Real Time Observations of Oceanographic and Meteorological Parameters for Maritime Transportation: Origins and Novel Applications

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Abstract— **The first NOAA Physical Oceanographic Real-Time System (PORTS®) was established in Tampa Bay, Florida, becoming operational in 1991 (https://tidesandcurrents.noaa.gov/ports/index.shtml?port=tb). In April 2018, the Miami Physical Oceanographic Real-Time System was dedicated as the 30th such system in the US, followed closely by Port Everglades PORTS® in June 2018 as the 31st. PORTS® collects and disseminates real time meteorological and oceanographic data within major harbors around the US. PORTS® data are an essential component for maintaining the safety and efficiency of maritime operations. Before the advent of PORTS®, knowledge of environmental conditions relevant to ship operations in US harbors was generally limited to wind and precipitation sensors at the local airports and similar shipboard instrumentation. Water levels were inferred from standard tide tables even though surface winds were known to produce significant deviations from predicted values. This incomplete knowledge often led to navigational errors and to accidents. This paper will review the history of PORTS® development, highlighting recent advances in sensor technologies and novel uses of PORTS® data.**

On May 9, 1980, the 580 foot, 20,000 ton bulk carrier Summit Venture was approaching a critical turn toward the Sunshine Skyway Bridge in Tampa Bay, Florida and was overtaken by a violent, blinding thunderstorm. The ship veered off course and crashed into a main support pier of the bridge, collapsing the southbound span. Thirty-six people in vehicles fell into the water; 35 did not survive. The main ship channel into Tampa Bay port facilities was closed for 6 weeks, causing severe disruption to supplies of fuel and other commodities to the entire central Florida region. In the wake of the disaster, the local maritime community, led by the Tampa Bay Pilots Association and the Tampa Port Authority, petitioned the US Congress for funding to the National Oceanic and Atmospheric Administration to improve environmental monitoring capabilities in the bay. Nearly a decade later, the Tampa Bay Oceanography Project (TOP) began in 1990 as part of NOAA's Coastal Ocean Circulation Program (COCP). This included a 15 month study of currents, water levels, water temperatures, salinity, winds, and other meteorological/oceanographic parameters. By the end of the project, TOP had collected the largest number of circulation measurements in one estuary in the 100-year history of COCP.

Successful completion of TOP was followed by permanent deployment of real-time telemetered sensors measuring winds, currents, and water levels at critical locations in the bay - the first official NOAA PORTS® installation. Since 1991, local operations and maintenance of the system have been directed by the Greater Tampa Bay Marine Advisory Council- PORTS, Inc., a non-profit consortium of maritime interests, through cooperative agreements with the NOAA National Ocean Service Center for Operational Products and Services and the University of South Florida Center for Maritime and Port Studies.

The success of TB-PORTS made it a prototype for a national program. Within three years of TB-PORTS becoming operational, San Francisco Bay and Houston/Galveston Bay implemented their own PORTS® networks. Today PORTS® operates 24 hours a day/7 days a week in 31 locations around the coasts and Great Lakes of the United States and is a component of the Integrated Ocean Observing System national backbone. The local operation and maintenance of PORTS® facilities in each port remains funded by local maritime interests under the direction of NOAA/NOS/CO-OPS, who sets operational standards and manages the data quality control and dissemination through the Continuous Operational Real-Time Monitoring System (CORMS).

PORTS® data are provided to the public through the NOAA website http://tidesandcurrents.noaa.gov/ports.html. A prototype project in Tampa Bay provides PORTS® data to pilots aboard ships over the Automatic Identification System (AIS), now required on all commercial vessels over 20 m in length, in collaboration with the US Coast Guard R&D Center. The long time series observations of winds, currents, water levels, and other parameters in Tampa Bay from PORTS® has fueled numerous scientific studies on the dynamics of the estuary. New sensor technologies have been incorporated into the PORTS® data stream in recent years, including wave height, period, and direction, atmospheric visibility, and most recently, current measurements from sensors mounted on standard US Coast Guard aids to navigation buoys.

