Control of Tactical-Scale, Micro-Unmanned Surface Vehicles (USVs)

Ocean Observations Platforms Systems and Observations

M. Patterson, R.Marston, S.Christopher ,A. Jacobs
Hydronalix, 1691 W. Duval Commerce Court, #141
Green Valley, Arizona, 85614 USA
Mark.patterson@hydronalix.com
Rori.marston@hydronalix.com

Alexander McDonald, Justyna Nicinska and Russ Chadwick
NOAA, Office of Oceanic and Atmospheric Research
1315 East-West Highway, Silver Spring MD 20910 USA
alexander.e.macdonald@noaa.gov
Justyna.nicinska@noaa.gov

***Abstract*—As sensors, communications devices and automation becomes more capable and powerful, there is an increase in the use of unmanned systems of all types. This paper describes the development and testing of a micro-USV platform based around an initial design capability called EMILY, for three different applications; expeditionary science missions, littoral mapping exercises and new techniques to track hurricanes while continuously gathering data from within the eye. Each of these applications has different requirements and these are discussed briefly for the first two applications and in detail for the third, hurricane application.**

***Index Terms*—EMILY, micro-USV, sensors, autonomous navigation, modeling, hurricane, unmanned surface vessels**

I. Introduction

There is a growing need for man-portable, affordable, unmanned platforms to support the expanding desire to explore and respond to unknown, dangerous and often time-consuming endeavors in support of scientific, commercial and defense applications. Underwater platforms require significant investment and capability since they generally operate "blind" or with limited communications for long periods of time and are therefore subjected to unknown and often unseen threats. Ground and air platforms have seen a tremendous investment in previous years and in the case of air platforms, have matured to the level that they will be readily integrated with manned flight now that there is an improved acceptance from regulatory. Unmanned surface vessels (USVs) are a class of autonomous vehicles that can readily access ocean environments and gather data particularly in the shallow water and littorals, yet do not exhibit many of the communication issues experienced by underwater systems. As communications and sensor technologies are developed and the operating cost for controlling autonomous platforms becomes more reasonable, USVs are finding an increased number of applications in replacing existing manned capabilities as well as establishing new applications for which they are ideally suited.

This paper describes the development, and application of both mono-hull and catamaran, man portable USVs tailored as data gathering tools for a range of applications. In addition to the three different activities described herein, there are several other missions under consideration for these micro-USV platforms capitalizing on the integration and operation of sensors such as imaging sonar, hyperspectral imagery, HD video and other electromagnetic devices. Many of these platforms require tight control over their position and orientation and often require tailoring of their attributes to accomplish these missions. This paper will describe some of the development efforts, prototype testing and provide lessons learned from some of these missions.

.

II. Description of Activities

A number of activities have been carried out which rely on a range of control capabilities. In this paper three different activities will be described with respect to the level of control required and the complexity of the activity.

II.I Exploration of Lake Imja Bathymetry

In late 2010 a micro-USV was carried to Lake Imja, in the Hindu Kish Himalayan range at an altitude of approximately 16,500 feet and just 5 miles from Mount Everest. The platform was equipped with a light weight, commercial side scan sonar and used to map the lake floor in and around the end moraine, so that an improved understanding could be attained as to some of the factors that might influence Glacial Lake Outburst Floods (GLOFs) which are a constant threat to villages downstream, in this and several other regions of the world. The objective of the proposed effort was to map the lake's bathymetry and to image the lake floor using high resolution side scan sonar and to observe the glacier's tongue from above and below the waterline so as to assess the condition of the glacier and the propensity for it to behave in a stable and predictable manner. Of particular interest was the end moraine and understanding how the melt pools that were forming there were coalescing and developing to potentially weaken the end moraine, resulting in a potential GLOF[1].

The current sonar system weighs approximately 0.5kg and is mounted onto the bottom of the hull. The sonar is a commercial system called Scaline, purchased from StarFish-TriTech[2]. What makes the current system useful and specifically tailored to this type of mission however, is its integration with SeeByte's SeeTrack software[3] which georectifies the sonar data and provides a final map of the surveyed area. For small platforms of this type, SeeTrack software was mounted onto a small PC-104 computer and waterproofed. Access to the computer (and the sonar data) can be achieved through one of two USB ports or through Wi-Fi connection which allows remote access to the sonar data. Selected elements of the end moraine lake scans are shown in Figure 1 and show the track where the USV travelled and overlay the corrected sonar imagery as shown. The survey was completed but is partially shown here to better observe the process. The purpose of this initial mapping exercise was to baseline the terrain so that further surveys could determine what changes were occurring to the end moraine with time.

