Sensing the coastal environment

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Abstract

The spatial and temporal dynamics of near-shore ecosystems are being studied by the Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi, with special consideration of episodic events associated with anthropogenic activity. Our growing array of estuarine and coastal monitoring stations in the Corpus Christi region supplies real-time, continuous input from a broad array of sensors (physical, chemical and biological) to feed comprehensive converged data sets that in turn foster, in a new context, the interpretation and evaluation of environmental perturbations (episodic events) and their ecological effects.

Keywords: coastal, sensors, environment, converged-data, HF-Radar, Texas

1. Introduction

Near-shore regions are some of the most productive regions in the world, providing habitat for diverse marine communities and natural resources of national economic and social importance. In many countries, these same coastal areas are also the fastest growing regions, leading to increasing anthropogenic degradation. Current pressures and stresses in near-shore regions include over-fishing, mineral depletion, sewage disposal, aquifer depletion, freshwater inflow diversion, vulnerability to coastal hazards, beach/wetland loss, contaminant releases, eutrophication, ecosystem health and integrity degradation, nuisance species invasions and harmful algal bloom inducement, and decreases of biodiversity. A changing climate can cause even more pressure on this interface between land and ocean. These regions also play a key role in on-going debate over human influence on the global carbon cycle. Many management policies associated with near-shore ecosystems do not provide adequate solutions to these problems, primarily due to a lack of scientific consideration and a citizenry uninformed of the elements compromising and controlling near-shore environmental quality and health.

There is a critical need to understand near-shore environmental history and the processes driving environmental changes on a range of spatial and temporal scales. Near-shore regions are non-linear and highly complex, and easily disrupted by external and internal forces and natural and human-induced processes that are not well understood. In the Gulf of Mexico, shallow embayments tend to be weather driven rather than tidally driven as in Atlantic or Pacific coasts. This leads to activity pulses

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during short time periods concurrent with episodic events. These pulses are stochastic, making prediction more difficult. A vast majority (~99%) of the environmental activity in coastal waters occurs during a very small percent (~1%) of the time. The "environmental activity" can be characterised as a series of episodic events (i.e. pulsed systems). These pulses may be nature-driven such as storm systems and harmful algal blooms, or they may be man-made such as oil spills and other chemical spills.

Standard observational research uses long-term trend analysis to characterise system changes. The coastal water sampling regimes for most governmental agencies is infrequent (seasonal to annual sampling) due to cost and logistical constraints. This approach is limited in its ability to provide data about short-term or broad spatial scale processes sufficient to distinguish between cause and effect. For example, Figure 1a depicts the total suspended solids (TSS) concentrations in Lavaca Bay (Texas) over a 20-month period. In the 1940s, an aluminium manufacturing plant (that used a Chlor-alkali process) was built on this bay. The plant has discharged significant amounts of Mercury (Hg), resulting in an underwater Superfund site (http://www.epa.gov/oerrpage/superfund/sites/npl/f940223.htm). Particle transport is one mechanism for Hg movement within this bay. Figure 1b depicts a relation between TSS and wind data over a 3-day period, where the higher wind speeds produced an increase in TSS concentrations (sediment resuspension) and the concomitant movement of Hg. If sampled biannually, only a handful of samples would have been collected during this time and the breadth of environmental activity (Hg transport, in this case) would have been grossly underestimated.

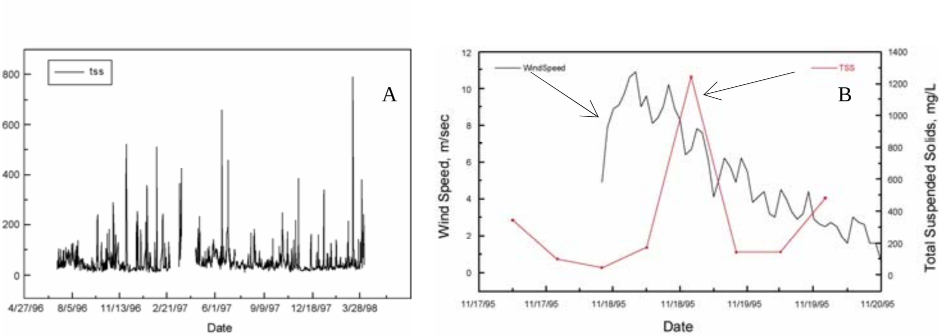

Figure 1. A) Total suspended solids (TSS, in mg/L) over a 20-month period in Lavaca Bay, Texas; B) wind speed (m/sec) and TSS (mg/L) over a 3-day period in Lavaca Bay.