Keywords—Maritime transportation; ocean observing; precision navigation

I. INTRODUCTION

It is estimated that 50% of the world's population lives in a coastal zone, primarily due to the proximity of maritime transportation and port facilities which are conduits for 90% of global commerce and 95% of US international trade. Accurate, up-to-the-minute information on winds, waves, currents, water

978-1-5386-4814-8/18/$31.00 ©2018 IEEE

level, visibility, and other oceanographic and meteorological parameters are necessary for safe and efficient vessel transits in and out of port facilities. To that end, the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Ocean Products and Services (CO-OPS) provides Physical Oceanographic Real Time Systems (PORTS®; http://www.co-ops.nos.noaa.gov/ports.html) in multiple ports and harbors around the US. PORTS® collects and disseminates real time meteorological and oceanographic data critical to safe and efficient vessel movements to the maritime community. Prior to the advent of PORTS®, knowledge of environmental conditions relevant to vessel operations in US harbors was generally limited to wind and precipitation sensors at the local airports and similar shipboard instrumentation. Water levels and currents were inferred from standard astronomical tidal predictions even though surface winds and other factors were known to produce significant deviations from predicted values. This incomplete knowledge often led to navigational errors and to accidents. This paper will review the origins of PORTS® development, highlighting recent advances in sensor technologies and novel uses of PORTS® data.

The Tampa Bay PORTS® (TB-PORTS) was the first PORTS® in the US, built in 1990, and became operational in 1991. Since that time, ship groundings have decreased by 60%. Loading of bulk cargo has become much more efficient and the slack current window for bringing large ships through current-restricted portions of the channel has been widened by several hours. A study by Kite-Powell (2006) indicates that the quantifiable economic benefits of TB-PORTS (reduced ship groundings, increased draft/cargo loading, reduced delays for commercial vessels, improved spill response, reduced distress cases, etc.) exceed the operating costs by at least a factor of 20 to 50. Less tangible benefits (e.g., educational use, scientific research, environmental management) are not included in the Kite-Powell study but likely would add another order of magnitude to these estimates of benefits.

Origins

On May 9, 1980 the tanker MV Summit Venture was approaching the Sunshine Skyway Bridge in Tampa Bay, Florida during a violent, blinding thunderstorm. The ship went off course and crashed into a support pier of the bridge, collapsing the center southbound span (Fig. 1). Thirty-six people in vehicles fell into the water; 35 did not survive. The main ship channel into Tampa Bay ports was closed for 6 weeks, with severe economic impacts that rippled through the region. Over 50% of the refined petroleum product for the state of Florida passes beneath the Sunshine Skyway Bridge, as do raw materials and refined products imported or exported for the phosphate industry and coal for a major base-load power generation facility. Until the main ship channel could be safely re-opened, cargo had to be lightered between ocean going vessels and smaller barges that could transit a shallow alternate channel, delaying cargo and increasing costs. Other cargo had to be re-routed to ports on the east coast of Florida, resulting in lost revenue to Tampa Bay ports and increased costs for shippers.

Fig. 1. A car teeters on the edge of the collapsed southbound span of the Skyway Bridge, May 9, 1980. The MV Summit Venture is seen below to the right of the photo. The intact northbound span is seen in the upper left of the photo. (Photo credit: Tampa Bay Times.)

This horrendous accident was attributed to an un-forecast localized storm of "enormous proportions" that blinded the ship's operators during a critical turn on the approach to the bridge. In the wake of the disaster, the local maritime community, led by the Tampa Bay Pilots Association and the Tampa Port Authority, petitioned the US Congress for funding to the National Oceanic and Atmospheric Administration to improve environmental monitoring capabilities in the bay. Nearly a decade later, the Tampa Bay Oceanography Project (TOP; NOAA, 1993) began in 1990 as part of NOAA's Coastal Ocean Circulation Program (COCP). This included a 15 month study of currents, water levels, water temperatures, salinity, winds, and other meteorological/oceanographic parameters. By the end of the project, TOP had collected the largest number of circulation measurements in one estuary in the 100-year history of COCP.