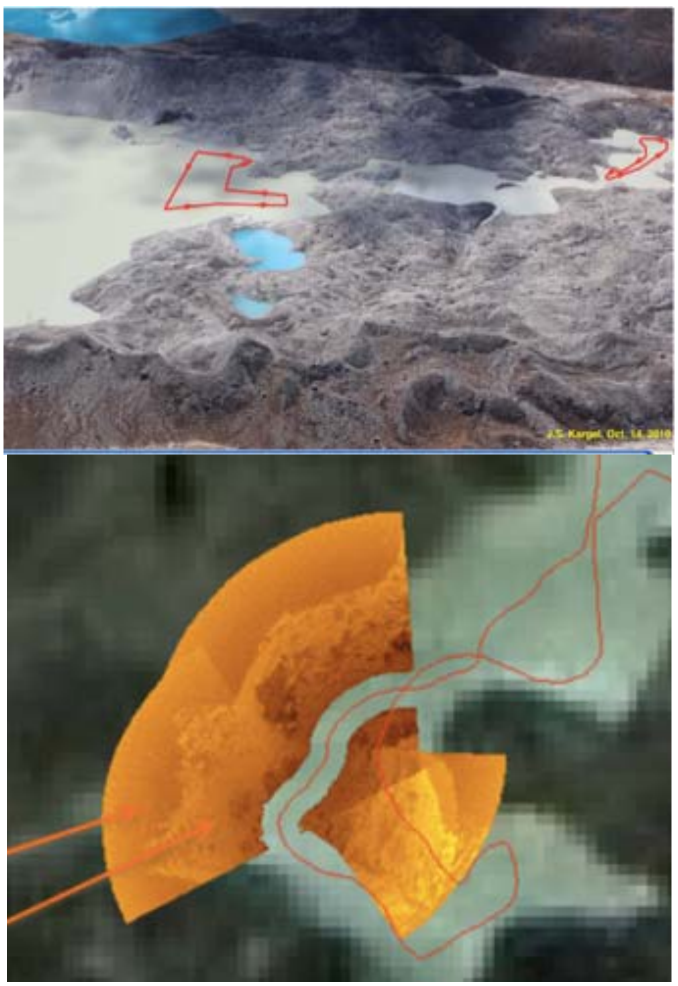

Figure 1. Image taken from the west end of Lake Imja showing the end moraine (top) and the two locations (in red) where the surveys were completed. A reconstructed side scan sonar image is shown (bottom) partially reconstructed to illustrate how SeaTrack georectifies the sonar data. Images by courtesy of Dr Jeff Kargell (University of Arizona) and Seebyte respectively.

II.2 Mapping of Littoral Waters

Catamaran configurations have been demonstrated to carry larger sensors and provide a more stable platform for imagery and other sensors. Recently a catamaran was built to carry a large electromagnetic sensor that was in turn used to map littoral regions and locate conductive articles. A simple autopilot was tuned to control the platform and execute mapping exercises over large areas >500m in size. The platform operated remotely for periods in excess of 6 hours and gave rise to the potential for these platforms to supplement manned expeditions and reduce human risk in dangerous areas. Additionally, machines have shown to exhibit improved spatial control over manned systems giving rise to a potentially improved mapping capability.

In this effort the USV catamaran was equipped with a simple Ardupilot[4] to control the vehicles positions and used simple GPS to navigate between waypoints. Figure 2 shows the catamaran during one of the survey legs and a part of a typical scan that was collected. The platform was controlled by differential thrust and had no way of determining heading other than by processing sequential GPS locations. Consequently the platform was prone to environmental influences that caused the USV to deviate from the specific vector between subsequent way-points. The survey was 620m in length and the end way-points were offset by 3m on each subsequent survey line.

