The Tropical cyclone ExperiMental Program to Enable unmanned surface SysTems (TEMPEST)

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Introduction

Unmanned Surface Vehicles (USVs) are a class of autonomous platforms, capable of collecting data from below and above the ocean surface, making them ideal for collecting observations from the marine environment. Since USVs can provide long-term, continuous observations in data-void and harsh environments, they have the potential to enhance in-situ observing capabilities in tropical cyclones with data that is at present limited. These unmanned platforms also provide an advantage of reduced risk for personnel, as well as lower operating costs than manned operations.

During the 2014 and 2015 Hurricane Seasons, a suite of USVs, specifically SV2 Wave Gliders® (WGs) leased from Liquid Robotics, and Emergency Integrated Lifesaving Lanyard (EMILY) USVs made by Hydronalix and owned by NOAA, will be deployed into Gulf of Mexico tropical cyclones for measuring surface weather data, water temperature, wave data, and ocean current profiles that are critical to understanding hurricane-ocean interactions, particularly in NOAA's future coupled atmosphere-ocean-wave models. The USVs will also loiter around buoys for data validation experiments. In the Shakespearean spirit, this exercise is known as the Tropical cyclone ExperiMental Program to Enable unmanned surface SysTems (TEMPEST).

Wave Glider® (WG)

Utilizing wave energy for propulsion (Fig. 1), this USV by Liquid Robotics (http://liquidr.com/) provides flexible environmental monitoring in the maritime environment (Fig. 2). It allows long-duration deployments with continuous real-time meteorology and oceanography data from an onboard satellite link, and have traveled more than 740,000 km in total thus far.