Successful completion of TOP was followed by permanent deployment of sensors in Tampa Bay - the first official PORTS® location. TB-PORTS was initially operated through the Mote Marine Laboratory in Sarasota, FL, through a cooperative agreement with the NOAA National Ocean Service (NOS). Funding was provided through the Greater Tampa Bay Marine Advisory Council, a consortium of maritime interests in Tampa Bay. In 1993 TB-PORTS relocated its operations to the University of South Florida (USF) College of Marine Science where it remains today as a component of the Center for Maritime and Port Studies.

II. Structure

TB-PORTS is operated by a nonprofit 501(c)(3) corporation, the Greater Tampa Bay Marine Advisory Council-PORTS, Inc. (GTBMAC-PORTS), through a cooperative agreement with the NOAA National Ocean Service. The nonprofit corporation is governed by a board of directors that includes representatives from the primary end-users of data and information products from the system. GTBMAC-PORTS has agreements with private-sector contractors to provide routine operations and maintenance on the system. Local operations and maintenance of TB-PORTS is funded entirely by local and state entities, primarily from trust funds that are derived from fees on petroleum and phosphate shipping with contributions from some primary users, like the Tampa Bay Pilots Association. The system is housed in the USF College of Marine Science through a separate cooperative agreement with GTBMAC-PORTS. This cooperative agreement has provided stipends and tuition for graduate students to conduct research using TB-PORTS data and has fueled 5 PhD dissertations and 6 Masters theses. NOS/CO-OPS provides continuous operational data quality assurance/quality control and technical support as in-kind contributions.

Jeff Buck was the General Manager of the Tampa Bay Pilots Association in 1991 and spearheaded the implementation of TB-PORTS and GTBMAC. He was the President of the GTBMAC-PORTS corporation from its founding in 1993 until his untimely passing in July 2018. Buck was instrumental in the establishment and continued operations of TB-PORTS. His influence is greatly missed.

III. Evolution

The success of TB-PORTS made it a prototype for an expanding program. Within three years of TB-PORTS becoming operational, San Francisco Bay and Houston/Galveston Bay implemented their own PORTS® installations. Today PORTS® operates 24 hours a day in 31 locations around the coast and Great Lakes of the United States. The operation and maintenance of all PORTS® facilities remains 100% funded by local maritime interests, with NOS/CO-OPS setting operational standards and managing the data quality control and dissemination. PORTS® data are provided to the maritime community and the general public through the NOAA website http://tidesandcurrents.noaa.gov/ports.html.

Tampa Bay was the first US harbor to implement a prototype of the Automatic Identification System (AIS) in 1998, now required on all commercial vessels over 20 m in length (Husick, 1999). A related prototype project in Tampa Bay, in collaboration with the US Coast Guard R&D Center, provides PORTS® data to pilots aboard ships, as an overlay on their Portable Pilot Units using the met/ocean data channels of the AIS, using the USCG AIS transceiver tower operated by L-3 Communications.

The original configuration of TB-PORTS in 1992 included 4 water level sites at the primary port facilities, 2 Acoustic Doppler Current Profilers (ADCPs) mounted on the bottom of the main ship channel beneath the center span of the new Sunshine Skyway Bridge and at the turn approaching Old Port Tampa (a major petroleum and dry bulk terminal), and wind sensors at each water level site and 2 other USCG range towers in the bay. Data telemetry was accomplished using basic amateur radio data modems and 5-watt single frequency radios operating at 410.1 MHz. Data dissemination was provided through dial-up modem and telephone voice response system. Dedicated terminals were kept at the Tampa Bay Pilots dispatchers' locations in Tampa and on Egmont Key, at the Tampa Port Authority, and at the USCG operations center in St. Petersburg.