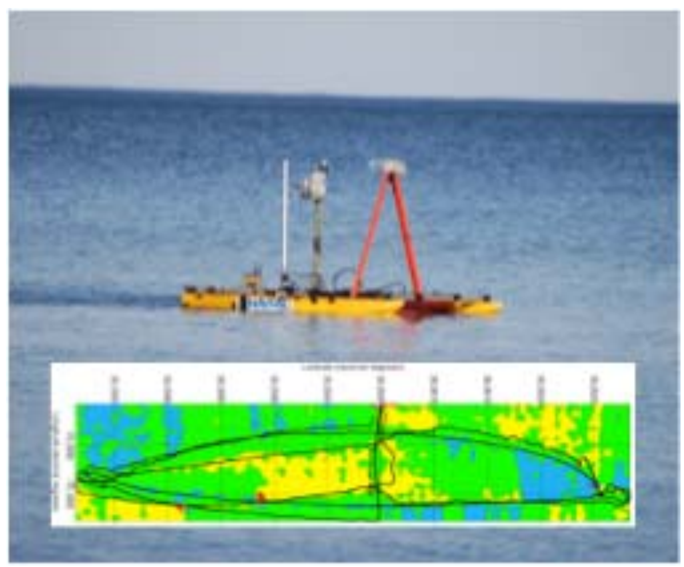

Figure 2. Autonomous catamaran platform (main) used for mapping in littoral regions. The platform was equipped with an electro-magnetic (EM) sensor and tasked to follow way-points at either end of the survey. The reconstructed EM data with just 3 the vehicle's tracks along the survey (insert) shows the deviation of the platform due to environmental influences.

II.3 Exploration and Monitoring of Hurricane Environments

The National Oceanic and Atmospheric Administration's (NOAA) plans for future research and challenges involve exploiting new technologies to better understand, monitor and predict behavior of the Earth's complex systems and determining the most cost-effective means for observing the atmosphere to support these requirements[5]. NOAA's Next Generation Strategic Plan calls for the utilization of unmanned observing platforms to support NOAA's multiple observing requirements particularly in remote regions, such as the deep oceans and the Arctic[6]. Optimization and acquisition of unmanned technologies will advance NOAA's mission goals through improved understanding of oceanic and atmospheric exchanges, hurricanes, marine ecosystems and other environmental and ecological processes leading to improved climate and weather predictions[7].

NOAA's Unmanned Aircraft Systems (UAS) program, based in the Office of Oceanic and Atmospheric Research (OAR) aims to fill exiting gaps in availability of observations between the Earth's surface and satellites. The program was established to advance UAS and sensor technologies to improve Earth observations and integrate these technologies into NOAA's observing capabilities. UAS, remotely operated aircraft, surface vessels and other platforms can fill critical data gaps where manned operations are too dangerous or remote, by collecting data in the poles, during wildfires, in sensitive habitats and during extreme weather events. The UAS program is presently focused on the NOAA mission areas of high impact oceanic weather (tropical cyclones, atmospheric rivers and Pacific winter storms), Arctic sea ice and climate change, and marine monitoring. These missions were selected due to their relevance in supporting NOAA's strategic goals, ability to provide observations that are not presently available through manned platforms and satellites, and the high risk to personnel operating in these dangerous and remote environments[8]. UAS and other unmanned platforms can provide data to complement existing observing capabilities and fill in critical data gaps. The data collected through unmanned platforms in storm environments can be utilized for extending hurricane landfall times, improving storm forecast accuracy and providing information to emergency managers and the public.

Hurricanes are one of the most economically disruptive and damaging natural disasters that impact the United States. Average U.S. insured losses are about $5.2 billion per year[9]. Hurricane Katrina in 2005, the costliest US hurricane on record and the third deadliest resulted in 1500 fatalities and $81 billion in economic damage[10]. Intensity forecast improvements over the past several decades have lagged behind progress made on hurricane track forecasts. Unexpected and rapid intensification of storms, such as Humberto in 2007 demonstrate the need for additional progress to enable emergency managers and the public with accurate and timely warnings. The goal of the proposed effort is to improve hurricane near-eyewall observing capabilities for intensity/ rapid intensity change forecasting by providing and assimilating continuous data from the eye of a tropical cyclone. This project aims to advance technology, limited at present, to collect continuous in-situ data about wind speed, air temperature, barometric pressure and sea-surface temperature in the eye of a tropical cyclone. The proposed application of the EMILY platform is to deploy it in the eye of a hurricane and successfully report back data.

