Eyes on the Ocean

Applying Operational Technology to Enable Science

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Abstract **- A revolution in ocean observations is taking place in the world's oceans. The National Data Buoy Center (NDBC), which is in the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) and located on Mississippi's Gulf Coast, is deploying an increasingly sophisticated and comprehensive operational ability to "see" and report back in real time what is happening in remote locations of the open, deep ocean, such as the equatorial Pacific Ocean, as well as in more near shore areas off the coastline of the United States (U.S.).**

The NDBC operates and maintains a network of more than 200 moored buoys deployed in areas near the shore of the United States coastline, off the coasts of Alaska and Hawaii, and across the entire Pacific Ocean from the Americas to the far Western Pacific. The buoys, outfitted with meteorological and ocean sensors, transmit observations hourly or more frequently, if necessary, for use by NOAA and others, including the public, for marine forecasts and warnings, ocean research, and real-time information of the marine environmental conditions.

Over time, human interference has caused catastrophic damage to buoys, resulting in loss of the observations and, in many cases, total loss of the equipment. For these reasons, buoy vandalism became the primary driver for the NDBC to develop and install a capability to improve awareness around the buoys and proactively counter human interference with buoys and moorings. Buoy vandalism is a significant challenge for the NDBC and other organizations who maintain operational ocean observing platforms, especially for those platforms deployed in remote areas of the ocean. Over the past two years, the NDBC has employed worldwide ship tracking tools such as the Automated Ship Identification System (AIS) that provide situational awareness of vessels operating near NOAA's operational buoys, and installed a real-time, reporting camera systems - *BuoyCAMs* - to provide clear, panoramic views of the environment and human activity such as fishing in remote ocean areas. Additionally, NDBC has improved the capabilities of its twenty-four-seven Mission Control Center (MCC) in monitoring, observing and recording the environment and activities around NDBC moorings.

The NDBC is actively working to increase the capabilities of the *BuoyCAM* system beyond the initial, prototype deployments. Currently, the NDBC is integrating an AIS receiver into the *BuoyCAM* system and increasing the two-way communications between the *BuoyCAM* and shore facilities that enables remote reconfigurations of the *BuoyCAM* system. Additionally, power system design enhancements are being incorporated to increase image frequency and operational longevity between battery exchanges, and enhancements to the metadata associated with each image, previously a date and time stamp, now include image location, position, and view headings.

These new and exciting technical capabilities are revealing unanticipated benefits and applications that provide "eyes on the ocean". The unique ability to see images of ocean waves and surface current, fog, and sky cover, of ship traffic, and of fishing activities and wildlife, and monitor station equipment and resources in the remote, open ocean and around the coastline, to researchers, forecasters, government agencies, and the public. The result promises significant expansion in maritime domain awareness and environmental intelligence.

I. BACKGROUND

The NDBC, located at the Stennis Space Center (SSC) near the Mississippi Gulf Coast, is in the Office of Observations in NOAA's NWS. Our primary mission is to provide marine meteorological, oceanographic, and geophysical observations accurately and in real-time to assist warning centers, marine forecasters, climate researchers, the U.S. Coast Guard, ocean platform operators, and the public in making sound decisions to safely operate in the marine environment.

The NDBC maintains and operates a global network of 250 ocean observing platforms. The "Weather Buoys" are moored in the coastal and offshore waters from the Western Atlantic to the Pacific Ocean around Hawaii, from the Bering Sea to the South Pacific, and in the Great Lakes of the U.S. The Coastal-Marine Automated Network (C-MAN) stations are installed on lighthouses, at capes and beaches, on near-shore islands, and on offshore platforms around the U.S coasts, Great Lakes, and southeastern Alaska. The NDBC operates and maintains the Equatorial Pacific climate observation system, the Tropical Atmosphere Ocean (TAO) array, designed for the study of year-to-year climatic variations related to El Niño and the Southern Oscillation (ENSO). The array consists of fifty-five (55) moored ocean buoys and four Acoustic Doppler Current Profilers (ADCP) in the equatorial Pacific, extending from 9° N to 8° S latitude and 95° W to 165° E longitude. The NDBC also operates and maintains thirty-nine (39) Deep-ocean Assessment and Reporting of Tsunami (DART) systems

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around the ring of fire in the Pacific Ocean, in the Caribbean Sea and Atlantic Ocean, and in the Gulf of Mexico.

NDBC's MCC provides full-spectrum quality services for millions of real-time observations. NDBC's MCC supports the collection, quality control, and distribution of these observations in real-time to the World Meteorological Organization's Global Telecommunications System and to the World Wide Web for more than 700 platforms - those operated by NDBC, as well as platforms operated by "partners" including NOAA's U.S. Integrated Ocean Observing System data providers and others.

