Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 16

The instrumental architecture of a Coral Reef Early Warning System (CREWS) station

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Abstract. The Integrated Coral Observing Network (ICON) program has constructed and installed a series of Coral Reef Early Warning System (CREWS) stations which provide a wealth of high-quality meteorological and oceanographic data in near real-time. CREWS stations date back to 2001 with the deployment of an early buoy-type design in the Bahamas. Beginning in 2002, the program shifted to a pylon-type design which was re-engineered in 2005, resulting in the modern CREWS stations found in the Bahamas, Puerto Rico, the US Virgin Islands and Jamaica. The CREWS instrumentation architecture described herein has evolved over time into a robust package that, combined with a regimen of regular instrument cleaning and recalibration, has yielded a continuous, long-term, high-quality dataset from these harsh marine environments.

Key words: coral, CREWS, monitoring, instruments, temperature, salinity, light, wind, pylon

Introduction

At the National Oceanic and Atmospheric Administration's (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML), the Integrated Coral Observing Network (ICON) program has evolved to provide both near real-time marine ecological forecasts ("ecoforecasts" Brandt et al. 2006; CENR 2001) and hourly checks on the status of the sensors it monitors, whether in situ, satellite or other (e.g., Wellen Radar; Shay et al. 2002). Coral Reef Early Warning System (CREWS) stations are a type of in situ station developed by the ICON program at AOML and so-called because of expert system software originally developed by Hendee et al. (1998), and improved by colleagues (Hendee et al. 2007), to monitor data from the SEAKEYS Network in the Florida Keys (Ogden et al. 1994). Newly engineered stations were developed to begin an expansion into U.S. coral reef areas, in response to recommendations by the U.S. Coral Reef Task Force (unpublished memoranda) and United States Executive Order 13089 (Anonymous 1998), and acquired the nickname "CREWS Stations." CREWS stations typically contain all the usual meteorological and oceanographic instruments, as well as instruments of special interest to specific research projects. The CREWS Network is but one in situ network now monitored by the ICON Program.

The present report expands upon Hendee et al. (2006), in outlining the instrumental architecture for CREWS stations.

Materials and Methods

Surface Instrumentation

Surface instruments on the station pylon (Fig. 1) measure light, wind, temperature, barometric pressure, humidity and precipitation. Most measurements are made redundantly by multiple instruments. Instruments which must be isolated from equipment that could block light or wind are mounted away from the station on aluminum masts. Other surface equipment includes five solar panels, a transmitter antenna, a lightning protector and a stand-alone solar-powered navigation light.

Figure 1. A CREWS Station in Discovery Bay, Jamaica.

Barometer (GE/Druck CS115)

The Barometer outputs a variable frequency which is measured by the data logger's period averaging instruction. It is mounted directly on the station's Control Unit (see below), inside the chamber at the top of the pylon

Wind Monitor, Electronic Compass (RM Young Models 05106, 32500)

The Wind Monitor measures horizontal wind speed and direction. It is connected to the data logger via the Electronic Compass, which accepts pulse counts and direction voltage as inputs and provides voltage outputs (updated once per second) for wind speed and corrected wind direction. Both instruments are mounted on an aluminum mast at 6.5 m above the ocean surface on the west side of the station. The Electronic Compass will be phased out during future maintenance visits to the stations.

Air Temperature Probe (Campbell Scientific Model 107)

The probe uses a thermistor to measure air temperature and is connected to one of the data logger's single-ended voltage channels, and is mounted near the top of the station out of direct sunlight, typically behind one of the station's solar panels.

Weather Transmitter (Vaisala WXT510)

The Vaisala Weather Transmitter (WXT) reports a wealth of meteorological measurements, some redundantly provided by other instruments on the station (air temperature, barometric pressure, wind speed and direction) and some not (humidity and precipitation amount, duration and intensity). Winds are measured acoustically by three ultrasonic transducers. Precipitation is also measured acoustically by a sensor that can distinguish between rain and hail. The WXT has a serial connection to the data logger by which it offers a full report once per minute, unprompted. It is mounted on an aluminum mast at 6.5 m above the ocean surface on the east side of the station.