The original Data Acquisition System base station (2 PCs driving data modem/radios, voice response system, and dial-up modems) was located at the USCG operations center and was relocated to the USF Marine Science Lab in 1993. Once the TB-PORTS data became readily available in our lab at USF, we began to experiment with data distribution methods over the then-fledgling Internet. A very sharp undergraduate intern in the lab, Linae Boehme, had learned about the Gopher server and set up protocols to serve the TB-PORTS data online. To the authors' knowledge, this was the first implementation of real-time oceanographic data available on the Internet. Soon thereafter, the Mosaic web browser (also developed by a sharp undergrad intern at the University of Illinois, Marc Andresen, and the precursor to all modern web browsers) became available and TB-PORTS data distribution was transferred to that platform. Today, all PORTS® data acquisition, quality control, and distribution are centralized at NOAA headquarters in Silver Spring, MD, through the Continuous Operational Real-Time Monitoring System (CORMS). The local TB-PORTS web page (http://tbports.org/) is a "landing page" that points to the CO-OPS web pages and provides additional information on local operations and maintenance of the system.

TB-PORTS continues to expand: the original 12 oceanographic and meteorological sensors at 8 sites have been increased to 31 individual sensors at 14 locations (Fig. 2), including a third ADCP at the turn approaching the Port Manatee channel, additional wind sites around the Port of Tampa to support cruise ship transits, two atmospheric visibility sensors, a directional wave buoy (operated in collaboration with the Coastal Data Information Program - http://cdip.ucsd.edu/ - and the US Army Corps of Engineers), and a new Acoustic Doppler Current Profiler (ADCP) mounted to a USCG Aid to Navigation buoy, dubbed the iATON (Fig. 3).

Based on our experience in operation of TB-PORTS, PORTS-style systems have been deployed to offshore sites. USF established the Coastal Ocean Monitoring and Prediction System (COMPS) in 1997 that operates instruments on and along the West Florida Shelf (Weisberg et al., 2009). COMPS data are provided to NOAA's National Buoy Data Center, providing similar services as PORTS® to offshore maritime activity as well as to environmental protection and emergency management applications. COMPS is now part of both the Southeast Coastal Ocean Observing Regional Association (SECOORA) and the Gulf of Mexico Coastal Ocean Observing System (GCOOS), two of the 11 Regional Observing Systems contributing to the Integrated Ocean Observing System (https://ioos.noaa.gov/) with over 2500 monitoring sites around the US and Pacific Islands.

IV. Benefits

Due to the availability of the PORTS® real-time water levels, larger ships with deeper drafts and larger cargo capacity can more safely navigate within harbors, significantly increasing the operational efficiency and safety. Economic benefits of PORTS® have been estimated to be as much as $7.0 million in Tampa Bay in 2005, $7.4 million in the Columbia River in 2007 and $15.6 million in Houston/Galveston Bay in 2010. As ship drafts have increased, their clearance with the