II. Operational Ocean Observing Networks

Maintenance of a functioning network of instrumentation in the open ocean presents many challenges. Organizations like the NDBC face extreme variations of the actual environment, which means preparing instruments and platforms for everything from the tropical nature of the equator to the extreme cold and ice of the Great Lakes of the U.S. and the Alaska region. Logistics and transportation are another challenge for any organization but unique to organizations that operate buoys at distances far from shipping ports. Of course, there is a wild card - buoy vandalism - the great destroyer of buoy operational availability.

The NDBC and ocean observing platform operators around the globe are challenged by human interference, to include unintentional ship collision, the use of the buoy and its mooring as a fish attracting device, and malicious vandalism, of their moored buoys and other offshore platforms that, in most cases, damages the platforms to the point of failure. Damage and destruction of the TAO buoys in the tropical Pacific has been a particular costly problem in the ten years since the NDBC took over operation of the array. Evidence found during regular maintenance cruises included indications of ships tying onto the buoys, of fastening fishing equipment to the buoy structure and mooring line and, sometimes, removing sensors, batteries, and even the metal structure off the buoys.

The NDBC initiated a counter-vandalism program in 2011 to address and mitigate human-caused damage, particularly to the TAO buoys. Over the past two years, the NDBC employed worldwide ship tracking tools, including a vessel AIS to provide situational awareness of vessels operating near NDBC buoys, installed real-time reporting *BuoyCAMs* to provide panoramic views of the environment and of human activity such as fishing in remote ocean areas, and improved the capabilities and capacity of its 24/7/365 MCC to monitor the environment and activities around NDBC's stations. All of these capabilities greatly improved our awareness of the environment around our moorings - particularly of ship traffic and fishing activity around the TAO array.

III. Buoy Vandalism

Buoy vandalism prompted the transformation of the NDBC's MCC from a data quality control activity that studied post-deployment analysis on vandalism to an active participant in real time counter-vandalism. The shift in philosophy occurred several years ago when it became obvious that buoy damage (primarily along the TAO array) was occurring at a pace that would exceed our ability to keep a reliable amount of data flowing with the 95° W and 110° W lines, which are closest to the western coast of South America, of primary concern. In fact, there was one instance in 2011 where vandalism occurred on a TAO buoy within twelve hours of deployment and resulted in a complete loss of all of the data.

In February of 2012, NDBC deployed twelve self-powered, self-recording cameras on the TAO buoys set to take periodic images that, once recovered during a subsequent service visit a year late, would be analyzed to see if any fishing activity had occurred. Only four of the cameras were recovered, with eight suspected to have been taken or damaged and lost at sea. The images (Fig. 1 and Fig. 2) were quite dramatic.

Fig. 1 Image from Cameras installed on TAO buoys in February 2012

Fig. 2 Image from Cameras installed on TAO buoys in February 2012

IV. NDBC *BuoyCAM*

A. BuoyCAM Generation-1

Subsequent to the deployment of the first, self-recording cameras, NDBC engineers began working on a camera design that could survive the yearlong deployment in the open ocean, and transmit images to shore in near real-time. Those efforts resulted in NDBC's 1st generation *BuoyCAM*. This design, comprised of five separate frames around our buoy and three images per hour, provided the NDBC with a 300° field of view with NDBC Smart Module technology used to control the five cameras and Linux processor. The images are and The Smart Module transfers the images, processed by the Linux Gumstix, to the battery box via Wireless fidelity (Wi-Fi). One of those pictures is transmitted back to the NDBC MCC every hour during daylight hours. The remaining images, including high-resolution images of the individual frames, are stored within the camera system and available for transmission on demand. Shown in Fig. 3 through Fig. 5 are the components of the 1st generation *BuoyCAM*.

Fig. 3 Upper Camera Housing (contains five web cameras, a camera interface board, and cabling)

Fig. 4 Lower Camera Housing (contains the Smart Module, Linux Gumstix processor, and Wi-Fi transmitter with the power port at the bottom of the housing)

Fig. 5 *BuoyCAM* Generation -1 Battery Box

B. BuoyCAM Generation-1 Deployments

The NDBC deployed the first *BuoyCAM* for testing on one of NDBC's "Weather Buoys" in the Gulf of Mexico, 115 nautical miles ESE of Pensacola, FL. An image from that first deployment is in Fig. 6.

Due to the high rate of vandalism, the buoys in the Eastern Pacific were of interest to the NDBC; thus, *BuoyCAMs* were installed on buoys in the TAO array (Fig. 7) to provide additional testing and situational awareness and, from an engineering perspective, allow for the deployment of multiple camera systems and a determination of ruggedness and endurance of the design. Additionally, *BuoyCAMs* were installed on NDBC's other platforms: two deployed off the Coast of New England, one installed on the buoy off Cape Canaveral, FL, four deployed on buoys in the Gulf of Alaska, and two more installed in the Gulf of Mexico.