Surface Light Sensor (Biospherical BIC2104R)

Biospherical Instruments' Multichannel Cosine Irradiance Profiling Spectroradiometers (BICs) are utilized for above water and underwater light measurements. The BICs used on CREWS stations are configured to take four kinds of light readings: three at discrete wavelengths of 305, 330 and 380 nm, and one across the Photosynthetically Active Radiation (PAR) range of wavelengths from 400 to 700 nm. The BICs additionally report low-resolution measurements of temperature and voltage. They communicate with the data logger via serial connections and are prompted for data once every 30 seconds. The surface BIC is mounted on an aluminum mast on the south-facing side of the station for the northern hemisphere.

Underwater Instrumentation

Underwater instruments include those which measure light, salinity, temperature and depth, as well as special deployments of instruments which measure the partial pressure of carbon dioxide and the fluorescent yield of corals. For added flexibility, all underwater instruments use the same type of connector (Impulse BH-4) and cable (multiply-layered with Kevlar, polyurethane, polypropylene and Vectran for maximum strength and resistance to fish bites and bio-fouling). The core instruments (Conductivity / Temperature / Depth sensors and underwater BICs) are doubled up with one set deployed "shallow" and one "deep," or at nominal 1 and 3 m depths. Such placement provides for redundant measurements, for calculating light attenuation, and to detect depth-dependent differences in temperature or salinity.

Conductivity/Temperature/Depth (Falmouth NXIC-CTD)

CTDs report measurements of conductivity, temperature, and pressure, and from these readings they calculate salinity, instrument depth and sound velocity. They also report instrument voltage and are equipped with flash memory and battery backup, and though they draw power from the CREWS station they continue to operate if the station is offline for maintenance. They power themselves up every 6 minutes, run for 30 seconds, and report averaged results from the run via RS-232 connections. They are mounted directly on the pylon at the same heights as the shallow and deep BICs. A simpler CT version of the same instrument is connected during station cleanings to provide ground-truth (i.e., validation) measurements.

Underwater BICs (Biospherical BIC2104U)

This is the same instrument as the Surface BIC (see above) except in a different housing. The underwater BICs are mounted on the sun-facing side of the station on extended arms to avoid light shading by other equipment.

SAMI pCO_2 (Sunburst Sensors)

Several Submersible Autonomous Moored Instruments (SAMIs) have been deployed on CREWS stations. One type of SAMI measures the partial pressure of carbon dioxide (pCO_2) and is important to ocean acidification research. The SAMI pCO_2, being autonomous, is self-powered and logs its data to flash memory for later retrieval, but it also produces a report once per hour which is communicated to the station via RS-232 connection. This report includes a calculated pCO_2 value as well as sea temperature, blanking constants, and raw numbers for intensities at 434, 620 and 740 nm.

Monitoring PAM Fluorometer (Gademann Instruments)

The Pulse Amplitude Modulation (PAM) Fluorometer is an instrument that has seen several successful short-term deployments, most notably at the Bahamas CREWS station during the bleaching season of 2005 (Manzello et al. 2008). It consists of a central distributor box and multiple PAM heads that are deployed in near proximity to live coral specimens in the immediate area. The PAM, which has an RS-232 connection to the data logger, continuously measures a specimen's at-rest fluorescent response (F_o) and, once per hour, measures the response (F_m) to an intense burst of fluorescent light. The fluorescent yield calculated from F_o and F_m may be thought of as a measure of the specimen's photosynthetic efficiency, and the effects of environmental stressors may show up in these yield values before there are any visible signs of stress or bleaching.

Data Acquisition and Transmittal

Control Unit

The Control Unit is a collection of instruments that manage data acquisition and transmittal; this collection is supported by a fiberglass plate and Vectra for instrument and cable attachments. The Control Unit is thus a package that is installed in a hollow space at the top of the station pylon and is accessed by climbing to the top on removable rungs. Except for the navigation light, all station instruments connect to this unit, including surface and underwater instruments, antennae, batteries, solar panels, grounding wires and lightning protector. These connections are made via weather-proof plugs that are uniquely keyed according to purpose to eliminate the possibility of incorrect connections.

Data Logger (Campbell Scientific CR1000)

The data logger constitutes the “brains” of a CREWS station. It communicates with every instrument on the station via analog or serial RS-232 connections. It auto-calculates data averages, minima, maxima and totals. It is programmed to keep track of how many measurements it has received from each instrument and is capable of re-running complex instrument setup routines if communications fail. It summarizes its data once per hour for reporting via satellite (see Transmitter, below). All data are redundantly stored locally in its Compact Flash Module for later retrieval.

