Data Quality Assurance and Measurement Technology Innovation in Coastal Ocean Monitoring

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Abstract

Due to new demands, applications and technological development, data quality assurance and measurement technology innovation have become increasingly important in coastal ocean monitoring. This paper discusses these two issues, using a National Ocean Services' coastal monitoring program as an example. They include laboratory calibrations of acoustic Doppler current profiling instruments and air acoustic water level sensors, continuous operational real-time system monitoring, and development of advanced measurement technologies. Sample calibration results are presented and matters of measurement requirements are discussed.

1. Introduction

Coastal ocean monitoring is an expensive and long-term developmental undertaking. As products become widely accepted by users, new demands such as more observation sites, additional measurement parameters, increasing sampling and reporting frequencies, and higher measurement accuracy and reliability are to be considered. There will also be new requirements to be included for new applications such as data for coastal ocean forecast (initial and boundary conditions, data assimilation, validation), oil and hazard material spill response and management, storm surge warning and natural hazard mitigation.

The development of new technologies in sensors, data recording and telemetry devices improves the quality and capability of measurements, enhances the efficiency of operations, and is a critical element in the evolution of the monitoring system. The new measurement requirements drive the expansion of functionality and capability of the monitoring system and the improvement of measurement standards. In the process of meeting needs and making progress, the role of quality assurance and technology innovation has become increasingly important.

This paper uses the NOAA's Physical Oceanography Real-Time System (PORTS) monitoring program as an example to illustrate several important quality control procedures and technology innovation.

2. The Physical Oceanography Real-Time System (PORTS)

PORTS collects real-time information from current, water level, salinity, and many meteorological sensors distributed in ports and bays and disseminates the data, near-term forecasts, and other geospatial information to mariners, vessel traffic system operators, and other users. It is an integrated decision support tool which improves the safety and efficiency of maritime commerce and coastal resource management [1, 2]. NOS deployed its first PORTS system in Tampa Bay, Florida during 1989. The system size and configuration vary and each is specifically designed to meet local user requirements. Presently there are four full systems (up to 26 instruments in each PORTS) installed in Tampa, New York, San Francisco, and Houston/Galveston and several small installations (basic water level gauge and associated meteorological sensors) at Anchorage and Nikiski, Alaska, Seattle and Tacoma, Washington, Baltimore and Chesapeake Bay , Maryland, Hampton Roads, Virginia, Narragansett, Rhode Island, and Delaware Bay, Delaware.

The NOS's Next Generation Water Level Measurement Systems (NGWLMS) and the associated Data Processing and Analysis System (DPAS) in the National Water Level Observation Network (NWLON) provide the infrastructure in PORTS development.

3. Quality Assurance Activities

NOS takes primary responsibility in maintaining adequate quality of all PORTS products. To this end, several quality assurance activities are carried out. These include:
a. Laboratory test and calibration of water level, current, and other hydro-meteorological instruments,
b. Field test and evaluation of new instruments, data communication designs, and integrated measurement systems,
c. Continuous Operational Real-time Monitoring System (CORMS).

In addition, there are other quality control measures including acceptance test of new and refurbished instruments, backup water level sensor, annual field inspection and datum stability check, etc., to maintain high data quality standards.

a. Laboratory test and calibration
Acoustic Doppler current profiling instruments, such as the RD instruments' 600 and 1200 KHz ADCP units (narrowband, broadband and Workhorse) and SonTek's 500 and 1500 KHz ADP units, are NOS' standard instruments for water current measurements. They are used in a variety of platform configurations such as towing (for rapid response survey), short taut-line mooring and bottom fixed platform (for 30-day or longer in circulation survey), and bottom fixed platform (for 6-month or longer in PORTS). With the proliferation of manufacturers of these type of instruments in recent years, an adequate calibration method becomes increasingly important.

Since 1988, NOS has been routinely conducting speed calibration of acoustic Doppler current profiling instruments in a towing basin at the U.S. David Taylor Naval Ship Research and Development Center in Carderock, MD. These include new and existing units prior to and after their deployment. The tow basin has a width of 15.5 m, depth of 6.7 m, and length up to 575 m. Sensor Speeds were calibrated from 5 cm/sec up to 180 cm/sec. Typically four bin velocities could be measured. The carriage speeds were verified against other speed measurement standards and have an uncertainty within ± 0.15 cm/sec. They are used as references for speed comparisons.