Tropical cyclone intensity forecast accuracy has shown almost no improvement since 1990, and only a small improvement in skill. Global dynamical models lack resolution and description of inner core processes that influence intensity change (Rappaport et al, pp. 404-406). One of the main data gaps in tropical cyclone observations stem from the absence of in-situ data availability in the eye of a hurricane. Pressure data is presently available about 30% of the time for Atlantic systems and about 5% of the time for Pacific systems. Recently, the National Weather Service's Environmental Modeling Center began using National Hurricane Center-provided estimates of the central pressure in the data assimilation system of the Global Forecast System. Such pseudo-observations significantly improve the GFS' resulting track and intensity forecasts (Lapenta et al. 2010)[11]. Actually measured, continuous observations of central pressure have the capability for even further improvements. New observing systems and technologies need to address this critical gap in order to improve the present intensity forecast[12]. Data provided by the EMILY platform can contain a broad range of parameters, which are not available at present, and can provide insight into the eye wall structure as well as microphysical processes of tropical cyclones. The platform shown in Figure 3 is controlled by a piccolo II autopilot[13] and associated mission computer and relays environmental data, and on-board health diagnostics over an SBD satellite link[14]. The link allows the platform to operate autonomously but also provides the ability to alter the mission profile in-real time.

Figure 3. The EMILY Hurricane Tracker developed for NOAA as a platform to enter and gather persistent environmental data from within a hurricane.

The French Aeroclipper experiment (BAMS, Jan09, pp. 63-71) in the Indian Ocean showed that it is possible to deploy a lighter-than-air balloon tethered to a watercraft near a tropical cyclone and have it drawn to the center, remain there and thus provide tracking of the tropical cyclone for over a week. This arrangement provides a relatively inexpensive platform for continuously monitoring hurricane central pressure, an important element of hurricane forecasting. Aeroclipper was a scientific experiment to measure flux characteristics of the air-sea interface and was not intended to be entrained by a tropical cyclone. This raised questions whether similar unmanned platforms, capable of autonomous could be developed to monitor key parameters such as, pressure, temperature and wind at the center of a hurricane. Currently besides the Aeroclipper similar platforms capable of continuous data collection for multiple days in the eye of a tropical cyclone are very limited. The EMILY Hurricane Tracker, micro-USV is a unique research concept for improved understanding of hurricane dynamics that may be used in future designs along with an unmanned aircraft systems and gliders. In the fall of 2012 NOAA plans to conduct initial testing and development of the EMILY platform followed by targeted hurricane deployments in 2013. The present deployment concept is for surface launch with the EMILY positioned ahead of the approaching storm, and piloted to the target entrainment point by utilizing a simulation. A simple model utilized to derive the simulation is detailed below, and represents the starting point in preparation for deploying the EMILY into a tropical cyclone.

Recently the National Oceanic and Atmospheric Administration (NOAA) has invested in the development of man portable micro-USV platforms to enter and track hurricanes from within, while collecting and relaying in near real time, critical data about the physical environment that they encounter. The platform has been developed to survive severe ocean environments and is expected to continue operating for between 5 and 10 days. Wind speed, direction, wind chill, humidity, barometric pressure sea and air temperatures will be monitored and relayed through a satellite link. In addition to being powered with a gas motor, alternative approaches are being investigated to help the platform remain within the eye of the hurricane.

II.4 Ways to Enhance the Possibility of an EMILY Platform being Entrained into a Hurricane

A simple hurricane surface winds model was developed to provide a way to visualize EMILY trajectories in a hurricane environment. The surface winds are modeled by a Rankine Vortex with tangential wind speed linearly related to distance from the center of the hurricane out to the Radius of Maximum Winds (RMW). Beyond the RMW, the tangential wind speed varies as the inverse of the radius. The radial wind speed is taken as 24% of the tangential wind and is directed inward toward the center. So, the wind field is continuous everywhere, but the gradient is discontinuous at the RMW from the center. For this simulation, the RMW is 47 km (the average for Atlantic hurricanes) and the maximum tangential wind is 40 m/s (category 1) and CCW (rotation for northern hemisphere). The hurricane is assumed moving northward at 4m/s over the 6 day simulation period. This simple model neglects several important things. First, there is assumed to be no surface current and no sea state. Second, hurricane dynamics (other than simple translation) are not considered. Third, the wind is assumed independent of azimuth from the hurricane center; only radial variation of wind is considered. In an operational scenario these would be considered, but are beyond the conceptual study presented here.