Transmitter (Campbell Scientific TX312)

The High Data Rate Geostationary Operational Environmental Satellites (GOES) transmitter is the main communications link between a CREWS station and the outside world. Each station has a 20-second window once per hour to send its data at 1200 baud. Data are currently transmitted plain-text but could be compressed to a binary format to make room in the future for more fields. The TX312 is connected to a satellite transmitter antenna and a GPS antenna on the outside, and has a direct connection to the data logger on the inside.

Radio (Campbell Scientific RF401)

Every station has a Spread Spectrum Radio for short-distance communications, used mainly for downloading data and for troubleshooting. The radio link is frequently used from a boat moored at the station, or from land-based locations within 500 m. Its antenna is mounted directly on the control unit.

Serial I/O (Campbell Scientific SDM-SIO4)

Instruments which communicate via serial RS-232 connections plug into a port on one of two 4-port interfaces which in turn connect to the data logger. Future control units may expand to include three such units (12 serial connections, total).

Power Supply and Peripherals

Batteries (Odyssey Drycell PC 1200 AGM)

CREWS stations use rechargeable dry cell Absorbed Glass Mat batteries. They are typically charged to between 12 and 14 V DC, with battery levels rising during the day when the solar panels are in sunlight and falling during the night. However, the station’s power design allows it to continue operating without interruption for more than two weeks even without recharging its batteries.

Solar Panels (BP Solar SX 10M)

Each station has five 10 watt solar panels (i.e., 50 watts total) installed in a ring about the top of the pylon. This arrangement is partly to take advantage of sunlight from different directions throughout the day, but also to keep the panels as close to the pylon as possible to minimize the risk from the high winds of a tropical storm or hurricane. A Double Pole, Double Throw switch is installed between the batteries and solar panels to completely disconnect all power components prior to removing the Control Unit for maintenance.

Navigation Light (Carmanah Technologies Marine 601)

The station's navigation light is an important safety feature, as it not only provides warning of the station's presence but allows it to be used as a navigational aid that is tracked on marine maps and charts. It is completely stand-alone with its own battery supply and solar panels, and operates independently of station operations or downtimes. Each light is programmed with a flashing pattern that is identified on navigational charts.

Lightning Protection (Forestar Lightning Master Static Dissipater 151100; Wonder Bar Grounding Plate, Mark I)

All metallic and electronic parts of the station are connected by copper grounding wires which run down the inside of the pylon, then exit and terminate on a 15.2cm x 5.1cm x 12.7cm porous bronze grounding plate which is mounted underwater near the ocean floor. This keeps all equipment at the same electric potential and eliminates risk of shock to anyone touching more than one piece of equipment at the same time. Additionally, a lightning protector is integrated into this grounding system and is mounted at the highest point of the station above all other instrumentation. The lightning protector makes use of the point discharge principle to dissipate static charges before they can accumulate to the point where lightning streamers (a prelude to a lightning strike) can form.

Timing

Timing of events on the station is controlled by a main "scan block" of instructions repeated every five seconds. There is also a block of instructions executed exclusively at data logger startup. Table 1 depicts the series of events for data acquisition and transmittal.

Results

There are many challenges faced when deploying electronic equipment in ocean environments. Station operations may be impacted by marine life, equipment failure and tropical storm activity, among other challenges. Perhaps most crucial is the station's satellite communications system, since in the absence of regular data reports it is impossible to monitor instrument performance and environmental conditions.

The early years of the CREWS program (through 2003) saw several impacts from tropical storms and satellite transmitter failures. As a result, station "uptimes," defined as the percentage of time that stations are operational, held steady near 70%. With modern-era (2005 and since) CREWS stations, uptimes have held steady at 95% and above. In addition, in 2004 the design evolved to include an on-site memory storage module, so even in cases where transmissions have been lost due to weather or equipment problems, data are recoverable during the next maintenance visit. Taking into account this after-the-fact recovery of missing transmissions, station uptimes have fallen no lower than 98.9% since this modern instrument architecture was implemented in 2005.

Table 1: Timing of data acquisition and transmittal.