Figure 1. The propulsion mechanism for Wave Gliders

A WG recently traveled 14,000 km across the Pacific Ocean while transmitting data (Griffith 2013). This trek included navigation through Tropical Cyclone Freda, demonstrating capability in tropical storm conditions with 11-m waves in the South Pacific Ocean. A WG also traversed Category 5 Supertyphoon Rammasun in July 2014. Three WGs participated in the Salinity Processes in the Upper Ocean Regional Study (SPURS) field program (http://cosee.umaine.edu/coseeos/spurs/index.htm), transmitting salinity, water temperature, and atmospheric measurements for a year in a 100-km box at the mid-Atlantic's salinity maximum (Farrar 2014). WGs have been used in other scientific studies as well as commercial applications for the oil industry. All transits are monitored 24 h by an operations center including vessel detection by AIS for rerouting.
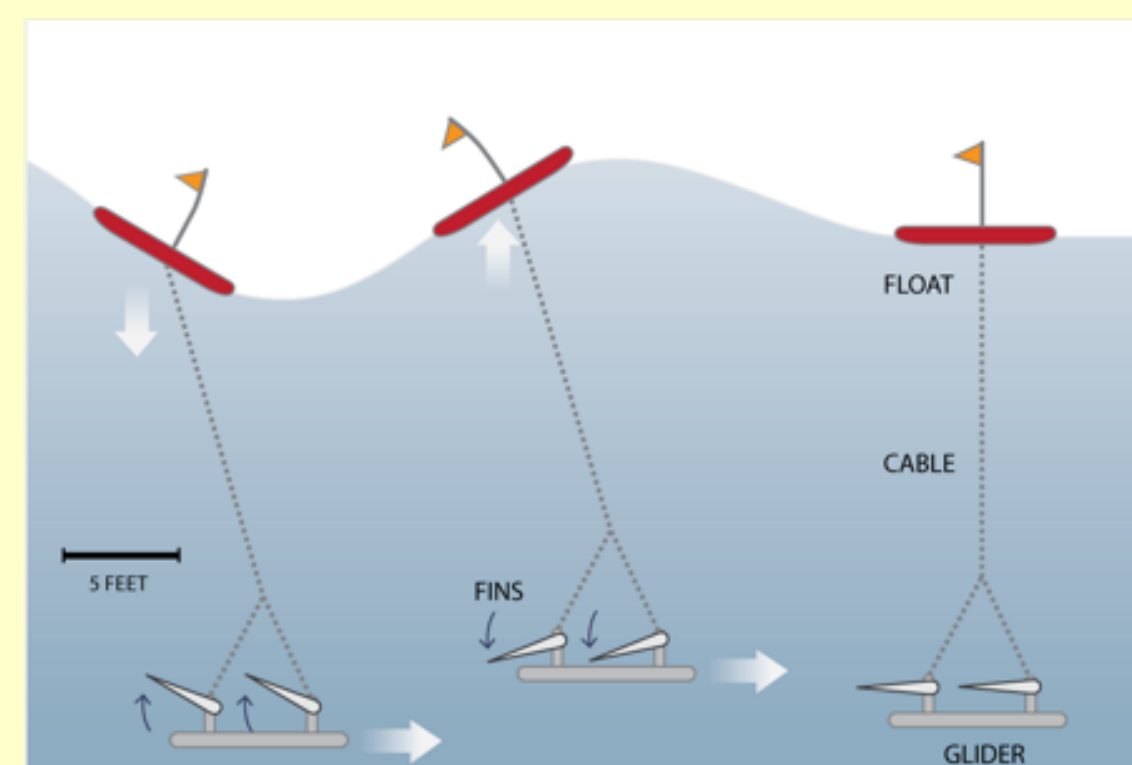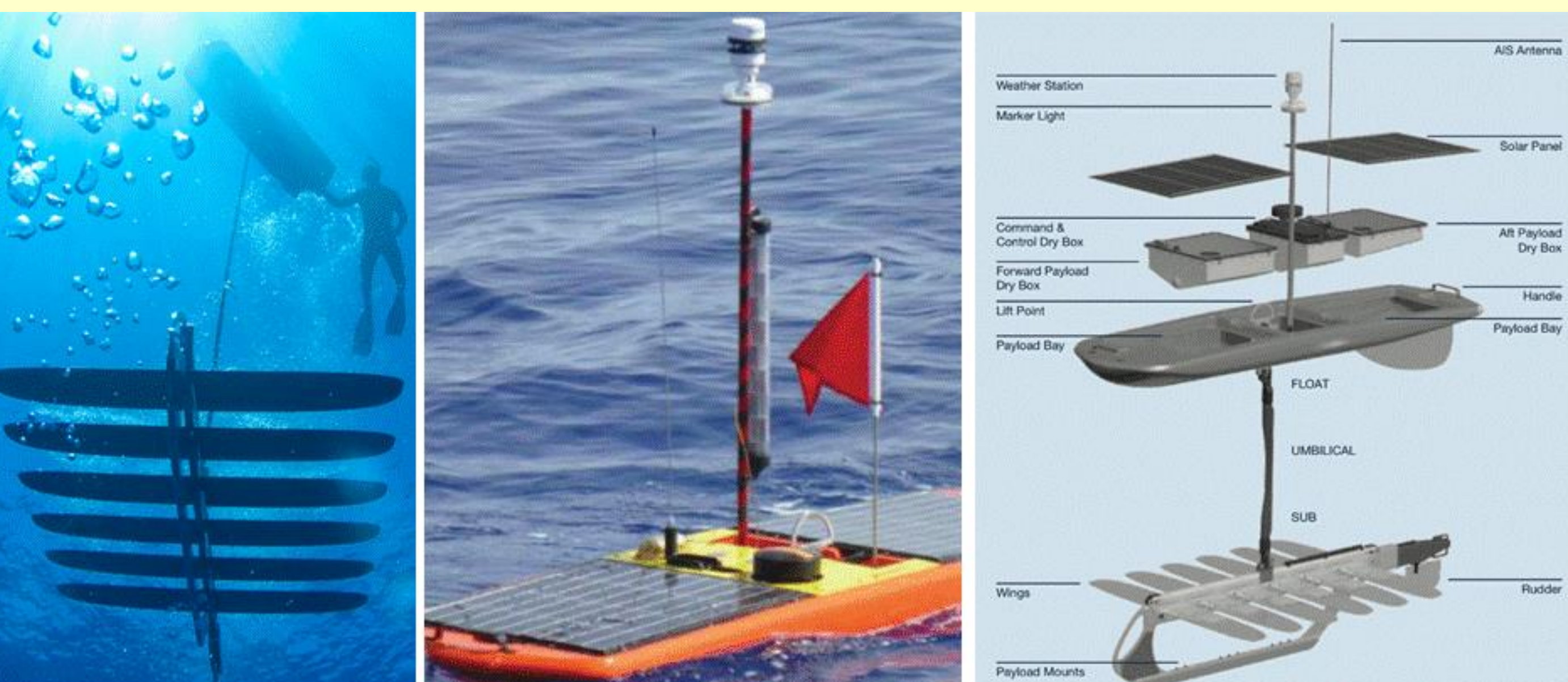