In the previous example, the traditional sampling approach would miss the environmental activity during pulsed events, but increasing the frequency of this sampling regime is cost prohibitive. Thus, a "smart sampling" regime is needed to capture the effects of these episodes or pulses. This can be accomplished by integrating existing observation networks, new technologies, and basic research from diverse engineering and natural and social sciences disciplines. Integrated data management and modelling can ensure the results obtained are analysed and synthesised for optimal use by end users and stakeholders. Optimal operation and feedback require an understanding of the interrelationships among physical, ecological, and human political and regulatory activities (e.g. Adams et al., 1998).

2. Problem definition

Most ecological response measurements of normal seasonal and annual cycles in near-shore ecosystems rely on sampling strategies that often under-sample, providing aliased results (e.g. Kostic, 2000), thus incorrectly portraying long-term trends. Monitoring cyclical and episodic events in near-shore ecosystems and integration of changes in both the physical environment and ecological integrity of such dynamic systems requires observations recorded in real-time and at different spatial and temporal scales. Storms influencing current patterns, increased stream flow into estuaries, dramatic changes in water quality, algal blooms, and anthropogenic activities such as oil spills can be considered events that directly or indirectly result in increased particle (trace metals, polycyclic aromatic hydrocarbons, nutrients, toxins from harmful algal blooms, etc.) suspension in the water column. A new, integrated, real-time, observational paradigm can supply the cross-disciplinary data needed to pursue an integrated research approach.

3. Research plan

Our research plan can be conceptualised by the creation of an Environmental Field Facility (EFF), a concept supported by the Collaborative Large-scale Engineering Assessment Network for Environmental Research (CLEANER) workshop, sponsored by the National Science Foundation (NSF) in December 2001. CLEANER defines an EFF as a well-instrumented site with remote and *in situ* sensors designed to characterise an anthropogenically-stressed environmental region in real-time. We are in the process of turning Corpus Christi Bay into an EFF. It is well instrumented and new sensor technologies are being applied as they become available. Eventually, this local network can be linked to regional networks and then linked to regional and global networks, which is a concept supported by other NSF programs such as the National Ecological Observatory Network (NEON; http://www.sdsc.edu/NEON/) and the Long-Term Ecological Research (LTER; http://lternet.edu/) program. The NEON has as its mission scientific infrastructure and intellectual capital development to take on global research challenges (e.g., biogeochemical imbalances, carbon dynamics, invasive species). This is accomplished through a full integrated and nationally distributed proposed network of environmental research instrumentation networks. The LTER network, in existence since 1980 with 24 current network sites nationally, has as its mission to develop ecological understanding, synthesise long-term data, disseminate valuable information, create a legacy of high quality data, create scientists experienced in long-term research, and provide community outreach on complex environmental issues.

3.1 Approach

In situ Observations

We currently utilise the data from existing observation systems such as Texas Coastal Ocean Observation Network (TCOON) (http://www.cbi.tamucc.edu/projects/tcoon/) (Michaud et al. 1994), Texas Automated Buoy System (TABS) (http://tabs.gerg.tamu.edu/tglo) (Kelly et al 1998), and Galveston/Houston PORTS. They currently provide observations mostly of physical oceanographic and meteorological parameters. We are upgrading selected sites with extended sensor arrays, including an alternate water quality sonde, an automated water sampler, and sensors to measure particle size and distribution, turbidity, horizontal and vertical current profiles and directional wave parameters, nutrients (Iron II, Iron III, nitrate, nitrite, ammonium, phosphate, silicate), and high-resolution particle source indices. We are extending the sensor technology by collaborating with industrial partners to develop new technology for underwater particle size analysis, low-level dissolved oxygen probes, and biofouling countermeasures. Currently in Corpus Christi Bay, there are 5 TCOON stations around the bay perimeter. In addition, there are 3 platforms in the bay with 3 more under construction. Instruments deployed include acoustic Doppler current profilers, water-quality sensors, oxygen sensors, fluorometers and optical backscatter instruments. Both a nutrient analyser and an in-situ flowcytometer are scheduled to be deployed soon. There are also 2 platforms in the offshore area just beyond Corpus Christi Bay with similar instrumentation as those within the bay. A geo-referenced survey boat (with sensor packages like those at the fixed sites) complement fixed observing platforms by spatial surveys during events exceeding trigger thresholds for parameters such as particulates, chlorophyll-a, dissolved oxygen, and nutrients. The vessel is a 7.5-metre Lafitte Skiff powered by an inboard diesel, and is equipped with a diesel generator to provide clean power for computer systems, cabin air conditioning, tow cable winch, and miscellaneous 110-VAC devices. A submersible, towed vehicle (Acrobat® by Sea Sciences Inc.) is used to deploy the *in-situ* instrument package. Both manual and software control allow the Acrobat to maintain either constant depth/elevation or undulating flight paths. The ability to follow an undulating flight path is a necessary sampling regime to determine vertical parameter gradients.