Timing	**Events**
startup	The logger program signature is recalculated. The logger clock is reset from GPS time. The transmitter is programmed with its GOES platform ID. Station instruments are initialized and/or programmed.
5 seconds	The logger program executes once. Meteorological instruments (air temperature, barometric pressure, wind speed/direction) are sampled.
30 seconds	Logger diagnostics are sampled. Light sensors are sampled (above and below the surface).
1 minute	The Vaisala Weather Station produces a full report. One-minute meteorological maxima, averages are calculated.
6 minutes	The CTDs produce their reports. The ground-truth CT, if connected, is sampled. The Monitoring PAM Fluorometer samples the at-rest fluorescent response (F_o). Transmitter diagnostics are sampled.
10 minutes	Ten-minute meteorological maxima, averages are calculated.
1 hour	The Monitoring PAM Fluorometer emits fluorescent flashes and measures the responses (F_m). The SAMI pCO_2 sensor produces a report. Hourly averages, maxima, minima are calculated. Error buffers, measurement counts are cleared. The station sends its hourly report via GOES (satellites).
1 day	The logger program signature is recalculated. The logger clock is reset from GPS time.

A graph of transmission uptimes is shown in Fig. 2. CREWS stations are identified by name in Table 2, which also shows "transmission uptimes" vs. "station uptimes." Transmission uptimes count the number of hourly satellite transmissions successfully received as a percentage of the total number of hours in the period, whereas station uptimes describe the same dataset following the recovery of missing transmissions from the local memory module during a maintenance visit.

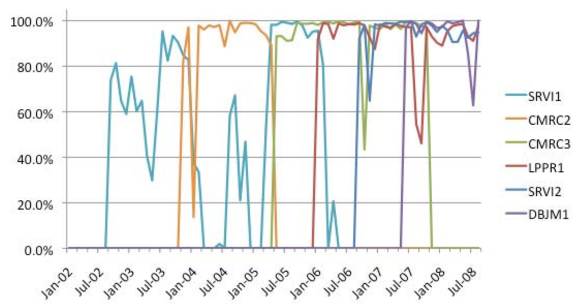

Figure 2. CREWS Station Uptimes, 2002 – present.

The graph shows the evolution of CREWS station performance. Earlier stations (CMRC2 and SRVI1) were of an intermediate pylon design and were prone to more frequent downtimes. The four stations installed since 2005 have much stronger uptimes and most of their outages can be traced to station upgrades or weather events. For example, the affect of Hurricane Dean on LPPR1 uptimes in August of 2007 is clearly seen. Note that one station (CMRC3) was placed on hiatus in October of 2007; its reinstallation is planned for late 2008.

Table 2: Transmission vs. Station Uptimes for CREWS stations, 2002 – present.

Station Name	Location	Station Lifetime	Transmit Uptime (%)	Station Uptime (%)
SRVI1	Salt River, St. Croix, USVI	2002/09 – 2006/06	55.5	80.7
CMRC2	Lee Stocking Island, Bahamas	2003/11 – 2005/04	91.4	93.8
CMRC3	Lee Stocking Island, Bahamas	2005/05 – 2007/10	95.7	99.4
LPPR1	La Parguera, Puerto Rico	2006/01 – present	93.0	99.4
SRVI2	Salt River, St. Croix, USVI	2006/09 – present	95.2	99.5
DBJM1	Discovery Bay, Jamaica	2007/06 – present	95.1	98.9

Discussion

As any marine scientist knows, the ocean is a harsh home for anything that does not live there, and this is why marine instrumentation is expensive and difficult to maintain over long periods of time. The ICON program has now been installing and maintaining stations that measure more than sea temperature for over eight years, and the experience gleaned over this time can serve to save valuable time and resources for other agencies and organizations wanting to conduct similar endeavors. The high quality data we have been able to collect has been used for important research findings (e.g., Hendee et al. 2002; Manzello et al. 2006, 2008) which would have been difficult to obtain without the architecture reported here.

Acknowledgments

NOAA's Coral Reef Conservation Program, and the High Performance Computing and Communications office are gratefully acknowledged for support of the ICON Project and related research. The authors wish to thank all of ICON's many contributors, past and present, including but not limited to Jeff Absten, Madeleine Adler, Nancy Ash, Hector Casanova, Jules Craynock, Louis Florit, Lew Gramer, Clarke Jeffris, Jeff Judas, Chris Langdon, Derek Manzello, Emy Rodriguez, Erik Stabenau and Scott Stolz.

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