Figure 2. (Left) An underwater view of the WG subunit wings which also holds some of the oceanic payload. (Middle) View of float with atmospheric instruments. (Right) A listing of all the parts.

Emergency Integrated Lifesaving LanYard (EMILY)

Developed by Hydronalix (http://hydronalix.com) for NOAA, EMILY was built to survive severe weather environments, to be periodically immersed in water as waves break over it, and a floating design which turns upright should it flip. It is 144 cm in length and constructed from four internally sealed bulkheads for instruments, batteries, fuel tank, carburetor, jet pump, motor, water pump, drive shaft, and exhaust system.

The EMILY can communicate via short-range radio link (remote-control) or short data burst (SBD) satellite link. This USV is controlled by a CloudCap Piccolo II autopilot with a portable ground station and antenna tree – the same used in unmanned air vehicle flights. The radio link allows tests before deployment, and manual maneuvers after deployment if needed. The radio link range depends on line-of-sight and atmospheric conditions, but can range from 0.8 to 8 km. The SBD is used for out-of-range communication to send commands and retrieve data. The mission computer is a gumstix® – so named because the small system board is the size of a stick of gum. The motor is a gasoline-powered Zenoah 28cc2 two-stroke.
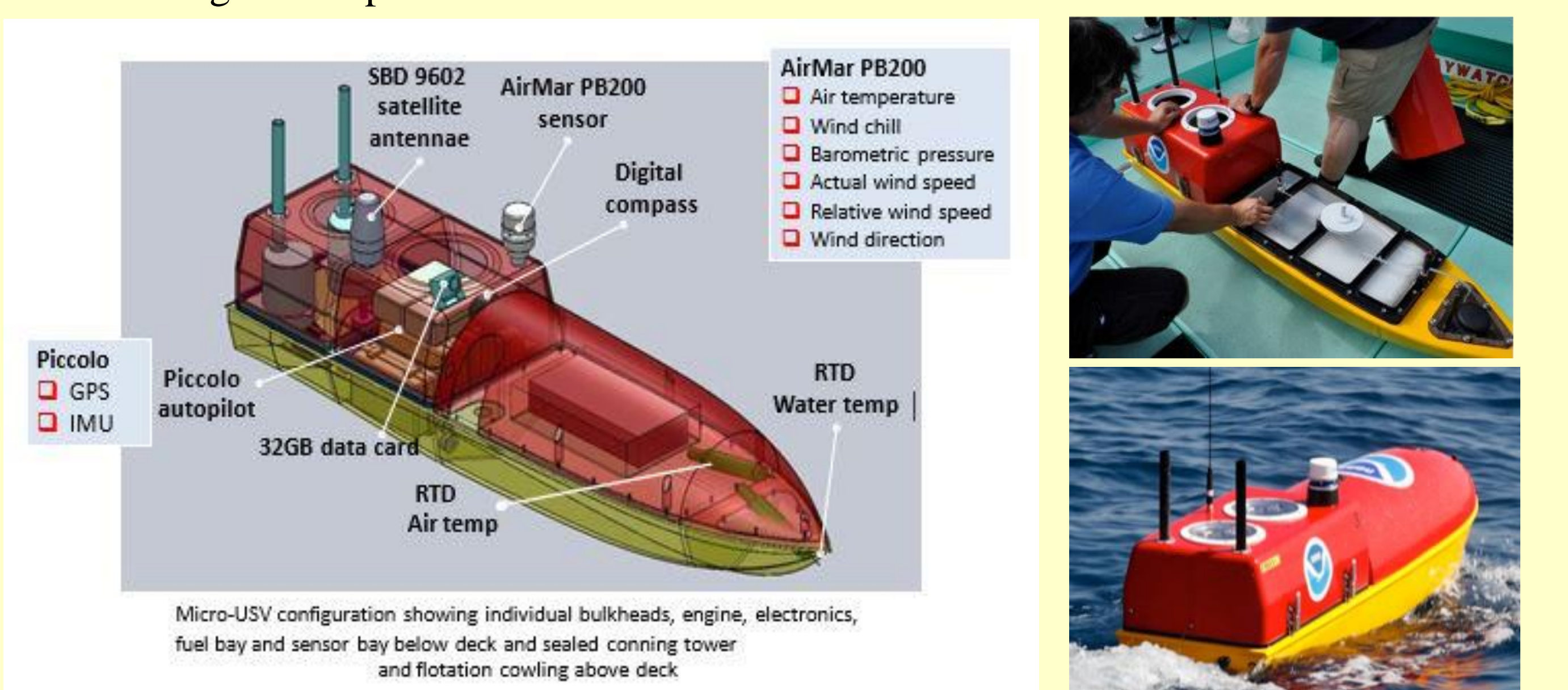