The calibration results are kept in the NOS database and are used for monitoring the quality of the instruments and serve as useful guide in instrument selection. Fig. 1 shows the instrument errors (in percentage of reference carriage speed) from recent calibrations [3]. The SonTek products, especially the lower frequency units exhibit larger variance between instruments.

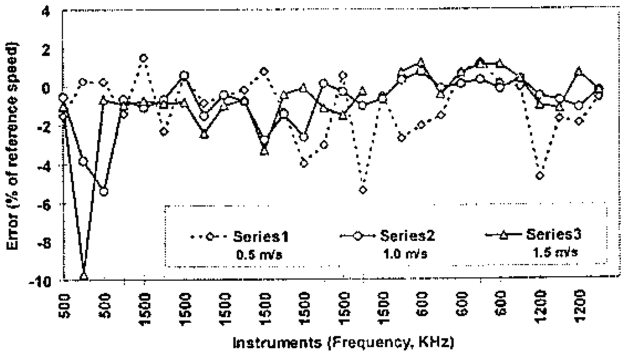

Fig. 1 Speed error of acoustic Doppler current profiling instruments

Air acoustic water level sensors (Aquatrak) are used in all NOS primary water level measurement stations and have been adapted internationally for the Global Sea Level Observing System (GLOSS). The sensor has a resolution of 3 mm, accuracy of 9 mm, and range of 10 m. It has a self-calibration capability to calibrate the sound speed along the top sensor section. The sensor measures water level at 1 sec interval. A 3-minute mean is reported every 6-minute. The standard deviations of the 3-minute data are also computed as a data quality check. Measurements greater than three standard deviations (plus mean) are considered as outliers and are rejected.

In order to assure that the water level measurements are sound and free from bias, continuous efforts have been made to monitor the performance of Aquatrak sensors. These include assessments of temperature gradient effect [4] and laboratory calibration at constant temperature facility [5]. Aquatrak sensors are calibrated prior to and after their deployment. Since early 1993, more than 800 units have been calibrated. A sample result of recent calibrations is shown in Fig. 2. The RMS error of these 275 units returned from field (normally after 1-year service) is 6.5 mm and dropped to 1.4 mm after adjustment.

b. Field test and evaluation
For instruments and measurement systems that can not be tested in the laboratory, they are evaluated in the field. A special test site near the Chesapeake Bay Bridge Tunnel, VA was designated as the field test and evaluation site. The site is next to a NOS primary water level system and is instrumented with many ancillary oceanographic and meteorological sensors.

Several experiments include a short taut-line moored upward looking ADCP system, deep water self-pop-up bottom mounted ADCP/ADP system, are being planned for the near future.

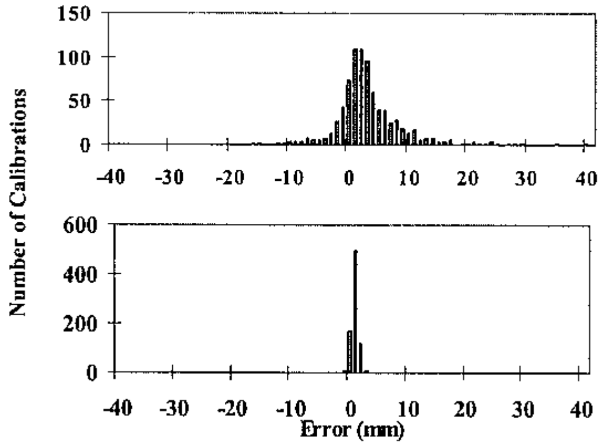

Fig. 2 Aquatrak calibration results: units returned from field (top) and same units adjusted for re-deployment (bottom)

c. <u>Continuous Operational Real-time Monitoring System (CORMS)</u>
The goal of PORTS is to provide ship operators essential real-time environmental information so that safe and efficient marine navigation can be achieved. CORMS is an automated monitoring system that determines data quality in real time and responses quickly to system performance issues [6]. It strengthens overall data quality assurance and reduces NOS's potential liability. The system computer server connects to all PORTS sites via a SGI 02 communication server. It also connects to the NOS DAPAS data base via a Sybase server. The DAPAS provides reference information including primary and backup water level sensor data and comparisons, relationship of predicted and observed water levels, differences from nearby stations, plots of ancillary measurements, and other quality control checks. CORMS operates 24 hours continuously and the operator scans the GUI display and monitors the health of all instruments in real time.