Consider the case of an EMILY with motor forward speed of 1 m/s and with a large sail that moves the EMILY in the direction of the wind at 82% of the wind speed. This case, while probably unrealistic, does clearly show in Figure 4 how EMILY can be entrained into a hurricane. This figure shows the EMILY position referenced to the center of the hurricane, i.e. imagine that the observer is located above the center of the hurricane for the entire mission. Entrainment occurs after about 5 days and then EMILY is located in the SE quadrant of the hurricane about 4 km from the center and proceeding North at 4 m/s exactly matching the hurricane movement. The purpose here is to investigate:

1) the possibility of using a smaller sail that can be deployed at any time during the mission; and
2) controlling the EMILY motor speed during the mission to increase the chance of entrainment.

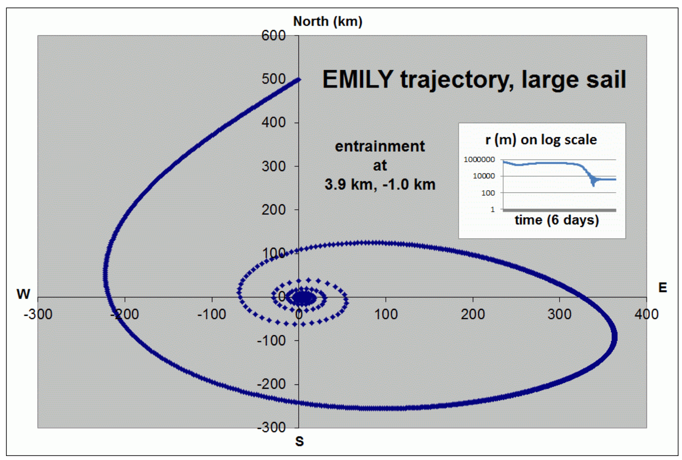

Figure 4. EMILY trajectory, with large sail deployed for entire mission, showing hurricane entrainment after 5 days.

Figure 5 shows the EMILY trajectory when fitted with a more realistic sail than the large sail used above. In this case, the sail will cause the EMILY to follow the wind direction with a speed of 9% of the wind speed, in addition to the 1 m/s speed imparted by the EMILY motor. The reduction in sail size causes a large change from that shown in Figure 4. The EMILY is not entrained and the trajectory never lies inside of the RMW, so it would be impossible to become entrained in the hurricane.

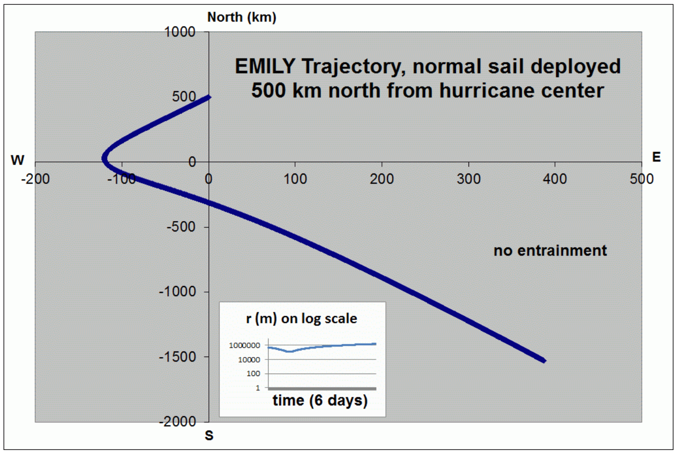

Figure 5. EMILY trajectory, with normal sail deployed for entire mission, showing no entrainment into hurricane and distance from center continuing to increase after 6 days. The inset shows that the closest approach to center was about 100 km, well outside of the RMW of 47 km.