Figure 3. (Left) A listing of all external parts. (Right) View of EMILY with cowling removed (top), and an EMILY deployed (bottom)

Wave Glider deployment

Three Wave Gliders left Point Cadet Harbor in Biloxi, MS August 25, 2014, on board the research vessel Tommy Munro. The WGs were deployed 37-km offshore (Fig. 4) for a 90-day mission. Two are conducting loitering exercises at Buoy 42040, 42039, and 42036 in the northeast Gulf (Fig. 5). Another WG is loitering at a data-void region of 26°N 84°W, and may loiter near the Florida Keys CMAN PLSF1 later.
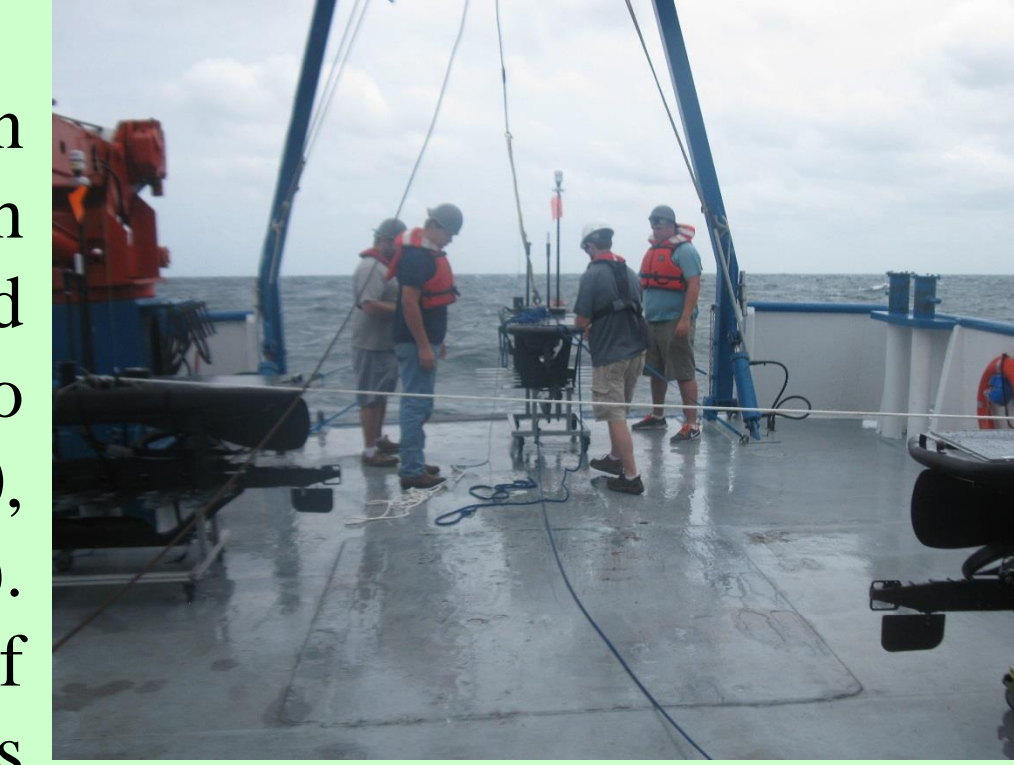