An automated data quality assurance process in the DPAS checks the quality of incoming data and flags the quality status. The CORM will display the quality status, action and information flags, and actions required. The data quality control parameters examined by the CORMS includes:
(i) water level data - maximum value, minimum value, flat value (number of consecutive data values with no change in magnitude), sample standard deviation, outliers, difference and tolerance limit of air temperatures in the two thermistors along the Aquatrak sounding tube, difference and tolerance limit between primary and backup water level sensors, difference and tolerance limit of Aquatrak value between neighboring stations.

(ii) current meter and ancillary sensor data - maximum value, minimum value, rate of change, reporting time difference, and comparison with neighboring station of all sensor measurement parameters, and instrument's measurement quality indicators (such as ADCP backscatter strength, tilt, compass reading, voltage level, etc.).

Note that these criteria are typically sensor and site specific. Knowledge of historical environmental conditions at the sensor location is useful in setting these criteria.

4. Technology Innovation

Technology innovation is critical in advancing the efficiency and quality of measurements. However, instrument development is often long-term and expensive. The limited marine market also hinders the development of new products in private sectors. With the passage of Small Business Research and Development Enhancement Act by the US Congress in 1992, the Small Business Innovative Research (SBIR) program has been adopted by several US Government agencies. It has become a major force in stimulate technological innovation in the private sector and has helped to meet the Federal Government R&D needs. The program consists of three phases: Phase 1 to determine the technical feasibility of ideas, phase 2 to develop prototype systems, and Phase 3 to start commercialization. Both Phase 1 and Phase 2 proposals are reviewed and selected annually for funding. About 5 to 10% Phase 1 applicants are awarded and about one third of the Phase 1 awardees are awarded for Phase 2. There is no funding award for Phase 3, but the government will assist the private sector to market their product.

The SBIR program within the Department of Commerce (sponsored by NOAA and NIST) has been a useful vehicle to meet some of PORTS' long-term measurement needs. Several new instrument technologies are currently being developed. These include:
(i) A high spatial resolution multi-frequency radar for

surface current mapping in harbors and bays [7] - 8.85-9 GHZ operating frequency, velocity cell resolution 100 m x 100 m, range up to 5 km, velocity resolution 5 cm/sec (at 15-minute data updates, or cm/sec with hourly updates).
(ii) An optical (laser) water level sensor - performance equal to or better than Aquatrak (resolution 3 mm or less, accuracy 9 mm, range 10 m).
(iii) A radar sensor for monitoring the bridge clearance over waterway - operation under all weather and water surface conditions, range 50 m or greater, accuracy 5 cm or better.
(iv) A horizontal acoustic Doppler current profiler - horizontal range up to 400 m in water depth of 15 m or deeper, resolution and accuracy equal or better than ADCP. Fig. 3 illustrates the use of this instrument for profiling the currents across a bending navigation channel (an example of PORTS at Newark Bay, NJ).
(v) An automated water density sensor - mean vertical density accuracy of 0.5% or better, water depth up to 100 m.

Other monitoring needs including water quality, high resolution underwater water sonar imaging, and GPS buoy design are on our list for the future. We are also seeking for collaboration with other agencies and institutions to coordinate our effort and maximize the benefit of technology development in marine instrumentation.

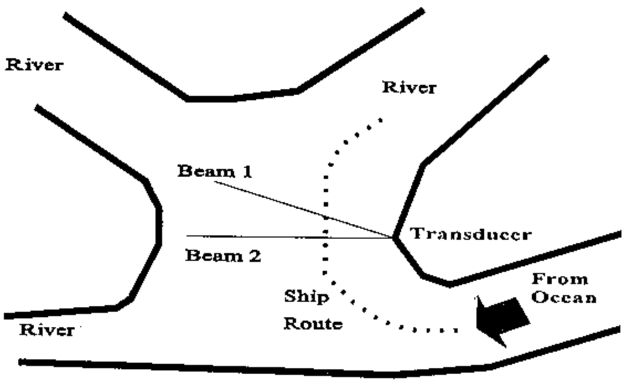

Fig. 3 Horizontal ADCP to profile currents across the river bend (example of Newark Bay, NJ)

5. Conclusions

Coastal monitoring is a continuously evolving effort. The rigorous measurement requirements associated with new demands and new applications call for increased emphasis in data quality assurance and technology innovation. The NOAA PORTS program provides an opportunity to develop tough real-time data quality control procedures. These procedures should be a continual development effort in response to experience. The NOAA SBIR program has been a useful vehicle in advancing the measurement technology to meet some of PORTS' long-term needs. To maximize the benefit of the SBIR program, close coordination with other agencies and institutions are important.

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