One way to increase the chances for entrainment would be to drive the EMILY so that it goes inside the RMW and then deploy the sail. While not guaranteeing entrainment, this would increase the chances. So, the strategy is to drive the EMILY toward the center of the hurricane without having a sail deployed and then deploy the sail near the point of closest approach to the center. After sail deployment, the EMILY naturally is steered in the direction of the wind. Throughout the mission, the EMILY motor operates at a single speed that would move EMILY forward at 1 m/s and this speed adds to that developed by the sail. The EMILY trajectory for this case is shown in Figure 6 below.

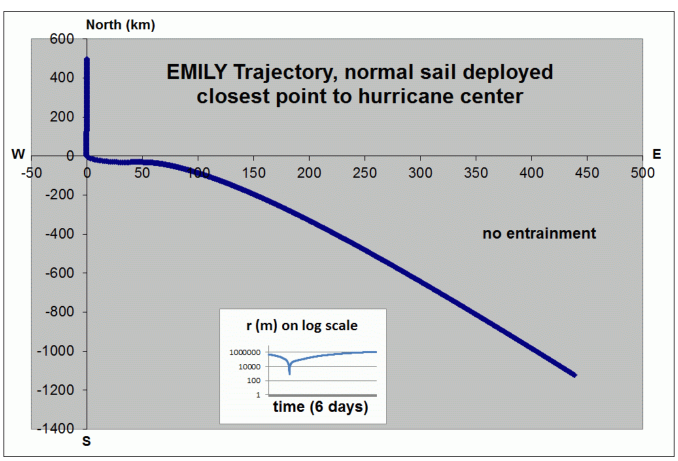

Figure 6. EMILY trajectory, with normal sail deployed when EMILY is closest to the hurricane center. As in previous Figure 5, this shows no entrainment into the hurricane, but now the EMILY comes within the RMW of 47 km as shown by the inset.

Note that when EMILY is about 50 km east of the center, there is a slight movement to the north, indicating that the sail is starting to pull EMILY to the north and the total speed is greater than the 4 m/s speed of the hurricane. However, at just about this same time, the EMILY goes outward through the RMW into the region of decreasing winds as radius increased. Then the pull of the sail starts to decrease and EMILY is beyond the region where she can be entrained. Figure 6 shows that EMILY is close to being entrained, but needs more exposure to the hurricane winds in the top of the SE quadrant. This can be done by increasing the EMILY motor speed in the SE quadrant when the wind has a north component. Specifically, the EMILY motor speed will be increased from 1 m/s to 2 m/s whenever Emily is within the 270° to 345° sector of the SE quadrant of the hurricane. Everything else remains as it was for the previous case, shown in Figure 6.

The results of using a sail deployed near the center and using higher motor speed in the SE quadrant are shown in Figure 7 where EMILY is entrained in the hurricane after about 1.5 days, Note that this is significantly faster than the 5 days it took to entrain EMILY and large sail of Figure 4. Also note that the motor is run at the higher speed for only a relatively short time and that once EMILY is in the 345° to 360° sector of the SE quadrant, the higher motor speed is not required to attain entrainment.

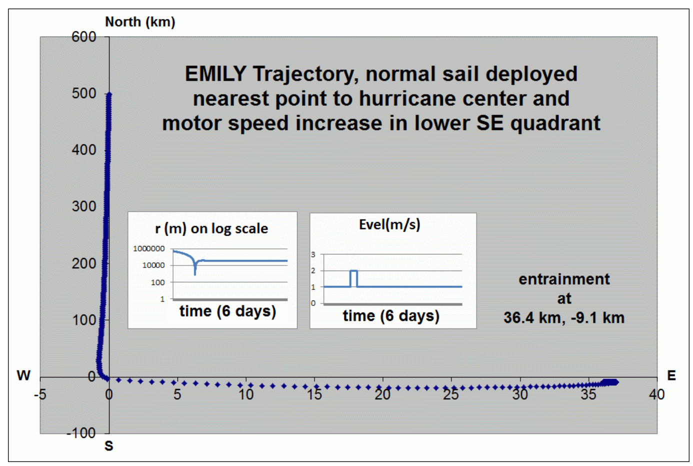

Figure 7. EMILY trajectory, with normal sail deployed when EMILY is closest to the hurricane center and motor speed increased when EMILY is in the 345° to 360° sector of the SE quadrant. Entrainment occurs after about 1.5 days as shown by the left inset where radius from the center takes on a constant value. The right inset shows the EMILY speed provided by the motor where the higher speed is needed to get close to entrainment, but not needed to remain entrained.