Figure 4. Deployment from the research vessel

Loitering locations are chosen from the following factors: 1) Avoidance of currents stronger than 1 ms⁻¹ which affect the WG propulsion (including the Loop Current); 2) maximum WG spread for higher probability of tropical cyclone measurements; and 3) validation versus different type of buoys and sensor heights. When a tropical cyclone enters the region, the WGs will be repositioned to intercept the storm. The typical WG translation speed range is 0.25-1 ms⁻¹ (with an average of 0.5 ms⁻¹) and is dependent on ocean currents and wave energy. So, assessing 5-7 day genesis and track probability from models and other guidance is critical. The decision-making is a joint exercise with the Liquid Robotics Operation Center, Mississippi State University (MSU), and NOAA. Liquid Robotics has provided an operational website interface (the Wave Glider Management System, or WGMS) to assist in this process. MSU is working on data dissemination to the Gulf of Mexico Coastal Ocean Observing System (GCOOS), local National Weather Service offices, and other NOAA entities.
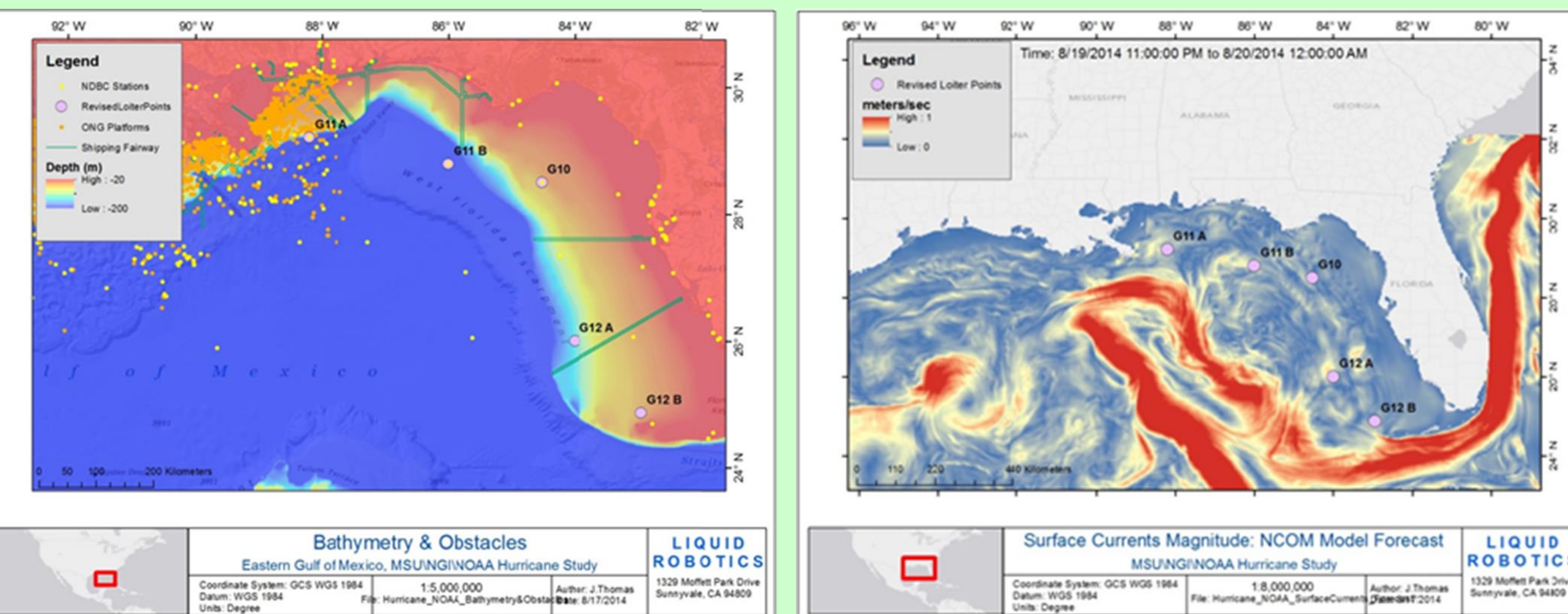

Figure 5. (Left) Location of Wave Glider loitering points relative to bathymetry, shipping fairways, and structures. Waypoint G11A is Buoy 42040, G11B is Buoy 42039, G10 is Buoy 42036, and G12B is CMAN PLSF1. G11 is 26°N 84°W. (Right) Same, but relative to the Loop Current on August 19, 2014, 11 UTC.

