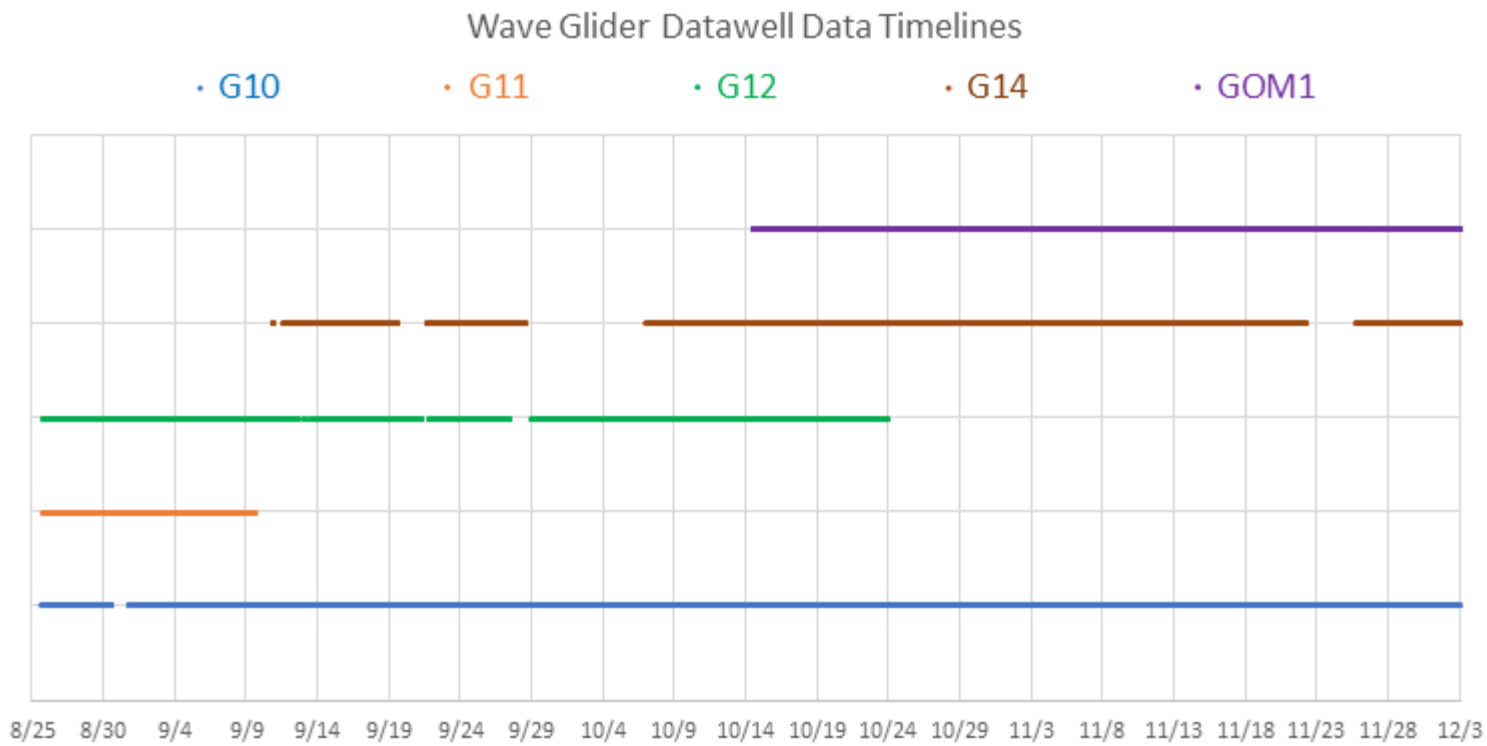
- Tampering or collisions need to be addressed by:
  - Better boater education and better signage
  - Increased distance from buoys during loitering. Buoys attract fish and fishermen.
- Require plans for international maneuvering
- Fast currents (i.e., “Loop Current”) should be examined with new SV3, which has more thrust
- Tropical cyclone intercept studies still needed to examine data viability

Bonus slides, not in main talk


Wave Glider Seabird Data Timelines
G10
G11
G12
G14
GOM1
8/25
8/30
9/4
9/9
9/14
9/19
9/24
9/29
10/4
10/9
10/14
10/19
10/24
10/29
11/3
11/8
11/13
11/18
11/23
11/28
12/3


Wave Glider Weather Data Timelines
G10
G11
G12
G14
GOM1
8/25
8/30
9/4
9/9
9/14
9/19
9/24
9/29
10/4
10/9
10/14
10/19
10/24
10/29
11/3
11/8
11/13
11/18
11/23
11/28
12/3


Wave Glider ADCP Data Timelines
G10
G11
G12
G14
GOM1
8/25
8/30
9/4
9/9
9/14
9/19
9/24
9/29
10/4
10/9
10/14
10/19
10/24
10/29
11/3
11/8
11/13
11/18
11/23
11/28
12/3


Wave Glider Datawell Data Timelines
G10
G11
G12
G14
GOM1
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