III. Summary

In conclusion, this paper describes how unmanned surface platforms, such the EMILY USV can be utilized to fill a variety of observing requirements, specifically for collecting data that is either dangerous, monotonous or otherwise unavailable on a continuous basis in extreme environments. Different levels of autonomy and capability have been briefly described, emphasizing a specific capability. The micro-USV equipped with a side scan sonar has been shown to be truly expeditionary, yet when equipped with sophisticated data processing software can be used to generate bathymetry and georectified underwater imagery in the most hostile of environments. The EMILY micro-USV platform is commercially available for first responders to support in situations where swimmers are in distress in surf, rip currents or swift water. When equipped with small sensor systems such as a camera or sonar this platform becomes an intelligence, surveillance and reconnaissance platform for first responders or scientists alike. Two such micro-USV platforms can be combined to form an autonomous catamaran platform for transporting large sensitive sensors, and with a low-cost rudimentary autopilot used to map littoral zones. Environmental influences on these micro-USV platforms however are significant and must be overcome. Finally, the most sophisticated platform described provides an initial strategy for long-term tracking of tropical cyclones[15]. The simple model described in this study represents an initial step towards the development of a deployment and entrainment strategy, which will be tested and applied in the field during the fall of 2012 and in 2013. The aim of this research program is to optimize autonomous platforms for filling critical missions, which are too dangerous to be conducted by manned platforms[16]. The data collected continuously by the EMILY will be utilized towards expanding current understanding of the rapid intensity change of hurricanes.

ACKNOWLEDGMENT

The authors wish to thank NOAA who partially funding this effort under contract # RA133R-11-CN-0188 and to the U.S. Navy who partially funded this work through contract # DAAH01-02-C-R190/ W31P4Q-06-C-R190/ W31P4Q-10-C-R190. We would also like to thank Dr Jeff Kargel (University of Arizona) who helped fund this work through the GLIMS program, Seebyte (Scotland), Heavy Fuels Engineering (Tucson), Battelfield Engineering (Canada) who provided technical support and hardware to accompany some of these efforts, and to James Fink, Geophysicist/consultant Tucson.

REFERENCES

[1] M.C.L.Patterson, J.Kargel, G.Leonard, R.Furfaro and W.Fink, "Current Technologies to Better Assess and Monitor Potential Glacial Hazards". Int. **!Unexpected End of Formula**. Benefiting from Earth Observations: Bridging the data gap for Adaptation to Climate Change in the Hindu Kush-Himalayan Regions. Kathmandu, Nepal, 4 – 6 Oct 2010

[2] www.starfishsonar.com

[3] www.seebyte.com

[4] http://code.google.com/p/ardupilot-mega/wiki/APM2board

[5] From "Framing NOAA's Future Research" and the NOAA Research 5-yr plan

[6] www.noaa.gov/ngsp, pp. 26-27

[7] http://uas.noaa.gov/

[8] See http://uas.noaa.gov/

[9] http://economics.noaa.gov/?goal=weather&file=events/hurricane

[10] Blake, E.S., E.N. Rappaport, and C.W. Landsea (2008): The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2006 (and other frequently requested hurricane facts). Tech Memo. NWS TPC-5, NOAA, U.S. Department of Commerce, 43pp.

[11] This reference is his presentation at the Interdepartmental Hurricane Conference (slide 14) http://www.ofcm.gov/ihc10/Presentations/Session07/s07-02ihc64_lapenta_final.ppt

[12] Rappaport, Edward N., et al. (April 2009) 'Advances and Challenges at the National Hurricane Center', *Weather and Forecasting*, Vol. 24, pp. 395-419.

[13] www.cloudcaptech.com/piccolo_II.shtm

[14] www.iridium.com/products/Iridium9601.aspx

[15] http://mobile.nationaljournal.com/tech/new-tool-for-hurricane-trackers-drones-20120828

[16] www.popsci.com/category/category-badges/feature.