EMILY testing and plans for deployment

Five EMILY USVs will be deployed in the Gulf of Mexico during TEMPEST either from onshore prior to an imminent tropical cyclone landfall, or from a research vessel several days in advance of a tropical cyclone passage. Training exercises were conducted by Hydronalix for MSU and NOAA personnel in the National Data Buoy Center canal on July 28-30, 2014 (Fig. 6). An EMILY was deployed for data validation near the Shell Beach, LA, CMAN SHBL1 on August 16, 2014. Other EMILYs are currently undergoing engine testing, endurance examination, and further communication protocol practices. Plans are also underway to develop an SBD-activated Mylar balloon (developed by Near Space Corporation) for wind-assisted thrust and spiral advection into a tropical cyclone inner core – a concept already proven in the VASCO experiment for Tropical Cyclone Dora in 2007 (Duvel et al. 2009).

Figure 6. (Top) EMILY training exercise for MSU and NOAA personnel at Stennis Space Center's National Data Buoy Center canal, showing radio communication system and deployment (left), and an EMILY under propulsion (right). (Bottom) EMILY loitering near CMAN SHBL1 at Shell Beach, LA (left), and EMILYs undergoing tests in water tank at MSU (right).

Acknowledgements

Wave Glider comparison to buoys

The WGs are equipped with a Teledyne RDI 600-kHz Acoustic Doppler Current Profiler (ADCP), a Datawell MOSE-G Directional Wave Sensor, an Airmar® 200WX WeatherStation, and a Sea-Bird GPCTD with Dissolved Oxygen Sensor. Currents are provided in 1-m bins to 25 m every 30 min. The 1-m height Airmar provides wind speed and direction, gusts, pressure, and air temperature every 10 min. Wave data is provided every 30 min as significant wave height, average period, peak period, and peak direction. Wave spectra is recorded for retrieval later. The CTD provides water temperature, oxygen, and conductivity at 6-m depth every 10 min. Time intervals and ADCP bin resolution are chosen for optimum solar power availability and Iridium data transmission limits.

Figure 7 shows WG-buoy comparisons. Wind and air temperature are converted from the WG sensor height to buoy instrument height based on Monin-Obukhov theory using eddy flux parameters from Louis (1979), thermal and aerodynamic roughness equations from Smith (1988), and stability parameters from Dyer (1974) and Paulson (1970). More weather and ocean comparisons are attached as printouts to this poster.