Coastal Radars

High Frequency (HF) Radar systems map surface currents and directional waves in real-time (Barrick, 1972; Teague et al., 1997), and can be utilised in modelling contaminant movement in coastal waters (Ojo et al., 2002; Tissot et al., 2001). The Conrad Blucher Institute (CBI) operates an HF radar system in Corpus Christi Bay, with several more systems scheduled to become operational along the Texas coast in the near future. In addition, CBI operates the only emergency-response HF radar in the Gulf of Mexico (http://www.cbi.tamucc.edu/projects/hfradar) (Kelly et al., 2002). The mobile system produces hourly grids (1-3 km) of bays and coastal waters out to 80 km. Surface velocity vectors (0.5 to 1.0 m, depth averaged, from HF radar observations at CBI) are highly correlated with wind direction and speed. For example, Figure 2 depicts the "before" (left figure) and "after" (right figure) as a weather front passes through Corpus Christi Bay. The surface current vectors (very small arrows) have shifted after the frontal passage. Environmental fluxes and environmental gradients are shown (larger arrows on the left figure). Fluxes indicate the forcings on an environmental system, while gradients indicate the transport potential within the system. Figure 2 demonstrates an example of the analysis possible through systemic deployment of sensors in synergy. These types of changes have environmental, social, and political impacts that need to be conveyed to stakeholders.

Data Communication and Management

The communication links for the system handle data being generated from different remote sources (boat, fixed platform(s), HF Radar) in a timely fashion. This is achieved by establishing several communication links (dial-in, direct radio connection) to the various sites. A network terminal server (Lantronics) along with a network filesystem (Snap Appliances) act as the core data infrastructure for the system. The terminal server allows the data logger/visualization computer on the boat or fixed platform to effectively "dial-in" to the local network that exists in the land-based, mobile, HF-Radar trailer through spread-spectrum radios (FreeWave Technologies) and access the network file system. Information from the HF-Radar system also uses the local network to transfer the generated JPG images of surface current maps onto the network file system. The data management strategy is to 1) preserve source data, 2) annotate source data, 3) automate acquisition, 4) maintain standard formats, 5) avoid proprietary components complicating dissemination, and 6) emphasise long-term reliability. The use of these principles results in a robust, stable, and flexible data support system. The integrated components include data acquisition, data archival, data extraction, and data world-wide-web interfaces.

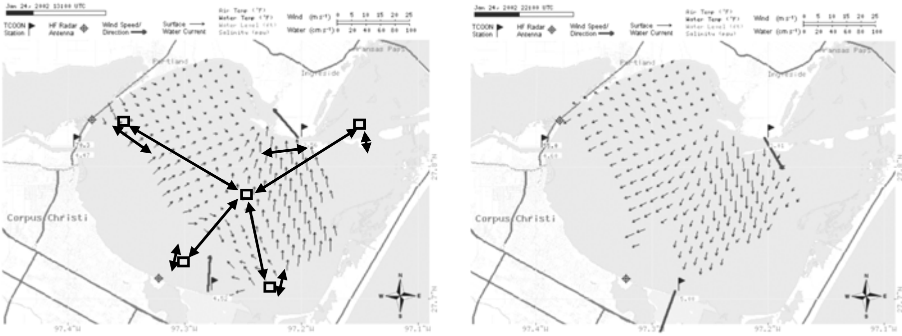

Figure 2. Corpus Christi Bay observations showing the change in wind velocity and resulting surface currents (very small arrows) over a two-hour period of time. The left figure occurred at 13:00 UTC on January 24, 2002 and the right figure occurred nine hours later. The left figure also shows environmental fluxes (short dark thick arrows) and gradients (long thick arrows). All of this shows the measured parameter accumulation in the Environmental Field Facility (EFF) concept.

3.2 Benefits and Contributions

Benefits to the overarching "smart sampling" research include 1) understanding complex cyclical near-shore ecological and physical parameters in real-time, allowing for accurate physical and biological coupling; 2) building a foundation for quantitative modelling and for designing long-term, cost-effective monitoring strategies; 3) predicting environmental stressor, fate and effects; 4) formulating operational tools for environmental managers; 5) disseminating results in "user-friendly" formats for the general public, educators, and policy makers; 6) providing replicate assessment of key processes; 7) highlighting regional differences for comparative study (e.g., high turbidity in west Gulf of Mexico vs. low turbidity in east Gulf of Mexico), and offering opportunities for others (e.g., Caribbean and Mexican collaborators) to join and expand our efforts; and 8) through industrial collaboration, developing sensor technology for critical water quality parameters and methods to combat sensor problems (e.g. biofouling). The multiple facets of this research are on-going efforts, operating in parallel. A recent demonstration of the ‘smart sampling’ concept was a simulated oil spill that was sanctioned by the U.S. Coast Guard. In this simulation (dye study), our geo-referenced boat was the designated monitoring vessel, arrayed with a fluorometer and a conductivity/temperature/depth instrument. The real-time data was successfully transmitted and spatially visualized at the command post onshore.

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