Fig. 6 Small Personal Recreational Vessel at Buoy 42039 on 13 August 2013

Fig. 7 Fishing Vessel Collision with TAO buoy 32315 at 5° N 110° W, 27 July through 3 August 2015, followed by images as the buoy capsized and sank

C. *BuoyCAM* Generation-2 Development

NDBC started work on a 2nd generation (Fig. 8) of the *BuoyCAM* with the goal of providing a 360° field of view, increasing the number of images taken each hour, increasing the camera's service life to eighteen months, and providing the ability to toggle a remote payload. *BuoyCAM2* consists of three major components: the *BuoyCAM*, the backup position and image storage device (Locus; Fig. 9), and the auxiliary power and expansion module (Wasp; Fig. 10).

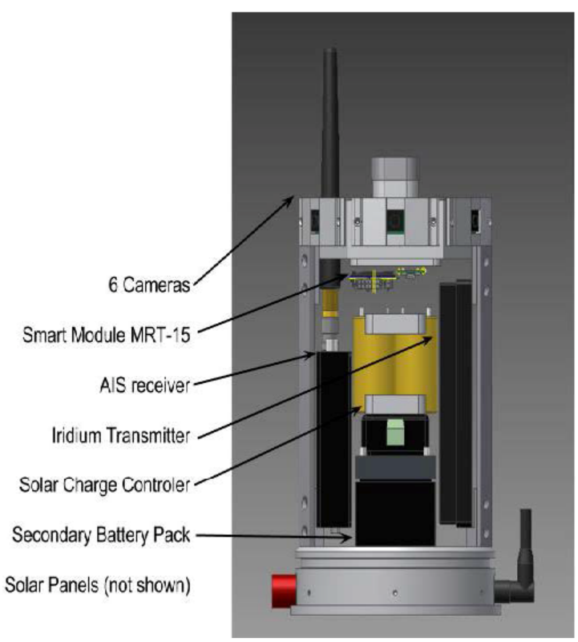

Fig. 8 *BuoyCAM*, Generation-2 Camera Housing and Major Equipment

BuoyCAM2 was designed to be a standalone unit capable of taking images every five minutes and transmitting the latest six-panel image once an hour with the camera housing utilizing a rechargeable power system to extend the deployment life of the camera. The new design increased two-way communication, allowed for reconfiguration at sea, and included an event driven mode and wireless communication between the Locus (Fig. 9) and the Wasp (Fig. 10).

The Locus tube (Fig. 9), that is used for image storage and as a backup position tracker, also contains its own primary battery pack and communicates with the camera through a wireless network. This optional component was designed to be concealed inside the buoy hull.

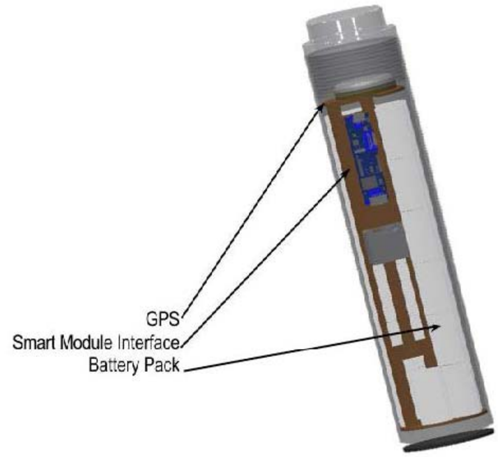

Fig. 9 Locus Major Components

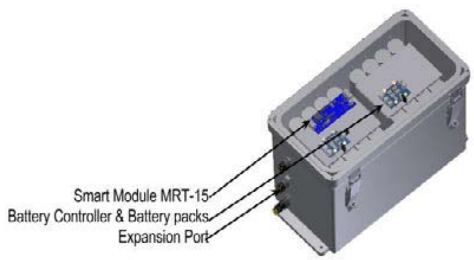

Fig. 10 *BuoyCAM2*'s Auxiliary Power and Expansion Module (Wasp)

The primary function of the Wasp (Fig. 10) is to provide backup power to the camera in time of poor solar energy. The Wasp's secondary functions are to allow for expansion of additional measurements or devices for use with *BuoyCAM2*. Interfacing an additional device would allow a trigger for entering into the event mode.

V. Additional Interest in Images from the Ocean

Although the driving force behind the operational use of real-time reporting buoy cameras was and remains the monitoring of human interaction with environmental and weather-monitoring buoy systems, there are other benefits from the availability of real-time imagery from buoys and coastal observation sites.