The height-adjusted Airmar wind compares favorably to the buoys. The Airmar's air temperature is susceptible to solar radiation heating as it isn't shielded nor equipped with a fan aspirator. The WG water sensor is deeper than the buoys' and not capturing the diurnal signal, but the daily mean compares well. The WG air temperature height conversion has issues, and possibly requires estimating the skin water temperature for the flux terms. Adjustments will be developed as the dataset samples become larger.
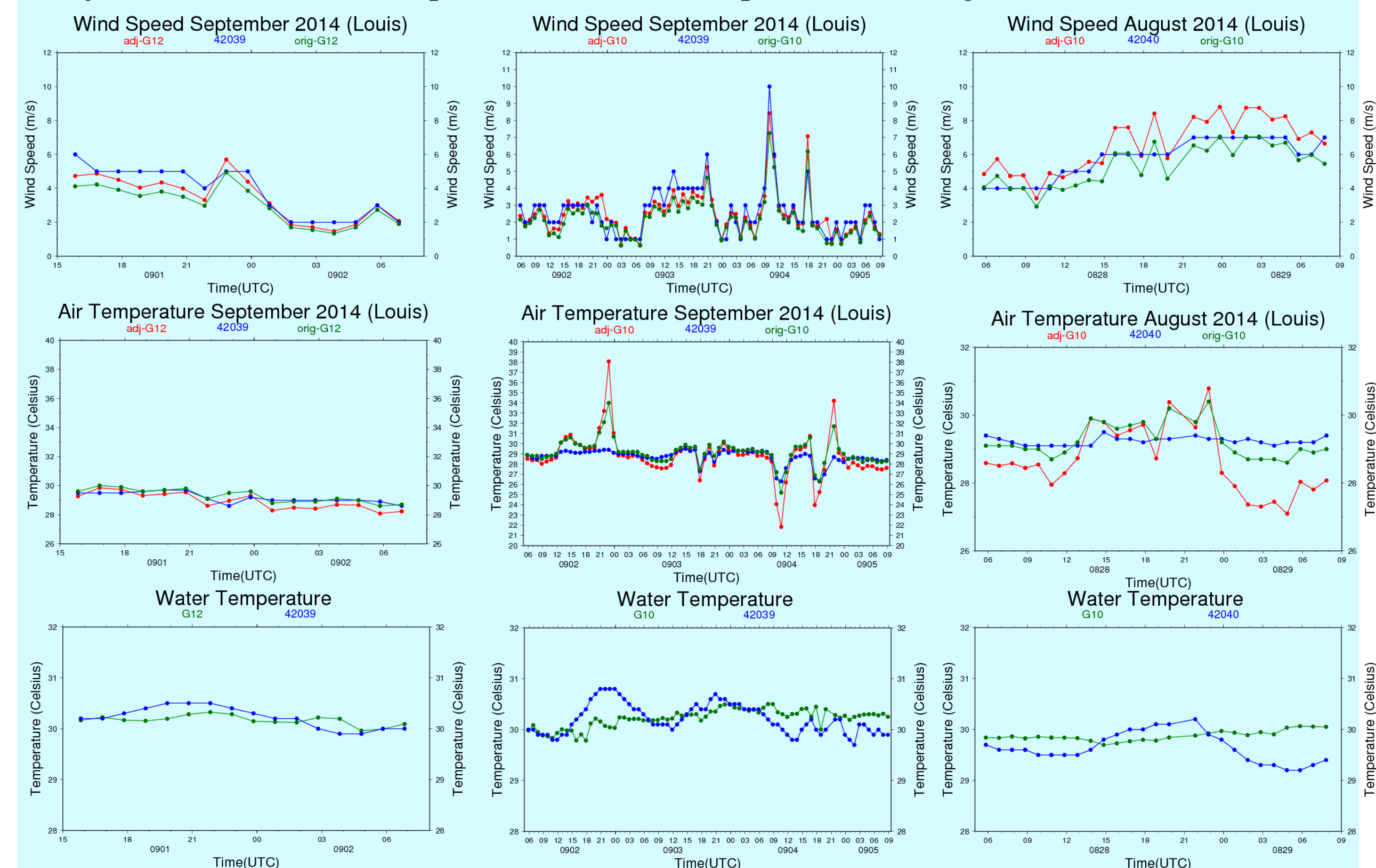