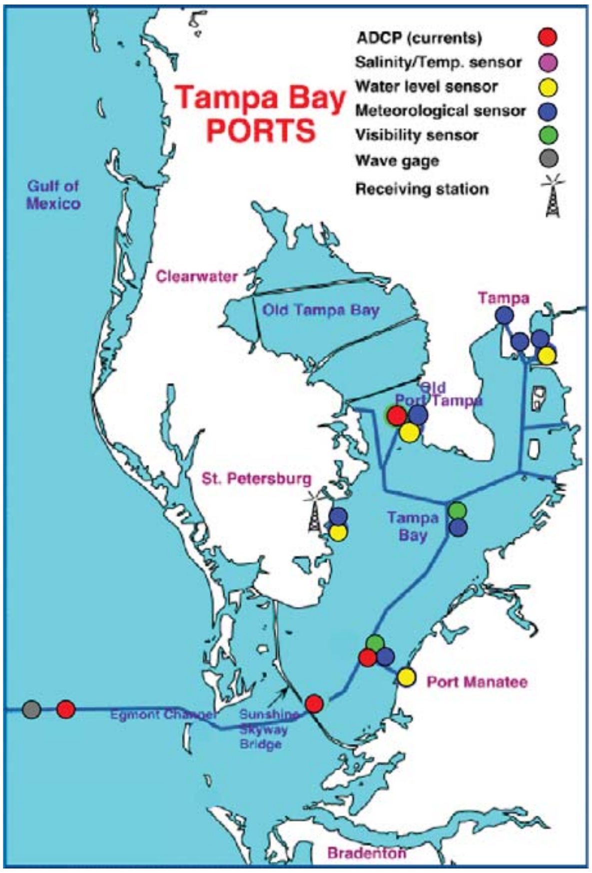

Fig. 2. Map showing TB-PORTS observing sites. Thin blue line shows main ship channel.

Fig. 3. iATON ADCP and Iridium satellite data telemetry system attached to a standard USCG Aid to Navigation (ATON) buoy in the Miami ship channel as a component of Miami PORTS®. (Photo credit M. Luther)

bottom has decreased, sometimes being as little as 1 m. Even with increased ship draft, PORTS® has yielded more than 60% decrease in ship groundings and collisions in some locations. This also has led to acommensurate decrease in related spills of pollutants; however, when spills do occur, the real-time information on water levels, currents, surface wave height, period and direction provided by PORTS® facilitates response and cleanup operations.

V. Related Applications

The near-continuous observational data provided by PORTS® can be used for a variety of purposes. Operational Forecast Systems (OFS) that include PORTS® data in their boundary conditions have been implemented by NOAA for 14 regions (https://tidesandcurrents.noaa.gov/forecast_info.html). These models are based on the three-dimensional hydrodynamic circulation models with spatial resolutions of typically 100-500 m, which is sufficient to resolve major features within the bay and its approaches. They provide estimates of marine conditions (winds, water levels, currents, salinity, air and water temperatures) across their domains in near real-time as well as 48-hrs into the future. An early prototype of the OFS was developed by Mark Vincent as a component of his Ph.D. dissertation research (Vincent et al., 1998, 2000). Vincent went on to the NOAA National Ocean Service to help develop the Operational Forecast Systems now operated by NOS/CO-OPS. Such models also can provide predictions of spill trajectories, allowing for more focused protection strategies to be applied to those areas most at risk from contamination.

In collaboration with the NOAA National Weather service, NOS has implemented a prototype Marine Channels Forecast for Tampa Bay (https://tidesandcurrents.noaa.gov/ofs/tbofs/tbofs_mcf.html), another first for Tampa Bay. The Marine Channels Forecast provides 24 hour forecasts of water level, winds, currents, significant wave height, precipitation probability, and atmospheric visibility at critical locations along the main ship channel and port facilities around the bay, based on information from TB-PORTS, the OFS, and weather forecast model guidance.

PORTS® data have recognized scientific value in addition to their maritime transportation and environmental protection applications. At USF, data from TB-PORTS has been an integral part of studies on estuarine flushing and residence time (Burwell et al., 2000; Meyers et al., 2008; Wilson et al. 2014; Meyers et al., 2017), hurricane storm surge evolution (Wilson et al. 2006), hazardous chemical spill tracking (Havens et al., 2009), the development Harmful Algal Blooms (Havens et al., 2010), atmospheric deposition of pollutants (Mizak et al. 2007; Sopkin et al., 2007), basic estuarine physical processes (Meyers et al., 2007, 2015; Arnott et al., 2012), and the restoration of sea grass in Tampa Bay (Shi et al., 2006; Chen et al., 2010). The accumulating water level and velocity data at PORTS® locations provide information relevant to the protection of ecologically important estuarine environments, particularly when paired with long-term water quality data and observational data from other sources. In the case of Tampa Bay, four decades of monthly water quality data collected by the Environmental Protection Commission of Hillsborough County (EPCHC) has supported ecological restoration efforts led by the Tampa Bay Estuary Program (Rutherford et al., 1995).