NDBC is currently investigating possible operational uses outside the scope of vandalism monitoring. One area of interest involves turning the cameras away from observing external threats to a station and toward monitoring the sensors and equipment themselves. Something as minor as a slow drip or accumulation of a substance along a wire or a damaged or a bent antenna can cause serious hardware damage or data corruption of a transmitted message. Having a real-time picture of the conditions within the hull and/or of the exterior equipment and instruments can aid in the quality control of transmitted data and the planning of operational service visits to the station; thus, minimizing data losses to sensor or system failures.

An example of the applicability of buoy cameras to station monitoring occurred at NDBC Station 44007 in early January 2014. Ice accumulation on a buoy can result in erratic or erroneous values of wind data, can dampen the wave measurements due to the added weight on the hull, and interrupt transmissions. As was the case in at least instance in the Chesapeake Bay during the winter of 2014-2015, ice could have caused a partner buoy to capsize. Often, icing events at buoys are accompanied by a drop in reported wind speed values, usually flat lining at zero meters per second. However, incoming wind reports from 44007 revealed no specific indication that icing had occurred. However, images (Fig. 11) from the camera mounted on 44007 revealed significant icing on the buoy, giving information on the condition of the buoy to the analyst on duty in NDBC's MCC in case any irregularities in incoming data were to arise.

Outside of equipment management and vandalism, the buoy cameras also allow for real-time monitoring of environmental conditions through observation imagery, under both "normal" conditions and conditions that draw greater public interest (Fig. 12). Organizations, such as the U.S. Coast Guard, the U.S. Navy, and others, would take in the observations as a part of their operational planning. Uncooperative sea conditions, such as high swells or winds, can increase the risk of NDBC operations and, if the risk is high enough, could lead to cancellation of a mission. The availability of these additional observations of the conditions at a buoy, particularly in data scarce regions such as the Pacific Ocean, can provide an observation of conditions that forecasting models may not have sufficiently represented, and lead to greater efficiency and better informed decisions by NDBC managements and field crews. Fig. 12 shows a tropical storm passing across a buoy in the Caribbean Sea in August 2015. Fig. 13 is an image from the Gulf of Alaska in October 2013, showing very rough sea conditions.

Fig. 11 Image of NDBC Station 44007, 12 nautical miles southeast of Portland, Maine (2 January 2015)

Fig. 12 The Center of Tropical Storm Erika passing within 35 NM of Station 42060

Fig. 13 Image of Buoy 46410, 188 nautical miles south-southeast of Cordova, AK (9 October 2013)

Prior to one of NDBC's scheduled deployment missions to Nantucket Sound in February 2015, satellite imagery revealed sea ice, which forms much more readily in calm conditions, in the general area of the station. However, without in situ imagery, information on the exact concentration or characteristics of the ice near the station was not readily available, and the risk to vessels transiting in the area unable to be accurately assessed. Later, photographs from the crew aboard the servicing vessel (Fig. 14) revealed a concentration of sea ice greater than 90% near the buoy, which could have posed a risk to ships (smaller vessels, in this instance) without the appropriate hull strength. Currently, two of NDBC's *BuoyCAMs* are installed on buoys (48214 and 48216) operated by Shell and deployed in the Chukchi Sea, off the northwestern coast of Alaska. One of the main purposes of these buoys is to monitor the freezing and encroachment of sea ice near NDBC-partner assets as winter approaches.

Fig. 14 "Gray Ice" with rafting around 44020 in Nantucket Sound (NDBC Field Service Technician James Lenoir, 23 February 2015)

BuoyCAMs can also be used to make meteorological and oceanographic observations, such as sea state, sea ice accretion, sky cover and cloud formations, visibility and precipitation. Other uses for *BuoyCAMs* range from flora and fauna monitoring, algae bloom observations, monitoring the elevation of the snowline on mountain ranges, monitoring estuary conditions and river discharge, and evaluating vessel traffic (Fig. 15 and Fig. 16).

As the *BuoyCAM* technology matures, spatial coverage increases, and general awareness of the camera deployments increases, the NDBC expects that a greater variety of uses will be discovered for the buoy camera technology.

Fig. 15 Mountain Snowline on Montague Island, AK (46061, 6 January 2014)

Fig. 16 Image of bird on Buoy 46022, near Eureka, CA, 5 August 2015

VI. SUMMARY

NDBC's *BuoyCAMs* are providing low-cost, deployable, sustainable real-time image technology from the ocean and coupled with the revolution of its 24/7/365 MCC has greatly expanded the capabilities for increased maritime-domain awareness and environmental intelligence. The NDBC has begun to realize a potential for unanticipated benefits that provide "eyes on the ocean", the ability to see images of ocean waves and surface current, fog, and sky cover, of ship traffic, and of fishing activities and wildlife in the remote open ocean and around the U.S. coastline, to researchers, forecasters, government agencies, and the public.