Figure 7. Validation of two WGs versus Buoys 42040 and 42039; "adj" mean the WG sensor is adjusted to the moored buoy sensor height. 42040's thermometer and anemometer height is 10 m. 42039's thermometer is at 4 m, and its anemometer is at 5 m.
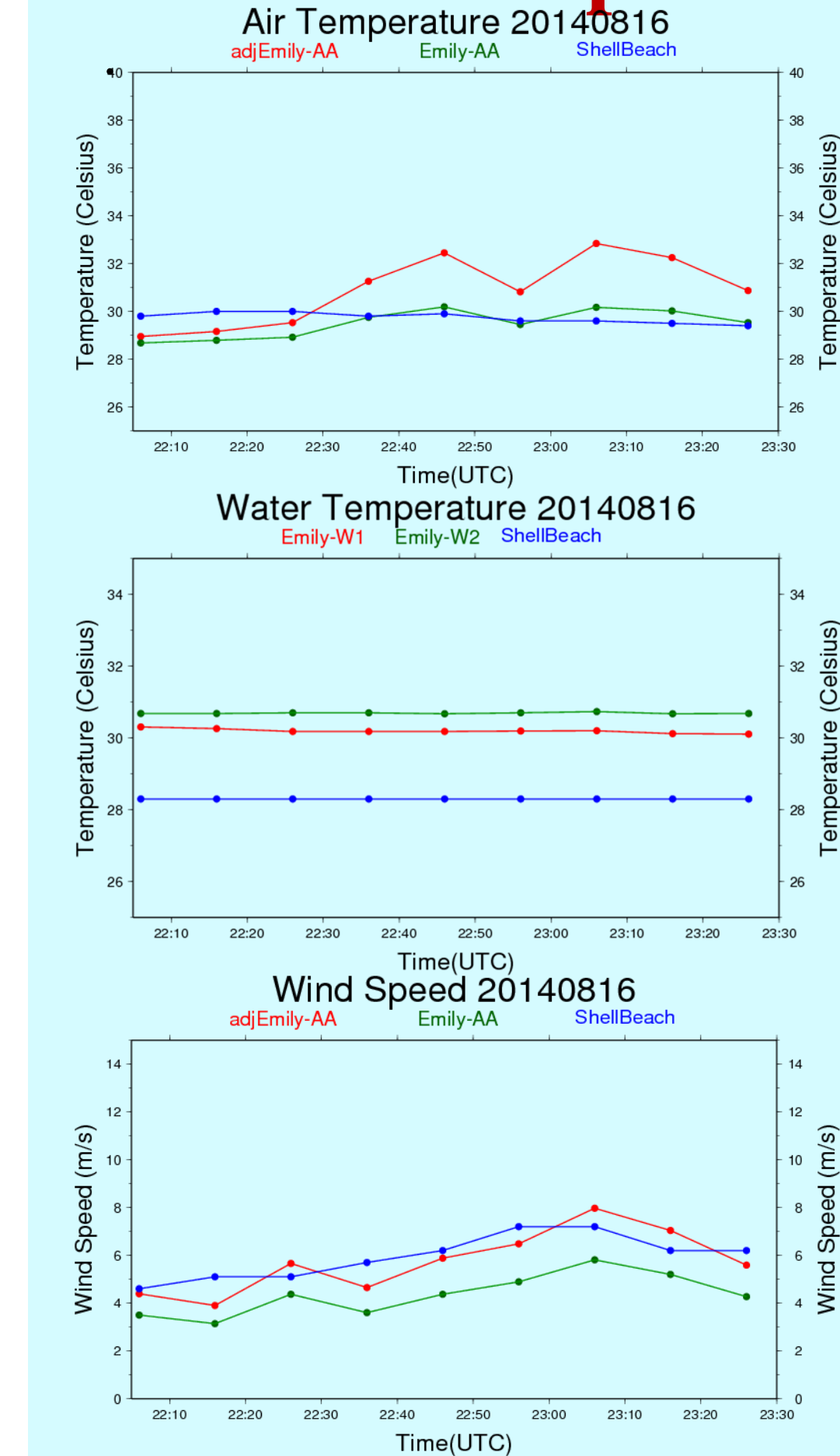
EMILY comparison to CMAN SHBL1

The EMILYs are equipped with an Airmar WeatherStation PB200 that provides the following data every 10 min at 0.37-m height: wind, gust, wind direction, pressure, and air temperature. Water temperature is measured twice using an Omega RTD temperature probe under the hull located on the front bow and off the keel line. A second air temperature is also measured using an RTD temperature probe on the front cowling. Finally, a second air pressure is measured using a RM Young probe located under the front cowling. Results from the Shell Beach deployment are shown in Fig. 8.

For this limited two-hour sample, the height-adjusted Airmar wind and RTD air temperature compares favorably to the CMAN. The CMAN's SST sensor is 1-m below the surface, and perhaps not in the daytime warm layer where both EMILY water sensors reside. The EMILY Airmar air temperature sensor possesses the same errors as the WG Airmar (not shown). Both pressure sensors match SHBL1 (not shown).

Figure 8. EMILY versus CMAN SHBL1; "adj" means the EMILY is adjusted to the CMAN thermometer height of 10 m, and to its anemometer height of 11 m.

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