The availability of both TB-PORTS data and infrastructure has facilitated other research projects. The TB-PORTS mid-bay site is comprised of a dedicated instrumented tower (Fig. 4) and has supported studies of Harmful Algal Blooms by the Florida Fish and Wildlife Research Institute (FWRI) and of ocean acidification by the US Geological Survey (USGS). FWRI and USGS maintain additional instrumentation on the tower to observe chlorophyll pigments, dissolved oxygen, pH, and other parameters, independently from the TB-PORTS data stream. The mid-bay tower also was a key element of the Bay Regional Atmospheric Chemistry Experiment that quantified atmospheric deposition of nitrogen compounds, polyaromatic hydrocarbons, and mercury into the bay Mizak et al., 2005, 2007; Sopkin et al., 2007). One conclusion from this study was that over half of the nitrogen input to the bay is through dry atmospheric deposition and is primarily from automobile exhaust and electrical generation.

The now 28 year time series of water level and current data at some TB-PORTS sites has allowed the identification of processes and phenomena that could not have been detected previously from more limited data sets. A recent study by Meyers et al. (2015) identified a hysteresis-like nonlinear response of the tidal residual estuarine circulation by analysis of the Sunshine Skyway Bridge ADCP data along with salinity data from the EPCHC monitoring program (Fig. 5). This estuarine circulation is driven by the salinity gradient along the axis of the bay (Galperin et al., 1992; NOAA, 1993). On a long-term seasonal average, the strength of this circulation increases nearly linearly with increasing salinity gradient with the onset of the rainy season but the circulation persists for some time after the salinity gradient dissipates in the dryer months. This study provides insight into the processes governing transport and fate of material properties in the bay that would not have been possible without the TB-PORTS data set.

ACKNOWLEDGMENTS

Partial support for this work was provided by the Greater Tampa Bay Marine Advisory Council-PORTS, Inc., by the National Oceanic and Atmospheric Administration through the Alliance for Coastal Technologies, the Southeast Coastal Ocean Observing Regional Association (SECOORA) and the Gulf of Mexico Coastal Ocean Observing System (GCOOS), and by the University of South Florida.

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Fig. 4. TB-PORTS instrumented tower at Middle Tampa Bay. This site houses dual RM Young wind monitors, air temperature/relative humidity, barometric pressure, visibility (fog), and ADCP currents as components of TB-PORTS. Additional sensors for other programs are mounted on the tower as well. Visibility sensor is to the upper-left of the photo. (Photo credit M. Luther)

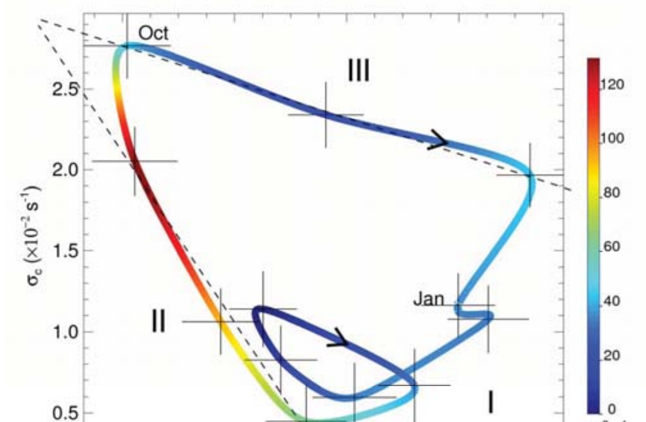

Fig. 5. The relationship between monthly climatologies of strength of estuarine circulation as indicated by vertical shear (σ_c) from the TB-PORTS ADCP at the Sunshine Skyway Bridge (vertical axis) vs along-bay salinity gradient (S_{cx}) from the EPCHC monitoring data. Curve is colored by river discharge as indicated by color bar to the right. Reference months are given along with arrows to indicate direction of progression in time. Standard errors of plotting variables for each month are shown. From Meyers et al., 2015.

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